Implementation Report for
Smart Community Demonstration Project in Greater Manchester, UK

November 2017

New Energy and Industrial Technology Development Organization (NEDO)

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Daikin Industries, Ltd.
Mizuho Corporate Bank, Ltd.
Mizuho Information & Research Institute Inc.
Greater Manchester Combined Authority
Wigan Council
Northwards Housing
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In Delivery with:
Procure Plus
Warmer Energy Services
NPS Group

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(Please see separate Executive Summary Document)

2. Background and Introduction

2.1. Business background and purpose of the project

The UK government's recently published Clean Growth Strategy states that it will be necessary to fully decarbonise heat in homes by 2050. There are a number of possible options to achieve this, including the use of heat pumps. In 2014, the domestic Renewable Heat Incentive (RHI) was introduced to encourage households to install measures to support the roll out of low carbon heating technologies which has led to the installation of over 55,000 low carbon heating technologies such as heat pumps.

One of the priorities for the Great Manchester "Low Carbon Hub" is to fast-track the delivery of domestic energy efficiency and renewable heat projects. In Greater Manchester, homes account for 37% of energy demand[1]. Housing therefore represents a major opportunity to cut energy use and CO_2 emissions.

Air source heat pumps are a renewable heat technology, extracting heat from the outside air and pumping it inside to heat indoor spaces, making use of air as an infinitely renewable energy resource. In addition to achieving between 30% to 50% reductions in CO_2 emissions compared to conventional gas boilers, heat pumps also offer high efficiency levels and may lower energy costs for users. They are therefore increasingly being considered a cost-effective option for heating homes, particularly in off-gas areas.

Widespread electrification of heating systems (such as heat pumps) may put an increased pressure on the electricity infrastructure network, potentially at peak demand times where the network is currently under the greatest stress. The balancing of demand and supply therefore becomes an increasingly important future challenge and Demand Response (DR) is one of the emerging solutions to manage this.

DR shifts electricity demand by managing the peaks and troughs of demand from individual dwellings. When used in conjunction with heat pumps, the building structure and domestic hot water tank is used as thermal energy storage, enabling a decoupling between the time of the delivery of thermal comfort and heat pump electricity demand.

DR enables the demand on the electricity grid to be "smoothed". This is known as "energy balancing". The energy saved can then be measured, opening up the potential to create a financial model to trade this energy on the market. "Nega watts" is an emerging term for measuring the amount of energy saved.

[1] https://www.gmcvo.org.uk/system/files/gmca_spatial_energy_plan_exec_summary.pdf

Greater Manchester's "Pioneer City" status for Low Carbon created an opportunity for Greater Manchester to be involved in a pilot Smart Community Demonstration Project. The project would develop and deliver a pilot within the social housing sector across Greater Manchester to trial the implementation and use of Air Source Heat Pumps (HP) at scale, testing the effectiveness of Demand Response in the social housing sector. As there is currently little evidence of heat pumps as a large scale retrofit DR solution, this demonstration project enabled the development of further understanding of the particular challenges these systems present and identified some solutions to those challenges.

The project was partially funded by the Japanese government's research and development agency – the New Energy and Industrial Technology Development Organisation ("NEDO")[2] and is an example of a truly bi-national partnership project between government, industry and academia. It involved a range of partners, including Hitachi Ltd, Daikin Industries Ltd, Mizuho Bank, Electricity Northwest and BEIS, providing an opportunity to test Japanese low carbon technologies and solutions for smart community business development in the growing global low carbon market.

Three Arm's Length Management Organisations (ALMOs); Wigan and Leigh Housing (WALH), Northwards Housing (NH) and Six Town Housing (STH) were selected to be involved in this project based on: the size and quality of their property portfolios, the reputation of the ALMOs in having a strong interest in the low carbon agenda, prior experience in delivering major programmes and public sector ownership of the properties, making it possible for a "public body to public body" transfer of the HP assets following the completion of the project.

Details of the partners involving the project can be found in Appendix 2.

Figure 2-1 shows a map of locations of the project within the context of Greater Manchester.

Figure 2-1:

[2] The agency has a budget of around £1.2 billion a year and is currently funding around a dozen energy research projects outside of Japan, developing advanced technologies with potential to stabilise energy supplies and address climate change.

2.2 Business Objectives

The core business objectives of this demonstration project were:

- To verify the effectiveness of electricity aggregation based on demand control capacity obtained by controlling Air Source Heat Pumps installed in social housing; and
- To establish sustainable business models for electricity aggregation.

These objectives were divided into the following three themes: demonstration of HP installation, aggregation system demonstration and establishment of a business model. In addition, a fourth theme covered a small-scale trial where a telecare system was installed alongside the HPs in 20 sheltered housing flats.

Theme 1: Demonstration of HP installation
The demonstration comprised a large-scale field trial to verify the effectiveness of Air Source Heat Pumps (HP) as an efficient solution for heating properties in the social housing sector. This was trialed through replacing old, inefficient heating systems in 550 social housing properties across Wigan, Bury and Manchester with a range of cutting-edge electrical and hybrid air-source heat pumps (HPs), plus the development of an energy aggregation system and ICT platform to control and coordinate the electricity usage of the HPs at each property. HP performance was measured through the analysis of usage data and feedback from the property tenants, who were asked to give their opinions on their experience of their new heating systems both during and at the end of the trial through a series of questionnaires and interviews.

Theme 2: Aggregation system demonstration
An electricity aggregation system was developed, linked virtually to the electricity market. This system enabled the verification of the capability and capacity of the demand response (DR) control system to trade in the electricity market and for this to be controlled based on the market's requirements.

Theme 3: Establishment of a business model
The objective of Theme 3 was to establish a robust business model and evaluation criteria to determine the viability of the commercialisation of the technology and electricity aggregation system used in the trial (including consideration of financing and ownership).

Theme 4: Telecare Trial
A separate smaller trial was undertaken to test a telecare system, installed alongside the HPs in 20 sheltered housing flats. These properties were provided with additional sensors to monitor the movement and activity levels of the occupants and each participating tenant was provided with a tablet to report their daily health to the sheltered housing managers. The purpose of this trial was to find out how technology can help people manage their own health whilst maintaining their independence.

2.3 Project Outline

Based on the initial feasibility study, produced in December 2013, four types of HPs were selected for the Demonstration Phase, from two different manufacturers. Seven scenarios (use cases) were identified to test the aggregated domestic HP electricity demand for trade in electricity markets. An ICT platform was identified and scoped and an initial ‘desk based’ business model was drafted to review financial / commercial benefits of electricity aggregation across the supply chain.

The feasibility study identified that the demonstration system should be able to generate around 200kW of nega-watts (i.e. reduced capacity demand), which would be sufficient to verify the trading of demand reduction capacity in practice through system interaction with existing aggregators.

The demonstration phase was implemented between 2014 and 2017. Each theme was split into a series of business components (BC) with appointed ‘lead’ partners responsible for delivery. These were referred to through the project as follows:

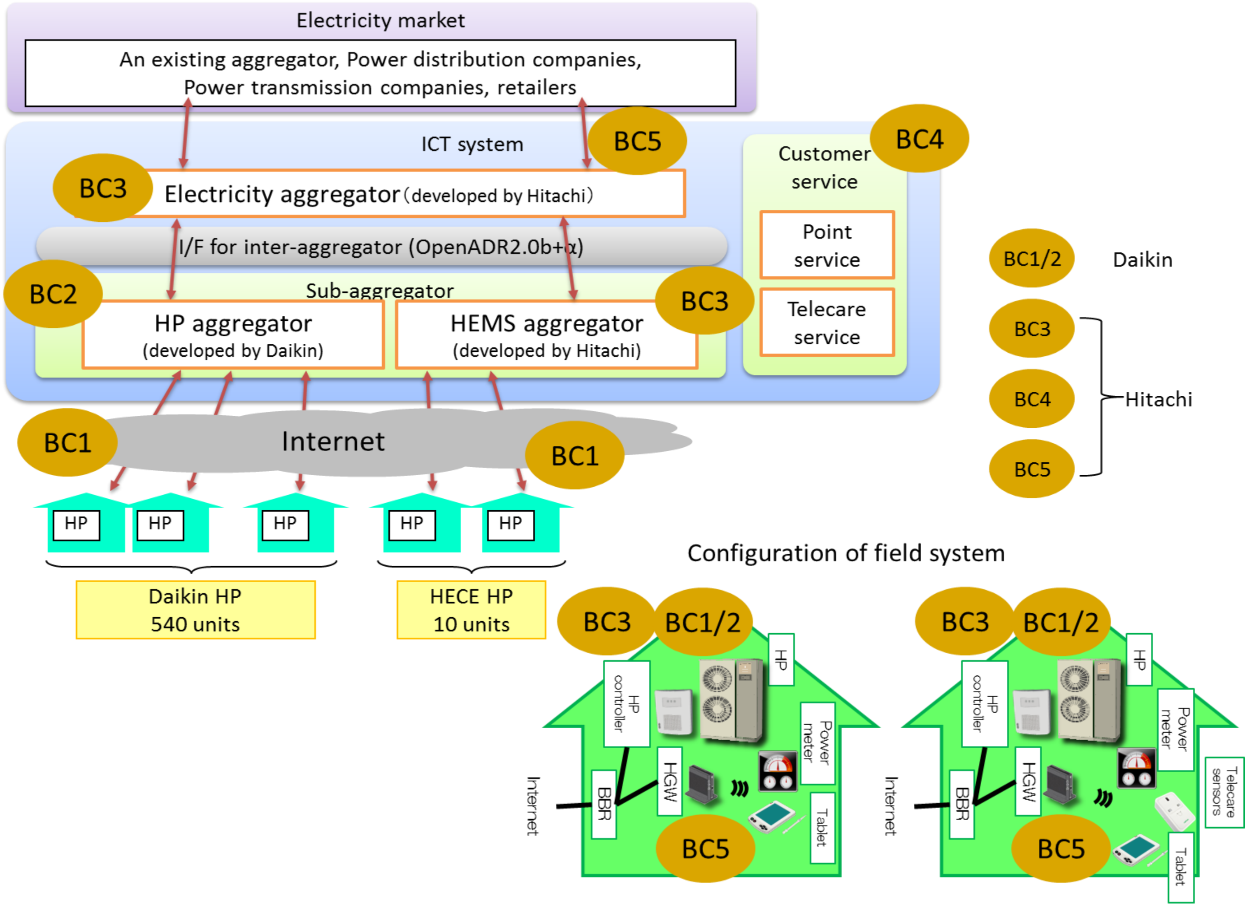
TE – Tenant Engagement
BC1 – Heat Pump (HP) Installation
BC2 - Implementation of the HP aggregation system structures
BC3 – Electricity Aggregation
BC4 – Consumer Service
BC5 – ICT Platform
BC6 – Business Model
DAE – Data Analytics

Daikin Industries Ltd was responsible for delivery of BC1 and BC2. Hitachi Ltd was responsible for BC3, BC4, and BC5, Mizuho Bank Ltd was in charge of BC6, ALMOs were responsible for delivery of the Tenant Engagement (TE) component and a project management office (PMO) was established by Hitachi, as lead consortia partner. The data analytics research also involved interviews and questionnaires with the project participants to feed into the business model development and understand the project participant’s views on the project (DAE). Hitachi Ltd also managed the telecare trial.

Data protection agreements were drawn up between all parties, both in the UK and in Japan, to ensure the proper management and disclosure of data between organisations and within different parts of a partner organisation (i.e. Hitachi). These were checked for compliance with UK laws.

Figure 2-2 shows an overview of all the system components of the project and how these link to the business components (BCs). A glossary of terms can be found in Appendix 1.

Figure 2-2 Overview of demonstration system and ICT platform



3. Project Management

3.1. Project Governance

The project was overseen by a steering committee, with membership comprising: NEDO, GMCA, senior ALMO representatives and representatives from the Programme Management Office (PMO). The steering committee met on a semi-annual basis to review the progress of the project.

A Project Board was established to oversee the overall management and delivery of the project. This was chaired by GMCA and met once per month, with representatives from all project partners (details of which are provided in Appendix 2).

Hitachi provided a project management office (PMO) function in both Japan and the UK to ensure smooth operational management of the project. The PMO gathered data about project progress, produced reports and information to support effective decision-making by the Board and acted as a central point of contact for communication between the UK partners and Japanese consortia partners.

3.2 Project Communications

GMCA led the project communications strand in the UK. A project website was developed http://www.gmsmartenergy.co.uk/ and news articles were produced along with a series of case studies as the project progressed. The project was also showcased at several high-profile events including the EuroScience Open Forum (ESOF) 2016 held in Manchester and the "Smart Community Summit 2017" held in Tokyo.

3.3 Project Financing

The provision of the HPs and associated monitoring equipment and network connectivity to enable HP monitoring and DR capability were funded directly by NEDO to the project consortia partners (Daikin Industries Ltd and Hitachi Ltd).

On the UK side, the ALMOs provided funding for the installation of the Broadband lines and routers in each property for a period of 2 years and covered the costs of the pre-installation surveys, and installation of associated 'wet systems' required for the project i.e. radiators, pipework etc. Larger radiators are required for HP systems, so that sufficient heat is emitted at the efficient running temperatures (about 40-50 degrees C).

The UK Department of Energy and Climate Change (now BEIS) also provided funding to GMCA to support project administration, communications and engagement. Additional 'in kind' support including staff time to oversee the successful management of the project was provided by all partners.

Some of the HPs installed were eligible for the Domestic Renewable Heat Incentive (Domestic RHI) scheme, with participating ALMOs able to apply to receive ongoing payments for the amount of renewable heat each system produces. The ALMOs each agreed to allocate a proportion of their anticipated RHI payments into a central 'contingency' fund for the project to cover any additional unforeseen project costs. This amounted to a fund of £80k for the duration of the project, with contributions from each ALMO based on the number of HPs to be installed in each area. This central pot of funding provided a valuable contribution to the project and was used to: support additional tenant engagement, digital IT literacy training on tablets; cover unexpected property works to make some of properties suitable for HP installation, such as strengthening beams and to pay for planning application costs, which was required at a few property archetypes i.e. flats.

4. Theme 1: Demonstration of HP installation

4.1 Tenant Sign Up

As this project was installing HP equipment in occupied social housing properties, the recruitment of volunteer tenants to sign up to a new, and to many tenants, 'unknown' heating system was a vital component of the project. Each ALMO assigned a tenant liaison officer (TLO) to undertake the initial sign up and explain the purpose of the project and resulting benefits to the tenants.

Tenants were contacted to sign up to participate in the project via letter, phone and door to door visits by the ALMOs and incentives were offered. Participating tenants were provided with a free Broadband connection for a 2-year period, or if they had existing Broadband they were provided a financial incentive towards their costs. All residents were also given a free ASUS tablet, which featured an interactive 'smart communities' web link to provide information on energy saved during the DR trial.

The sign up of tenants was split into two phases. WALH and NH participated in phase 1 and an initial 'long list' of potentially suitable properties was identified by each ALMO. This was based on an assessment of the age and type of current heating systems installed in the properties, with older and inefficient heating systems prioritised.

The ALMOs each took a different approach to tenant sign up, primarily based on the in-house resource available to undertake this activity. WALH took the approach of targeting many properties by letter, based on an assessment of properties due for boiler replacement schemes. Northwards had a smaller initial target number and had a dedicated tenant liaison officer who undertook direct door to door tenant visits, again based on an initial assessment of properties due for a boiler replacement. The success rate of the Northwards approach led to them eventually installing more than double their initial target, installing 153 HPs in total.

Six Town joined the project installation phase at an agreed later date than the other two ALMOs and they also pursued a more direct approach via telephone and face to face visits.

Actions to accelerate tenant sign up included using a mobile unit provided by Daikin to show the HP equipment to prospective project participants and a 'demonstration home' installed with all project equipment to show prospective participants around. The ALMOs also supported each other through sharing information and Northwards actively supported the Six Town's tenant engagement.

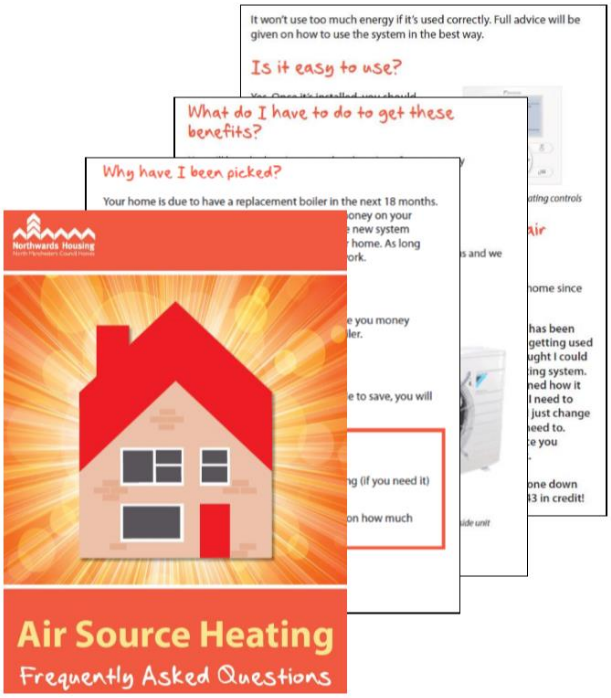
Following sign up, each property was assessed to ensure suitability for HP installation. The contractor (Warmer Energy Services), procured by the project via Procure Plus, undertook the initial surveys of the properties. This included a survey of the size and layout of each property and an energy performance assessment. Each property was provided with an Energy Performance Certificate (EPC).

Throughout the project, the ALMOs engaged tenants on the project, using information leaflets and FAQs to explain the purpose of the project and explain demand response, with contact telephone numbers provided for tenants to contact with any queries.

A 'Reward Points' service, which granted consumers points in accordance with service use, was explored as part of the trial where participants would accumulate points for participating in DR events and would be able to use accumulated points to buy services and products at discounted prices, or to exchange points for services and products. The activation of a 'live' point service was not possible in the scope of this DR trial.

Figure 4-1 shows an example of the leaflets distributed to the tenants.

Figure 4-1: Tenant engagement leaflets



4.2 Selection of HP type

To select the most suitable heat pump for each property, a pre-installation property survey was undertaken by the contractor design team, which included heat loss calculations. Appropriate HPs were selected accordingly. Properties that were not sufficiently insulated underwent a programme of insulation works first to ensure that all the properties in the trial were appropriately insulated.

Three types of HPs were installed in the trial, these were:

- **LT split systems**. Installations where a refrigerant to water heat exchanger is separate to the outdoor condensing unit
- **Monobloc systems**. Installations where a refrigerant to water heat exchanger forms an integral part of the outdoor condensing unit (hence, no external refrigerant pipework)

- **Hybrid systems**. Installations where the outdoor unit is installed in conjunction with a high efficiency gas combi boiler

In addition, some of the electrical HPs (LT split and Monobloc) were installed with additional buffer vessels to increase the demand response capacity. Further details of the HP types are explained below and figure 4-2 illustrates the components of each HP type.

Daikin Heat Pump Units
New controlling software features were embedded into existing manufactured HPs, including features to enable the extraction of running data from internal RAM memory, cooperating with detailed demand response signals. Additionally, new DR-ready Monobloc HP systems were installed which achieve a high energy efficiency with demand response features and provide installers with easy installation processes. The original project plan was to install 550 Daikin HP units. In total 540 units were installed

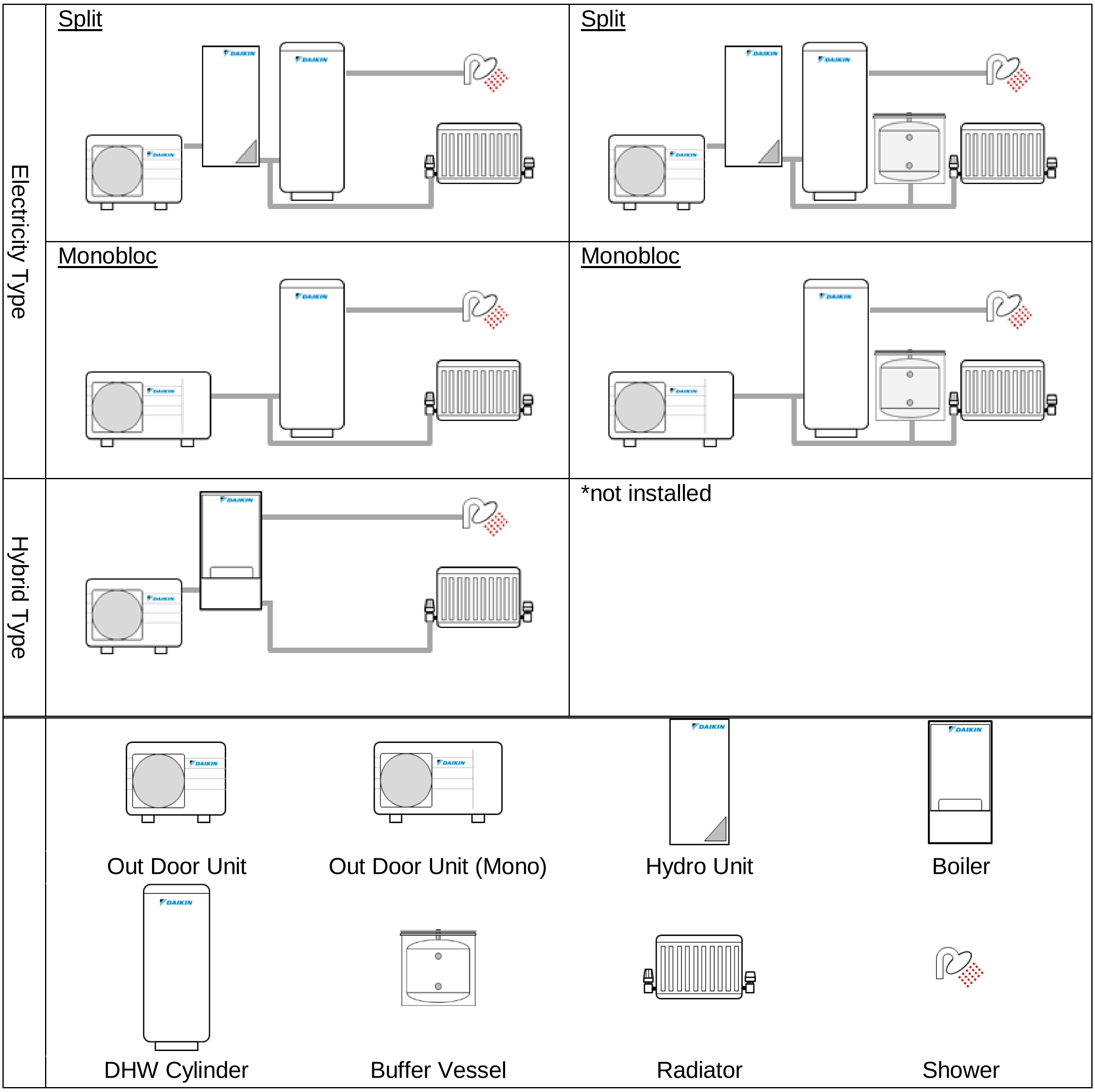
Hitachi (HACE) Heat Pump Units
The original plan in the NEDO project was to bring in multi HP vendors and Hitachi Air Conditioning Europe (HACE) was one of them. Taking into consideration the UK social housing market requirements, such as limited space within properties to install units, the HACE LT split type heat pump was selected as an appropriate model. The original project plan was to install 48 HACE HP units. Due to several reasons, including the relative size of the HACE HPs, additional training requirements for the installers and some technical issues arising on the initial installations, the final number installed was 10 units (8 in Wigan and 2 in Manchester).

Heat pump units from EU manufacturer
The original plan was to install heat pumps from Stiebel Eltron in Germany; however, there were difficulties in obtaining information from Stiebel Eltron and engagement was carried forward with CTC in Sweden to implement a demand response feature to allow CTC HPs to interact with HP aggregation servers. In the end however, a decision was made not to install CTC HPs on site for various reasons including, the size of HPs, scheduling issues, training issues, and avoiding unexpected issues for tenants. During the assessment as to whether to install EU manufacturer's heat pumps, it became apparent that there are similar characteristics in several EU manufacturers where the outdoor units are much bigger compared to those of Japanese manufacturers.

Heat pump units with Buffer Vessel
To add flexibility to the DR capacity, a buffer vessel was designed which bypasses the hot water heating circuits. This buffer vessel unit had its own controller called "Thermal Storage Controller" and operated independently to heat pump systems and DR controllers. In total, 23 buffer vessel units were installed in the properties. This was lower than the original anticipated number, as many of the properties selected for the trial did not have sufficient space capacity to install these.

Figure 4-2: HP types

	Normal Type	Buffer Vessel Type



4.3 HP aggregation components

Figure 4-3 illustrates the different functions of the HP aggregation system. These components are:

4.3.1 DR Controller

The main function of the DR controller is to execute Demand Response via interpreting a DR signal from the HP aggregation server. Other important functions include remotely gathering running data from the heat pump systems. HP data was collected every minute. Every five minutes, the DR controller sent this data for analysis to the cloud server system. In addition, the DR controller was connected to external thermal sensors to measure the temperature in different rooms.

4.3.2 HP Aggregation Server

The Heat Pump aggregation server consists of five independent virtual machines in the cloud. Within each server, application software was embedded based on open-source Application Programming Interfaces (APIs). These applications include electric power load balancing, HP group management system, and remote monitoring. A schematic of the HP Aggregation Server System is shown in figure 4-4.

Figure 4-3: Example of a Daikin heat pump system (without buffer vessel)

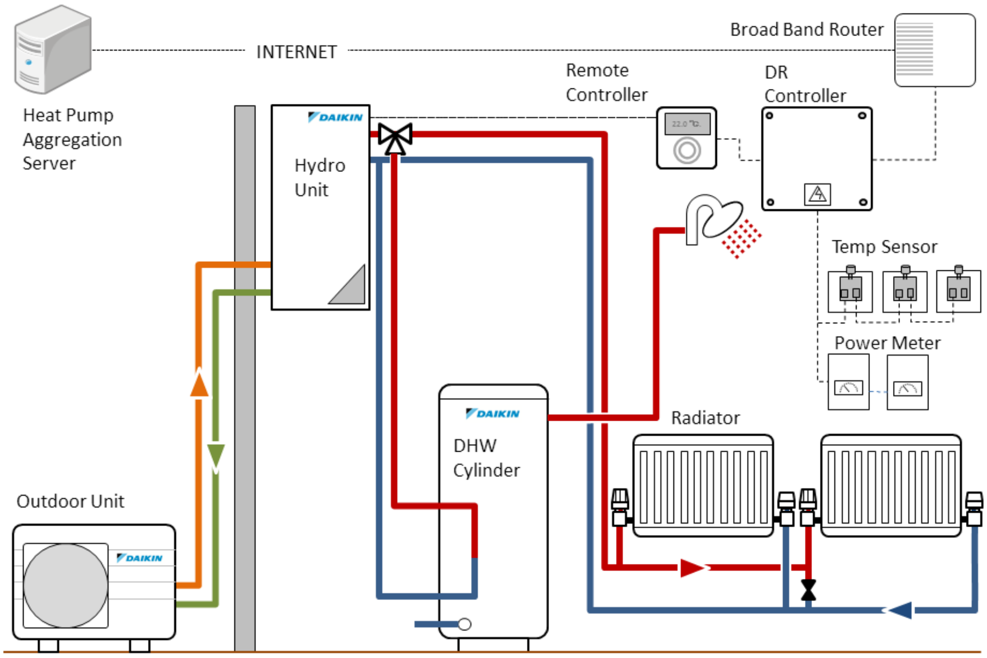
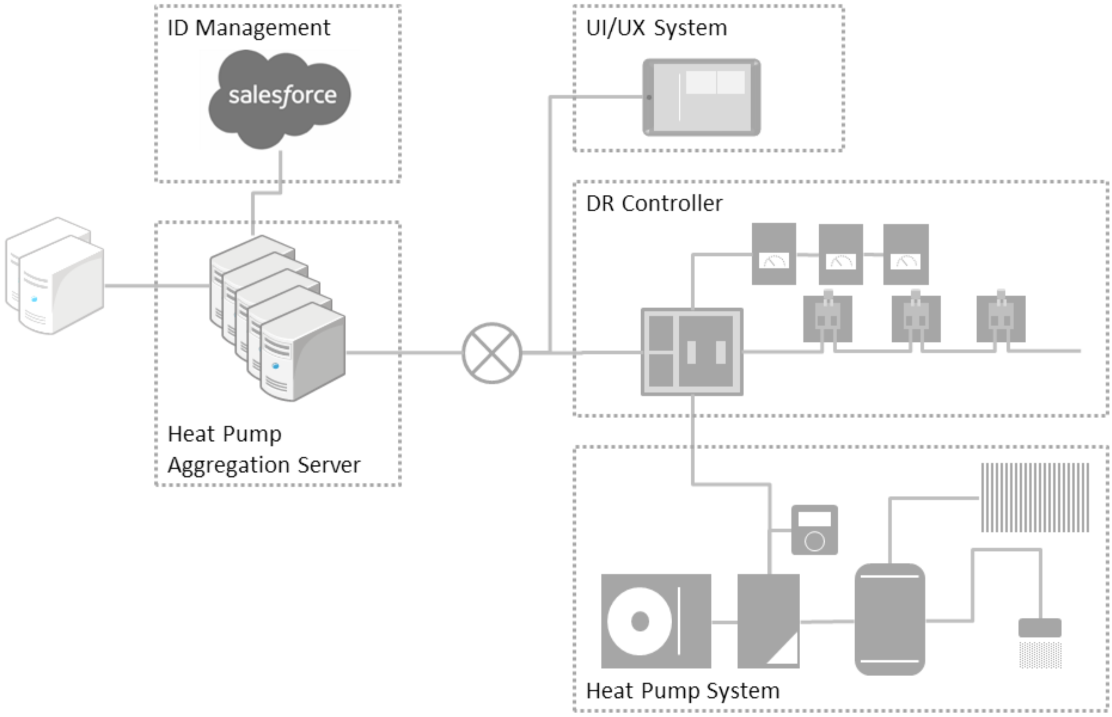


Figure 4-4 – The HP Aggregation Server System



For the Hitachi (HACE) HPs, a separate Home Energy Management System (HEMS) Aggregator was developed to plan and execute DR to tenants for the 10 HACE HPs that were installed. This system had an interface with PassivSystems to achieve the HP DR control. A DR vizualisation system was also developed for this system to allow tenant users to be able to see the DR results on their tablets.

4.3.3 ICT Platform

In addition to the HP aggregation system, an ICT platform was developed by Hitachi to:

- collect and store sensor data measured by the power meters (and telecare sensors)
- offer a common interface for other applications to manage the stored data.

The ICT platform was divided into 2 systems. One was a field system, with several functions to measure power consumption and send this data to a data centre system. The data centre system comprised of several servers to operate the demonstration process and services.

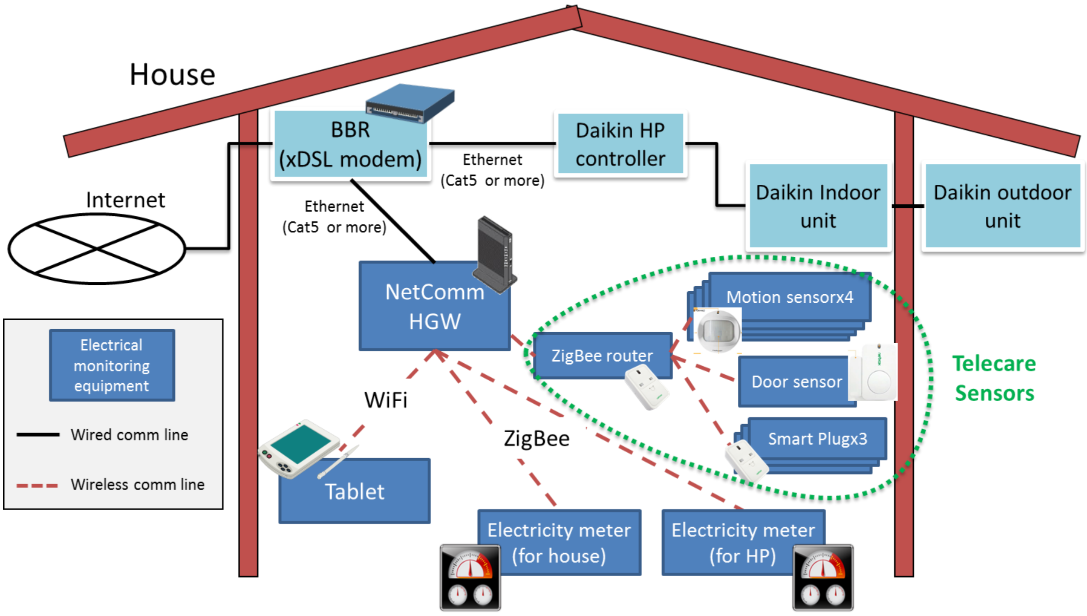
Field system

The purpose of the field system was to measure the power consumption data of the HP, collect sensor data and send this to the data centre system in real time. Figure 4-5 outlines the components of the field system. Two smart electricity meters (power meters) were installed in each property. One to measure power consumption of the HP and one to measure the total consumption amount for the whole house (to enable a comparison with the power consumption of the HP). These were connected to a Netcomm Home Gateway (HGW) via Zigbee communication transmitter and transmitted to a data centre via the broadband router (BBR) in real time.

This is referred to in the remainder of the report as the ‘electrical monitoring equipment’.

In addition, for the 20 sheltered housing flats involved in the telecare trial, telecare sensors were installed in each property, comprising of motion sensors, a door sensor and smart plugs, connected to the HGW via a zigbee router. Details of the telecare trial are outlined in chapter 7.

Figure 4-5: Field system



Data Centre / Electricity Aggregation System
The key purpose of the NEDO demonstration project was to conduct a trial of demand balancing capacity for the UK electricity trading market, using the electrical load adjustment capacity of residential heat pumps. To achieve this, an Electricity Aggregation System was developed which could communicate with the electricity trading market

In the electricity market, the minimum amount of demand control capacity for electricity trading is equivalent to 9,000 houses. One of the objectives of the ICT platform (via the data centre) was to be able to scale up the data collated from the 550 properties and to model this to show estimated performance data for 9,000 properties, for trading demonstration purposes. The system offered an inter-aggregator interface with features of scalability and flexibility with real time processing ability as an aggregation system. Further details on the aggregation system are explained in chapter 5.

4.4 HP Installation

550 HPs were installed, including 540 Daikin units and 10 Hitachi units. The table in figure 4-6 shows the result of the HP installation.

The most commonly selected heat pump was Daikin's Low Temperature (LT) Split, which offered the highest levels of efficiency and flexibility from a heat pump system when faced with space, aesthetic and noise restrictions.

Figure 4-6 HP Installation Result

	Without Buffer Tank				With Buffer Tank			Sub Total
	Electricity			Gas Hybrid	Electricity		Gas Hybrid	
	LT Split	LT Split Hitachi	Monobloc	Hybrid	LT Split	Monobloc	Hybrid	
WALH	161	8	127	7	3	1	0	**307**
NWH	70	2	27	35	19	0	0	**153**
STH	0	0	15	75	0	0	0	**90**
Sub Total	**231**	**10**	**169**	**117**	**22**	**1**	**0**	**550**
Category Total	**410**			**117**	**23**		**0**	**550**

The map in figure 4-7 highlights the geographical spread of the installations.

Figure 4-7: Location of HP installations

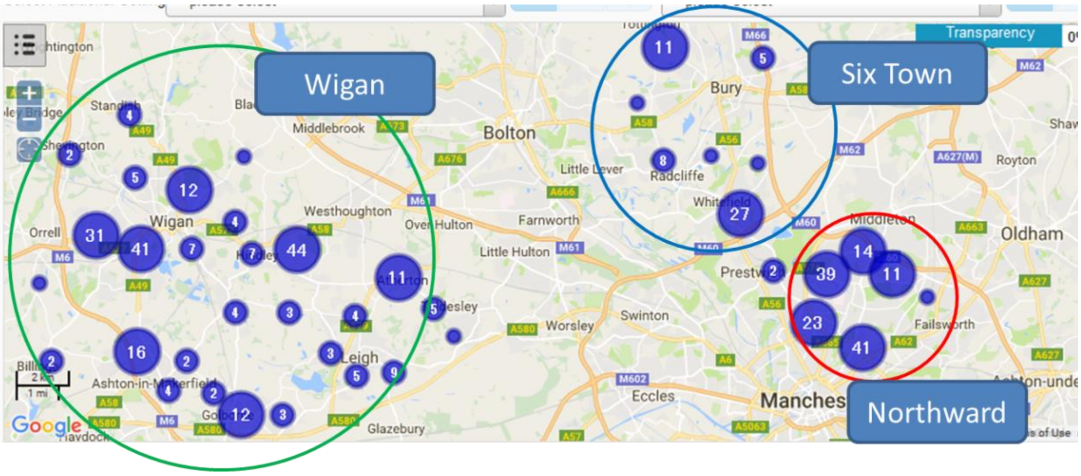
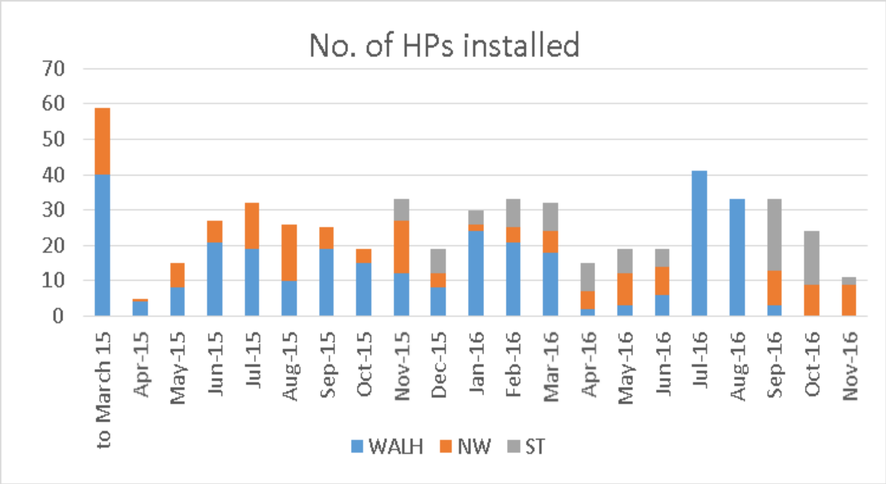


Figure 4-8 shows the HP installation profile for the project split by ALMO. The average installation rate was 6 per week over the total installation period. The maximum rate of installation achieved was 10 per week on two occasions.

Figure 4-8: HP installations over time split by ALMO



To improve installation targets and increase the available pipeline of properties, the ALMOs agreed to install HPs in void (empty) properties. This approach had pros and cons. It meant that installations could be planned and carried out quickly without relying on tenant availability, or having to cause any tenant disruption, as these could be slotted in with resource availability. However, it also meant that these properties were not connected with Broadband[3] at the time of HP/HGW installation as they were not occupied.

On some occasions installations in void properties had to take priority over some of the scheduled installations, due to the pressure to re-occupy these properties quickly. Figure 4-9 shows that in total, 103 installations were completed in void properties.

Figure 4.9: Number of installations in void properties

ALMO	WALH	NWH	STH	Totals
Completed	74	13	16	103

Additionally, 40 heat pumps were installed in two blocks of sheltered flats in Wigan and a further 11 in Northwards.

4.5 HP Operation Monitoring and Management

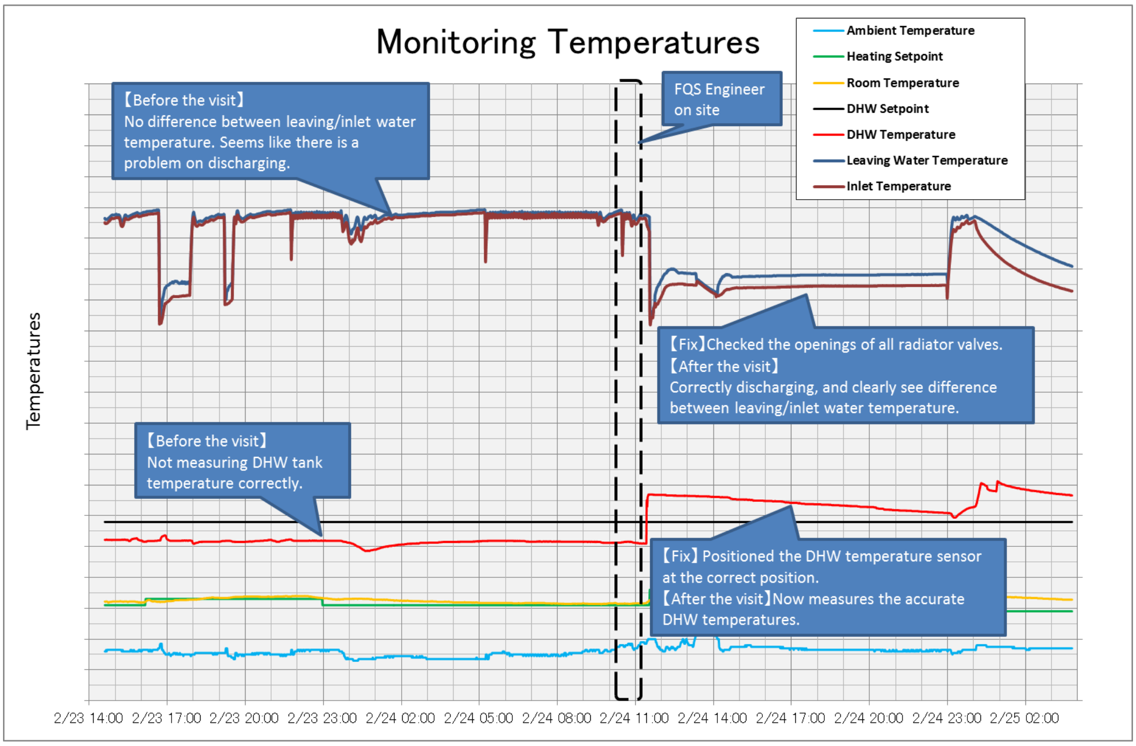
Once the HPs and associated electrical monitoring equipment were installed, processes were established by both Daikin and Hitachi, in collaboration with the ALMOs, to monitor the HP systems and respond to any technical issues identified and call outs from tenants reporting issues.

A triage system was set up to identify issues and who should respond to these, with the contractor (WES) established as the first responder upon a call to the ALMO customer services departments.

The granularity of monitoring of data enabled HP operational issues to be picked up quickly and engineers notified to attend the properties and resolve these. An example of a HP monitoring profile is detailed in figure 4-14 below:

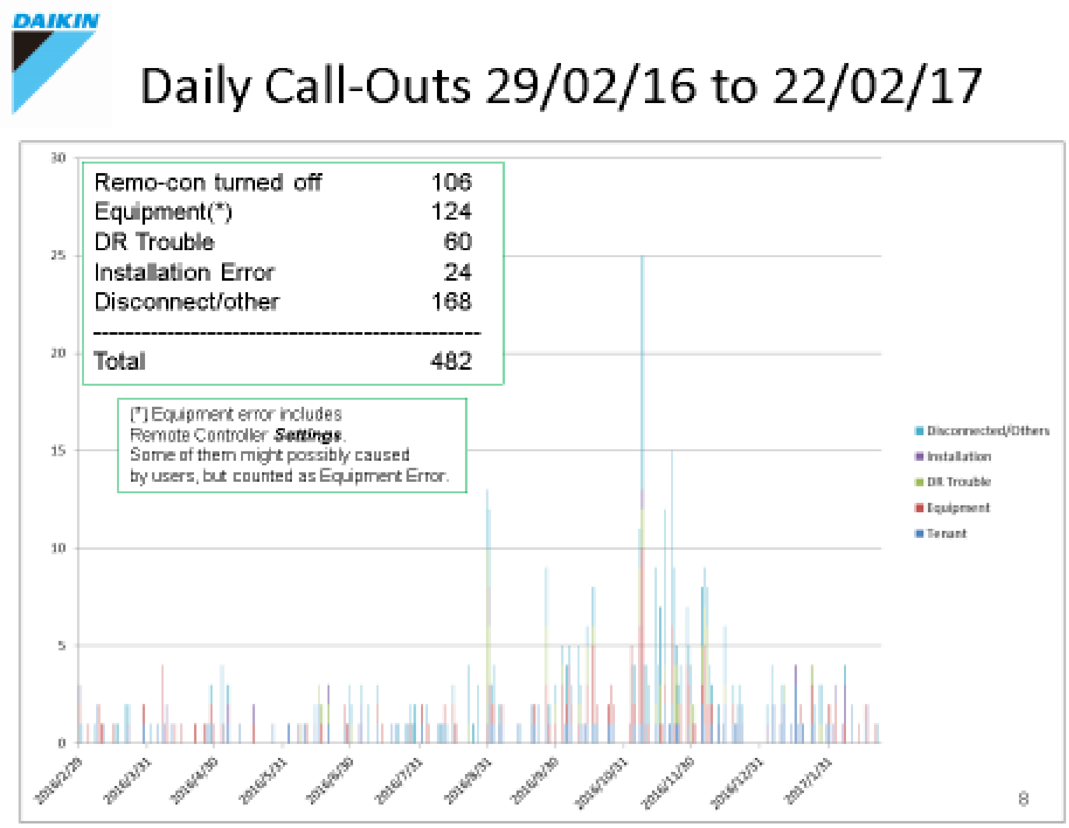
[3] ALMOs did not want to install Broadband into void properties, in the event that any new tenants would likely provide their own BB / set up their own BB contract.

Figure 4-14: Monitoring the activity of a heat pump system.



Calls made by tenants were monitored by Daikin to establish trends between issues. Figure 4-15 below demonstrates the daily call outs received by Daikin during the demonstration phase of the project.

Figure 4-15: Graph showing daily callouts to Daikin



Examples of technical reasons for call outs include:

- Remote-controller turned off - when service engineers called or visited properties, the remote controllers were turned off, without any factors related to equipment or the system. Presumably, they were simply turned off by tenants.
- Gas valve issues – a fault with some of the valves was identified and the affected valves were replaced
- DR policy error – the DR code to re-start the HP after a DR event didn't re-start the heating and hot water functions. This is shown as the spike in call outs seen on the graph above and was quickly identified and rectified.
- Installation faults identified including loose cables, wiring errors

Many call outs were due to tenants' lack of knowledge of their new heating system and included calls relating to radiators not being as hot as their previous systems, tenants inadvertently switching their HP system off and reports of heating systems being off during a DR event.

4.6 HP Installation – Challenges

During the installation phase, several difficulties were encountered which slowed down the installation process for both the HPs and the associated electrical monitoring equipment, eventually reducing the overall installation numbers and resulting in a significantly longer installation period than originally planned. These challenges are outlined below:

4.6.1 Insufficient Pipeline of Properties

The original implementation plan assumed a strong 'pipeline of properties with signed up tenants and DNO approval at the start of installation phase. The installation rate was dependent on the available pipeline of properties each week.

Tenant participation in this demonstration project was voluntary therefore, for the project to be viable, the uptake by project participants was vital. Despite the recruitment incentives including free Broadband for up to 2 years and a free tablet, tenant sign up to the project was particularly challenging, with uptake lower than anticipated.

By the end of the project, over 1650 properties were identified as potential properties to target in the trial, across the three ALMOs. These were selected primarily based on the age and type of their existing heating and whether they were due to be included in forthcoming boiler replacement schemes. Tenants in all 1650 properties were approached to ask if they wanted to participate in the trial.

Approaches to tenant sign up differed by ALMO, primarily based on the resources available to undertake this activity. Where tenants were directly approached by a telephone or face to face visit there was a higher uptake than when they were invited to participate by letter.

The table below in figure 4-10 shows the number of tenants engaged and subsequently 'signed up' by each ALMO. As originally agreed, STH didn't start installations until November 2015, which increased the pressure on the other two ALMOs in the first10 months of the project.

Figure 4-10: Number of tenant engaged, and number of tenants signed up and installed

ALMO	Tenants Engaged	Tenants Signed Up	% of engaged tenants signed up	No. HPs installed	Initial HP installation target
Wigan and Leigh Housing	1082	315	29.1%	307	300
Northwards Housing	258	163	63.2%	153	75
Six Town Housing	418	160	38.3%	90	225

A significantly high proportion of properties with initial tenant agreement to participate did not proceed to installation phase. This was due to a combination of technical issues and tenant decisions:

Properties not suitable for installation

Each selected property underwent a survey to assess current energy performance and suitability for HP installation. Of the initial properties selected and signed up, 159 were deemed 'not suitable' for a HP installation. Reasons for this were varied and included:

- no space in the properties for the installation works (either HP/ radiators or pipework required); properties not insulated sufficiently (and not able to be insulated in the scope of project);
- structure of properties was not suitable for a HP (too much external works required i.e. foundation work, asbestos issues, strengthening of beams, wall partitions);

- properties containing too much clutter / not suitable for an installation.

Tenants 'dropping out' of the demonstration

Of those that signed up and were deemed 'suitable properties' at survey stage, 108 did not proceed to installation, the reasons for this were varied, including:

- tenants simply changing their minds, there was often a delay between sign up and implementation
- long term health issues of tenants or their relatives not wanting the HP installation to proceed (particularly in the cases of elderly or vulnerable tenants);
- tenants not prepared to move their furniture / flooring to accommodate the installation.
- tenants felt they were not fully aware of the extent of the work required at initial sign up stage and did not want the disruption.

The table in figure 4-11 below outlines the total number of properties surveyed vs the number that were installed. This shows that 817 properties were 'signed up 'to participate in the trial, however of these 159 were deemed unsuitable for the HP installation and a further 108 (suitable properties) were cancelled by the tenant, an overall drop out of 33%, which was higher than anticipated.

Figure 4-11: Number of cancelled installations

Details	WALH	NWH	STH	Total	
Installed	307	153	90	550	67.3%
Not Suitable for Installations	76	25	58	159	19.5%
Cancellations	35	39	34	108	13.2%
Total	418	217	182	817	100.0%

4.6.2 DNO Approval - Policy

Electricity North West (ENW) operates and maintains the North West's electricity distribution network, connecting 2.4 million properties, and more than 5 million people in the region to the National Grid.

In this project, ENW worked in collaboration with the project partners to ensure the project could complete the number of installations without overloading the network.

In phase 1 of the project (the first 60 installations) ENW undertook network reinforcement works on an initial 'long list' of 300 properties provided by the ALMOs. It was assumed that the majority of tenants would be signed up from this initial list, however many of these initial properties were either not suitable (structurally) for a HP or the tenants did not wish to participate in the trial (in many cases they simply did not respond to the letters sent to them). This meant that the ALMOs needed to create further 'long lists' of potential properties.

In phase 2 of the project (from April 2016), ENW took a 'business as usual' approach assessing the network capacity for the selected properties. This required the project partners to voluntarily notify and seek approval from ENW in advance of the installations taking place for each property. DNO assessments were undertaken under normal operating conditions and the guidelines set by the DNO caused an initial delay to the project. For example, a Form B approval takes up to three months and a requirement for reinforcement work of the network can take up to 12 months to complete (leading to a high risk of tenants dropping out of the process).

To overcome this delay, ENW met with each ALMO informally to review the likelihood of network reinforcement requirements and set up a 2-stage ‘filter’ process to reduce the complexity and timescales of the network capacity analysis, with ALMOs undertaking an initial review to understand potential looping constraints. In addition, Daikin ensured that the heat pumps operated within the required limits allowed by the DNO. This significantly reduced the planning time for future installations.

4.6.3 Delays to Electrical Monitoring Equipment Installation

The electrical monitoring equipment was installed to measure the power consumption of the HP, measure the total consumption amount for the whole house (to enable a comparison with the power consumption of the HP) and enable communication to the HP aggregation system and data centre. It was an integral component of the project and essential for the DR trial.

A significant delay was encountered in installing the electrical monitoring equipment for the project (the Netcomm Home Gateway Units (HGW) and electrical power meters (EDMI meters). This occurred due to an unforeseen delay in the development and initial testing of the electrical monitoring equipment and hardware changes.

The initial schedule for installation of the HGW and EDMI meters was pushed back to start from September 2015. This meant that between January 2015 and September 2015, 162 HPs were installed without the associated electrical monitoring equipment.

The electrical monitoring equipment installation commenced in autumn 2015. However, several defects (firmware bugs) were subsequently found on the devices during the installation period. Analysis of these defects found that these could not be fixed remotely. The installation was then suspended in March 2016 for a further 2 months, in order to modify and retest the equipment.

The HP installation continued on without the electrical monitoring equipment during this time, which resulted in the need to put in place a retrofit plan, to schedule revisits to the properties and replace the 162 defect equipment already installed in properties, at the same time as installing the remaining electrical equipment in properties (with HP already installed) and also moving forward to install electrical equipment at the same time as new HP installations once the bugs had been resolved.

This multiple programme of installation increased the complexity of the scope of the installations and was implemented with finite electrical expert resource available. The delay in installation of this equipment led to a significant number of ‘revisits’ to properties to retrospectively install the equipment. This created a strain on the project resources to meet the challenging installation timescales.

Figure 4-12 shows the installation schedule of the Electrical Monitoring Equipment. In the end, the project installation phase was extended by 3 months, to December 2016, to complete this work and for a small number of outstanding properties, installation booking continued until February 2017. This had a knock to effect to the length of time available within the timescales of the project to monitor the performance of the HPs and undertake the DR trial on these properties.

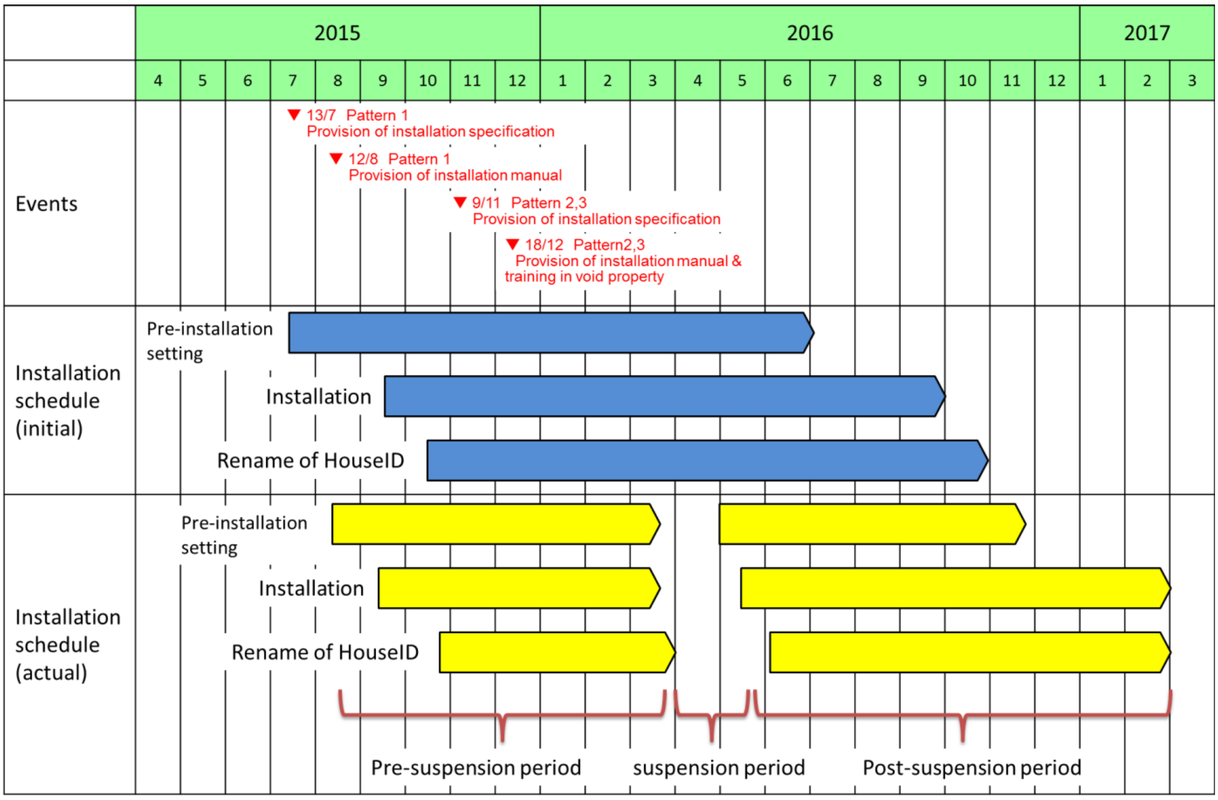


Figure 4-12 Installation schedule of electrical monitoring equipment

4.6.4 Resource constraints

The delay to the installation phase created significant additional workload for the contractor and ALMOs to re-book and revisit properties to install and commission all the equipment. This was compounded by the tight timescales remaining to install the equipment and led to challenging targets being set to meet these timescales.

The installation programme was re-scheduled a number of times, due to slippages, to try and meet the final install date of the end of September 2016. This put pressure on the contractor to increase HP install rates to 10 per week over the spring and summer 2016, and HGW installation rates to up to 20 per week.

Whilst in theory, the appointed contractor, Warmer Energy Service (WES), had internal resource to meet these increased installation rates, they also had other work commitments and resource was sometimes allocated elsewhere.

The project consortia partners worked closely with WES to provide training on the HP systems, however, it proved difficult to maintain a high skill level amongst the engineers in WES. This was due to the high mobility of human resources in WES and additional contractor resources required to manage the HGW retrofit programme at the same time as the HP installation. This was compounded by the installation of two different brands of HP, and the interface between the systems.

There were instances reported where tenant appointments were made and the installers arrived on site without all the items necessary, resulting in re-scheduled visits to complete jobs that should have been completed in 1 day.

There was also a higher than anticipated number of ‘snagging’ issues identified following the HP installation, including incorrect piping works and electrical connections and some errors in undertaking installation steps. Errors in installation arose partly due to the intense pressure of installation timescales and limited resource on site, for example, in some instances, the quality of LAN cable which was used to connect HGW and broadband router was found to be of poor quality resulting in disconnections occurring after installation and a number of mistakes were found after installation when exploring reasons for disconnections.

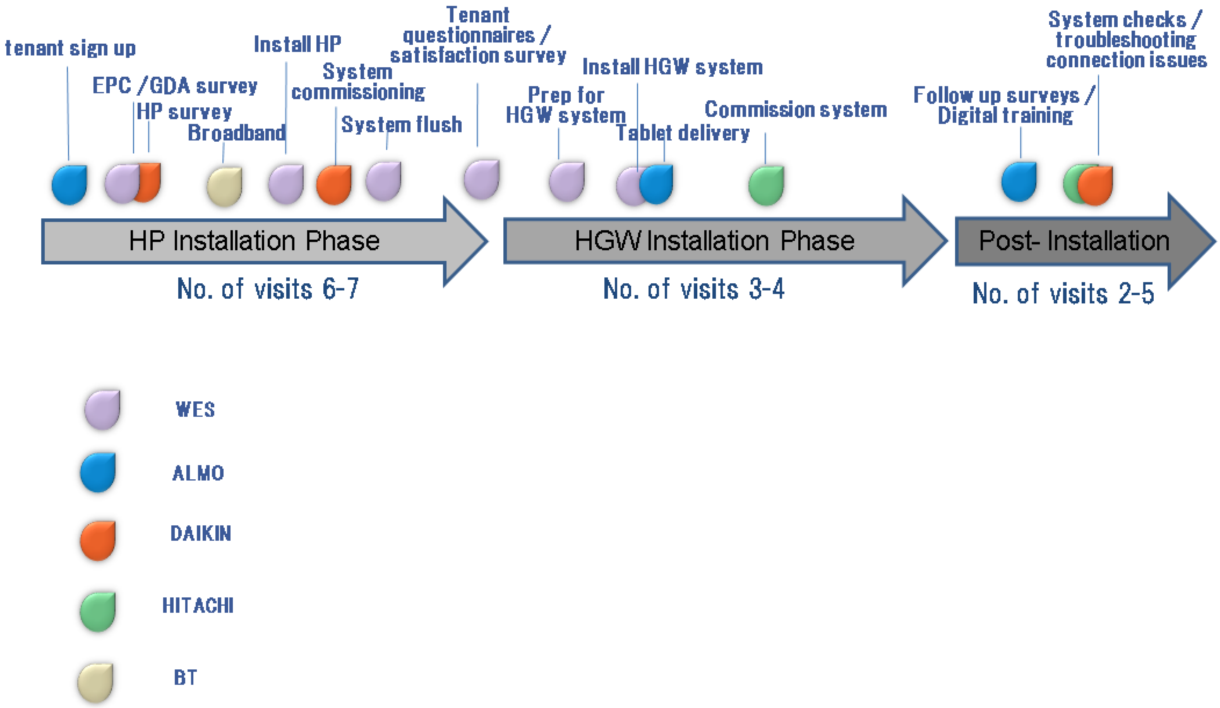
The requirement for electrical surveys/works and testing and training of the installation process was not realistically factored into the overall resource planning.

4.6.5 Tenant Access Issues

Installation was impacted by the lack of tenant access to the properties. With an average cancellation of 30% (this figure includes multiple attempts at the same property), over 30 bookings needed to be made each week to try and meet the target install rate.

This was a much bigger issue than anticipated, compounded by the multiple visits required due to the delay in the equipment installation. Rather than one short programme of installation, in some cases this was spread out over several months. As the diagram below shows in figure 4-13 multiple access requirements at each property and the ad hoc installation of equipment by different parties meant that the number of repeat visits to the properties was much higher than originally anticipated with, in some instances, over 20 visits required to successfully complete the full installation phase. The result of this was that some tenants were uncooperative in allowing access into their properties.

Figure 4-13: Average number of property visits for separate installations



Difficulty with access was encountered at all stages of the process; design stage, sign up stage and even on the day of installation. This created a real issue for allocation of project resources and time wasted making visits to properties.

By the end of the project, following a period of intense tenant engagement by the ALMOs, only 7 properties did not have the electrical equipment installed after the HPs had been installed. The project partners tried to gain access multiple times, with letters sent to the addresses and house visits made by the ALMOs, but unfortunately access was not granted as these tenants either refused access to their properties or were unable to be contacted after the HP installation.

It was anticipated that the provision of the tablets would encourage tenants to allow access into their properties, as these were not delivered to the tenants until the HGW was installed. However, the tablet did not appear to act as an incentive in many instances. In addition, the delay in the rollout of the tablets impacted on the number of tenants actively engaged with using these to monitor the demand response events in their properties.

4.6.6 Broadband Installation

A further challenge arose with the installation of broadband routers (BBR) in the properties, an essential component of the full system connection. The installation process was time consuming, relied on tenants (or ALMOs, in the case of void properties) waiting for long periods for BBR installers. Additionally, the BBR contracts proved to be more expensive than anticipated, as they were managed on a commercial basis, as opposed to a domestic tariff.

It was essential for the BBR to be installed before the full system could be commissioned. Towards the end of the project, the lack of BBR had an impact on the length of time that a number of properties could be monitored in the DR trial. This was an issue for the void properties, as BBR could not be installed until after the properties had been re-tenanted.

4.6.7 Planning Approvals / Acoustics

As part of the procedure for gaining planning approval for the installations in sheltered housing blocks of flats, the heat pumps had to meet the requirements set for noise levels in residential spaces. Delays in acoustic testing and planning submissions for the blocks of flats were experienced

If more than one heat pump was installed in an adjoining or curtailment of a building, then there was a chance the noise level would have an effect on the neighbouring property. Assessments had to be carried out in connected or adjacent properties. Liaising with residents and providing clear information was vital for effective assessment.

Wigan and Leigh Homes contracted an acoustic engineer to survey the noise levels emitted from the site during day and night. This data was then used to apply an average minimum noise level for each. With the data assessed, it was noted that the heat pumps were not meeting night time noise level requirements. Following a consideration of all options, Daikin was able to set the silent running mode to occur automatically on a timer, the solution was accepted on the basis that the setting could be made at the commissioning stage.

Overall, project partners felt that Local Authority planning teams involved in this project struggled to fully understand the requirements of the project and the new technologies involved.

5. Theme 2: Aggregation System Demonstration

This chapter is split into two sections:

- **Data Collection and Analysis**
- **Demand Response Trial Results**

5.1 Data Collection

HP operation data was collected between October 2015 and March 2017 on the number of HPs that were installed at the time. The advanced meters installed allowed electricity consumption data acquisition at 1-minute interval. This granular data was communicated to the HGW using ZigBee, which meant that real time data from Electrical Monitoring Equipment could be reflected in the data centre.

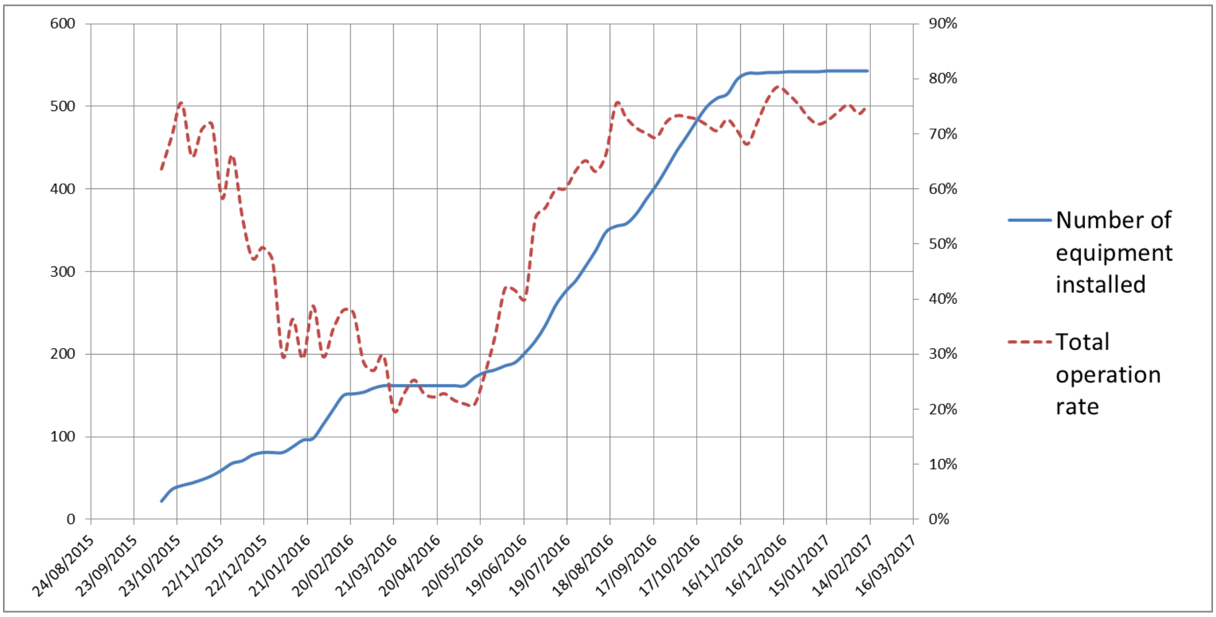
The table in figure 5-3 shows the general specifications of the data collected.

Figure 5-3: Data collected

No	Item	Explanation
1	Data source	Power value measured by sensors in Daikin HP (DK) Power value measured by sensors in HACE HP (HACE) Power meter value via Hitachi HGW (both HP and whole tenant) (HGW)
2	Data interval	1 minute
3	Period	Oct. 2015 – Mar. 2017 (18 months)
4	Number of data available tenants	9 – 428
5	Significance level	5% (Usual value in statistical analysis)

The graph in figure 5-4 below shows how many systems were fully connected and operational for the DR trial. The number of HPs (and associated monitoring equipment) installed are shown in the left vertical line vs the number of operational systems (right vertical line).

Figure 5-4



As the graph shows, the volume of DR equipment in effective operation is lower than the total equipment installed. By the end of the project trial 70% of the total installed equipment was DR operational and the highest operation level achieved during the project was 79%.

The operation rate of the equipment (March 2016 to May 2016) was due to the delay and subsequent defects of the electrical equipment, however there was also a significant volume of properties where previously connected and operational equipment was suddenly no longer connected.

Several visits were made to tenants' properties to switch back on the HGW and where disconnections were repeatedly identified, phone calls were made to tenants to talk them through the re-connection. "Do not unplug' labels were printed and placed on all new installed cables once the tenant unplugging issue was identified. Letters were sent out to all tenants requesting that they did not touch any equipment. Tenants were also asked to pre-notify their ALMOs if they were considering changing BBR provider.

5.2 Data Analysis

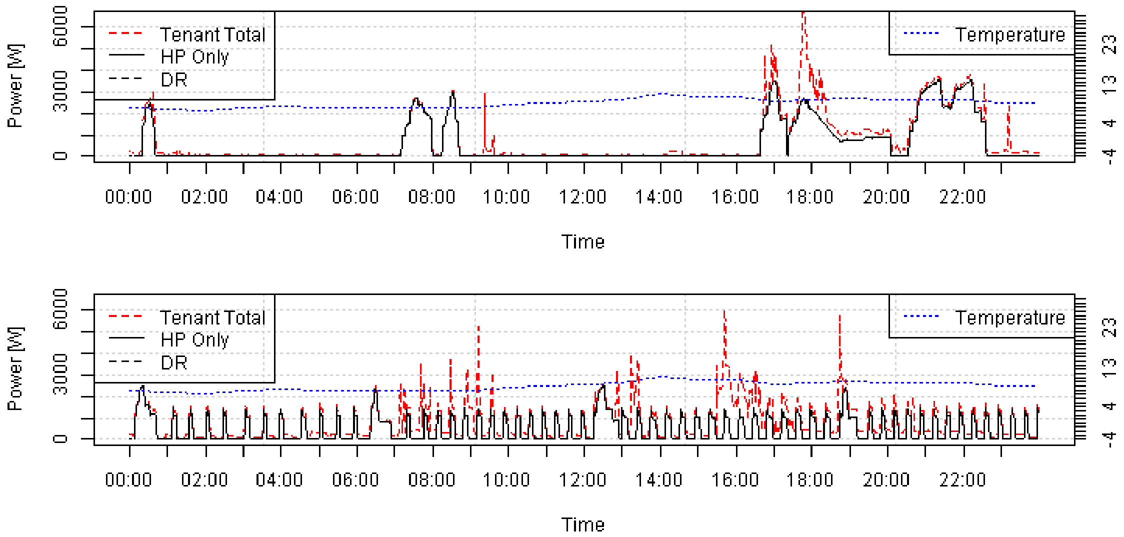
Analysis of the data collected from the Heat Pumps was undertaken by Hitachi Ltd. Initial analysis looked at the power consumption profiles of the properties to look at trends in the data and establish the appropriate times to undertake the demand response trials.

For the purposes of trading and settlement, electricity is generated, transported, delivered and used in half hour segments called 'Settlement Periods'. For each half hour, those with demand for electricity will assess in advance what the demand will be. They then contract with Generator(s) for that volume of electricity. The energy generation savings from the DR trial in this demonstration were measured in 'settlement period' half hourly amounts.

5.2.1 Power Consumption Profiles

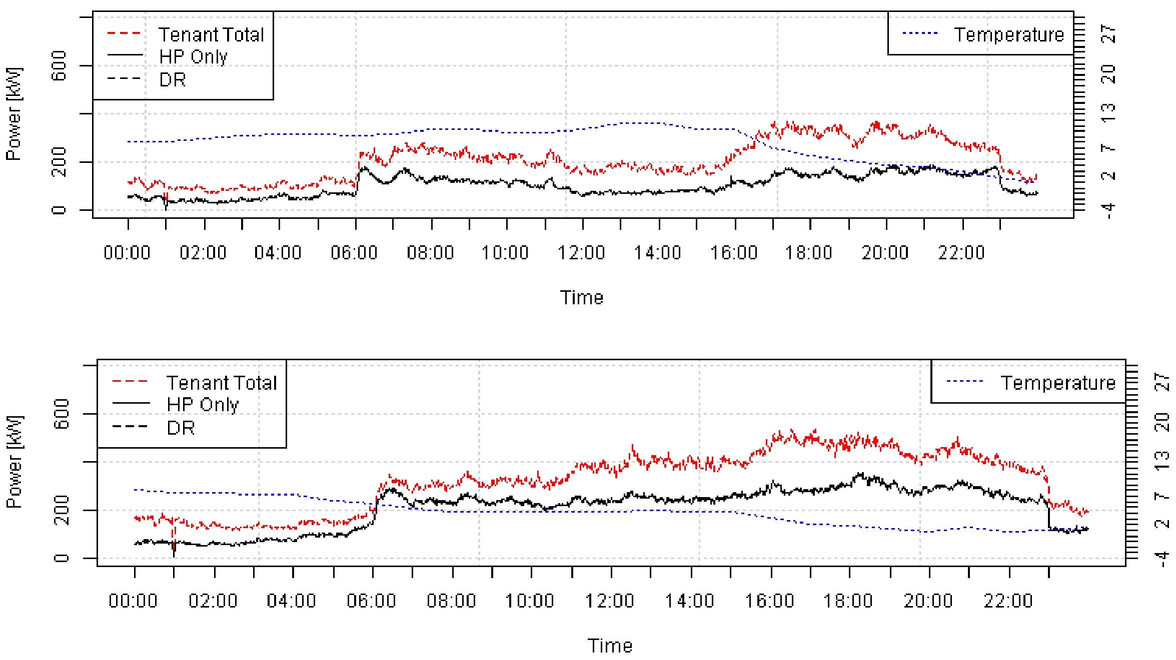
The graphs in Figure 5-5 show two example property profiles. The graphs show a day profile of HP power consumption ("HP Only") and whole property power consumption ("Tenant Total"). As shown in these two examples, each HP operates with an irregular cycle, dependent on each tenant's heating settings and usage behaviour with no significant pattern. The blue dotted line is external temperature.

Figure 5-5: Examples of power consumption profile of single properties (without DR)



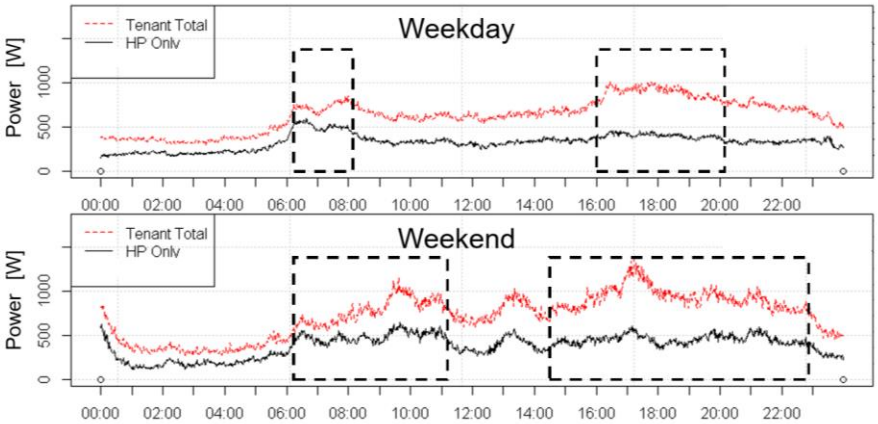
The data collected from the individual HPs was aggregated together to review trends in HP performance across a large number of properties. Figure 5-6 below shows examples of aggregated data profiles. The aggregated profiles show a clear pattern showing two peaks in a day; from 6 am to 8 am in the morning and around 6 pm in the evening.

Figure 5-6 Examples of aggregated profiles



These peaks can be seen clearly for both weekday and weekend periods, as shown in figure 5-7 below.

Figure 5-7: Peak profiles



The observed peak profiles were used to identify the appropriate timings for the DR events, which were performed twice a day between 06:30-08.00 and 17.00-18:30, with the period of each DR event varying depending on the use case being tested.

The graph below in figure 5-8 shows the total mean power consumption profile of all connected properties during the trial. This clearly shows the morning and evening peak values. Time granularity is 30 minutes average power value.

Three key Settlement Periods (SPs) were identified to undertake the DR trial to correspond to two peaks and one or two valleys. The two time peaks (identified as KeySP1 and KeySP3) were used to test load shedding DR and the valley (identified as KepSP2) was used to test power absorption DR.

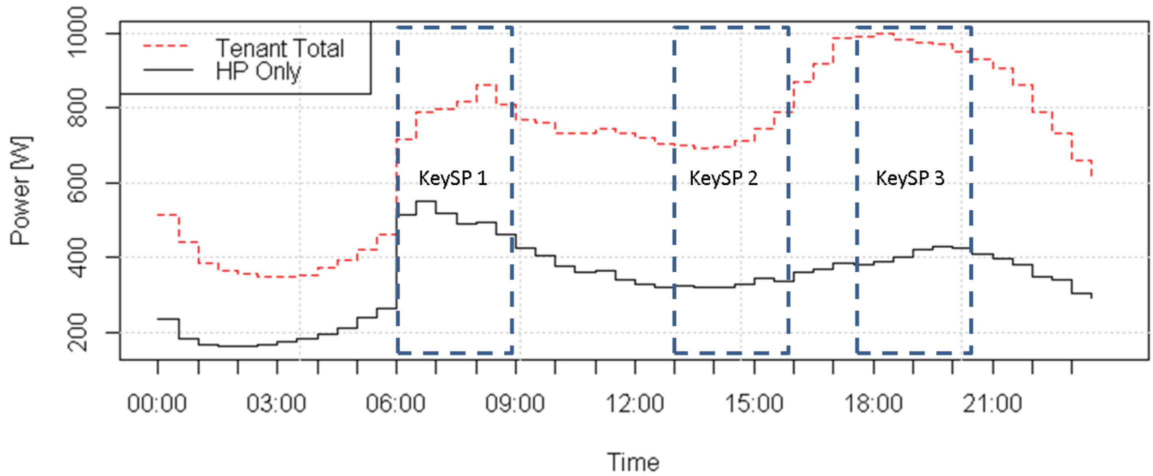


Figure 5-8 Average day profiles of all data

Data from the demonstration trial was extrapolated and tested to produce a simulation model to test the viability of the trading conditions (use cases) in the project.

Key points to note are:

1. There is a clear variation in a day even with aggregated data which reflect residents' life

patterns and intermittent power demands. It is therefore difficult to develop one mathematical model for the cycle. Thus, an approach to develop models to treat certain time parts of a day was adopted.

2. The time unit of DR trading in the UK is Settlement Periods (SP) which is also a unit of trading in electricity market.
3. As there are peaks and valleys in HP power day profile, load shedding DR should be performed in the peaks and absorption DR should be performed in the valleys. So, these peaks and valleys are focused. There are two valleys as shown in Figure 5-8, so there are two options for absorption; daytime and night time. Among the two, only daytime was adopted considering ALMOs' concern that operation noise at night time may be troublesome to tenants.

5.2.2 Power consumption analysis

The HP data was used to undertake stratified analysis of the SPs within the peak values against external factors to create and test assumptions. Examples are outlined in the graphs below which show the mean HP power consumption for key settlement periods (SPs) analysed against HP capacity, weekend vs. weekdays and external temperature.

The graphs show that the value of the morning peak is larger than in the evening and that there is little observed difference between peak power consumption during the week and at weekends. As the external temperature increases, the power consumption decreases in all Key SPs.

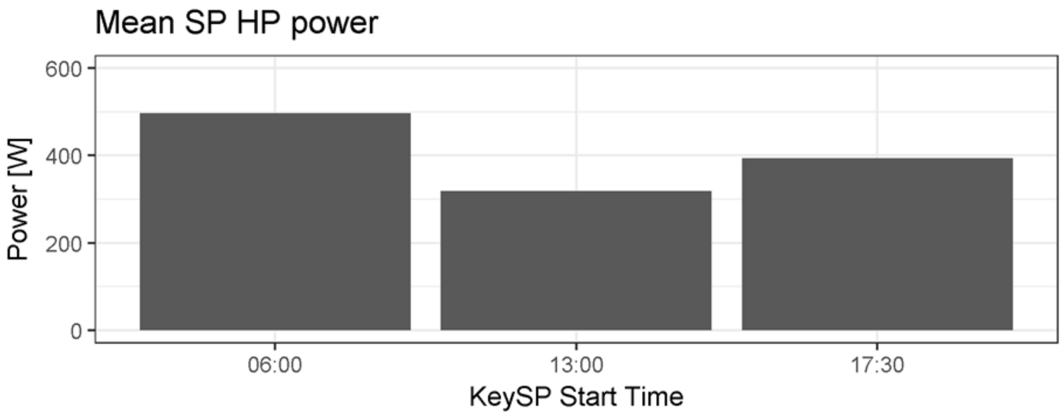


Figure 5-9 Mean HP power consumption of Key SPs

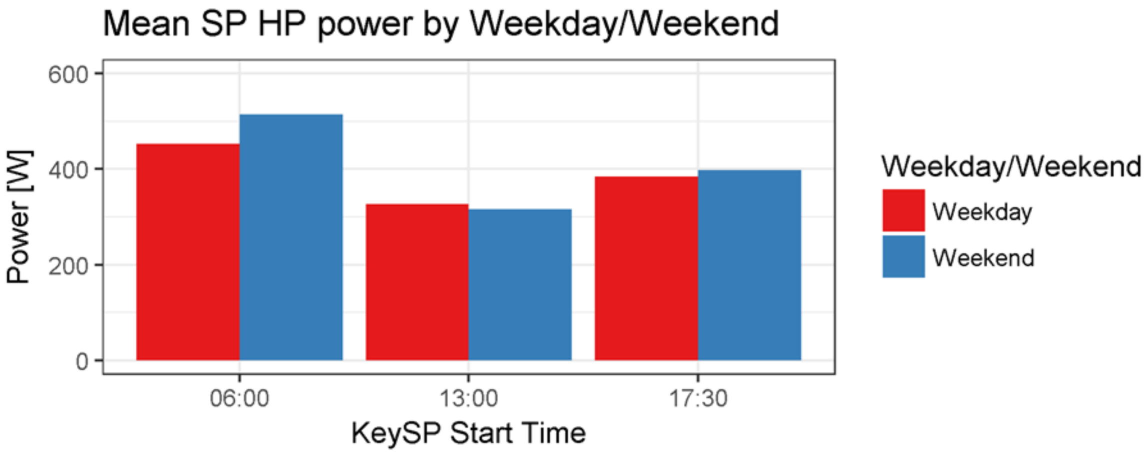


Figure 5-10 HP power stratified by weekday/weekend in Key SPs

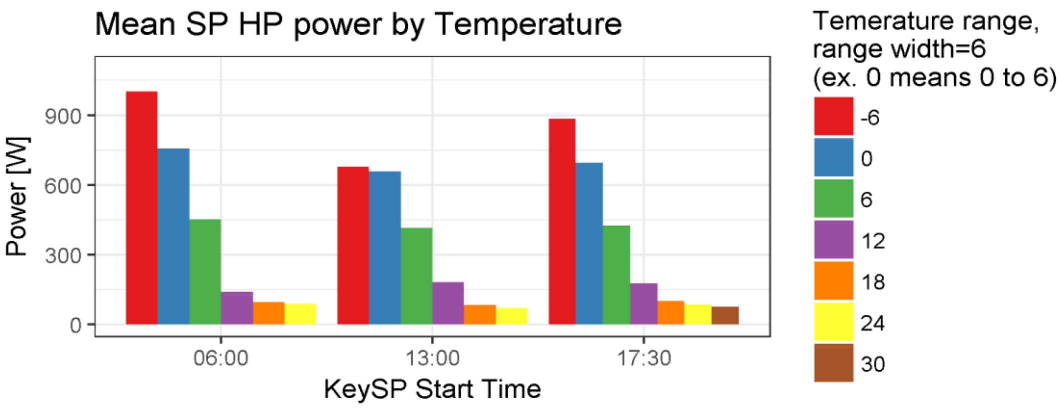


Figure 5-11 HP Power stratified by external temperature in Key SPs

Figure 5-12 below shows the average HP power consumption stratified by HP type and capacity. The Hybrid systems show lower power consumption compared with electric systems (without reference to capacity). In general, power consumption increases along with increase of capacity, however it was observed that the Split 8kW type was an exception to this, as this showed a lower power consumption than the Monobloc 7Kw. This anomaly could not be explained, and further analysis would be required to factor in installation of buffer vessels for example.

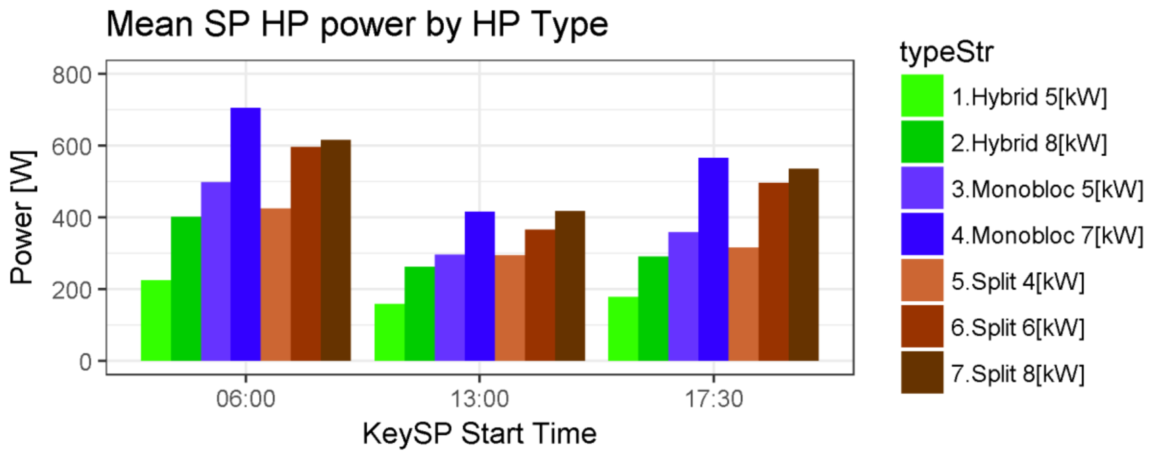


Figure 5-12 HP Power stratified by HP Type and capacity in Key SPs

Figure 5-13 shows time sequence of estimated HP power by month, focusing on the Key SP starting from 6:00am. As expected, in summer time, the values are smaller than in winter. This variation is thought to reflect external temperature and the relation is consistent with that shown in Figure ~~8-7~~5-11

The number of participants in the project increased over time, therefore in order to get an accurate average HP power by month, data was extrapolated for those periods where the tenant participation was low (at the start of the trial). Figure ~~8-9~~5-13 shows the estimated average HP SP power from October 2015 – to March 2017.

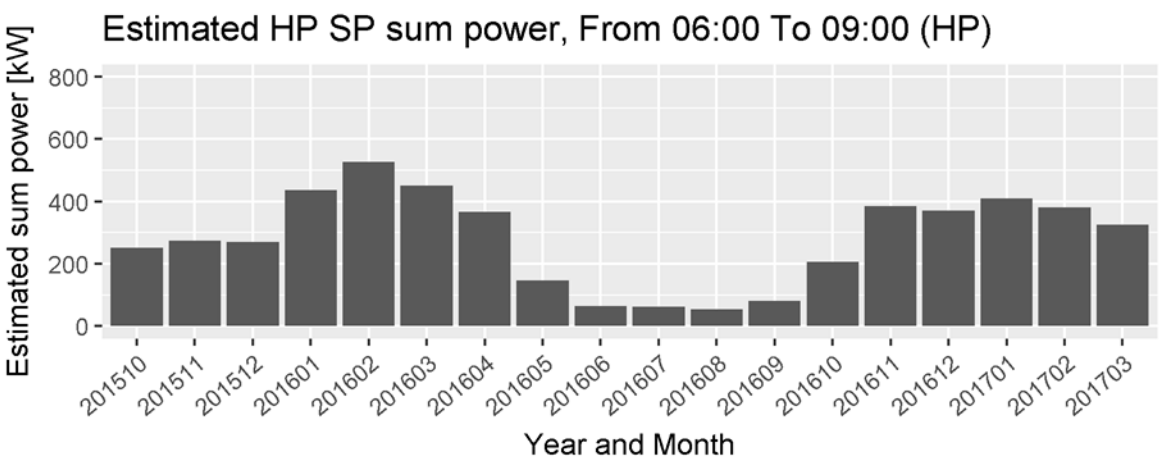


Figure 5-13 Estimated monthly average HP Power in Key SP starting from 6:00

5.2.3 Power Consumption Model

5.2.3.1 HP Operation

There is a difference in physical configuration and operation policy between the two types of HP (electric and hybrid) which result in different HP power consumption profiles under the same conditions.

A hierarchical Bayesian model was adopted to express features of the HP operation policy, considering the trends identified. Models were developed for each HP type, factoring in HP capacity and using external temperature as model parameter. These models were then integrated, resulting in a higher coefficient of correlation.

The diagram in figure 5-14 demonstrates the different power consumption profiles between the electric model and the hybrid model.

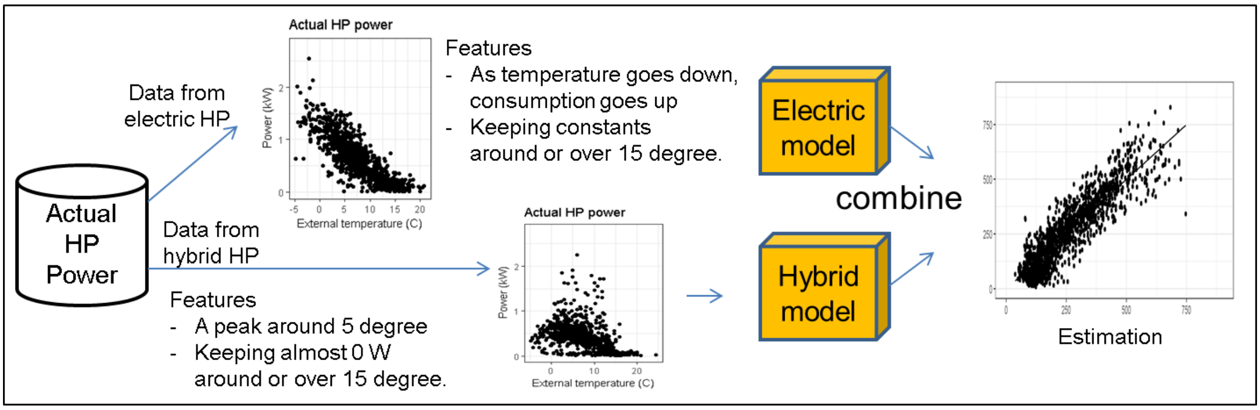


Figure 5-14: Difference between electric and hybrid HP power profiles

The diagrams in Figure 5-15 explain more fully the difference in operating policy between an electric HP model and a hybrid model.

In the hybrid model, the HP is used only for space heating and little space heating demand occurs when the external temperature is around or above 15 degrees C. Gas is used for space heating when external temperature is around or below -5 degrees C.

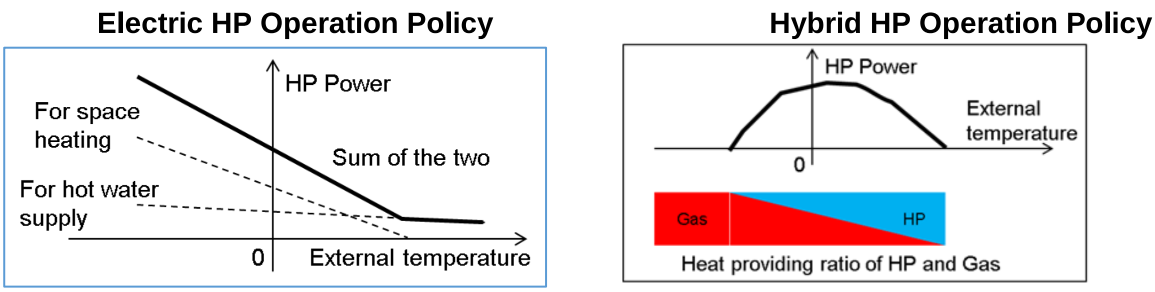


Figure 5-15: Operation Policy of HP types

The hierarchical Bayesian model was adopted to represent HP power with following features:

- Stochastic selection of heat usage in electric model
- Branching by external temperature range
- Variations over a year were considered, using monthly changes in parameters in the Bayesian model.
- MCMC (Markov chain Monte Carlo methods) was used for parameter estimation

A detailed explanation of the equations used to develop the model is covered in Appendix 4.

The actual and estimated (modelled) data of the power consumption for the Split 8kW type HP are shown in Figure 5-16 below, plotted against external temperature. There are multiple scenarios for the power values in the estimated figure, which reflect monthly changes in the model, as similar external temperatures in different months result in different values.

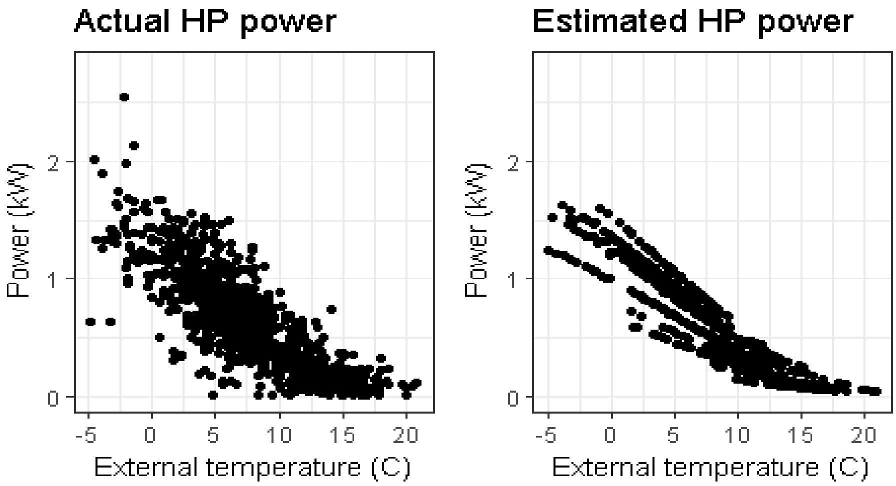


Figure 5-16 Actual and estimated HP power (Split 8Kw, Key SP of 6:00-)

The graph in figure 5-17 shows the correlation between the actual and estimated HP power consumption.
X axis: Estimated values by the model assuming 550 tenants
Y axis: Actual HP power values adjusted to 550 tenants

The solid line is the guide line, where estimated values equal actual value. A statistical test to evaluate how well the model fits was undertaken, giving a Pearson's product-moment correlation of 0.90, which indicates a strong correlation. The distribution of error is explored further in Appendix 4.

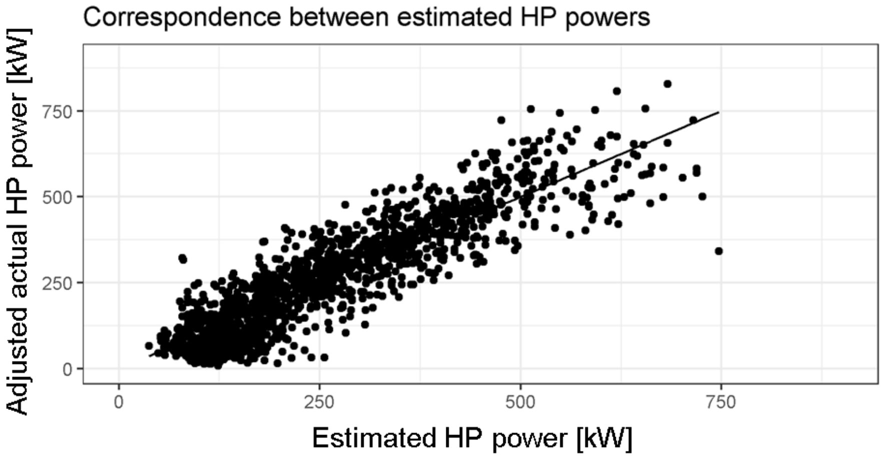


Figure 5-17 Correlation between actual and estimated HP power (Split 8Kw, Key SP of 6:00-)

5.2.3.2 Whole House Operation

One of the purposes of understanding whole house tenant power consumption is to understand the impact of the HP installation on the distribution network.

There are two consumption peaks which have large impact on the network, in the morning and in the evening. In general, the whole house power (tenant total) is about 2 or 3 times the HP power. As the graph in Figure 5-8 illustrates, the HP contributes a significant share of the whole house energy, particularly in the morning peak period.

Figure 5-18 shows the correlation between external temperature and whole tenant power consumption in Key SP 1 and 3. As with HP power consumption shown in Figure ~~5-11~~5-18, power consumption decreases along with increase of external temperature. In this case, when external temperature reaches around 15 degrees, power consumption remains constant.

There are two key points to note on the diagram:

1) The distribution of the graph for whole house consumption is similar to electric HP units
2) There is a large fluctuation in the spread of data - deviation in this scenario is approximately 500kW and this is larger than that of the HP. This deviation is thought to arise from variations in the number and type of electric appliances in the properties and their and usage by tenants.

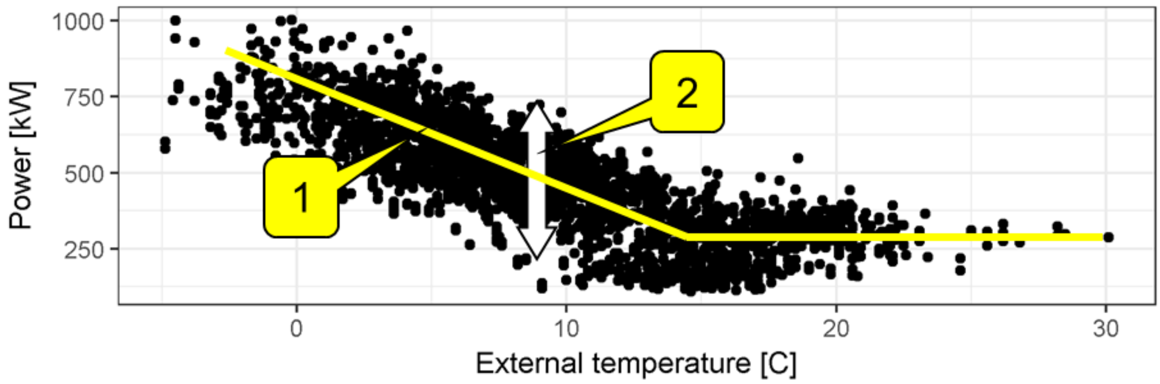


Figure 5-18 Correlation between external temperature and whole tenant power

Deviation models calculated for 'whole house' consumption are explored in Appendix 4.

An analysis of the top 10% of data was undertaken (Figure 5-19). Boxplot graphs were produced to understand the distribution of the peak values by month, by Settlement Period (SP) and by days of the week. The resulting graphs in figures ~~5-19~~5-20 – 5-22 show that peak values throughout the year are observed in winter, data generally peaks higher in the evenings and data distributes almost evenly between days of the week, with small observed increases between Sunday to Thursday.

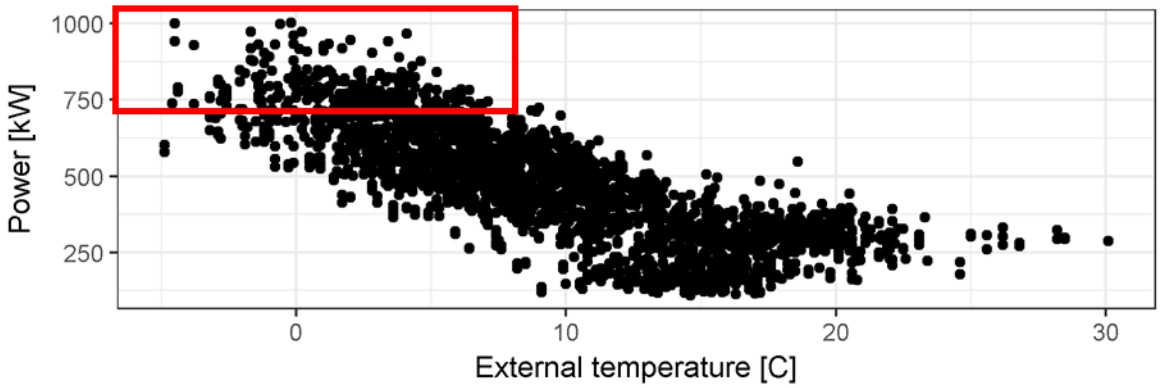


Figure 5-19: Top 10% HP power consumption data

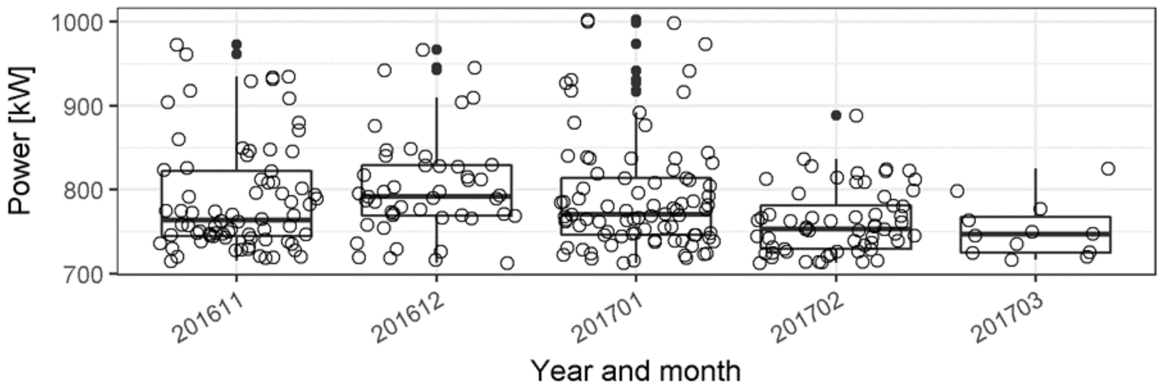


Figure 5-20: Top 10% data plotted by month between Nov 2016 and March 2017

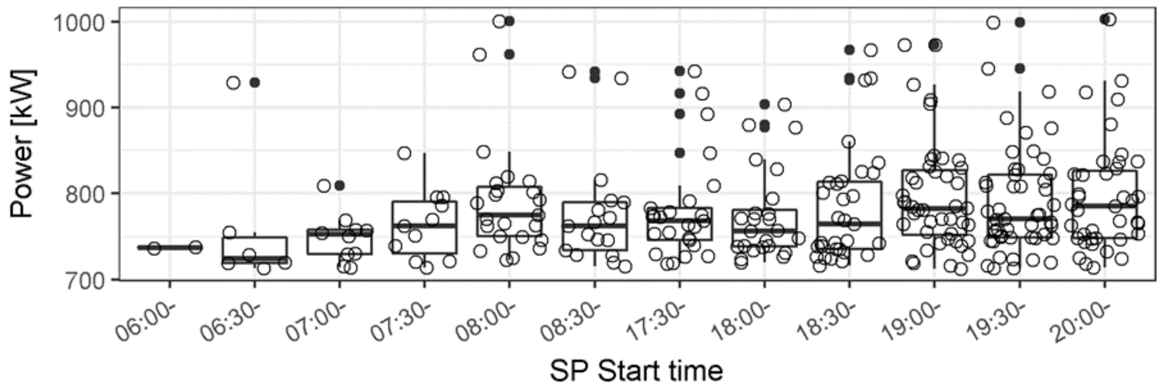


Figure 5-21: Top 10% data plotted by SP period start time

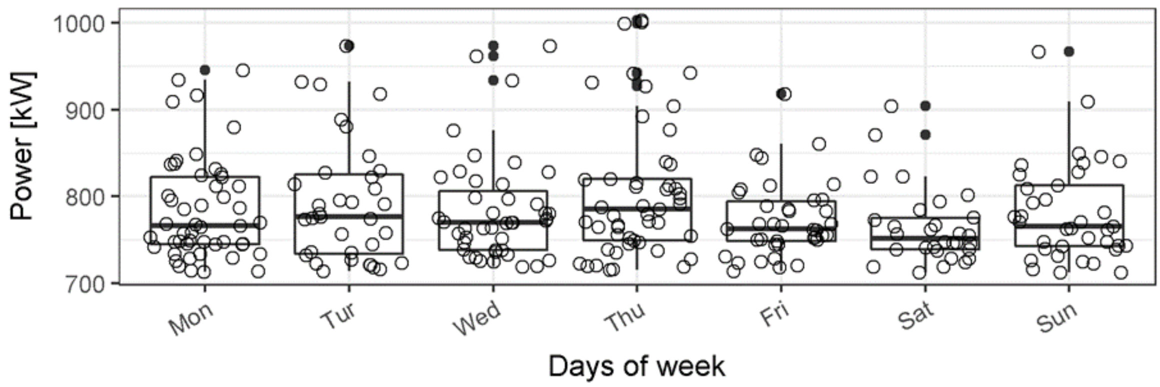


Figure 5-22: Top 10% data plotted by days of the week

5.3 Electricity Aggregation – Use Cases tested

Business Objective: To verify the effectiveness of electricity aggregation based on demand control capacity obtained by controlling Air Source Heat Pumps installed in social housing.

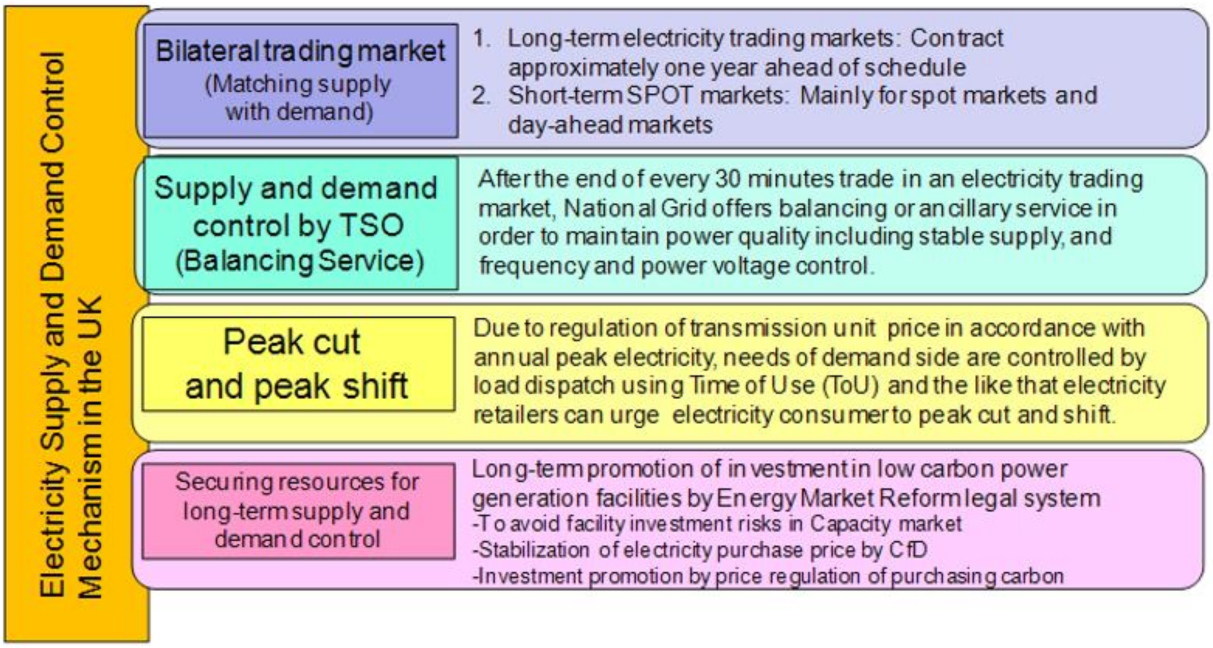
Financially, the electricity market needs to be balanced between estimated electricity generation and actual demand. In Britain, this is primarily done by suppliers, generators, traders and customers trading in the competitive wholesale electricity market. Trading can take place bilaterally or on exchanges, and contracts for electricity can be struck over timescales ranging from several years ahead to on-the-day trading markets.

The demand and supply control mechanisms in the UK can be roughly divided into 4 components as shown in figure 5-23 below.

(A) ***Bilateral market*** including short term SPOT markets and long-term electricity trading markets;
(B) ***Balancing Service market*** to execute imbalance adjustments after gate closure of electricity markets. National Grid procures Balancing Services in order to balance demand and supply and to ensure the security and quality of electricity supply across the GB Transmission System;
(C) ***Peak cut and peak shift demand*** - mitigating the effects of large energy load blocks during a period of time by advancing or delaying their effects until the power supply system can readily accept additional load;
(D) **Energy Market Reform (EMR)** - long term investment in low-carbon electricity generation;

As a variety of business partners and products are present in the UK electricity trading market, this demonstration aimed to test real market situations (trading conditions, system cooperation requirements, etc.) and identify cases where electricity aggregation using HPs can be used effectively.

Figure 5-23: Electricity Supply and Demand Control Mechanism in the UK



The Electricity Aggregation System was developed to be compatible with a variety of 'use case' trading schemes. In this demonstration, 7 use cases (UC) were defined at the feasibility study stage. The defined trading partners and purposes of trading are outlined below. Each UC is also explained in more detail in Appendix 3.

Figure 5-24: Overview of trading partners and target trades tested

Trading partner	Traded product or trading target	Details of trading target	Trading use case (UC)	Tested in this Project?
Existing aggregator	Demand reduction for ancillary service market	An aggregator (Flexitricity) sells electricity for ancillary service market. The electricity comes from demand reduction made by Electricity Aggregation system.	UC1	Tested using data from demo
Existing aggregator	Surplus absorption for ancillary service market	An aggregator (Flexitricity) sells electricity for ancillary service market. The electricity comes from surplus absorption made by Electricity Aggregation system.	UC2	Tested using data from demo
Distribution Network Operator	Demand reduction in abnormal circumstances	To provide demand reduction by Electricity Aggregation system upon	UC3	Tested using data from demo

(DNO)		request from electricity distributors in abnormal circumstances.		
National Grid	STOR (Short Term Operation Reserve)	To supply or consume electricity by Electricity Aggregation system according to demand fluctuation.	UC4	Tested using extrapolated data from demo
Electricity retailer	SPOT	A retailor sells electricity for Spot market. The electricity comes from demand reduction made by Electricity Aggregation system in a short time frame.	UC5	Tested using a simulator model
Electricity retailer	Load shift due to the increased demand	This service is for load shift due to the increased demand.	UC6	Tested using a simulator model
Electricity retailer	Peak shift and peak cut by tariff	This service is for peak shift and peak cut based on hourly electricity tariff.	UC7	Tested using a simulator model

The primary test set by NEDO was to establish whether 200kW of nega-watts energy saving could be achieved from up to 550 properties.

UC1 to UC3, shown in Figure 5-24, were tested during the demonstration using actual data obtained in the trial. To conduct a demonstration close to actual trades, it was necessary to meet a variety of conditions stipulated in the trade rules. The minimum trade amount is 200kW (UC1). Therefore, the number of HPs required for assuring the negawatt to be offered (200kW) was estimated and assumed to be circa 550 (from the feasibility study).

UC4-7 were tested using simulation models developed in the demonstration. For UC4, a calculation was undertaken to estimate that 9,000 HPs would be necessary to achieve the minimum trading volume and this was simulated (extrapolated based on the results of the HPs in the trial).

As it was not feasible to designate a single Retailer as a partner in the Demonstration Phase, it was not possible to conduct the demonstration by establishing a connection with the trading system for UC5-7. However, as these trades represent a viable business opportunity, the demonstration was conducted by way of simulation using an emulator (a mechanical environment simulating the system of the business partner) instead of the system of the business partner, generating pseudo transactions.

5.4 Demand Response conditions

Data collected from 18th Nov 2016 onwards was used for the quantitative DR evaluation, when the number of DR target tenants were sufficient in number to evaluate the DR. The aggregated heat profiles were used to determine the timing of the DR events.

DR events were performed twice a day between 06:30-08.00 and 17.00-18:30 with the period of each DR event per property varying depending on the use case being tested.

The trial was delivered on the basis that all participating tenants ‘opted in’ to the Demand Response (DR) events, however in order to protect tenant comfort and inherent safety, the system automatically opted out from DR under two ‘failsafe’ conditions:

- If the room temperature decreases by 2°C from the start of the event (from user settings)
- If the room temperature dropped to a temperature lower than 18°C.

In addition, tenants were notified in advance and given the option to ‘opt-out’ of each DR event via the ‘smart communities’ link on their tablet and were also able to override the DR event at any time by ~~pressing a button on~~ operating their HP thermostat.

Multiple tenants were controlled in one DR event and these are referred to as “groups”. Divided group means two groups participate in the DR event and the DR switches between them i.e. First 1-hour DR for one group and then next 1 hour for the other group.

In this project, types of DR can be classified into three categories; load shedding DR, absorption DR and peak shift.

UC1, 3, 4, 5, 6 correspond to load shedding DR
UC2 corresponds to absorption DR.

Conditions of each category are shown in Figure 5-25.

Figure 5-25 Conditions of DR

No.	Category	UC	Condition	Condition value
1	Load shedding DR	1,3, 4,5, 6	DR target group and duration	Whole group, 1 hour Whole group, 2 hours Divided group, 2 hours with change
			Time period	Morning, Evening / Weekday, Weekend
2	Absorption DR	2	DR target group and duration	Whole group, 1 hour
			Time period	13:00-14:00 or 15:00-16:00
3	Peak shift	7	Discount time period	22:30-08:30
			Electricity unit cost [pence/kWh]	Flat tariff 14 Discount, low : 7 Discount, high : 15

For the peak shift use case, an electricity aggregator doesn’t issue DR command, instead each tenant controls HPs (as local HP controllers), taking into consideration a discount tariff. In this project, a tariff showing no difference in unit cost by time period is called “flat tariff”. The discount time period is defined as shown in the table and electricity unit cost is defined as shown in the table.

5.5 Outline of obtained DR data

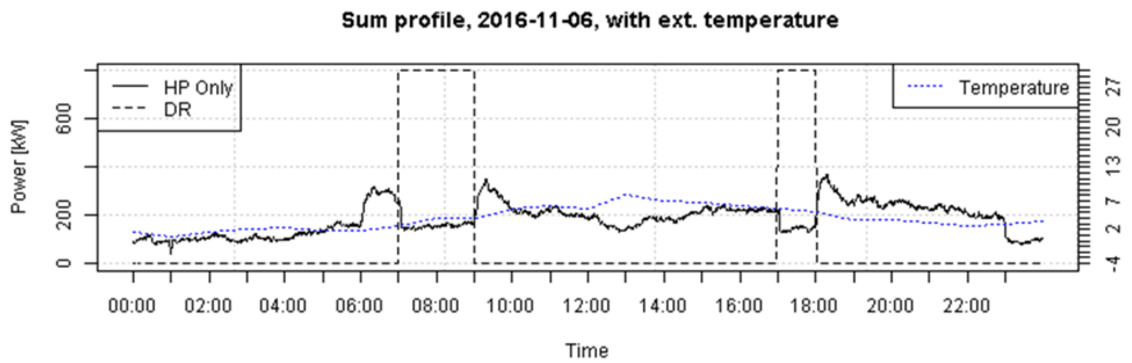
Figure 5-26 gives and outline of the targeted and obtained DR results.

Figure 5-26 Outline of DR results

No	Item	Value	
1	Number of DR target tenants	4～550	
2	DR date range	From Oct. 2015 to Mar. 201７ (18 months)	
3	Number of DR event by UC	UC1	231 times
		UC2	47 times
		UC3	231 times
		UC4	231 times
		UC5	230 times
		UC6	230 times
		UC7	21 times
4	DR amount (average by SP)	375 kW at maximum (Load shedding) 438kW at maximum (Absorption)	
5	Response time	1 minute or less at fastest	
6	Duration	120 minutes at maximum	

Overall, the maximum value of DR amount observed in the trial (load shedding) was 375kW, demonstrating that the overall project target of 200kW DR set by NEDO was achieved. In total, the target DR amount (200kW) was achieved 144 times.

Figure 5-27 below three example day profile charts for different dates. The chart is drawn at 1-minute data interval to accurately observe the response time. The black dashed lines show DR periods, black solid lines show HP power consumption and blue dotted lines show external temperature.



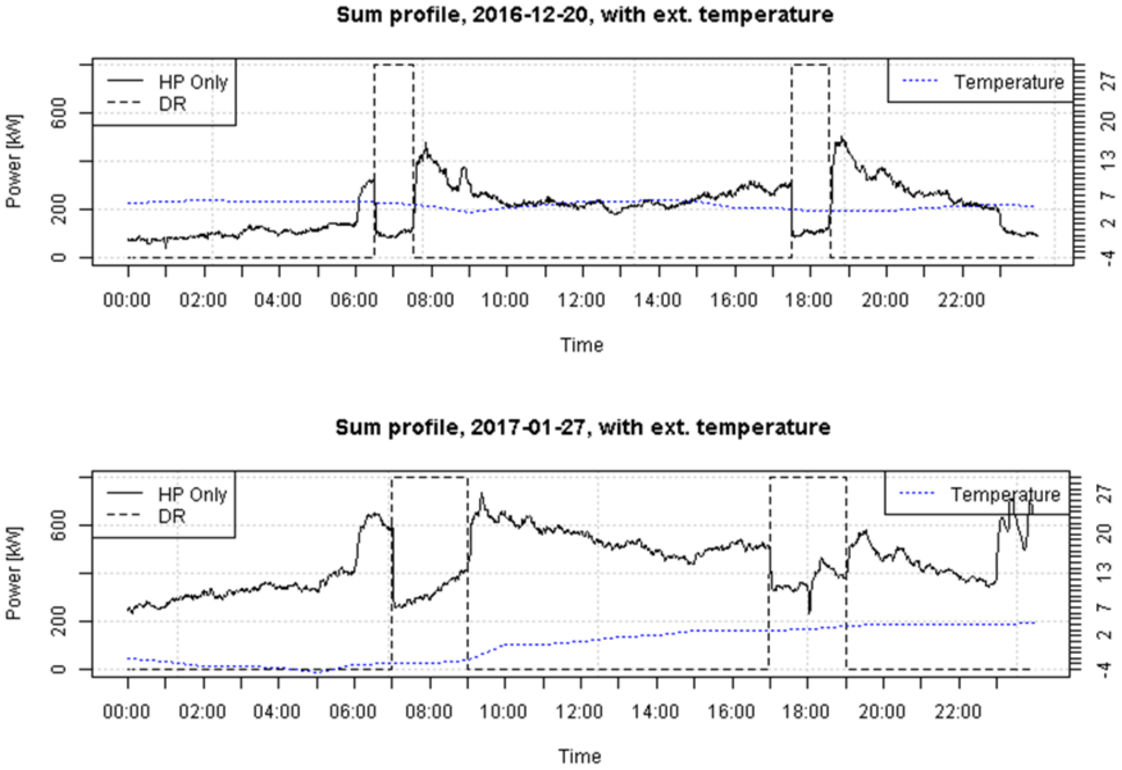


Figure 5-27 Examples of DR results

In the graphs above it is observed that HP power consumption goes down and up along with DR periods, as a result, so-called bathtub curves can be observed. The depth of the bathtub curves is the DR amount – which corresponds to No.4 in Table Figure 5-26.

Observation of these sharp bathtub curves is one of findings of this project. Because there are multiple DR resources and they may not perform in a synchronized way, it can sometimes be difficult to observe sharp bathtub curves in aggregated DR systems. However, in this trial, the fast response time of the DR events (1 minute being the fastest response time) demonstrates that sharp bathtub curves can be achieved with an aggregated DR system using HPs.

The bottom graph in figure 5-27 shows that during the morning DR event on 27th Jan 2017 the HP power seems to increase a little during DR over time. This observation is consistent with the controlling DR policy of sub aggregators, the failsafe function and Opt-out by tenant.

Sub aggregators send a control signal to stop the HP operation of the DR target tenants at the start of DR, however, after a period of time, some HPs will begin to operate again within the DR period, due to either the failsafe mode being activated, or tenants selecting to opt-out. This results in an overall increase of HP power during the DR period.

Figure 5-28 below shows an example of a 90-minute total DR event, which comprises of 4 distinct half-hourly settlement periods (SPs). As the length of time of the DR event increases, the amount of DR obtained decreases, resulting in a risk of increased DR failure in later SPs.

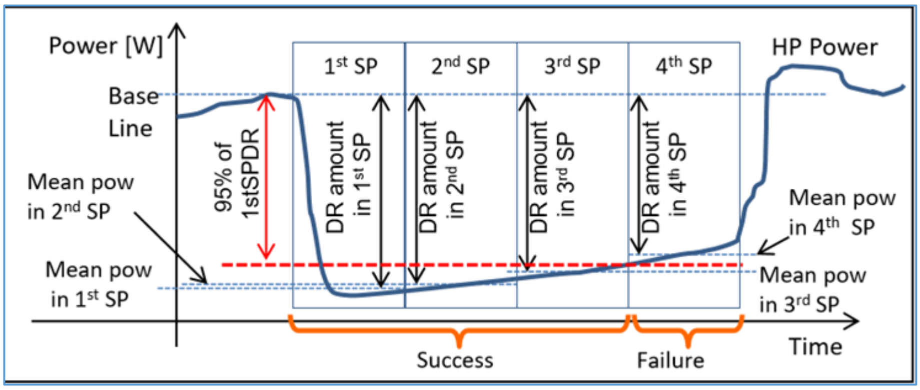
DR amount (V) is calculated by the following formula for each SP

V = Baseline – Average power

Duration is defined as sum of consecutive successful SP durations.

The DR amount decreases as time proceeds because the number of Opt Out tenants increases with time. SPs with DR amounts less than 95% of the 1st SP are judged as failed, in terms of the definition of failure in settlement rules set out by Flexitricity.

According to the actual data obtained in the trial, and as illustrated in Figure 5-28, the optimum DR duration is therefore 60 mins.



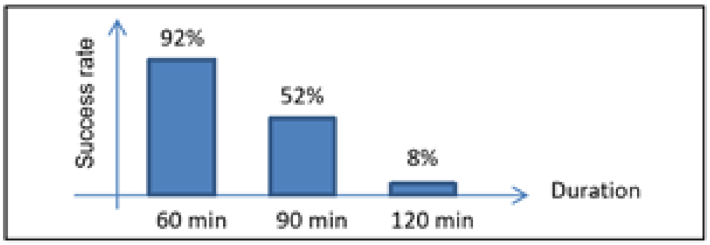


Figure 5-28: Example of a 90-minute DR duration and success rate by planned duration

5.6 Response Time Evaluation

The qualified response time for STOR is within 20 minutes. STOR units with a long notice response time (a response time greater than 20 minutes) do not contribute to the optimal STOR MW level.

Response Time is defined as being the time that it will take a unit/site to reach the Contracted MW level after the Reserve Provider receives an Instruction from National Grid. Figure 5-29 illustrates that in this trial, the response time is the time between the DR start time and the time the HP power reaches the SP average.

The response time was tested for the DR events in the trial and an average response time of 2.3 minutes was achieved, with the slowest being 6 minutes. Both load shedding DR and absorption DR showed similar response times.

The statistics of the achieved response times in the trial for both the load shedding and absorption trials are outlined in figure 5-30.

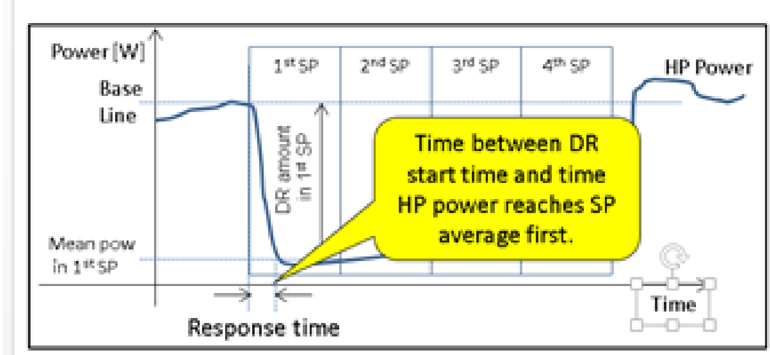


Figure 5-29: Definition of response time

Statistics of response time

DR Type	Median	Average	Standard deviation	Maximum
load shedding	2min	2.3min	0.75	6min
absorption	2min	2.1min	0.56	3min

Figure 5-30: Statistics of response time

5.7 DR Model

A DR estimation model was developed using the HP power consumption model.

The formula used to calculate the DR amount using multiple regression model is:

$$amount = \beta_0 + \beta_1 \cdot HP\ Power + \beta_2 \cdot Opt\ out\ ratio$$

No.	Variable name	Explanation
1	*amount*	Estimated value of DR amount
2	*HP Power*	HP power consumption calculated using the model described in section 8
3	*Opt out ratio*	DR opt out ratio by tenant.
4	β_i	In case of $i = 0$, means intercept of the linear model. In other cases, it means coefficients of the linear model.

Figure 5-31 shows the correlation between actual and estimated DR amount in the model, showing a scattered plot between estimated and tuned actual DR amount, with a 95% prediction interval. The interval ranges from 142kW to 144kW. This value share is approximately 70% compared with DR target amount of this project (200kW). This percentage is as a result of compressed deviation by aggregation, including margins for commitment of DR amount in actual business operation.

The deviation between estimation and adjusted actual value is approximately 80kW which is almost independent on DR amount.

It is observed that the precision increases as DR amount (=num. of tenants) increases.

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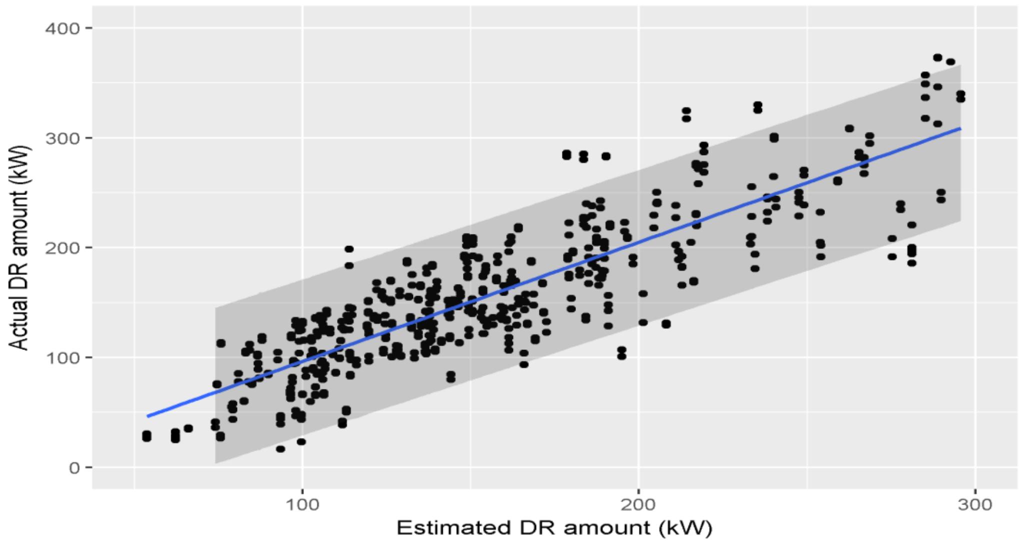


Figure 5-31 Correlation between actual and estimated DR amount

There was a large variation observed in the monthly averages of the actual DR amounts. The estimation model used actual external temperature (from the Met Office) and the monthly average of the maximum and minimum DR amounts as outlined in figure 5-32. Values are adjusted to 550 tenants in order to remove the influence of the variation of number of tenants The Opt-out ratio was set as 10% (constant). ~~This is explained further in section~~

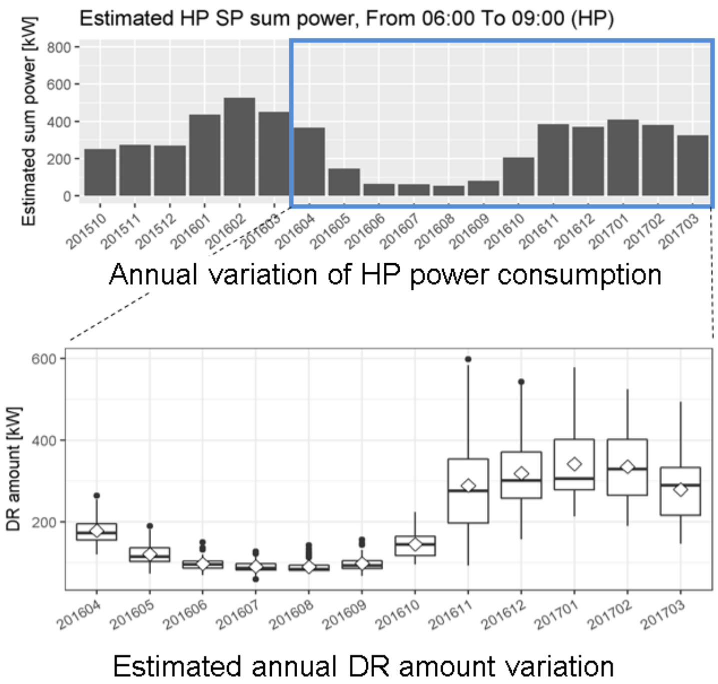


Figure 5-32: Estimated annual DR amount variation

Figure 5-33 shows the average monthly DR amounts and the standard deviation of the estimation. The averages correspond to diamonds in Figure ~~9-8~~5-32

Figure 5-33 Estimated monthly DR amount in a year

No.	Month-Year	DR amount [kW]	Standard Deviation
1	Apr-16	178.5	29.9
2	May-16	120.7	25.8
3	Jun-16	97.4	14.1
4	Jul-16	90.7	13.1
5	Aug-16	90.0	13.7
6	Sep-16	98.1	19.3
7	Oct-16	145.3	31.1
8	Nov-16	288.7	122.5
9	Dec-16	318.7	101.4
10	Jan-17	341.6	88.1
11	Feb-17	334.7	82.8
12	Mar-17	279.3	74.8

Figure 5-34 shows the distribution of error in the model. According to this distribution, the error doesn't follow normal distribution, so there is a possibility to improve the precision of the model.

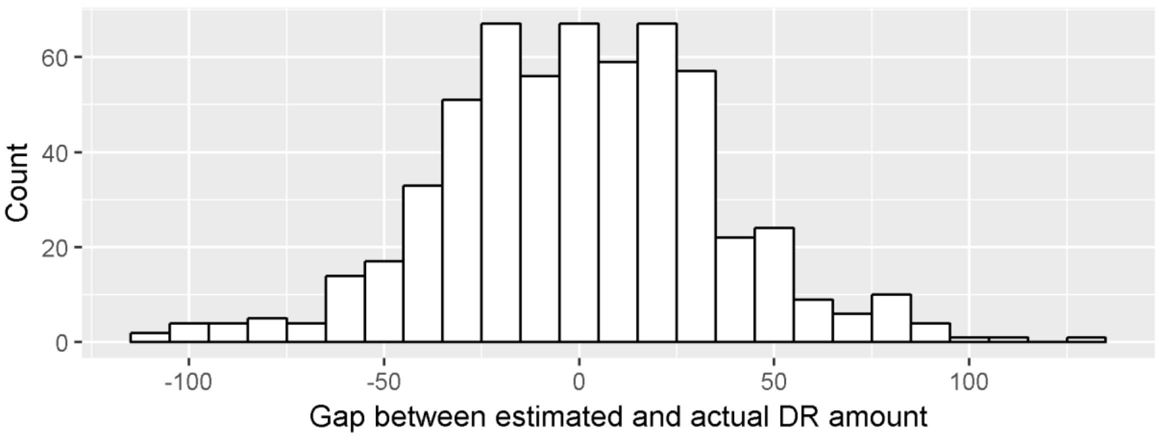


Figure 5-34 Distribution of error in the model

5.8 DR Evaluation

5.8.1 Results of multiple sub-aggregator management (supplemental execution)

In this project, a DR experiment using multiple sub aggregators was performed. Multiple sub aggregators mean HP aggregator and HEMS aggregator in this project.

As a background to the experiment, it is assumed that there is a risk of shortage of total DR amount during an actual DR business operation. In order to respond to a DR requirement from business partners, an electricity aggregator issues a DR command to a sub aggregator (not to individual tenants). If an electricity aggregator manages multiple sub aggregators, in the event of a DR shortage they can issue a DR command to other sub aggregators to compensate for this shortage. The purpose of this experiment is to prove operability of this compensation approach.

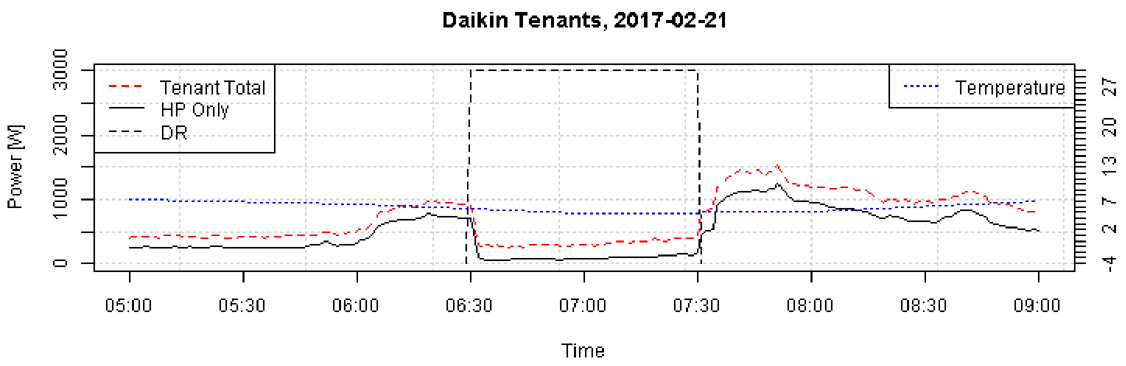
Figure 5-35 shows steps and issues of this compensation process. The DR plan using this approach is named “supplemental execution” in this project.

Figure 5-35 Steps and issues for the compensation

Step #	Action	Issue	Tested ?
1	An electricity aggregator issues a DR command to a sub aggregator (sub A). After that, the electricity aggregator monitors DR amount.	The electricity aggregator can monitor DR amount during DR in real time.	–
2	The electricity aggregator decides to start compensation in certain condition[4]	The electricity aggregator can develop a plan and issue supplemental execution DR command.	–
3	In order to compensate DR amount, the electricity aggregator issues a supplemental execution DR command to another sub aggregator (sub B) other than sub A.	The electricity aggregator can issue DR commands to multiple sub aggregators independently.	✓
4	Go back to step 1.	-	–

Step 3 above is the target of this experiment. Steps 1, 2 and 4 outlined above are out of target, because they relate to performance.

Figure 5-36 shows profiles of parallel and independent DR to sub aggregators. Both profiles show successful DR.



[4] For example, DR amount shortage is forecasted by monitoring DR amount.

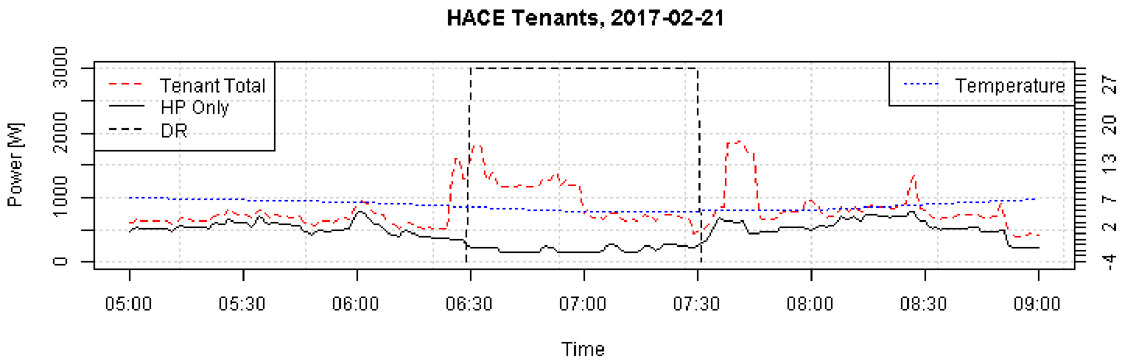


Figure 5-36 Parallel and independent DR to sub aggregators

The upper graph in figure 5-36 is an average consumption profile of a group of 397 tenants, controlled by HP aggregator. The lower is a profile of an average consumption profile of a group of 8 tenants, controlled by HEMS aggregator. Neither of the tenant groups share the same tenant.

In this experiment, DR commands to both sub aggregators were issued by an electricity aggregator and control operation by both sub aggregator were independently executed. Thus, operability of compensation above is thought to be proven.

Note - the odd profile of 'tenant total' in the bottom graph is due to the small sample of HACE HPs.

5.8.2 Results of long term DR by switching group

In this project, an experiment of long term DR by switching groups was performed.

As background to the experiment, the following scenario was envisaged. When long term DR is performed, the room temperature of target tenants decreases as HPs' stop operating, then some tenants opt out of the DR event, as a result, the DR event is deduced as 'failed' by a business partner. A method was considered to avoid this result. In this method, DR groups are pre-defined and an aggregator controls one group immediately after another for the one DR event.

With this method, although a DR event is long term DR for the aggregator, the DR event is shorter term (i.e. 1 hour) for each tenant. Both the electricity aggregator and sub aggregators can perform this control to 'switch' active groups within the DR event. The electricity aggregator is used to prove operability of this method in this project. "Long term" was defined longer than 1 hour in this project.

Figure 5-37 shows an example result profile of a DR by switching groups. A DR in the evening is shown in this example. 1-hour DRs in series were issued to two tenant groups.

From a viewpoint of duration, the target as expected at planning stage was achieved. On the other hand, from a viewpoint of quality, an issue of instability was observed at the switching timing. The switching timing in this figure is 18:00. As the graph shows, a valley and a peak can be observed around the time as marked by an oval in the figure.

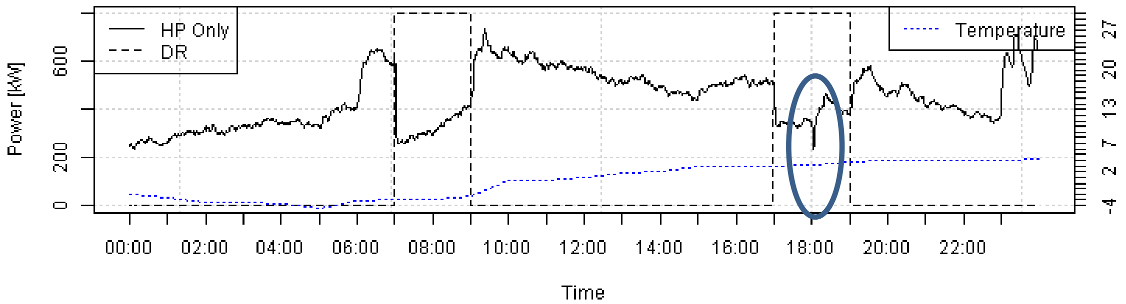


Figure 5-37 - An example of DR by group switching result profile

The 1st DR target group is named Gr.A and 2nd DR target group is named Gr.B . Deviation of switching timing of each HP means the end of Gr.A DR time can be after the start of Gr.B DR time. In this case, there is a short time period in which both groups are in DR. The short time period is observed as a valley in a profile because HPs in two groups of tenants stop operating within the time period. Because deviation makes the valley, it sometimes cannot be observed.

The peak is produced when the aggregated HP power consumption after a DR event is larger than that before the DR starts. This is named “Reactive operation” in this project.

As a precondition of the reactive operation, residential HP ~~are~~ is controlled by a local controller in each property and its operation policy controls the temperature set point schedule in each property. Because factors for temperature variation such as room size and insulation differ between properties, even if external temperature is the same, intermittent HP operation timing differ. However, many HPs start working all together at the same time just after the DR event. As a result, a peak can be observed in the profile such as that in Figure 5-37.

As a result, there is a risk of instability in DR by switching groups with the current control method, and for this example, it cannot be said that stable DR was achieved. In order to provide stable long-term DR, more precise control methods which enable both groups to avoid overlapping and to suppress reactive operation is needed.

5.8.3 Tenant Response to DR

In this project, the intention was to perform DR without affecting tenants’ comfort from a viewpoint of room temperature. Two approaches were adopted to understand the views of the tenants involved in the trial

(1) Confirmation of tenants’ activities via observation of HP operation by tenants
(2) Confirmation of tenants’ views via questionnaire and interview

The following functions were implemented:

- Default participation was assumed for each tenant (Opt In), so if they did not want to participate, they needed to perform an explicit action to Opt Out.
- To prevent the DR events from impacting tenants’ comfort, a fail-safe function was implemented. DRs were automatically rejected if the room temperature dropped below 18 degrees or room temperature was 2 degrees or more below the thermostat set point.

Figure 5-38 explains the definition of Opt out.

Figure 5-38 Definition of Opt Out and its breakdown

No	Name	Definition
1	Opt Out	Tenants' refusal to participate in particular DR event.
2	Opt Out by tenant(s)	Opt out by tenants via operation of tablet or HP remote controller during a DR event.
3	Fail Safe	DRs are automatically rejected in cases where room temperature is less than 18 degree or room temperature is 2 degrees or more below set point. Opt out by this function.

Results of these functions are shown in Figures 5-39 and 5-40.

Figure 5-39 shows the combined result of tenant opt out and fail safe opt out over time. This shows a high level of fail-safe (safety stops) occurring within the first 5 minutes of the DR start time. This is thought to be due to the room temperatures very near to 18 degrees ~~at the time of the DR start~~or the room temperature is lower than set point more than 2 degrees at the time of the DR start.

Average opt out ratio including opt out by tenants and fail safe is 10.6% and standard deviation is 7.3%. It can be said opt out ratio is approximately 10%. Focusing on opt out by tenants, average value is 5.6% and standard deviation is 4.3%. From these values, it is also possible to say that opt out by tenants was limited.

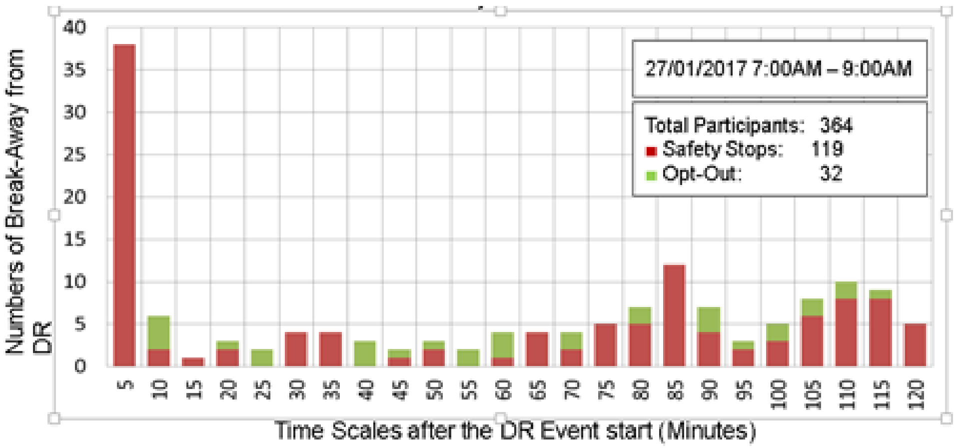


Figure 5-39 Opt out and fail-safe ratio

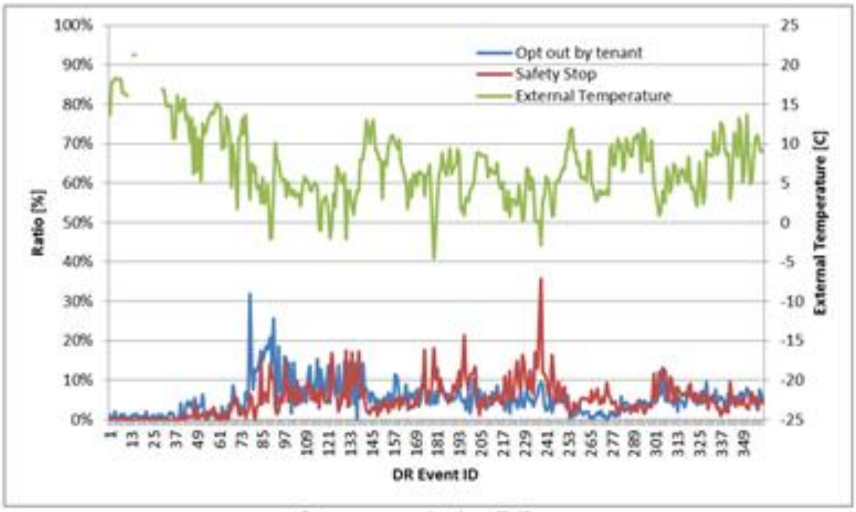


Figure 5-40 Opt out ratio vs. temperature

Figure 5-40 shows the correlation between opt out / fail safe (safety stop) and external temperature. The correlation between external temperature and safety stop is -0.71, so a strong correlation exists. The correlation between external temperature and tenant opt-out is -0.39, so this correlation is weak.

A telephone questionnaire was undertaken with 70 tenants and face to face interview with 16 tenants during the project. In response to a question about overall comfort, 82% of tenants answered `good' or `no change' compared with the previous heating system. In response to a question about level of awareness of DR, 89% of tenants answered that they did not notice DR events. If they were not aware of DR, they couldn't have opted out. This consideration explains the low ratio of opt-out by tenants.

As a result of the interview, there were no negative opinions about DR, although it was clear that there was very little understanding of exactly what it was. Once explained, positive answers were received from 11 out of 16 tenants. These answers were received after tenants had experienced DR, so based on this limited information, it is fair enough to say that they were generally not concerned with HP being controlled by aggregators.

5.9 Use Case Results

5.9.1 Summarised results of each Use Case

Figure 5-41 is a summary of the target/guide and achievement status for each UC from UC1 to UC7. 'Target' is the value to be met in the trial. 'Guide' is where there is no set target, but the achieved value should be measured.

The main target set by NEDO for the project was 200 kW DR target, which was achieved on multiple occasions.

Figure 5-41 DR target or guide with their status by UC

UC	Index	Target	Guide	Status	Explanation
UC 1 (Load shedding for an aggregator; Flexitricity)	DR amount	200kW	–	✓	DR of 200kW or greater was observed in 144 SP out of 513 SP (28%). Target was cleared.
	RT*	12min	–	✓✓	Response time of 6 mins or less was observed in all 231 DR events (100%). Target was cleared in all cases.
	Duration	30min	–	✓✓	Duration of 30 mins or more was observed in all 231 DR events (100%). Target was cleared in all cases.
UC 2 (Absorption for an aggregator; Flexitricity)	DR amount	–	100kW	✓	DR of 100kW was observed in 26 SP out of 94 SP (28%). Guide was cleared.
	RT*	–	12min	✓	Response time of 3 mins or less was observed in all 47 DR events (100%). Guide was cleared in all cases.
	Duration	–	60min		No DR event of 60 min or more duration was observed. (0%). (Guide was not cleared)
UC 3 (Load shedding for DNO; ENW)	DR amount	–	200kW	✓	DR of 200KW was observed in 144 SP out of 513 SP (28%). Guide was cleared.
	RT*	–	60sec	✓	Response time of 60 secs or less was observed in only 7 out of 231 DR events (3%). Data was successfully obtained (guide was cleared)
	Duration	–	60min	✓	Duration of 60 mins or more was observed in 212 out of 231 DR events (92%). Guide Target was cleared.
UC 4 (Load shedding for STOR)	DR amount	–	200kW	✓	DR of 200kW was observed in 144 SP out of 513 SP (28%). Guide was cleared.
	RT*	10min	–	✓✓	Response time of 6 mins or less was observed in all 231 DR events (100%). Target was cleared in all cases.
	Duration	–	60min	✓	Duration of 60 mins or more was observed in 212 out of 47 DR events (92%). Guide was cleared.
UC 5,6 (Load shedding for emulated retailor)	DR amount	–	200kW	✓	DR or 200kW or more was observed in 65 SP out of 511 SP (13%). Guide was cleared.
	RT*	–	12min	✓	Response time of 6 mins was observed in all 230 DR events (100%). Guide was cleared in all cases.
	Duration	120min	–	✓	There were 25 DR events whose duration were planned to be 120min. Duration of 120 mins was observed in 6 out of 25 DR events (24%). Target was cleared.
UC7 (Peak shift using HP emulator)	Shift time	–	60min	✓	More than 60min shift cases were observed. Guide was cleared.
	Shift amount	–	350 Wh/tenant	✓	More than 350Wh/tenants' decreases were observed. Guide was cleared.
	Cost difference	minus	–	✓	Minus value was observed. Target was cleared.

* RT: Response Time

UC5 and UC6 are treated as the same. Because target, guide and baseline rule are common in these UCs, results are the same.

For UC1, 3, 4, 5 and 6, the same data is used to evaluate the multiple UCs. The difference is target, guide and baseline rule.

Indices for UC7 are different from other UCs. HP operation for UC7 is shown in Figure 5-42. In the top row of the figure, set point schedule is shown. If a tenant has flat tariff, its HP controller operates HP like middle row of the figure. Note that this HP operation status is either 1 or 0 (not output power consumption value). If a tenant has discount tariff, HP operating time tends to be assigned in cheaper unit cost period on a priority basis. For example, as shown in the middle and the bottom row in the figure, early morning operation is shifted from [A1] (middle) to [B1] (bottom).

With the above preconditions, the index of shift time is defined as difference between HP operating time in discount tariff case and HP operating time in flat tariff case. For example, [B2] - [A1] + [A2] in Figure 5-42 is shift time.

Index of shift amount is defined as difference between HP power consumption in discount tariff case and HP power consumption in flat tariff case. HP operating timing can be obtained from output of the emulator and HP power consumption can be calculated from actual HP power consumption data, so shift amount is calculated using both data sources.

The Index of cost difference is defined as difference between electricity cost in discount tariff case and electricity cost in flat tariff case. The difference was calculated using power consumption above and unit cost in tariff.

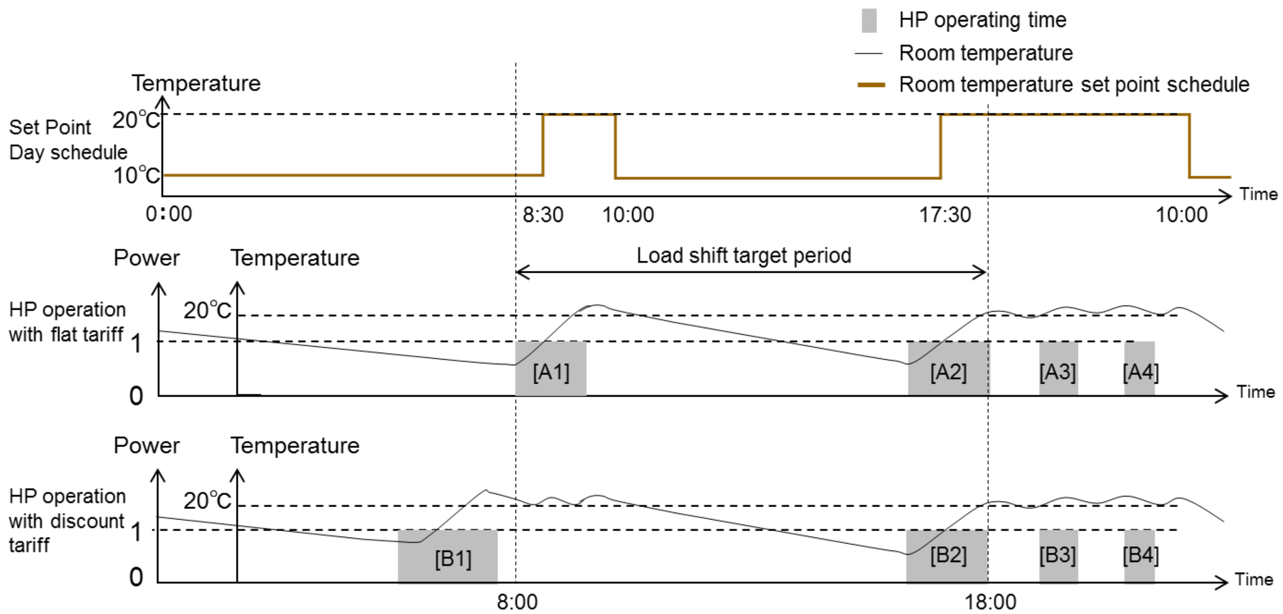


Figure 5-42 HP operation image in UC7 emulator

5.9.2 Results of UC1

The purpose of this UC is to prove possibility of trade with Flexitricity using aggregated HPs as load shedding DR resources. Target is based on discussion with Flexitricity and evaluation of DR results.

As shown in Figure 5-43 targets were cleared, resulting in a positive outcome for this UC.

Figure 5-43 DR result evaluation in UC1

<table>
<tr><td></td><td>DR amount</td><td>Response time</td><td colspan="5">Duration</td></tr>
<tr><td>Target</td><td>200 k W</td><td>12min</td><td colspan="5">30mn</td></tr>
<tr><td>Status</td><td>✓</td><td>✓✓</td><td colspan="5">✓✓</td></tr>
<tr><td rowspan="4">Results</td><td rowspan="4">200kW DRs were observed in 144 SP out of 513 SP (28%).
Target was cleared.</td><td rowspan="4">Equal or less than 6 mins RT were observed in all 231 DR events (100%).
Target was cleared in all cases.</td><td rowspan="2">Plan</td><td colspan="4">Actual</td></tr>
<tr><td>30min</td><td>60min</td><td>90min</td><td>120min</td></tr>
<tr><td>60min</td><td>17</td><td>189</td><td></td><td></td></tr>
<tr><td>120min</td><td>2</td><td>10</td><td>11</td><td>2</td></tr>
</table>

Baseline (Flexitricity Rule): 2 minutes average just before the DR

Results show a DR amount of 200kW or more was observed in 144 SPs, thus the target was achieved. In this UC, results show a response time of 6 minutes or less in all DR events, thus the target was achieved.

The sub table in Figure ~~9-19~~5-43 shows the number of DR events planned vs achieved for each set time duration. 60min DR was planned 206 times – in the end 189 DR events were achieved for 60 minutes. Only 2 DR events achieved 120 minutes duration. This indicates that 1-hour DR is clearly possible and reliable, whereas longer DR periods are thought to be difficult.

In this UC, results were shared with Flexitricity to estimate the possibility of DR trading. Assuming Flexitricity as upper layer DR aggregator of the electricity aggregator, Flexitricity made a settlement sheet using the DR results in this project, as if each DR events were requested by Flexitricity. Flexitricity evaluated the DR results from Oct. 2016 to Feb. 2017.The biggest issue was stability. As previously stated, the variation of DR amount in this project was significant. If the volume of participating tenants increases, the deviation will decrease, however the yearly and daily cycle of variation would have to be accounted for in the DR operation.

5.9.3 Results of UC2

The purpose of this UC is to measure raw power, using aggregated HPs as absorption DR resources. The raw power data was obtained as shown in Figure 5-44. DR amounts of 100kW or more were observed in 26 SPs. Thus, guidance threshold was achieved. A response of 3 minutes or less was observed in all DR events, thus guidance level was achieved

60 minutes DRs were planned, however no DR events achieved 60 minutes. So, in this instance the guidance level was not cleared.

Figure 5-44 DR result evaluation in UC2

<table>
<tr><td></td><td>DR amount</td><td>Response time</td><td colspan="3">Duration</td></tr>
<tr><td>Target</td><td>None(Guide:100kW)</td><td>None(Guide:12min)</td><td colspan="3">None(Guide:60min)</td></tr>
<tr><td>Status</td><td>✓</td><td>✓</td><td colspan="3">✓</td></tr>
<tr><td rowspan="2">Results</td><td rowspan="2">100kW DRs were observed in 26 SP out</td><td rowspan="2">Equal or less than 3 mins RT were</td><td rowspan="2">Plan</td><td colspan="2">Actual</td></tr>
<tr><td>30min</td><td>60min</td></tr>
</table>

	DR amount	Response time	Duration		
	of 94 SP (28%). Guide was cleared.	observed in all 47 DR events (100%). Target was cleared in all cases.	60min	47	0

Baseline (Flexitricity Rule): 24 hours average just before the DR

Two key issues were found in UC2. The first is the issue of the DR amount levelling during the DR period. As shown in Figure 5-45, there is a wide range of variation in power consumption in DR periods in this UC.

When a sub aggregator issues a DR command at the start time of DR, all target tenants start operating at that time. However, almost all properties appear to opt out (likely via fail safe) because there is limited absorption amount obtained for each property.

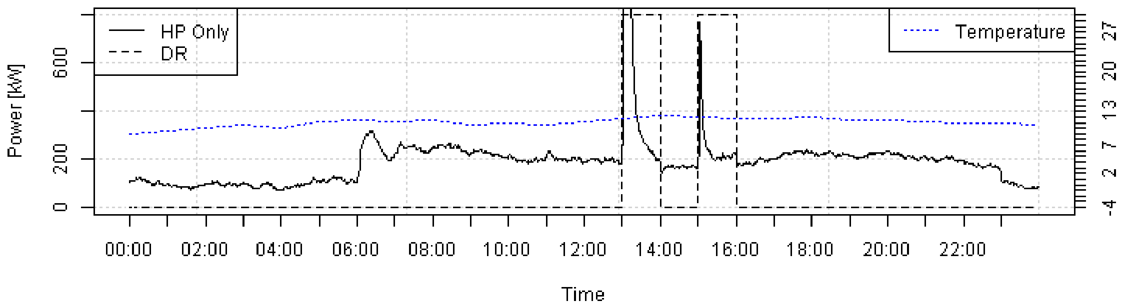


Figure 5-45 - An example of UC2 DR profile

The second point to note is the correlation between absorbed power and storage equipment. In this project, absorbed power is consumed to heat a water tank. In the tank, water temperature is always kept at a set temperature by feedback control which is original function of HP. The amount of absorption depends on the capacity of the hot water tank when the DR signal is sent.

In this project, the DR controller doesn't have any function to reference the capacity of the hot water tank and delay heating by forecast to make a larger amount of absorption DR. Also, absorption DR are performed without the associated space heating function.

5.9.4 Results of UC3

The purpose of UC3 is to explore the impact of HPs on the distribution network in cooperation with ENWL (Electricity North West Ltd). The purpose of this UC is to obtain raw power data to review the overall impact. In this UC, targets were not set. The raw power data was obtained as shown in Figure 5-46

Figure 5-46 result evaluation in UC3

	DR amount	Response time	Duration	
Target	None(Guide:200kW)	None(Guide:60sec)	None(Guide:60min)	
Status	✓	✓	✓	
Results	200kW DRs were	Equal or less than	Plan	Actual

	DR amount	Response time	Duration				
	observed in 144 SP out of 513 SP (28%). Guide was cleared.	60 secs RT were observed in 7 out of 231 DR events (3%). Guide was cleared.		30min	60min	90min	120min
			60min	17	189		
			120min	2	10	11	2

Baseline (Following Flexitricity Rule): 2 minutes average just before the DR

DR amounts of 200kW or more were observed in 144 SPs, thus the guide value was achieved. In this UC, the baseline rule is the average HP power consumption for 2 minutes just before the DR start time. This rule was agreed with ENWL (referencing Flexitricity baseline rule of load shedding DR).

The results of response time show 60 seconds or less were observed in only 7 out of 231 DR events. This shows that even though the guide level was achieved, this was achieved infrequently.

The DR duration results are the same as UC1, so the conclusion is also the same; 1-hour DR is possible and reliable whereas longer DR than that is thought to be difficult.

5.9.5 Results of UC4

In this UC, trade in the ancillary service market is envisaged. However, the limited number of participants in the trial prevented this system from connecting to the market system at this phase, so the target of indices of DR amount and duration were not set in order to obtain raw power data. The target of response time was set using the markets regulations.

Figure 5-47 shows results of this UC. DR amounts of 200kW or more were observed in 144 SPs. Thus, the guide level was achieved. The market requirement is circa 8,250 tenants (3MW system), which is assumed possible to achieve with a calculation based on the number of properties participating in this trial.

In this UC, the baseline used was the average HP power consumption 4 minutes immediately prior to the DR start. This rule was based on an open proposal from National Grid.[5]

A response time of 4 minutes or less as observed in all 231 DR events. Thus, the target was cleared in all events.

Figure 5-47 DR result evaluation in UC4

	DR amount	Response time	Duration				
Target	None(Guide:200kW)	10min	None(Guide:60min)				
Status	✓	✓✓	✓				
Results	200kW DRs were observed in 144 SP out of 513 SP (28%). Guide was cleared.	Equal or less than 6 mins RT were observed in all 231 DR events (100%). Target was cleared in all cases.		Actual			
			Plan	30min	60min	90min	120min
			60min	17	189		
			120min	2	10	10	3

[5] National Grid Variable Baselines
http://www2.nationalgrid.com/WorkArea/DownloadAsset.aspx?id=11694

5.9.6 Results of UC5, UC6

As results of UC5 and UC6 are the same, both are mentioned here as a set. The purpose of these UCs was to obtain raw power data to prepare for discussions with retailers.

The target of indices of DR amount and duration were not set because the retailer was not specified. The DR guideline is set with reference to UC1. The duration guide is set considering retail markets' regulation. The response time is thought to have little impact in DR trading, so it is set considering Flexitricity's regulation.

Figure 5-48 shows results of this UC. DR amounts of 200kW or greater were observed in 65 SPs. thus, the guide was cleared. In this UC, baseline rule is based on proposal by National Grid for aggregated DR:

1. Target dates of the baseline calculation following three days; one, two and three weeks before the DR date
2. Average HP power consumption data on the target dates (in the same time period of the DR) is used as baseline

The results of response time of 6 minutes or less were observed in all 230 DR events. Thus, the target was cleared in all events.

According to the sub table, results are different from those of UC1, UC3 and UC4 because baseline rule is different. Only 6 DR events achieved the guide level (120 minutes), from 25 planned 120-minute DR events. Thus, further ingenuity like switching groups is needed to meet the guide level.

Figure 5-48 DR result evaluation in UC5, 6

<table>
<tr><td></td><td>DR amount</td><td>Response time</td><td colspan="5">Duration</td></tr>
<tr><td>Target</td><td>None(Guide:200kW)</td><td>12min</td><td colspan="5">None(Guide:120min)</td></tr>
<tr><td>Status</td><td>✓</td><td>✓</td><td colspan="5">✓</td></tr>
<tr><td rowspan="4">Results</td><td rowspan="4">200kW DRs were observed in 65 SP out of 511 SP (13%). Guide was cleared.</td><td rowspan="4">Equal or less than 6 mins RT were observed in all 230 DR events (100%). Guide was cleared in all cases.</td><td rowspan="2">Plan</td><td colspan="4">Actual</td></tr>
<tr><td>30min</td><td>60min</td><td>90min</td><td>120min</td></tr>
<tr><td>60min</td><td>18</td><td>187</td><td></td><td></td></tr>
<tr><td>120min</td><td>1</td><td>10</td><td>8</td><td>6</td></tr>
</table>

5.9.7 Results of UC7

The purpose of this UC is to confirm the availability of a discount tariff to enable peak shift of aggregated HPs. In this UC, it is assumed that a retailer sets a discount tariff to achieve a peak shift of tenants' HP power consumption. All results in UC7 are calculated using a simulator model, not by actual data, except for power consumption amount per minute by temperature range. It is also assumed that HP controllers control the HPs instead of the tenants. Under this assumption, the amount of peak shift is calculated with HP simulation model. Results are shown in Figure 5-49

Figure 5-49 Results of Peak shift in UC7

	Shift time	Shift amount	Cost difference
Target	None(Guide: 60min)	None(Guide: 350 Wh/tenant)	minus
Status	✓	✓	✓
Results	More than 60min shift cases were observed. Guide was cleared.	More than 350Wh/tenants' decreases were observed. Guide was cleared.	Minus value was observed. Target was cleared.

Figure 5-50 shows the simulation results for one-day operating time. 21 samples were obtained with both discount tariff mode and flat tariff mode.

The simulation used in this project set external temperature at random within a set range in every case, so not set to the exact same condition each time. In order to compare results between discount tariff mode and flat tariff mode, results were grouped by external temperature range and average values were calculated using samples belonging to the same ranges. External temperature ranges were made focusing on temperature in daytime (8:00-18:00).

Figure 5-50 Results of emulation 1, HP operating time in a day

Temperature range in daytime	Discount tariff		Flat tariff	
	Operating time [min]	Number of tenants	Operating time [min]	Number of tenants
10～15℃	169	8	228	6
5～10℃	340	7	400	3
0～5℃	546	3	509	10
-5～0℃	653	3	590	2

When comparing a day HP operating time between the discount tariff mode and flat tariff mode in the same temperature range, they are thought to be similar[6].The physical mechanism of the similarity can be assumed to be that a small load shift in a day makes little difference, especially in insulated properties. Among different temperature ranges, the lower the temperature range is, the longer the operating time is. These results are reasonable because HP operation is mainly for space heating.

Figure 5-51 shows the HP operating time but they are broken down into two time periods; discount target time period (Target) whose unit cost of power is lower than flat tariff and non-discount target time period (Non-T). Difference from Target to Non-T is shown in the "Shift time" column. Shift time in all temperature ranges are more than 60 minutes which is a guide of this UC.

Figure 5-51 Results of emulation 2, HP operating time and shift time

Temperature range in daytime	Discount tariff		Flat tariff		Shift time		Cost diff. minus
	Target [min]	Non-T [min]	Target [min]	Non-T [min]	Target [min]	Non-T [min]	
10～15℃	48	121	128	100	-80	+21	

[6] p value resulting in Welch's t test and Cohen's d are calculated for four temperature ranges with hypothesis of "true difference in average is equal to 0" . p = 0.18, 0.26, 0.58, 0.36 and d = -0.77, -0.74, -0.39, 1.1. Here the hypotheses are all reserved, however small sample size may affect these results.

5 ~ 10℃	105	235	209	191	-104	+44	minus
0 ~ 5℃	178	368	257	252	-79	+116	minus
-5 ~ 0℃	228	365	315	275	-87	+90	minus

The simulation outputs were set to 1 or 0 for HP operation, so in order to estimate power consumption, actual HP power data with similar time and similar temperature data is used for each time period and temperature range. Multiplying power consumption and unit cost in tariff makes a day electricity fee. "Cost diff." columns show sign of difference of a day electricity fee from discount tariff mode and flat tariff mode; values here can be plus or minus only. Figure 5-52 shows the power consumption.

Average shift amounts were observed more than 350 Wh/tenants and cost differences are minus.

Figure 5-52: Results of emulation 3, HP power consumption and shift amount

Temperature range in daytime	Discount tariff		Flat tariff		Shift time	
	Target [Wh/tenant]	Non-T [Wh/tenant]	Target [Wh/tenant]	Non-T [Wh/tenant]	Target [Wh/tenant]	Non-T [Wh/tenant]
10 ~ 15℃	308	766	821	641	-513	+135
5 ~ 10℃	855	1913	1702	1555	-847	+358
0 ~ 5℃	2164	4475	3125	3064	-961	+1411
-5 ~ 0℃	4010	6420	5540	4837	-1530	+4837

From the above, as a precondition of automatic control by HP controller, peak shift with lower cost of tenants by discount tariff is thought to be achieved through simulation.

6 Theme 3: Establishment of a Business Model

6.1 Business Model Development

A business model was developed for the project to understand the commercialization potential of the smart energy demonstration. This was developed by Mizuho Bank, in collaboration with Hitachi Ltd.

In the feasibility study, an economic evaluation of the business model showed that it was possible to gain a certain size of sales and revenue, given pre-assumptions based on the results of studies and surveys.

In order to more fully understand the commercialization potential with more accuracy, it was necessary to conduct further research, using the actual data obtained from equipment operation in this demonstration and building this into the economic evaluation (cash flow analysis) from the feasibility study. This research included:

1. **Identification and evaluation of business environment**
   Policies and regulations closely related to this demonstration project were studied, including recent changes, issues and future direction of the Electricity Market Reform (EMR), Renewable Heat Incentive (RHI), Green Deal, and Energy Company Obligation (ECO). In addition, desktop research, interviews with government departments, including BEIS and Ofgem were conducted in February 2016 to obtain information on the current status and future prospect for each relevant policy.

   In addition, business overviews and contract conditions with customers of existing electricity aggregators, National Grid, Distribution Network Operators (DNO) and retailers as assumed customers were surveyed and analysed by desktop research, and information related to demand for DSR, marketability of DSR in a domestic sector and requests for regulators was collected via interviews and email correspondence

2. **Evaluation on product variation for electricity aggregation**
   In the feasibility study, a draft product portfolio of the seven use cases was developed using existing published papers and statistical data. More concretely, monthly and hourly use case portfolios were studied for two scenarios depending on the number of deployed heat pumps after the trial, the portfolio was refined using actual DSR data provided by Hitachi.

3 **Evaluation on multi-vendors in HP aggregation architecture**
   Following the research on terms and conditions of the contracts with potential customers, National Grid and existing electricity aggregators (Flexitricity) and interviews with other electricity aggregators, contract conditions (unit price, penalty and transaction schedule) when commercialized between electricity aggregators and HP aggregators in this demonstration

project were studied. In addition to this, potential contract conditions and rewards to participants in DSR programs were discussed.

4 Evaluation of HP penetration

A HP penetration scenario set in the feasibility study, to deploy 8 million HPs across UK by 2030 (National Grid's goal) was re-evaluated based on a result of the HP satisfaction survey, policy development and price trends. The feasibility study and economic evaluation was implemented for the new scenarios studied in the demonstration project.

5 Analysis and evaluation of acceptability for DR and HP

To analyse and evaluate the acceptance of the participants in this trial of both DR and HP, the following four surveys were conducted.

i. Survey of participant attributes
Basic data (family structure, age range, health conditions and environmental awareness) of the participants in the demonstration project was collected through questionnaire surveys, in order to analyse the relationship between the tenant attributes and the satisfaction levels for use of the HP and the satisfaction levels for participation in the DR programme.

ii. Survey of satisfaction levels for participation in the DR programme
The survey of satisfaction levels for participation in the DR programme was conducted with the tenants through a questionnaire on tablet and/or telephone interviews, in order to analyse the relationship between the tenant attributes and the satisfaction level for participation in the DR programme.

iii. Survey of awareness of the general public in UK for DR
To evaluate the opportunity of expanding the result of the demonstration project all over the UK, a web-survey on awareness of the general public in the UK of DR was conducted.

iv. Survey of satisfaction levels for use of the HP
A survey of satisfaction levels of the participants in the demonstration project for use of the HP was conducted through a questionnaire and via telephone interviews with tenants, conducted on behalf of the project by the University of Salford.

6 Policy proposal of UK governmental agencies, etc.

To facilitate DR in the domestic sector, a policy change proposal was studied for the Short-Term Operating Reserve (STOR) trading of National Grid. When discussing the proposal, information obtained from interviews with existing electricity aggregators and email communication with National Grid was taken into consideration.
For example, the minimum capability requirements for the STOR contracting balancing service are as follows:

- Minimum Contracted MW capability = 3MW.
- Contracted MW must be achievable no later than 240 minutes after instruction from National Grid.
- Contracted MW must be deliverable for no less than 2 hours.

7 Overall evaluation of business model

A trial calculation was carried out by applying actual operation data, market data and updated cost data to the model developed in feasibility study.

Additional qualitative information, including issues experienced in equipment installation and operation, answers to questionnaires from project participants and comments gained in interviews with project partners, government agencies and experts, as well as latest policy trends were also taken into consideration.

Each of the above are discussed in turn below:

6.2 Identification and evaluation of business environment

Overviews, recent changes, issues and future direction of Electricity Market Reform (EMR), Renewable Heat Incentive (RHI), Green Deal, and Energy Company Obligation (ECO) were studied as policies and regulations closely related to the demonstration project.

In particular, the capacity market in EMR is strongly related to demand side response (DSR) and the increase in presence of DSR in auctions which have been conducted since 2014 was important to note. A trend of DSR capacity in the capacity market auction is shown in the table below.

Figure 6-1 Increasing presence of DSR in capacity market auction

			Capacity (MW)	Ratio of DSR to total (%)
2016	Total		1,410.953	**2.69**
		Proven DSR	44.068	0.08
		Unproven DR	1,366.885	2.61
2015	Total		456.455	**0.99**
		Proven DSR	7.960	0.02
		Unproven DR	448.495	0.97
2014	Total		174.17	**0.36**
		Proven DSR	8.225	0.02
		Unproven DR	165.945	0.34

Along with desktop research, interviews with government agencies, such as BEIS (formerly DECC) and Ofgem were conducted in February 2016 and information on the current status and future prospect for each relevant policy was gained

In addition, analysis of the business structures and contract conditions of customers of existing electricity aggregators, National Grid, Distribution Network Operators (DNO) and retailers as assumed customers was undertaken by desktop research. Information related to demand for DSR, marketability of DSR in a domestic sector and requests for regulators was collected via interviews and email communication. This showed that the assumed customers have needs for DSR and they predict and expect market growth in future. However, they consider industry and commercial sector as the primary DSR source and think it will take years to actually commercialize domestic sector DSR from an economic point of view.

Since the interviews were undertaken, a number of changes have come into force. In March 2017, Ofgem announced the extension of ECO until September 2018, and the extended scheme began on 1 April 2017.

RHI was reformed in April 2017 and the incentive tariff for air-source HP has been raised. Details are to be explained in the following chapter, but this is one of the biggest changes for studying HP diffusion in future.

6.3 Evaluation on product variation for electricity aggregation

At first, a draft product portfolio of the seven use cases (UC) (described in chapter 5) was made using existing published papers and statistical data. More concretely, monthly and hourly use case portfolios were studied for two scenarios depending on the number of deployed heat pumps (whether or not minimum requirement of STOR transaction, 3MW is met). After the study, the portfolio was refined using actual DSR data provided by Hitachi.

After these studies, it was determined that it was appropriate to conduct an economic evaluation based on a product portfolio which consists of UC 1 and UC 4 (STOR only). The reasons why other use cases were excluded respectively are summarized in the table below.

Figure 6-2 Reasons to exclude use cases form economic evaluation

Use case	Reasons
UC 2	Could not secure a sufficient amount of DSR capacity after trial operation.
UC 3	Should be treated as an activity to work with DNOs to develop an electricity aggregation business using HPs as a DSR source and it is inappropriate to include this UC as one of the factors to improve profitability.
UC 4 (Fast Reserve)	Although fast reserve requests service providers to respond within two minutes or less, it takes approx. one to three minutes in trial operation and therefore did not meet the condition
UC 5	Although it was confirmed retailers have a certain level of demands for DSR via interviews, it was difficult to study details about transaction conditions.
UC 6	Same as UC 5.
UC 7	Same as UC 5.

6.4 Evaluation on multi-vendors in HP aggregation architecture

Research was undertaken on terms and conditions of the contracts with customers, National Grid and existing electricity aggregators (Flexitricity) and interviews with electricity aggregators. Contract conditions (unit price, penalty and payment schedule) for commercialisation between electricity aggregators and HP aggregators in this demonstration project were also studied.

After all these studies and discussions, it was found that firstly, a unit price is set based on a distribution ratio between an electricity aggregator and HP aggregator, not per amount price for a DSR amount provided by a HP aggregator.

Secondly, a penalty is paid by a company which fails in its role. A basic idea is as follows.

Basic penalty idea:

To manage potential deviation between requested and activated energy, a penalty would be imposed when participants in the DR activity fail to fulfill their prior commitment. If the participants are successful, they obtain the full amount of money (reward) based on their commitment of electricity amount provided. If they are unsuccessful, a penalty is imposed, whereby the originally committed amount of money (reward) is partially reduced. This could be either a fixed amount, or based on a formula

If parties are part of a joint contract and if one party does not meet the energy requirement for an event, then the whole contract is penalized – in this instance the penalty would be shared.

Thirdly, it is appropriate that the payment is made between an electricity aggregator and a HP aggregator after a transaction of an upper layer is completed.

The business model of the electricity aggregation business is summarized in Figure 6-3 below, depending on who distributes incentives to program participants.

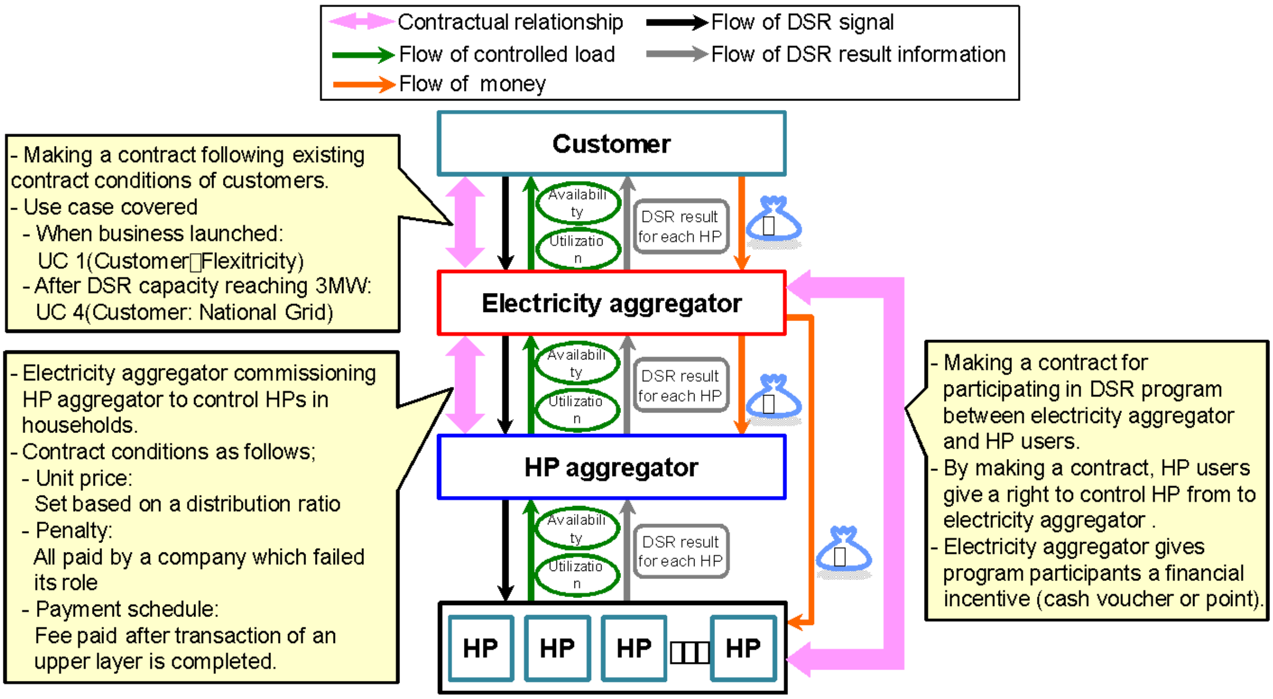


Figure 6-3 Business model of electricity aggregation business when electricity aggregator distributed financial incentives

6.5 Evaluation of HP penetration

In order to analyse and forecast a level of HP penetration in the UK, desk top research was conducted. In particular, the report prepared for the UK Government's Committee on Climate Change (CCC) by Delta Element Energy and Frontier Economics (2013)[7] was referred to, in which three scenarios were established for future HP penetration into the market.

Under the CCC's "stretch" heat scenario for meeting the 2050 carbon target, the total heat pump uptake producing around 365 TWh of heat output by 2050 would be required. This includes 31m domestic installations, representing more than 80% of properties.

The report assessed the roll-out of heat pumps needed by 2030 to meet this scenario. This looked at two pathways:

- "Cost-effective path". This pathway is consistent with meeting the first four carbon budgets and the 2050 target at least cost.
- "Critical path". This is the minimum level of heat pump uptake required to make meeting the 2050 target possible, given "hard constraints" on uptake.

The report estimated the number of HPs introduced in UK by 2030 would increase to approx. 700,000 units in a current policy path scenario (of which 660,000 in the domestic sector), 2.3 million units in a critical path and 6.8 million units in a cost-effective path.

[7] https://www.theccc.org.uk/wp-content/uploads/2013/12/Frontier-Economics-Element-Energy-Pathways-to-high-penetration-of-heat-pumps.pdf

For the purposes of this demonstration project and the development of the business model, it is assumed that the critical pathway is adopted (assuming 2.3 million units of HPs would be installed in UK by 2030).

6.6 UK government policy

DECC's (now BEIS) 2050 Pathways Analysis[8] report explored combinations of heat pumps (air and ground source), resistive heating, power station off take, district heating biogas and biomass as the principal low carbon heat technologies.

RHI plays a key role in the projected uptake of domestic HPs. On 15 March 2017, the Government published the draft Domestic Renewable Heat Incentive Scheme (Amendment) Regulations 2017[9]. These changes to the Regulations come into effect in two stages. The first stage came into effect on 20 September 2017. The second stage of planned changes will follow later in 2017/2018. One of the biggest changes in the reform is an uplift in tariff for air-source HP (from 7.63 pence/kWh to 10.18 pence/kWh). Such an increase is likely to encourage an increase in heat pump installation volumes.

BEIS is also introducing 'heat demand limits' to the Domestic RHI scheme. This means that there will be a limit to the financial support that scheme participants can receive for their heat use annually. Annual Heat Demand Limit for Air Source Heat Pumps will be 20,000 (kWh).

In order for the actual commercialization of the demonstration project and expansion of the business, a change in rules which makes domestic sector DSR easier to participate in STOR trading of National Grid, is strongly desired. However, National Grid responded in interview that it does not currently plan to change the current STOR contract and transaction rules for a domestic sector DSR and mainly works on the promotion of DSR in industrial and commercial sectors although they regard DSR in domestic sector as important.

STOR projects are required to fulfil a number of criteria, including an ability to deliver at least 3 MW of reserve and an ability to deliver for a minimum of two hours.

6.7 Economic evaluation of business model

The business model was developed around a proposed New Company (New Co) to be established as a joint venture to handle the energy management system.

In the business model, the New Co. controls large amounts of HPs collectively by the energy management system and creates nega-watts sufficient for transactions, so as to earn income by trading those nega-watts in the STOR market (via tier-1 aggregator).

The number of HPs already installed in GMCA's social housing is limited, and the number of participating HPs is insufficient to earn income in the DSR aggregation business. So, New Co. assumes to use electrical equipment in public facilities in addition to household HPs, as DSR

[8] https://www.gov.uk/guidance/2050-pathways-analysis
[9] http://www.legislation.gov.uk/ukdsi/2017/9780111156353/contents

resources in order to increase the electrical load and strengthen profitability.

Electrical equipment in public facilities was not included in scope of this demonstration project, so actual data was not collected, and the additional cost is therefore not clear. A simple trial calculation was undertaken based on the data collected and desk research.

The overview of the basic structure of the business model, is shown in figure 6-4

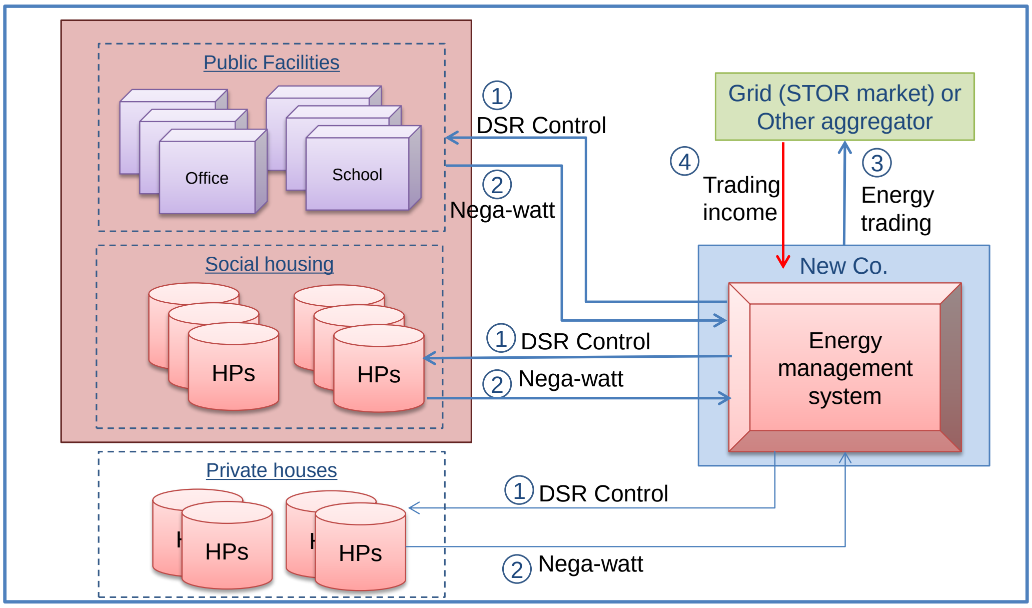


Figure 6-4 Basic structure of the business model

It is assumed at the beginning of the business start-up; New Co. starts its aggregation business with:

STEP1

1. Electric equipment within public sector facilities in GM,
2. HPs installed in the social housing within the GM area, in cooperation with local authorities, and four years later,

STEP2

3. Incorporate HPs installed in private houses in the GM area as DSR target.

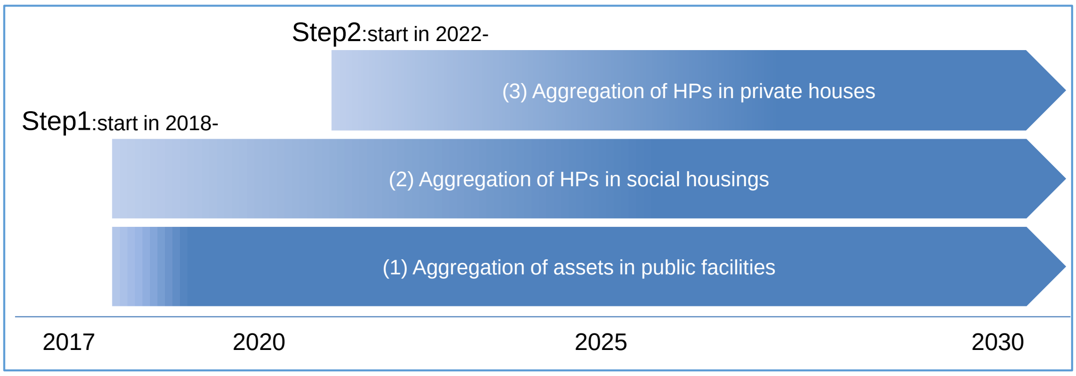


Figure 6-5 Business model development

6.8 HP penetration and DSR participation rate

6.8.1 HP penetration in the social housing sector in GM

For social housing in the GM area, it was assumed that GMCA's positive environmental efforts promote the introduction of heat pumps at a faster rate than other regions.

It was assumed that the number of social housing existing in the GM area is approximately 260,000 and that half of the social housing in the GM area is under the control of the local government and cooperates with them to actively electrify household heating (130,000).

To introduce HPs to the social housing sector, it is necessary to consider the constraints due to suitability for HP heating for each house and the burden on the surrounding electricity distribution network. In this trial calculation, it is assumed that about 40,000 household heating systems (30% of the 130,000 social housing properties) will be replaced by a heat pump from a gas boiler by 2030.

It is assumed that all the social housing properties with HP installed will participate in DR program provided by New Co. through provision to participate in that program by a tenant contract. This would involve strategic decision making to reduce the current number of gas boiler replacements in the future. A mechanism to change the current gas boiler replacement schemes with HPs would need to be implemented.

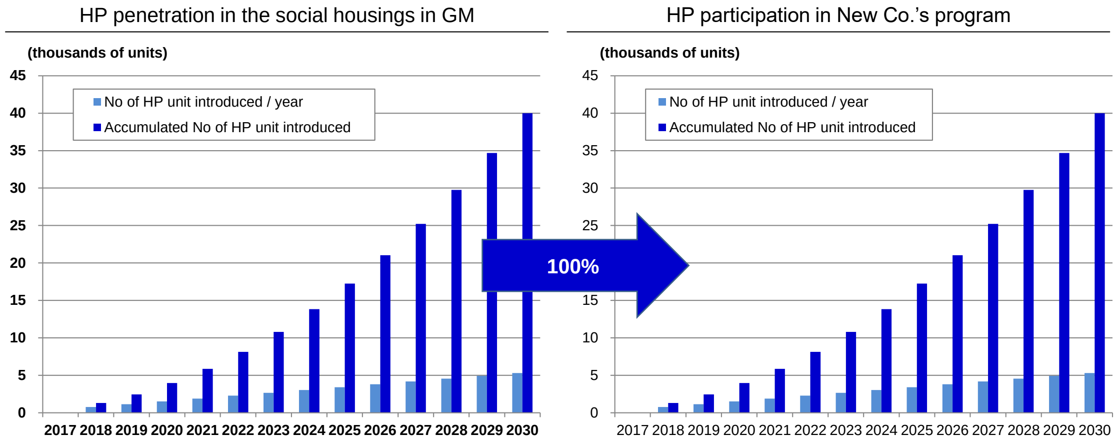


Figure 6-6 HP penetration in the social housings in GM

6.8.2 Estimation of income from DSR in public facilities

Since public facilities and private housing are not included in the demonstration experiment and information is limited, rough estimates were made, based on assumptions outlined below:

Firstly, it was assumed that the total electricity consumption of public facilities in GM is approx. 200 GWh annually. Of this electricity consumption, it was assumed that the amount of electric energy used for space heating is 12% and 30% of public facilities take part in the DSR, half of which join the DSR program.

Based on these assumptions, an income of about £600,000 per year is estimated from this business.

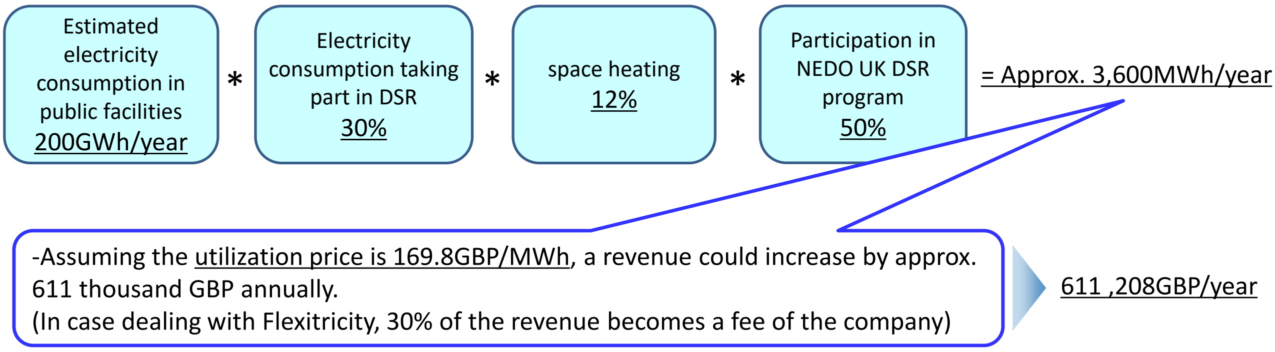


Figure 6-7 Estimate of a possible DSR transaction in public facilities in GM

6.8.3 HP penetration in private houses in GM

Although the penetration of HP in private houses is anticipated to be slower than that of the social housing sector, it is assumed that introduction will progress at a faster pace than in other areas due to the positive environmental policy of GMCA.

It is assumed 20% of all households in GM will have HPs by 2030 and that approximately 30% of introduced HPs will participate in some DSR program and assumed that the share of the New Co.'s DSR program in that participant is 50%.

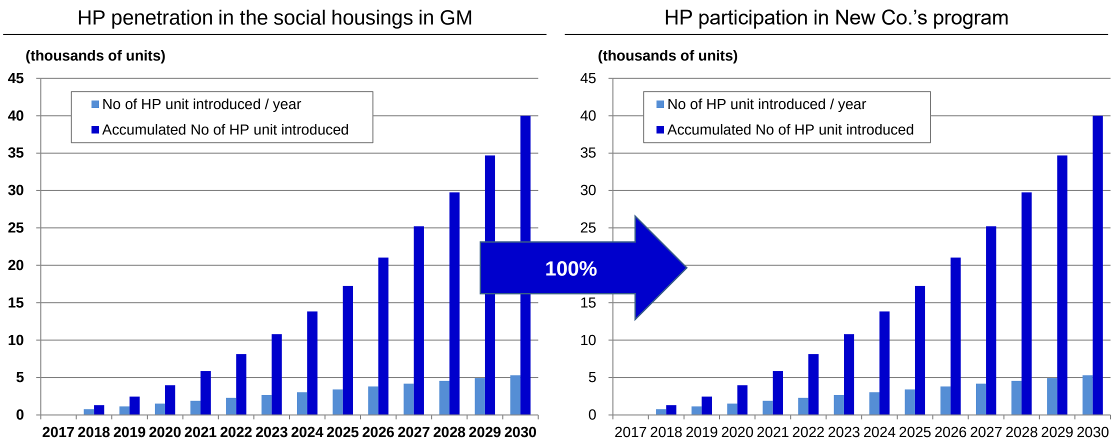


Figure 6-8 HP penetration in private houses in GM

6.9 Assumptions made in DSR simulation for Business Model

Based on the actual data obtained from the demonstration project, DSR sales were calculated under the following assumptions.

Figure 6-9 Assumption of DSR calculation

Items	Values

Nega-watt	Capacity from HP	January		0.621kW/unit
		February		0.609kW/unit
		March		0.508kW/unit
		April		0.325kW/unit
		May		0.219kW/unit
		June		0.177kW/unit
		July		0.165kW/unit
		August		0.164kW/unit
		September		0.178kW/unit
		October		0.264kW/unit
		November		0,525kW/unit
		December		0.579kW/unit
	Price /STOR	Availability		365times/year, 2h/time,
		Utilization	Winter season	155times/year, 1.7h/time, GBP0.16978/kWh
			Seasons other than winter and summer	98times/year, 1.5h/time GBP0.16978/kWh

The cost estimation for the aggregation business was developed by taking into consideration the system investment cost and support fee of EMS, the investment cost, installation cost and labour cost of the HGW.

The following costs were identified:

CAPEX

(1) Energy management system

Initial investment of about £ 1.1 million in the first year (server costs, network costs, software costs) will be made and then additional investment of approximately £ 0.2 million in the tenth year. Estimated depreciation expenses assuming that these investments will be amortized over five years.

(2) HGW

NewCo. a program operator, incurs the investment of HGW for new participants in the DR program, and renews the equipment (HGW) every 5 years, of which renewal fee is entailed. Estimated depreciation expenses assume that these investments will be amortized over five years.

OPEX

(3) Energy management system

Assumption made that £538,000 to £552,000 per year is paid as a support service fee for the energy management system. Estimated expenses included the assumption that personnel expenses (six to eight persons as personnel for system operation etc.) and office operating costs will be borne.

(2) HGW

In order to install HGW for participants living in the GM social housing, the installation cost to cover one installer is estimated to be £31,764. This is calculated based on 4 installs/day x 5 days/week x 50 weeks = 1000pcs. 1 person is necessary for the installation of 1000pcs HGWs.

A householder incentive for participation in the trial was tentatively set at £15 in the model. With the incentive paid as a one-off cost when a participant joins the program. This was discussed by the Project Board and deemed too low for a financial incentive, however research undertaken via questionnaires has identified that a reduction of electricity bills and a sense of contribution to the environment (by reducing CO_2 emissions) seems to be an ample incentive for participation.

Below is a profit simulation taking the costs into consideration. In this simulation, it will take 10 years for the New Co. to gain profit in a single fiscal year which means it will take longer to pay dividend to the local government investors. In this simulation, the number of potential participating HPs is limited because it assumes one business only within the region governed by GMCA.

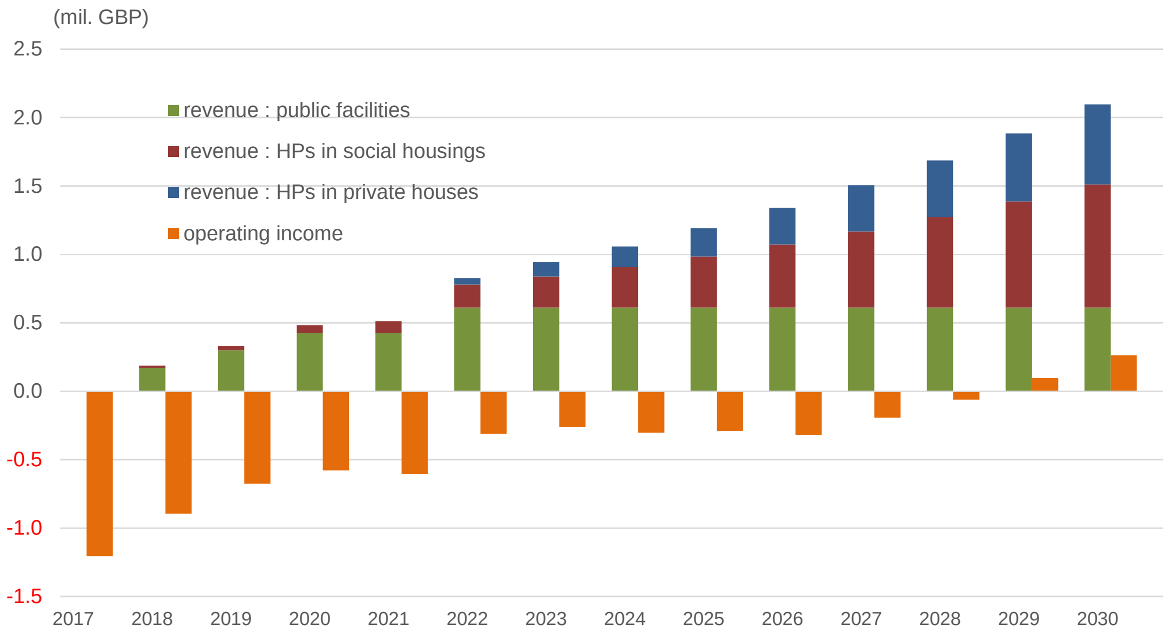


Figure 6-10 Projection for revenue and income of New Co.

As the key is to have as many HPs participate in the program, the business model explored expansion outside the GM area, to increase the number of HPs, top bring forward the profit period.

As a reference, assuming areas outside GM begin the DR aggregation of household HP after year 2020, the revenue and expenditure simulation is as below.

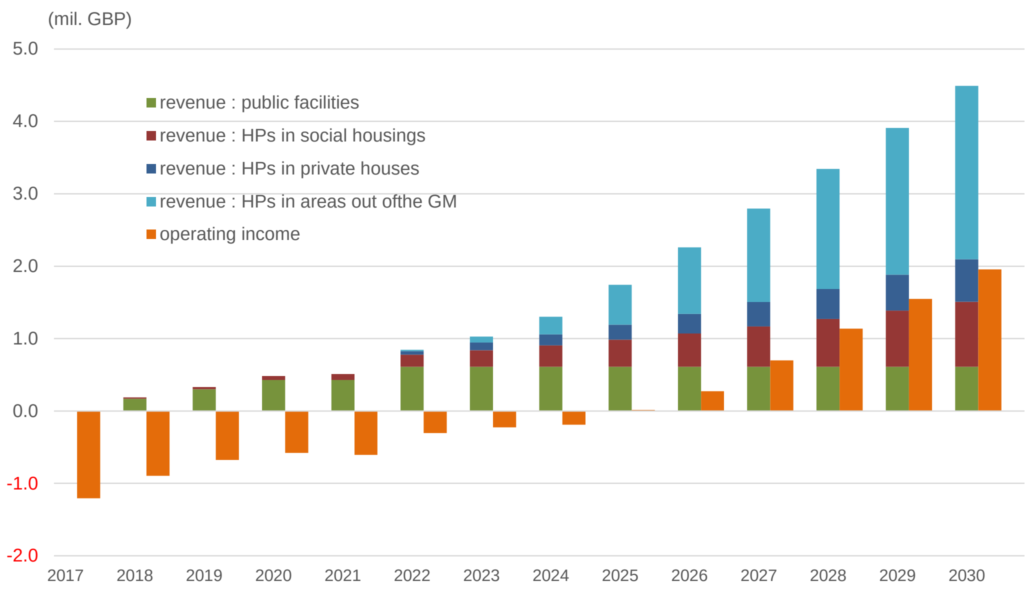


Figure 6-11 Projection for revenue and income of New Co. (including areas other than GM)

In this scenario, profit was gained 3 years earlier, (4 years after the business spreads out of the GM area). It is assumed that when expanding outside the area, the participants in the program will increase, which anticipates faster profit. However, looking at the current situation in the UK, the expansion of HP itself which is the biggest challenge.

As a part of strengthening the profitability of New Co., possible initiatives could be taken forward to expand the target of DR. potentially through the acquisition of other program participants, such as local authorities, ALMOs and regional power companies, and providing DR programs for residential HPs as an additional service to the customers.

A promising opportunity for DR is storage batteries which is also gaining attention in the UK alongside Solar Photovoltaics (PV). BEIS has noted an increase in deployment of household PV installations (increase of 10% from 2016-2017)[10], It is assumed an increase of PV installation in social housing would reduce overall household energy costs. There are existing companies proposing to start power trading businesses by selling a package of PV and storage batteries for low prices and networking those installed storage batteries. Since there is anticipation that household storage batteries will spread, by including storage batteries to the target for the DR program, it may be possible to expand

[10] https://www.gov.uk/government/statistics/solar-photovoltaics-deployment

the customer base and means of controlling energy.

Further cooperation with electricity retail businesses can also be considered as a way to expand the business. At the moment, New Co. is not expected to operate an electricity retail business nor reusable energy generation business, but, by cooperating with local power generation companies or individual electricity retail companies, there are possibilities to expand the DR aggregation business to those companies' customers. To electricity retail companies, it will be an added service to its customers and a way to avoid the imbalance of energy procurement and customer's energy consumption.

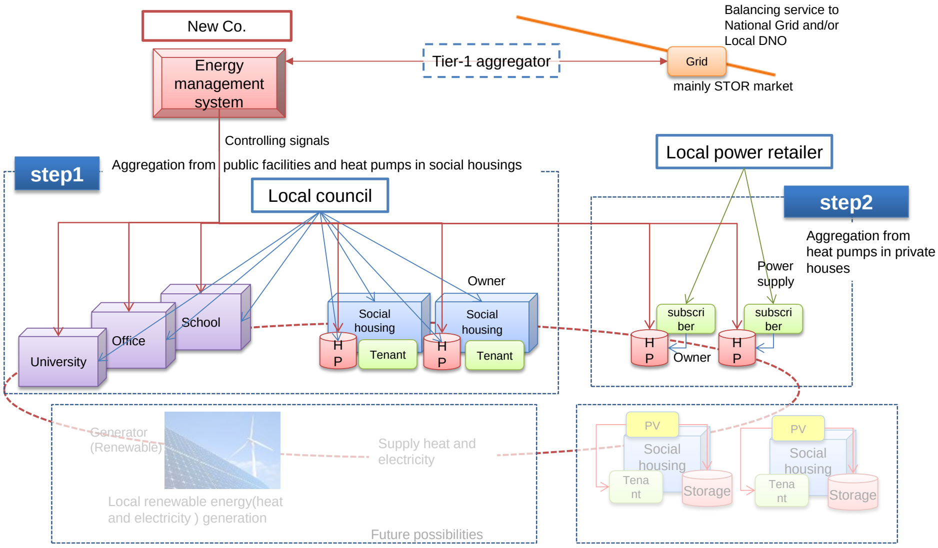


Figure 6-12 Image of business development including future possibilities

In the assumed business model, it is vital for GMCA, local authority partners and residents to work together to launch the business. A JV scheme with a local authority might make this happen.

When beginning the New Co. business, the installation cost of HP in the social housing was assumed to be paid by participating local authorities.

However, as both the capital cost and installation cost of HP is much higher than that of gas boilers, local authorities will have to bear additional costs. Whilst the capital cost of HP is not a cost for which the New Co. needs to pay, in order to proceed with the project, the installation cost needs to be borne, which is an important factor. This cost has been calculated in comparison to a gas boiler as below:

Table 6-13 Comparison Capital and Installation Costs

	Equipment cost	Installation cost
Gas boiler	£2,700	£1,000
HP (Electric)	£5,150	£4,050
HP (Gas hybrid)	£5,250	£4,050

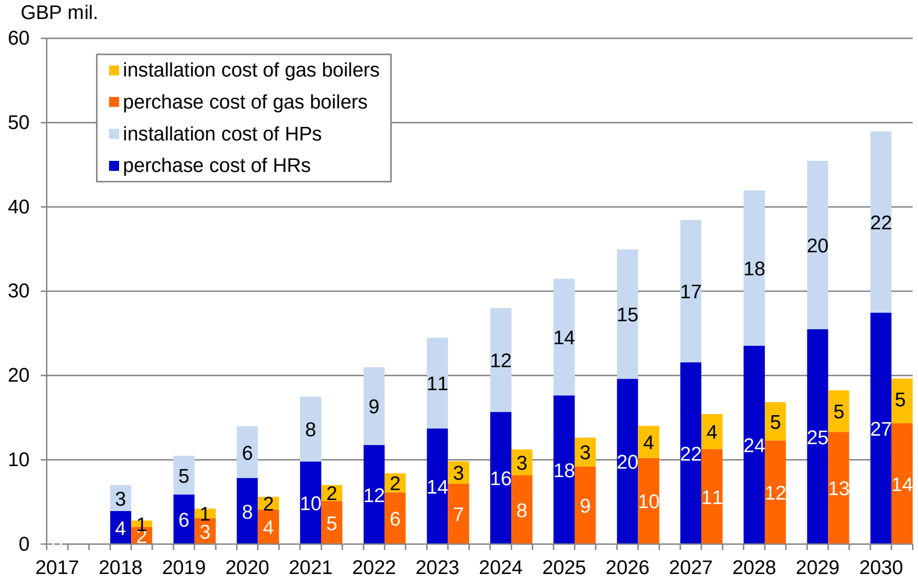


Figure 6-14 Projection of the cost of introducing gas boiler and HP in social housings

According to the estimate, in the case of electric HP, RHI subsidies totaling £6,334 can be received in 7 years against the capital cost £5,520. As a result, if the owner can receive full RHI subsidies, the owner could potentially reduce the cost differential to £814 per unit. (Not including the additional installation costs). In the case of Gas Hybrid HP, the total value of RHI subsidies that can be received in 7 years is lower at £4,614. In this case, the cost difference is circa £1,000.

Although this will not directly financially help local authorities bear the cost, considering the social significance of reducing CO_2 emissions and the merit of reducing the heating expenses for tenants, it can be considered that introduction of HP is meaningful and reasonable from the viewpoint of wider benefits.

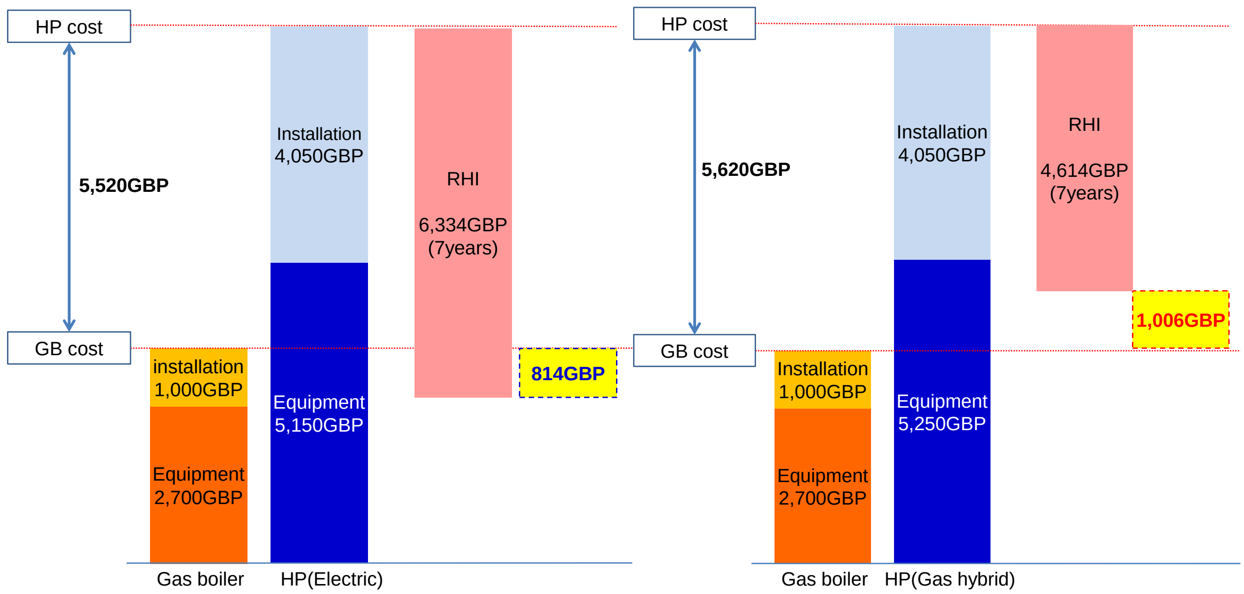


Figure 6-15 Cost difference of Gas boiler and HP

6.10 Financing Options

When considering fundraising for the New Co., since UK is not an ODA company, a two-step loan (offered by Japan Bank for International Cooperation) is not a possibility. 'ODA means Official Development Assistance, a governmental and international fund for developing countries or regions for the purpose of their development activities

A leasing scheme could be considered for the procurement of the energy management system (i.e. HGW equipment) for the New Co. If a UK lease company provides the New Co. with lease finance, there is a possibility that a Japanese bank could provide backing finance.

There is also a possibility of using lease finance for the following purchases of HP:

1. When local government purchases HP to install in social housing
2. When individuals purchase HP for private housing:

1. When local authorities purchase HP to install in social housing

HPs cost significantly more than current gas boilers. To raise the funding for this, leasing was considered but since local authorities will have to bear a lease cost that adds on an interest amount equivalent to the depreciation and amortization cost, there are no clear advantages to leasing.

- Although the installation cost is a high portion of the total cost, this cost is not subject to leasing.
- There is no secondary market for HP so it will be a finance lease.
- Since RHI interest cannot be determined at the time of purchasing HP, it cannot be deducted from the lease fee.

2. When individuals purchase HP for individual housing

Installment finance is considered for individuals purchasing HP. As same as lease for local authorities, the installation fee is not included and RHI cannot be deducted beforehand. However, offering finance packages may make it easier for individuals.

When introducing HP to individual households in the future, financial help will be necessary. To promote this finance, it is considered possible that Japan could offer to back finance to UK companies that offer installment finance to individuals.

6.11 Conclusion of Business Model Evaluation

The economic evaluation for the business model was made from the feasibility study by applying the actual HP operation data, market data, and the updated costs. As a result, when assuming commercialization of the HP aggregation business within social housing in the Greater Manchester area, in order to monetize the business, it is necessary for 55-60 thousand units of HP to participate in the DR. This is estimated to take 13 years from the startup of the business when taking the diffusion scenario into consideration.

To establish an aggregation business using household HPs, the spread of HP usage in the UK households is necessary, which currently is not sufficient. Therefore, in order to monetize the business model considered in this study, there is need to expand the model to increase the number of participating electric appliances other than HP and customers other than social housing. The expansion of DR source will also be necessary, and one consideration could be the inclusion of battery storage for example. Other considerations are the possibility of future cooperation with other power related companies, such as electric power retailers, in order to strengthen profitability.

The initial capital and installation costs of the HPs remain a barrier and an installment finance scheme to promote household usage of HPs needs to be considered.

The expansion of HP usage is an important factor for the success of this business. However, currently in the UK, the expansion of the HPs is not making as much progress as assumed in the feasibility study. Hereafter, in order to establish the aggregation business targeting the household sector, the expansion of the HPs will be a major premise.

7 Telecare Trial

7.1 Telecare Trial Overview

As an ancillary element to the demonstration, a telecare service system was installed in 20 flats in two sheltered accommodation blocks (Thorburn House and Winster House) in Wigan. This system was installed in tandem with the Heat Pumps as an additional support service/ incentive to the residents in these properties.

The aim of the telecare trial was to find out how technology can help people manage their own health while maintaining their independence. This trial explored the service level improvement and the economic value of the telecare system, along with the motivation of users to participate with the services.

The operation of the telecare trial was led by Wigan and Leigh Homes (WALH), and day to day management was tested with the support managers in the two sheltered housing blocks. One of the aims of the telecare trial was to help the Support Managers to be able to regularly monitor the welfare of tenants, currently reliant on a phone call made each morning to the residents.

Activity monitoring sensors were installed in the properties and tenants were also provided with tablets to record 'daily self-assessment checks' of their health condition that could both be reviewed by the Support Manager from a PC screen.

The functions of the telecare services are shown in Figure 7-1.

Figure 7-1: Telecare Functions Overview

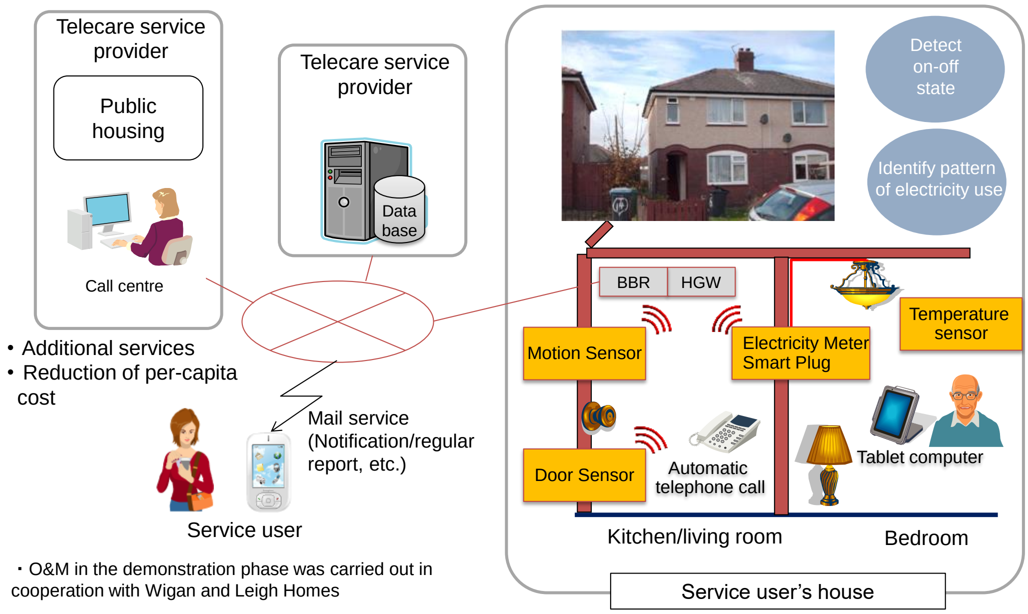


Table 7-2 outlines the various sensors which were installed in tenants' property and their location in each property.

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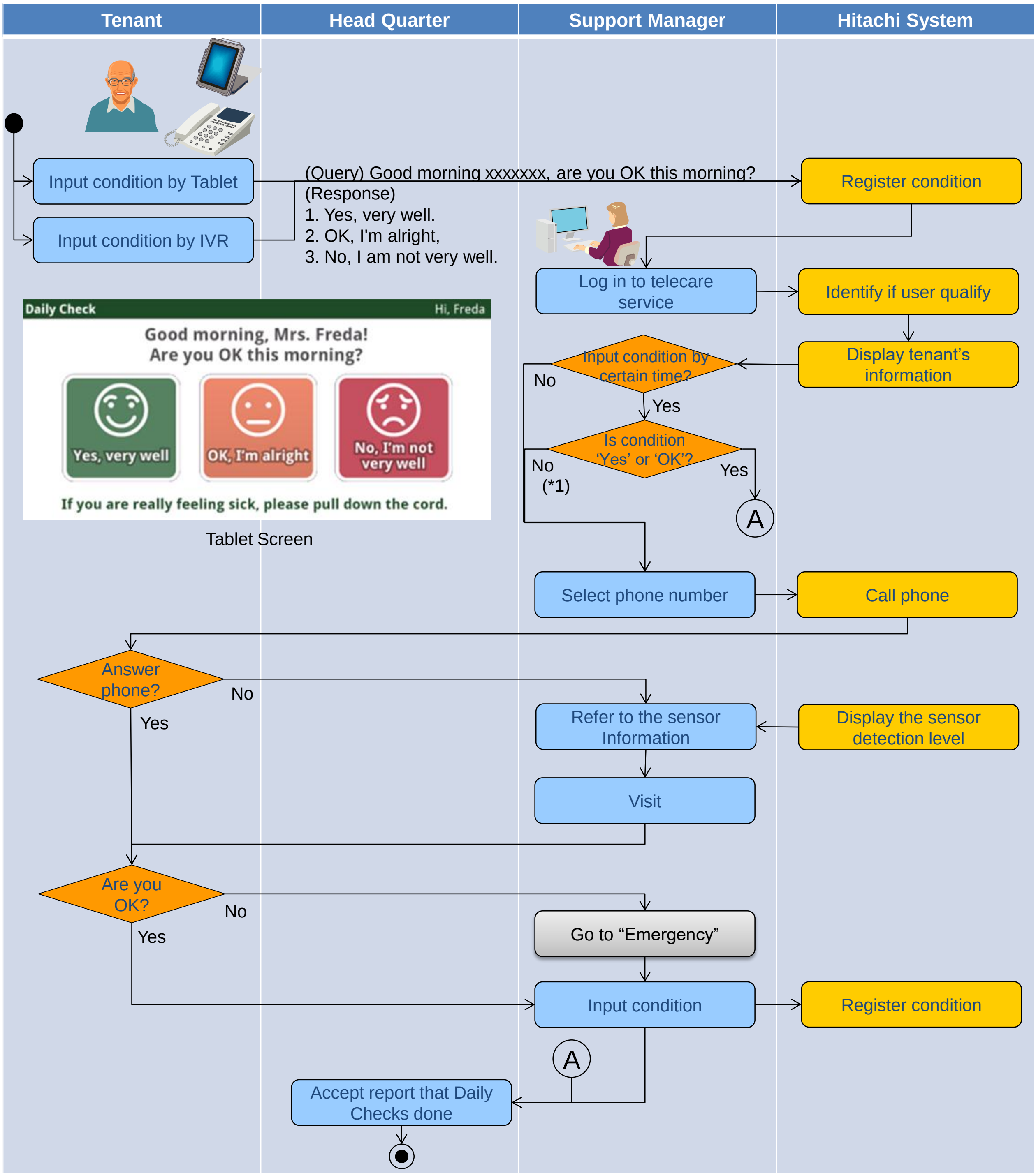
Figure 7-2: Telecare Sensors

No.	Sensor Name	Functionality	Installing Place
1	Motion Sensor 1	Notify human motion to the system.	Ceiling or Wall of bathroom
2	Motion Sensor 2		Ceiling or Wall of Entry Hall
3	Motion Sensor 3		Living Room
4	Motion Sensor 4		Bed Room
5	Door Sensor	Notify door's opening and closing to the system	Entry / Exit Door
6	Smart Plug 1	Notify electricity consumption of specified consumer electronics.	Kettle or toaster
7	Smart Plug 2		TV
8	Smart Plug 3		Microware oven
9	Temperature Alarm	Notify the abnormal of tenants' room temperature	Heat Pump (BC2)

Participating tenants were invited to register their health condition daily using the telecare system on their tablet or telephone between 6AM to 9AM. A flow chart showing the daily check operation is shown in the following diagram 7-3.

Figure 7-3: Flow chart of telecare daily



7.2. Telecare Results

This section outlines the results of the telecare trial.

7.2.1 Number of active participants

The results of the telecare trial show that the number of actual 'active' tenants who used the tablet more than once is 12 (out of 20 participants) Tables 7-4 and 7-5 show the ratio of tablet usage to input the daily check during February 2017.

Table 7-4 Active Tenants

	Scheme	Participating tenants	Active tenants (Feb.)
Telecare Service User	Thorburn House	10	4
	Winster House	10	8
Total		20	12

Table 7-5 Ratio of Tablet Usage on "Daily Check" in February

	User Ratio			
	Scheme	Over 50%	10 – 49 %	Less than 10%
Telecare Service User	Thorburn House	2 / 10	2 / 10	6 / 10
	Winster House	7 / 10	1 / 10	2 / 10
Total		9 / 20 (45%)	3 / 20 (15%)	8 / 10 (40%)

Approximately 50% (+/-) used the "Daily Check" on the tablet but 30% of the residents remained fully reliant on direct calls from Support Manager, rather than the tablet.

7.3 Evaluation of Telecare service

7.3.1 Tenant Acceptance

A questionnaire and interviews with participants of the Telecare trial were undertaken to evaluate the views of tenants in using this service. The number of respondents to the questionnaire was 5 tenants and 1 Support Manager.

Table 7-6 Satisfaction questionnaire on use of Telecare service (Tenants)

Category	Question	Answer
Satisfaction	Please rate your satisfaction with "Daily check"	Extremely satisfied (5 / 5)
	Please let us know the reason for satisfaction.	Easy to use (5 / 5)
Usability	Were you able to operate the tablet screen with ease?	Yes (5 / 5) No (0 / 5)
Acceptability	After demonstration, do you think that you want to continuously utilize the tele-care services?	I want to use it. (5 / 5) I don't need it. (0 / 5)

Table 7-7 Satisfaction questionnaire on use of Telecare service (Support Manager)

Category	Question	Answer
Satisfaction	Please rate your satisfaction with "Daily check"	Extremely satisfied (1 / 1)
	Please rate your satisfaction with "Activity Monitoring"	Slightly satisfied (1 / 1)

	Please let us know the reason for satisfaction.	Easy to follow (1 / 1)
Usability	Were you able to operate easily on the operation screen?	Yes (1 / 1)
	Was tenant training able to perform smoothly?	Tenants understood, but not easy (1 / 1)
	Please let us know which part was mostly difficult for.	Logging in to the tablet and options (1 / 1)
Acceptability	Is telecare service effective as an additional consumer service?	Effective (1 / 1)
	Do you think the operational efficiency about daily check contact has improved by the tele-care services?	Improve (1 / 1)
	After demonstration, do you think that you want to continuously utilize the tele-care services or to expand the scope of application to the other scheme?	I want to expand to other schemes. (1 / 1)

Based on the questionnaire results, it can be said that the 5 tenants and 1 support manager who completed this reported a strong satisfaction level in using the telecare service and would use the telecare service after the demonstration, however this is just the view of 5 tenants.

On the other hand, some tenants did not fully use the Daily Check function on the tablet. Interviews were conducted with the tenants who did not use the function. In this interview, the tenants reported that it was too difficult to input the passcode operation and there were too many steps to reach the Daily check function. The steps to reach the Daily check function were as follows:

1) Switch on by pushing hardware button of Tablet
2) Enter passcode for OS Security
3) Enter passcode for Screen Lock
4) Click Shortcut link for this project
5) Enter user ID and password for logging into Web portal
6) Select “Daily Check” from the menu of Top page

7.3.2 Monitoring of Activity

Figure 7-8 shows an example of activity monitoring in one property, based on the motion sensors, door sensors and smart plugs.

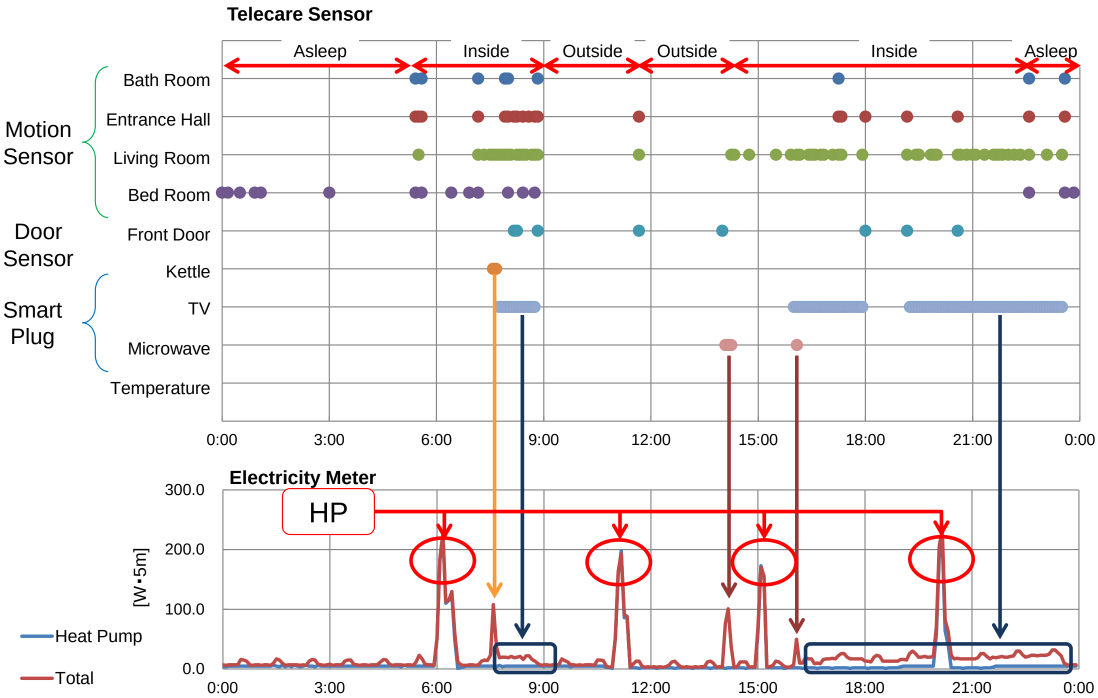


Figure 7-8 Examples of Activity Monitoring

Feedback on the activity monitoring can be summarised as follows:

- **Motion Sensor and Door Sensor**
  This provided an easy way for support managers to monitor tenant activities, and was well received by the support managers, however, some tenants did not like the idea of sensors monitoring their every movement.
- **Smart Plug**
  This provided that, whilst frequently-used appliances could help to monitor activity with less stress / intrusion than motion sensor, this is reliant on the tenant regularly using these appliances and some data i.e. TV and lighting cannot always detect activity as this equipment was often left switched on for long periods of time.
- **Electricity Meter**
  Tenant activity through the electricity meter could only be observed by closely monitoring the fluctuation of power consumption. This proved difficult to use as a signal to the Support Manager, as it was difficult to distinguish fluctuations.

7.4 Challenges for the Telecare Trial

There was a delay in the installation of the telecare equipment which shortened the duration of the trial. This was due to the timescales it took for planning to be approved for the installation of HPs at the two sheltered properties. As this equipment was installed in tandem with the HP, the planning delays impacted on the timescales of this trial.

7.5 Telecare Conclusion

The conclusion from the telecare trial was that, as an additional service for a DR system, the minimum and reasonable option to monitor tenant activity would be the installation of a smart plug for manual "frequently-used" electrical appliances (e.g. a kettle or a microwave oven), where daily activity information can be monitored efficiently and with little intrusion for the residents.

WALH were asked whether they would be likely, based on this trial, to install such equipment and they responded that although the trial gave a good insight into the opportunities and limitations of a telecare service, there are other telecare service options currently in the market that could prove more cost effective.

The telecare sensing devices selected for this project did not have the support of remote maintenance, so could not be remotely recovered if disconnected from the network. The importance of having function to remotely maintain devices was realised and would be deemed necessary when defining requirements in future similar projects.

8 Social Research

The tenants involved in the trial were communicated with at a number of levels, as discussed in chapter 2. An important element of the project was to develop an understanding of the level of tenant engagement with the project and their feedback on the new heating system and the demand response 'heat saving' events.

8.1 Summary of social research undertaken

To evaluate the level of acceptance of the participants involved in the trial for both HP and DR, the following surveys were conducted during the demonstration project. The table below summarises the surveys undertaken.

Figure 8-1 Summary of approached for tenant feedback

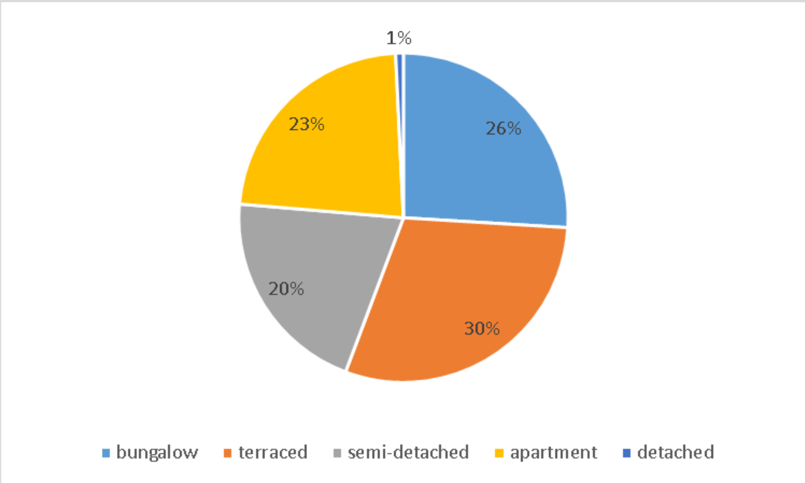
#	Objective	# of respondents	Media
1	Survey on tenant attributes (family structure, age, health condition, IT literacy, environmental awareness etc.)	About 180 tenants	paper
2	Satisfaction survey on installation process of HP	About 180 tenants	paper
3	Satisfaction survey on use of HP	About 32 tenants	paper
4	Interviews on the participation of demonstration project as a whole	16 tenants	Individual face to face interview
5	Satisfaction survey on participation on the DR program	12 tenants	Tablet
6	Survey on awareness of the general public in UK for the DR	570 samples	Survey on web

7	Follow up satisfaction survey on use of HP and participation in DR program	68 tenants	Telephone interview

8.2 Demographics of tenant involvement

In terms of property types participating in the project, there was a good split between terraced properties, bungalows, semi-detached houses and flats/apartments, but very few detached properties, as outlined in figure 8-2

Figure 8-2 – Property type



A paper questionnaire was issued to all participating tenants in the trial at the beginning of the project before the installation phase. This asked questions about the general attributes of the tenants. 178 responses were received in total (a response rate of 32%). In many cases the respondents didn't answer all the questions asked. A summary of the responses shows that the over 50% of participating properties were occupied by just 1 or 2 residents and that of this 30% were over the age of 65. Of the residents who responded to the questionnaire, 74% had access to the internet.

Figure 8-3 How many people live in your property? (# of respondents: 105)

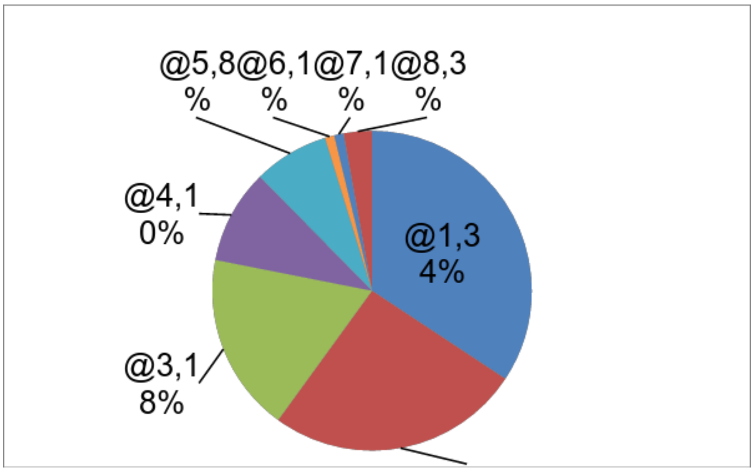


Figure 8-4 Is anyone in your house over the age of 65? (# of respondents: 172)

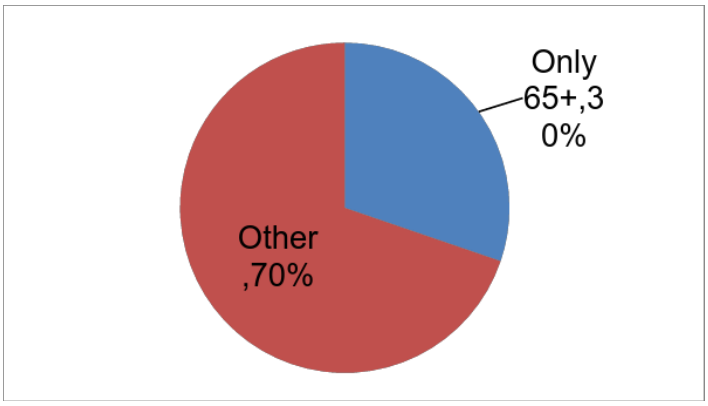
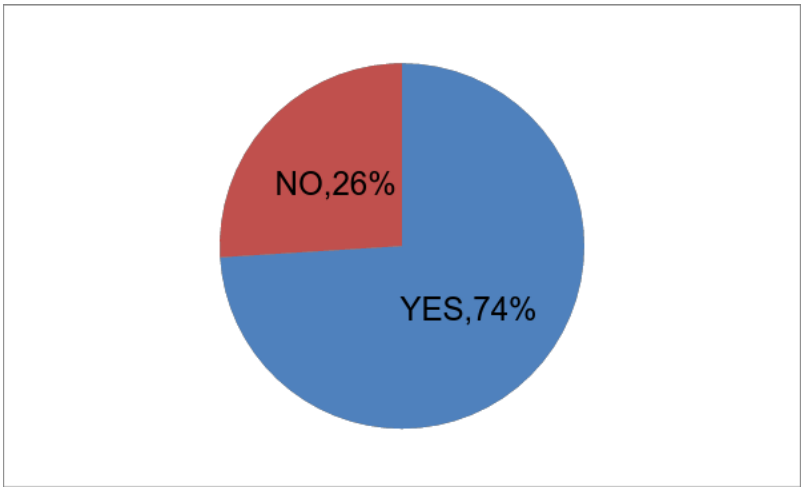


Figure 8-5 Does anyone in your house use the internet? (# of respondents: 177)



An initial feedback survey on satisfaction level for use of the HP and satisfaction level for participation in the DR program received a very limited response. This proved difficult to analyse statistically. As a result, further telephone interviews and face to face interviews were conducted at the end of the trial, which resulted in a further 86 responses. A summary of the tenant satisfaction responses from the interviews are outlined in section 8.3 below. A separate report on the detailed findings of the telephone interviews is available.

8.3 Tenant responses (interview and questionnaires)

In December 2016, Salford University conducted individual face to face interviews with 16 tenants. The tenants were selected based on the survey of the tenant attributes that included both male and female tenants, a range of age groups, each of the three participating Greater Manchester areas,

In addition, a telephone interview was undertaken with 70 tenants in March 2017. The interviews were conducted to investigate tenant views on the demonstration project as a whole including overall satisfaction with the heating system, environmental awareness and understanding and participation in the DR trial.

In general, positive feedback was obtained from tenants during the 16 face to face interviews. "*No interviewees expressed negativity towards the idea of DR, and many, 11, were explicitly positive.*" The majority of tenants interviewed did not notice DR and therefore did not feel the need to Opt Out.

The results of the telephone interview showed that in general the majority of tenants (69%) were either 'satisfied' or 'extremely' satisfied with their HP. Those that were not satisfied felt that the system was more difficult to understand and use than their old heating system, some had experienced technical issues following installation and some felt that the cost of their heating had increased compared to their old heating system. Each tenant was provided with information on 'energy switching' options to lower tariffs and advice on energy efficiency as part of the trial.

Further analysis of this data and of the tenant demographics and behavioural trends is needed to more fully understand the correlations. Initial analysis indicates that there is an emerging trend between overall satisfaction level and the length of time the system has been installed, indicating that a new system may take time to get used to (Figure 8-7).

In addition, there was a strong correlation between overall satisfaction and level of understanding of how the system works, demonstrating that it is important for new systems such as HPs to be fully explained. (figure 8-8).

Figure 8-6: Reported overall satisfaction level with new heating system

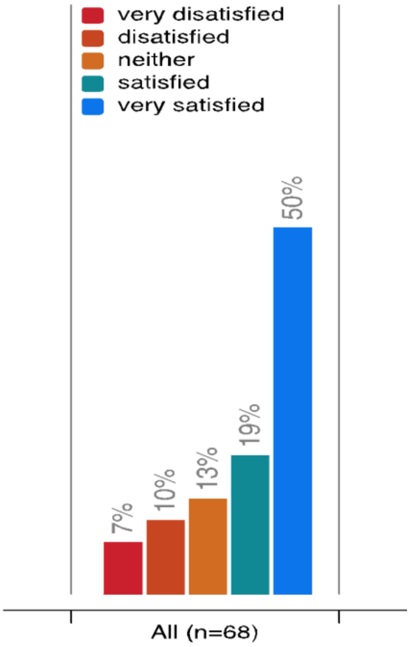


Figure 8-7: Reported overall satisfaction vs date of installation

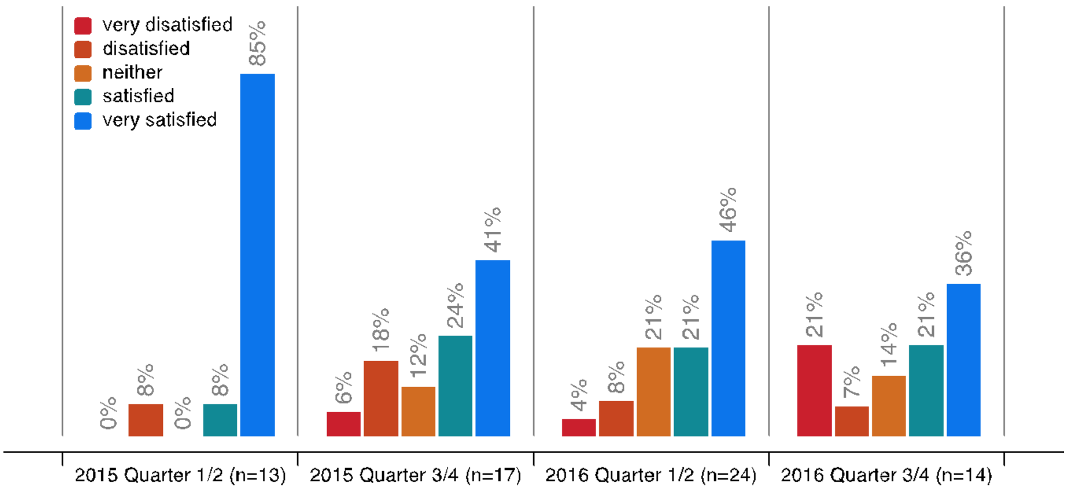
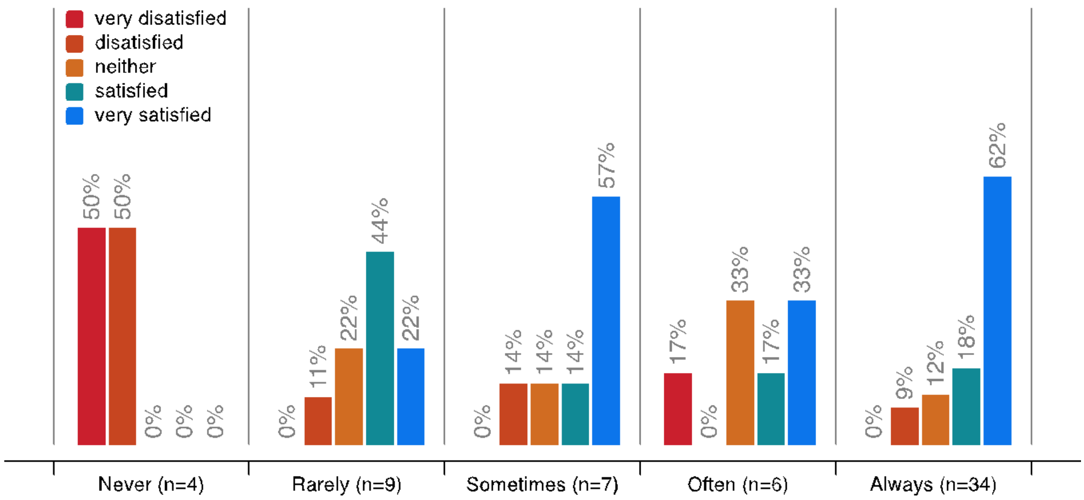


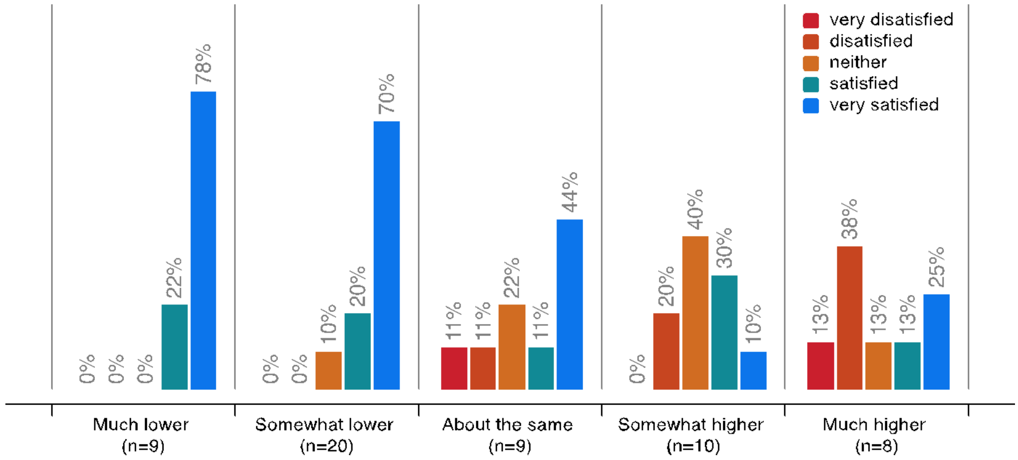
Figure 8-8: Relationship between overall satisfaction with heating system (vertical) and ease of using the controls (horizontal – ranging never easy to always easy)



The graph in figure 8-9 below indicates that those interviewees who experience lower costs are more likely to say they are satisfied with their new heating system.

Following the completion of the project, the ALMOs have each followed up with tenants to explore energy costs and why there are some cases where energy bills are perceived to be higher. Initial findings indicate that whilst in some instances the electricity bill has increased (for example when replacing a gas boiler) the tenant has not taken into consideration the fact that they no longer receive a gas bill and therefore their overall energy bill is lower. In other instances, there has not yet been a sufficient amount of time to compare ‘like for like; energy bills across a whole year and there are some examples where the tenant behaviour and interaction with their new heating system has resulted in higher bills, for example where the room temperature has been set to 26 degrees and windows are left open.

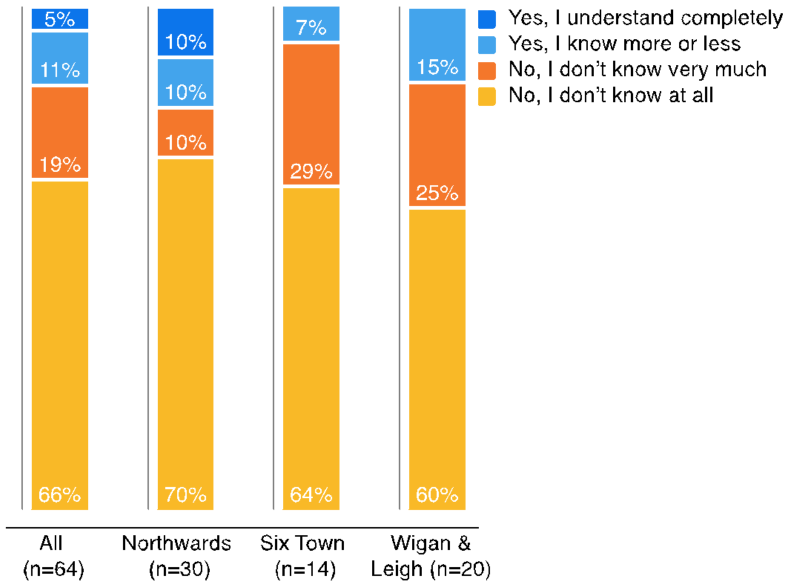
Figure 8-9 Relationship between reported overall satisfaction (vertical) and perceived change in energy costs (horizontal)



There was no correlation identified between overall satisfaction level and the type of previous heating system the HP was replacing.

Figure 8-10 shows that despite being provided with information, very few respondents understood what a DR event was. Because they didn't know what one was many interviewees didn't respond to how often they noticed an event. Of those that did respond, 71% stated that they had not noticed any DR events taking place with a further 22% 'rarely' noticing. Only one interviewee stated that they actually took steps to override a DR event.

Figure 8-10: Interviewees' understanding of what a heating saving event is, split by ALMO



Over 50% of respondents did not use the tablets provided to them, either for general use or to look at the 'smart communities' app. The main reasons given were lack of interest and lack of skills / understanding, this is despite digital inclusion training being offered to all participating tenants.

One of the interesting findings from the project has been that the tablet was not as strong an incentive to participants as expected. This may be linked to many factors, including that technology advancements have moved on significantly since the project development phase (2013) and whereas a tablet would have been a 'luxury' item, reduction of costs and prevalence in the market now means that anyone who wants one probably already has one.

Generic feedback received from the face to face interviews suggested that, in general, increases in comfort and savings on energy bills were sufficient incentive to participate in the DR trials, and that tenants would appreciate further information on how much energy they have actually saved, however and additional reward for participating would be welcomed.

8.4 UK Survey – General Public Awareness of DR

To support the development of the business model, Mizuho bank commissioned a survey on awareness of the general public in the UK of DR as a concept. This comprised of an online survey with 570 householders across the UK in September 2016. The survey was managed by Salford University.

The majority of respondents had gas boiler central heating as shown in figure 8-11 below.

Figure 8-11: Current heating system of interviewees

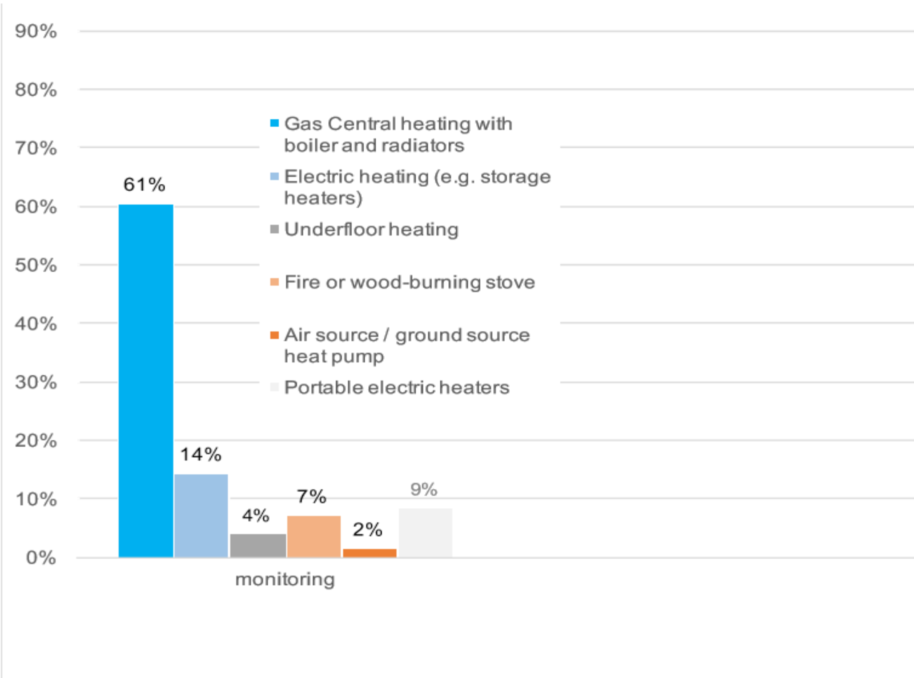
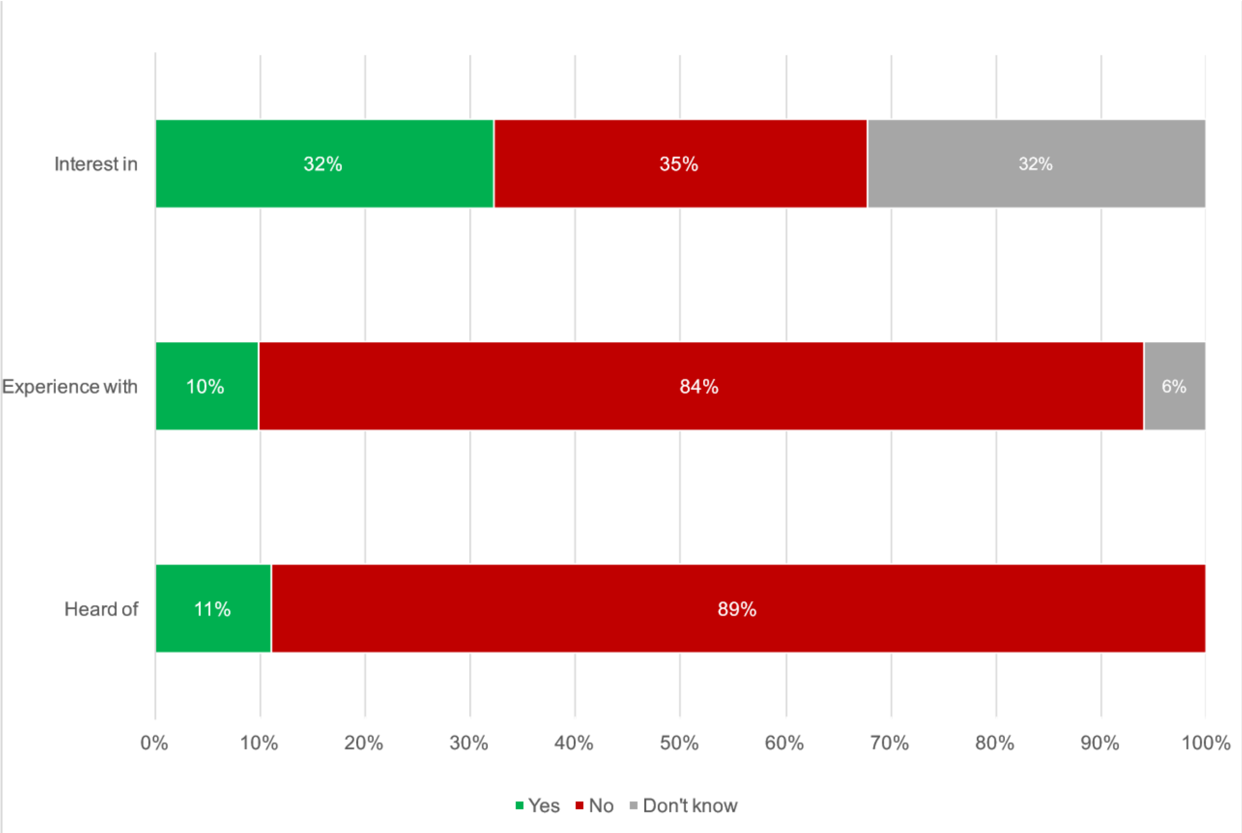


Figure 8-12 shows the level of current knowledge and experience of DR and the level of potential interest (once DR had been explained).

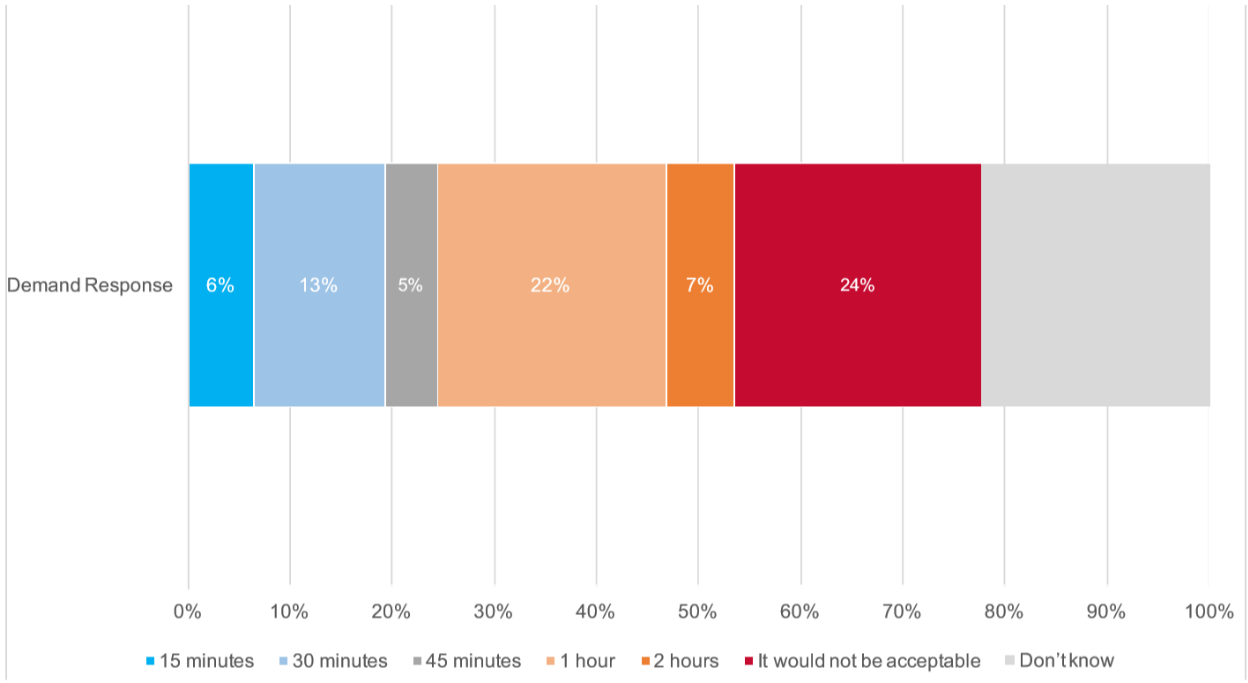
Figure 8-12: Level of engagement with DR



This revealed that generally, people in the UK are not familiar with the concept of DR. However, after having it explained, about 30% of those interviewed showed interest in the future participation in a DR program.

Figure 8-13 shows the acceptable time the respondents would be prepared to accept for a single DR event. This indicates that the majority of those who would accept DR would be happy with anything up to one hour

Figure 8-13: Feedback on acceptable duration of a single Heat Saving Event


Demand Response
6%
13%
5%
22%
7%
24%
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
15 minutes
30 minutes
45 minutes
1 hour
2 hours
It would not be acceptable
Don't know

9. Lessons Learned from the Project

The following section sets out the key lessons learned from this demonstration project for consideration in any future project of this type.

9.1 Project Planning

The timing of the design of the system components is crucial. In this project, the electrical monitoring system was still being finalised and tested after the HP installation phase commenced. This led to a complex installation programme, with retrofitting of equipment and technical faults identified as the 'whole system' had not been tested together prior rollout. In future a strong recommendation would be for the complete system to be fully developed and tested in advance. A small-scale pilot would have identified and managed the risks earlier prior to full implementation rollout. As well as ironing out any technical faults and communication errors between system components a pilot phase would also have picked up the 'user interference' encountered with the BBR routers, HGW box and cables.

Due to the volume of installations, a real challenge for this project was maintaining a consistent pipeline of 'ready to install' properties Early sign up of participants, creating a pipeline of properties in advance of the installation phase, quick turnaround of property surveys and prior DNO consent would have ensured a smoother installation phase and prevented some of the installation delays at the start of the project.

A full understanding of the DNO property selection and approval policy at start of project would have resulted in a more streamlined approach to property selection. Early engagement with the DNO is essential for a project of this scale. Consideration of the geographical spread of heat pumps to ensure they operate within the required DNO network grid connection limits would reduce planning time for future installations. Development of a protocol to enable quick assessment of network reinforcement requirements would be required for any future large-scale HP rollout programme,

Ensuring all operational partners have knowledge of how the HP and electrical monitoring systems work at the start of the project and building awareness raising and training into the project planning process is essential, to enable partners to identify, triage and troubleshoot issues quickly. In this project, equipment was provided by and managed by two separate organisations (Daikin and Hitachi) and there wasn't a full overview of the 'whole system' operation. Manuals provided at the start of the project on the system operation, a clear understanding of each partner's role and responsibilities, a clear 'triage' system with training for all partners on the 'whole system' would increase overall visibility of issues arising make trouble-shooting issues easier and quicker to solve. With so many partners involved, project coordination and sharing of information is vital. The establishment of cross-partner meetings to bring operational resources together across the delivery in this project enabled challenges to be identified and dealt with quickly.

A 'contingency fund' was set up early in the project to cover any additional unforeseen project costs and proved to be a useful resource for the project. The ALMOs each agreed to allocate a proportion of their anticipated RHI payments into this central 'contingency' fund. This funding was used to: support additional tenant engagement, including digital IT literacy training on tablets; cover unexpected property works to make some of properties suitable for HP installation, such as strengthening beams and to pay for planning application costs.

Engaging the appointed installation contractor earlier in the overall project scope to assist in planning and establishing agreed procedures would have provided the contractor with a clearer idea of what the resource needs and training requirements were. In addition, planning and accounting for long term O&M for the lifetime of the HP (not just the duration of the project) is essential and should be factored and costing into the project planning stage.

9.2 Operation

The main challenge encountered with the data collection was the number of 'live' properties that were connected and able to collect data (and therefore participate in the DR trial) at any one time. The monitoring equipment was connected via BBR and the HGW device. These are portable items that could be unplugged and switched off by the tenants. Following investigation of the data, the review found that whilst in some instances disconnections were down to technical faults (with the HGW or cables), the majority were down to 'user' disconnection. Systems need to be carefully designed to remove 'user' interference, i.e. by removing reliance on BBR connectivity for example consideration of another means of connection such as 3G, removing the ability to disconnect the system by hardwiring elements, making it difficult to unplug the power cable and LAN cable.

DR events were performed twice a day between 06:30-08.00 and 17.00-18:30. This was based on the 'peak profiles' identified in the aggregated data, but did not take in-to account the individual set heating schedules of the tenants. This meant that in some instances, the DR event was not successful at activation time as the property was not yet at the minimum temperature. This is seen by the spike in fail safe stops on the DR events within the first 5 minutes. This was particularly apparent in the morning DR periods. A more focused approach to target DR events to the individual tenant heating schedules would likely result in a higher DR success rate.

The absorption DR trial was only tested in the daytime, taking in-to consideration the ALMOs' concern that operation noise during the night may be disruptive to tenants. As a result, the absorption DR was not tested at the optimum time for heat absorption, resulting in a shorter DR event time than anticipated. A small-scale test of absorption trial in the early hours on some properties, would have enabled this use case to be tested more fully.

Despite comprehensive tenant engagement, the trend lines of the 'call outs received by Daikin during the DR period demonstrates a lack of understanding of DR by the tenant, with a link between calls received coinciding with a DR event. There were incidences where this was reported by the tenant as their HP not working, when in fact it was in a state of DR. A function display on the HP or controller to indicate that the HP was in a DR event, rather than 'off' would have assisted in managing some of this confusion.

9.3. Tenant Engagement

The properties were selected based on the age and type of the existing heating systems (asset management approach). ALMOs have noted that in many social housing schemes, tenant access is a major hurdle. In this project, due to the nature of the work involved and the new technology being provided the issue was exacerbated. Tenant access may have been improved if further consideration was given to the tenant demographics / tenant suitability at the start of the project (in addition to the property asset management approach), as there were a number of tenants who although happily signed up to the project initially, were either not in a position to allow repeated access to the properties (i.e. those at work all day) or were deemed 'not suitable' for further access by contractors (e,g. due to unacceptable behaviour towards project partners). Consideration of tenant demographics and suitability of participants may have increased overall participation in the trial, removed some of the tenant access issues encountered and resulted in potentially less tenant interference with the equipment than was encountered with this project.

Resource availability for tenant engagement differed across the ALMOs and the resource requirements were found to be higher than initially anticipated (due to the number of re-visits required at properties). Whilst the ALMOs felt that they provided sufficient information to their tenants, additional engagement and agreed processes to share consistent information (including the expected level of disruption and number of visits to be expected during the installation) would have made the tenant engagement simpler. In most cases, a detailed conversation with residents did take place pre-install by both the ALMOs and the contractor (WES) in line with FAQ documents that were developed.

FAQs user guides, letters and face to face surveys were all undertaken in this project and energy saving advice was offered to all residents, however many residents fed back in questionnaires that they didn't fully understand how to control their heating system and the majority, when asked, did not understand the concept of DR, despite being provided a separate |FAQ| leaflet to explain DR before the trials commenced. The provision of more simplified information, including an explanation of each piece of equipment and its purpose may have reduced the overall number of call outs by tenants. A dedicated 'shared' contact number to direct questions from tenants on the operation of the equipment might have proved helpful.

In the feasibility study, there was a perception that free Broadband connection for up to 2 years and a free tablet were strong incentives, however technology moved on rapidly in the 4 years between feasibility and completion of the project and tablets are now widely available on the market at much reduced cost. They were therefore perhaps less of an incentive than they would have been at the start of the feasibility phase. Future projects should consider more tangible incentives to tenants to increase uptake, i.e. direct financial incentives.

The tenant questionnaire / feedback element of the project was extremely important to gauge the tenant reaction to HPs and views of participating in the DR trial. It is important to factor feedback into the planning and overall costing of the project, to ensure that there is sufficient time and resources to collect and analyse the data received.

10 Project Conclusion

There is currently little evidence of heat pumps as a large scale retrofit DR solution and this project represents the largest UK trial with air source heat pumps in social housing known to date. The demonstration project enabled the development of further understanding of the challenges these systems present and identified some solutions to those challenges. Moreover, the complex nature of this project, involving multiple delivery partners, the social housing sector and new innovative techniques has resulted in significant lessons that can be passed on for future smart energy projects to learn from.

The project successfully demonstrated that a significant amount of energy can be saved through collective DR across social housing properties. Each DR activation resulted in accumulated energy demand reduction of between 50kW and 320kW depending primarily on the external temperature during the activation and the number of properties involved in each DR event. This surpassed the expectations of the trial and could have been higher still if all installed properties had been fully connected.

The biggest challenge faced in the project was particularly in maintaining ‘live’ connection of the systems to be able to collect the data and to perform the DR function on a large number of properties, any future project would need to review how to maintain internet connectivity with the systems, however, even given these constraints the trial has demonstrated that it is possible to achieve well over 200kW Nega-watts of energy consumption reduction through Demand Response events in less than 400 social housing properties, with an average ‘response time’ of 2.3 minutes and an average DR event time of 1 hour per property, drawing the conclusion that an aggregated group of heat pumps in the social housing sector can be utilized as effective resources for demand response, with very little impact on residents comfort levels.

These response times would be more than sufficient to meet the requirements of the STOR (UC4), however were not fast enough response times to meet the target response time of 60 seconds set by Electricity Northwest (UC3), further refinement of the aggregation technology would be required to ensure consistency in meeting a 60 second response time. A trial to test ‘group switching’ to extend the overall DR event period proved that a 2 hour plus target was feasible by swapping over different groups of properties in DR, however an issue of instability was observed. To provide stable long-term DR, more precise control methods which enable both groups to avoid overlapping and to suppress reactive operation is needed.

A key finding of the project is that the take up of new technologies needs to be supported with user friendly interfaces, with appropriate information and training provision to both the end users and the operational staff involved with the installation and management of the project. The overall level of awareness of tenants of DR and their awareness of participation in DR events was very low, despite lots of information being provided to them. The overall level of ‘opt-out’ by participants in the DR trial was therefore low, with many tenants unaware that a DR event was taking place.

The project has observed a general overall reduction in energy use by the participating residents. This is based on direct feedback from project participants, who have reported that the heat pump is saving them money and keeping their home at a steady temperature. This compares with their previous heating gas-combi boilers, which left some rooms in their home colder than others. The impact of occupant behaviour on energy consumption is a complex area and it has proved difficult to obtain baseline energy use data for the 12 months preceding the installations to undertake a direct comparison. At the time of completion of the project, many residents did not have a full year of bill data to compare, however, following the completion of the project, with the consent of the ALMOs, Hitachi has continued to collect HP operation data to March 2018, enabling a full year of data to be collected for all participating properties. This is a valuable source of information to be analysed.

An interesting finding from the project was that the incentive of a tablet did not seem to make a material difference to whether the tenants were engaged in the project and the majority of participants did not use the tablet to engage with the project. General feedback from the tenant interviews concludes that increases in comfort and savings on energy bills were sufficient incentive to participate in the DR trials. For any future project, taking into consideration tenant demographics and suitability for involvement in the demonstration, rather than just taking a property 'asset management view' would likely increase tenant engagement and reduce the risk of restricted access and tenant interference with the equipment, as was encountered with this project and planning DR events around specific heating schedules of groups of individual properties may increase the participation in the DR events, focusing on the optimum 'peak times' for each property.

The small-scale telecare trial undertaken at 20 sheltered housing flats in Wigan explored the service level improvement and the economic value of installing a telecare system alongside the HP system, along with the motivation of users to participate with the services. This trial demonstrated that it is possible to extend the scope of the HP system to include wider technology to assist in remotely monitor the welfare of tenants. The conclusion of this trial was that whilst the telecare service demonstrated the functionality of remote sensors in monitoring tenant activity, the drawback of this equipment was that they could not be remotely maintained and there are other options currently in the market that could prove more cost effective.

A positive outcome from this demonstration project has been a greater understanding and knowledge of HP technologies amongst the ALMOs, who are now actively moving away from gas boiler installations and considering wider spread installation of HPs, to reduce CO2 emissions and energy costs in their properties. This was a complex installation programme with innovative new technology, A key lesson learned for future projects would be for the complete system to be fully developed and tested in advance of rollout via a small-scale pilot to identify and manage risks earlier, prior to full implementation.

The findings from the business model developed in this demonstration indicate that the development of a commercial venture for DR in the social housing sector does not currently present a strong viable economic return on investment, based on the current limited uptake of HP systems, the market cost of these and the payback period of a commercial venture. Further analysis of the data obtained in this trial and testing of the scenario models developed would give a clearer understanding of the market benefits. The business model, developed in Japan has used a series of assumptions which would need to be further analysed and tested in the UK, which could alter the payback period, for example the future of the Renewable Heat Incentive (RHI) will play an important role in the development of the HP market. The aim of the RHI is to incentivise the cost-effective installation and generation of renewable heat. The recent increase to 10p per kWh for renewable heat has meant the future HP proposition is improving significantly. In addition, the introduction of further energy generation (e.g. Photovoltaics) and storage technologies into the home system may also positively impact on the business model. This would need to be explored in future trials.

Appendix 1: Definition of Terms / Glossary

No.	Term	Definition
1	Existing aggregator	Existing aggregator trading in the UK electricity market able to aggregate electrical capacity from partners (e.g. call upon additional generation or reduction of demand) and provides this capacity as services to other parties and markets
2	Electricity aggregator	Electricity aggregator gathers the DR capacity created by HP aggregators or HEMS aggregators and trades DR capacity with electricity market.
3	HP aggregator	Sub Aggregator of an electricity aggregator, controls HPs according to the request of the electricity aggregator. HP aggregator simultaneously controls the consumption of energy for any given group of Daikin HPs, by controlling the demand timing of the HP operation. By doing this, HP aggregator can either restrain energy consumption for a short period to (creating nega-watt), or promote consumption (absorption posi-watt).
4	HEMS aggregator	HEMS aggregator is device aggregator to control the Home Energy Management System (HEMS). In this demonstration, the target device is HACE HP HEMS aggregator controls devices through standard home automation communication protocols.
5	DR	Demand Response. Changes in electric usage by end-use customers from their normal consumption patterns in response to changes in the price of electricity over time, or to incentive payments designed to induce lower electricity use at times of high wholesale market prices or when system reliability is jeopardized.
6	HGW	Home Gateway. A communications device which will be used to connect the devices installed in homes. A residential gateway allows the connection of a local area network (LAN) to a wide area network (WAN). In the case of this demonstration, the HGW is used to connect to the ICT platform via WAN over an internet connection.
7	ICT Platform	A platform/system which facilitates the transfer of information and control signals between different devices and systems. For example, the electricity aggregator utilises an ICT platform to receive and send signals to the HP aggregators.

8	OpenADR	A research and standards development effort for energy management led by North American research labs and companies. The typical use is to initiate demand response by sending information and signals to cause electrical power-using devices to be turned off during periods of high demand.
9	Consumer	End user of the system. In the context of the Demonstration project, a consumer the tenant who will have the heat pump system installed and will be paying for the energy consumed by the heat pump.
10	ALMO	Arm's Length Management Organisation
11	NegaWatt	Negawatt power is a theoretical unit of power representing an amount of electrical power (measured in watts) saved.
12	Ancillary Service Market	Ancillary services help balance the transmission system as it moves electricity from generating sources to ultimate consumers
13	SPOT Market	The SPOT market or cash market is a public financial market in which financial instruments or commodities are traded for immediate delivery
14	Emulator	A mechanical environment simulating the system of the business partner
15	Zigbee	ZigBee is a wireless technology developed as an open global standard to address the unique needs of low-cost, low-power wireless M2M networks
16	Power meters	In this demonstration, two types of power meters are installed in each property. One is for measuring HP electric energy. The other is for measuring total electric energy of the property. The electric energy from the power meters is transmitted to HGW by ZigBee communication.
17	BBR	BBR is an abbreviation for broad band router. It offers a wireless communication environment in each property
18	Point Service	A service offering incentives as a form of points based on the DR contribution.
19	ICT-PF	New Co. means a new company that is supposed to be established as a joint venture who would handle the energy management system in the business model described in the report.

Appendix 2: Project Partners

The project was developed by the Greater Manchester Combined Authority (GMCA) and Japan's NEDO in collaboration with a range of industry partners, including Hitachi, Daikin, Mizuho Bank and Electricity Northwest.

Consortium partners in Greater Manchester

GMCA GREATER MANCHESTER COMBINED AUTHORITY

Greater Manchester Combined Authority – The Greater Manchester Combined Authority (GMCA) was formed in 2011 to statutorily compliment the work of the Association of Greater Manchester Authorities on behalf of the 10 Greater Manchester Authorities. The ten councils have worked together voluntarily for many years on issues that affect everyone in the region, e.g. transport, regeneration and attracting investment; the GMCA gives more local control over issues that affect people who live in the area. Our role in the Smart Communities project is to help coordinate the other partners and to help ensure the learning and successes of the project is shared across GM.
https://www.greatermanchester-ca.gov.uk/site/index.php

Wigan & Leigh HOMES
Building Communities for Everyone

Wigan and Leigh Homes - Wigan and Leigh Homes manages and maintains all landlord services for Wigan Council's 22,000 homes. Set up in 2002, its vision is to 'build communities for everyone'. As a top performing social landlord, Wigan and Leigh Homes understands that a home is much more than bricks and mortar. Through schemes like NEDO, Wigan and Leigh Homes is showing how housing providers can be at the forefront of innovation helping to protect the environment, improving energy efficiency and giving tenants a home they can be proud of.

Northwards Housing - Northwards Housing is an arms-length management organisation (ALMO) which manages 13,500 homes on behalf of Manchester City Council. Although the homes are owned by the council, most services offered to tenants are managed by Northwards. Their vision is: “We will make a difference in north Manchester by helping to make it a place where people choose to live, learn and work. Affordable, energy-efficient homes and strong community pride will make our neighbourhoods thrive.”

Six Town Housing - Six Town Housing manages around 8,000 housing stock on behalf of Bury Council. It aspires to deliver great customer service, improving the quality of homes and communities. A show home is based in Bury to demonstrate the technology to Six Town Housing tenants before installation.

Electricity Northwest – Electricity North West own the regional electricity distribution network in the North West of England, taking power from the National Grid, and distributing it at lower voltages to business and domestic customers. They are committed to gaining the knowledge and experience of the installation of new low carbon heating technologies and understanding their impact on the distribution network to benefit customers and meet UK emission targets
Electricity North West (ENW)

University of Manchester – The University of Manchester’s energy research spans across all the faculties, schools and institutes of the University and extends to global partnerships with industry, public bodies and academia.

University of Salford – Established in 1996 the Sustainable Housing and Urban Studies Unit (SHUSU) is a multiple award-winning research and consultancy unit based within the University of Salford.

BEIS – The Government department brings together responsibilities for business, industrial strategy, science, innovation, energy, and climate change.

Warmer Energy Services (WES) – WES was the appointed procured contractor to install the HPs and associated equipment in the properties. WES has more than 20 years' experience in installing and maintaining heating, renewable technology and insulation systems. It is a preferred installation partner to many of the UK's largest social landlords.

Consortium partners in Japan

Nedo -Established in 1980, New Energy and Industrial Technology Development Organization (NEDO) has been one of the largest public research and development management organisation in Japan and has worked with the government to promote economic and industrial policy. NEDO undertakes technology development and demonstration activities to carry out two basic missions, addressing energy and global environmental problems and enhancing industrial technology. To accomplish these two missions, NEDO coordinates and integrates the technological capabilities of

private enterprises and research abilities of universities, instead of hiring its own researchers, and organises technology development activities as national projects to realise fundamental technologies. NEDO covers a wide range of technology development fields such as energy conservation technologies, renewable energy technologies, rechargeable batteries, materials and nanotechnologies, robot technologies, and electronics, information and telecommunications. By supporting private sectors and research institutes, NEDO promotes the development of technologies necessary for the future.
http://www.nedo.go.jp/english/

HITACHI
Inspire the Next

Hitachi Ltd - Hitachi, Ltd. (TSE: 6501), headquartered in Tokyo, Japan, is a leading global electronics company. Hitachi is focusing more than ever on the Social Innovation Business, which includes infrastructure systems, information & telecommunication systems, power systems, construction machinery, high functional material & components, automotive systems and others. Hitachi provides Aggregation system and ICT system electrical power aggregation functions, which aggregate the load-balancing capacity from the heat pumps for trading in the electricity trading markets in this project.
http://www.hitachi.com/

DAIKIN

Daikin Industries Ltd - Daikin Industries, Ltd. (TSE: 6367) is a global leader in the market of residential, commercial and industrial use air conditioning systems, with a well-established presence in Japan, China, Southeast Asia, Europe, and North America. The company is also one of the leaders in the fluorochemicals industry. Daikin is installing 550 HPs for residents and provide heat pump aggregation system which balances the load of the heat pumps.
http://www.daikin.co.jp/

MIZUHO

Mizuho Bank Ltd - Mizuho Bank provides financial and strategic solutions for the increasingly diverse and sophisticated needs of clients, focusing its efforts on serving major corporations, financial institutions, individuals, public sector entities and small and medium-sized enterprises. Mizuho investigate the Electricity Aggregation Business Model using heat pumps, and set out to popularise and expand the heat pump aggregation business with Hitachi and Daikin.

http://www.mizuhobank.com/index.html

Appendix 3: Detailed Use Cases for DR Trials

UC1 Demand Reduction

In UC1, the Electricity Aggregator signs a nega-watt trading contract with the existing aggregator, who trades with the electricity balancing market. The Electricity Aggregator formulates a demand reduction plan to declare available condition of reduction electricity capacity and duration. Existing aggregator executes electricity demand reduction by submitting DR request to Electricity Aggregator. Electricity Aggregator gain profits against contribution to the electricity balancing service market via existing aggregator. (There will be no actual money exchange in this demonstration)

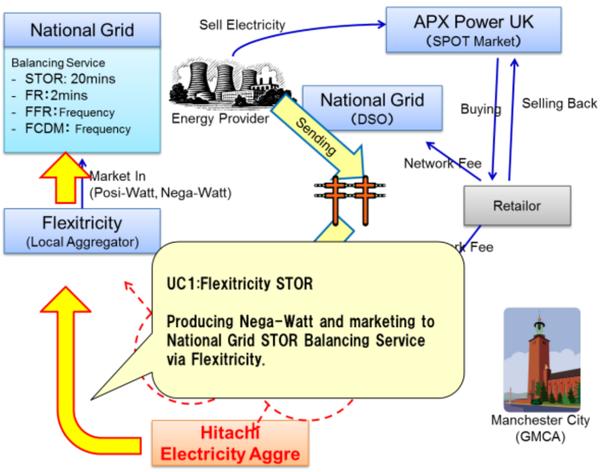


Figure 2-2 Overview of UC1

UC2 Demand Absorption

In this trading process the Electricity Aggregator signs a demand absorption trading contract with existing aggregator who is trading with electricity balancing market. The Electricity Aggregator formulates demand absorption plan to declare available absorption electricity capacity and duration. Existing Aggregator executes electricity demand absorption by submitting DR request to Electricity Aggregator within declaration limits of Electricity Aggregator. Electricity Aggregator gain profits against contribution to the electricity balancing service market via existing aggregator. (There will be no actual money exchange in this demonstration)

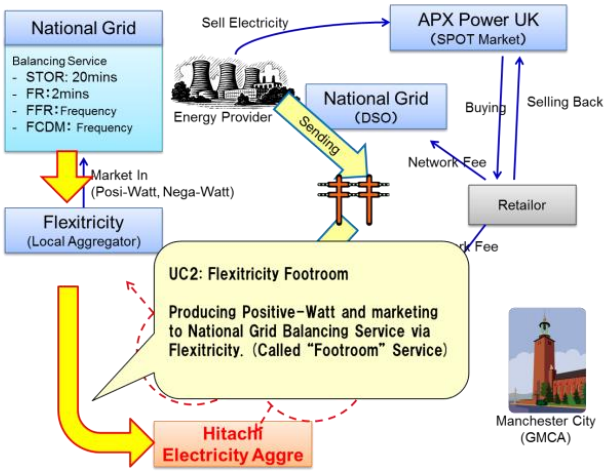


Figure 2-3 Overview of UC2

UC3 Demand Reduction for System Abnormal

"System abnormal" is a when the electricity demand becomes larger than the electricity supply. The Electricity Aggregator formulates demand reduction plan to present available condition of reduction electricity capacity and duration to DNO. DNO internally assesses the condition submitted by the Electricity Aggregator. Electricity Aggregator and DNO sign a 'System Abnormal' contract to undertake DR execution during an emergency event, in order to keep the balance between the demand and the supply to prevent damage to the distribution network.

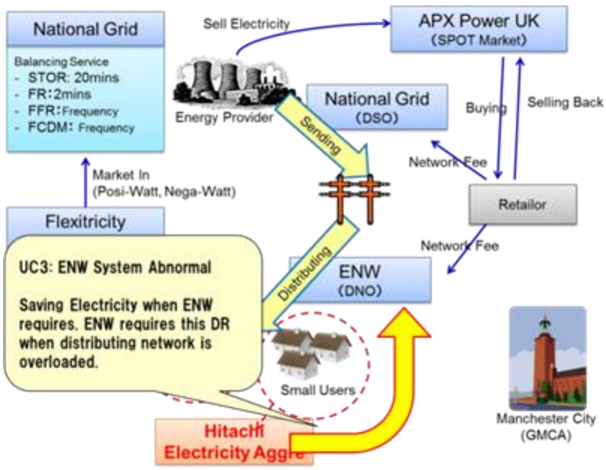


Figure 2-4 Overview of UC3

UC4 Demand Balance Arrangement

Electricity Aggregator signs nega-watt trading contract with ancillary service market (the balancing service offered by UK TSO (National Grid). The Electricity Aggregator formulates demand reduction plan to present available condition for reduction electricity capacity and duration to the market. The market requests the DR to Electricity Aggregator and Electricity Aggregator executes demand reduction to the HPs.

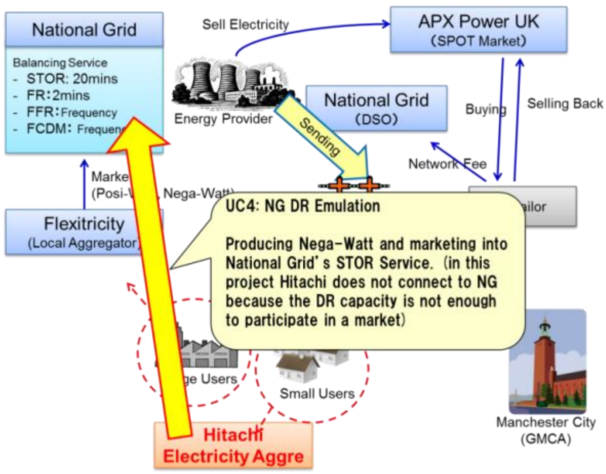


Figure 2-5 Overview of UC4

UC5 Demand Reduction for SPOT Trading

The electricity aggregator formulates a demand reduction plan, and then offers a retailer bids for the SPOT market[11] by specifying available conditions (electric capacity, unit price). A retailer examines a proposal and issues a sell request to the SPOT market. If the SPOT market agrees a sell request, a retailer asks the electricity aggregator to execute a demand reduction plan, and then the aggregator start demand reduction based on a starting time.

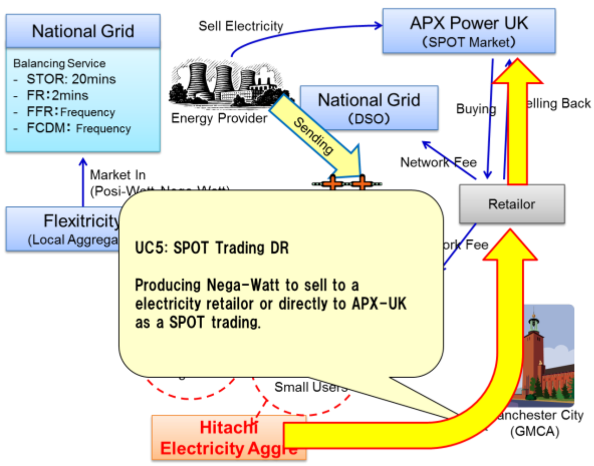


Figure 2-6 Overview of UC5

UC6 Retailer Load Shift DR

The electricity aggregator makes a nega-watt sales contract for a retailer. A retailer asks the electricity aggregator demand reduction when a retailer finds the power demand is expected to exceed the baseline as the result of its demand forecast. The electricity aggregator formulates a demand reduction plan and offers some conditions (electricity power (nega-watt), response time) to a retailer. After receiving a DR request from a retailer, the electricity aggregator implements a plan

11 The SPOT market was established in 2000 as Britain's first independent power exchange.
This is used for balancing and trading purposes and consists of half hourly products of electricity as well as discrete standardized blocks made up of the individual half hours.
https://www.apxgroup.com/trading-clearing/apx-power-uk/

for adjusting demand and supply balance.

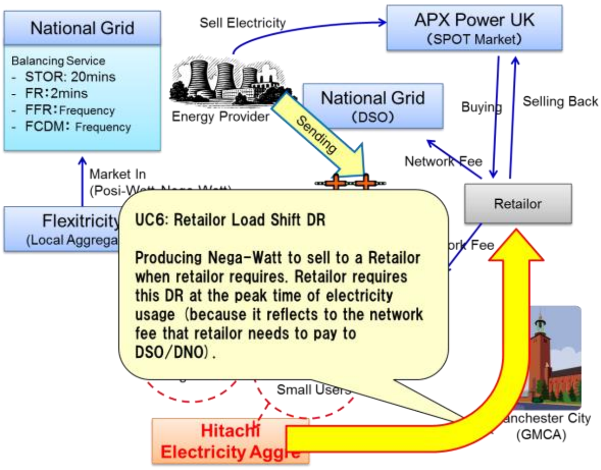


Figure 2-7 Overview of UC6

UC7 Peak Shift / Peak Cut Based on a Tariff

The electricity aggregator makes a contract for implementing TOU (Time of Use) controls based on the agreement with electricity consumers with retailers. The electricity aggregator also gets contract information on electricity consumers and tariffs from retailers. Based on these information and demand statistics for each consumer, the electricity aggregator does adjust demand and supply balance.

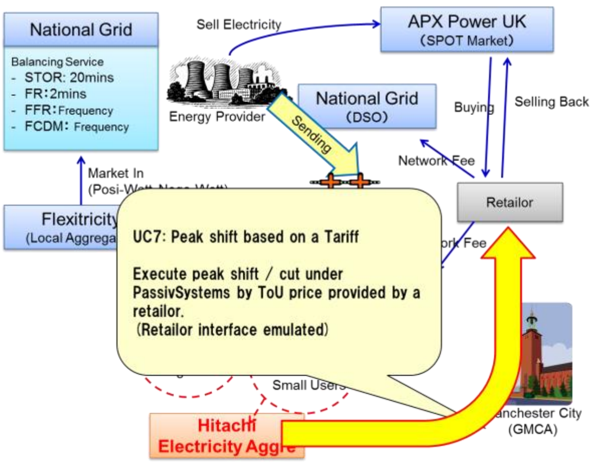


Figure 2-8 Overview of UC7

Appendix 4: HP Data Analysis – Equations and Assumptions

A) Data for HP Power Consumption Model

In an Electric HP system, there are two usages of a HP; hot-water supply and space heating. For hot-water supply, a HP supplies hot-water to a water tank called domestic hot water cylinder and heats water inside so that resident(s) can use hot water. For space heating, a HP supplies hot water to radiators in a tenant so that they can warm the tenant. Because switching the two usages is achieved by switching a valve in water circuit, only one usage between the two could be selected at a time.

Equation A1:

$$Pow_{HP} \sim p \cdot N(\mu_{sh}\,, \sigma) + (1-p) \cdot N(\mu_{hw}\,, \sigma)$$

Right hand side of the equation is a mixed normal distribution model reflecting the usage switching as a probability process. A variable p is the probability of space heating and its value varies from 0 to 1. As a result, probability of hot-water supply is (1-p). In each usage, HP power consumption normally distribute with averageμ and standard deviationσ. Suffixes *sh* and *hw* shows averages are different. However, the standard deviation is the same because the HP is the same.

Left hand side of the equation is HP power consumption. Meaning of a symbol "~" means that left hand side value follows distribution of right hand side.

Another model was developed for Hybrid system.

Figure A2 shows distribution of error calculated for the HP operation policy model. If the error distributes normally, error values distributes normally. This means major factors have been taken into consideration in the model. In this case, it can be said to be normal, and the model is thought to include major factors[12]。

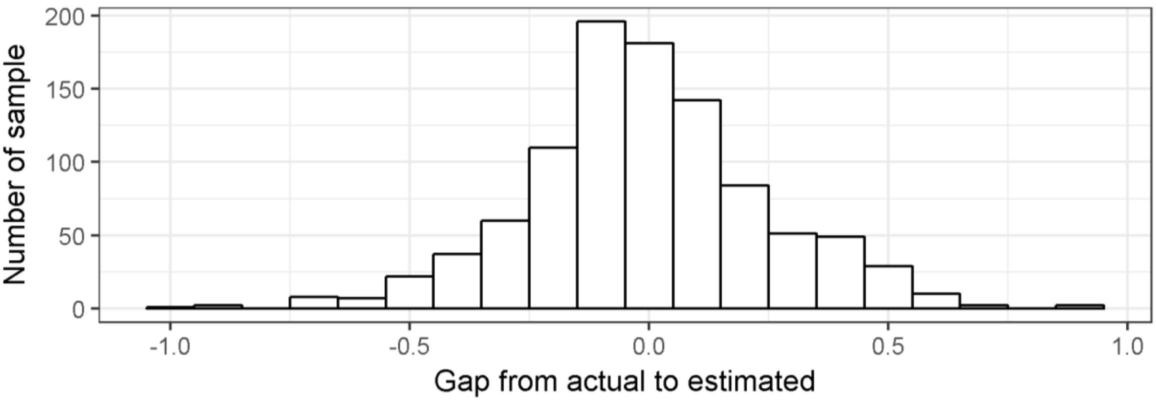


Figure A2 Distribution of error in the model (Split 8Kw, Key SP of 6:00-)

Like the example of the Split 8kW model shown above, parameter for other types and capacities were also estimated, and they were integrated into the HP power consumption model.

An external factor of the model is external temperature and its distribution is shown in figure A3

[12] As a result of Shapiro-wilk test with a hypothesis of "It distributes normal", it is reserved.

This figure is combination of boxplot diagram and average value. Diamonds mean average value in each month. Other elements are for boxplot[13].

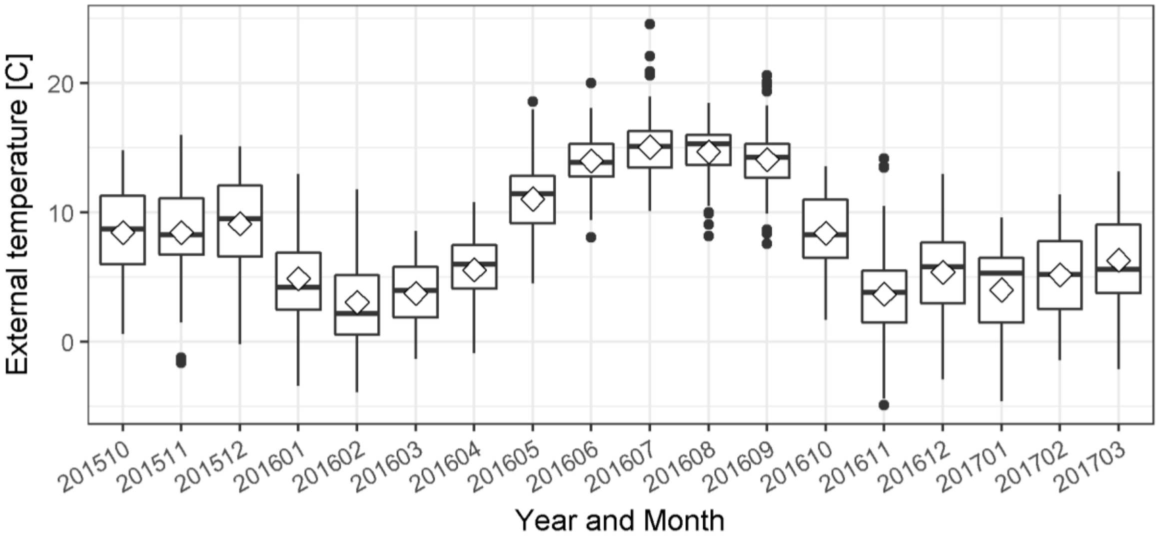


Figure A3 Distribution of external temperature

With external temperature, estimated HP power consumption is shown in A4. In this figure, the number of tenants is set to 550. It is possible to read from the figure that HP power consumption is low in hot season and it is high and its deviation is large in cold season.

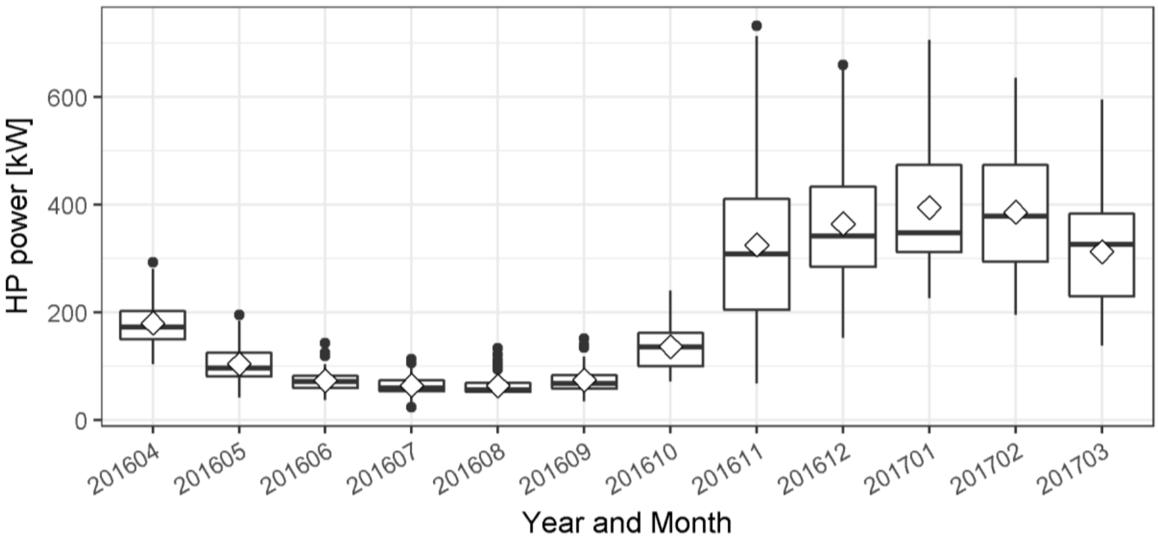


Figure A4 Distribution of estimated HP power consumption (Key SP of 6:00-)

B) Whole House Power Consumption

13 Rectangles are drawn with using 1st quartiles as the top horizontal lines and 3rd quartiles as the bottom horizontal lines. Thick horizontal lines in the rectangles are medium and are equal to 2nd quartiles. Lines drawn from rectangles to upper and downward directions are drawn to existing data level in the range of 1.5 times the height of the rectangles. If there are other data which are not covered by the lines in each month, they are drawn with filled black circle.

Data analysis has shown that HP power shares half or one third of whole house power. The deviation found for this correlation is approximately 500kW and this is larger than that of HP. This deviation is thought to be from not only that of HP but also variations in the number and kind of electric appliances and usage timing among tenants.

The top 10% power consumption was observed to review data distribution. A chart grouped by SP is drawn as shown in Figure A5. Data distribution is biased to evening time period rather than early morning[14]. The figure is a combination of boxplot and scatter plot.

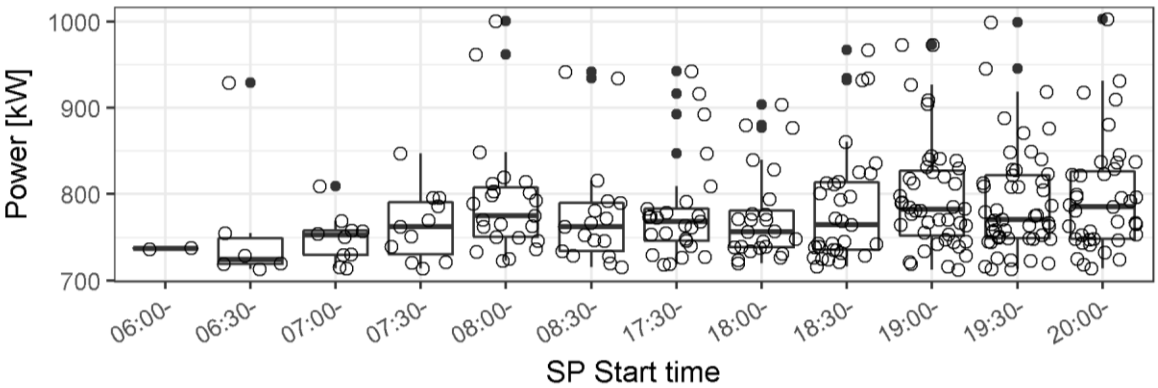


Figure A5 Top 10% of whole tenant power by SPs

Figure A6 shows distribution of the same top 10% data grouped by year and month. All top 10% data distributes between Nov. 2016 and Mar. 2017. Because data with high values in a year are biased to between Nov. 2016 and Jan. 2017, yearly peak can be said to be observed mid-winter. It is reasonable considering large portion of power consumption is shared by HP.

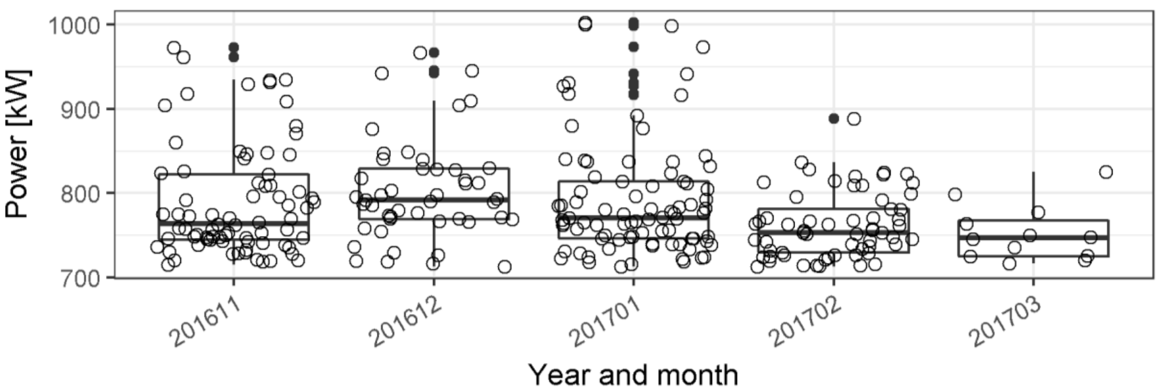


Figure A6 Top 10% of whole tenant power by year and months

Figure A7 shows distribution of the same top 10% data grouped by days of week. It is not strong tendency but it may be said that data with relatively high value are biased to between Monday to Thursday.

[14] As a result of binomial-test with a hypothesis "Numbers of data are equal between evening and morning", it is rejected ($p << 0.01$).

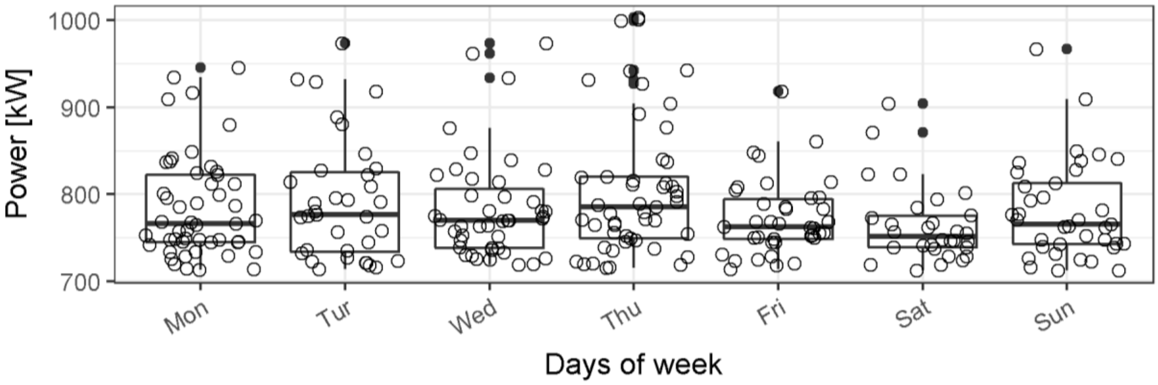


Figure A7 Top 10% of whole tenant power by days of week

From the above, data with the highest values of whole tenant power consumption are biased to from Nov. to Jan. from a viewpoint of time period in a year, are biased to from Monday to Thursday from a viewpoint of days of weeks, and are biased to evening peak from a viewpoint of time period in a day.