Scottish & Southern Electricity Networks

University of Strathclyde Engineering

NINES

1A DSM Customer Impact Report

Prepared by

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Summary

A Demand Side Management system has been successfully implemented in Shetland within the SSEN NINES project. DSM allows the network operator to balance demand with intermittent generation by controlling the charging of smart domestic space heaters and hot water tanks. The heaters can be switched on and off at varying power levels every 15 minutes, according to a target schedule transmitted from the network control centre; they also estimate their next day's energy requirement and transmit this back to the centre for next day scheduling. This is the first operational smart grid in the UK using this technology.

The devices are currently installed in 223 socially-owned houses, which together provide 1.6 MW of connected capacity. 199 houses with 1.44 MW are currently on flexible charging; the rest are on fixed schedules, either because customers are unwilling to share data or because they are on tariffs where a fixed time clock will not allow a 24 hour low rate supply.

This report gives an overview of how DSM has impacted the customers - occupants as well HHA - and how different tariffs, occupant behaviours and occupancy patterns can affect how effectively DSM operates from the customer's point of view. The implications for future rollout into the private market in Shetland and elsewhere are also discussed.

Conclusions are based on data on customer queries, practical issues and customer satisfaction surveys collected by SSEN's customer service group; data collected by the network from the heaters and hot water tanks themselves; and on independent monitoring data on customer comfort (room temperatures and hot water consumption) in a representative sample of 35 homes. Field data has been supplemented by modelling studies where appropriate.

Participation rate has been high, possibly because the DSM system is managed by the network with safeguards for customer amenity, and does not require customers to change behavior. Metering can be a barrier to participating in DSM, which needs meters that can support a 24-hour low rate supply.

There is some evidence that DSM space heating did not result in systematically higher consumption or costs, although direct meter readings were not available. Room temperatures were unchanged; the new space heaters are better insulated than those they replaced, and modelling studies show that, other things being equal, the new heaters should use 10-18% less energy to maintain the same room temperature. DSM may have slightly increased energy consumption in the form of hot water: higher availability may have translated into higher use, and discretionary customer comfort and hygiene settings meant that tanks operated at higher average temperatures than with normal customer control.

Schedule timing in itself had no impact on cost or consumption, no difference was observed in the performance of devices on flexible scheduling and those on fixed timing. The Quantum devices were designed to meet customer requirements in both stand-alone mode and with remote control. However, two design flaws can lead to increased energy use under specific circumstances and these should be addressed ahead of future rollouts.

A model for rolling out into the private market has been tested but will not now be implemented. The NINES DSM technology is best suited to large, poorly insulated houses, which need a lot of energy to maintain comfortable temperatures. The technology is inherently a poor fit in modern, well insulated houses requiring little heating, often less than the uncontrolled output of storage heaters. Even if heater insulation were to improve radically, the contribution of such houses to controllable power and storage would be very small relative to the overhead.

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1. Introduction

Scottish & Southern Electricity Networks

1.1 Project Background

In 2010, a license obligation was put in place requiring Scottish and Southern Electricity Networks (SSEN) to present an Integrated Plan to manage supply and demand on Shetland. The Shetland Islands are not connected to the main GB electricity network and, as such, face unique electrical challenges – but also a unique opportunity to decarbonise supply. Under the license condition, this Integrated Plan was required to demonstrate that it had identified a solution based on the lowest lifecycle costs, taking into account its environmental obligations.

As part of the Integrated Plan submission, consideration was given to, amongst other things, the upgrading or replacement of Lerwick Power Station, the impact of third party generation requirements, the abundance of renewable energy resources, and the future demand on Shetland. The factors influencing the supply and demand issues on Shetland necessitated an innovative approach to their management. However, with innovation comes the need to trial solutions before reaching an answer. As a result, SSEN originally proposed to split the implementation of the Integrated Plan into two phases:

Phase 1 Shetland Trial (Northern Isles New Energy Solutions 'NINES') – implementation of the infrastructure necessary to actively manage demand, generation, reactive compensation and energy storage assets. These elements were coordinated to maximise the amount of energy harvested from renewable generation while maintaining supply quality and security. In doing so, two principal effects are achieved:

- a reduction in maximum demand; and
- a reduction in the electricity units generated by fossil fuels

Phase 2 (Shetland Repowering) – upgrading or replacement of Lerwick Power Station by SSEN, taking into account the learning acquired during Phase 1 and, where appropriate, extending the Phase 1 technology.

1.2 NINES Elements

NINES was originally designed and developed to operate in conjunction with Lerwick Power Station or its replacement operated by SSEN, and was developed with the main aim of informing the optimum repowering solution. Whilst its primary objective was to trial 'smarter' initiatives, importantly NINES has funded elements and infrastructure that are expected to endure as part of, or alongside, the new energy solution. Central to the project has been the creation of an integrated set of models designed to anticipate the impact of NINES, covering the following themes:

- Dynamic stability model
- Steady state model
- Unit scheduling model
- Customer demand forecast model
- System development optimisation model
- Strategic risk and operational risk model
- Shetland economic model
- Commercial model

Facilitated by modelling and practical learning, the aims of NINES have been to:

1. Increase understanding of how best to accommodate Shetland's significant wind potential on a small distribution network; and
2. Increase understanding of how the existing and known future demand on the island can be best managed on a constrained, isolated system.

The above models served to predict the behaviour of the energy systems on Shetland, and to validate each of the key elements of NINES as they were added. Following this validation process, these models have been used to inform the development of the New Energy Solution realised through the competitive process. With the successful operation of NINES, the infrastructure and knowledge to reduce the peak capacity requirement for any replacement solution to a level dependent on the particular assets connected, and the characteristics of the new solution has been determined. The NINES project assets are described below.

1. 1 MW battery at Lerwick Power Station
This battery acts as an energy storage system on the Shetland Network. In addition to facilitating the connection of new renewables, the battery assists in optimising and stabilising the operation of the existing island network by helping to reduce demand peaks. The battery has helped to accommodate the connection of a significant amount of new renewable generation that would otherwise not have been possible.

2. Domestic demand side management with frequency response

As part of the wider NINES benefits, Hjaltland Housing Association contracted with Glen Dimplex to install advanced storage heating and water heating in 234 existing homes. These devices were provided through Hjaltland and ERDF funding and have been specifically designed to use a much more flexible electrical charging arrangement which is based upon the predicted demand, weather forecasts, availability of renewables and any network constraints. This initial rollout was intended to help gauge the effectiveness of storage and demand side response at the domestic level.

The heaters incorporate additional insulation to minimise heat loss and are fitted with programmable timers to allow users better control of temperature and operating times when compared with conventional space and water heating systems. The new heating system is designed to be more efficient, while giving the customer full control of both temperature and operating time and allowing for charging at times that best suit the network.

3. Renewable generation

Shetland has some of the richest renewable resources in Europe and there is significant interest on the islands to connect a range of new renewable generators. There is a mix of wind and tidal generators currently connected that range in scale from 45 kW up to 4.5 MW. However, before the advent of NINES these generators could not connect to the network due to the underlying voltage and stability constraints. Connecting more renewable generation, which is unavoidably intermittent, would have exacerbated these problems.

To address this, NINES has trialled an active network management regime offering renewable connections to developers. In return, they are required to give their agreement to being constrained when the system cannot accommodate their generation. The measures that have been developed and trialled under NINES are reducing this constraint by being able to actively provide demand when there is renewable resource available.

Indeed, these arrangements could be necessary even if Shetland is to become electrically connected to the mainland at some point in the future. If a single mainland link is damaged, this could result in a prolonged outage, which would mean that Shetland would once again be electrically islanded. Therefore the prospect of and ability to constrain will remain for generators on Shetland, albeit on a less frequent basis.

4. Active Network Management (ANM) system

This is the NINES project's nerve centre: it monitors the different parameters affecting the network, including embedded constraints, frequency stability and weather, and manages an appropriate response. It responds to, and tunes, the models which are being developed to monitor and understand how new storage assets will behave. By creating flexible demand on the island progress has been made in exploiting and maximising Shetland's wind generation potential on an islanded basis, and in reducing the generated output from replacement thermal generation.

A key driver for the trial has been to develop an understanding of how these technologies work and interact in a real-life environment. The learning from NINES has demonstrated that in general terms (with the exception of additional renewables) all NINES technologies predominately involve energy shifting rather than energy reduction.

The following report is one of a number of related reports undertaken by the University of Strathclyde research team and focuses on the impact of Demand Side Management (DSM) on customers.

The DSM element of NINES uses innovative smart heaters remotely controlled by an Active Network Management System to store energy in homes during periods of excess electricity supply. Prototypes of these smart storage heaters and hot water tanks were developed by Glen Dimplex under the trade name 'Quantum', and were trialled in 6 houses in Lerwick, Shetland from 2011-2013. Glen Dimplex incorporated lessons learned from the trial into the design of the production versions, which were installed between July 2013 and October 2014 in 234 electrically heated properties owned by the Hjaltland Housing Association (HHA).

The University of Strathclyde (UoS) is a partner in NINES. This report is based on work carried out on DSM by the Energy Systems Research Unit (ESRU). It gives an overview of how DSM has affected customers and how different tariffs, occupant behaviour and occupancy patterns can influence how effectively DSM operates from the customer's point of view. The implications for further rollouts into the private market in Shetland and elsewhere in the UK are also discussed. Other reports by ESRU address the infrastructure required for DSM[1] and the impact on the network[2]. Further reports address the operational effectiveness of DSM in frequency response mode[3] and the operational effectiveness of the ANM system[4]. See figure 1 for details of related reports.

The report makes a partial input to the following NINES learning objective:

'What is the impact of the low carbon network on domestic and industrial customers? Effect on fuel poverty; changes in attitudes, awareness and behaviour amongst customers; extent of financial impact on participants.'

NINES UoS Reports	
1A	DSM: Customer Impact
1B	DSM: Infrastructure
1C	DSM: Network Benefits
2A	Battery: Operational Effectiveness
3A	Frequency Response: Customer Impact
3B	Frequency Response: Operational Effectiveness
4A	ANM: Operational Effectiveness
4B	ANM: Functional Design Report
6A	Commercial Arrangements and Economics Report
7A	UoS Knowledge & Learning Report

Table 1 NINES UoS learning reports

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DSM concept overview

2. DSM concept overview

Scottish & Southern Electricity Networks

2.1 Background

As part of Phase 1 of the Integrated Plan for Shetland, submitted to Ofgem in 2011[5] SSEN were required to provide the infrastructure necessary to actively manage demand, generation, reactive compensation and energy storage assets including water and space heaters to store energy in the form of heat. Heater charging is controlled by the DNO using an Active Network Management (ANM) system. The ANM system schedules generation from the wind farms, and uses a 1 MW battery as well as DSM to balance peaks and troughs in electricity demand and generation dynamically. This system will allow more intermittent renewable generation to be connected to the network. Figure 2.1 shows the main components of NINES in Shetland.

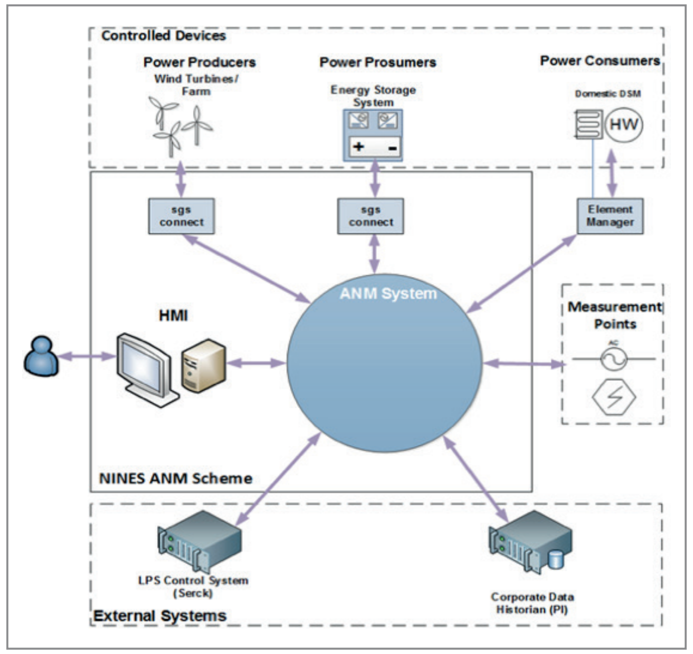


Figure 2.1 NINES ANM, with DSM components and communications at top right.

At the end of the prototype trial it was concluded that every DSM house where the heating elements are fully charging allows an additional 2.37 kW of wind generation online, as well as contributing to network stability[6].

Originally DSM was intended to operate at an industrial scale as well as domestic, through a 4MW/130 MWh hot water tank to be installed by the district heating provider, Shetland Heat, Energy and Power Ltd. (SHEAP). In early 2015 SHEAP advised SSEN they would no longer be taking part in NINES due to funding and commercial issues.

	2011 proposal to Ofgem	2013 plan	June 2016 live
Houses	750-1000	250	228
Appliances	–	922	708
Flexible power kW/house	15.0	8.2	7.2
Physical storage capacity kWh/house	–	46.8	42.4

Table 2.1 Evolution of SSEN domestic DSM scope.

Included in the original NINES submission was the installation of DSM into 750 homes provided by Hjaltland Housing Association and Shetland Islands Council (SIC). However due to internal financial constraints, SIC announced in October 2012 that they would be withdrawing from the project leaving only the HHA dwellings (Table 2.1). To limit the impact of this change on the project, and provide new learning around domestic DSM, SSEN proposed to recruit private domestic customers to provide DSM and customer engagement events were held in 2014[7].

In April 2014 SSEN's initial Integrated Plan for a replacement power station was rejected by Ofgem in favour of a competitive process to identify a new energy solution for Shetland. This new obligation to invite tenders for network services of the kind offered by DSM caused SSEN to decide that it would be more appropriate to allow the market to take on the development of DSM to a larger scale, so the rollout to the private market was put on hold.

Production versions of the DSM equipment were installed in 234 houses owned by HHA by October 2014: this represents 2% of all homes in Shetland and 9% of social rented dwellings. Most of these houses are newer stock and smaller properties than the typical Council home, demanding fewer heaters. In addition, only two-thirds of the NINES houses received new hot water tanks: the Quantum tanks were larger than those they replaced, and could not be installed in the constrained space available in some of the houses. A variety of issues led to the removal of the DSM equipment from 6 houses, and another 4 were disconnected although the kit is still installed within those homes. In June 2016, 228 DSM enabled homes were operational, with a total demand of 1.6MW (Table 2.1).

SSEN introduced the flexible charging regime in March 2015, making Shetland the first operational Smart Grid in the UK that incorporates domestic DSM. The system started to operate in its final mode in early February 2016.

2.2 The DSM system

The Quantum heaters at the core of DSM were developed and are marketed by Glen Dimplex[8]. For NINES, Dimplex developed customised device controllers: the devices in Shetland can accept instructions for altering input power every 15 minutes, and relay back status information to the centre. They also contribute to network stability, automatically shutting down charging when the network frequency drops below an acceptable, configurable level and increasing charging when the frequency rises.

The heaters are well insulated, allowing fan-assisted regulation of active output by a user-controlled temperature set-point (USP) within user-set heating hours. They contain three separate heating coils to allow them to be charged at varying power levels. They also incorporate a maximum temperature cut-off for safety and a minimum temperature switch-on setting to ensure occupant comfort. The hot water tanks also have three heater coils of different sizes to allow variable level charging and were built specifically for NINES. The NINES-specific device controllers in both space and water heaters operate in the same way.

The device controllers employ an automatic charge control algorithm to predict the energy required for the next day (Daily Energy Requirement, DER) based on a number of factors. For space heaters, these include the predicted outdoor temperature for the next day, user settings for room temperature, and heating hours. For hot water tanks, the DER is the average of the energy used in the previous three days. Embedded in the control rules is a requirement to prioritise customer comfort over the needs of the network in order to maximise customer satisfaction.

DSM-specific equipment supplied by HHA (the owner of the properties) consists of a transceiver on each heater and hot water tank, which communicates by RF with a Glen Dimplex Home Hub. The Hub in turn is connected serially to a Local Interface Controller (LIC) supplied by SSEN.

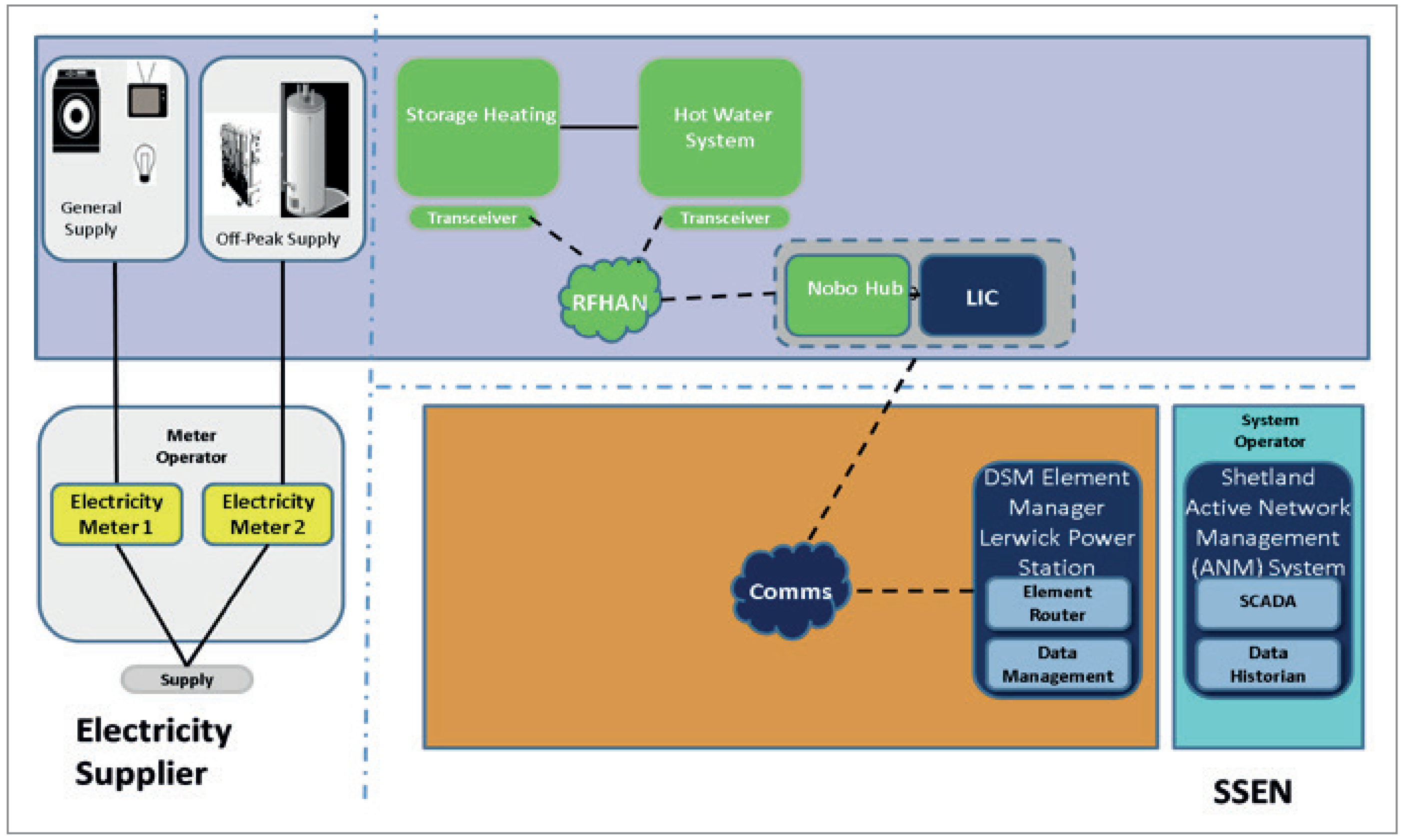


Figure 2.2 Logical view of DSM equipment and communications

Figure 2.2 shows a logical view of DSM communications. The LIC collects status data from the devices and forwards it from the house to a central Element Manager (EM) via a Wide Area Network (WAN) supplied by Airwave Solutions. The EM can poll each LIC at configurable intervals, currently set to 4 times per hour. It aggregates the data into groups for ease of handling, before transmitting it on to the ANM system at Lerwick Power Station. The key data sent are the energy required for the next day (DER) as calculated by the device controllers at midnight GMT, plus the number of devices in communication within the group and their overall rated power and storage capacity.

This data is used by the ANM system to generate 15-minutely target schedules for all the controllable generators and controllable storage on the network. The system was designed to be capable of re-computing and re-transmitting schedules every 15 minutes if necessary, although for operational reasons currently this is done once a day just after midnight. The target schedule for each group is sent back to the EM together with a forecast for the outdoor temperature the next day. EM passes this information down to the LICs; it also sends out heater configuration instructions, such as the minimum core temperature or frequency control parameters.

The daily charging schedule for each group consists of a target power profile expressed as a percentage of the total power available at 15 minute intervals. This target power can vary continuously from 0 to 100%. The LIC must translate the continuous profile into a set of instructions that each device is physically capable of following with its individual fixed charging levels, at the same time as delivering the DER. Figure 2.3 illustrates how a group schedule works out at an individual device level.

Each device is assigned to one of 18 groups depending on:

- the type of device (space or water heater) as these have different demand profiles;
- the type of tariff, as customers were not asked to change commercial arrangements with their energy supplier;
- whether the customer's metering arrangement allows DSM to be operated: where a fixed time clock does not allow a 24-hour low-rate supply, DSM is set to allow charging at all times, and the actual charging is controlled by the time clock at full power as before;
- whether occupants are vulnerable: priority service customers and those on prepayment were initially put onto fixed timing DSM where the charging level could be varied but the times were fixed;
- whether the customers have opted out of allowing their devices to transmit status data, in which case the communications network cannot be used – these homes receive the same fixed-timing target schedule as the equivalent opted-in vulnerable group.

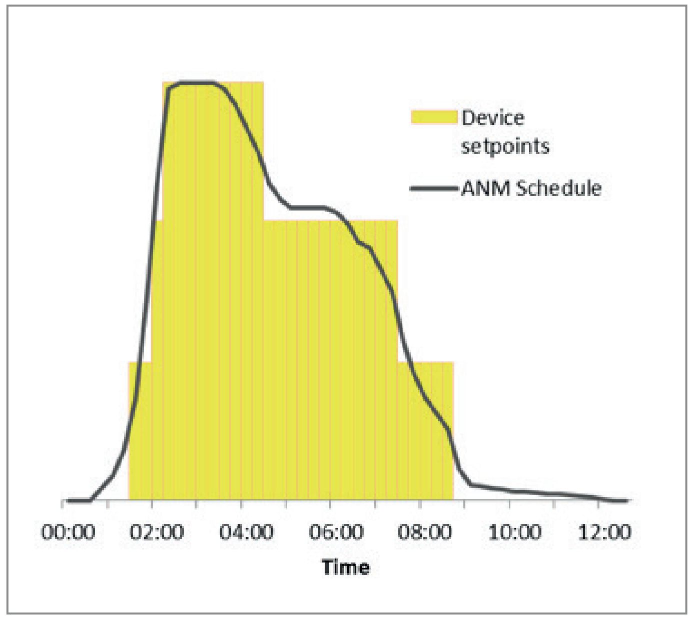


Figure 2.3 ANM generated schedule and its translation to device level

At the completion of the NINES Project, 199 houses with 1.44 MW of controllable power were in groups with fully flexible charging. 88 of these houses with 0.59 MW are prepayment customers who were transferred to flexible charging at the end of September 2016, after the system had proved that the change to flexible charging would not lead to the customer's credit being used at unexpected times, in order to provide storage for the network. Only 24 houses with 0.17 MW are currently either opted out or have meters and tariffs which do not allow flexible charging.

2.3 Data collection

The system was designed to have no adverse impact on customer comfort or cost while giving the DNO flexibility to run the network in the most effective way. Throughout the project, close contact was maintained with the customers via a dedicated Housing Officer at HHA and the NINES Project team within SSEN, who recorded customer queries, practical issues and conducted customer satisfaction surveys.

The performance of all the devices could be monitored centrally from data from built-in sensors transmitted by the LIC. Device data collected by EM over an 18-week period from 15 February to 19 June 2016 was analysed, as was 12 weeks of group level data from 29 February to 22 May 2016. In addition, customer comfort was monitored independently in a sample of houses selected to be representative of the whole rollout estate: room temperatures were monitored in 35 houses, and hot water consumption in 19, from the time the devices were installed until April 2016. The 8 million lines of data collected, with over 90 million individual data points, were analysed by ESRU, and modelling studies were carried out to supplement the field data. Analysis did not cover the behaviour of devices in frequency response mode as the data collection frequency was too low to permit this: this topic is covered in the Frequency Response Operational Effectiveness Report[9].

3

Customer proposition and participation

3. Customer proposition and participation

The Quantum devices were upgrades to old storage heaters and hot water tanks, in houses selected by the landlord HHA and purchased by them. The proposition for HHA was that they could accelerate their heater replacement programme with the available grants.

The tenants who occupied the houses were already on tariffs that allowed some flexibility in the timing of charging, so there was no behaviour change involved. They were asked only to consent to SSEN collecting the status data sent by the devices, with a one-off payment of £100 as an incentive (Appendix I); this was payable 6 months after installation and sign up, and tenants who either did not consent to data collection or who withdrew consent within the 6 months were not eligible for the payment. An additional £50 was paid to tenants who agreed to have the independent monitoring installed as well.

Whether or not they signed up to NINES, the tenants benefited from HHA's upgrades in that they received modern heaters that allowed them better control over when they used heat. However, they did have to learn to use a new heater with more sophisticated controls, and to allow installation and follow-up visits.

3.1 Protection of vulnerable customers

In order to protect the most vulnerable until both network and customers had gained experience with the system, SSEN decided to put vulnerable customers – Priority Service Register (PSR) and those on prepayment - on a partial form of DSM at startup. These customers' heaters were charged at fixed times through the day, as before NINES, so that there was no change in the accustomed pattern of heat delivery and no risk that their credit could be used up by system storage.

PSR customers were transferred to fully flexible charging in June 2015 and prepayment customers at the end of September 2016 (Table 3.1). Before these were moved, SSEN carried out more analysis on potential impacts, and delivered additional customer education about the possible risk of using up credit where the customer is not necessarily expecting it due to the nature of flexible charging. Table 3.1 shows the number of customers on the different DSM regimes.

	Space heating	Hot water	DSM Regime
Normal	111	74	Fully flexible DSM
Prepayment customers	88	57	Fixed timing, flexible power level
Opted out customers	20	15	Fixed timing, flexible power level
Tariffs with no 24-hr low rate meters	8	6	Fixed timing, fixed power level (time clock controlled)

Table 2.1 Evolution of SSEN domestic DSM scope.

3.2 Participation and opting out

SSEN report that 79% of tenants signed up in response to the original letter of invitation, and 94% had consented by October 2014 when the rollout programme was completed. Currently, 88% of the households with DSM equipment have opted in to data collection (Table 3.1). 11 tenants declined to take part in NINES initially; the rest simply did not respond to the letter with the consent form. In the opted out houses at a tenancy change, most new tenants opted in even though £100 incentive was not available. Only one new tenant opted out where the previous occupier had opted in. Of the 24 customers who had opted out on completion of the NINES Project, only 7 have actively declined to share their data. Again, on a change of tenancy most customers with independent monitoring agreed to continue without any incentive payment: only two did not agree to continue.

Three years from the start of the project, 85% of households where the system was installed are on flexible charging. This is significantly better than the participation rate seen with pricing –based demand-side response (DSR) projects. In France a 'Tempo' tariff offers varying prices per kWh based upon the actual weather on particular days, and customers could achieve 10% or better savings by moving consumption to low-cost time of day, but only 20% of target users have signed up[10]. In the US, 98% of the original participants in a Utah DSR programme switched back to a fixed rate tariff after two years, and a time of use tariff introduced at Puget Sound was withdrawn because so few people retained it after the trial period[11]. In the UK, Northern Powergrid ran a 1-year trial of a time-of-use tariff where 40% of participants would have lost money because users, especially high peak time users, did not move their consumption to cheaper time periods[12].

The high participation rate in NINES is thought to be because the DSM system is managed by the network with safeguards for customer amenity, and does not require customers to change behavior. This hypothesis is supported by the findings of a recent UK survey carried to test the relative attraction of five different approaches to DSM among domestic customers[13]. The most acceptable version was a tariff permitting limited network control of domestic loads, and the least popular option was the dynamic time-of-use tariff where customers must actively choose when to use energy in response to varying prices.

3.3 Impact of tariffs and meters

A handful of customers turned out to be on tariffs where a fixed time clock does not allow a 24 hour low rate supply and therefore cannot support flexible charging of heaters (Table 3.1). Although DSM enabling equipment was installed in these properties, SSEN decided to leave them on the legacy off-peak heating schedules, where charging is controlled by the time clock. The heaters themselves have the same functionality as all the rest, calculating DER and charging until that demand has been met.

3.4 Visits to households

From the customers' point of view the most visible impact of the change came when they had to allow various workmen into the house to install and test equipment, update control firmware and replace kit, or decommission houses that were leaving DSM.

3.4.1 Installation

SSEN and HHA report that installation involved at least two visits from representatives of the landlord and as well as some disruption.

1) Customers were visited by the meter operator before installation to install an isolator block to ensure that a 24-hr low rate supply would be available – typically 20-30 minutes.

2) During the installation they had a maximum of two days without heating, and one day without hot water. The old storage heaters had to be switched off for 24 hours before the installation to cool off, although HHA provided temporary heating when requested. Hot water tanks could be drained on the day of the visit.

3) Two electricians were in the house for a half to one day to install and test the storage heaters, and a plumber as well if there was a hot water tank.

4) The LIC and Hub were installed on the same day by the same electricians, as far as possible. This took only 20 minutes if the centre could 'see' the LIC immediately the communications were turned on. In other cases it could take up to 4 hours to install new aerials or move the Hub and LIC until communications could be established.

3.4.2 Follow up visits

Because of the various commissioning problems and the persistent issues with communications, two follow-up visits had to be made to all households in addition to ad-hoc visits to sort out reported problems.

1) A follow-up visit was made to all houses by an electrician to reprogram the heaters controls.

2) In a subsequent set of visits between November 2015 and April 2016 the Home Hubs were replaced and the LIC firmware was upgraded. A high number of revisits were required because Home Hubs did not have the capability of taking over-the-air updates.

3.4.3 Removal and decommissioning

In 6 of the HHA houses the DSM enabling equipment – Home Hub and LIC – was removed and the heaters re-programmed to operate as conventional Quantum heaters. SSEN reported that only two were at the request of the tenants: one had experienced inconsistent heating due to installation faults; the other was due to personal reasons. The other four cases were homes on the most northerly island where it proved to be impossible to establish communications between the power station and the LICs even after repeated attempts. Four more houses were subsequently decommissioned because of communications problems.

The removal process involved reprogramming heaters to operate in standard Quantum mode, and minor wiring modifications as well as removing the LIC and the Hub. Although the customer did have to be in while the electrician is in the house, this took at most 2 hours and power had to be turned off for around 20 minutes. Smart meters may eventually expedite both installation and removal issues, but at present they are not capable of supporting remotely controlled devices.

3.5 Customer feedback

Two customers were uninterested after the initial installation, and did not respond when contacted about follow-up visits. These houses operated in stand-alone mode as the Home Hubs and LICs have not been updated.

Positive feedback was received from some customers about the visual impact of the new heaters. However, two respondents commented that they needed to redecorate after the installation – although this is likely to have been due to repositioning as the new heaters had a slightly larger footprint on wall and floor than the old.

4

Impact on customers' energy consumption

4. Impact on customers' energy consumption

An important part of the customer proposition is that they should not see any increases in costs, for which energy consumption is a good proxy.

4.1 Evidence from field monitoring

Field data was analysed to see whether the devices are operating as intended. The data sent by the devices to Element Manager was however plagued by communications outages, with only about half of the devices visible on any one day, and even some of those gave poor quality data; this is discussed in detail in the DSM Infrastructure Report[14]. The analysis was therefore based only on those devices which gave clean data for more than 90% of the time on any day. Data from independent monitoring was of better quality, although a few of the temperature sensors did eventually fail

4.1.1 Hot water consumption

Direct measurements of hot water use in the 19 independently monitored DSM households shows that their consumption is well within the normal range. Figure 4.1 compares the average volumes for the NINES households over 18-30 months and those seen in a two-year UK-wide monitoring programme on 112 houses conducted by the Energy Saving Trust (EST)[15]. The distribution of users was very similar, with 63% of the NINES households using +/-50% of the EST average, compared to 65% in the original study. The proportion falling into the low consumption category was higher than found by EST, although the sample was small.

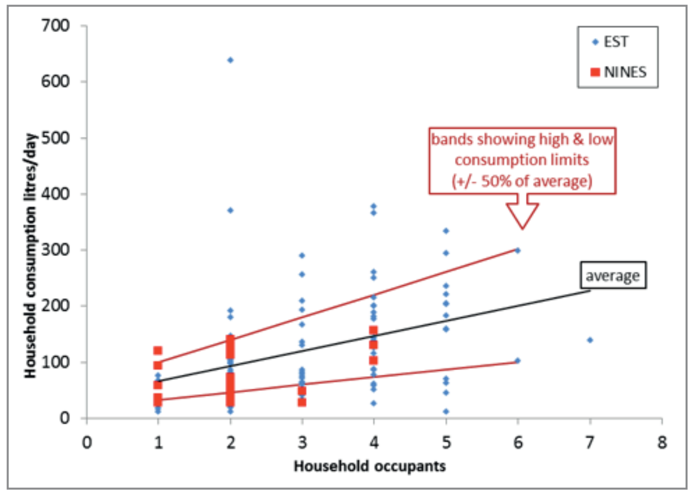


Figure 4.1 Average daily hot water use: NINES vs EST households

In terms of time of day of use, households tend to follow a regular pattern especially on weekdays. Figure 4.2 shows the most common pattern, seen in one third of the monitored households: these use half or more of their daily hot water between 16:00-20:00. This is rather different to the findings of the EST data for the UK overall, where households that used water mainly in the evening did so after 20:00. In Shetland only 2 out of 18 households used any significant amount after 20:00.

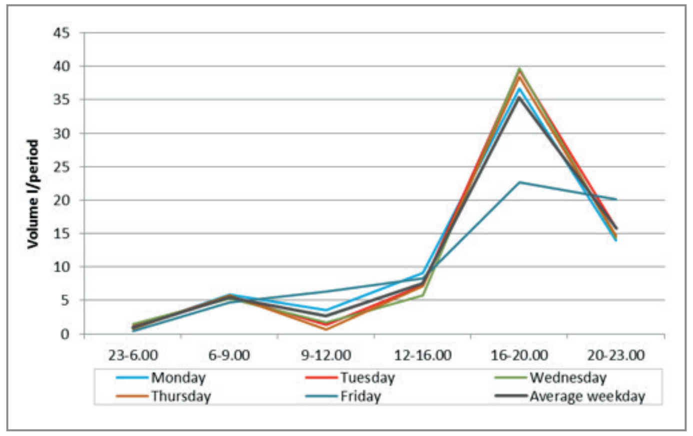


Figure 4.2 Example of daily hot water consumption pattern

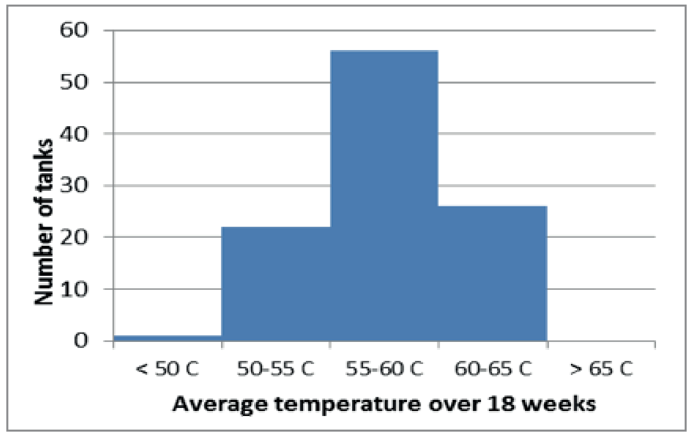


Figure 4.3 Average temperature of hot water tanks

4.1.2 Standing losses in hot water tanks

Although direct consumption of hot water appears normal, it is likely that occupants are using slightly more energy than before as standing losses in the hot water tanks are higher. This is driven partly by design factors and partly by customer behaviour. Although these tanks are better insulated than the ones they replaced, they are operating at higher temperatures so can still have higher standing losses. Factors that tend to increase the average water temperature in the tanks are:

- the new tanks have a higher allowable maximum temperature than the ones they replaced;
- for customer comfort reasons the tanks are set to refill to at least 40 C average temperature as soon as hot water is used;
- a requirement programmed in by Glen Dimplex is that hot water tanks must cycle up to 60 C at least once a day to prevent the risk of bacterial infection (this would not happen in customer-controlled hot water tanks); and
- when they set timers themselves, most households programme hot water to be available just before main bathing and dishwashing times, and do not fill up again until the next period – here, the timing of charging is not linked to use times.

Figure 4.3 shows the range of average water temperatures recorded by the devices in the 105 hot water tanks with valid data. Most tanks consistently averaged between 55 C and 60 C, with little variation from week to week. Standing losses are therefore around 1 kWh/day in the smallest tanks, and 1.5 kWh/day in the largest ones.

The impact of standing losses is higher for low consumption households. Figure 4.4 shows that in around 10% of households standing losses make up more than half of the total energy consumption in the form of hot water, while in the majority of households it is 20-50%. Here again the emitted heat will make some contribution to heating the house, unless the hot water tank is sited outside the heated area.

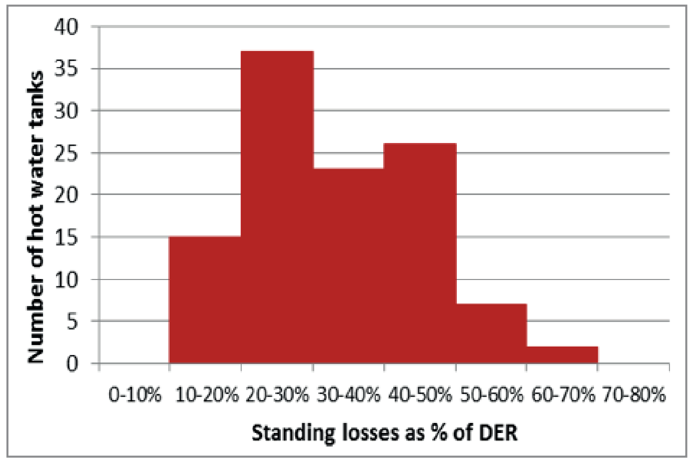


Figure 4.4 Standing losses in hot water tanks

4.1.3 Space heaters and uncontrolled output

Space heaters operate in two modes. Active output occurs when the fan pushes air through the core to heat it; this is triggered when the room temperature falls below that set by the user during heating hours. When the heater is full, the core temperature exceeds 600 C so even with the best insulation the heaters emit uncontrolled power output of 450-750 W depending on size. Although it is often also referred to as standing loss, this uncontrolled output comprises a significant proportion of the total energy delivered into the room and is useful heat. From the 18 weeks of device data, it is estimated that the larger heaters emitted 4-8 kWh/day as uncontrolled heat and the smaller ones 2-6 kWh/day. A quarter of the heaters used the fan for less than an hour a day on average, and in half of those it was less than 15 minutes per day.

At the margin, if the uncontrolled heat output between midnight and 06:00 is considered as unnecessary consumption, this amounts to 1-2 kWh per heater per day at most. And since the Quantum heaters emit much less uncontrolled heat than the storage heaters they replaced, customers will be using less rather than more energy for space heating than before if other factors are constant.

4.1.4 Scheduled energy compared to DER

The LIC has the job of turning a continuously varying target power profile into a set of instructions that each heater with its discrete power settings can physically follow, while at the same time delivering the DER. Because the heaters operate at fixed charge values, the smallest unit for scheduling is the minimum power for 15 minutes, called the 'charge unit'. For water tanks this is 0.09 kWh, while for space heaters it varies between 0.10 and 0.28 kWh.

In the data studied, the target energy delivery could be either higher or lower than DER by several charge units each day, although more appeared to over- than under-deliver in schedule translation. Figure 4.5 shows how accurately DER was fulfilled by the schedule calculated by the LIC, for 22,450 space heater days and 7,250 hot water tank days.

With space heaters, 38% of target profiles were within ±2 charge units of DER each day, and 57% within ±5 units. However, 10% of target profiles would deliver more than 20 charge units in excess of DER and 4% would under-supply by more than the same amount. The hot water tank schedules are less good, with only 18% of device days within ±2 charge units – although this is still very small at 0.2 kWh. It is not entirely clear why the LIC schedule translator performs so much worse here, although scheduling hot water tanks is more complicated than scheduling space heaters. In addition to maintaining the group target profile and delivering DER, the hot water tanks have to be cycled through 60 C once a day for health and safety reasons; it took several iterations of the firmware to achieve the present state[16].

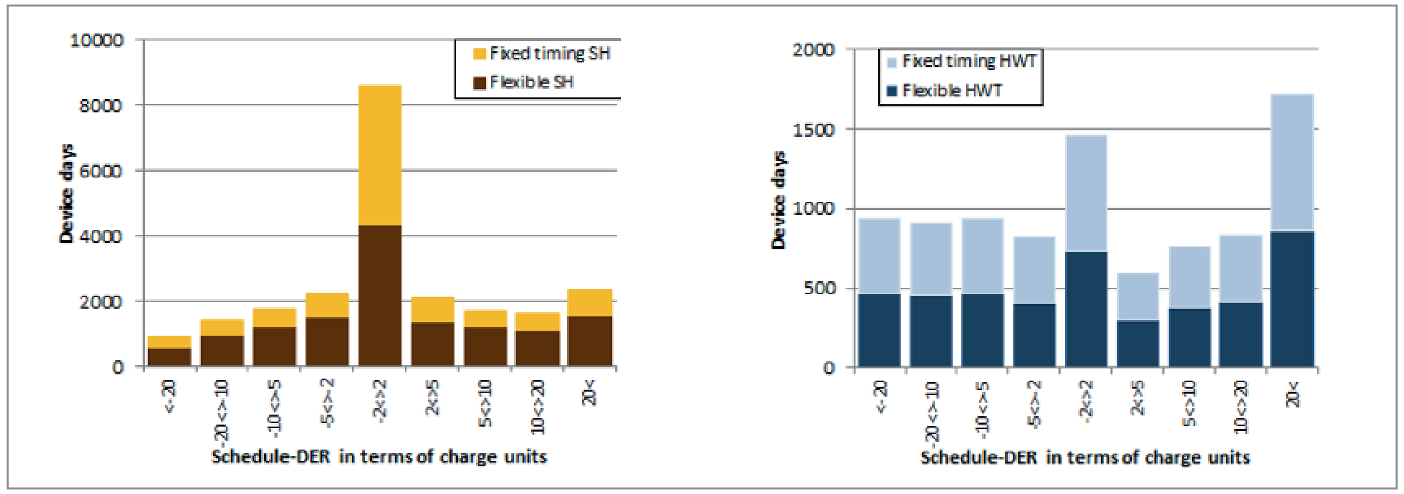


Figure 4.5 Scheduled energy relative to DER in terms of charge units

4.1.5 Delivered energy compared to DER

Although the LICs appear to over-shoot DER in the device schedules, the actual energy drawn is generally less than both the schedule and DER (Figure 4.6).

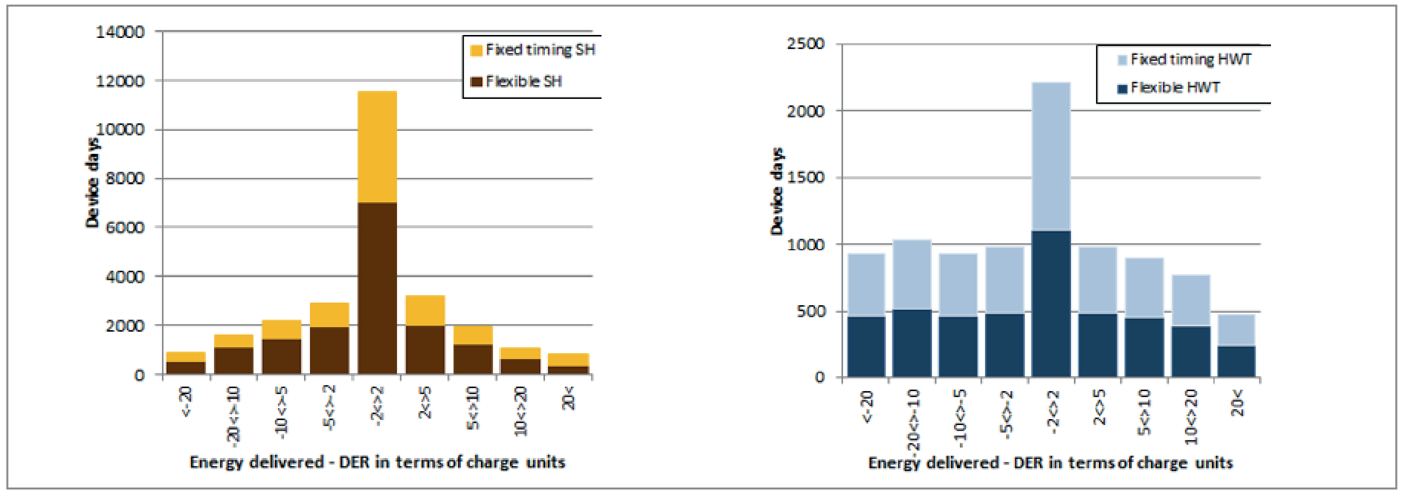


Figure 4.6 Delivered energy relative to DER in terms of charge units

The actual energy delivery is within ±2 charge units in 44% of space heater days and there are slightly more cases where less than DER is drawn than more. The algorithm used to calculate DER in the space heaters is complex, based on a combination of factors ranging from the forecast outside temperature, the previous day's energy use, and whether it had been enough to maintain the set-point, and the need to maintain a minimum heat reserve in the core[17]. However, even the most sophisticated algorithm cannot predict when an occupant will take a holiday or turn up the thermostat for personal reasons, so the accuracy of the DER forecast is remarkably good.

Hot water tank controllers are worse at predicting demand (Figure 4.6). Only 25% of device days saw delivered energy within ±2 charge units of DER; 31% of the time delivery was over 5 charge units less. This is not really surprising as hot water DER is calculated simply as the average consumption over the previous 3 days.

Hot water consumption can vary hugely and unpredictably from one day to the next; as an illustration, Figure 4.7 compares the actual daily consumption of one household over 2 months against a prediction based on the previous 3 days' demand. This household was a fairly average user both in terms of volume and time of day use. However, until 'Big Data' enables the day to day activities of individual humans to be predicted accurately, an average value is still the best forecast.

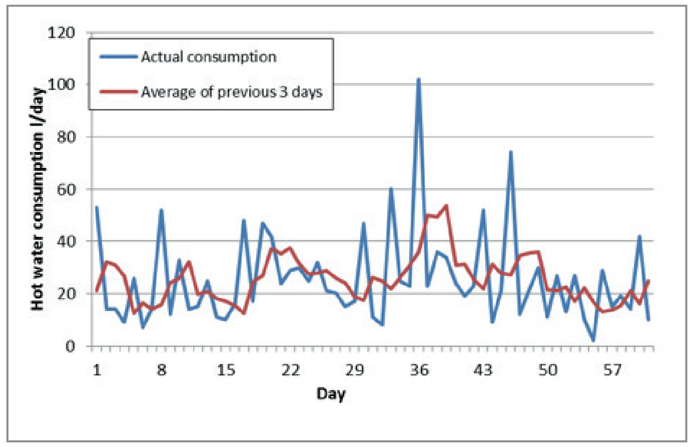


Figure 4.7 Daily hot water use profile in one house over 2 months

4.1.6 DER higher than heater or tank capacity

There are regular occurrences where the DER is higher than the tank capacity. The hot water used in a quarter of the independently monitored houses averaged more than one tank per day over the whole 18-30 months of measurements. In 18 weeks of device data, 56% of hot water tanks had days when DER was higher than storage capacity, and 6 had days where it was at least double capacity. Among space heaters, 44% had days when DER is higher than storage capacity and the proportion was higher in living rooms and halls (Figure 4.8).

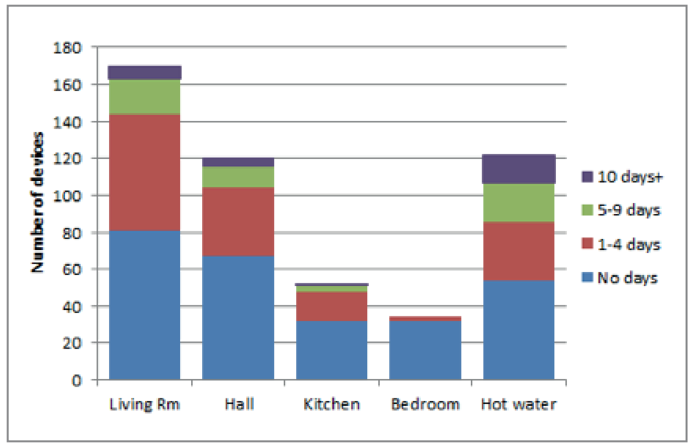


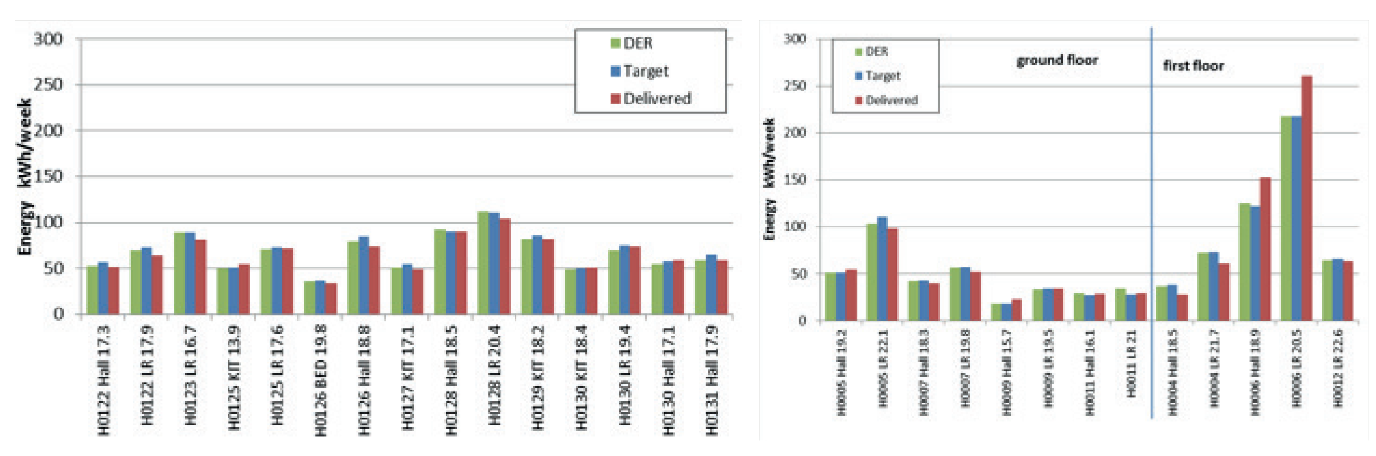
Figure 4.8 Occurrences of heaters with DER higher than tank capacity

In these cases the LIC still produces a target schedule in line with the overall profile for the group but the heater will stop charging when full. Charging will resume when the core or water temperature has fallen about 10 C and continue until fully charged again; this cycle continues until the full DER has been drawn. This will generally impact the network rather than the customer; however, there will be instances where there is not enough time to deliver DER fully, for example if the group profile is scheduled later in the day.

4.1.7 Consistency of DER calculations in space heaters

The energy required to heat a room is mainly driven by the volume of the room, the construction (wall type, level of insulation) and the difference between the inside and outside temperature. So comparing the energy used over a period in different houses with the same construction and layout can indicate where there may be a problem with heater control. Figure 4.9 compares heaters in houses within two different estates but with similar properties.

In estate a) there is consistency between the energy required and the room temperature for a given room type even though the actual room sizes vary. In estate b), where all the dwellings have the same layout, there are two outliers with very high consumption indicating a problem – not only is the DER unusually high, but the energy delivered is significantly higher than DER, and yet the room temperature set-points are not met. The reasons for these anomalies are unclear and could include occupant behaviours (for example, leaving doors/ windows open or could indicate a fault with device sensors or controller. It should be noted that this issue occurs in only one home (H006).



a) Poorly insulated detached bungalows, South Mainland

b) Timber clad, modern four-in-block flats, Scalloway

Figure 4.5 Scheduled energy relative to DER in terms of charge units

4.2 Evidence from modelling

Modelling studies indicate that flexible scheduling will reduce consumption relative to the previous tele-switching regime without impacting occupant comfort, provided that the energy required next day is calculated approximately correctly. The timing of when that energy is delivered does not affect overall consumption.

Before the rollouts started, a simulation study was undertaken to establish how the different kinds of schedule in the live ANM might impact both occupants and network operator[18]. Three very different, typical rollout houses were modelled with a high level of internal detail from construction drawings using the ESP-r[19] program. Two of the modelled dwellings were those in the prototype trial so the model could be validated against field data. The third was a larger detached bungalow with minimal insulation, a type that is well represented in the rollout. Quantum heaters were modelled in detail to represent the charging and control system explicitly. Various typical occupancy patterns and occupant temperature preferences were simulated.

20 different charging schedules were applied to the heaters, falling into three basic types: tele-switching with the same timing as before; different fixed time/ variable power schedules that delivered the daily demand either exactly or approximately; and flexible schedules of the type generated by the ANM. Figure 4.10 shows along the horizontal axis how the total energy required for heating the bungalow varied with different schedules while the vertical axis shows how closely each schedule was followed over the 6 months.

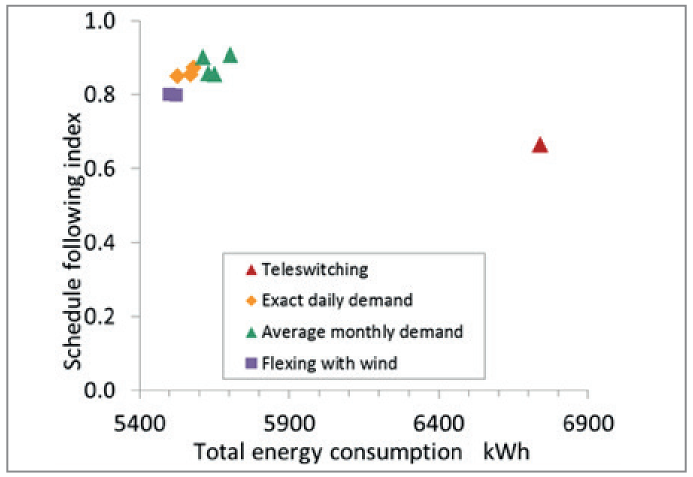


Figure 4.10 Modelled heating consumption January-June with different types of heater charging schedules (from Clarke et al 2015)

There was little variation between the different active schedules, with the maximum energy consumption being 2-7% higher than the minimum even where energy was stored over more than one day. This pattern was found for all modelled houses – all 3 used significantly less energy (10-18%) with active scheduling compared with operation in tele-switching mode. This is because with tele-switching the heaters charge to a set level irrespective of demand and then emit unneeded uncontrolled heat.

4.3 Evidence from customer feedback

4.3.1 Customer satisfaction survey

A customer satisfaction survey of a random 50 homes was commissioned by SSEN in June 2015, about 3 months after flexible charging was introduced. Even though there was a great deal of media comment at the time of the survey about why electricity prices had not fallen in line with the then recent spectacular fall in the price of crude oil, only one of the 19 respondents commented that it cost too much, and another that it was too expensive to run all of the heaters all the time. Other respondents made positive comments about higher availability of hot water.

4.3.2 Problems reported to the project

Table 4.1 shows all the issues logged and followed up by the NINES team over the course of the project. A small number of customers (14) reported high energy consumption after DSM was installed. Investigation revealed that heaters are particularly susceptible to even momentary interruptions to power supply: the controller retains the DER calculation but resets the amount charged so far that day to zero, so that more energy is drawn than needed. This appeared to be a particular problem in the exposed south end of the mainland where 37 reportable outages occurred between January 2014 and June 2016. The change required to fix this problem is described in the DSM Infrastructure Report[20].

Other short term cost impacts during commissioning occurred as follows:

- In 2014, when the frequency control functionality was tested, the parameters were accidentally left at unusually tight settings and all the heaters turned on to permanent charge for a period in an attempt to regulate the network frequency. This is discussed in detail in the Frequency Response Operational Effectiveness Report[21].
- Faulty equipment in 3 hot water tanks caused additional costs until fixed because a faulty cylinder activated the dump valve, dumping hot water and then re-charging multiple times[22].

	Number of houses
High usage queries	14
Heating faults	8
Consumption not registering on meter	2
Hot water tank controller faults	6
Hot water tank dump valve activation	3
Difficult to reach customers, hubs not updated	4

Table 4.1 1 Summary of DSM customer queries

4.4 Impact of problems seen in the device data

There have been persistent problems with communications throughout the project. Only about half the devices were visible consistently in the EM, and a third of the devices on any one day were not seen[21]. However, although this caused problems for the network, customers were not affected because each heater and tank reverts to stand-alone mode when it cannot see the LIC. DER is calculated using seasonal average temperatures rather than a daily forecast, and a fixed schedule is programmed into the device controller which is set to 100% charging at defined periods through the day: this is similar to the charging regime that operated before NINES.

A number of heaters reported exceptionally high DER: they registered as charging all the time but the core temperature remained flat at 50 C. This arose when an occupant has switched off the heating circuit without switching off the second circuit to the controller and so the controller continued to calculate ever higher DERs to try to meet the temperature set-point. This did not impact the customer because consumption and costs are calculated from the meter and not the heater controller but it did affect the System Operator because the ANM cannot distinguish between real and spurious energy demand which can make up 10% of the total. A solution is discussed in the DSM Infrastructure Report[23].

5

Impact on customer amenity

5. Impact on customer amenity

As well as having no adverse impact on costs, DSM promised that the customers should not be adversely impacted in terms of comfort. Consumption and comfort level are closely linked, so if the better insulated heaters can maintain the same room or water temperature with less energy, customers could be taking this benefit by having higher temperatures and using more hot water rather than in lower costs.

In June 2015, SSEN conducted a survey of customers' experience of DSM. When asked "Have you noticed any recent change in the level of comfort you receive from your heating system?" typical responses from customers included:

- "Much easier to control."
- "The house is much warmer."
- "Feels a lot warmer."
- "I am able to control my heating now."
- "Warmer and can be controlled better."
- "More efficient, heat stays hot longer."

5.1 Evidence from field data

5.1.1 Room temperatures

In the 35 independently monitored houses, occupants' temperature preferences were inferred from the average winter evening temperatures recorded in the living and other rooms. Compared to a large scale survey of room temperatures conducted in England and Wales in 2009-10[24] (Table 5.1), a higher proportion of households fell into the average temperature band and a lower proportion into the warm preference band. This may however be a reflection of different expectations in a northerly climate and in a social housing context.

Preference	No. houses	Proportion	Shipworth 2010
Cool (<20 C)	9	26%	30%
Average (20-22 C)	19	54%	30%
Warm (>22 C)	7	20%	40%

Table 5.1 Living room temperatures in monitored houses

No data is available about room temperatures before the new heaters were installed. However, the experience with the prototype devices from the 6-house trial[25] was that the better insulation in the Quantum heaters led to less variability, i.e. less tendency to overheat and fewer occurrences of low temperatures where the heaters had run out of charge.
Table 5.2 and Figure 5.1 show how average evening living room temperatures in monitored houses changed where data exists for two or more winters – the average is taken between 17.00-23.00 each day from December to March. In half of the houses, living room temperatures remained consistent, varying by less than 1 C throughout. Another 18% varied by less than 2 C, with 5 decreasing slightly and only one increasing.

Average temperatures within 1 C over 2 or 3 winters	17
Average temperatures within 2 C over 2 or 3 winters	6
Movements >2 C up and down over 3 years	4
Decrease by >2 C over 2 or 3 winters	7

Table 5.2 Movements in average living room temperatures on winter evenings, 34 houses

In each of the 35 monitored houses, room temperatures in the rooms with storage heaters varied less than in the rooms without heaters, consistent with the findings in the prototype trial[26].

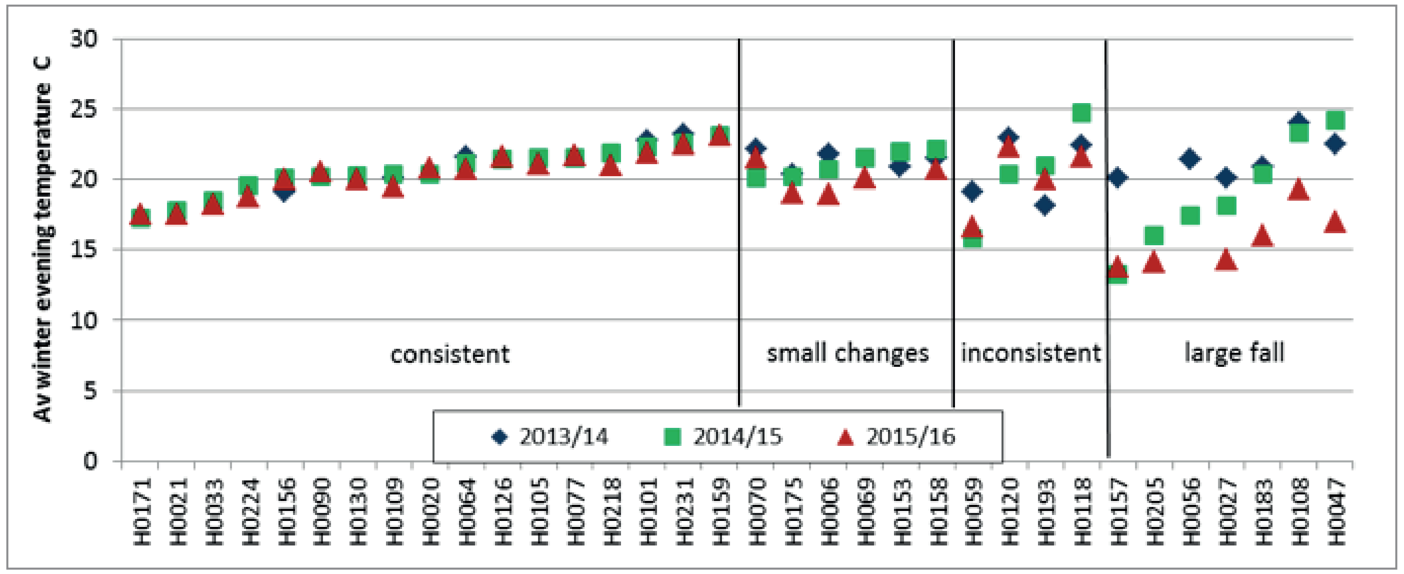


Figure 5.1 Changes in living room temperatures in monitored houses on winter evenings

In winter 2015/16, 5 of the living rooms experienced average evening temperatures lower than 17 C: this is below the generally accepted level of comfort. In some cases the house turned out to have been unoccupied but in other cases individual heaters may have been switched off either because of absence or for reasons of economy. Neither HHA nor SSEN received complaints from any of these households about the heating.

The heaters all have built-in room temperature sensors used by the device controllers. Figure 5.2 shows sensor temperatures recorded by living room heaters over one particularly cold winter week.

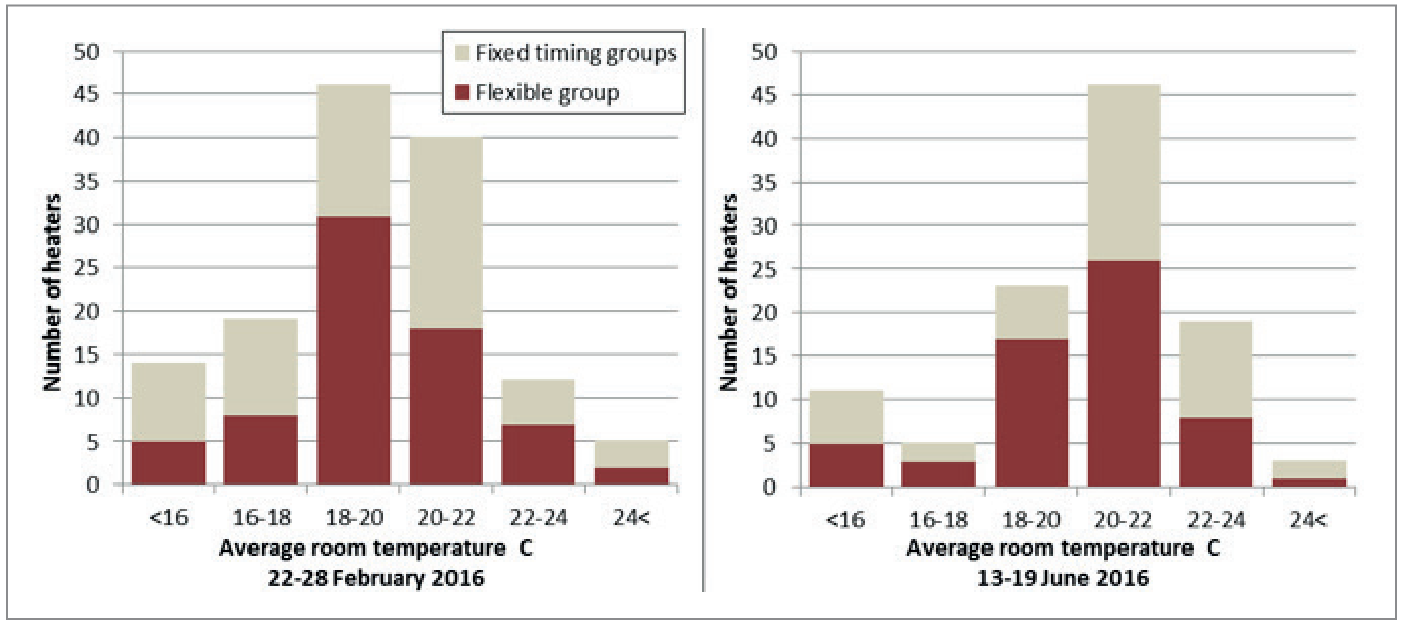


Figure 5.2 Living room temperatures measured by device sensors over the coldest and warmest weeks

Allowing for the fact that these are averaged over unheated as well as heated periods, over 85% of the rooms appear to fall into the same distribution as the large scale survey by Shipworth (2010)[27]. The distribution is similar irrespective of how the heaters were being charged. However, 14 living rooms were below 16 C all week. An average warm week in June is shown for comparison: temperatures have shifted upwards but more than 20% of heaters appear to have been switched off.

5.1.2 Meeting user setpoints

The heaters are capable of maintaining the desired temperature reasonably consistently, although there are exceptions where a heater is attempting to heat more than the room where it is installed.

Figure 5.3 compares the average room temperature recorded by each device over a week with the average user temperature set-point (USP) that week, over 18 weeks.

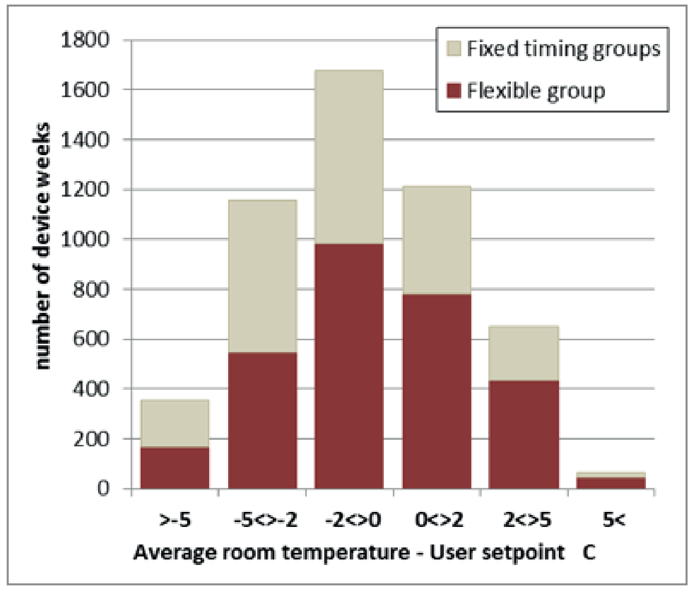


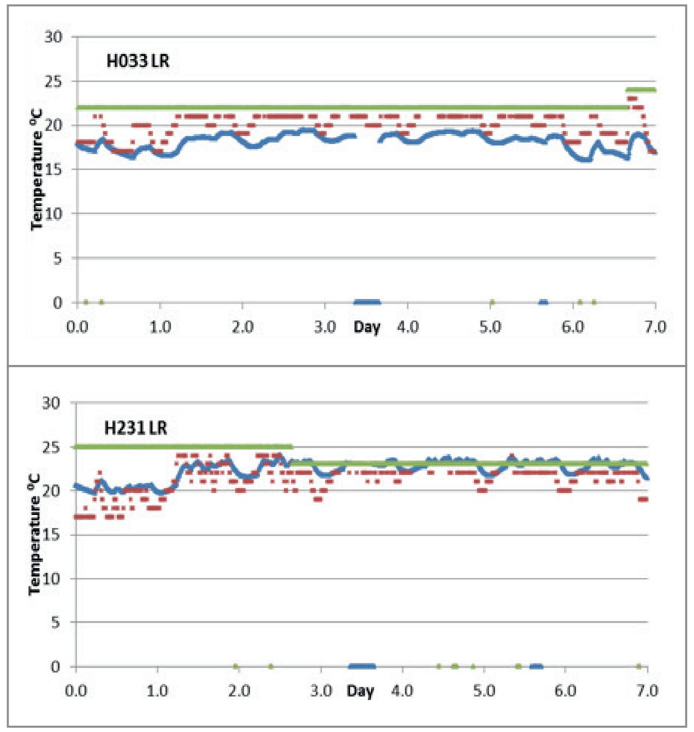
Figure 5.3 Device room temperature sensor vs user setpoint.

This chart ought to show a distinct bias to the lower side of zero because active fan output occurs only during user-set heating periods whereas the averages are taken across the whole week. However, even so in more than half the cases the devices maintained ±C of the USP. Here again there is no difference between the flexibly charged heaters and those of fixed schedules. 10% of the heaters kept to within ±2 C all the time, and one third had no weeks when they were more than 2 C below USP. Two-thirds never over-heated to more than 2 C above USP.

Where the USP was not met consistently it was mainly either in kitchens or halls where the heating time may be limited or in houses where one or more other heaters were apparently not in use. However, in a small number of cases the device was drawing very high amounts of energy while not meeting the set-point, an indicator that the heaters may be under-sized for the layout of the house.

That said the device room temperature sensor is not a particularly good proxy for the temperature experienced by the occupants as it is located at floor level directly under the heater body. The independent room temperature sensors ought to be better as they were originally placed close to eye level for a seated occupant, however they could have been moved by the occupants during the period of the trial. Both the device and the independent sensor readings will be affected by local conditions: location relative to draughts, incident light, cold surfaces and to the heat radiated from the device itself.

Figure 5.4 compares room temperature as read by the device sensor in three different houses. Three living room temperatures are compared over a cold week where independent monitoring measurements (blue line) were available as well as device data (red line). The user set-point level is shown in green for comparison.



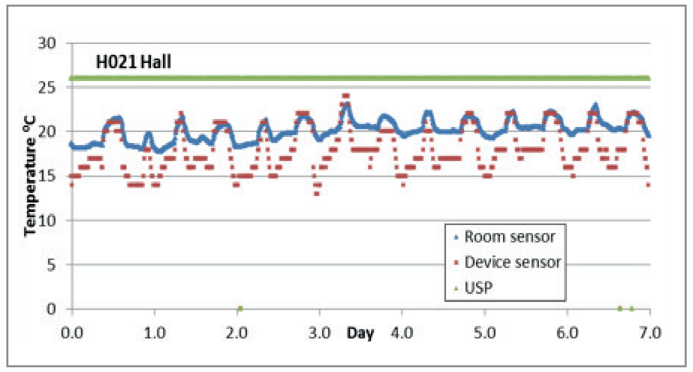


Figure 5.4 Room temperature seen by device sensors and independent room temperature sensors

- In House 231, the device gave almost the same readings as the room sensor and the setpoint (green line) was met during heated periods.
- In H033 the device sensor measured 2-3 C higher than the room sensor, which can happen if the heater is away from draughts and the floor is well insulated. Here the device sensor reported that the set-point was met even though the occupants experienced a lower temperature; and by the end of the week the set-point was increased to try to compensate.
- In H021 the device consistently measured 2-5 C lower than the room temperature sensor, except for the short periods when the fan was on. This could happen either because there was a draught at floor level or the floor is cold. In fact both these factors operated in this case as the dwelling is a small ground floor flat in a converted stone warehouse, with a concrete floor with air movement supplying heat to the bedroom and bathroom from the hall.

5.1.3 Use of manual boost

If the 3 kW manual boost heater is used regularly, this indicates that heaters are not meeting comfort levels. During the 18 weeks of data analysed, 11 heaters had boost on for at least 10 hours, drawing at least 30 kWh each (Figure 5.5).

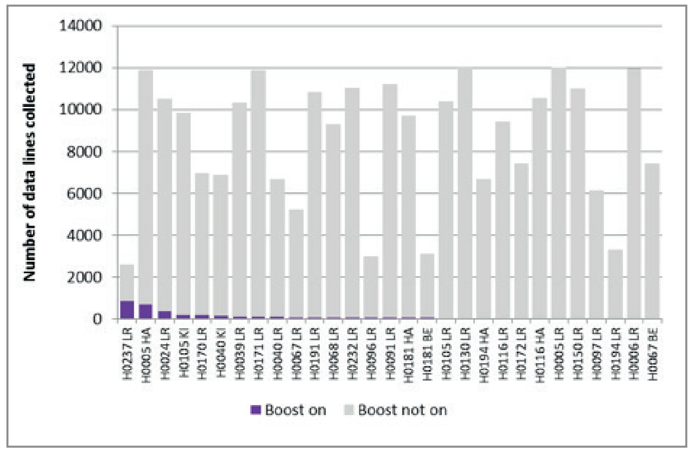


Figure 5.5 Highest users of the boost over 18 weeks

Unsurprisingly there was considerable overlap with the under-heating devices in 5.1.2. On field investigation some heaters turned out to have been installed incorrectly. In other cases the heater was not powerful enough for the location: two are in a group of houses with open-plan stairs to a mezzanine bedroom so the living room heater was also trying to heat an uninsulated space above.

A design problem with these heaters is that when the boost is switched on it continues to run until the next heating period unless the customer remembers to switch it off. Since the boost is generally also connected to the low rate meter there is no disincentive to use it, and in one case a customer reported overheating which turned out to be because the boost was regularly running all night. This could be solved if the manufacturer were to modify the heater controller algorithm to switches off the boost after a fixed time.

5.1.4 Hot water availability

The hot water tanks are set to maintain a minimum of 40 C in the top half of the tank, and they will start charging irrespective of schedule when this happens. Device data shows that hot water is in fact available most of the time: the highest occurrences of unavailability lasted less than an hour a day on average (Figure 5.6) and the two highest are on fixed timing charging. In 15% of the tanks the temperature at the top never fell below 40 C.

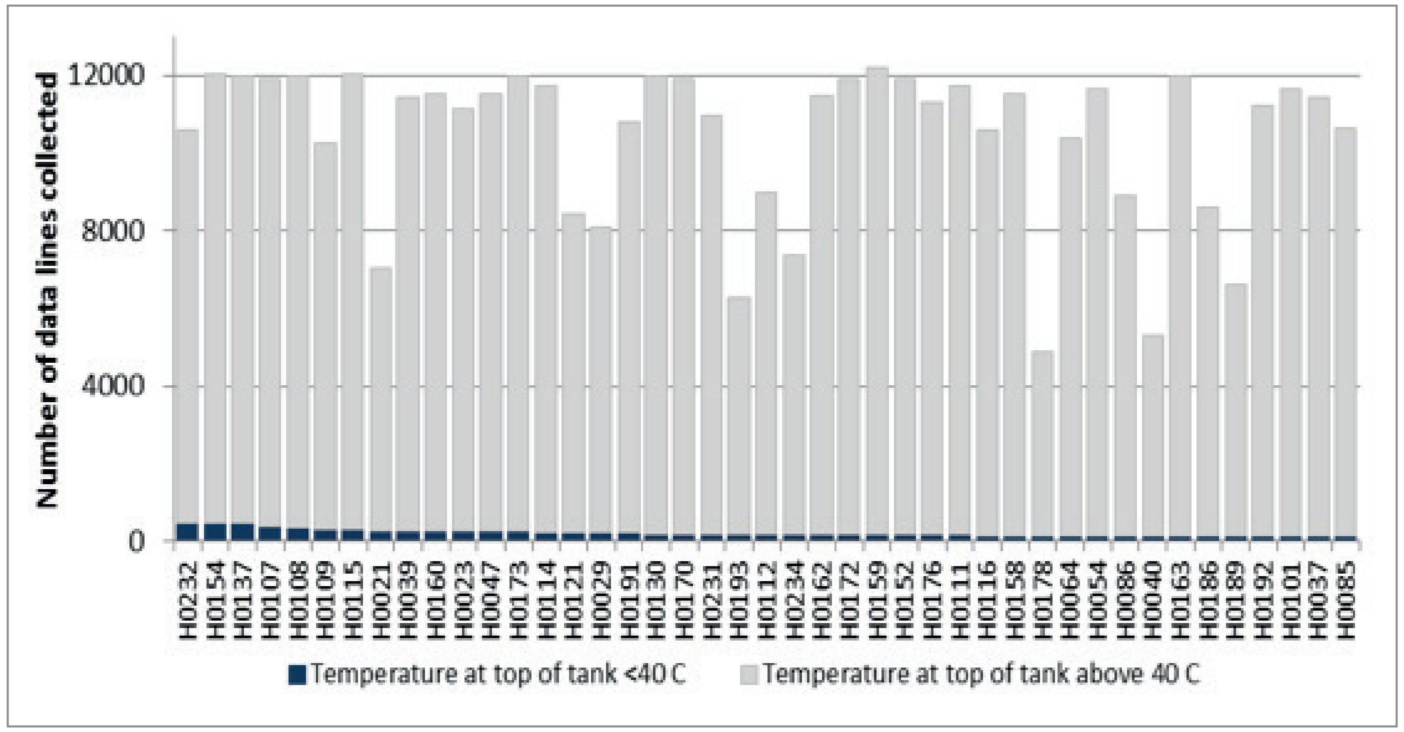


Figure 5.6 Hot water availability – highest occurrences of low temperature over 18 weeks

5.2 Evidence from modelling

The modelling study described in Section 4.2 showed that, compared to tele-switching, controlling heat input though active scheduling gives better temperature regulation as well as using less energy. Figure 5.7 shows the range of living room temperatures relative to the set-point with different types of schedules.

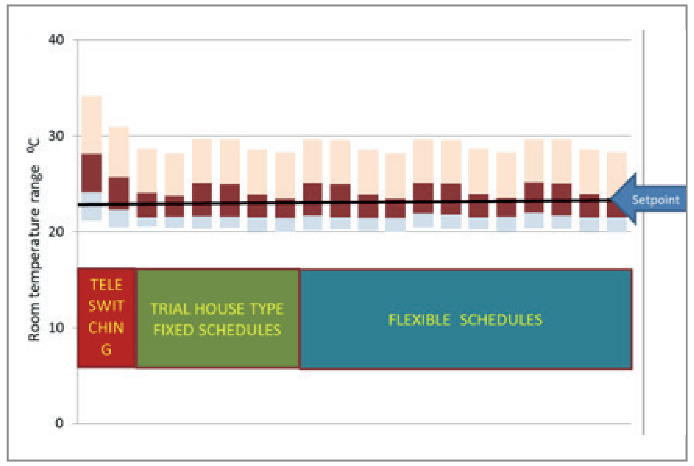


Figure 5.7 Modelled living room temperatures with various charging schedules

The dark brown band indicates the middle quartiles of the temperature range recorded, and the paler bands the highest and lowest quartile. Although there is some variation, all the active schedules were able to maintain the set-point much better than tele-switching. The two right- hand columns represent schedules where energy was stored over more than one day.

5.3 Evidence from customer feedback and reported problems

In the customer satisfaction survey carried out by SSEN in June 2015, 50% of the respondents reported no change in comfort level with either the heating or the hot water system. Where there was perceived change most of the comments were about increased heat and easier control.

One house reported serious under-heating in late 2015, to the point where the occupant withdrew from DSM. A number of others in the same estate also complained about under-heating. The problem was subsequently traced to poor wiring of the heaters during installation and electricians re-visited the whole estate to ensure that the heater coils were correctly connected.

In the customer survey, comments about hot water quality were mixed, some reporting better availability of hot water, others that water seemed to take longer to heat than before. One commented that they had been without hot water on two occasions. As this was a general comment in an anonymous survey it was not possible to follow up why: but this is a normal occurrence in houses where the occupants control timing; hot water is programmed to be available just before main bathing and dishwashing times, and then not until the next period. In these HHA houses the occupants had previously been on a fixed tele-switching schedule where water was typically heated in three blocks during the day and it may be that the occupants had become used to expecting that.

5.4 Are customers taking benefits in lower consumption or higher comfort level?

For space heating, the evidence indicates that customers are not using the heating more or setting higher temperatures than before NINES. Room temperatures fall into the distribution that is normal elsewhere or even slightly lower. Modelling studies show that customers changing from old time-clock controls, where the heater fills to a set level every time the switch is open, could see up to 10% lower energy consumption with closer control of charging. However, this is on the assumption that heaters estimate DER correctly and the occupants use the system correctly.

For hot water, there is some anecdotal evidence that on-demand availability is influencing customers to use more, and the design and operation of the new tanks will lead to higher consumption through standing losses. A re-evaluation of the requirements to maintain a constant minimum hot water temperature, and to cycle the tanks through 60 C every day, would reduce standing losses.

6

Future rollouts

Scottish & Southern Electricity Networks

The plan to add 500 private homes to NINES DSM was ceased in December 2016 following Ofgem's acceptance of a detailed change request, and it is expected that future rollouts will be managed by an independent DSM Service Operator rather than the DNO. Lessons can however be drawn from the HHA rollout to guide future activity.

6.1 Housing stock best suited to DSM

6.1.2 Influence of house construction fabric

The HHA rollout houses are relatively low-demand properties and are unrepresentative of the general housing stock in Shetland[28].

- The majority are small, with an average floor area of 65m2.
- A high proportion are flats, and a high proportion have only 1-2 bedrooms (Figure 6.1).
- They are significantly younger than the typical Shetland stock, and so better insulated.
- A high proportion have insulated walls, and there are very few solid or hard to treat cavity walls (Figure 6.2).
- HHA have already installed double glazing and at least 250mm of loft insulation in each.

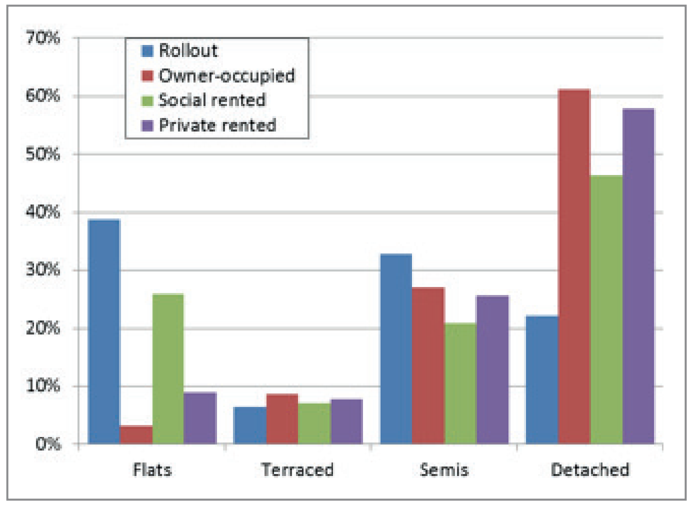


Figure 6.1 HHA rollout properties compared to Shetland as a whole

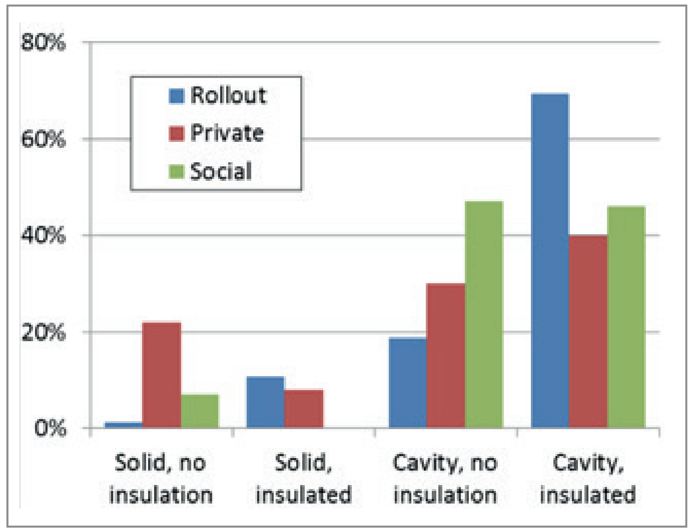


Figure 6.2 Insulation level in HHA rollout properties compared to Shetland as a whole

Occupants of large, hard to insulate houses have more to gain from installing DSM: they need more heat, and the uncontrolled output from the heaters makes a valuable contribution to keeping overnight temperatures from falling too far. These attributes also make them more attractive to the DSM Service Provider as each house will provide larger controllable capacity and is more likely to make full use of that capacity. The most suitable types of property are:

- Pre 1945, with solid or hard to insulate cavity walls, large rooms, high ceilings - estimated 1200 private dwellings in Shetland (Figure 6.3).
- Built in the period 1945-93, typically timber frame, block & render cladding, and no or moderate retrofit insulation - estimated 3100 private dwellings in Shetland.

Figure 6.3 Typical pre-1945 housing in Shetland

The difference that construction materials and insulation level can make to the energy needs of the same basic house is illustrated in Figure 6.4. The orange bars show modelled energy demand for the same, typical medium sized, two-storey, semi-detached house built from different materials and to a range of insulation standards, with standard occupancy and temperature. The 1970s house is a typical Type II, and the bottom three are Type I constructions, which will require more than three times as much energy to keep them at the same room temperature as one of HHA's 15-20 year old stock, represented by the 1990s and 2000s built houses. Houses built since 2007 to current energy efficiency standards, are even better insulated and are unsuitable for storage heating and DSM as they typically need less energy than the uncontrolled output of the Quantum heaters.

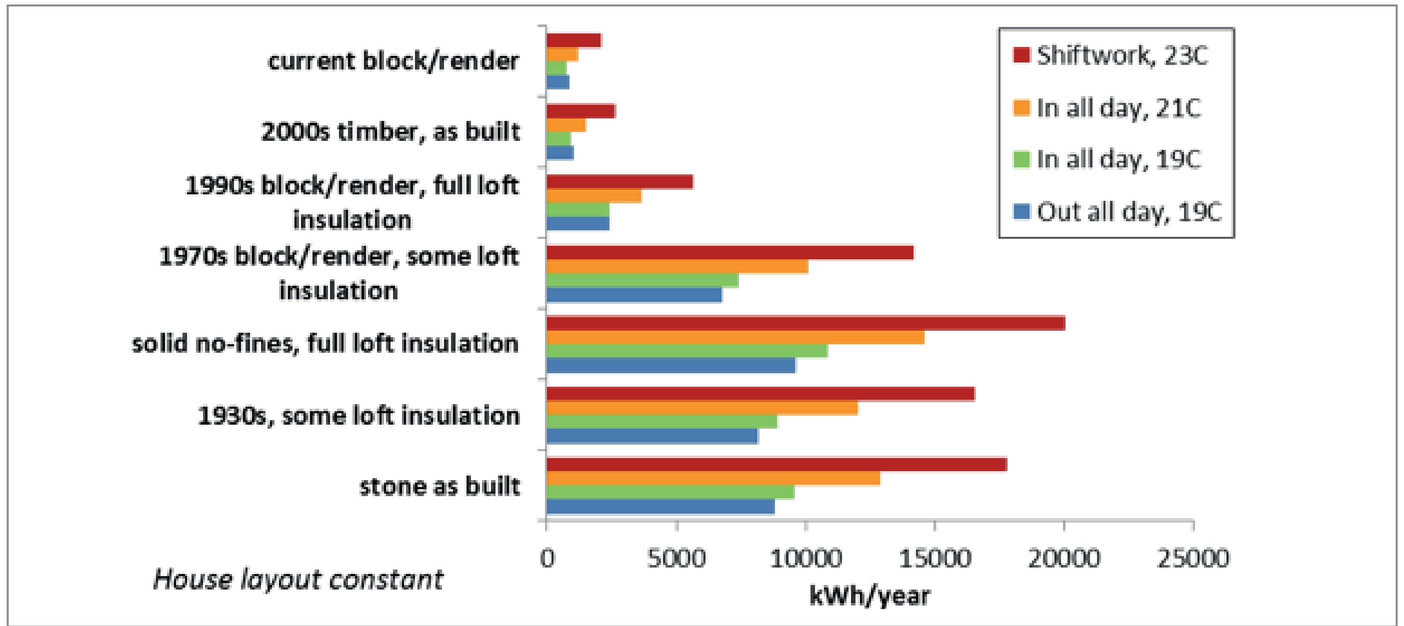


Figure 6.4 Heating demand range for a typical 95 m2 semi-detached house with different build, occupant comfort preferences and occupancy patterns

6.1.2 Influence of occupancy and occupant preference on energy demand

In addition to house size and fabric, heating demand is heavily influenced by how occupants choose to live – the hours they heat the house, preferred temperature, or desire for fresh air.

The modelling study outcomes in Figure 6.4 also illustrate the effect that different occupancy patterns and room temperatures can have on the heating demand for the same house. A range of ±50% on the 'standard occupancy' demand in any house is quite normal. Some individuals can be even more extreme – in the prototype trial, the house which had by far the highest energy consumption had the lowest room temperatures, presumably because the occupants kept the windows open most of the time[29].

Occupancy patterns may be slightly different on average in private than in the social housing. The private sector has a lower proportion of single person households[30] so the buildings are less likely to be occupied during the day where the occupants are younger (Figure 6.5).

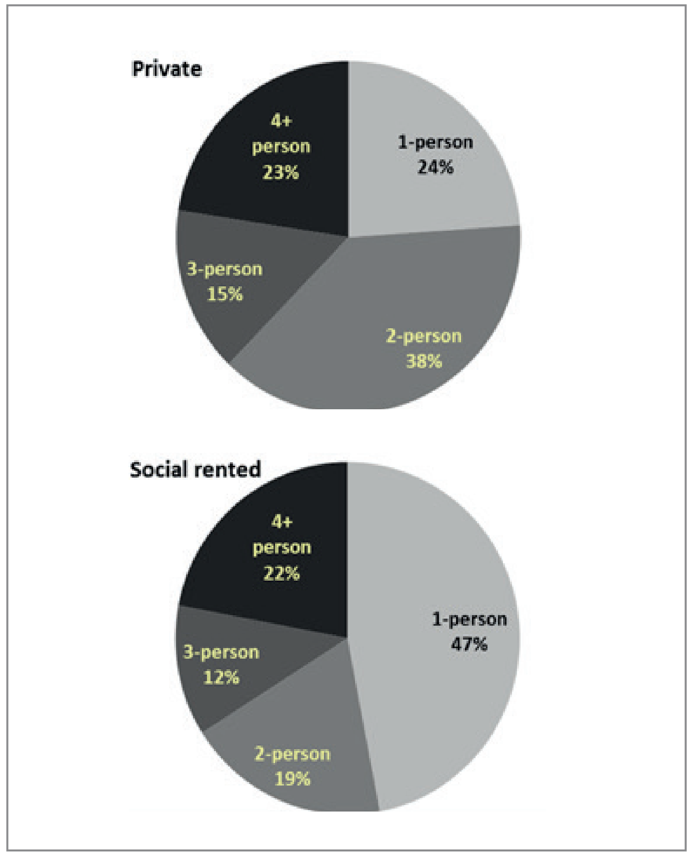


Figure 6.5 Household size distribution in Shetland's social rented and private sectors

Although suitable houses can be targeted, suitable customers are less easy to identify. Occupants can come and go, and even the same occupants can change behaviour over time, so in general a marketing campaign focused on the most suitable house types would be most effective rather than trying to target particular customer types.

6.1.3 Occupant interaction with DSM heaters

In future rollouts some general behavioural pointers may help to make a smoother transition for both the customer and the DSM Service Provider. DSM is designed to be set to defined heating hours at a constant user set-point, and the algorithm assumes that these are fixed. If occupants frequently alter heater thermostat settings and timings, the demand calculations can see-saw from day to day and the central schedule is less likely to fulfil demand. So the customer who will see the most benefit from DSM is a household with a high demand and regular habits.

6.2 Customer proposition in the private market

Early in the project SSEN recognized that a different market model would be required to rollout DSM in the private market and a preferred model was agreed in late 2013[31]. In social housing, the occupants do not have to pay the capital expense of the new kit and the social landlords have obligations to bring housing up to at least a 'C' or 'D' energy rating[32]. In the private market occupant and the homeowner are the same and benefits and costs play out differently.

DSM-capable space heaters are available on the market and are a reasonable stand-alone proposition for customers who are off the gas grid, offering both low-rate electricity and closer control of charging. There is however unlikely to be much of an appetite for private customers to buy DSM-ready hot water tanks as their performance is not unique; they are also more expensive and need to be custom-manufactured as Dimplex have no plans to market these.

The NINES DSM market model has two specific financial elements:

i) an annual payment of £50 to encourage customers to join DSM and provide a DSM service to the network, when they purchase new heaters. The customer must buy DSM-ready heaters while the DSM Service Operator provides the upgrade kit consisting of LIC, Home Hub, transceivers, home energy monitoring kit, and hot water controller if appropriate; and

ii) the customers are advised to change to a single rate tariff - such as general domestic - but receive a levelisation payment to compensate for the difference to the customer of not running the heating at a lower off-peak rate.

If a customer is already on electric storage heating, DSM can be introduced only if all the storage heaters are changed. Customers with oil or LPG can have one single storage heater and be on DSM as they are generally already on a single rate tariff. A clamped-on meter is placed on the heating and DHW circuit to monitor usage.

Additional maintenance requirements for DSM heaters are as follows.

- The battery in the User Interface lasts less than the theoretical 5 years and must be replaced at the homeowner's cost. No maintenance was needed on old heaters.
- Private customers will have to have an annual inspection by the DSM Service Operator to check that meter readings are correct and to replace the battery in the home energy monitoring device

6.3 Size and location of heaters

The payback to the homeowner as well as effectiveness to the network depends on the heat throughput of DSM heaters. Heaters in rooms used as living areas have the highest throughput and therefore these are the best targets. Heaters in halls are also useful as they often provide heating for other areas without storage heaters if doors are left open – high consumption was seen in houses where a single heater is supplying an open plan living room and bedroom, or where a downstairs hall heater is supplying the upstairs as well. Bedroom heaters are the least effective: they have low throughput as they are generally kept at lower temperatures, have shorter heating periods, and are the most likely to be switched off.

Oversized heaters will either over-heat rooms and waste heat at night or else will be switched off. The better the insulation in a house, the more important it is to get the heater configuration (number and size of heaters) right because heaters' uncontrolled output supplies a progressively greater proportion of demand.

Figure 6.6 shows the results of simulations with different heater configurations. The different colours represent different types of building fabric and insulation level, with the oldest houses on the right in red. Three different, plausible heater configurations are modelled in each house and compared to a baseline demand from direct heating as needed. The proportion of summer to winter demand indicates the amount of additional heat needed by the storage heaters. In poorly insulated houses consumption does not vary much with heater configuration, but in new houses built to the latest insulation standards, demand will be driven mainly by the need to maintain a minimum core temperature.

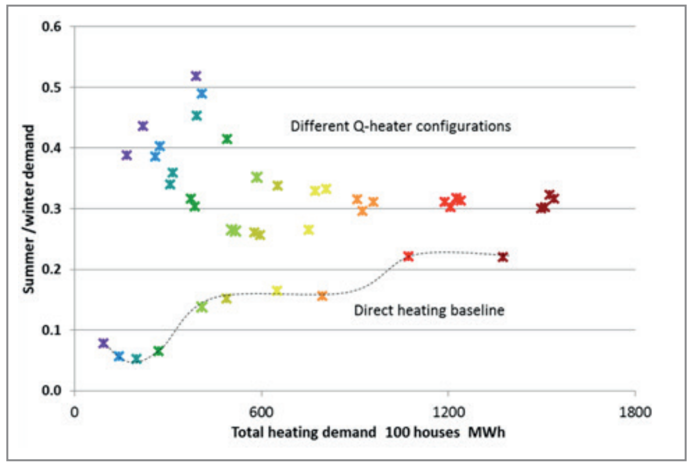


Figure 6.6 Proportion of wasted heat depends on heater sizing and insulation level

Sub-optimal heaters can also end up being installed for reasons unrelated to heating efficiency and the DSM Service operator will have only a limited influence over heater selection and location. In the rollout, heaters were bought by HHA based on a like-for-like replacement, which meant that the same basic house could end up with quite different heater numbers, sizes and locations because of historical decisions. There were also instances of too small heaters installed because of lack of wall space to accommodate the correct size, or positioning behind doors or curtains where heat flow was impeded.

6.4 Impact on fuel poor customers

DSM space heating should be beneficial for fuel poor customers. Those who switch from using older storage heaters to Quantum should, other things being equal, require less energy to maintain a given indoor temperature – although, with less overheating occurring they may at first feel unaccustomedly cold. Customers switching from direct heating in older, poorly insulated housing have the most to gain as they should be able to maintain warmer temperatures with the same or less expenditure, although this depends on the specific tariff and on the cost of heaters. In well insulated houses however, switching from direct heating to DSM could increase consumption by 50%+, more than can be compensated by tariff.

DSM hot water works less well for the fuel poor who are likely to be low volume consumers. They will experience the biggest impact on energy used for this purpose as standing losses make up such a large proportion of the total.

6.5 Impact of building energy efficiency improvements on DSM

Existing storage heaters are not suitable for heating new, well insulated houses built to current standards because level of demand is driven by the heater's uncontrolled output rather by occupant comfort (Section 6.1.1). As an example of the very low heat requirement that can be achieved, there is a row of 20 two-storey, three-bedroom houses in Sweden that can be kept at comfortable indoor temperatures all year with only a single 900 W fan heater per house, and even this is used only on particularly cold days[33].

The Quantum heaters emit 4-6 kWh/day when half full, and around 2 kWh/day at the minimum core temperature. It is not therefore surprising that the SAP energy assessment method rates even high retention storage heaters such as Quantum as inherently less efficient than direct electric heating[34]. To make storage heating fit with energy efficient housing, much better insulated and lower storage capacity heaters would need to be developed. But modelling studies show that a very large improvement in insulation would be needed before the effect would be significant.

Figure 6.7 shows this for one of the HHA houses, a typical two-storey timber clad semi-detached house built around 15 years ago. The house has 3 Quantum heaters, in the living room, kitchen and hall respectively, and a relatively low winter heating demand of 2,200 kWh. If the heaters' uncontrolled output is reduced by 50%, heating demand will be 5% lower and if 90% can be eliminated it goes down by 15%. The impact is more dramatic if the heaters are on tele-switching, where heaters fill up during scheduled hours whether the heat is needed or not and more heat is wasted.

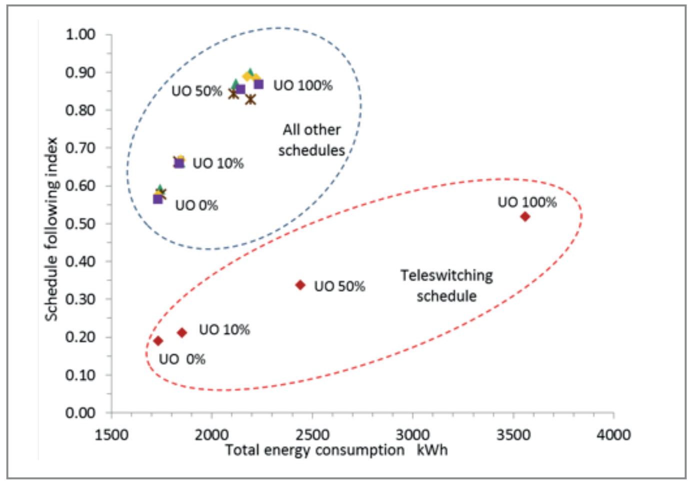


Figure 6.7 Potential efficiency gains from cutting uncontrolled output of Quantum heaters (2000s timber clad 95m2 house with 3 heaters, typical HHA)

Even if the technical problem could be overcome, the energy throughput in such heaters would be very small and several houses would be needed to give the same level of controllable demand and storage as one large, old stone property, but each would have to carry the full DSM enabling infrastructure of Hub, LIC, installation and communications. Other low-carbon electric heating technologies such as heat pumps will be a better functional fit in modern houses. In very well-insulated houses the timing of heat pump operation is less critical and they could potentially operate as flexible load[35].

7

Learning outcomes

This review of the impact on customers over the first two years of operating Demand Side Management in social housing in Shetland contributes to the NINES learning objective:

'What is the impact of the low carbon network on domestic and industrial customers? Effect on fuel poverty; changes in attitudes, awareness and behaviour amongst customers; extent of financial impact on participants.'

- NINES replaced old off-peak storage heaters and hot water tanks with smart, remotely controlled models. Customers were not asked to change behaviour and so the participation rate has been high, significantly more so than in demand-side response programs with variable pricing. Financial incentives were offered initially but they were not needed to maintain participation through changes in tenancy.
- DSM can operate only with meters that are capable of providing a 24 hour low rate supply; if the meter is not suitable then the customer will need to change tariff and possibly supplier. The NINES households that fall into this category are still operating on the old fixed timing system.
- It is best to move vulnerable customers and those on prepayment to DSM in stages after it has been demonstrated that they are not at risk of using up their prepayments to facilitate storage.
- In some houses RF communication between the devices and Home Hub have proved to be difficult to maintain. Future installations should be agreed only after communications have been fully tested on site.
- There is some evidence that DSM space heating did not result in systematically higher consumption or costs. The new space heaters are better insulated than those they replaced, so the customers have more control over when the stored heat is used. Modelling studies show that, other things being equal, the new heaters should use 10-18% less energy to maintain the same room temperatures because they are able to take only the energy they will need and control the time when it is used. Customers did not appear to be taking this benefit in higher room temperatures. Where customers have reported higher costs this has been because of specific faults. In future rollouts this should be monitored directly by measuring baseline consumption over a winter before installing DSM.
- Schedule timing in itself has minimal impact on cost or customer comfort provided that roughly the correct amount of energy is delivered. No difference was seen between the performance of devices in flexible timing groups and those on fixed timing. This is also evidenced by modelling studies.
- DSM has probably slightly increased energy consumption in the form of hot water. Occupants have commented favourably on hot water availability and this may indicate that they are using more. The new hot water tanks also have higher standing losses than those they replaced: they run at higher average temperatures because they are required to maintain a minimum comfort temperature, cycle through 60 C every day in order to prevent the risk of Legionella, and inherently have a higher maximum operating temperature.
- The Quantum control system has been designed to prioritise the customer rather than the network, so most of the communications problems and those encountered during commissioning have had no impact on customers – the devices continued to work in standalone mode. However, two design flaws have caused some customers to use more energy than needed. First, when there is an even momentary power outage, the daily energy requirement is retained in memory but the calculation of the energy delivered against that requirement is re-set. Second, the manual boost heating circuit in the space heaters does not switch off automatically until the next heating period starts so the customer must remember to switch it off if not required.
- A model for rolling DSM out into the private market has been tested but not yet implemented. This will apply to space heating only as Quantum hot water tanks are not available off the shelf. New customers will be need to switch to a single-rate tariff but will receive levelisation payments to bring their heating expenditure in line with off-peak charges. They will also receive an annual service fee.
- Occupants can come and go, and even the same occupants can change behavior over time, so in general a marketing campaign focused on the most suitable house types will be more effective rather than trying to target particular customer types. Future rollouts should target occupants of large, poorly insulated houses who have most to gain from DSM: they use more heat, and the uncontrolled output from the heaters makes a valuable contribution to keeping overnight temperatures from falling too far. These attributes also make them more attractive to the DSM Service Operator. Around half of the housing stock in Shetland is of this type.
- The technology inherently does not suit modern, well-insulated houses, where demand may be less than the uncontrolled output of these heaters. Even if heater insulation were to improve radically, the contribution of such houses to controllable power and storage would be very small relative to the overhead.
- Installing storage heaters in living areas and halls is most beneficial to both the customer and network. Heaters in rooms that are used for short periods only or are kept at low temperatures are the most likely to be switched off.

Appendix 1

Consent letter

Scottish and Southern Energy
Power Distribution

Inveralmond House
200 Dunkeld Road
PERTH
PH1 3AQ

Telephone: 0845 300 2315
Email: futurenetworks@sse.com

<Customer name>
<Address>

Date: 17 October 2013

Dear <Customer name>

Northern Isles New Energy Solutions (NINES)

We are constantly looking at ways in which we can improve how our networks operate. As part of that continual improvement, the NINES project aims to solve a number of the challenges the islands' networks are currently facing.

To alleviate these challenges SHEPD are working in partnership with Hjaltland Housing Association, to upgrade your existing electricity heating system. This means you will be provided with a more efficient, controllable heating system enhancing the level of comfort in your home.

To ensure you are receiving the best service possible, SHEPD will make changes to your current flexible charging regime, allowing new renewable generation to connect to the electricity network in Shetland whilst ensuring that you have heat and hot water available when you need it. These changes will not affect your current agreement with your chosen electricity supplier; however we will notify them that your home has been selected to participate in the project.

To establish the effect the new heating system has on your levels of energy consumption, SHEPD will arrange to install a monitor in your home, which will help us gather energy usage information on your heating and hot water use. The information we gather will form part of the data we will analyse for research and development purposes. All data collected will be used to demonstrate the effectiveness of the systems we are evaluating. All data will remain confidential and no personal data will be disclosed. As a token of our appreciation for allowing us to store energy, alongside collecting and analysing the data, a payment of £100 will be made payable to you.

Hjaltland Housing Association will be in touch to arrange access to your home to install the heating system and monitor. Once you have read, understood and agree to the terms and conditions, please complete the attached form and send it back to ourselves in the prepaid envelope.

If you have any questions please do not hesitate to contact us on the above contact details.

Yours faithfully

Colin Mathieson

Footnotes

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www.ninessmartgrid.co.uk