LCNF Tier 1 Close-Down Report

Trial evaluation of domestic demand side management

SSET1003

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Project Title

Trial Evaluation of Domestic Demand Side Management[1] (DDSM)

Project Reference

SSET1003

Contents

[1] The term Domestic Demand Management Solutions (DDMS) was used by SHEPD at the initiation of this project to characterise the solution trialled. However, during the course of the project 'Domestic Demand Side Management' (DDSM) has emerged within the industry as a generic term for this type of solution. We have therefore updated our project to reflect this development and avoid confusion – the term DDSM is used throughout the report.

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Executive Summary

Project scope

SHEPD (Scottish Hydro Electric Power Distribution) partnered with Glen Dimplex to develop and trial a new range of domestic energy efficient storage heaters and immersion water heaters (hot water cylinders) designed for grid energy storage, demand side management and frequency response. In addition to these network benefits, the design was projected to benefit customers by providing a more efficient and controllable heating system.

The project scope was to install new heating systems in six homes in Lerwick, Shetland with suitable communications back to a central interface, providing SHEPD with a degree of control over local demand and frequency response.

Aims

1. To prove the integration of these technologies
2. To generate learning for a wider roll out in Shetland and other DDSM (Domestic Demand Side Management) projects

Activities

SHEPD worked with Smarter Grid Solutions (SGS) to deliver a control solution capable of communicating to the new heating systems and providing the following functionality:

- Control of the heaters via a daily schedule, implemented through a Local Interface Controller (LIC)
- Remotely update schedules to the LIC
- Remotely over-ride the schedule in real-time with active setpoint instructions
- Automatic frequency response by the Dimplex Controllers and heaters
- Remotely provide updated frequency response characteristics to the Dimplex Controllers
- Retrieval of data from the Dimplex Controllers via the LIC and into a remote historical recording system

To meet these objectives, SGS developed the requirements and functional design specification for the LIC and a Central Interface. These documents were reviewed and updated at each stage of project delivery.

SHEPD partnered with Hjaltland Housing Association (HHA) to identify six tenant households as potential trial participants. Following initial contact by letter – including a Statement of Good Practice approved by Ofgem – HHA's Senior Technical Officer and a SHEPD Project Engineer visited each home to explain the project in detail and seek written consent for participation. Households were offered a £100 ex-gratia payment as an incentive to participate.

Installation was carried out by local plumbing and electrical contractors. SHEPD prepared a comprehensive method statement and risk assessment pack for contractors for each phase of the project to ensure high safety standards were met.

Outcomes and key learning

Testing carried out by SGS – against the functional requirements above – demonstrated the successful integration of DDSM components. This was detailed in the final test specification. The project advanced the Technology Readiness Level (TRL) level from 6 to 7, as an actual system prototype has been demonstrated in a working environment.

SHEPD commissioned the University of Strathclyde's Energy Systems Research Unit (ESRU) to monitor the supply and demand profiles associated with the heating systems. ESRU used this data to analyse the system performance: assessing the extent to which the heaters and cylinders operated as expected during the trial; and providing an initial assessment of their energy efficiency and storage capabilities.

While the sample size is too small to draw statistically significant conclusions; analysis has shown the heaters are more controllable and demonstrated additional hot water availability. An evaluation of tenant perceptions supported these outcomes and indicated they were well received by trial participants. Evidence suggests this has been achieved without causing households to use more energy. ESRU measured energy storage capacity to be 12.1 and 14.9 kWh for the two sizes of storage heater and 14.0 and 17.1 kWh for the two sizes of hot water cylinder.

The analysis recommended that design aspects relating to the hierarchy of control logic should be examined in more detail and refined as part of the control system design for the large scale roll out in Shetland. This would maximise the DNO's demand side management capability while maintaining user comfort.

The second principle aim was to generate knowledge to inform both a large-scale roll out in Shetland and other projects relating to DDSM. The trial has provided extensive learning related to the:

- Development of a DDSM heating system
- Requirements for a communications solution
- Resource requirements
- Understanding of customer perceptions
- Skills development and safe working procedures
- Input to further academic work on modelling household energy use to forecast customer demand.

Conclusions and future work

This trial has demonstrated the functionality of a DDSM system and provided an initial indication of the network and customer benefits. The next step required for progression towards Business As Usual (BAU) deployment is to trial dynamic scheduling and control. A large-scale roll out to 750 homes in Shetland through SHEPD's NINES[2] project will enable this. SHEPD will install communications equipment and integrate DDSM into an Active Network Management (ANM) system to provide dynamic control functionality. The NINES project will therefore allow the technology to be tested, both at scale and by integrating it into an existing system – advancing the TRL to 8 – and enabling SHEPD to determine the value of DDSM to DNOs.

Intellectual property

The project increased the technology readiness level of a new technology for use on a distribution network via a small scale trial. The trial resulted in learning which informed some modification of the products used (DDSM storage heaters, immersion water heaters and control system) by manufacturers, but did not change core functionality. These items are commercial products available to other DNOs, as such no Relevant Foreground intellectual property (IP) has been registered for this project.

The main benefits and knowledge delivered by the project relate to learning around system procurement, deployment and customer engagement. Details necessary to allow the project to be replicated by other GB DNOs are set out in this close-down report. Any additional information required can be requested through jenny.1.rogers@sse.com

[2] NINES - Northern Isles New Energy Solutions, see http://www.ssepd.co.uk/News/NINES/ for further details.

1 Project Background

As part of SHEPD's Tier 2 submission for the Northern Isles New Energy Solutions (NINES) project[3] there is provision for large quantities of domestic responsive demand. As a precursor to this, SHEPD propose to trial a small number of these solutions in the same geographic area as the Tier 2 submission. By working with our partners at Glen Dimplex, Hjaltland Housing Association (HHA) and Smarter Grid Solutions Ltd. (SGS) this is seen as the first step towards a larger roll out of the solutions under the auspices of Tier 2.

2 Scope and Objectives

This submission seeks to install DDSM in 6 houses with suitable control and signalling back to a central control hub. The aim being to control domestic electrical heat demand during times of network strain such as exceptionally low or high demand periods. Heat storage devices (immersion water heaters & space storage heaters) will be installed with control systems enabling them to become inertial energy storage devices on the electrical network, thus allowing the local DNO to have a degree of control over local demand response and frequency response.

3 Success Criteria

Any information gathered during this project will inform the larger Tier 2 proposal along with other modelling/projects/products around the UK regarding DDSM. The project success criteria will be to prove the integration of the technologies in order to provide knowledge and learning for the Tier 2 project and wider UK DNO rollout.

[3] The NINES project did not secure LCNF Tier 2 funding but since the registration of this Tier 1 project, it has been awarded funding through an exceptional mechanism. The scope, objectives and success criteria of this Tier 1 project are therefore still valid.

4 Details of the work carried out

Section 4 describes the trialling methodology for the project.

4.1 Developing the Dimplex Quantum Energy System

SHEPD partnered with Glen Dimplex to develop a new range of domestic energy efficient storage heaters and immersion water heaters (hot water cylinders) specifically designed for grid energy storage, demand side management and frequency response.

4.1.1 Storage Heaters

Main features of the prototype storage heaters installed are:

§ Highly insulated storage core to reduce standing losses during non heating periods.
§ Energy efficient heat output giving accurate time and temperature control.
§ Three core elements capable of providing variable power input between 0% and 100%.
§ User interface for setting comfort level and programming heating times.
§ Electronic control, which is fully compatible with the DNO interface, that provides:
  o Communications link to utility for demand side management and frequency response.
  o Mains frequency monitoring.
  o Variable frequency response.
  o Variable input power.
  o Core temperature sensing / setting.
  o Ambient / room temperature sensing / setting.

Table 1 - *Storage Heater Technical Data*

Model	**P100**	**P125**
Output rating (kW)	1.0	1.25
Storage element rating (Watts)	3 x 650	3x 800
Maximum storage capacity (kWh)	12.1	14.9
Dimensions(L x D x H) inc. wall bracket (mm)	790 x 210 x 700	940 x 210 x 700
Storage cells (pack of 6)	3	4
Installed weight (kg)	104	133
Insulation	Micro porous silica aero gel / Calcium silicate	
Storage cells	Feolite	
Fan rating	15 Watts	
Metalwork (Internal / External)	Zinc coated steel / Polyester powder coating	
Supply	240V, 50 Hz Supply	

Scottish and Southern Energy Power Distribution

Installation Specification

The new heaters were designed as a direct replacement for existing storage heaters. Dimensionally the new heaters are slightly longer and deeper but of similar height. The heaters are floor standing and screwed to the wall but required new fixing points to be drilled. Full installation instructions were provided to the electrical contractor along with set up instructions to the customer.

Communications link

The new heaters were designed to communicate with the Distribution Network Operator (DNO) to enable demand side management and frequency response. Communication to each heater was achieved by running a RS485 cable to each of the heaters from a Dimplex control box mounted at the water cylinder or consumer unit. The communications cable was connected into the heater electronics mounted in the right hand side of the heater. If the communications link was disabled or failed, the heater control logic continued to ensure user comfort was maintained.

Controls

Each heater has its own device controller to regulate the energy stored in the core and the heat output. A user interface mounted on the top of the heater provides:

- An electronic temperature control for setting the required comfort level. Customers may set the user interface setpoint from 0-8 which corresponds to a target room temperature. The ‘Min’ setting represents a room temperature of approximately 7°C and may be used for protection against frost. The ‘Max’ setting represents a room temperature of approximately 25°C.
- A programmable timer for setting the required heating periods (fan on). Three modes are available: **Manual Off** – the heater fan is permanently off; **Manual On** – the fan shall operate if the room temperature falls below the room temperature setpoint; and **Auto** – runs the programmed on/off times. Up to four on/off times can be selected for weekdays with separate times selectable for weekends.
- Boost operation. The additional boost heating element is selected by pressing the boost button for 3 seconds. The boost light will illuminate to indicate that the boost element is on. The boost will automatically switch off after 2 hours or when the room temperature target is reached. The boost can only operate when the fan is running.
- A child lock for the user interface and programmer can be selected.

Customer Benefits

Compared to traditional storage heaters, the Quantum device has a much higher degree of efficiency and superior insulation. This ensures a greater percentage of heat is stored until required by the user. The device is more controllable too whereby the customer can access heat quickly through the user interface. This employs a small fan which draws heat from the heater core and quickly increases the room temperature.

4.1.2 Water Heaters

Main features of the prototype hot water cylinders installed are:

- Three immersion heating element design to provide variable input power between 0% and 100%.
- Immersion elements with built in thermostat for water temperature measurement and over temperature safety cut out.
- Additional 3kW boost element fitted.
- Foam insulation to minimise standing heat loss.
- Inlet diffuser to prevent cold water and hot water mixing.
- Minimal stratification.
- Electronic controller, which is fully compatible with the DNO interface, that provides:
    - Communication link to utility for demand side management and frequency response.
    - Mains frequency monitoring.
    - Variable frequency response.
    - Variable input power.
    - Water temperature control – thermostat senses water temperature.

Table 2 - *Hot Water Cylinder Technical Data*

Immersions	Main elements – 750W, 750W and 1500W.	
	Boost element – 3kW.	
Maximum Storage Capacity (10-80 ^{o}C)	175 di	14.0 kWh
	215 di	17.1 kWh
Element sheath	825 incoloy, titanium also available.	
Insulation	CFC free, ODP zero, fire retardant foam.	
Outer casing	Leather grain plastic coating.	
Inner cylinder	Duplex stainless steel.	
Inlet / Outlet	22mm stainless steel pipe.	
Water supply	1.5 bar, 15 lire per minute minimum, 15 bar maximum.	
Pressure test	15 bar.	
Thermostat	Main elements thermistor control and thermal cut out.	
Safety	T&P valve – factory fitted 7 bar 90^{o}C. External expansion vessel, pressure reducing valve, pressure relief valve, and tundish supplied.	
Approvals	WRAS, BBA, CE.	
Supply	240V, 50 Hz Supply.	

Table 3 - *Hot Water Cylinder Dimensions and Weights*

Product	Capacity (litres)	Diameter (mm)	Overall Height (mm)	Weight (kg)	
				Full	Empty
175 di	175	578	1242	237	37
215 di	215	578	2484	258	43

Plumbing Specification

The water cylinders were designed as a direct replacement for existing unvented water cylinders. Modifications were required to the existing plumbing to accommodate the differences in the position of inlet and outlet pipes and to add a thermostatic mixing valve to the outlet. To maximise the energy storage capacity, water can be heated up to 85 degrees Celsius. Additional safety measures such as a thermal cut out and pressure release valve are fitted to achieve this safely. The thermostatic mixing valve is capable of delivering hot water to the home up to a maximum of 60^{o}C. Cylinders required the addition of an external expansion vessel which was supplied along with the other safety devices. The expansion vessel was mounted on a wall adjacent to the water cylinder. Full installation instructions were provided to the plumbing contractor.

Wiring Specification

Cylinders have a total of four immersion elements per cylinder. Three of the elements are mounted at the bottom of the cylinder with one boost element at the top. The three main immersion elements are powered through the Dimplex control box which is mounted either on a wall adjacent to the cylinder or at the consumer unit. Three supplies were run from the control box – one for each of the lower immersion elements. A two core cable also had to be run from the control box to the thermistor which is located at the middle of the three lower elements. The top mounted boost element was connected to existing wiring.

Customer Benefits

The hot water cylinder offers class leading efficiency. In addition the increased water storage temperature provides an increase in hot water available to the customer – a smaller volume of water at 85^{o}C is required in the mix delivered to the home. This was well received by trial participants.

4.1.3 Certification

The heating systems were tested by Glen Dimplex to ensure compliance with relevant legislative standards (listed below) and obtained CE marking.

§ BS EN 60335–1
Household and similar electrical appliances. Safety. General Requirements.

§ BS EN 60335–2-30
Household and similar electrical appliances. Safety. Particular requirements for room heaters.

§ BS EN 60335-2-61
Household and similar electrical appliances. Safety. Particular requirements for thermal storage room heaters.

§ BS EN 55014 – 1
Electromagnetic compatibility - Requirements for household appliances, electric tools and similar apparatus - Part 1: Emission.

§ EN 55104 – 2
Electromagnetic compatibility - Requirements for household appliances, electric tools and similar apparatus - Part 2: Immunity - Product family standard.

§ EN 61000 – 3 – 2
Electromagnetic compatibility (EMC). Limits. Limits for harmonic current emissions (equipment input current • 16 A per phase)

§ EN 61000 – 3 – 3
Electromagnetic compatibility (EMC) - Part 3-3: Limits - Limitation of voltage changes, voltage fluctuations and flicker in public low-voltage supply systems, for equipment with rated current <= 16 A per phase and not subject to conditional connection.

§ EN 62233
Measurement methods for electromagnetic fields of household appliances and similar apparatus with regard to human exposure.

4.2 Control Solution

SHEPD contracted to work with SGS to deliver a control solution capable of communicating to the new heating systems to provide the following functionality:

§ Control of the heaters via a daily schedule, implemented through a Local Interface Controller (LIC).
§ Remotely update schedules to the LIC.
§ Remotely over-ride the schedule in real-time with active setpoint instructions.
§ Automatic frequency response by the Dimplex Controllers and heaters.
§ Remotely provide updated frequency response characteristics to the Dimplex Controllers.
§ Retrieval of data from the Dimplex Controllers via the LIC and into a remote historical recording system.

The purpose of each function is discussed in Section 6.

4.2.1 Requirements Specification

To meet these objectives, SGS developed the requirements for the LIC and a Central Interface. These requirements were reviewed and updated at each stage of the project delivery. The LIC requirements were grouped under the following headings:

- General Functionality and Physical Characteristic Requirements
- Day Ahead Schedule Processing
- Active Setpoint
- Droop Characteristic Processing
- Ramp Rate Processing
- Set-point Limits Processing
- Other Configurable Values Processing
- LIC to Device Controller Communications
- LIC to Central Interface Communications
- LIC Programming and Remote Controllability
- Watchdogs and Error Handling
- Device Characteristics Reporting and Feedback

A full description of the requirements can be found at Appendix I.

4.2.2 Functional Design

The Functional Design Specification (FDS) produced by SGS forms the main body of work for the project. A comprehensive engineering document, the FDS sets out:

- How the logical functions required by the LIC will be achieved.
- The data points that will be transferred to the device including:–
    - Setpoint and droop characteristic processing.
    - Commanded operational characteristics.
    - Static and dynamic operational characteristics reporting.
    - Watchdog and error handling.
- Data schedules and memory maps.
- Data transfer methodology.
- Configuration of software and hardware components.

The Functional Design is located at Appendix II. The high level system architecture and a summary data schedule can be found below.

High Level System Architecture

Figure 1 shows the final high-level system architecture for the project:

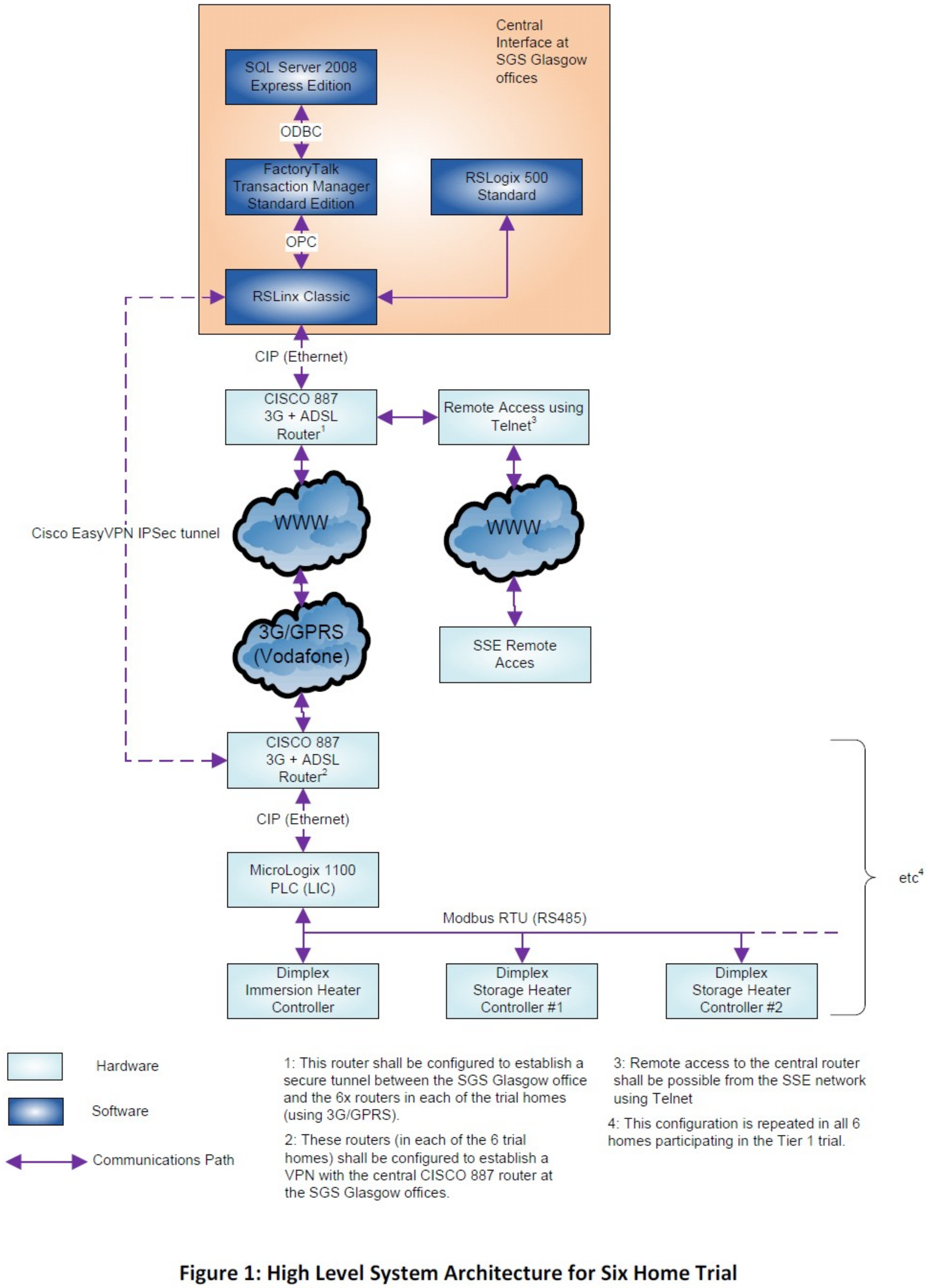

Figure 1 - *System Architecture June 2011*

“The specification includes equipment installed in six homes to control Immersion Heaters and Storage Heaters. A Central Interface shall be configured at SGS’ Glasgow offices to gather and store information from the six trial homes (via a GPRS link). This server will also provide the capability to remotely interrogate and program the LICs in the six trial homes.

The MicroLogix 1100 PLC (performing the role of the LIC) in each of the trial homes shall be connected to a single Dimplex Immersion Heater Controller and up to three Dimplex Storage Heater Controllers via an RS485 multi-drop serial connection.

The communications path between the central and remote routers will use the Internet and Vodafone 3G/GPRS networks to establish an IPSec tunnel connection. This connection enables secure two-way communication of data for control and logging purposes.

SHEPD requested access to the central router located at SGS’ Glasgow offices. SGS will provide remote access to the central router by provision of Telnet access to SHEPD”.

Data Schedule

A data schedule summarising the precise information stored in the Central Interface can be found at Table 4. The LIC and Device Controller contain similar data schedules. Each data point is provided with an associated source and destination where the:

- Source represents the location from whence the data originates.
- Destination represents the location where the data is to be transferred.

The source and destination may be:

- *ANM:* Indicating that the source or destination for the data point is the Central Interface.
- *LIC:* Indicating that the source or destination for the data point is the LIC.
- *DC:* Indicating that the source or destination for the data point is the Device Controller.

Data points may have multiple destinations, e.g. a data point within the LIC may be sent to a connected Device Controller and to the Central Interface.

Table 4 - *Central Interface Data Schedule*

Data	Device	Quantity	Type	Raw Range	Eng Range	Eng Units	Source	Dest
Day Ahead Schedule	IH	96	Integer	-10,000 → 10,000	-100 → 100	% of Rated Power	ANM	LIC
Default Day Ahead Schedule	IH	96	Integer	-10,000 → 10,000	-100 → 100	% of Rated Power	ANM	LIC
Day Ahead Schedule	SH	96	Integer	-10,000 → 10,000	-100 → 100	% of Rated Power	ANM	LIC
Default Day Ahead Schedule	SH	96	Integer	-10,000 → 10,000	-100 → 100	% of Rated Power	ANM	LIC
Active Setpoint	All	1	Integer	-10,000 → 10,000	-100 → 100	% of Rated Power	ANM	LIC
Active Setpoint Operational	All	1	Integer	0 → 1	0 → 1	N/A	ANM	LIC
Device Number	IH	1	Integer	1 → 10	1 → 10	N/A	LIC/ANM	ANM/LIC
Load Setpoint	IH	1	Integer	-20,000 → 20,000	-200 → 200	% of Rated Power	ANM	LIC
Upper Setpoint Limit	IH	1	Integer	-10,000 → 10,000	-100 → 100	% of Rated Power	ANM	LIC
Droop Characteristic Deadband	IH	1	Integer	0 → 30,000	0 → 3	Hz	ANM	LIC
Droop Characteristic Gradient	IH	1	Integer	0 → 10,000	0 → 1,000	% of Rated Power / Hz	ANM	LIC
Default Droop Char Deadband	IH	1	Integer	0 → 30,000	0 → 3	Hz	ANM	LIC
Default Droop Char Gradient	IH	1	Integer	0 → 10,000	0 → 1,000	% of Rated Power / Hz	ANM	LIC
Positive Power Step	IH	1	Integer	0 → 10,000	0 → 100	% of Rated Power Change/cycle	ANM	LIC
Negative Power Step	IH	1	Integer	0 → 10,000	0 → 100	% of Rated Power Change/cycle	ANM	LIC
Minimum Water Temperature	IH	1	Integer	0 → 99	0 → 99	°C	ANM	LIC
Absolute Minimum Water Temp	IH	1	Integer	0 → 99	0 → 99	°C	ANM	LIC
Device Controller Watchdog Counter	IH	1	Integer	0 → 32,767	0 → 32,767	N/A	LIC	ANM
Device Controller Watchdog Status	IH	1	Integer	0 → 1	0 → 1	N/A	LIC	ANM
Device Rated Power	IH	1	Integer	-32,798→ 32,797	-32,798→ 32,797	Watts	LIC	ANM
Maximum Energy Storage Capacity	IH	1	Integer	0→32,797	0→32,797	Watt Hours	LIC	ANM
Remaining Energy Storage Capacity	IH	1	Integer	0 → 10,000	0 → 100	% of Maximum Energy Storage	LIC	ANM
Temperature	IH	2	Integer	0 → 100	0 → 100	°C	LIC	ANM
Instantaneous Power	IH	1	Integer	-20,000 → 20,000	-200 → 200	% of Rated Power	LIC	ANM
Device Number	SH	X	Integer	1 → 10	1 → 10	N/A	LIC	ANM
Load Setpoint	SH	X	Integer	-20,000 → 20,000	-200 → 200	% of Rated Power	ANM	LIC
Upper Setpoint Limit	SH	X	Integer	-10,000 → 10,000	-100 → 100	% of Rated Power	ANM	LIC
Droop Characteristic Deadband	SH	X	Integer	0 → 30,000	0 → 3	Hz	ANM	LIC
Droop Characteristic Gradient	SH	X	Integer	0 → 10,000	0 → 1,000	% of Rated Power / Hz	ANM	LIC
Default Droop Char Deadband	SH	X	Integer	0 → 30,000	0 → 3	Hz	ANM	LIC
Default Droop Char Gradient	SH	X	Integer	0 → 10,000	0 → 1,000	% of Rated Power / Hz	ANM	LIC
Positive Power Step	SH	X	Integer	0 → 10,000	0 → 100	% of Rated Power Change/cycle	ANM	LIC
Negative Power Step	SH	X	Integer	0 → 10,000	0 → 100	% of Rated Power Change/cycle	ANM	LIC
Device Controller Watchdog Counter	SH	X	Integer	0 → 32,767	0 → 32,767	N/A	LIC	ANM
Device Controller Watchdog Status	SH	X	Integer	0 → 1	0 → 1	N/A	LIC	ANM
Device Rated Power	SH	X	Integer	-32,798 →32,797	-32,798→32,797	Watts	LIC	ANM
Maximum Energy Storage Capacity	SH	X	Integer	0→32,797	0→32,797	Watt Hours	LIC	ANM
Remaining Energy Storage Capacity	SH	X	Integer	0 → 10,000	0 → 100	% of Max Energy Storage	LIC	ANM
Temperature	SH	X	Integer	0 → 750	0 → 750	°C	LIC	ANM
Instantaneous Power	SH	X	Integer	-20,000 → 20,000	-200 → 200	% of Rated Power	LIC	ANM
User-Setpoint	SH	X	Integer	0 → 750	0 → 750	°C	ANM	LIC
Average Ambient Outside Temp	SH	X * 12	Integer	-20 → 50	-20 → 50	°C	ANM	LIC
Maximum Core Temperature	SH	X	Integer	0 → 750	0 → 750	°C	LIC	ANM
Room Temperature	SH	X	Integer	10 → 50	10 → 50	°C	LIC	ANM
Charge Controller Fan Status	SH	X	Integer	0 → 1	0 → 1	N/A	LIC	ANM
User Interface Set-Point	SH	X	Integer	0 → 10	0 → 10	N/A	LIC	ANM
Boost Operation	SH	X	Integer	0 → 1	0 → 1	N/A	LIC	ANM
Fan Duct Temperature	SH	X	Integer	0 → 300	0 → 300	°C	LIC	ANM
Charge Profile (Accumulated Energy)	SH	X	Integer	***	***	***	LIC	ANM

Where **X** is the number of storage heaters connected to the LIC.

4.3 Trial of DDSM System with Hjaltland Housing Association

Hjaltland Housing Association (HHA) are the main independent housing agency in the Shetland Islands. HHA currently manage over 530 houses for rent or shared ownership which includes: general needs, sheltered and amenity, and other special needs housing. SHEPD partnered with HHA to identify six tenant households as potential trial participants.

4.3.1 Participant Recruitment

HHA's existing relationships with tenants provided sufficient knowledge to identify households likely to be willing to participate in a research trial (i.e. tolerant of disruption associated with installation; and willing to provide feedback on heating system via interviews and surveys etc).

SHEPD provided the potential participants with information about the trial by letter including a Statement of Good Practice approved by Ofgem. This can be found at Appendix III. HHA's Senior Technical Officer and a SHEPD Project Engineer visited each home to explain the project in detail and seek written consent for tenants' participation. Households were offered a £100 ex-gratia payment as an incentive to participate. One household chose not to opt in on the basis that the works would cause too much disruption. Another home was given the opportunity to sign up to the project instead. Households were notified of all further visits to install or modify equipment by letter and provided with contact details for both a SHEPD and HHA member of staff to report any queries or problems with their new heating system.

4.3.2 Trial Sample

Table 5 outlines the trial household characteristics and the new heaters selected for installation by HHA and Glen Dimplex. Home 1 is located within a 2004 conversion of an old, stone built public building into flats. Homes 2–6 are located close to each other, and were built in the late 1990s to the same specification.

Table 5 - *Trial household characteristics*

ID	Type	No. of Occupants	Heater Living Area	Heater Hall	Hot Water Cylinder
1	1-bed flat	1	P125	P100	175 l
2	3-bed semi 2-storey	4	P125 + P100	P100	215 l
3	2-bed semi 1-storey	4	P125	P100	215 l
4	1-bed flat	1	P125	P100	175 l
5[4]	2-bed semi 1-storey	3	P125	P100	215 l
6	1-bed flat	2	P125	P100	215 l

[4] A change in tenancy occurred in August 2011.

4.4 Installation, Testing and Monitoring

4.4.1 Installation Schedule

Installation was carried out by local plumbing and electrical contractors. SHEPD prepared a comprehensive method statement and risk assessment pack for contractors for each phase of the project to ensure high safety standards were met. Examples for the storage heater installation can be found at Appendix IV. Table 6 details the installation work carried out during the trial.

Table 6 - *Installation schedule*

Date	Installation	Purpose
November 2010	Phase one installation including: § Hot Water Cylinder § Dimplex Control Box § Programmable Logic Controller (LIC)	Test operation in stand-alone mode: Disconnected from the teleswitch, charging signals provided by PLC.
February 2011	Routers installed in homes enabling two-way communications between homes and central interface.	Test operation in controlled mode: charging signals provided by the Central Interface. Test remote modification of charging pattern, control parameters and retrieval of data.
June 2011	Phase two installation including: Storage heaters and associated RS485 cable wiring.	Test operation in controlled mode.
December 2011	Additional monitoring equipment installed on behalf of the Energy Systems Research Unit from the University of Strathclyde.	Monitor supply and demand profiles associated with new systems.
February 2012	Test rooms replicating set up of equipment in homes installed at SHEPD and Glen Dimplex offices.	Implement software and hardware updates in test environment prior to implementation in homes.
March 2012	Glen Dimplex, SGS and SHEPD carried out a software upgrade to the six homes in March 2012 to capture additional measurement data.	Provide better feedback to customers; improve the level of control; and to assist with the research work being undertaken by the University of Strathclyde.

4.4.2 Phase One Installation

Hot Water Cylinders were provided by Glen Dimplex and installation costs were borne by SHEPD. Installation was carried out by: a two man plumbing team; an electrician and apprentice; and support from a labourer where required. The remainder of the working party consisted of: a SHEPD site supervisor; SGS engineer; and a Glen Dimplex engineer. Each installation took the majority of a working day to complete.

SGS developed a Test Specification to formalise the testing and commissioning of the LIC installations and the remote control and monitoring facilities that support them. SGS produced a series of test outcomes to validate that both the hardware and application software meet the requirements defined in the Requirements Specification and Functional Design Specification and to ensure that the LIC interfaces with the Dimplex Device Controllers as intended. A checklist was used to standardise the test process and ensure tests were executed in a thorough and sequential manner.

Initial LIC Installation

Figure 2 displays the layout of the hardware and communications installed for the first project phase in November 2010. Table 7 displays the checklist for the initial LIC testing.

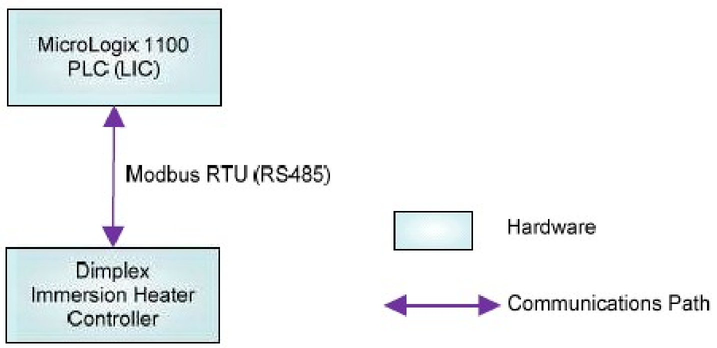

Figure 2 - *System Architecture November 2010*

Table 7 - *LIC Test and Commissioning Procedure*

Test#	Purpose	Description	Comments	Pass or Fail
1	Check installation of PLC has been carried out correctly	Review the PLC connections including the power source and communication cable to device controller (as per Appendix A)		1 P 2 P 3 P 4 P 5 P 6 P
2	Verify operation of PLC hardware	Power on the PLC and view the custom HMI screen to confirm LIC programme is loaded		1 P 2 P 3 P 4 P 5 P 6 P
3	Verify data is being *written* to Device Controller Modbus register addresses correctly	Connect serial cable to PLC from laptop running RSLogix 500 and review feedback data (as per Appendix B)	This is difficult to tell from a remote run of the LIC. However, the IH device controller accepted all write commands, observed by the message 'DN' flags	1 P 2 P 3 P 4 P 5 P 6 P
4	Verify data is being *read* from Device Controller Modbus register addresses correctly	Connect serial cable to PLC from laptop running RSLogix 500 and review data register values (as per Appendix B)		1 P 2 P 3 P 4 P 5 P 6 P
5	Confirm the correct values are stored in the PLC data files	Use Appendix C to confirm the correct day ahead schedule, droop values etc		1 P 2 P 3 P 4 P 5 P 6 P
6	Confirm the PLC recovers correctly from a restart or abrupt power loss	Power off the PLC and power back on after a 5-second delay. Confirm that communications are re-established		1 P 2 P 3 P 4 P 5 P 6 P
7	Confirm the PLC recovers correctly from loss of communication with the Device Controller	Disconnect the communication link between the LIC and the Device Controller. Restore the link and verify operation		1 P 2 P 3 P 4 P 5 P 6 P
8	Confirm that the correct time is configured on the PLC real time clock	Use the Remote Run function to view the RTC settings on the PLC		1 P 2 P 3 P 4 P 5 P 6 P

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Communications Link

In February 2011 SHEPD installed GPRS routers in each of the six homes to provide remote access to the LICs for monitoring, control and data logging. Figure 3 below outlines the system architecture after installation. At this time, tests ensured that the LIC was remotely accessible using the newly installed GPRS communications link. Successful installation of the communications link confirmed the working functionality of the system as follows:

1. The ability to remotely control the six immersion heaters with a day ahead schedule provided by the LIC.
2. The ability to remotely provide updated day ahead schedules to the LIC.
3. The ability to remotely alter working parameters within the LIC code including the minimum set-point temperature and the droop characteristic.
4. The ability to remotely review the operation of the immersion heaters, including their instantaneous power consumption and tank temperatures.
5. The ability to retrieve feedback signals from the Dimplex Controller, reading the LIC over the GPRS communications link, and log data in an SQL database.

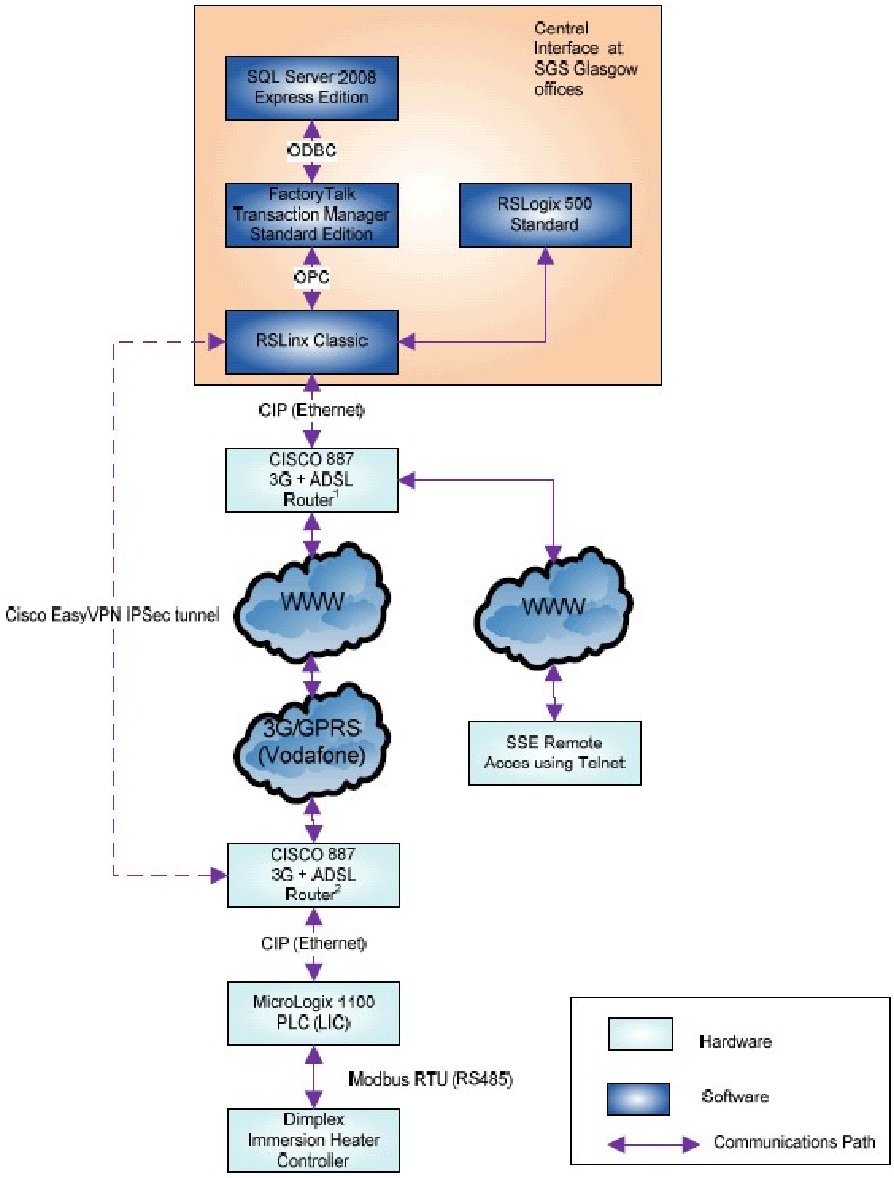

Figure 3 - *System Architecture February 2011*

Table 8 displays the checklist for the communication link testing.

Table 8 - *Test Checklist for the Communications Link*

Test #	Purpose	Description	Comments	Pass or Fail
1	Confirm the correct installation of the GPRS router and the communication link to the LIC	Check the router power supply is connected appropriately. Ensure Ethernet cable is connected from LIC to the appropriate port of the router		1 P 2 P 3 P 4 P 5 P 6 P
2	Confirm that all routers are able to receive a secure GPRS signal	Look at the GPRS module plugged into the router. Confirm a permanent non-flashing blue LED is present		1 P 2 P 3 P 4 P 5 P 6 P
3	Confirm that the IPSec tunnel is established between the router in the SGS office and each remote router	Use a command prompt window to ping the address of each router and view the ping statistics	Some trouble shooting was required from SSE but all routers visible after a short while	1 P 2 P 3 P 4 P 5 P 6 P
4	Confirm visibility of each LIC from the Central Interface	Use RSLinx to browse all LICs. Confirm each LIC is online		1 P 2 P 3 P 4 P 5 P 6 P
5	Confirm LIC data can be monitored using RSLinx	Check the "Data Monitor Tool" can read PLC data registers		1 P 2 P 3 P 4 P 5 P 6 P
6	Confirm that remote user can go online with PLCs. Make amendments to the code and register values	Using RS Logix500, go online with each PLC, amend a single data point and then return to original value		1 P 2 P 3 P 4 P 5 P 6 P
7	Confirm that data can be logged into an SQL database and stored historically	Use Factory Talk Transaction Manager to populate an SQL data base with live operating parameters		1 P 2 P 3 P 4 P 5 P 6 P

4.4.3 Phase Two Installation

Code Revision to LIC

Ahead of the storage heater installation, an update of the LIC code to incorporate the Storage Heaters was required. SGS tested the functionality of this code and the integration of the LIC with the new Dimplex Storage Heater Device Controllers at their offices in Glasgow. Figure 1 outlines the system architecture following installation. Table 9 displays the checklist for this stage of testing.

Table 9 – *Storage Heater Test Checklist*

Test #	Purpose	Description	Comments	Pass or Fail
1	To confirm that all configurable data has an available memory location within the LIC to accept programmed changes	Configurable operational parameters are changed by changing register values within the PLC, it must be confirmed all of these are available		P
2	To confirm that all data and configurable values stored in the LIC are mapped correctly to the required locations, ready to be sent to the device controller	The configurable operational parameters described above are used in several locations throughout the LIC code and must be distributed accordingly		P
3	To confirm that the values stored within data file N26 represent the correct operational characteristics and charging schedules agreed with SSE	The values within N26 store the static and dynamic operational parameters that the LIC sends to Device Controllers. These values can be updated remotely but must match what has been agreed with SSE at the time of installation	Schedules may be changed prior to installation according to SSE instruction	P
4	To confirm that all 'write' message functions send the correct data to the appropriate Modbus register addresses	The LIC will write operational parameters to a number of device controllers over a multidrop RS485 link and the successful execution of the write commands must be confirmed	This is difficult to tell from a remote run of the LIC. However, the device controllers accepted all write commands as seen by the messages 'DN' flag	P
5	To confirm that all 'read' message functions are reading the correct Modbus register addresses	The LIC will read operational parameters from a number of device controllers over a multidrop RS485 link and the successful execution of the read commands must be confirmed	All values read appropriately except the device IDs of the Storage Heaters. This was discussed with Glen Dimplex who said that a bug existed in **their** code. The Dimplex code will be revised prior to the installation trip	P
6	To confirm that when communications between the LIC and the Central Controller are removed that the LIC enters a failsafe state	A watchdog value will be maintained between the LIC and the Central Controller. If this watchdog fails then the LIC should enter a failsafe mode and issue default operational parameters to Device Controllers		P

Table 9 - *Storage Heater Test Checklist (continued)*

Test #	Purpose	Description	Comments	Pass or Fail
7	To confirm that upon return of communications between the LIC and the Central Controller that normal operation is resumed	If the watchdog value between the LIC and the Central Controller recommences then the LIC should return to normal DSM operation		P
8	To confirm that when an active setpoint operational signal is set that the active setpoint takes precedence over the day ahead schedule	By viewing the adjusted setpoint value within the LIC code it should be possible to determine if the active setpoint is used at the appropriate time		P
9	To confirm that the active setpoint operational signal is cleared when communications between the Central Controller and the LIC are lost	By deliberately failing communications between the LIC and the Central Controller it can be seen if the LIC reverts to the (default) day ahead charging schedules	Yes. However, it also had to be configured for the Active Setpoint Operational Flag to clear when communications are lost. This will prevent an unwanted Active Setpoint issue upon restoration of communications	P
10	To confirm that when communications between the LIC and the device controller are lost that the Device Controller WDT failure flag is set and seen at the central controller	By deliberately failing communications between the LIC and a device controller it will be possible to confirm the watchdog error flag is operating correctly	This was not possible to confirm until after the installation date however it should be no different than logging any other data point, which is already proven. This has since been proven back at SGS Glasgow office	P
11	To confirm that the LIC code can be updated over the GPRS/GSM communications link	Using a replica router within SGS offices, a LIC was reprogrammed with the latest code base using the GPRS/GSM network		P
12	To confirm that the LIC can receive an updated date/time from the Central Controller	Using the Rockwell Software clock update tool the LIC date/time will be updated to match that of the Central Controller		P
13	To confirm that the LIC returns to normal operation after a complete power failure	By failing and returning the power to the LIC it can be observed if normal operation of the LIC is resumed		P

Storage Heater Installation

Storage heaters were provided by Glen Dimplex and installation costs were borne by SHEPD. The installation was carried out by an electrician and apprentice with support from a labourer where required. The remainder of the working party consisted of: a SHEPD site supervisor; SGS engineer; and a Glen Dimplex engineer. Each physical installation was complete in half a day. SGS and Glen Dimplex carried out site acceptance testing and commissioning of the LIC and Dimplex equipment. Table 10 outlines the tests undertaken and the results.

Table 10 - *Storage Heater Site Test Checklist*

Test #	Purpose	Description	Comments	Pass or Fail	
1	To confirm that the LIC is talking to each associated device controller	Viewing the WDT counter for each Device Controller will confirm health of communications		1	P
				2	P
				3	P
				4	P
				5	P
				6	P
2	To confirm that the LIC is programmed with the correct date and time	While online to the LIC, viewing the RTC will confirm the date and time currently stored		1	P
				2	P
				3	P
				4	P
				5	P
				6	P
3	To confirm that the LIC is communicating with the Central Interface	A check from the Central Interface in Glasgow was completed after the installation of each router	The communications from the central interface to home number 6 were down at the time of installation	1	P
				2	P
				3	P
				4	P
				5	P
				6	F
4	To confirm that all 'read' message functions are reading the correct Modbus register addresses	View the associated data register locations and ensure appropriate data is read and passed to appropriate locations	It appears that the LIC is reading the correct Modbus registers however, it is also clear that the Dimplex Device Controller is not populating the registers as per design. The read values seem wrong	1	F
				2	F
				3	F
				4	F
				5	F
				6	F
5	To confirm that all 'write' message functions are executing correctly	View ladder logic in remote run mode and verify all write commands are executing by viewing the 'DN' message flag	All message DN flags were observed	1	P
				2	P
				3	P
				4	P
				5	P
				6	P
6	Confirm the PLC recovers correctly from a restart or abrupt power loss	Power off the PLC and power back on after a 5-second delay. Confirm that communications are successfully re-established		1	P
				2	P
				3	P
				4	P
				5	P
				6	P
7	Confirm the PLC recovers from loss of communications with the Device Controller	Disconnect the communication link between the LIC and the Device Controller. Restore the link and verify operation		1	P
				2	P
				3	P
				4	P
				5	P
				6	P

The SGS engineer noted that the Dimplex Device Controllers were not populating the registers as per design. A configuration error occurred when both the Immersion Heater and Storage Heater were connected. In addition, there were instances of Glen Dimplex using engineering values as opposed to the raw values specified in the Functional Design Specification. Glen Dimplex amended the code accordingly. Following successful integration testing with SGS in Glasgow, the new code was updated on each device locally.

4.4.4 Installation Commissioning Documentation

In addition to the Test Checklists carried out by SGS, plumbing contractors completed a mains pressure hot water storage system commissioning checklist for the hot water cylinder installation. Electrical contractors completed a SELECT minor electrical installation works certificate after each works programme. Examples can be found at Appendix V.

4.4.5 Additional Monitoring

SHEPD commissioned the Energy Systems Research Unit from the University of Strathclyde (UoS) to monitor the demand and supply profiles associated with the new heating systems, analyse this data to determine the efficacy of system performance over time, and relate outcomes to user satisfaction.

An additional monitoring system was installed. Only 5 of the 6 houses were selected for additional monitoring by UoS since they are located close together in range for radio frequency communication. The following parameters were monitored:

- Surface temperature at the top and bottom of the hot water tank (Ttu, Ttl).
- Hot water output volume flow and its temperature (Li, Ti).
- Cold water volume flow into the mixer and its temperature (Lo, To).
- Air temperature in living room and one or two other rooms (Tl, Tb).
- Ambient air temperature in the area (Tx1).

To achieve this, mass flow meters were installed on the hot water cylinder by a plumbing team; and temperature sensors and logging equipment were installed by UoS personnel. The UoS System Architecture for data communications is illustrated in Figure 4.

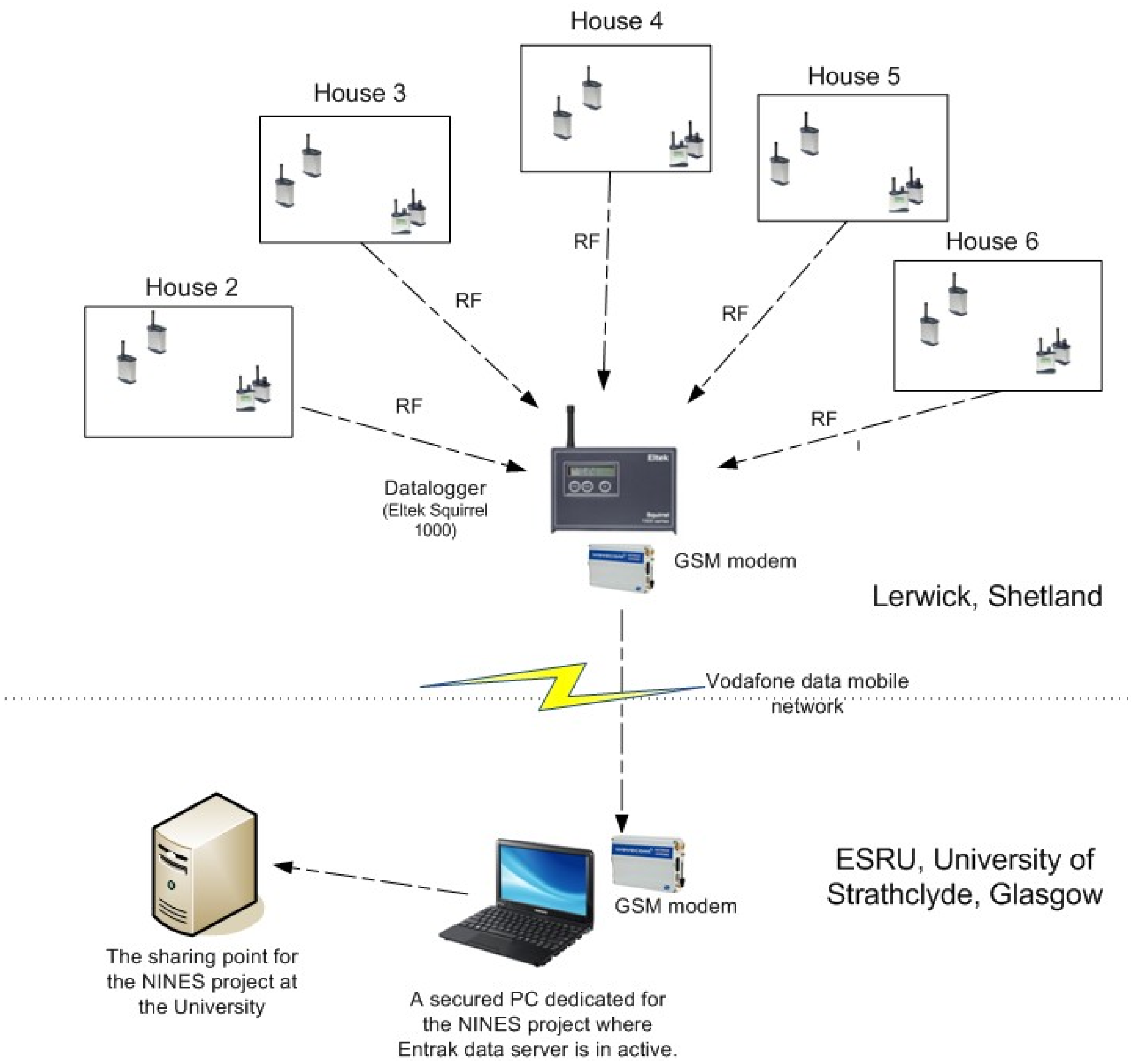

Figure 4 - *UoS System Architecture for data communications*

All transmitters are wireless devices equipped with either internal or external sensors. These transmitters sent data to a local data logger, with a maximum transmission range of approximately 100m. The data logger sent its aggregated data set on request to a PC located at the University of Strathclyde via Vodafone GPRS. The EltekDarca software was used to initiate this download, typically on a weekly basis. The downloaded data was stored in a database under the management of ESRU's Entrak program: an energy management application utilising a mySQL database server with secured access protocols. The system was protected by a firewall and physically located in a secure space accessible only by ESRU staff.

The additional monitoring system was designed to be complementary to the existing SGS system with the aim of providing a full set of data that would allow temporal energy balances to be determined and basic occupant comfort states evaluated. All of the energy flow data on the storage heaters are derived from the SGS system with the UoS system monitoring air temperatures in the main living areas. This is shown in Figure 5.

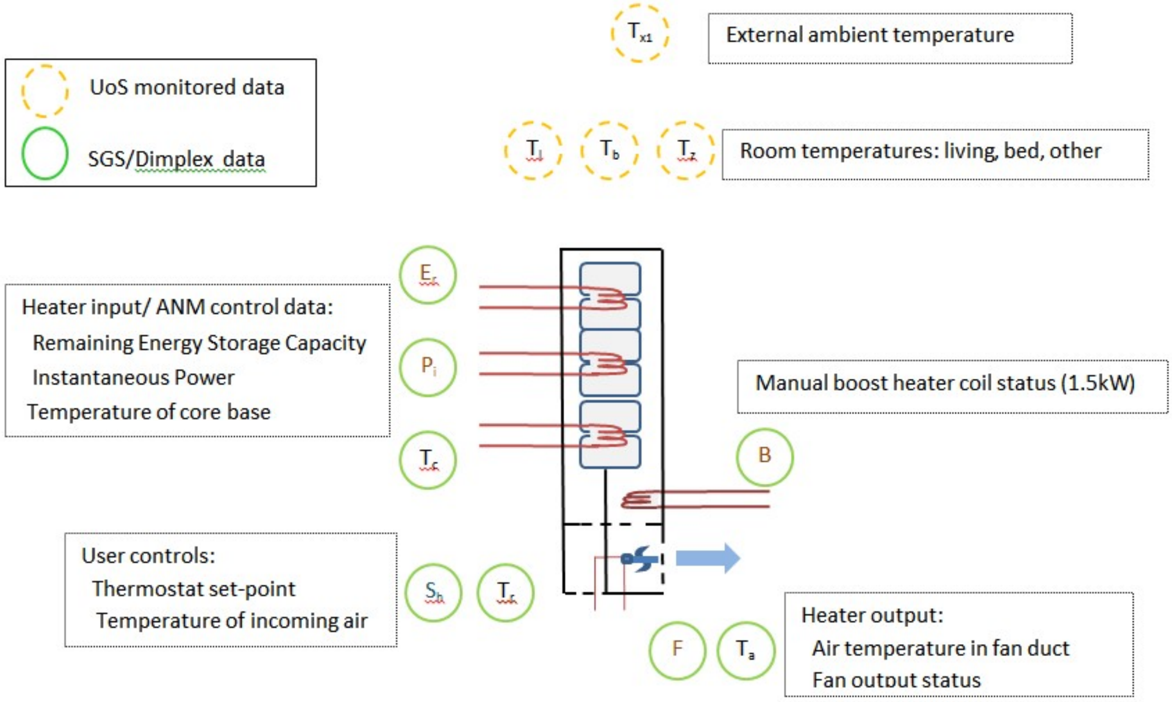

Figure 5 - *Dynamic data collection from storage heaters*

For the hot water cylinders energy input is monitored by the SGS system; with energy output and hot water temperatures measured by the UoS system. This is shown in Figure 6.

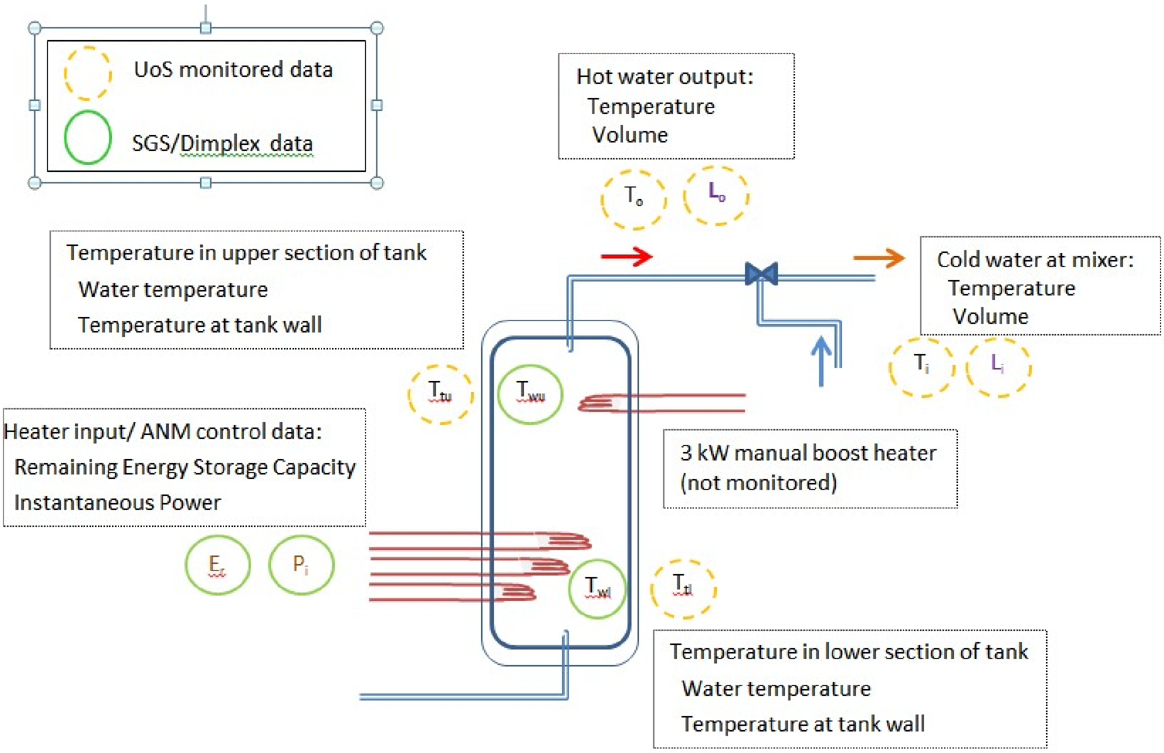

Figure 6 - *Dynamic data collection from hot water cylinders*

4.4.6 Data Logging

All data points from the SGS system were instantaneous measurements at 1-minute intervals. Time stamps show local time. Core dynamic data used consists of heater input Instantaneous Power (Pi) and Remaining Energy Storage Capacity (Er), which was calculated by the Device Controller based on measured temperature. For the UoS System, temperature measurements were instantaneous with air sampled at 1-minute and water at 2-minute intervals. Flow volumes were integrated over 5 minutes. Time stamps show GMT. Data was not captured while the logger was being downloaded. Data logging was in SGS' Glasgow office, and data was transferred monthly to a secure UoS Sharepoint site as csv files.

Storage Heaters

In the storage heaters, the temperature was measured by a sensor at the base of the core (Tc). The maximum allowable temperature of 190•C at the base corresponds to around 600•C within the core itself. Additional sensors monitored heater output by means of the fan output status (F) and the air temperature in the fan duct (Ta); laboratory performance tests carried out by Glen Dimplex established the relationship between fan duct temperature and output power. The status of the boost circuit was also monitored (B); in this case, the input and output power are equal at 1.5kW.

Heater thermostats measure room air temperature (Tr). The user interface setting (Sh) was also monitored: settings 1- 8 corresponding to a range 12-26° C.

Hot Water Cylinders

A more limited range of sensors are built in to the hot water cylinders. Core dynamic data was the same as the storage heaters, but in this case Er is calculated based on the average of the water temperatures measured by sensors attached to the upper, 3kW boost element (Twu) and the central controllable element (Twl). The boost operation was not monitored for the hot water cylinder.

Static Data and Communications Watchdog

Static data about each device was also included in the data stream: rated power (R); maximum energy storage capacity (Emax); Load Set Point - the scheduled charge level – (Rc); as well as information about whether Active Control was operating and its setting. Communications watchdogs recorded whether device-to-LIC and LIC-to-central communications were working. Two-way communication was scheduled to take place every minute.

4.4.7 Additional Measurement Points

Following the storage heater installation and an initial period of data assessment, Glen Dimplex proposed the introduction of additional measurement points (MODBUS registers) that would increase system control, allow for a better response to customer feedback and meet some of the UoS monitoring aims. These are shown in Table 11.

Table 11 - *Additional Measurement Points*

Additional Modbus Register	Function
User Setpoint Storage	Minimum core temperature permitted.
Max Core Temperature	Maximum core temperature permitted.
Average Ambient Temperature	Average outside temperature. May be used to determine max core temperature.
Water Temperature 2	Additional temperature measurement in water cylinder to improve accuracy.
Room Temperature	Measured in the storage heater.
User Interface Setpoint	Setting on storage heater user interface.
Fan Status	Data point captures if fan is operating.
Boost Status	Data point captures is boost is in operation.

This upgrade involved a number of changes to the LIC code and therefore it was necessary to perform a complete test of the system functionality before the updated code was deployed. The system testing was comprised of three stages: checking that the LIC is installed correctly and operating as required; checking the functionality of the communications link between the test room and the SGS central interface; and performing a functional test of the LIC code.

The initial system testing was carried out at SGS offices (Test A) followed by a second test in conjunction with Glen Dimplex at the SHEPD facility in Perth (Test B) in February 2012. The results of these tests are documented in Tables 12–14. Further Factory Acceptance Tests (FAT) have been defined in Table 15 to repeat tests which failed the initial FAT.

Figure 7- *SGS Smart Grid Engineer inspects code on the Programmable Logic Controller*

Table 12 - *Update LIC Installation and Commissioning Tests*

Test#	Purpose	Description	Comments	Pass or Fail	
1	Check installation of PLC has been carried out correctly	Review the PLC connections including the power source and communication cable to device controller		A	P
				B	P
2	Verify operation of PLC hardware	Power on the PLC and view the custom HMI screen to confirm LIC programme is loaded		A	P
				B	P
3	Verify data is being *written* to Device Controller Modbus register addresses correctly	Connect to the PLC from laptop running RSLogix 500 and review feedback data (as per Appendix B)		A	P
				B	P
4	Verify data is being *read* from Device Controller Modbus register addresses correctly	Connect to the PLC from laptop running RSLogix 500 and review data register values (as per Appendix B)	Immersion heater device controller does not provide a register to read the watchdog value.	A	F
				B	F
5	Confirm the correct values are stored in the PLC data files	Use Appendix B to confirm the correct day ahead schedule, droop values etc		A	P
				B	P
6	Confirm the PLC recovers correctly from a restart or abrupt power loss	Power off the PLC and power back on after a 5-second delay. Confirm that communications are re-established		A	P
				B	P
7	Confirm the PLC recovers correctly from loss of communication with the Device Controller	Disconnect the communication link between the LIC and the Device Controller. Restore the link and verify operation		A	P
				B	P
8	Confirm that the correct time is configured on the PLC real time clock	Use the Remote Run function to view the RTC settings on the PLC		A	P
				B	P

Table 13 - *Update Communication Link Tests*

Test #	Purpose	Description	Comments	Pass or Fail	
1	Confirm the correct installation of the GPRS router and the communication link to the LIC	Check the router power supply is connected appropriately. Ensure Ethernet cable is connected from LIC to the appropriate port of the router		A	**N/A**
				B	**P**
2	Confirm that router is able to receive a secure GPRS signal	Look at the GPRS module plugged into the router. Confirm a permanent non-flashing blue LED is present		A	**N/A**
				B	**P**
3	Confirm that the IPSec tunnel is established between the router in the SGS office and each remote router	Use a command prompt window to ping the address of the router and view the ping statistics		A	**N/A**
				B	**P**
4	Confirm visibility of the LIC from the Central Interface	Use RSLinx to browse the LIC and. confirm it is online		A	**N/A**
				B	**P**
5	Confirm LIC data can be monitored using RSLinx	Check the "Data Monitor Tool" can read PLC data registers		A	**P**
				B	**P**
5	Confirm LIC data can be monitored using RSLinx	Check the "Data Monitor Tool" can read PLC data registers		A	**N/A**
				B	**P**
6	Confirm that remote user can go online with PLCs. Make amendments to the code and register values	Using RS Logix500, go online with each PLC, amend a single data point and then return to original value		A	**N/A**
				B	**P**
7	Confirm that data can be logged into an SQL database and stored historically	Use Factory Talk Transaction Manager to populate an SQL data base with live operating parameters		A	**N/A**
				B	**P**

Table 14 - *Update LIC Functional Test Checklist*

Test #	Purpose	Description	Comments	Pass or Fail	
1	To confirm that all configurable data has an available memory location within the LIC to accept programmed changes	Configurable operational parameters are changed by changing register values within the PLC, it must be confirmed all of these are available		A	P
				B	P
2	To confirm that all data and configurable values stored in the LIC are mapped correctly to the required locations, ready to be sent to the device controller	The configurable operational parameters described above are used in several locations throughout the LIC code and must be distributed accordingly		A	P
				B	P
3	To confirm that the values stored within data file N26 represent the correct operational characteristics and charging schedules agreed with SSE	The values within N26 store the static and dynamic operational parameters that the LIC sends to Device Controllers. These values can be updated remotely but must match what has been agreed with SSE at the time of installation		A	P
				B	P
4	To confirm that all 'write' message functions send the correct data to the appropriate Modbus register addresses	The LIC will write operational parameters to a number of device controllers over a multidrop RS485 link and the successful execution of the write commands must be confirmed		A	P
				B	P
5	To confirm that all 'read' message functions are reading the correct Modbus register addresses	The LIC will read operational parameters from a number of device controllers over a multidrop RS485 link and the successful execution of the read commands must be confirmed		A	P
				B	P
6	To confirm that when communications between the LIC and the Central Controller are removed that the LIC enters a failsafe state	A watchdog value will be maintained between the LIC and the Central Controller. If this watchdog fails then the LIC should enter a failsafe mode and issue default operational parameters to Device Controllers		A	P
				B	P
7	To confirm that upon return of communications between the LIC and the Central Controller that normal operation is resumed	If the watchdog value between the LIC and the Central Controller recommences then the LIC should return to normal DSM operation		A	P
				B	P

Table 15 - *Update LIC Functional Test Checklist (continued)*

Test #	Purpose	Description	Comments	Pass or Fail	
8	To confirm that when an active setpoint operational signal is set that the active setpoint takes precedence over the day ahead schedule	By viewing the adjusted setpoint value within the LIC code it should be possible to determine if the active setpoint is used at the appropriate time		A	**P**
				B	**P**
9	To confirm that the active setpoint operational signal is cleared when communications between the Central Controller and the LIC are lost	By deliberately failing communications between the LIC and the Central Controller it can be seen if the LIC reverts to the (default) day ahead charging schedules		A	**P**
				B	**P**
10	To confirm that when communications between the LIC and the device controller are lost that the Device Controller WDT failure flag is set and seen at the central controller	By deliberately failing communications between the LIC and a device controller it will be possible to confirm the watchdog error flag is operating correctly		A	**P**
				B	**P**
11	To confirm that the LIC code can be updated over the GPRS/GSM communications link	Using a replica router within SGS offices, a LIC was reprogrammed with the latest code base using the GPRS/GSM network		A	**N/A**
				B	**P**
12	To confirm that the LIC can receive an updated date/time from the Central Controller	Using the Rockwell Software clock update tool the LIC date/time will be updated to match that of the Central Controller		A	**N/A**
				B	**P**

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Table 16 - *Update LIC Functional Test Checklist (continued)*

Test #	Purpose	Description	Comments	Pass or Fail	
13	To confirm that the LIC returns to normal operation after a complete power failure	By failing and returning the power to the LIC it can be observed if normal operation of the LIC is resumed		A	P
				B	P
14	Confirm that the requested set-point is followed by the device controller.	Using the "Active Set-point" function, modify the set-point and check that both the storage heater and immersion heater controllers adjust their output power accordingly.		A	P
				B	P
15	Confirm that the upper set-point limit has overriding control of the device controller.	Set the upper set-point limit to zero for all DCs and ensure that the heater power consumption falls to zero. Restore the upper set-point limit to 100% and observe the heaters becoming operational again.		A	P
				B	P

A repeat Factory Acceptance Test was carried out on items which failed the initial test.

Table 17 - *Update: Repeat Factory Acceptance Testing*

Test#	Purpose	Description	Comments	Pass or Fail
1	To determine that the Immersion Heater Device Controller Watchdog read register has been implemented.	No watchdog read Modbus register was provided on the immersion heater DC. This test ensures that the register is now available and that the IH watchdog status is being reported correctly by the LIC.		P
2	To determine that the user interface set-point is being reported correctly by the storage heater device controller.	The storage heater device controller was incorrectly reporting the UI set-point under certain conditions. This test ensures that the value is now correctly recorded by the LIC.		P

Site Acceptance Testing

The Site Acceptance Tests were a reduced set of test cases carried out when the code was updated on the LICs installed in the six homes. The purpose of these tests was to ensure that each installed LIC functioned correctly after the code update.

Table 18 - *Update Site Acceptance Test*

Test #	Purpose	Description	Comments	Pass or Fail	
1	To confirm that the LIC is talking to each associated device controller	Viewing the WDT counter for each Device Controller will confirm health of communications		1	P
				2	P
				3	P
				4	P
				5	P
				6	P
2	To confirm that the LIC is configured for the correct number of storage heaters	Change the register value within the LIC to match the number of connected heaters.		1	P
				2	P
				3	P
				4	P
				5	P
				6	P
3	To confirm that the LIC is programmed with the correct date and time	While online to the LIC, viewing the RTC will confirm the date and time currently stored	Times were incorrect by up to 15 minutes in some PLCs. The correct time was programmed during the installation visit.	1	P
				2	P
				3	P
				4	P
				5	P
				6	P
4	To confirm that the LIC is communicating with the Central Interface	A check from the Central Interface in Glasgow will be completed after the update of each LIC. Also check "ANM" indication on LIC display.	Upon completion of installation, all homes were connected to the Central Interface.	1	P
				2	P
				3	P
				4	P
				5	P
				6	P
5	To confirm that the LIC is communicating with the connected device controllers.	Observe device controller connections on LIC display.		1	P
				2	P
				3	P
				4	P
				5	P
				6	P
6	To confirm that all 'read' message functions are reading the correct Modbus register addresses	View the associated data register locations and ensure appropriate data is read and passed to correct locations	MODBUS communication initially failed when carrying out some tests but this was rectified by re-programming the Dimplex storage heater DSM boards.	1	P
				2	P
				3	P
				4	P
				5	P
				6	P

Table 19 - *Update Site Acceptance Test (continued)*

Test #	Purpose	Description	Comments	Pass or Fail	
7	To confirm that all 'write' message functions are executing correctly	View ladder logic in remote run mode and verify all write commands are executing by viewing the 'DN' message flag		1	P
				2	P
				3	P
				4	P
				5	P
				6	P
8	Confirm the PLC recovers correctly from a restart or abrupt power loss	Power off the PLC and power back on after a 5-second delay. Confirm that communications are successfully re-established		1	P
				2	P
				3	P
				4	P
				5	P
				6	P
9	Confirm the PLC recovers from loss of communications with the Device Controller	Disconnect the communication link between the LIC and the Device Controller. Restore the link and verify operation		1	P
				2	P
				3	P
				4	P
				5	P
				6	P
10	Confirm that the PLC can communicate with the central interface	Attempt to go online with the PLC from the central interface.		1	P
				2	P
				3	P
				4	P
				5	P
				6	P
11	Confirm that the central interface can read data from the PLC	Confirm that the PLC registers that are updated from the Device Controller can be read on the Central Interface.		1	P
				2	P
				3	P
				4	P
				5	P
				6	P
12	Ensure that the central interface can modify values on the PLC	Modify a configurable value and confirm that the data is updated on the PLC and on the Device Controller.		1	P
				2	P
				3	P
				4	P
				5	P
				6	P

4.4.8 Frequency Response Testing

The communications equipment installed was limited to data logging at one minute intervals. As frequency events often last only a few seconds and the initial response required is sub second, a specialist power quality monitor was procured and a frequency response test plan devised. This can be found at Appendix VI. Outcomes of the testing are discussed in Section 5.2.4.

4.5 Understanding of Customer Perceptions

4.5.1 Methodology

Evaluations of the tenants' perceptions of the trial were carried out in November 2011 via a tenant questionnaire compiled by SHEPD (Appendix VII). The questionnaire consisted of 22 questions, broken into four sections, related to the tenants' experience of the trial prior to installation; the installation process; using their new hot water and energy store heaters; and a section for any additional information they wished to provide. In May 2012, qualitative interviews were also carried out with tenants to assess whether their assessment of the new heating systems had changed and to find out whether the trial had influenced their attitudes and perceptions of energy use.

In one of the properties the tenants took part in a house swap and were therefore replaced by a new tenant. The original tenants were however included in both the questionnaires and the interviews.

5 The outcomes of the Project

Section 5 details the outcomes of the project. A summary is provided in Section 5.6.

5.1 Integration of DDSM Components

Testing has demonstrated the successful integration of DDSM components. The project has advanced the TRL level from 6 to 7, as an actual system prototype has been demonstrated in a working environment.

Control of the heaters was implemented through a daily schedule comprising 96 15-minute blocks stored on the SGS LIC under programmable logic controller (PLC) memory maps. A default schedule could also be stored. Every 15 minutes the corresponding load setpoint was sent to the device controller.

SGS demonstrated the ability to: remotely update schedules; over-ride the schedule with an active set point; and update frequency response characteristics in real time from the Central Interface to the LIC.

Data was retrieved from the Dimplex Controllers via the LIC and into a remote historical recording system. Data was sent to SHEPD – and later UoS – on a monthly basis as CSV files. This data forms the basis of analysis carried out by the University of Strathclyde's Energy Systems Research Unit and is detailed in Section 5.2.2. The University of Strathclyde used this data to analyse the performance of the DDSM system to assess the extent to which the heaters and cylinders have behaved as expected during this trial. The purpose of this analysis was to identify system refinements which may be needed and provide an initial assessment of the energy efficiency and storage capabilities of the devices. While the sample size is too small to draw statistically significant conclusions, the analysis provides useful indicative findings.

This will input to further academic work on modelling household energy use to forecast customer demand. For NINES, the University of Strathclyde will create a 'Demand Forecasting' model to estimate flexible heat demand for the system and establish constraints relating to end user amenity through high resolution end use heat flow models. Data from the trial evaluation of DDSM will be used in an initial calibration of this model.

5.2 DDSM System Performance

5.2.1 Data Quality

Data is transmitted from the LIC to the Central Interface every minute. Data cannot be logged to memory in the home therefore availability of data depends on an unbroken communications path, otherwise data for that minute is lost. An exercise to calculate the percentage of data available from each home was carried out covering the period April 2011 – March 2012.

Table 20 - *Percentage of data available for each of the Six Homes for the year 2011-12*

Year 2011/12	Home 1	Home 2	Home 3	Home 4	Home 5	Home 6
% Data Available	27.1%	35.6%	49.7%	55.9%	55.6%	21.3%

A proportion of this down time can be attributed to periods where software upgrades were carried out and data logging by SGS ceased. The most notable of these occurred following the storage heater installation in June 2011 whereby several modifications to code were required by Glen Dimplex.

However, even accounting for this planned downtime, there were significant periods of lost data. While this has not prevented data analysis, the data availability figures (summarised above) prompted an investigation into the reliability of the communications infrastructure. The communications infrastructure installed for the Six Home Trial relies upon Vodafone GPRS networks and Cisco routers. Analysis revealed the comms infrastructure which had been put in place for immediate functionality was not fit for purpose for the following reasons:

1. The system is not designed for communication to be initiated from the central end. In normal operation the remote routers would set up a call and receive a dynamic IP address from Vodafone.

2. As data needs to be collected from the homes as it is generated, the communication links need to be available 24 hours a day. The solution as built does not support this; instead, attempting, and often failing, to initiate communications as required.

3. As both of the above were necessary, the system had to be jury-rigged using Cisco Easy VPN. This ensured the remote end received a static IP address that would hence enable the central end to initiate comms to each remote site (Vodafone do not provide static IP's on their GPRS network).

4. The system as configured had problems with the IPSec sessions hanging so a fix was implemented to force the sessions to reset every hour in case they became inactive.

5. The system is not manageable from the existing SSE Telecoms management systems and as a result SHEPD do not have any real time information on how it is behaving.

A combined solution of on site dataloggers and a connection via IPStream (similar to conventional ADSL) was put forward as a resolution. However, the University of Strathclyde indicated that it would be too late for new data to feed into their modelling outputs – for the initial phase of an Active Network Management deployment – and SHEPD had been successful in proving the integration of the technologies in line with the project's aims. The cost benefit of the solution was not appropriate therefore no combative action was taken. However, important lessons have been learned; and future projects specifying a communications solution will have to fulfil functional and non functional requirements.

5.2.2 Operation and Performance

How do the storage heaters compare to those they replaced?

The new heaters are designed to be more efficient than existing models, with better heat retention and output control. A comparison of their draft technical specifications with those of Glen Dimplex's currently marketed range is presented below.

The new storage heaters in the trial houses have similar power ratings to those they replaced. The larger version (P125) replaced the Dimplex CXL18 model in the living rooms: 2.4 kW for a new heater compared to 2.55 kW. The smaller heater (P100) replaces the previous XL12 model in the hall and also in the kitchen area of house 2. The new heaters are rated at 1.95 kW compared to 1.7 kW previously.

Regarding insulation, the new heaters have at least 2.5 times the amount of insulation material as those they replace (assuming the bricks in the core are no wider). The insulation, comprising micro-porous silica aero gel and calcium silicate is of a higher specification. These materials have a thermal conductivity 35% lower than their counterparts in the old heaters. Since no information is given on how these materials are used, or on the comparative size of the feolite bricks in the core, it is not possible to quantify precisely how much more insulated the new heaters are although a factor of 2.5 times greater is considered reasonable.

How do the hot water cylinders compare to those they replaced?

The new cylinders are unvented, so water temperatures of up to 90•C are possible rather than the 55-60•C limit for the previous, vented cylinders – the same size of unvented cylinder can hold 60-70% more thermal energy. The new cylinders are marginally larger than those they replaced. The power rating is now slightly lower than previously installed – 2.625 kW rather than 3 kW.

The quoted standing losses in the new cylinders are the same as those in Glen Dimplex's currently marketed range of pressurised unvented cylinders: 1.41 kWh/day for the larger cylinder, and 1.21 kWh/day for the smaller one[5]. These are based on laboratory measurements of the power required to maintain a constant, stable water temperature of 65•C in an environment with a constant air temperature of 20•C[6]. Therefore, the quoted standing losses are around 11% of the energy required to bring a full tank from a mains average temperature of 10•C up to 65•C.

How long do heaters take to heat up from cold, and to cool down from hot?

Laboratory tests carried out by Glen Dimplex show that 7 hours charging at full power from cold raises the core temperature of the smaller heater (P100) to 590•C, and that of the larger heater (P125) to 620•C. Within the SGS monitoring scheme, the core temperature is not measured directly but via a thermistor at the base of the thermal storage bricks; the equivalent measured 'core temperatures' are 165•C for the P100 and 175•C for the P125.

Performance test data for passive discharging without fan operation indicates that the heaters can continue to emit heat for over a day, with the larger heater discharging more slowly than the smaller one.

§ The P125 loses 258•C over 20.5 hours at which time it is still emitting 270 W. Based on the rate of loss in the last 4 hours, it would take a further 30 hours to discharge to 100•C, which is the lowest actual core temperature that can be detected by the sensor at the base of the storage bricks.

§ The P100 loses 217•C over 15.8 hours at which time it is still emitting 230 W. Based on the rate of loss in the last 4 hours, it would take a further 29 hours to discharge to 100•C.

Do heaters switch on and off as instructed?

An issue of fundamental importance for the successful operation of an ANM system is that the DDSM devices should switch on and off when instructed to do so by the central interface, except occasionally

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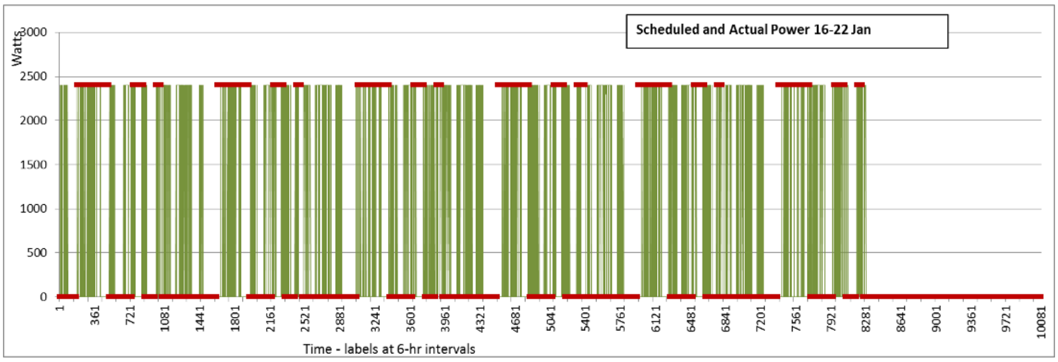
[5] *Glen Dimplex, Draft Technical Specification for Dimplex Appliances NINES Installation, 11 August 2012*

[6] *BS EN 12897:2006: Water supply- Specification for indirectly heated unvented (closed) storage water heaters*

when local control takes priority because of safety or comfort considerations. From the monitoring data analysed, a local override appears to be the prime operating mode.

Figure 8 shows data for a one week period. The red bars show the scheduled load set-point, while the green lines show the actual power drawn.



House 1 Living room heater

Figure 8 - *Scheduled and actual power input - variable power heater elements*

While there are some periods where the central control is dominant, there are many occasions when the heater is drawing power at times when not commanded to do so and not drawing power at scheduled times. This is due to the control logic applied by the Dimplex Controller. Upon reaching a minimum temperature setpoint, the logic overrides the DNO control and increases the input power of the device. Similarly a device will ignore a load instruction to charge if the maximum temperature has been reached. Further work to refine this control logic is required. This will include seeking to reduce the relatively high minimum temperature setpoint without impacting customer comfort.

Two separate two-day periods in house 4 are presented in Figure 9. The red lines represent the commands initiated via active control, the green lines the actual power input to the water cylinder, and the purple dots the remaining energy storage capacity as calculated by the heater controller. As can be seen the heater starts to draw power when commanded to do so. At this time, however, the cylinder is almost fully charged so the actual power draw is less than that scheduled. Then, when the water temperature falls below the setting of 55•C, there is an immediate call for power which overrides both the day-ahead schedule and active control directive.

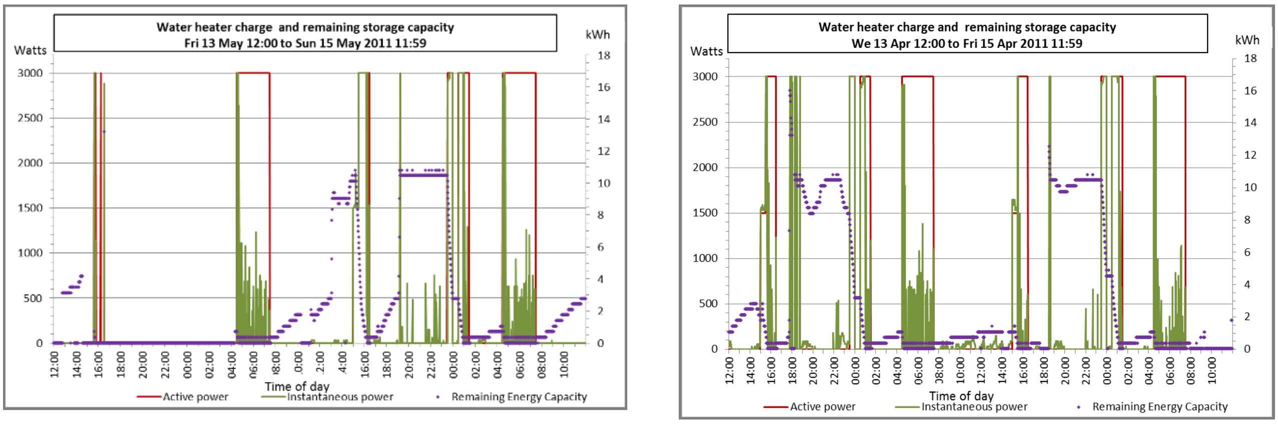


Figure 9 - *Active control operational in House 4*

Are the heaters operating within scheduled hours?

The amount of time that the heaters charge as scheduled, charge outside schedule hours, or do not charge within schedule hours, was assessed for each heater. Figure 10 shows the operation of the water heater in house 4 over the 14 months of operation. The left hand graphs show the amount of time each week that the heaters draw power, while the right hand graphs show the energy delivered to occupants (or not drawn). Green bars indicate that the heater was charging outside the scheduled period, orange depicts scheduled load not being drawn, brown depicts the heater charging when scheduled, and grey the total amount of valid data for the week.

In the period up to June 2011 the heaters were set to charge at full capacity, so the amount of time spent charging was relatively low and the need to top up at unscheduled times was low. From August 2011 until February 2012, the water heaters could operate at low power without time constraint, so there was no opportunity for unscheduled power input. However, a high amount of the energy expected to be delivered was not in fact needed. In the last phase, when low power settings and restricted schedule hours were applied, both the time during which unscheduled load was being drawn and the amount of energy delivered increased.

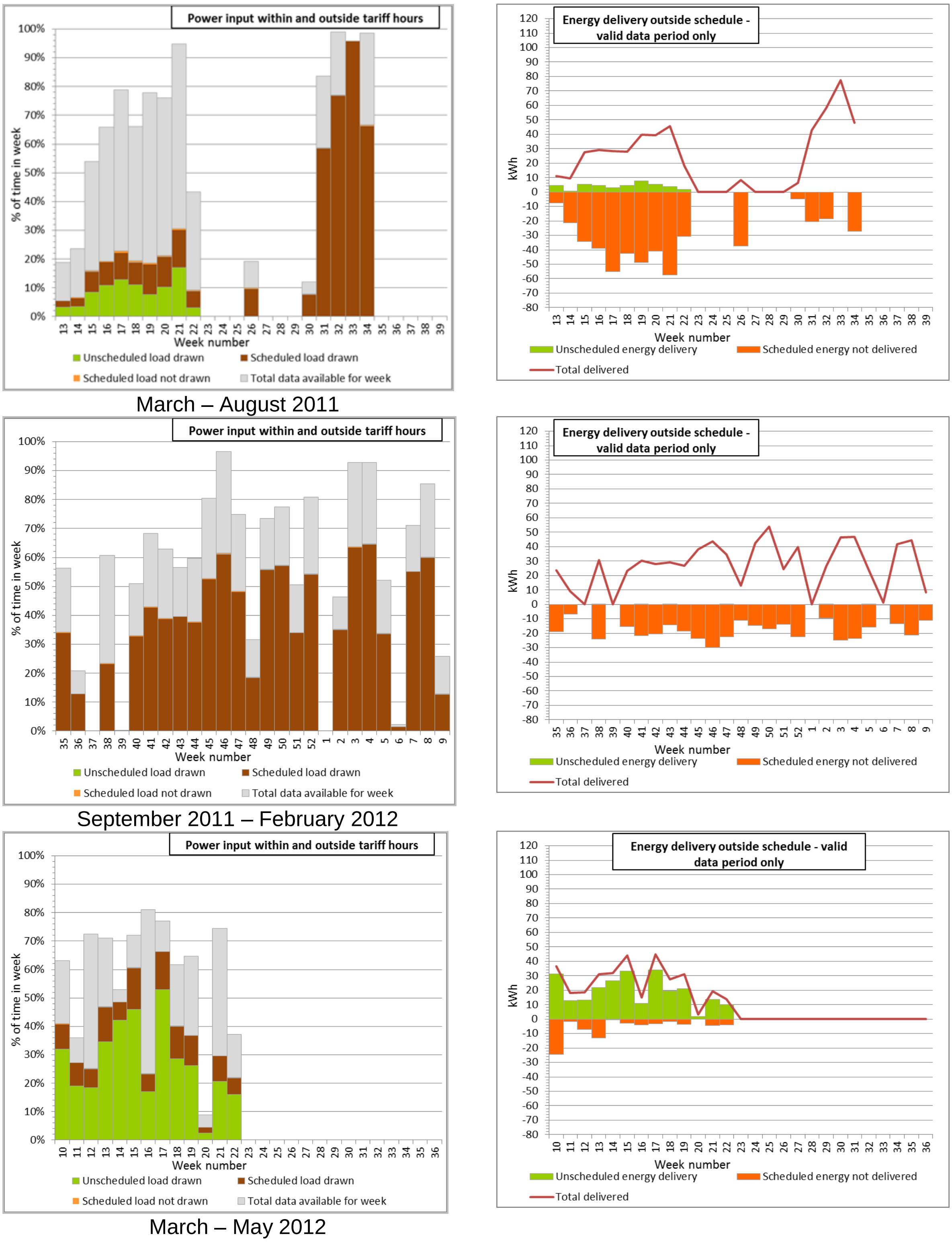
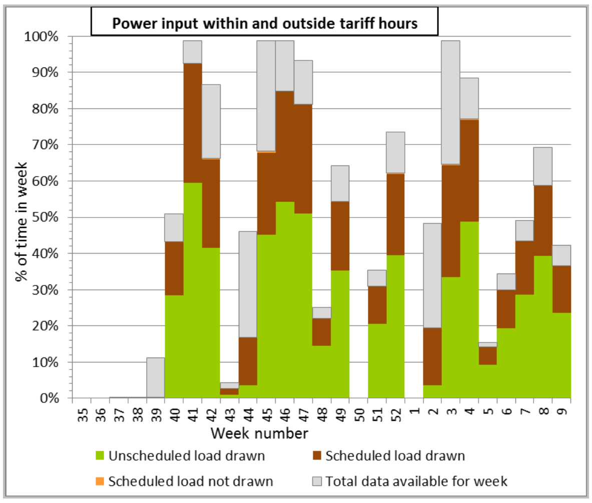
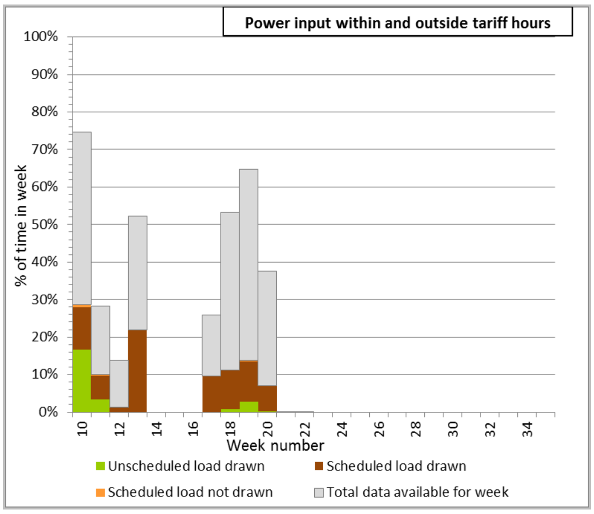


Figure 10 - *Scheduled and unscheduled power input over time, water heater in House 4*

Similar behaviour is seen with the storage heaters, although here the low power, restricted timing schedule was applied from installation. House 3, as shown in Figure 11, illustrates the pattern in all houses. It is not entirely clear why the amount of time when unscheduled load is drawn and the energy delivered both went down, although the likely cause was the introduction of adaptive control in the heater controllers, which limit the maximum permissible core temperature based on energy used the previous day.



Sep 2011-Feb 2012

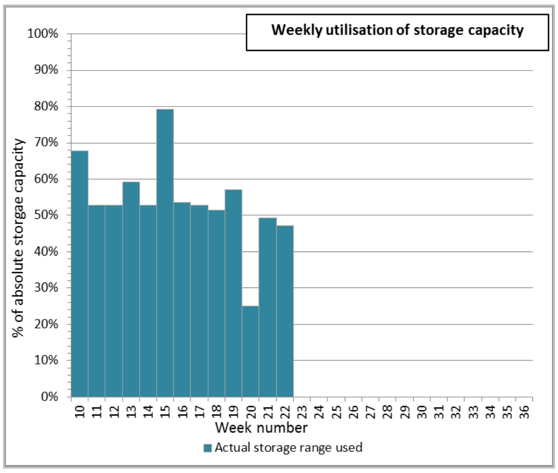


March-May 2012

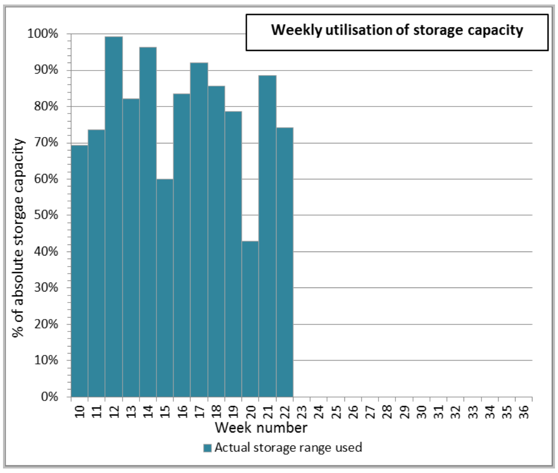
Figure 11 - *Scheduled and unscheduled power input by week, living room heater, House 3*

How much of the storage capacity is actually used?

Figure 12 shows how much of the storage capacity was used each week by two of the water cylinders. House 5 has the largest range, occasionally at 90% or more in one week.



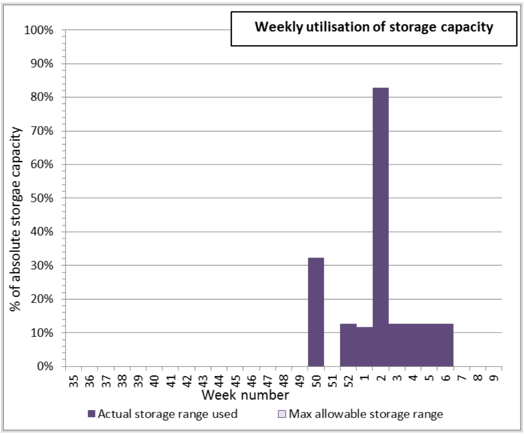
House 4, Water Cylinder



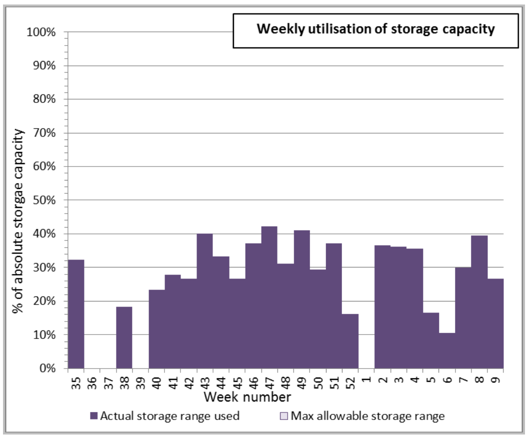
House 5 Water Cylinder

Figure 12 - *Typical utilisation of storage capacity - Hot Water Cylinders*

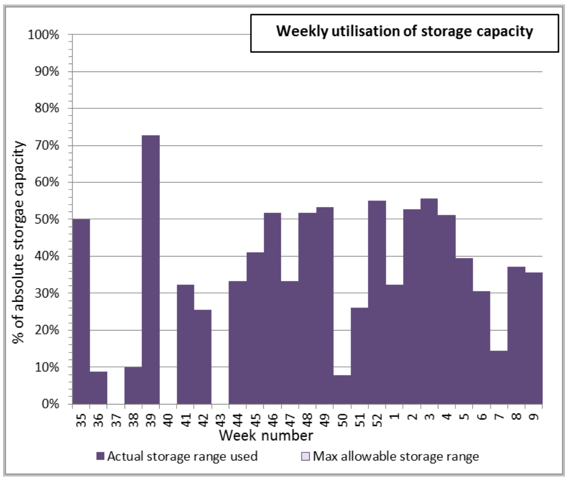
Figure 13 shows the same information for three of the storage heaters. This varies more, but on average is of lower efficacy: less than 40% utilisation is typical. However, most of the time the range is even narrower: the final graph in the series shows the weekly distribution of temperature in the core, from which it can be seen that the first and third quartile values are close to the median.



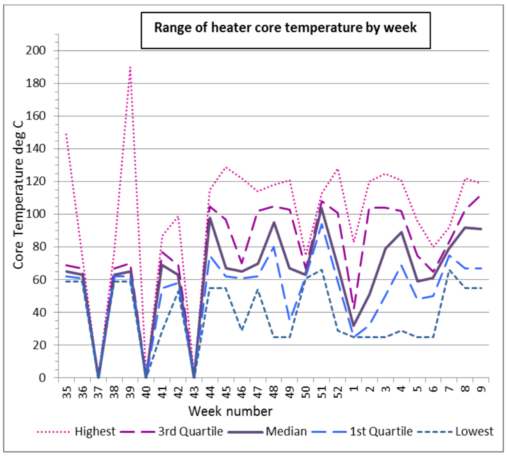
House 1, Living room



House 4, Living room



House 5, Hall



House 5, Hall, weekly distributions of core temperature

Figure 13 - *Typical utilisation of storage capacity - Storage Heaters*

How much of heater output is actively driven by the fan?

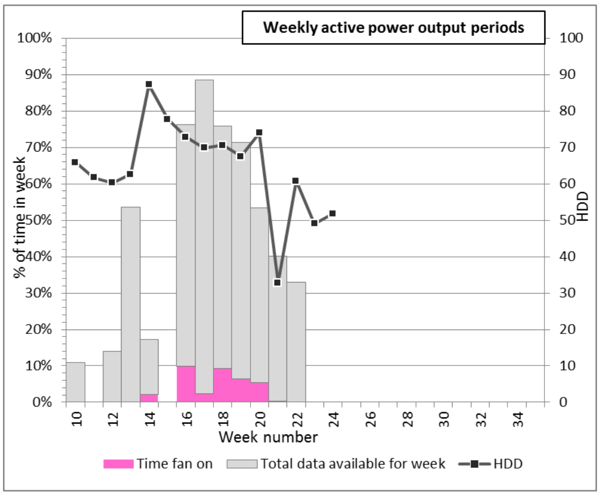
The storage heaters release operate in two modes – active output and passive output. Active output is where the fan pushes air through the core to heat it – this is triggered when the heater controller determines that the room temperature has fallen below the user interface setpoint. The larger heater can produce around 2.2 kW in active mode when fully charged and the smaller one 1.4 kW.

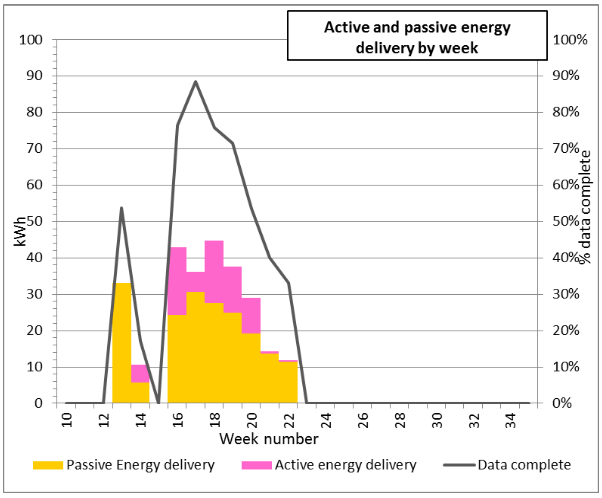
Passive output refers to the continuous, low level of power output often referred to as the standing loss. Fully charged, the larger heater emits around 450 Wh passively and the smaller one 340 Wh.

Data on energy output has been available only since March 2012 and during this period there occurred a transition from unseasonably warm weather in March to temperatures typical of mid-winter in April. Even during the cold spell, the insulated, well-sealed, timber houses obtained most of their heat via passive output.

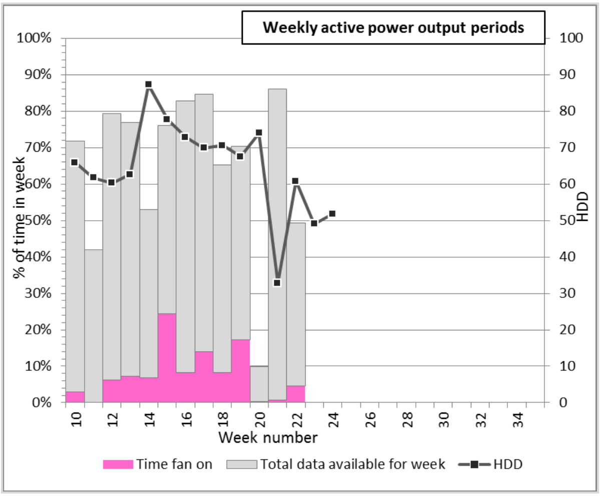
This can be seen in Figure 14, where the three pairs of graphs show the amount of time the fan was operating each week in different houses, together with the energy output from active (pink) and passive (yellow) heater output (for the valid data set only).

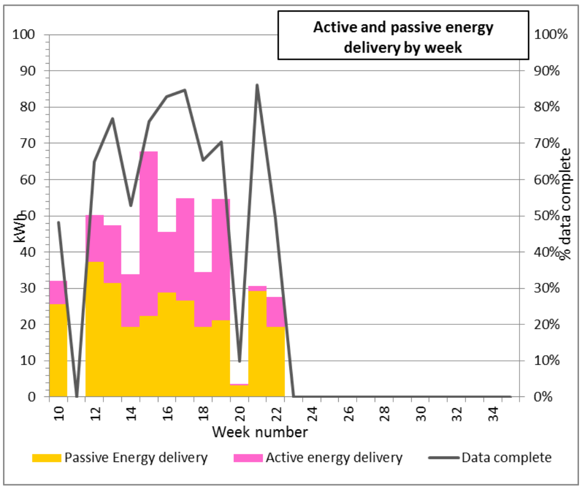
Although comparisons are difficult due to the different amounts of valid data, it can be seen that the two larger houses use more energy than the smaller flat, and that the house which is occupied most of the day calls for the highest active output.



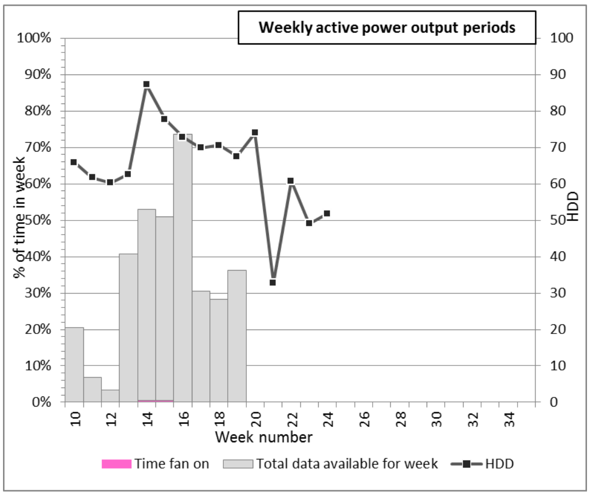


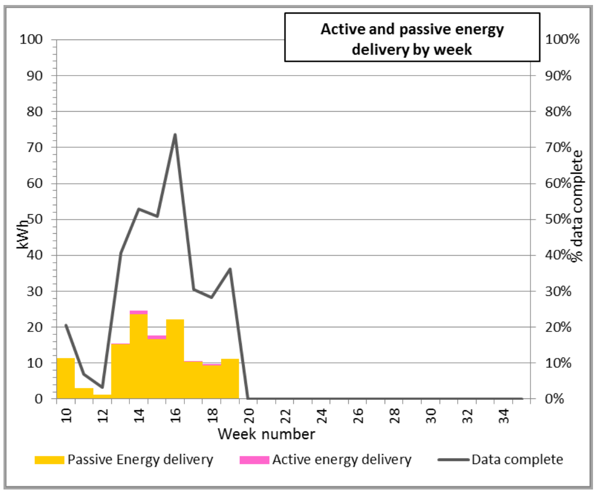
House 2: 3-bed semi, 4 occupants at work/school





House 5: 2-bed bungalow, 4 occupants at home

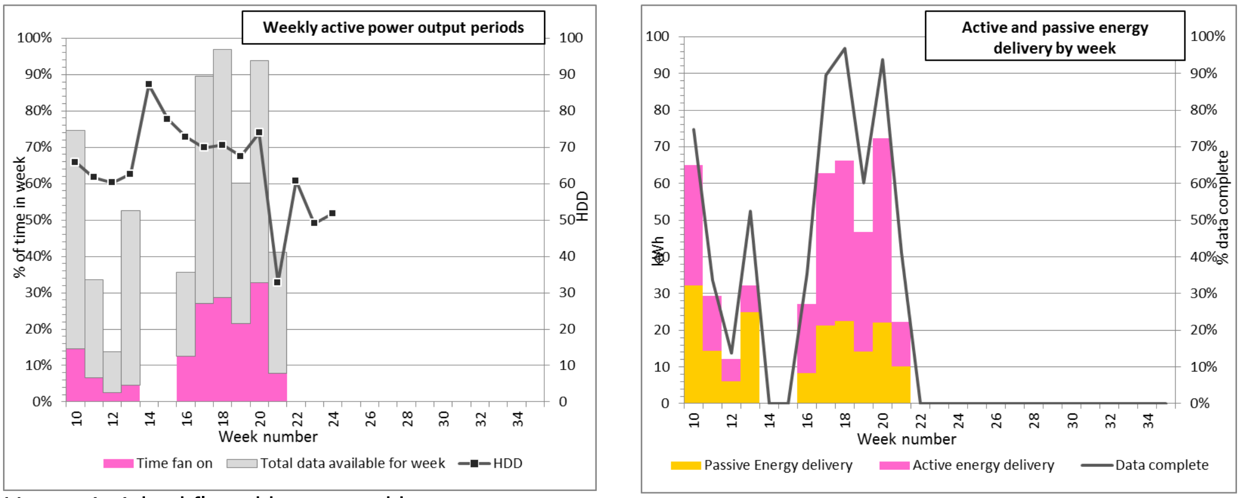




House 4: 1-bed flat, one working occupant

Figure 14 - *Fan operation and heat output from living room heaters in insulated timber houses, March-May 2012*

Figure 15 presents the same graph pairs for the renovated stone flat. This is the smallest house in the trial, is in the lower half of the distribution for room temperature, and is not occupied during the day: it does, however, require more active energy than any of the timber houses.



House 1: 1-bed flat with one working occupant

Figure 15 - *Fan operation and heat output from living room heater in renovated stone flat, March-May 2012*

In all houses, the hall heaters are providing less heat input than those located in the living room. Even with the additional insulation, these heaters are emitting between 100 W and 400 W in passive mode (depending on the heater core temperature). In these highly insulated and sealed houses, this passive output satisfies most of the heating need and there is little evidence of fan operation in any of the heaters except for the week in early April when the external temperature dropped significantly. However, this outcome is not typical for general housing stock.

How much energy is being used for hot water?

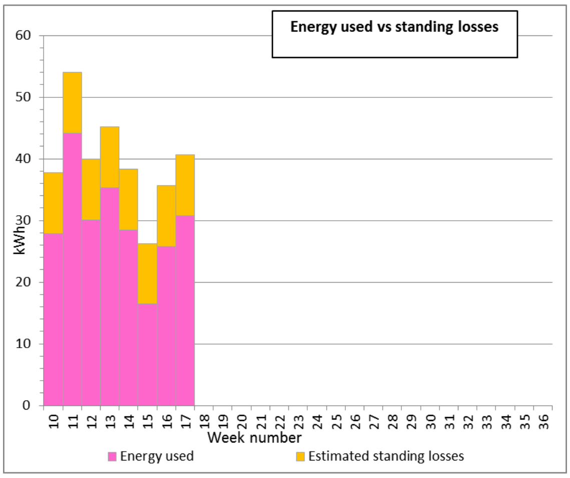
The useful energy delivered as hot water was calculated from the hot water flow volume and the temperatures of the hot water outlet and cold water inlet. An attempt was also made to estimate standing losses in situ from the fall in temperature at times when no heat was being added or extracted from the cylinder. However, this yielded different outcomes depending on which sensors were used to determine the average water temperature. This is illustrated in Table 18, which shows the apparent rate of standing loss over the same 5-hour period in House 4. The pair of sensors in the water shows a 4•C higher average tank temperature over the period than the pair of sensors on the cylinder walls. This yields an apparent standing loss of 325 W, compared to 20 W from the wall sensors. The quoted cylinder steady-state standing loss at a similar temperature is 50 W.

Table 21 - *Estimating average cylinder temperature and change in energy stored*

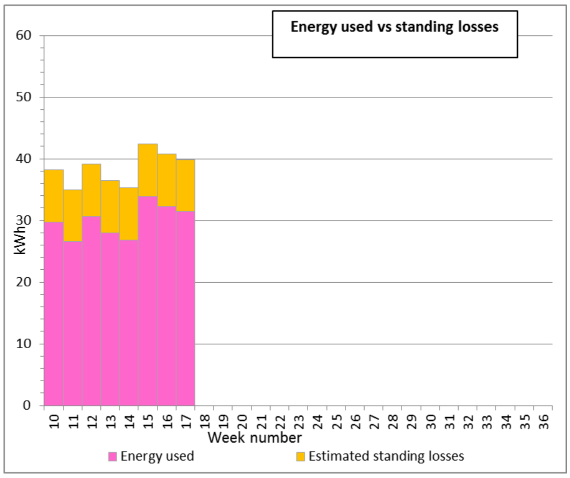
Basis for estimate	Mean Cylinder Temperature (•C)	Apparent Temperature Difference (•C)	Apparent Change In Energy Stored (Wh)	Apparent Rate of Standing Loss (W)
Mean of water sensors	71	8.5	1696	325
Mean of cylinder wall sensors	67	0.5	100	20
Mean of all 4 sensors	69	5.0	998	200
Steady state loss 1.21 kWh/day	*65*	-	-	*50*

The reason for these differences is that the lower water sensor is located too close to the heating element. The water temperature measured at the lower heating element shortly after charging is considerably higher than the temperature sensor further up the cylinder. If the amount of energy delivered is calculated from the change in average temperature using these sensors, it indicates approximately 50% more than using the actual power measurement. As the water mixes this non-existent energy is lost. A further consequence of this phenomenon is that the cylinder sensor will indicate that the maximum temperature has been reached too early therefore the cylinder will fail to charge to its maximum capacity.

Figure 16 shows the weekly energy use for two houses in March and April 2012. Data was comparable between houses because the time series data were almost complete and, where data is missing, this applies to both houses. The week-by-week variation is in line with, although not exactly the same as, that of the hot water volume. As this depiction is expressed in energy terms, the weekly consumption is not affected by the higher water temperature.



House 5 – moderate, irregular water use



House 4 – moderate, regular water use

Figure 16 - *Energy delivered as hot water, and cylinder standing losses*

Standing losses were based on the quoted daily steady-state values. This is likely to be an under-estimate for two reasons: First, the temperatures in the rooms where the cylinders are located are lower than the test setting of 20•C; and second, there are periods when the average cylinder temperature is over 75•C. The rate of standing loss is a non-linear function of the temperature difference inside and outside the cylinder so periods with higher temperature difference will make a higher contribution to the total. Even so, standing losses add another 30% to the useful energy consumed as hot water.

How have living room temperatures changed since heater installation?

In February 2011, a few months prior to the storage heater installation, a sensor was placed in each living room to record the air temperature at half hour frequency. Data was captured until May 2012 to discern whether the room temperature changed following the introduction of the new system.

able 19 shows the average living room temperature recorded during the winter. The second winter period was warmer than the first, with an average daily HDD of 11.1 during February and March 2011 and 9.2 from October 2011 to March 2012. The pattern of change appears to be that in those houses where the temperature was previously lower (houses 3, 4 and 5), there was an increase of around ~2•C after the heaters were installed, whereas in those where it had previously been high (houses 1, 2 and 6) the average temperature was 1-2•C lower in the second winter.

Table 22 - *Change in average living room air temperature during winter months*

House	Average Temperature	
	Feb-Mar 2011 (•C)	Oct 11 – Mar 2012 (•C)
1	21.6	19.4
2	24.2	22.2
3	19.7	21.7
4	17.2	18.9
5	17.1	18.9
6	21.2	20.3

However, the variation among the houses decreased noticeably with the new heaters, confirming the claim that the new heaters are more controllable. Further support for this conclusion comes from the fact that the daily temperature range in the two houses occupied by single, working people also appeared to be larger after the heaters were installed. This is illustrated in Figure 17.

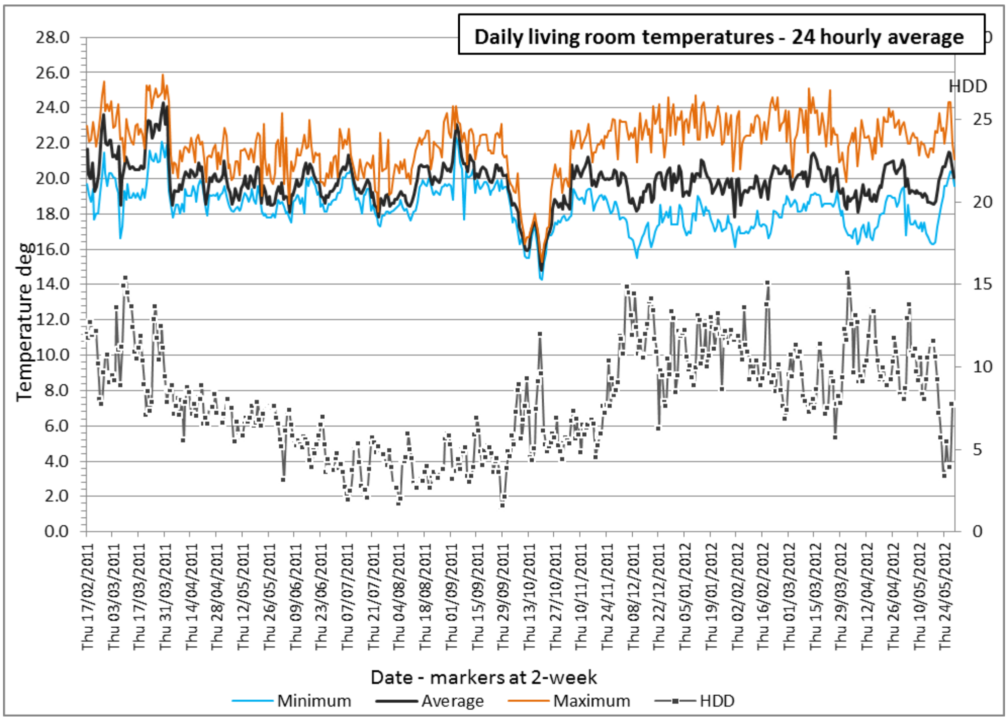
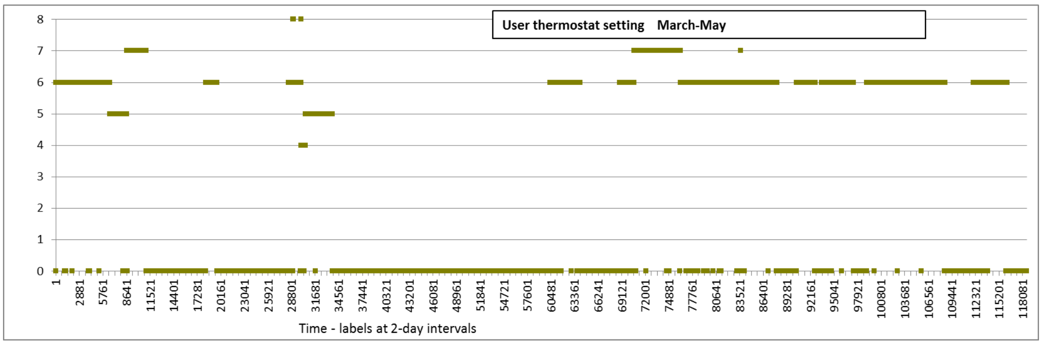


Figure 17 - *Daily variation of living room temperature, House 1*

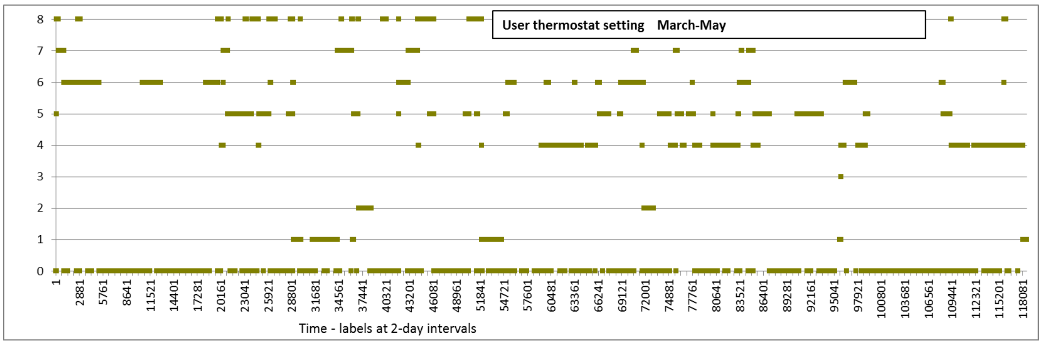
All readings show that a stable air temperature is maintained in all houses. If the average temperature is calculated for the daytime or evening periods only, there is little difference in the 24-hour average. This confirms the high, continuous passive output from the space heaters.

How do occupants use the heater thermostats?

The active output controls for the storage comprise a programmable timer and an adjustable thermostat (0-8). Occupants have different approaches to how they use this control. While House 1 uses the thermostat as intended, House 5 demonstrates the more typical case where the thermostat is adjusted manually to boost or reduce the temperature. This is apparent in a detailed examination of shorter time sequences, where the level is sometimes adjusted every half-hour. Figure 18 illustrates this behaviour.



House 1, Living room heater



House 5, Living room heater

Figure 18 - *Different approaches to using the storage heater thermostat*

What is the variation in hot water use?

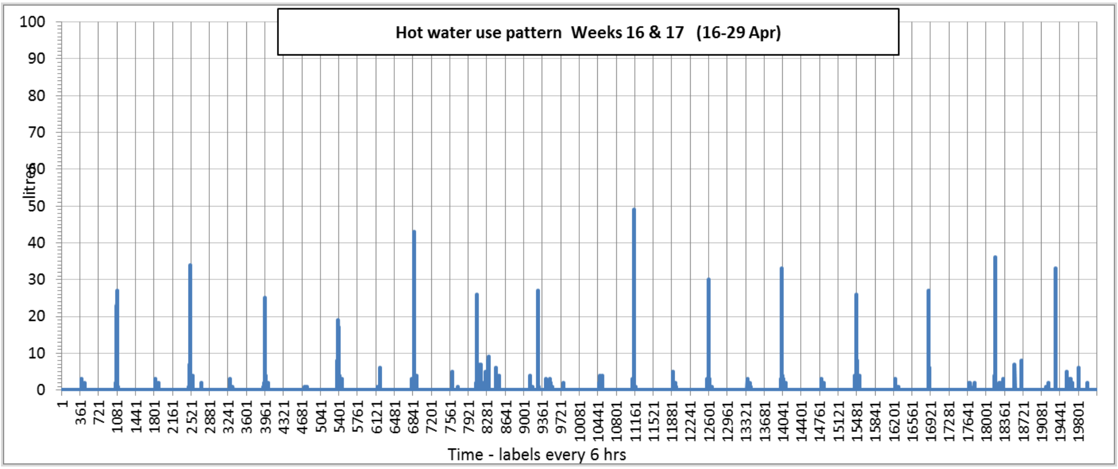
There is a wide variation in patterns of hot water use among the four houses for which most data is available. The weekly consumption ranges are shown in Table 20. Turnover within each cylinder is low, at most only 3.5 cylinders per week. This will partly be due to the higher water temperatures.

Table 23 - *Variation in weekly hot water consumption*

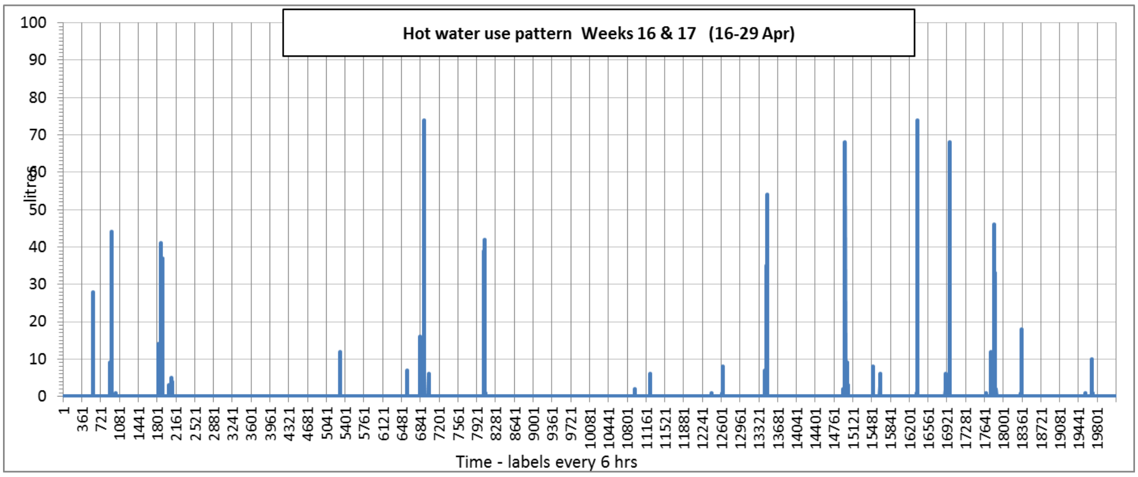
House	Occupants	Highest Weekly Daily Use	Lowest Weekly Daily Use	Tank volume
3	4	629 l	382 l	215 l
4	1	541 l	481 l	175 l
5	3	770 l	299 l	215 l
6	2	508 l	276 l	215 l

The daily hot water profiles are also different. Figure 19 shows typical two-week profiles for two houses. House 4 shows a regular daily pattern of timing and volume, while in House 5 both of these parameters are irregular and difficult to predict. The other two houses where reliable data is available fall somewhere between these two. Some hot water use has gone unrecorded at times when data was being downloaded, so the actual consumption will be slightly higher than measured.

Scottish and Southern Energy Power Distribution



House 4 – moderate, regular use



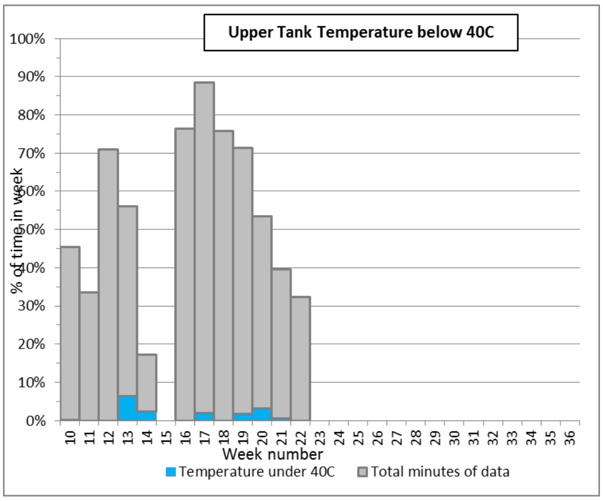
House 5 – high, irregular use

Figure 19 - *Hot water consumption profiles for two houses over 2 weeks*

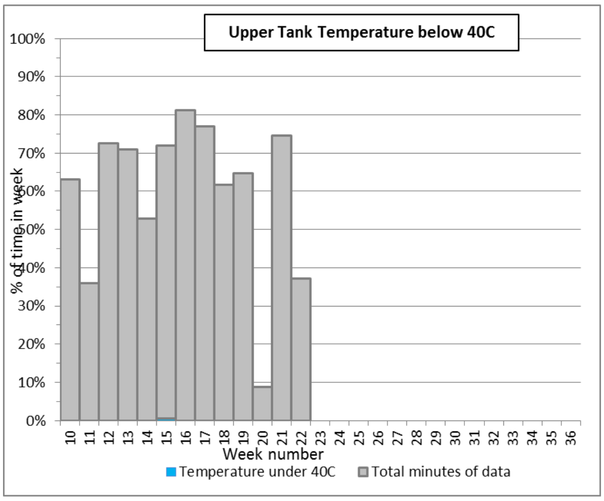
How often does hot water run out?

Since March 2012 the hot water cylinders have been operating on a restricted time schedule and at low power setting. Under these conditions, there is a possibility of hot water not being available when required. This can be quantified by examining the amount of time that the temperature in the upper part of the tank falls below 40•C, a comfortable temperature for showering. Figure 20 depicts the homes with the highest and lowest incidence of low temperatures by week. Even in House 2, which appears to use the most hot water, there is a very low probability that the occupants will not have hot water when they want it.

This is convenient for the users, and feedback interviews conducted by HHA were particularly emphatic in praising the improvements to the hot water supply. However, this improvement in amenity means that water at high temperature resides in the tanks for long periods when not required. Under the previous charging regime, if the occupants had happened to use a lot of hot water just after a scheduled charging period, they would have had to either wait for some hours for hot water or else pay extra for using the booster element.



House 2 – highest



House 4 – lowest

Figure 20 - *Hot water not available - highest and lowest occurrences*

How do heater controls impact storage effectiveness?

The heaters are designed so that their internal comfort and safety controls override commands sent from the Central Interface. It was shown that the override condition are not an exceptional situation but a regular occurrence, for both the storage and the water heaters. This has a negative impact on the predictability as well as flexibility of the system seen by the DNO. In particular, the adaptive control functionality in the storage heaters has a dominant effect especially at times when changes in the external temperture are changing the dwelling's heating requirements. A time-series showing maximum allowable core temperature is shown in Figure 21.

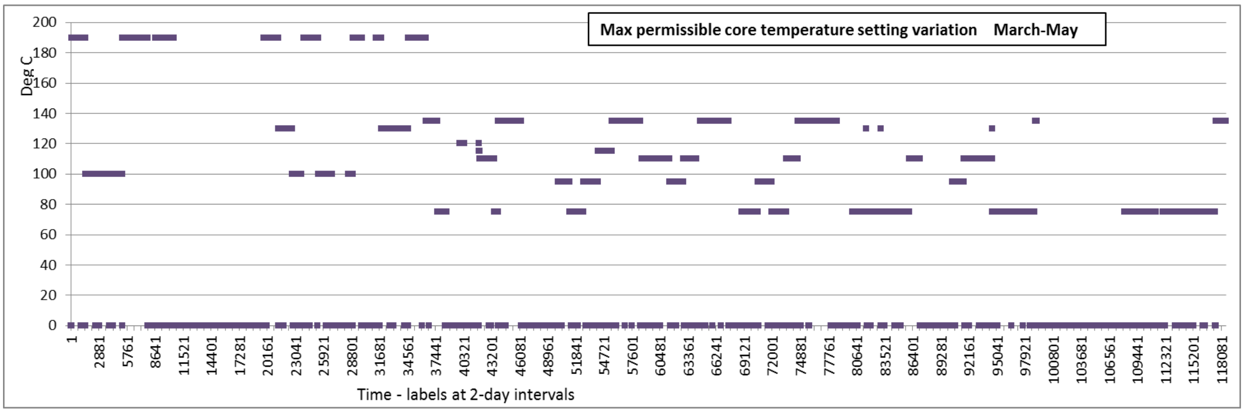


Figure 21 - *Adaptive control functionality variations in maximum allowable core temperature, House 5*

An example of how the different controls interacted with each other and with occupant behaviour to give different outcomes is shown. To fill data gaps, these figures display 5-minute average values rather than the raw 1-minute data. In House 5, the adaptive control has dictated that, at the start, the heater core is no hotter than 75•C. This is reached within the first charging period and, at that point, the maximum is re-set to 95•C. Even when the maximum is re-set to 95•C, no more energy is accepted after the first scheduled charging period.

On the second day, the room temperature is low; the occupants turn the thermostat to its maximum position and the fan comes on. This rapidly depletes the small stored heat reserve and the minimum temperature limit is reached. This sets the heater to start charging again just after the scheduled charging period is over, and now it is drawing full power rather than the pre-set level of one-third.

The cold weather continues, occupants use the thermostat actively, turning it up for short periods when they feel cold. At this point the device is operating like a panel heater, drawing directly from the network rather than from its heat store. The fan is on for much of the time, and the scheduled charge period is insufficient to build up the heat level in the core. The adaptive control mechanism raises the maximum core temperature each day in response to the increasing heat draw but this is never actually reached. This is illustrated in Figure 22.

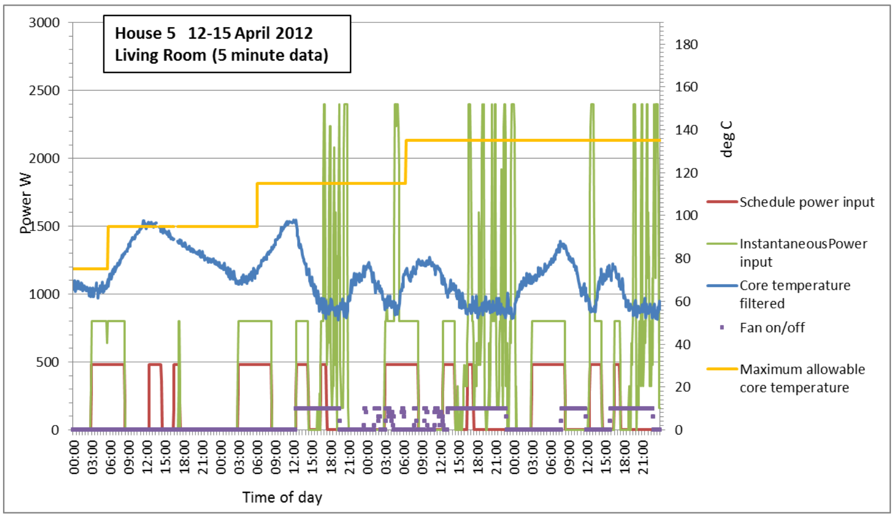


Figure 22 - *Interaction of heater and central controls over a 4-day period, House 5*

During this same period, however, House 4 continues to behave as commanded (Figure 23). In this case, the thermostat remains at a constant, medium setting so the fan does not activate so often and the adaptive control does not re-set the maximum core temperature.

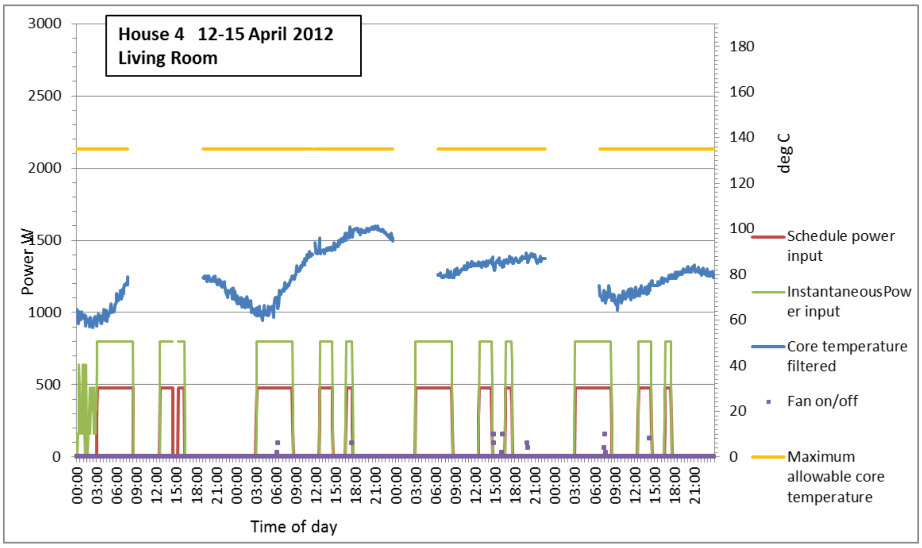


Figure 23 - *Interaction of heater and central controls over a 4-day period, House 4*

The long-term average temperatures in these two houses are similar, and they are similar in size and exposure level. The differences lie in the occupancy patterns. In House 4 the occupant is at work all day and the hot water use and room temperature fluctuations show a regular pattern. In contrast, the daily patterns in House 5 are unpredictable and it seems likely that this is driving the frequent changes in the heaters' adaptive control.

The hot water cylinders also have examples where the central controls, heater controls and occupants interact to cause problems for active network management. This can be seen in Figure 24 which illustrates a 48-hour period in House 5, during which the 10.5 kWh energy delivered was considerably less than the 15.1 kWh possible in the schedule. In addition, the majority of charging took place outside the scheduled period. The heater came on immediately after there has been a large hot water draw and then recharged itself. This is the result of the control logic operating correctly to maintain customer comfort. However rather than maintaining the minimum temperature or increasing the energy stored to a suitable minimum, the logic currently instructs the device to charge to 100% and DNO control is lost.

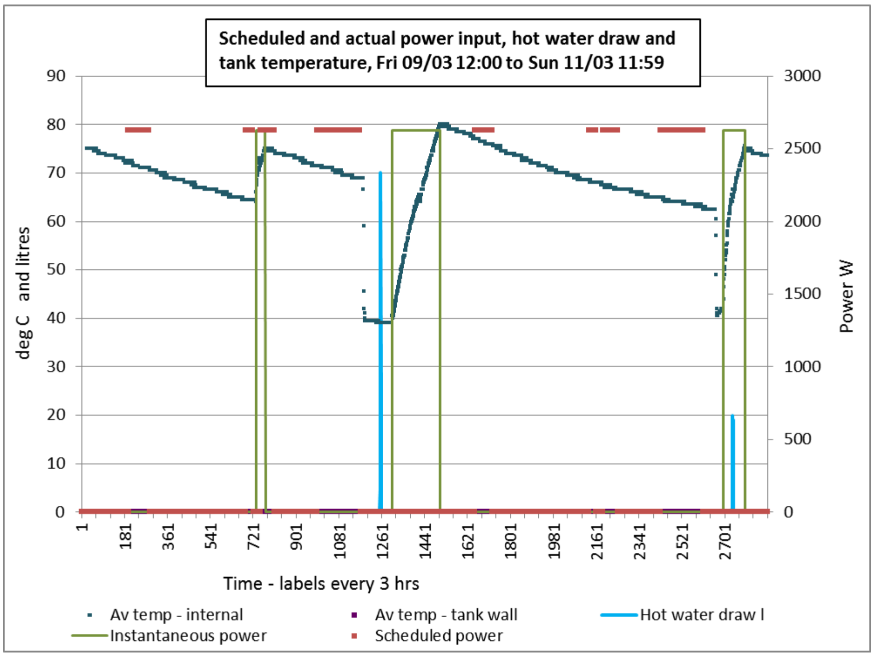


Figure 24 - *Interaction of hot water cylinder controls, House 5*

It is recommended that design aspects pertaining to operation and control should be examined in more detail and refined as part of the control system design for the large scale roll out in Shetland.

5.2.3 Storage Potential

A large scale roll out of 750 homes is seen as the next stage in trialling DDSM. For 750 homes, research indicates that the storage heaters could provide approximately 31MWh of thermal storage capacity and the hot water cylinders, a further 12MWh. These figures are subject to several caveats:

- Contract agreement to install devices in all 750 homes;
- High minimum comfort settings will limit flexibility in terms of storage capacity and the ability to schedule flexible charging.
- High passive output from storage heaters may cause occupants to switch them off – *This may be addressed through the outside ambient temperature register*.
- Heat loss characteristics for the trial will not be the same for the general roll out stock.

5.2.4 Frequency Response

SGS set out the requirements for droop characteristic processing – *Appendix I Section 1.1.4* – and defined this further in the functional design specification – *Appendix II Section 2.3.2*. SHEPD proved the integration of technologies during scheduled testing where SGS demonstrated that: they were able to modify frequency response characteristics in real time; the SGS LIC accepted these instructions correctly; the Dimplex Controller responded; and SGS were able to read the change in instantaneous power. However an error occurred in how the Dimplex Controller handled the Droop Gradient setpoint received which prevented the test schedule from being completed. Glen Dimplex believe this to be a hardware fault in a second batch of controllers and have carried out further lab testing to confirm this. Further frequency response testing of the DDSM devices will be carried out in a test environment once this error has been resolved. SHEPD have responded to this by proposing a DSM standards group similar to G59, G83 etc. This is further documented in Section 9.1.

5.3 Development of DDSM Heating System

Experience gained through the development, installation and operation of the equipment for this trial has paved the way for the next generation of storage heaters and immersion water heaters capable of domestic demand side management, energy storage and frequency response. Learning from this trial has been incorporated with lessons from other research and trials by Dimplex to inform refinement of the original prototype designs, although core functionality remains the same. Heaters and immersion water heaters analogous to those used in the trial are available as commercial products under the new 'Dimplex Quantum'[7] brand. Glen Dimplex are currently testing with the Building Research Establishment (BRE) to determine a Standard Assessment Procedure (SAP) rating[8] for the new Dimplex Quantum devices.

Storage Heaters

Figure 25 - *Dimplex prototype storage heater for SSET1003 trial (left) and modified Dimplex Quantum storage heater (right).*

[7] Further information about the Quantum products are available: http://www.quantumheating.co.uk/

[8] SAP rating is used to fulfil requirements of the Building Regulations to notify and display an energy rating in dwellings. Homes with traditional storage heaters receive a relatively low SAP rating and presently storage heaters cannot be considered for new build properties. Glen Dimplex believe the significant increase in efficiency of the new devices warrants a higher rating.

Hot Water Cylinders

Figure 26 - *Dimplex prototype hot water cylinder for SSET1003 trial (left) and Dimplex Quantum hot water cylinder (right).*

5.4 Skills Development and Safe Working Procedures

Local contractors have gained experienced in the installation of the new heating systems. Additionally, an installation protocol has been developed including method statements (Appendix IV) for physical installation detailing health and safety procedures, customer engagement and commissioning. The protocol was used as a standard to assess procedures provided by third parties for installation of additional monitoring equipment and to identify additional requirements. This has demonstrated the protocol is sufficiently robust and comprehensive to inform future deployment of equipment in domestic properties.

5.5 Understanding of Customer Perceptions

This section describes findings from questionnaires and interviews with trial participants.

5.5.1 Questionnaire - Installation process

All households stated that, prior to the installation, they received enough information; however two felt more information on the appearance of the heaters and how they worked would have been useful.

One felt this could have come in the format of a step-by step guide on how to programme the heaters, possibly including the most cost effective ways to run them.

Tenants were asked to grade their experience of the installation process from 1 (unsatisfactory) to 5 (very satisfactory). All felt it had been satisfactory, with all of those who had been in the property during that period scoring it a 5, with the exception of one tenant group which scored it a 3. All tenants felt that they were able to ask questions during the process. They were also asked to grade how useful any answers they received were; and again all of the tenants reported the highest score of 5 - "very useful".

This indicates the installation contractors were briefed sufficiently well to provide the information tenants required. No tenants suggested anything that would have improved the installation process.

The opinions on training on the systems were slightly more varied. For the water heaters, two households felt they received enough (giving a maximum rating of 5), while two felt they could have done with more (scoring this as 3) and one did not answer; and for the heaters, three tenants scored training at a 5, one scored this at 3 and one at 2. Only one of the tenants gave an answer as to how the training on the hot water systems could be improved and said that they weren't told how the controls work. Suggestions for improvements for the heaters included providing a hands-on demo or a "quick start" manual addressing common usage issues such as how to adjust for unexpected cold weather or going on holiday; while another tenant felt more information on how to use them in general would have been useful.

5.5.2 Questionnaire - Using the DDSM system

All of the tenants rated the hot water systems at a 5 (very good) with the reasons ranging from *"We now have a consistent supply of hot water that does not appear to diminish with heavier use, we are delighted!"* to *"The old water system was unreliable as the water was cold after one bath full."*

The energy storage heaters were also all scored highly at either a 4 or 5, with one tenant not answering. Only two gave explanations for their score, with one tenant stating they scored a 5 as they maintain the heat for much longer than traditional heaters. The tenant who scored the heaters a 4 said they felt they did not understand fully how to work them and this is why they had scored lower.

The tenants understanding of how the heating system will affect their energy use was mixed: two tenants stated they didn't know how it would be affected and three answered that they thought it would decrease energy use. When asked "how much change do you think you will see in your electricity bill each month (in £'s or %)?" most of the tenants felt they needed more time to see any difference in their usage or bills.

Wider understanding of how the systems support renewable energy in Shetland was mixed, with two tenants stating they understood very clearly, at 5. The others rated their level of understating lower at 4 and 3 and two of these households felt they would like to understand this better.

The tenants were asked to rate which of a total of ten features were most important in the heaters. Safety and running costs came out on top, with reliability and ease of use also featuring highly. Factors such as where the heaters were made and environmental issues scored the least.
The tenants were also offered the opportunity to add any comments on any aspects of the heating system installation process or their involvement with the trial in general. Their answers are included below:

"We did have a problem earlier in the summer. The heaters were becoming very hot and we could not control their heat. We had to switch them off completely, even though the setting was on the lowest marking. Once switched off, we did not know how to reprogram the heaters. The fans are becoming noisier with use – whirring increases the hotter the setting."

"Overall I'm delighted with the new heaters: easy to work, cheaper to run, well installed – moving my heater from the window to inside the main front room door was a good move, heat seems to stay in the heater longer. Can't ask much more than that."

"I would be a lot more happier with the heaters if they were more reliable and kept the heat in the room so I didn't have to keep putting on the booster. The water heater however is really good."

It is clear from these answers the tenant groups had varying levels of understanding about how to use the heaters.

5.5.3 Follow up interviews - ongoing experience

The answers to the interviews broadly reflect those given in the questionnaire, but suggest that the tenants gained confidence in how to use their heater, and some tenants began to see the benefits of them in terms of savings on energy use and cost.

Overall, the feedback was positive. All tenants reported an increase in the amount of hot water available to them. Some said the trial had also resulted in a saving on bills, but the majority noticed no real change or hadn't been monitoring the amount of money they spent and/or the unit change.

It is clear that the tenants had varying expectations of what impact the trial would have on their energy use, and what heating would be available to them. Some of the tenants thought their energy consumption might decrease while others had not thought about this.

Tenants from two properties felt the trial had had a positive impact on their attitudes to energy use, and as a result they made more effort to reduce consumption and wastage by using electrical appliances less or switching them off altogether. This could also have had an impact on the reduction in energy use in the homes

At least one tenant said it had also affected how they thought about energy production and consumption in Shetland as a whole. The majority of the tenants seemed not to have given much thought to the wider NINES project and it's relation to renewables in Shetland.

While most of the tenants had some problems with their heating over the trial period, the majority were happy with the reasons for this and the way the problem was dealt with. Finally, all of the tenants spoken to would recommend the systems to a friend.

Overall, feedback from trial participants suggest that from a user point of view, the DDSM system trialled provides a user friendly, manageable system with the potential to offer users cost savings. Tenants were very pleased with how easy the system was to use and the controllability of the heaters. Comments included:

"With being able to programme the heaters we can get it to within an hour or two from when we get up or when we get home in the afternoon so it's far more efficient for us" and "Because obviously you can programme in your… heating, I'm actually using less heating".

5.6 Conclusions

Testing has demonstrated the successful integration of a DDSM technology with suitable control back to a Central Interface. The analysis by ESRU and evaluation of tenants' perceptions have also shown the heaters are more controllable and demonstrated the additional hot water available. Both these outcomes have been well received by customers. Evidence suggests this has been achieved without causing households to use more energy.

While integration has been achieved, the analysis by the University of Strathclyde and SHEPD presented above has also shown that further refinement of the Glen Dimplex control logic for the DDSM devices is required. Refinements are required for a number of reasons including the following:

- The droop gradient function which contributes to the frequency response capability was not responding as per the SGS Functional Design specification.
- Devices were found to be charging out with DNO control more often than expected. This over-ride condition was a result of control logic which correctly commanded the device to charge if a minimum temperature setpoint was reached. Maintaining customer comfort is a priority but this logic can be fine tuned to maintain a suitable comfort level rather than instructing the device to charge to 100% and removing all DNO control.
- The adaptive control function of the storage heaters was introduced in March 2012. Analysis found evidence to suggest in changeable weather, this did not respond quickly enough to maintain comfort levels or desirable operation of the heater.

The second principle aim of the project was to generate knowledge and learning for both: a large scale roll out in Shetland (NINES); and other DNO projects relating to domestic demand side management. Experience gained as a direct result of the trial has provided the following:

- Development of a DDSM heating system
- Requirements for a communications solution
- Resource requirements
- Understanding of customer perceptions
- Skills development and safe working procedures
- Input to further academic work on modelling household energy use to forecast customer demand

6 Performance compared to original project aims, objectives and success criteria

The project aim was to control domestic electrical heat demand to demonstrate a local demand response and frequency response capability. New devices capable of Domestic Demand Side Management were installed in six homes with suitable communication equipment to a Central Interface. The project success criteria would be to prove the integration of the technologies, providing knowledge and learning for a larger roll out. Table 21 sets out the objectives required to prove the integration of technologies; their purpose; and whether the project met this objective. Further knowledge and lessons learned as a result of the project are detailed in Section 7 and Section 9.

Table 24 - *Functional elements required to prove the integration of technologies*

Objective	Purpose	Did the project meet this objective?	Comments
Control of the Heaters with a daily schedule, implemented through the LIC.	Determines the charging times of the storage heaters and hot water cylinders.	P	UoS research indicates that Glen Dimplex control logic may need some fine tuning to ensure that any override conditions do not impact on the flexibility of the system.
Remotely provide updated schedules from the central interface to the LIC.	To cater for flexible charging, the ability to remotely update schedules is key.	P	
Remotely over-ride the schedule in real-time with active setpoint instructions.	Large changes in load, weather or a network event may prompt the need to over-ride the default schedule.	P	
Automatic frequency response from the Glen Dimplex heaters.	Fast acting frequency response is a fundamental requirement of the DDSM devices.	P	Devices automatically responded to changes in frequency however further work to modify the code is required by Glen Dimplex prior to the large scale roll out.
Remotely provide updated frequency response characteristics to the Dimplex controllers.	The ability to remotely update frequency response characteristics is required to respond to changes to the network, such as an increase in Distributed Generation, or as a result from learning.	P	During frequency response testing the SGS engineer was able to remotely update frequency response characteristics to the Dimplex controllers.
Retrieval of data from the Dimplex Controllers via the LIC and into a remote historical recording system.	Data is required by the system to determine the instantaneous power and remaining storage capacity available. It is also used to respond to feedback and generate learning.	P	Informed requirements for tender of communications solution for large scale roll out.

7 Required modifications to the planned approach during the course of the Project

7.1 Switching Strategy (Load Control)

Initial mains power quality tests highlighted 'flicker' measurements out with BS EN 61000-3-3:2008 limits. The flicker was due to the pulse width modulation (PWM) element switching controller that was implemented on the appliances. The PWM element could achieve a high granularity of load control. For the hot water cylinder the PWM element (750W) was variable in 37.5W steps. Therefore input to the hot water cylinder could be varied from 0 to 3kW in 37.5W steps. Discussions between Glen Dimplex, SGS and SHEPD engineers took place to identify possible solutions. There were three solutions proposed:

1. Resolve the original solution using power electronics.
2. Switch the appliance elements using a group structure with element state either **on** or **off** and not variable.
3. Switch the appliance elements using a group structure with element state either **on** or **off** and not variable; and introduce switching in series and parallel to increase number of switching options.

Option 1 was ruled out for a number of reasons but primarily cost. Even if the flicker element could be overcome by filtering, it was felt that a large number of devices on a small feeder could introduce harmonics. It was also indicated that such a high degree of control at device level was not required as network operation would likely switch groups of devices.

Option 2 was selected over Option 3 as the benefits the additional switching options offered were not perceived to outweigh the cost both in terms of hardware and modifications to software.

To make the Option 2 solution viable, it was proposed to replace the 750W PWM element with a 375W element. This increased the number of switching options from 4 to 7. The element replacement was timed to coincide with the first phase of the software upgrade and UoS additional monitoring work to minimise disruption to tenants. The outcome of this element change resulted in the hot water cylinder providing a finer degree of control. The design change will be carried forward to the large scale roll out under NINES.

7.2 Hot Water Cylinder - Temperature Measurement

The initial solution provided a single temperature measurement from one of the elements in the base of the cylinder. However as the water temperature at the top of the tank is higher, this proved to provide an inaccurate reading. In one case this prevented the thermal cut off from detecting excessive temperatures and operating when required. In this instance the pressure release value operated and released hot water through the waste pipe. As an interim solution the temperature sensor was moved further up the tank in line with the boost element. During the upgrade works, a second temperature measurement was introduced. For the large roll out, four temperature measurements will be made from the top to the bottom of the tank, and an average taken.

7.3 Test room

An iterative approach was required to develop the software used to monitor and control the Dimplex devices. A requirement for test rooms containing equipment similar to that installed in the homes was established. This provided an opportunity for software and hardware updates to be implemented in a test environment before being replicated in the homes. These were set up for SHEPD in Perth and another for Glen Dimplex in Portadown.

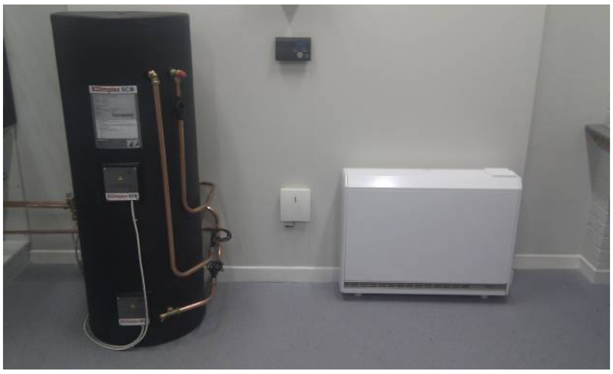


Figure 27 - *Basis of Dimplex Test Room, Portadown, Northern Ireland*

7.4 Additional Ex-Gratia Payment

An additional ex-gratia payment of £100 was paid to each participating household following the need for additional home visits to investigate and resolve comms problems, modify Dimplex code and install additional monitoring equipment.

8 Significant variance in expected costs and benefits

Variances in cost are outlined in Table 25 with variances greater than 10% further described below.

Table 25 - *Cost Variance*

Cost	Predicted	Actual	Variance (£)	Variance (%)
Contractor (SGS)	£157k	£172.9k	£15.9k	10.1%
Contractor (Electrical / Plumbing)	£10.8k	£10.7k	-£0.1k	-0.9%
Equipment	£47.4k	£35.3k	-£12.1k	-25.6%
Project Management	£64.8k	£43.1k	-£21.7k	-33.5%
Total	£280k	£262k	-£18k	-6.4%

8.1 Cost Increases

§ An increase in SGS services was required as a result of:
  - o extended support to troubleshoot code following the storage heater installation; and
  - o the update to project documentation and code as part of the system upgrade.

  This provided substantial benefits to the knowledge gained in the project and costs were met within the original project budget.

8.2 Cost Decreases

§ Glen Dimplex provided the new heating systems in lieu of SHEPD meeting some travel costs.

§ A dedicated Project Manager based in Shetland reduced the cost of travel and accommodation.

8.3 DNO Expectation of Benefits

The project set out to prove the integration of technologies in a proof of concept trial. There were no planned changes to incentive payments or expected savings in revenue (allowed for in DPCR5 settlement). The project details the potential of domestic energy storage and frequency response. A larger trial with statistical analysis is recommended to determine the benefit of DDSM to DNO's. This is documented further in Section 9 and Section 10.

9 Lessons learnt for future projects

In addition to the lessons learned regarding switching strategy (load control) and the requirement for up to four temperature measurements in the hot water cylinder, a number of lessons have been learnt for future projects.

9.1 Requirements Specification

Lessons were learned from the trial and used to help formulate functional and non-functional requirements for the NINES project's Invitation to Tender (ITT) for a DDSM communications solution. Requirements relating to communications reliability, scheduling, security, physical dimensions, data storage, service level agreements and safety testing were developed as a result of the project.

9.2 Wireless Solution

One aspect of the storage heater installation required running a RS485 communications cable to each device. This comprised the majority of the installation time as it required a labourer to cut hatches in the floor or assist in running the cable up into a loft space. Dimplex have indicated that for the Quantum roll out, a wireless solution shall be implemented. This is expected to considerably reduce installation time from four and a half hours to two hours.

9.3 System Access

Access to real time data required contacting SGS in Glasgow and a smart grid engineer relaying what they could see on the system. The inherent communications problems were not anticipated or accommodated for in the contract. As such, resolving on site problems was increasingly difficult. For future projects the engineer on site must be able to interrogate the system locally.

9.4 Resources for large scale roll out

9.4.1 Recruitment of NINES Development Officer

A significant administration element was required for the six homes during the life-cycle of the project. To assist with the 750 home roll out proposed for NINES, a dedicated resource was specified to:

§ Carry out home surveys and audits to collect, collate and analyse information.
§ Explain the project benefits to tenants and provide a first point of contact for tenant enquiries.
§ Assist in other planning and delivery actions that support the activities of project stakeholders.
§ Work with installers and maintenance teams to build an understanding of the new technology and appliances.

- Ensure that the maximum environmental and financial benefits are derived for the tenants and landlords.
- Maximise learning from the project which shall assist in rolling it out to other housing tenures.
- Promote and raise awareness of the project.

9.4.2 Recruitment of Glen Dimplex Service Engineer

Glen Dimplex are currently recruiting a service engineer to support the large scale roll out in Shetland. The trial identified the need for a dedicated resource based locally. The engineer will be responsible for faults with Glen Dimplex equipment and shall assist in the commissioning of installations. This may include carrying out commissioning tests of the Dimplex Home Hub and assisting customers to set up their new heating system for the first time.

9.4.3 Customer requirements for Installation and Operation

Questionnaire and interview data showed that prior to installation more information about the design and operation of the heaters would be useful. As a result of tenant feedback the participant engagement process for NINES will include the following steps:

At time of installation, the installer will provide a basic instruction as to how to use the system. The tenant will be left with instruction materials and contact details for the landlord and development officer.

A visit from the development officer is planned for around a month after the installation where there will be a chance for the tenant to ask questions and if required, get a demonstration on how to programme the heaters. This visit will also allow an opportunity to capture tenant feedback.

The development officer will also be available to be contacted by telephone, email or letter to answer any questions about the systems and provide information on usability at any period during and/or after installation.

In addition, training materials are being developed for the large scale trial of DDSM planned as part of the NINES project which will include:

- A quick start or troubleshooting user guide;
- A guide to best use and programming for cost effectiveness;
- A NINES website which features user guides, troubleshooting and information about the wider project.

A priority for the learning materials the tenants receive could be a troubleshooting guide which would also give a guide to the most cost effective way to run the heaters.

9.5 DDSM Standards Group

SHEPD do not have a direct contract with Glen Dimplex – and under the structure of the project it is not appropriate to – however as the DNO we recognise the responsibility to prevent equipment from being installed where it can have a negative impact on the network. As a result we are in a position to clearly define the minimum functionality and characteristics of the heating systems to be installed.

Following discussions with Glen Dimplex, it is proposed to initiate a "Standards Group" for DDSM on Shetland. Initially SHEPD shall produce an outline document which includes the following:

- General characteristics
  - Harmonic and Flicker limits
  - Frequency control
  - Frequency response behaviour
  - Ramp curves range of control
  - Speed of response
  - Group setting requirements

- Communications requirements
  - Comms protocol
  - Comms failure default values
  - Data definitions
  - Remotely configurable parameters
  - Black start behaviour
  - Testing requirements
  - Type testing
  - Commissioning tests
  - Routine tests

This document will be a learning output from the project and could be used as a standard that other manufacturers could reference should they apply to put equivalent Demand Side Management equipment on the island.

10 Planned implementation

The next step required – in order to progress towards BAU – is to trial dynamic scheduling and control. The scheduling and control of the current heating systems can be considered static – although changes can be made remotely by an engineer in real time. While static control demonstrates the successful integration of the technologies in a real world environment, making use of the functionality of DDSM requires trialling dynamic control.

Dynamic control will enable control of heating systems in groups of homes based on the available renewable energy output and other network conditions. SHEPD will trial dynamic control through the NINES project. The new Dimplex Quantum heating systems will be rolled out to 750 homes in Shetland. SHEPD will install communications equipment and integrate DDSM into an Active Network Management (ANM) system which will provide dynamic control functionality. The NINES project will therefore allow the technology to be tested, both at scale and by integrating it into an existing system – advancing the TRL to 8 – and enabling SHEPD to determine the value of DDSM to DNOs.

Suppliers will be asked to register an interest in the project and will be consulted on the impact of DDSM and potential solutions. DNOs will have to work with Supply businesses to establish suitable tariffs. SHEPD will engage with all Suppliers on the outcomes of the trial.

SHEPD will also engage with participants in the NINES trial to identify and understand any customer issues which would need to be resolved to enable widespread implementation.

11 Project replication and intellectual property

The following tables list all physical components and knowledge required to replicate the outcomes of this project, showing how the required IP can be accessed by other GB DNOs. All physical components are commercial products available for purchase. Further detail relating to any knowledge item is available from SHEPD on request through jenny.1.rogers@sse.com

Table 26 – *Components required for project replication*

Component	Products used in project or commercially available equivalents
Domestic energy storage devices with thermal inertia and frequency response	Dimplex Quantum Storage Heater Dimplex Quantum Hot Water Cylinder
Control system	Local Interface Controller – Allen Bradley Micrologix 1100 PLC running SGS propriety code Central interface – Engineering laptop running: SQL Server 2008 Express Edition Factory Talk Transaction Manager RSLinx Classic RSLogix 500 Standard Product numbers and descriptions can be found in Appendix II
Communications system	3G/GPRS Vodafone – Cisco 887 (3G+ADSL) routers Vodafone GPRS SIM cards Vodafone sure signal
Energy monitoring system	Eltek GC05 room temperature transmitter Eltek GC32 water temperature transmitter Eltek GC62 water flow rate transmitter Eltek Squirrel 1000 datalogger with GSM modem mySQL database server

Table 27 – *Knowledge products required for project replication*

Knowledge item	Application	IP ownership and availability
Requirements, functional design specification and test specification for control system	Procurement of control system for similar application	SHEPD Close-Down report Sections 4.2, 4.4 and Appendices I & II
Principles and methodology for domestic customer engagement	Engagement of domestic customers as DDSM trial participants	SHEPD Close-Down Report Sections 4.3, 4.5, 5.5, 9.4 and Appendix III
Methodology for installation, testing and commissioning of DDSM system	Deployment of DDSM in domestic properties	SHEPD Close-Down Report Sections 4.4, 7, 9 and Appendices IV, V & VI