CP758
Alternative Heating systems, WDH

Technical Evaluation Report

Josh Sawyer – October 2018

Background

About National Energy Action

National Energy Action is the national fuel poverty charity working across England, Wales and Northern Ireland, and with sister charity Energy Action Scotland (EAS), to ensure that everyone can afford to live in a warm, dry home. In partnership with central and local government, fuel utilities, housing providers, consumer groups and voluntary organisations, it undertakes a range of activities to address the causes and treat the symptoms of fuel poverty. Its work encompasses all aspects of fuel poverty, but in particular emphasises the importance of greater investment in domestic energy efficiency.

About the Technical Innovation Fund

NEA believes that there is huge potential for new technologies to provide solutions for some of the 4 million UK households currently living in fuel poverty, particularly those residing in properties which have traditionally been considered too difficult or expensive to include in mandated fuel poverty and energy efficiency schemes. However, more robust monitoring and evaluation is needed to understand the application of these technologies and assess their suitability for inclusion in future schemes.

The Technical Innovation Fund (TIF) which was designed and administered by NEA, formed part of the larger £26.2m Health and Innovation Programme along with the Warm Zone Fund and Warm and Healthy Homes Fund.

TIF facilitated a number of trials to identify the suitability of a range of technologies in different household and property types and had two strands: a large measures programme to fund the installation and evaluation of technologies costing up to a maximum £7,400 per household, and a smaller measures programme with up to the value of £1,000 per household. It launched in May 2015, with expressions of interest sought from local authorities, housing associations, community organisations and charities wishing to deliver projects in England and Wales.

Over 200 initial expressions of interest were received and NEA invited 75 organisations to submit full proposals. Applications were assessed by a Technical Oversight Group, chaired by Chris Underwood, Professor of Energy Modelling in the Mechanical and Construction Engineering Department at Northumbria University who is also a trustee of NEA. In total, 44 projects were awarded funding to trial 19 different types of technologies and around 70 products (although this number reduced slightly as some products proved not to be suitable and were withdrawn).

More than 2,100 households have received some form of intervention under this programme that has resulted in a positive impact on either their warmth and wellbeing, or on energy bill savings. Of course, the amount of benefit varies depending on the household make up and the measures installed. In a small number of instances, we removed the measures and took remedial action.

Technical monitoring and evaluation

NEA has been working with grant recipients to monitor the application of these technologies and assess performance, as well as understand householder experiences and impacts.

A sample of households from each TIF project was selected for monitoring purposes. Participation was entirely voluntary, and householders were free to withdraw at any time. This involved the installation of various monitoring devices within the home which collected data for analysis by NEA's technical team. Some residents were also asked to take regular meter readings. In some instances, a control group of properties that had not received interventions under TIF were also recruited and monitored.

The technical product evaluation was conducted alongside a social impact evaluation to inform our understanding of actual energy behaviour changes, perceived comfort levels and energy bill savings, as well as any other reported benefits. Householders were asked to complete a questionnaire both before and after the installation of the measures which captured resident demographic data including any health conditions. Small incentives in the form of shopping vouchers were offered to maintain engagement over the course of the evaluation period.

The HIP fund was principally designed to fund capital measures to be installed into fuel poor households. A small proportion of the funding enabled NEA to conduct limited research and monitoring of products installed and was restricted to ensure that the majority of funds were spent on the products. All products included in the trials were deemed to offer costs savings and energy efficient solutions as proposed by the delivery partners. The research and monitoring aimed to provide insights to inform future programme design and interested parties of the applicability of the product to a fuel poor household. We recognise that due to the limited number of households involved in the monitoring exercises and the limited period we were able to monitor a product's performance, we may recommend that further research is needed to better understand the application of these products in a wider range of circumstances over a longer period of time.

The research was conducted according to NEA's ethics policy, which adopts best practice as recommended by the Social Research Association (SRA) Ethical Guidelines 2002.

An accompanying programme of training and outreach work was also delivered to 292 frontline workers to increase local skills and capacity.

Individual project reports are being compiled and will be made available publicly on NEA's website from September 2017, along with a full Technical Innovation Fund Impact Report.

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Executive summary

Project overview

This project focused on the installation and evaluation of measures or combinations of measures in homes at risk of fuel poverty. There was a mix of innovative and more well-established technologies installed in the properties. WDH’s standard heating replacement programme focuses on standard energy efficiency measures and typical gas and electricity heating systems. These measures have been available through ECO and its previous iterations.

Trialling the new technologies was intended to help shape WDH’s and WMDC’s home retrofit strategy for the future. Learnings from innovative technologies would help WDH select which measures have potential and require further trials before becoming part of their retrofit strategy.

6 properties within each sub-group received a measure or combination of measures, the low number of installs enabled each property to be monitored. The number of properties that were monitored and quality of data was impacted as residents moved out or dropped out.

Context

In the most recent figures 11.2% of households (16,600) within the Wakefield District were in fuel poverty.[1] The Index of Multiple Deprivation 2015 (IMD) shows that the Wakefield district was the 65th most deprived district in England (out of 326), 47,400 people in the district were living in neighbourhoods amongst the top 10% most deprived.

The majority of WDH’s housing stock is heated by gas, yet there are off-grid properties reliant on solid fuel and electricity to heat their properties.

The technology

Some of the properties received a combination of measures and some received just one. Most of the technologies or combinations of them were innovative for properties at risk of fuel poverty.

Logicor Clear Heater System and InLine hot water system
An infrared heating system installed alongside an instantaneous hot water system.

Mitsubishi Ecodan air source heat pump & Solar PV system
An air source heat pump installed alongside solar PV panels, the PV array varied in size from 1.7kWp to 2.9kWp to 4.06kWp.

Worcester Bosch gas boiler and Mitsubishi Ecodan air source heat pump
A hybrid heat pump system that utilises a gas boiler alongside an air source heat pump to provide heat when the external temperature is low. The original proposal was altered, and the two units did not work in sync, the heat pump provided space heating whilst the gas boiler provided hot water.

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[1] http://www.wakefieldjsna.co.uk/wider-determinants/poverty/

Worcester Bosch gas boiler and Greenskies solar thermal hot water
A new gas boiler installed alongside a solar thermal hot water system to meet some of the hot water demand.

Worcester Bosch gas boiler (control)
A standard gas boiler installed to offer a control group.

Worcester Bosch gas boiler with Ecoflow FGHR and Wave smart control
A standard gas boiler with additional add-ons and features. These included a passive flue gas heat recovery unit and a smart control that offered load and weather compensation.

Dimplex Quantum storage heaters with iQ controller
High heat retention storage heaters with in-built weather compensation.

Mitsubishi Ecodan air source heat pump
A standard air source heat pump

Summary of findings

A brief overview of the key findings from each technology trialled in the properties. It should be noted that sample sizes were low, around 5-6 properties, and sometimes lower. The sample sizes were low due to the number of technologies trialled and the availability of resources for monitoring. These low sample sizes do not offer statistically significant findings and instead should be viewed as indicators of performance in specific households. Having a larger sample size would also reduce the impact of residents dropping out or monitoring equipment failing

Logicor

- There was an increase in annual costs after the Logicor system was installed.
- Continual issues with the hot water system despite steps being taken to rectify the issue.
- The Logicor system was removed from 1 property, this household had continual issues with the system, they found the system unsuitable for their needs and expensive to run.

ASHP & PV

- There was a marked improvement in SAP points, 4 properties are now rated band C and 2 are rated as band D.
- There was an increase in resident satisfaction with the performance of the heating system, including control and ease of use.
- 4 of the 5 residents reduced their annual costs after install.
- All residents achieved an average living room temperature of 18°C – 21°C.
- There is a high upfront cost which is in part mitigated by FIT and RHI payments. The Feed-in Tariff will no longer be available in March 2019.
- Whilst having solar PV is an advantage and has an impact on cost peak supply (PV generation in the summer) does not coincide with peak demand (heat pump demand in the winter).
- 2 of the properties had SCOPs of less than 2.5, an SCOP of 2.5 is the minimum level of efficiency to be eligible for metered RHI payments.

Hybrid ASHP

- The system was not configured as intended therefore not operating as a recognised hybrid system.
- The performance of the system reflects its set up. Only 10% of energy costs were met by the gas boiler as it was only providing hot water.
- Electricity costs were high in 4 of the properties with an average electricity cost of £1340. The properties that received hybrids were larger than the other properties that received an ASHP which in part explains the higher annual costs of the hybrid properties. 1 of the other subgroups (ASHP & PV) also received solar PV generation which had an impact on their costs.

Gas boiler and solar thermal hot water system

- The hot water demand of the property and number of direct feed/instantaneous hot water appliances should be considered before installing a solar thermal system.
- These properties did not have a high hot water demand, and all had instantaneous electric showers.
- 2 of the residents reduced their annual energy costs.

Gas boiler (control)

- 3 of the properties were rated band C and 1 at band D post install.
- High levels of satisfaction regarding cost, ease of use and level of control.
- The temperature in the living room of all properties was between 18°C – 21°C.
- 2 of the residents reduced their annual costs after the new gas boiler was installed, the other 2 residents did not have enough consumption data to calculate any savings.

Gas boiler with smart controls

- High levels of satisfaction expressed by residents regarding cost, ease of use and level of control.
- Annual gas costs were low.
- There is evidence that the smart aspects of the Wave controller such as the weather compensation increased the level of control over the heating system.
- Residents had to have access to the Wave app to make changes to their heating schedule, this could not be done from the in-home display. Some residents noted that they did not have the app or had forgotten their password for it.

Dimplex Quantum high heat retention storage heaters

- Only minor increases or decreases in annual cost post install, 3 of the properties had post install costs of around £1,150.
- A high proportion of electricity was used on the cheaper economy 7 rate, this ranged from 63% - 90%.
- All residents achieved living room temperatures within or above 18°C – 21°C.
- There is some evidence that the Dimplex Quantum altered energy consumption according to changes in the external temperature.
- Some residents were overheating their properties, 2 heated their properties above 24°C.

ASHP

- A significant increase in SAP after moving from solid fuel, 3 properties moved up to band D and 1 to band E.
- There was an average annual electricity cost of £1,013 post install.
- 1 property had a SCOP of 2 whilst the other had an SCOP of 2.5. This is a measurement of the heat pumps efficiency. An SCOP of 2.5 is the minimum efficiency a heat pump can be to be eligible for RHI. However, this would not be the case if the property only used a heat pump to meet its heating demand. Low SCOP.
- 3 of 4 residents had a living room temperature of 18°C – 21°C.

Overall observations

Standard Assessment Procedure

The most significant increases in SAP points were noted in properties where solid fuel had been replaced, ASHP systems and ASHP systems with PV were the technologies used to replace the solid fuel systems. Post install 4 of these properties were band C rated properties, 8 were band D rated properties and only 1 was in a band E although this property had the lowest SAP rating of all monitored properties pre-install, moving from 27 (F) to 52 (E).

Well established renewable technologies such as heat pumps and solar thermal hot water systems are well represented by the rdSAP software. Other technologies are newer to the market and the rdSAP software has not been adapted to accommodate for innovative systems. The hybrid system was not configured as intended on this project however if it had been then the Standard Assessment Procedure would not have represented it as a truly hybrid system. If innovative technologies are not accurately represented, then this will have an impact on future deployment of innovative measures as landlords and homeowners seek to increase their SAP rating.

Satisfaction levels with heating systems

Those residents that used gas as their main form of heating expressed the highest levels of satisfaction with the following statements; ‘cost of running the system’, ‘amount of control over the system’ and ‘how easy the system is to use’. All but 1 of these properties previously had gas boilers in place, this familiarity likely explains why residents were so satisfied with the above statements. Despite this it is still clear that gas boilers are considered simpler to use and the most affordable way in which to heat the home.

Gas systems will continue to be the benchmark against which innovative technologies are measured against. There is evidence that the more established renewable technologies are moving closer to this level of performance and acceptability. Those residents that received an ASHP alongside solar PV were satisfied with the amount of control they had and how easy the system was to use however satisfaction fell short regarding energy costs.

Project overview

1.1 Introduction

This project installed, monitored and evaluated innovative heating systems in homes at risk of fuel poverty. WDH's standard heating replacement programme (their Decent Homes Programme) focuses on standard energy efficiency measures and well-established gas and electric heating technologies. These measures are well-established and have been available through the Energy Company Obligation (ECO) and its predecessors.

This project focused on trialling new and lesser known technologies such as hybrid heat pumps and combinations of other technologies such as ASHP installed alongside solar PV. The deployment and evaluation of these technologies will help to inform WDH's future retrofit programme and Wakefield Metropolitan District Councils (WMDC) private sector home energy efficiency improvement programme.

WMDC were a project partner in this project, working alongside WDH. Both partners provided eligible properties, which included both private and social housing for the study.

8 technologies and combinations of technologies were selected for the project which were monitored by NEA and WDH. The 8 groups of technologies were:

- Hybrid heat pumps – a combination of a gas boiler and air source heat pump
- Solar thermal installed alongside new gas boilers.
- Air source heat pumps alongside solar PV
- Infrared heating
- Gas boilers with smart controls and heat recovery systems
- High heat retention storage heaters
- Gas boilers
- Air source heat pumps

1.2 Aims

The project had the following aims:

NEA

- To determine the annual running costs of the new heating systems
- To determine if residents were more comfortable after the heating systems were installed.
- To determine if residents were able to use and control the systems effectively.

WDH

- To inform future retrofit and investment plans for their 31,000 properties.
- To establish the performance of these heating systems against more conventional means of heating.

1.3 Context

Around 11.2% of the Wakefield District is in fuel poverty and over 40% of WDH's properties are in the 15% most deprived areas in England. 26,000 properties out of WDH's 31,000 housing stock are primarily heated by gas, whilst 21,000 are of cavity construction.[2]

Some of the properties were situated in off-gas areas and included some properties heated by solid fuel. The properties were spread across the Wakefield District, which meant that the type and tenure of property varied across the project – complicating analysis of data across groups.

1.4 Project timeline

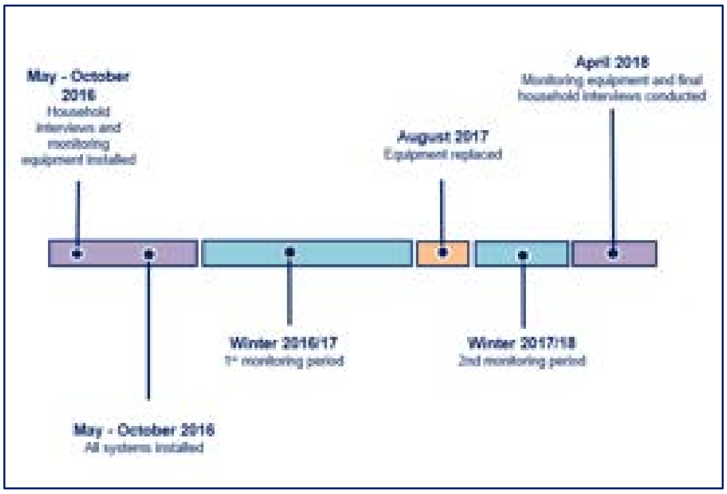


Figure 1.1 project timeline

1.5 Attracting beneficiaries and establishing a monitored group

Areas of higher levels of fuel poverty and areas with old central heating systems were targeted to receive measures. The majority of properties targeted were 3 bedroom semi-detached and of cavity wall constucted properties. These properties were selected as they were most representative of the housing stock within the Wakefield district, and were recognised as providing some stability in the sample groups of properties, allowing better cross comparison of results between properties and sample groupd of technologies being trialled.

WDH identifed 168 properties across five estates that met some or all of the above criteria. The five estates covered areas of west, east and central Wakefield district. Where possible WMDC targeted private properties in the proposed estates that met similar criteria.

All properties that received measures were required to take part in the monitoring process. WDH informed residents that this was a condition of the study and briefed them about NEA's ongoing involvement. NEA subsequently arranged to fit the non-invasive monitoring equipment within the property and carry out an initial questionnaire with the resident.

1.6 Factors affecting the planned evaluation methodology

2 Sourced from original project proposal submitted by WDH

Issue	Description and mitigation
Size of monitoring group	The original aim of the project was to monitor all subgroups and the 6 properties that received each measure. In some cases, the numbers were reduced due to residents dropping out of the monitoring.
Identification of the monitored group and control group	All properties receiving measures were to be monitored. These properties were identified by WDH and WMDC.
Change of measures	Micro combined heating power (MCHP) boilers were originally planned to be installed. This element of the project was removed due to space constraints, and product installation requirements.
Start of monitoring	In most cases monitoring equipment was put in place prior to the installation of the measures. However, this was during the spring and summer when residents' heating was unlikely to be on. This meant that pre-install temperature data was unavailable for the properties during a heating season.
Monitored group	The monitored group reduced in number over the duration of the project. Residents dropped out after the 1st year of monitoring reducing the size of the monitored groups.
System performance	The following issues are covered in more detail in the relevant sections. **Logicor** – Several residents found that the water pressure and temperature was inadequate for their needs. Steps were taken by the manufacturer to resolve these issues (new circuit board, installing a larger coil) however these were not always successful. Some residents stated that they had issues with a grit like substance found in their hot water. Filters were put in place to resolve the issue despite this the grit substance remained. **Hybrid ASHP** – Due to sizing issues, the setup of the hybrid system had to be significantly altered. In the end, the gas boiler was configured to provide hot water whilst the ASHP unit provided all space heating. The gas usage in these properties was low at an average of 9% of total energy use. A hybrid set up normally utilises the ASHP for most of the heating demand with the gas boiler assisting progressively more as the external temperature drops.
Meter readings	Meter readings post-install were available for most properties, even those who dropped out during the project's duration. The number of pre-install readings varied between property and in some cases only estimated annual usage was available, if this was the case then the usage would not be used.
Monitoring equipment	The majority of heat meters (installed by contractors alongside technologies) failed to record data, showing Zero kWh on the

	display. This meant that analysis of certain aspects could not be carried out i.e. • Seasonal performance factor of the ASHP units. • Proportion of energy used by the central heating system and domestic hot water. • Proportion of energy demand met by gas boiler vs heat pump • Some loggers monitoring PV generation and ASHP electrical input failed to record. Thermal loggers were lost or moved by residents to unsuitable areas.
Other factors	Private owner occupiers were often unaware of who to contact if they had any performance or maintenance issues regarding their heating systems. Residents were provided with details of who to contact when they had the installation work completed.

1.7 Calculating cost

This section is used to detail how costs were calculated for each of the technologies tested. Different methodologies were adopted for calculating the annual cost of heating were employed as the main method of heating varied. For instance, an electric storage heater utilises a cheaper electricity rate during off peak periods to charge up and store heat. Using the same price per kWh for an ASHP would be an inappropriate method to compare running costs of these two technologies.

To determine the annual costs of gas and electricity it was important to record accurate gas and electricity consumption at regular intervals throughout the duration of the study. Consumption was obtained through a variety of means including smart meters, current clamps and on-site manual meter readings taken by residents. Historical consumption was obtained [where possible] from previous energy suppliers to enable a comparison of energy costs before and after the various technologies were installed. Where possible the period selected for analysis before and after the installation included at least 1 winter period.

To analyse energy use for space heating, the impact of the external temperature must be considered. It is poor practice to compare the heating costs for two periods without compensating for different outdoor temperatures. An external temperature of 15.5°C is accepted by energy professionals as the outside temperature below which heating will be required, and above which no heating is necessary.[3] The heating requirement for a building is proportional to the number of heating degree days (HDD) i.e. the number of degrees below 15.5°C that the average temperature is on each day during the period. When the average outside temperature drops to 14.5°C, this is classed as 1 degree-day. Degree days are added together for the required period to give the total number of degree days for the period. Different periods can then be compared for their energy consumption and the results used to predict energy consumption on a normalised basis considering the outside temperature for those different periods.

[3] https://www.carbontrust.com/resources/guides/energy-efficiency/degree-days/ [Accessed 23/03/2018]

The degree day data for the area was obtained from the weather station at Leeds Airport, which is the closest [reliable] location to most properties involved in the study. The degree day data is reliable and available over an extended period. To normalise the usage 20-year average degree day values are used, these are only available on a regional basis i.e. the ‘East Pennine’ region.

Prices per kWh were established for the different energy sources used. Using standardised figures enabled a comparison of residents within a sub group and across the whole project. The following costs per kWh were used.

Gas	Electricity single rate	Electricity off peak	Electricity on peak
5p per kWh	16p per kWh	7p per kWh	18p per kWh

The [normalised] annual heating costs were calculated by dividing the total energy cost (used due to complexities introduced through mixed previous heating sources) for a period by the number of degree days recorded for that period and then multiplying by the average annual number of degree days in the appropriate area.

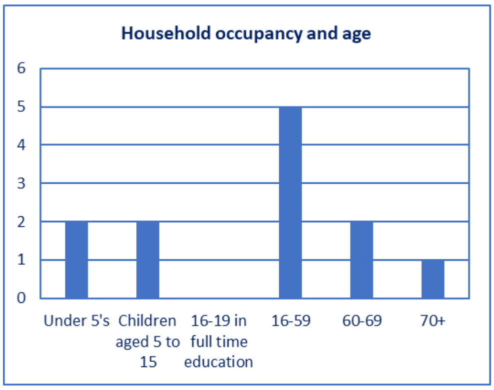
For those properties that did not use electricity for their heating requirements there was no need to account for the external temperature, as electricity was used for non-weather-related appliances such as washing machines or cookers.

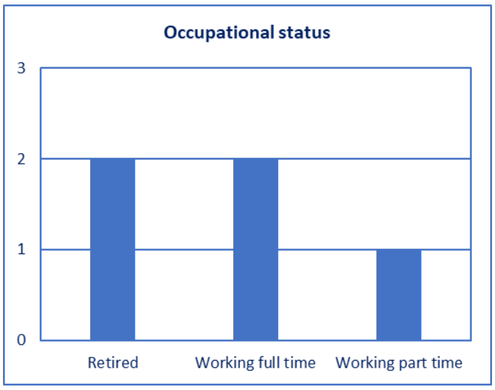
2.1 Logicor

6 households received the Logicor Clear Heater system for their space heating demands and the Logicor InLine hot water system for their hot water demands, 1 resident had the system removed as it was not suitable for their needs. The Clear Heater system[4] is made up of infrared heating panels that heat objects within a room rather than the air as a convection system would. The InLine hot water system[5] provides hot water on demand and replaces the need for a hot water storage tank. The properties were previously heated by electric storage heaters and their hot water demand was met from an immersion heater, the properties operated on an Economy 7 tariff and moved to a single tariff when the Logicor system was installed.

2.2 Social evaluation and impacts

Qualitative feedback from initial questionnaire





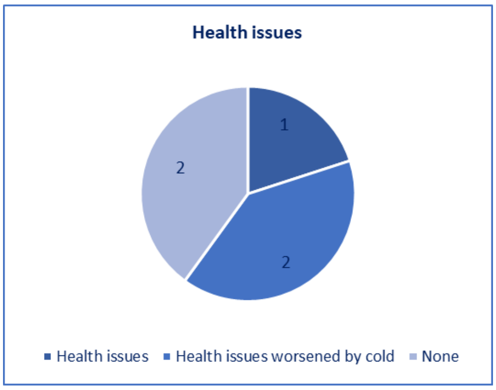


Figure 2.1 (a) household occupancy (b) occupational status (c) health issues

Figure 2.1 (a) shows that there were 12 residents living within the 5 households monitored and they ranged in age from Under 5s to 70 plus. 1 of these households had 3 children and 2 adults whilst another only had 1 resident living over the age of 70. 2 residents were retired and 2 were working full time. All these factors indicate that the residents were likely to have varying space heating and hot water requirements.

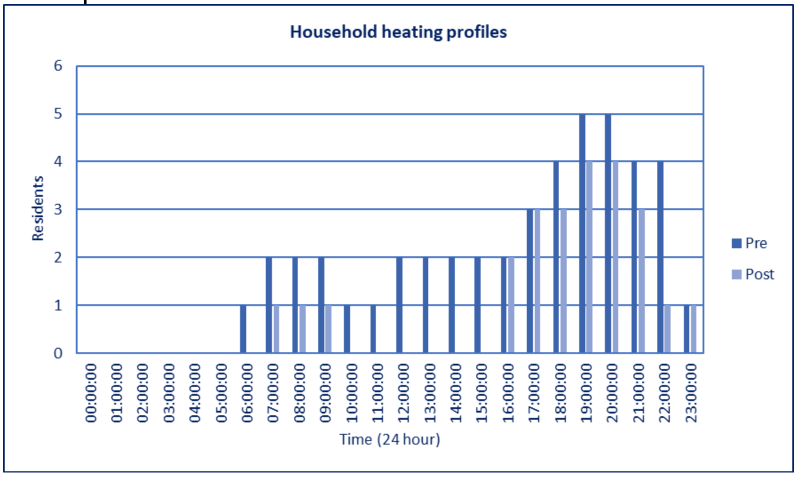


Figure 2.2 household heating profiles pre and post install

[4] http://www.clear-heater.co.uk/clear-heater-system.html

[5] http://www.clear-heater.co.uk/inline-hot-water-system.html

Residents were asked if there was a specific time of the day when they felt it was most important to have a warm home. This might be when they are least active e.g. sitting watching TV in the evening or when washing/dressing first thing in the morning. For comparison, residents were asked this in the question at the start of the project and then again at the end.

Figure 2.2 shows the results amalgamated across all respondents. There is a peak in required heat from residents between 6pm–10pm, this is particularly prevalent in the pre-installation questionnaire. There were some residents who wanted to be warm in the morning and others that would prefer to be warm later in the afternoon. This is due to the varied occupancy and lifestyles of those involved in the study. This data is used to consider achieved temperatures in section 2.9.

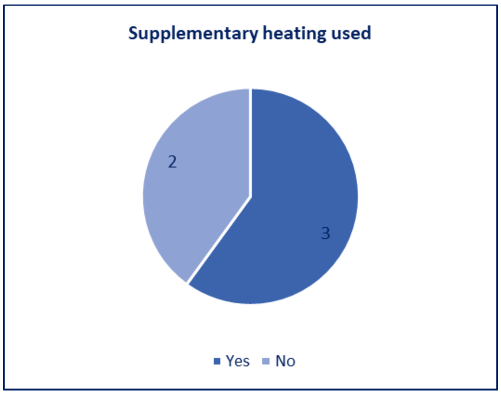


Figure 2.3 use of supplementary heating pre-install

All properties had previously heated their properties with storage heaters, and water heating provided by immersion heaters. 3 Residents noted that they used supplementary heating alongside their storage heaters (figure 2.3), most using electric fires and oil filled radiators.

			Pre		Post	
Tech Ref	**Size (m²)**	**House type**	**Rating**	**Band**	**Rating**	**Band**
T-45	87	Semi-detached house	62	D	52	E
T-50	49	Top floor flat	66	D	59	D
T-34	70	Semi-detached house	57	D	46	E
T-66	67	Semi-detached house	55	D	50	E
T-33	71	Semi-detached house	59	D	49	E

Table 2.4 property characteristics

Table 2.4 shows that all monitored properties experienced a decrease in their EPC rating after the Logicor systems were installed. Prior to the install all 5 properties were in Band D which is the average EPC Band for UK properties, after the install all but 1 fell into Band E. 4 of the 5 properties were semi-detached houses that ranged between 67m² and 87m², the final property was a top floor flat that was significantly smaller.

2.3 Resident acceptance and satisfaction

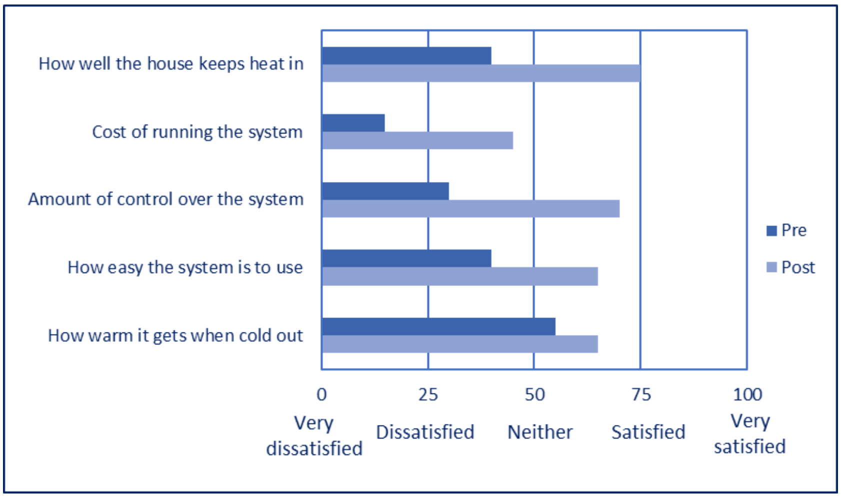


Figure 2.5 resident satisfaction with system performance

Resident's noted an improvement in the above statements (figure 2.5). The most improved aspect related to "how well the house keeps the heat in", this likely relates to an improvement in the availability of heat rather than the fabric of the house. Previously the storage heaters would provide too much heat during the day and not enough heat in the evenings hence supplementary heating being used. Now residents were able to keep warm in the evening as the Logicor system would still be providing heat.

Other significant improvements related to the "amount of control over the system" and "how easy the system is to use". In the initial questionnaire all 5 residents knew how to use the input and output controls on their storage heaters and 4 of the 5 stated that they used them regularly. Despite this, residents did not find the system easy to use and felt they did not have adequate control. The Logicor system could be programmed on a controller to specify temperatures for individual or grouped rooms and was not influenced by the fixed 7 charging hours of an economy 7 (used with storage heating). 1 resident did note that their son had to visit her to make alterations to the heating on her behalf. It should also be noted that some residents were still heating their homes throughout the whole day as had been set up on install (and recommended as the setup by the manufacturer). None of the residents had altered the programmer to add 'events' to increase or decrease room temperature for a selected period.

Whilst there was an improvement in satisfaction of "cost of running the system" it was a comparatively low level of satisfaction when compared to other questions. In a separate question – represented in Figure 2.6 shows that 3 of the residents found it more expensive than the older system. There is pre and post energy consumption data for 4 of the 5 properties monitored, all 4 saw an increase in their annual costs. The 1 resident that stated their costs were cheaper also saw an increase in costs. The resident only took part in the interim questionnaire. They did not carry out a final questionnaire after the winter of 2017/18 therefore their responses would not reflect the weather over the 2nd winter monitoring period.

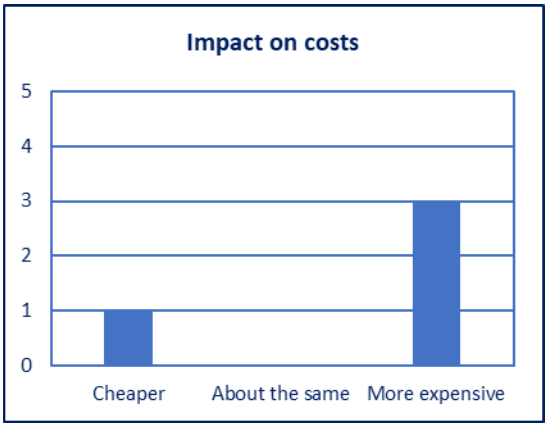


Figure 2.6 impact of the system on heating costs post install

2.4 Affordability of energy bills

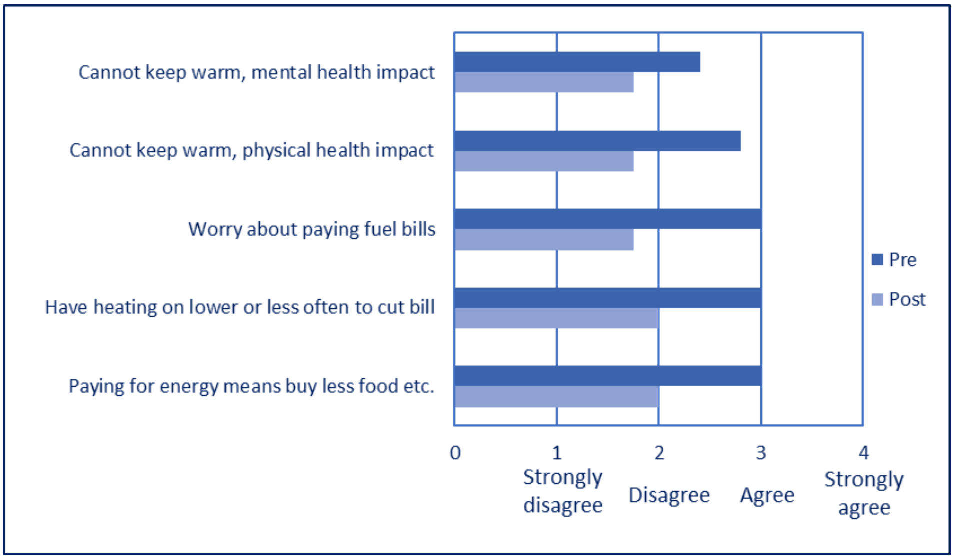


Figure 2.7 residents' level of agreement with affordability of energy

There were improvements in all the above statements (figure 2.7) at the end of the project. Despite the increased costs experienced by residents they now disagreed that they 'worry about paying fuel bills', 'Have heating on lower or less often to cut bill' or 'paying for energy means buy less food etc'. None of the residents expressed any changes in occupancy or employment status. Residents now disagreed that they could not keep warm and this affected their mental and physical health, an improvement in health was not specified as one of the benefits experienced by residents as noted in the figure below (figure 2.8).

2.5 Perceived comfort and benefits

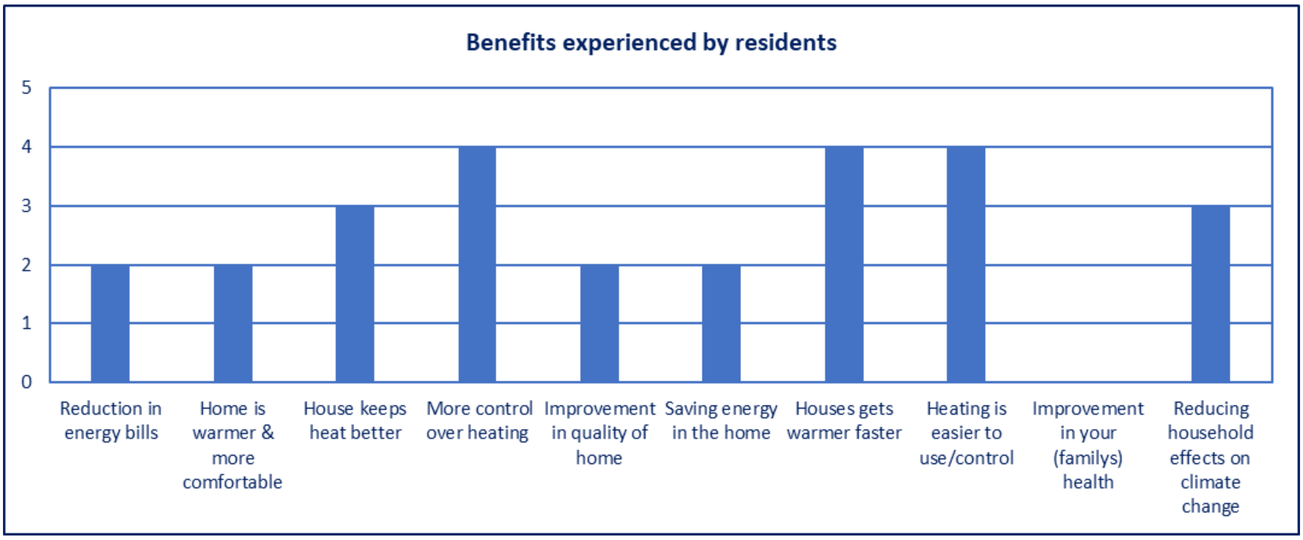


Figure 2.8 benefits noted by resident's post install

2 residents noted a reduction in energy bills as one of the benefits experienced (figure 2.8), this is despite the cost analysis showing that 4 of the 5 residents saw significant increases in their annual costs (table 2.12). One of the residents (T-34) that stated they experienced a reduction in energy bills paid by direct debit so may not have noticed the increase in cost until the annual statement arrived or the supplier contacted to increase the direct debit. The other resident (T-66) only took part in the interim questionnaire so did not experience the colder weather over the 2nd winter monitoring period.

4 of the 5 residents remarked that the 'house gets warmer faster' with the Logicor system. One of the benefits of a far infrared system is the instant warmth felt when the panels are switched on, residents are likely feeling the infrareds direct warmth before it has warmed up the air in the room. 4 of the residents noted that they felt they had more control over their heating and that it was also easier to use.

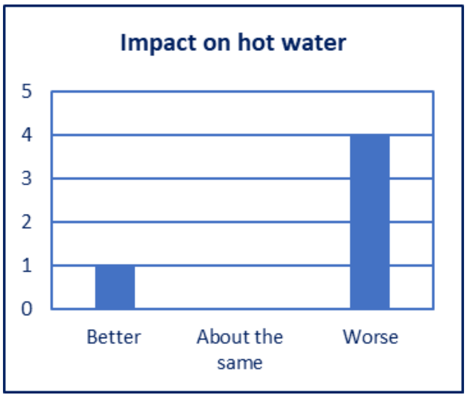


Figure 2.9 impact of the new system on use of hot water

A significant issue experienced by residents related to the output of hot water, figure 2.9 shows that 3 of the 5 residents thought the Inline hot water system had a negative impact on their hot water. The Inline system provides instantaneous hot water, whereas previously residents had heated an immersion heater over E7 charging hours to be used the next day. 3 of the residents stated issues with 'water pressure' and 2 residents stated issues concerning the low temperature of the hot water.

2 residents noted that when they used the InLine hot water system solid white crystals was present in the water. These residents received replacement systems and filtration devices (see figure 2.10), both solutions have failed to resolve the issue. One resident purchased a cold fill dishwasher as the dishes were left with debris on them after washing up by hand.

Figure 2.10 filtration system fitted to an InLine hot water system

2.6 Technical evaluation and results

Overview of technology

Logicor

Figure 2.11 Logicor Clear Heater system panel

Clear Heating System

The Logicor system is an on peak infrared heating system. The infrared panels are easily installed and can be mounted on walls or ceilings. The panels use "pulsed electricity and infrared heat to minimise energy use".[6] Infrared heating works by heating objects within a room rather than the air in a room as a convection heating system works.

The number and size of heaters are selected based on the floor area of the room. The manufacturer states that a large heater can cover up to 12 m^2 space and a small heater up to 6 m^2 of floor area. The heaters have a very thin carbon heating element sandwiched between two sheets of toughened glass with a mica insert to minimise rear facing heat loss.

The temperature is controlled via a control panel. Users can set temperatures and heating patterns for individual rooms whilst also zoning certain areas i.e. bathroom and kitchen areas.

InLine Hot Water System

The InLine Hot Water System uses electricity to provide hot water on demand. The system is designed to eliminate the need for a storage tank to meet hot water demand. He system has an output flow of 6 litres/min and a maximum temperature of 46°C. The system is also operated from the control panel although it can be used as a standalone unit.

2.7 Technical monitoring

- Lascar USB-2 thermal loggers were used to monitor the temperature and humidity within the living room and main bedrooms of the property.
- Tiny Tag View 2 current clamps were used to monitor the electricity consumption of the Logicor system.

A full schematic of the technical monitoring is available in Appendix 2.

2.8 Cost

	Before						After						Comparison	
Tech ref	Days	Total Period (kWh)	Total Cost	Degree days	kWh per Degree Day	Estimated annual cost	Days	Total Period (kWh)	Total Cost	Degree days	kWh per Degree Day	Estimated annual cost	Estimated saving (£)	Estimated saving (%)
T-34	505	15560	£1,547	3875	4.0	£856	495	11297	£1,808	3850	2.9	£1,007	-£151	-18%
T-33	504	11443	£1,191	3421	3.3	£747	502	11724	£1,876	3964	3.0	£1,015	-£268	-36%
T-45	-	-	-	-	-	-	490	18878	£3,020	3540	5.3	£1,830	-	-
T-66	601	22733	£2,213	4360	5.2	£1,089	279	8601	£1,413	1946	4.4	£1,558	-£469	-43%
T-50	409	10245	£916	2578	3.9	£762	545	19624	£3,140	4334	4.5	£1,554	-£792	-104%
Average					4.1	£864					4.0	£1,393	-£420	-50.13%

Table 2.12 annual energy costs pre and post install

Table 2.12 shows that 4 of the 5 residents annual electricity costs increased after the installation of the Logicor system. Costs could not be calculated for resident (T-45) as pre-install energy consumption data was not available. However, their post-install energy costs were the highest of all the households at £1,830 per annum. T-50 experienced the largest increase in annual costs

[6] http://www.clear-heater.co.uk/

which increased from £762 to £1554 per annum. This property was the smallest property and the only flat involved in the study. The increase in costs was associated with the resident achieving consistently warm room temperatures and the highest temperatures of all the properties (see table 2.16).

The household with a modest cost increase of 18% (T-34) experienced the second lowest temperatures in the living room and bedroom across the first monitoring period. Over the second monitoring period the property had the lowest temperatures (see tables 2.16 & 2.19).

Only 1 property saw an increase in the amount of energy required to heat the property (T-50). 3 properties experienced a decrease in energy use required to heat their properties, yet their costs still increased. This is related to the cost of electricity that residents were paying pre and post-install. Table 2.13 helps explain this as it shows the percentage of electricity residents were using on and off peak before the Logicor system was installed. All residents with available data were using an average of 75% of their energy off peak, taking advantage of lower electricity rates. The Logicor system operates on a single rate therefore residents lost the E7 hours of electricity that enabled them to heat their storage heaters at a lower cost per kWh. Whilst the kWh required to heat the home per degree day reduced there was no cost reduction as prior to Logicor system the price of a kWh was cheaper when used off-peak. The cheapest single unit rate available for these properties at the time of writing this report is around 11p per kWh with a standing charge of 22.5p per day, this price is provided by a smaller energy supplier who does not offer the warm homes discount.

Tech ref	On peak (kWh)	% used	Off peak (kWh)	% used	Total
T-34	4161	27	11399	73	15560
T-33	3549	31	7894	69	11443
T-45	-	-	-	-	-
T-66	5654	25	17079	75	22733
T-50	1807	18	8438	82	10245
Average		**25**		**75**	

Table 2.13 percentage of on and off peak usage before the infrared heating system was installed

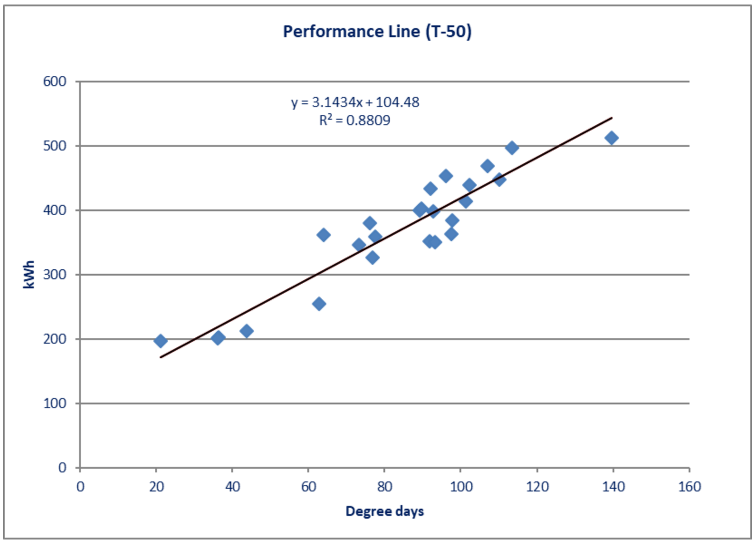


Figure 2.14 performance line of T-50 using the Logicor system

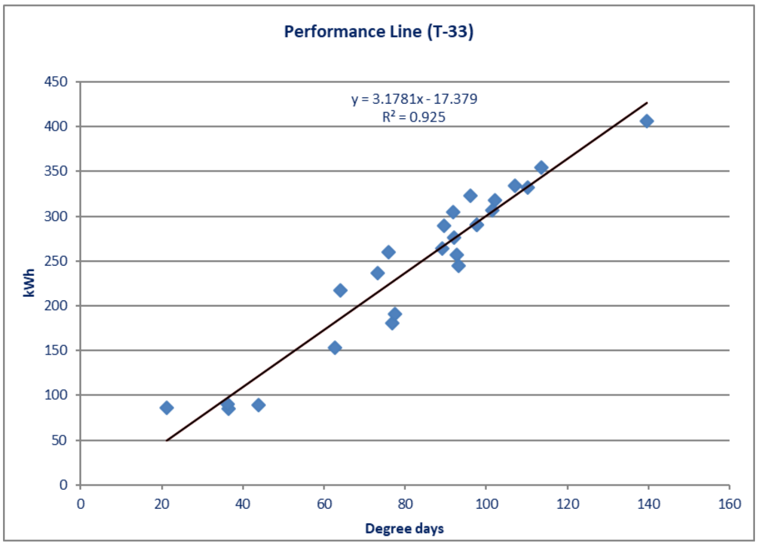


Figure 2.15 performance line of T-33 using the Logicor system

Figures 2.14 and 2.15 show the relationship between electricity used in the property and the number of degree days. The performance lines of T-50 & T-33 indicate good control of the heating system. This is indicated by the R^2 values of 0.89 and 0.92 respectively, an R^2 value of 0.75 and above indicates a reasonable correlation between degree days and consumption. As the degree days increase (external temperature decreases) the Logicor system responds to provide enough energy to meet internal temperature demand.

2.9 Temperature and thermal comfort

Temperature and humidity loggers were placed in the properties prior to the installation of the new system. These loggers were put in place to capture temperature levels whilst residents were still using the storage heaters. Unfortunately, the pre-data collected was during the summer months when heating was not in use.

Living room

Tech Ref No.	Average temperature (°C) *	Target temperature (°C) ↕	Post install - 19th November 2016 -1st April 2017				Post install - 1st November 2017 - 1st April 2018			
			6-10 pm	24 hours	24 hours	24 hours	6-10 pm	24 hours	24 hours	24 hours
			Average temperature (°C)	Average temperature (°C)	Maximum temperature (°C)	Minimum temperature (°C)	Average temperature (°C)	Average temperature (°C)	Maximum temperature (°C)	Minimum temperature (°C)
T-50	23.9°C		21.8	21.6	28.5	18.0	22.7	22.4	25.5	19.5
T-33	19.3°C	19	20.1	19.7	22.0	17.5	20.5	20.1	22.5	16.5
T-34	19.3°C	18	19.4	19.4	21.0	17.5	18.0	17.9	21.5	15
T-66			17.2	17.1	22.5	13.0	-	-	-	-
T-45			19.7	19.6	22.0	16.5	18.9	18.6	24.5	10
Average			19.7	19.5			20.0	19.8		

Table 2.16 living room temperatures post install

All but one of the residents experienced temperatures that were either within the 18°C - 21°C range or exceeded it. In the 2nd monitoring period all residents were within that range. The 2nd and 3rd columns reveal the average temperatures in the living room and the target temperature for that room, these were obtained from the Logicor controller unit. The average temperatures are within +1.5°C of the target temperatures, the placement of loggers likely contributes to the difference between average temperature and target temperature.

There was hardly any variation in average temperatures across the 24-hour period and the 6 – 10pm comfort period. T-66's 24-hour average temperature was 17.1°C and the temperature in the 6 - 10pm period was 17.2°C. The most significant difference was T-33 where the temperature difference between the two periods was 0.4°C. The lack of temperature change indicates that these temperatures were close to being achieved throughout the whole 24-hour period, therefore T-50 was heating the property to 21.5°C plus throughout a 24-hour period.

Logicor recommend that the system is "switched on at all times to achieve optimal heating performance and cost savings". There is the option to vary temperatures during the day using the programmer, yet none of the systems had been set up to work in that manner. This meant that some residents were heating rooms that were not always in use which could have been heated at lower temperatures. Table 2.17 below shows the average temperatures recorded by the Logicor units in 3 of the households' rooms. The table shows that for all 3 properties only 1 heated room was heated at an average temperature below the 18°C – 21°C range, the excessive periods of heating and additional rooms being heated explains why the costs experienced by residents are high.

Tech ref	Lounge	Master bedroom	Additional bedrooms	Bathroom	Kitchen	Hall	Landing	Other room
T-50	23.9°C	23.3°C	-	22°C		21.7°C		22.1°C
T-33	19.3°C	18.1°C	17.6°C	-	19.5°C	18°C	18.5°C	19.5°C
T-34	19.3°C	21°C	20.3°C	20.3°C	20°C	-	21.4°C	-

Table 2.17 average temperatures of different rooms taken from the Logicor in home display

‘*It is recommended to leave your heater system switched on at all times to achieve optimal heating performance and cost savings. You may prefer to vary the temperature during the day. To do this, schedule your heater system to heat at different temperatures at set times of the day for each day of the week*.’
Logicor CHS user guide

‘Events’ can be added to increase or decrease the internal temperature throughout the day. The display is shown below in figure 2.18. The programmer element is not intuitive to use and none of the residents had these events set up.

Figure 2.18 example of daily heating schedule on the Logicor in home display

One of the benefits of infrared heating cited by Logicor is that objects within the room such as the sofa and person sitting on it are heated rather than the air. This should mean that heat is almost instantaneous, and energy is not wasted heating the remainder of the room. The main method of controlling the temperature of the infrared system is through a thermostat which will turn off when the set temperature is reached. This thermostat will respond to the air temperature within the room therefore, the infrared panels are still required to heat the air even if it is indirectly.

Bedroom

Tech Ref No.	Average temperature (°C) *	Target temperature (°C) ǂ	Post install - 19th November 2016 -1st April 2017				Post install - 1st November 2017 - 1st April 2018			
			6-10 pm	24 hours	24 hours	24 hours	6-10 pm	24 hours	24 hours	24 hours
			Average temperature (°C)	Average temperature (°C)	Maximum temperature (°C)	Minimum temperature (°C)	Average temperature (°C)	Average temperature (°C)	Maximum temperature (°C)	Minimum temperature (°C)
T-50	23.3		22.8	22.7	28.0	19.5	22.8	22.8	27	21.5
T-33	18.1°C	17	15.4	15.5	19.5	13.5	16.3	16.3	19.5	14.5
T-34	21°C	18	16.2	16.2	19.5	13.5	14.1	14.1	16.5	10.5
T-66			16.9	16.8	20.5	13.0	-	-	-	-
T-45			17.9	18.0	21.5	15.0	18.0	18.1	25	14.5
Average			17.8	17.8			17.8	17.8		

Table 2.19 bedroom temperatures post install

The bedroom temperatures are like those in the living room, the average temperature does not vary much between the 24-hour period and 6-10pm period. 1 of the residents has the bedroom warmer than the living room but the rest have cooler bedrooms. There is a significant degree of difference in the average temperatures recorded by the Logicor unit and those recorded by the temperature loggers. Both sets of figures are not close to the target temperature of 18°C in either period post install.

2.10 Humidity

Water vapour in the air is, usually referred to as relative humidity (RH) and quantifies the percentage of water vapour held by the air when compared to the saturation level (the highest quantity of water able to be supported by the air at a given temperature), is not usually considered to be an indoor contaminant or a cause of health problems. In fact, some level of humidity is necessary for comfort. Conversely, the relative humidity of indoor environments (over the range of normal indoor temperatures of 19 to 27°C), has both direct and indirect effects on health and comfort. The direct effects are the result of the effect of relative humidity on physiological processes, whereas the indirect effects result from the impact of humidity on pathogenic organisms or chemicals which may affect health.

The automated data-loggers used in this project record both temperature and relative humidity (RH) at pre-determined intervals across the study properties. RH is a ratio (expressed as a percentage) of the amount of moisture present in the air at each logging point, relative to the amount that would be present if the air were saturated. Since the latter amount is dependent on temperature, relative humidity is a function of both moisture content and temperature. Relative Humidity is derived from the associated Temperature and Dew Point for the indicated sample. The higher the value of RH, the more water vapour is contained in the air. High values are problematic, and can cause damage to building fabric and furnishings, and can cause mould growth and cause health problems associated with this high humidity. From the Building regulations part F[7]; the suggested average monthly maximum humidity levels for domestic dwellings during the heating season is 65%.

[7] Available from https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/468871/ADF_LOCKED.pdf [Accessed 21/03/2017]

Living room

Tech Ref No.	Post install - 19th November 2016 -1st April 2017				Post install - 1st November 2017 - 1st April 2018			
	6-10 pm	24 hours	24 hours	24 hours	6-10 pm	24 hours	24 hours	24 hours
	Average humidity (RH%)	Average humidity (RH%)	Maximum humidity (RH%)	Minimum humidity (RH%)	Average humidity (RH%)	Average humidity (RH%)	Maximum humidity (RH%)	Minimum humidity (RH%)
T-50	45.0	43.5	55.5	30.0	38.5	37.2	54.5	21.5
T-33	61.4	59.4	81.0	42.5	56.5	55.1	79	33
T-34	53.8	53.5	65.5	39.0	56.5	56.4	77	45
T-66	53.5	53.4	67.5	31.5	-	-	-	-
T-45	60.8	60.1	76.0	39.0	58.1	55.7	75.5	29.5
Average	54.9	54.0			52.4	51.1		

Table 2.20 living room humidity levels post install

Over a 24-hour period humidity levels were between the 40% - 60% recommended range in all properties in the living room (table 2.20). There were 2 properties that were at the upper end of this range (T-33 & T-45) and 1 at the lower end of the range (T-50)

In the main bedrooms (table 2.21) 4 of the 5 residents were outside of the 40% - 60% range. One of these properties was just under the threshold and was the same resident that experienced the highest room temperatures. Higher humidity levels are associated with lower temperatures, which these 4 residents did experience.

Bedroom

Tech Ref No.	Post install - 19th November 2016 -1st April 2017				Post install - 1st November 2017 - 1st April 2018			
	6-10 pm	24 hours	24 hours	24 hours	6-10 pm	24 hours	24 hours	24 hours
	Average humidity (RH%)	Average humidity (RH%)	Maximum humidity (RH%)	Minimum humidity (RH%)	Average humidity (RH%)	Average humidity (RH%)	Maximum humidity (RH%)	Minimum humidity (RH%)
T-50	39.2	39.5	49.5	24.5	38.6	38.8	51.5	26
T-33	66.6	68.2	77.5	54.0	58.9	60.6	73	40.5
T-34	66.2	67.0	78.0	47.5	74.2	74.9	86	53
T-66	56.1	57.7	82.0	38.5	-	-	-	-
T-45	66.4	67.4	79.0	46.5	62.8	64.5	78.5	32.5
Average	58.9	60.0			58.6	59.7		

Table 2.21 bedroom humidity levels post install

2.11 Conclusions and recommendations

Conclusions

Annual energy costs increased for 4 of the 5 residents in this study, the final resident had no pre-data available. This is despite the actual amount of electricity consumed reducing in all but one of the properties. When the residents had storage heaters they consumed around 75% of their energy during Economy 7 hours, this proportion of usage combined with the lower price per kWh meant that despite using more energy they paid less. Most of the systems were set up to operate on a room by room basis, where the temperature always remained the same i.e. 21°C. The system could be set up to operate on a timed basis where the temperature level could be altered however none of the systems had been set up in this manner. There has been a significant trade-off for residents between increased control over their heating and the cost that they pay for their energy.

A comparison table that features key performance indicators for all the technologies trialled can be found in section 10.1.

Recommendations for potential future installations

It is not recommended that this technology is installed in homes of those at risk of fuel poverty, particularly those that require heating throughout the day and night. This technology may be suitable in homes where intermittent heating is required, if the system is set up to reduce temperatures across different periods.

Only properties with a significant amount of thermal insulation should be selected for this system and they should be placed on low single rate tariff for the system to be price competitive against storage heaters. Regular reviews and comparisons of available tariffs should be done to ensure the best deal is selected.

Impact on fuel poverty

The Logicor infrared clear heater system and InLine hot water system are expensive to purchase, install and use. 3 of the residents had costs more than £1,500, 1 of those resident’s costs were c.£1800. Residents did have more control over their heating, they were able to set exact temperatures and times when they wanted to be warm. This was something they were unable to do with the storage heaters. However, despite achieving desired temperatures the trade-off between increased comfort but an increase in cost was too great for some residents.

Additionally, the hot water system was problematic in several properties. The issues cited were related to low water temperature, flow rates and a grit like substance in the water from the hot water tap. 2 of the properties experienced a grit like substance in their hot water. Measures were put in place to attempt to solve these issues, these included replacements of the system and the addition of a filtration system. All residents noted that they were still having some form of issue with their hot water during the final questionnaire. 1 resident cited they do not use the bath and have had to buy a dishwasher because of the grit like substance. Hot water is a significant proportion of energy use within the home whilst also an essential source of residents’ well-being.

Performance comparison against manufacturer’s/manufacturers’ claims

Logicor does not state how much its customers can expect to save when installing the Clear Heater system and InLine hot water system, only stating that savings are substantial.[8]

Economic business case for installation of measures

The cost to purchase and install the Logicor system in this project was £6,266. There is no subsidy such as the feed-in-tariff or renewable heat incentive received for installing using this technology, this means the high upfront cost cannot be offset like it can against an ASHP. All resident costs increased and, in some cases, substantially. Residents are likely to be in a worse financial position after installation, this may affect their ability to purchase other essential goods and services.

The SAP rating also reduced in all the properties, in part this is because the rdSAP does not differentiate the Logicor Clear Heater system from other forms of on peak electric heating. This will have a significant impact as housing associations and private landlords look to increase EPC ratings up to a band C in line with government targets.

[8] http://www.clear-heater.co.uk/save-energy.html

3.1 ASHP & Solar PV

6 households had solar photovoltaic panels and an air source heat pump installed. The properties were situated in off-gas areas and previously used other sources of fuel to heat their homes, 5 of the properties were reliant on coal central heating systems.

3.2 Social evaluation and impacts

Qualitative feedback from initial questionnaire

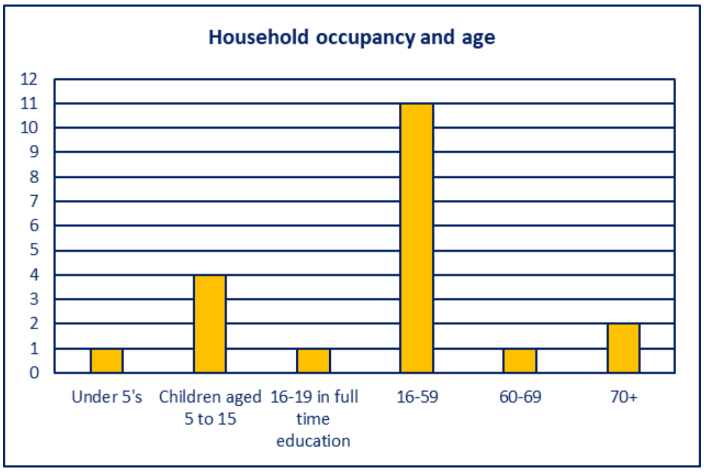


Figure 3.1 household occupancy and age

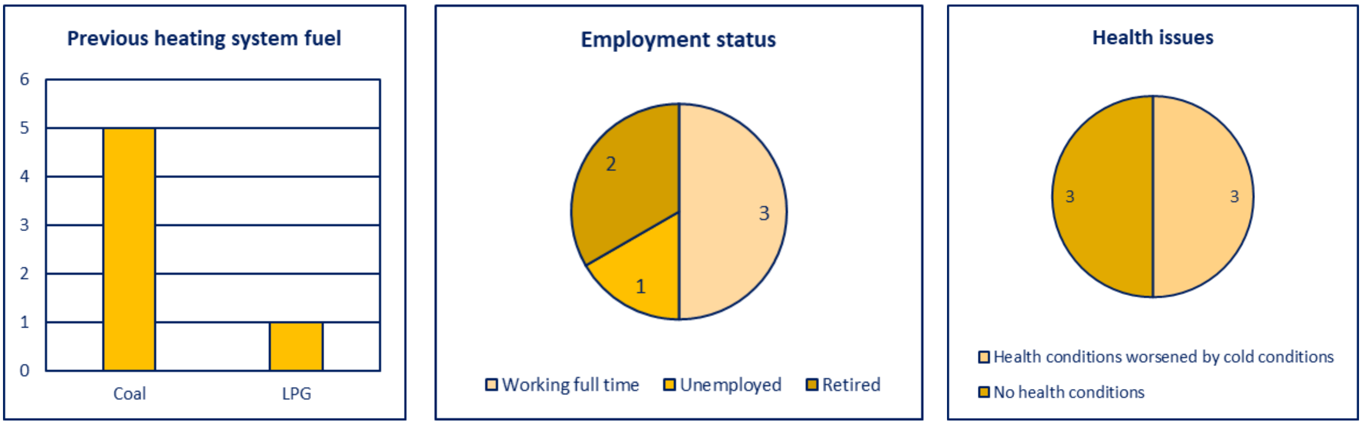


Figure 3.2 (a) previous heating fuel (b) employment status (c) health issues

Figure 3.1 shows that the residents involved in the study ranged from under 5 years old up to 70 plus, though most residents were between the ages of 16-59. 4 of the 6 households comprised more than 3 residents, with 1 household comprising of 7 residents. 3 residents interviewed worked full time, 2 were retired and 1 unemployed (figure 3.2 b). 3 of the residents stated that they had health conditions that were worsened by the cold, the issues stated included; asthma, COPD, osteoarthritis and angina (figure 3.2 c). These factors all influence the heating demand of each household.

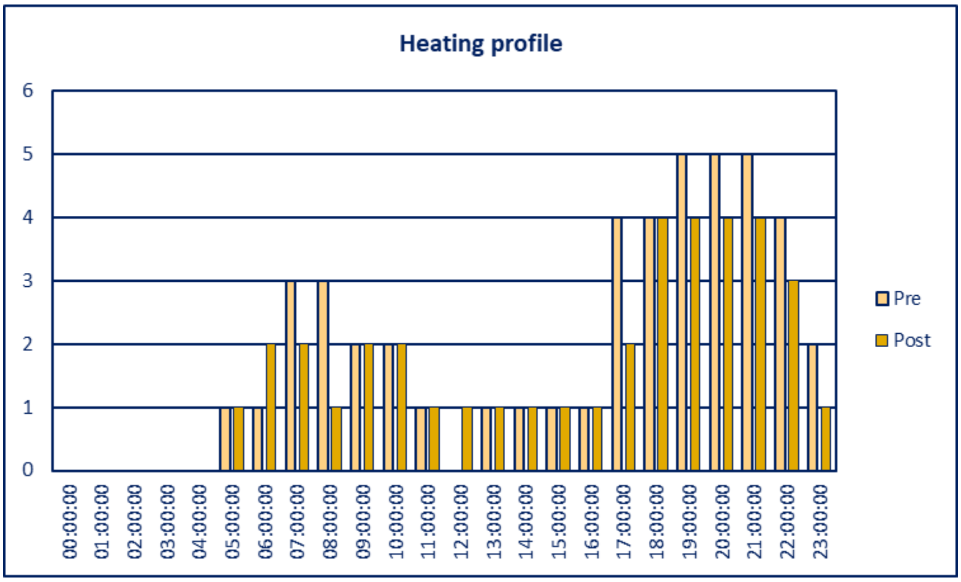


Figure 3.3 household heating profiles

Residents were asked if there was a specific time of the day when they felt it was most important to have a warm home. This might be when they are least active e.g. sitting watching TV in the evening or when washing/dressing first thing in the morning. Residents were asked this in the questionnaire at the start of the project and then again at the end.

Figure 3.3 shows the results summed up across all respondents. There is a peak in demand for heating from residents between 5pm – 10 pm, this is particularly prevalent in the pre-installation questionnaire. There were some residents who wanted to be warm in the morning, this is due to the varied occupancy and lifestyles of those involved in the study.

			Pre		Post	
Tech Ref	Size (m²)	House type	Rating	Band	Rating	Band
T-51	89	Semi-detached House	54	E	63	D
T-27	99	Semi-detached House	56	D	81	C
T-20	109	Semi-detached House	53	E	77	C
T-06	75	Semi-detached House	-	-	74	C
T-10	70	Semi-detached House	34	F	74	C
T-18	71	End-terrace House	60	D	63	D

Table 3.4 property characteristics

Table 3.4 shows that of the 5 residents that have pre and post install SAP certificates all saw an increase in their rating. 4 of the 6 were now in band C and the remaining 2 were rated in band D. 1 resident (T-10) moved from a band F to a band C. All but 1 property was semi-detached with 3 bedrooms (T-18). All properties had either cavity wall insulation or external wall insulation.

3.3 Resident acceptance and satisfaction

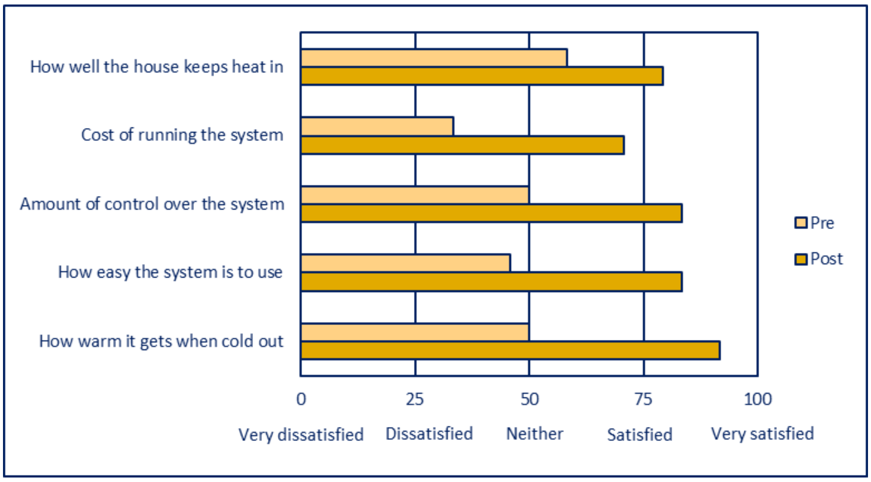


Figure 3.5 resident's satisfaction with system performance

Residents noted significant improvement in satisfaction related to the statements above. Post install satisfaction levels rose to satisfied for nearly all the questions, the only statement that fell short was "cost of running the system". Satisfaction with the cost of running the system still increased, prior to the install it had the lowest satisfaction level of the 5 statements. 1 resident previously received free coal, so they saw an increase in their annual costs. Residents were satisfied with how warm their homes got when it was cold outside after the ASHP was installed. Residents had a system installed that they could leave to operate on a pre-programmed set up or control manually through the thermostat. The old coal system had to be topped up to continually provide heat and some properties previously had no heating upstairs.

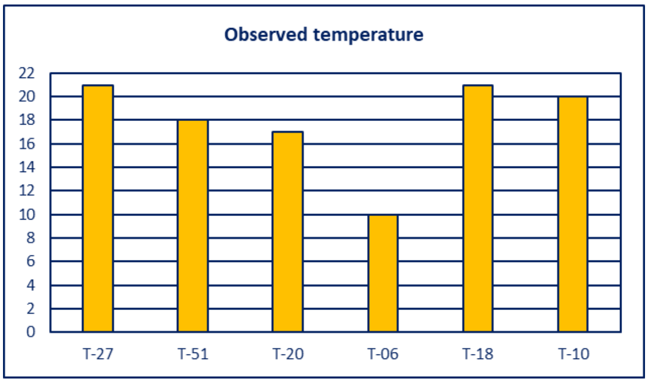


Figure 3.6 observed thermostat temperatures settings post install

Room temperatures varied in properties and differed depending on the time of day. Many residents had the system set up to run continuously but at different temperatures for instance T-20 had the heating set at 17°C during the day and 21°C in the evening (daytime temperature shown in figure 3.6). A heat pump should be more efficient when running at lower temperatures over extended periods.

3.4 Affordability of energy bills

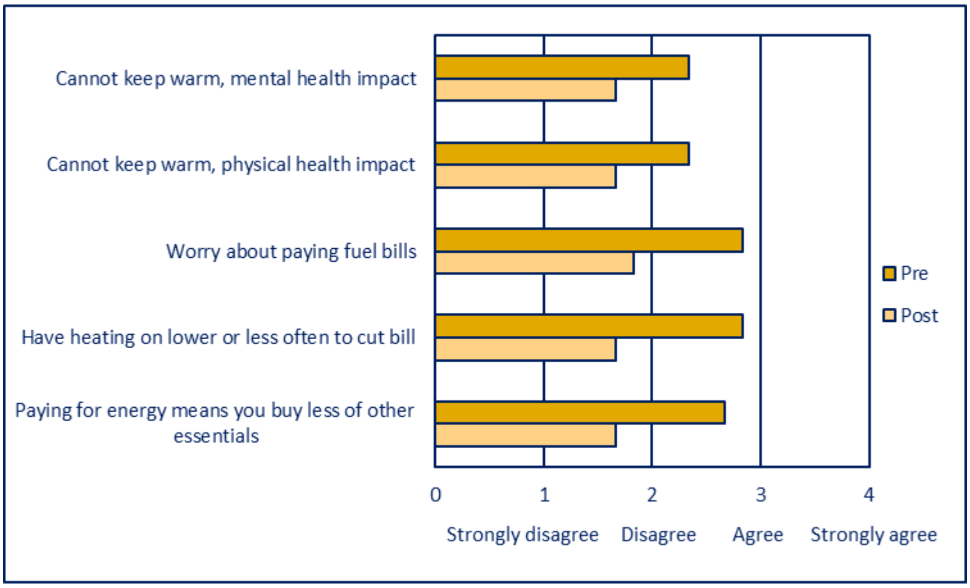


Figure 3.7 resident's level of agreement with affordability of energy

Figure 3.7 shows that some residents had concerns relating to the affordability of their energy and ability to ensure a warm home. These concerns lessened after the ASHP was installed and only 1 resident stated that they worried about paying their fuel bills. Post install residents were considerably less concerned about having the heating on lower or less often to keep the bill affordable. 1 resident had previously used their heating every other day due to the cost of coal.

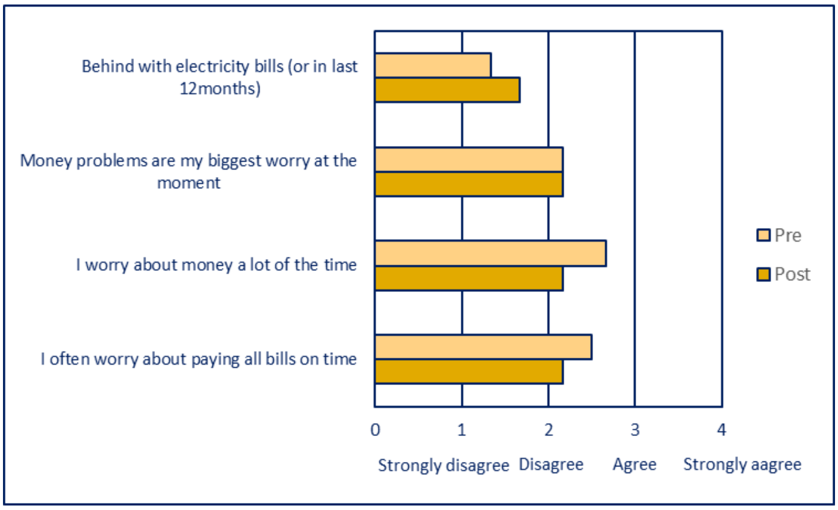


Figure 3.8 resident's level of agreement with money concerns

General money worries lessened across the residents, with most no longer worrying about money 'a lot of the time'. All residents stated that they were not behind with their electricity bills at present or in the last 12 months. This was the case both pre and post install, the slight increase post install relates to fewer residents stating that they strongly disagreed with the statement.

3.5 Ease of use and reliability

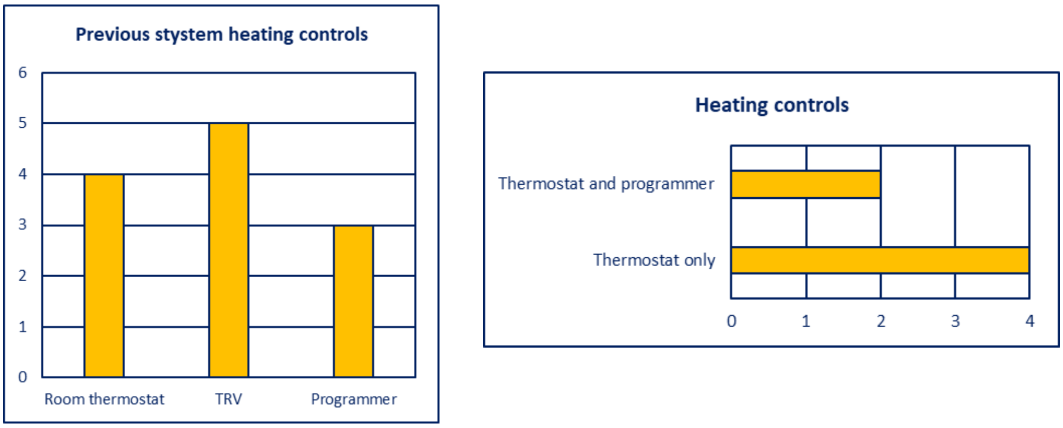


Figure 3.9 (a) previous method of controlling the heating system (b) method of controlling the new system

Residents had several different ways of controlling their heating before the ASHP system was installed as show in in figure 3.9 (a). Once the ASHP system was installed all the residents had a room thermostat, programmer and TRV's to control their heating system (b). In the final questionnaire all the residents stated that they knew how to use these controls and used them regularly. Using the room thermostat was the most popular method to control the system pre and post install of the ASHP system.

3.6 Perceived comfort and benefits

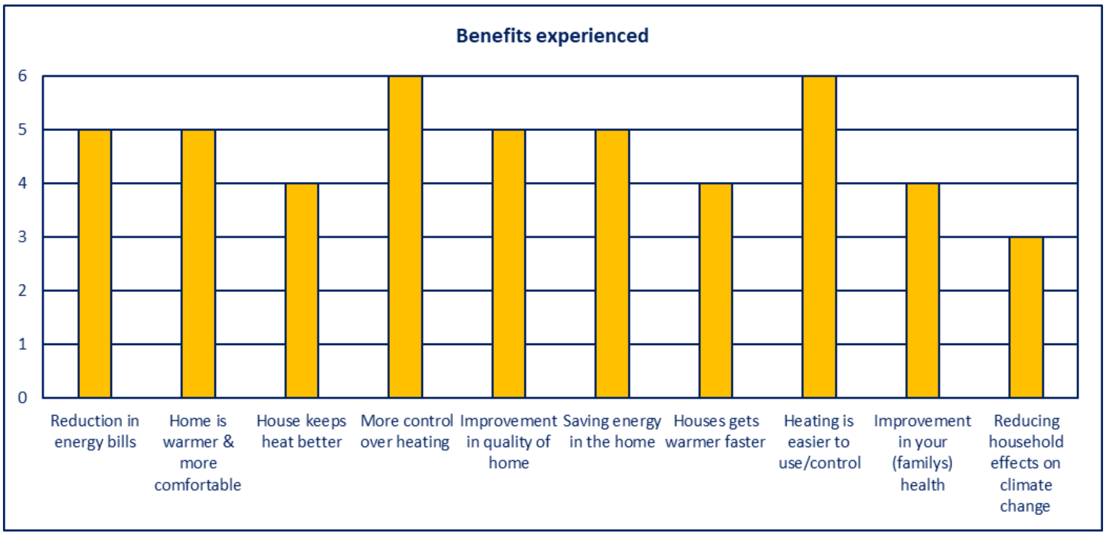


Figure 3.10 benefits noted by the residents' post install

Many benefits were noted by residents after the ASHP was installed. All 6 residents noted that they had more control over their heating and that it was easier to use. 5 residents noted that there was a reduction in their energy bills whilst there also being an increase in the warmth and comfort of their homes. 5 residents stated that they thought there was an improvement in the quality of their home. Some of these residents previously had open coal fires which when burning can release particulates that can irritate airways and exacerbate underlying conditions such as COPD and Asthma. 4 of the residents cited an improvement in their health as one of the benefits experienced after having the ASHP installed. 1 resident suffered from asthma and had to visit the GP 5 or 6 times a year (T-51) since having the new system installed they have only had to visit the GP twice. A case study in Appendix 3 reveals the impact that a new heating system has had on the residents of one property.

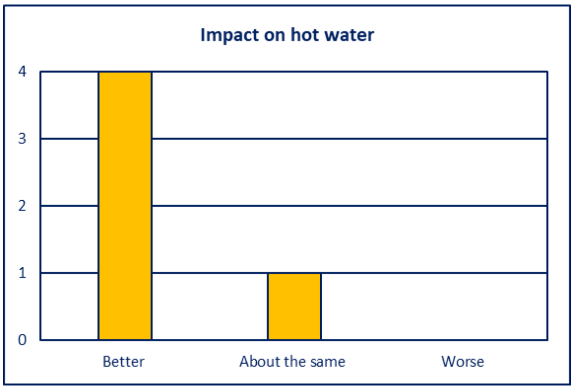


Figure 3.11 impact of the system on use of hot water post install

Figure 3.11 shows 4 residents stated that the ease of using the hot water was better with the new system. Using the previous coal system some residents had to put the heating on to heat their hot water, something that would be costly, wasteful and uncomfortable to do in the summer. The new system improved the availability of hot water and reduced costs.

3.7 Technical evaluation and results

Overview of technology

A Mitsubishi Ecodan heat pump and Canadian Solar Cs6p-m PV system were installed in 6 properties. Heat pumps and solar PV are well established renewable technologies. It is unusual for an older property to have a heat pump and associated solar PV system installed, both technologies have high upfront purchase costs and must be retrofitted to existing structures.

Utilising a PV system alongside a heat pump has the potential to reduce the amount of electricity purchased from the grid that is required to operate the heat pump. The generation of solar derived electricity (PV) will have some overlap with heating demand but most of the generation will take place when the demand for heat is lowest. The study aimed to quantify the cost of running the systems with PV over at least a full year.

3.8 Technical monitoring

- Lascar USB-2 thermal loggers were used to monitor the temperature and humidity within the living room and main bedrooms of the property.
- Tiny Tag View 2 current clamps were used to monitor the electricity used within the property.
- Heat meters alongside event loggers were installed to monitor the heat output of the heat pump – failed to record data

- Watt hour meters alongside pulse loggers were fitted to monitor the electrical input into the heat pump.

A full schematic of the technical monitoring is available in Appendix 2.

3.9 Cost

Pre							Post						Comparison	
Combined coal/LPG and electricity costs							Electricity costs							
Tech Ref	Period	Days	Degree Days	Coal annual costs*	Electricity annual costs	Total annual costs	Period	Days	Total Period (kWh)	Degree days	Total annual cost	Saving (£)	Saving (%)
T-51	8/5/16 - 19/7/16	438	2,776	£600	£1,260	£1,860	19/11/16 - 24/2/18	462	17585	3461	£1,744	£116	6%
T-10	28/5/16 - 30/8/16	460	2,711	£910	£683	£1,593	25/10/16 - 8/3/18	499	11414	3873	£1,011	£581	36%
T-27	2/12/14 - 2/6/16	548	4,336	£1,440	£619	£2,059	31/8/16 - 5/4/18	582	14736	4404	£1,148	£910	44%
T-06**	1/8/14 - 31/7/15	364	2,470	£0	£348	£348	3/10/16 - 16/4/18	560	6306	4425	£489	-£141	-40%
T-18 ƚ	2/7/15 - 1/7/16	365	2,496	£784	£900	£1,684	12/10/16 - 12/4/18	551	13202	4375	£1,036	£648	38%

Table 3.12 annual energy costs pre and post install

* Coal costs have been calculated based on the amount of coal residents reported they used across a year.
** T-06 received free coal
ƚ T-18 used LPG

It was not possible to monitor the energy (kWh) provided by the coal central heating system prior to install of the new systems. The analysis is reliant on residents reported usage i.e. how many bags of fuel they used, how often and at what cost per bag.

4 of the 5 residents costs decreased after the installation of the ASHP and solar PV panels (table 3.12). The 1 resident that experienced an increase in cost used to receive free coal. Their annual cost remained the lowest of the monitored group at £489 per annum. Annual costs pre and post install varied between households, 1 resident paid over £2000 per year on their energy costs. This household used coal and logs to meet their heating and hot water demand throughout the year.

T-51 had particularly high energy costs pre and post install. The property did not have highest internal temperatures although the property did maintain temperatures of 21°C in the living room and 20°C in the bedroom (see tables 3.18 & 3.19). The high heat demand can be partly explained by the fact that there were 7 people living in this property including young children. The resident stated during the interim questionnaire that they that they often set the room temperature at 26°C, the resident was made aware that this was not an efficient way to operate a heat pump. The change in behaviour is reflected in that the resident's living room temperature was 21°C between 6pm-10pm. The heat pump would not operate as efficiently when trying to reach that temperature, particularly when it was cold outside. Unfortunately, there was no data on the PV generation for this property in table 3.13 so the impact the PV had could not be assessed.

T-10, T-18 and T-27 all maintained temperatures above 21°C and kept their annual costs below £1,150.

Tech ref	PV generation	50% used onsite	Amount saved	Amount saved over 1 year	Annual costs	Annual costs excluding PV
T-27	5228	2614	£418	£269	£1,148	£1,417
T-10	2247	1123.5	£180	£116	£1,011	£1,127
T-18	1950	975	£156	£100	£1,035	£1,135
T-06	3788	1894	£303	£195	£489	£684

Table 3.13 impact of PV usage on annual costs

The solar PV system had a significant impact on some of the residents' annual electricity costs. T-27 had the 2nd highest annual costs at £1,148. The value of PV generated, assuming 50% was used on site, was £279 which is a significant cost to be offset from the annual electricity bill (see table 3.13). Whilst the PV does not provide electricity at times when electricity demand is at highest (see figure 3.16) it still reduces residents' electricity costs.

3.10 Seasonal Coefficient of Performance

The Seasonal Coefficient of Performance (SCOP) is a measure of the efficiency of a heat pump over a year. It is the ratio of the energy supplied by the heat pump to the energy used in its operation (electricity). The following section illustrated the valued measured through this project.

Tech ref	Year	Heating output	Hot water output	Total output	Heating input	Hot water input	Total input	SCOP	Heat SCOP	HW SCOP
T-06	2017	2956	792	3748	1588	575	2163	1.73	1.86	1.38
T-20	2017	6860	1871	8731	3120	1327	4447	1.96	2.20	1.41
T-18	2017	8252	2619	10871	2419	942	3361	3.23	3.41	2.78
T-10	2017	7984	3141	11125	2897	1535	4432	2.51	2.76	2.05
T-51	2017	11031	3190	14221	3823	1344	5167	2.75	2.89	2.37

Table 3.14 electrical input and heat output of the heat pumps

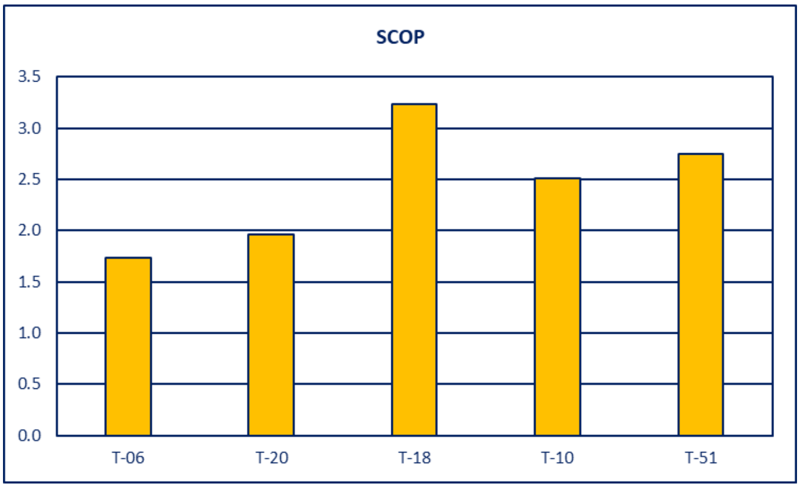


Figure 3.15 seasonal coefficient of performance of the heat pumps

Renewable Heat Incentive Payments (RHI) for ASHP systems are based on a deemed heat demand figure. A SCOP of 2.5 is the minimum level of performance that makes a heat pump eligible for RHI payments. If these systems were metered and payments based on actual readings, then 2 properties would not be eligible for RHI payments T-06 & T-20. This would have a significant impact on the financial viability of installing an ASHP. The efficiency of an ASHP can be affected by several factors such as intermittent heating cycles, low external temperature and high hot water demand.

T-06 had the lowest SCOP at 1.75 (figure 3.15). This resident also had their ASHP system set up to provide a temperature of 10°C during the day that rose to 18°C for 2-4 hours a day. The low set back temperature meant it was unlikely that the ASHP was operating continuously therefore having to work harder to raise the internal temperature when that heat demand was required. T-10 and T-20 both had low SCOP of 2.51 and 1.96 respectively. These properties had the highest hot water demand (see table 3.14) of all 5 properties as a percentage of usage and amount of electricity used. All the heat pumps were less efficient at providing hot water as evidenced in table 3.14.

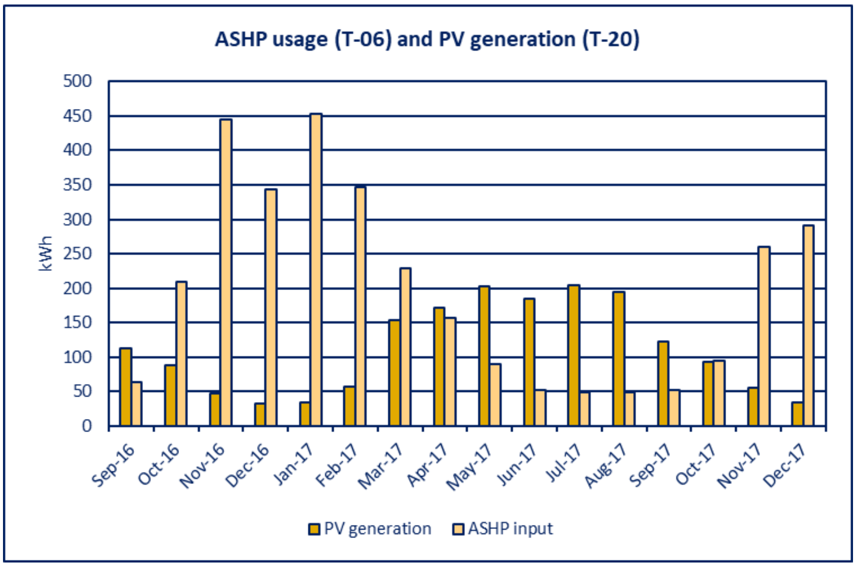


Figure 3.16 chart comparing the use of PV generation against use of the heat pump

Figure 3.16 shows the ASHP usage and PV generation at 2 separate properties (T-06 & T-20) from September 2016 to December 2017. The chart highlights that the solar PV generates most electricity at times when the demand for heating from the ASHP is at its lowest i.e. May to September. This still has a significant impact on residents' costs however the benefit will be seen over the summer period rather than the winter. 2 of the residents paid their electricity costs by direct debit which may mean that over the spring and summer they are able to build up credit for the winter period when heating demand is higher.

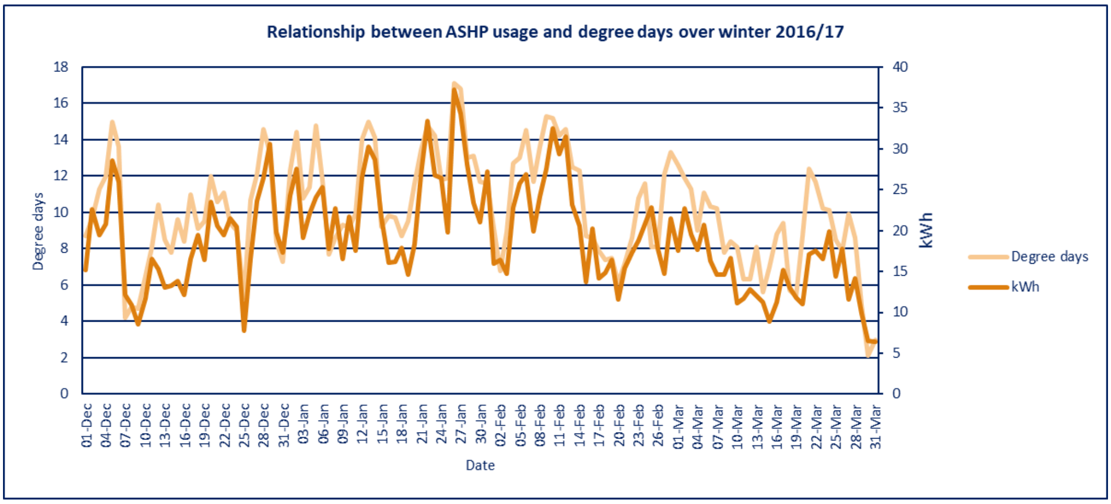


Figure 3.17 relationship between ASHP usage and changes in external temperature

Figure 3.17 shows the relationship between the ASHP usage and the degree days (outside temperature) at T-10. The chart shows the ASHP responding to the external temperature i.e. when it gets colder (degree days increasing) the input into the ASHP increases to maintain the internal temperature. An R^2 value of 0.9 indicates a strong correlation between the ASHP usage and degree days over the winter of 16/17.

3.11 Temperature and thermal comfort

Living room

Tech Ref No.	Post install - 19th November 2016 - 1st April 2017				Post install - 1st November 2017 - 1st April 2018			
	6-10 pm Average temperature (°C)	24 hours Average temperature (°C)	24 hours Maximum temperature (°C)	24 hours Minimum temperature (°C)	6-10 pm Average temperature (°C)	24 hours Average temperature (°C)	24 hours Maximum temperature (°C)	24 hours Minimum temperature (°C)
T-51	-	-	-	-	21.0	21.2	26.5	7.5
T-10	23.6	23.4	27.0	21.0	23.2	23.2	26.5	19
T-20	21.1	20.9	24.0	17.5	20.6	20.5	23.5	16.5
T-27	23.0	22.9	25.0	19.5	22.4	22.4	26	17
T-06	19.5	18.5	23.0	12.5	-	-	-	-
T-18	22.1	21.2	25.0	16.5	21.6	21.5	24.5	16
Average	21.8	21.4			21.8	21.8		

Table 3.18 living room temperatures post install

Table 3.18 reveals that all residents achieved living room temperatures between or above 18°C – 21°C across the monitored periods. This was across the 24-hour average period and the preferred comfort period of 6pm–10pm. There was no significant variation in the average 24-hour temperature and the 6pm–10pm temperature. The first period post install shows that there was a 0.4°C difference between the temperature between the 2 specified times, the second period shows there was no difference at all. The biggest difference was 1°C at T-06. Table 3.19 shows the temperatures when residents want to be warm and then the setback temperature. A setback temperature is common in UK households and works well for responsive heating systems such as gas boilers[9]. A setback temperature is normally set when residents are least active i.e. night or absent from the property when the temperature can be lower. Table 3.19 shows that there was 3-4°C difference in normal temperatures and setback temperatures, but this was not reflected in the temperatures achieved. The similar temperatures across both periods (6-10pm & 24 hours) indicate either that the setback temperatures are not in place or that the properties are retaining the heat and the ASHP is meeting the heating demand over a winter heating period. The ASHP will operate most efficiently when left to operate over an extended period at a low temperature and the setback temperature should only be 2°C less than the normal temperature.

Tech ref	Normal temperature	Setback temperature
T-27	21°C	17°C
T-51	18°C - 26°C	-
T-20	21°C	17°C
T-06	18°C	10°C
T-10	20°C	17°C

Table 3.19 system temperatures and set back temperatures as reported by residents

Bedroom

Tech Ref No.	Post install - 19th November 2016 - 1st April 2017				Post install - 1st November 2017 - 1st April 2018			
	6-10 pm Average temperature (°C)	24 hours Average temperature (°C)	24 hours Maximum temperature (°C)	24 hours Minimum temperature (°C)	6-10 pm Average temperature (°C)	24 hours Average temperature (°C)	24 hours Maximum temperature (°C)	24 hours Minimum temperature (°C)
T-51	20.3	19.8	23.0	17.0	-	-	-	-
T-10	23.2	23.0	25.5	20.0	23.1	22.9	26	18.5
T-20	-	-	-	-	19.6	19.2	23.5	15
T-27	20.0	19.8	24.0	14.5	19.1	18.6	25	11.5
T-06	17.4	16.6	20.5	10.5	15.4	14.8	20	10
T-18	20.0	19.8	23.5	16.5	19.6	19.4	22.5	16
Average	20.2	19.8			19.4	19.0		

Table 3.20 bedroom temperatures post install

5 of the residents achieved bedroom temperatures between or above 18°C – 21°C across 1 or both monitored periods. T-06 had the lowest bedroom temperatures at 16.6°C in the first period and 14.8°C in the second period. This resident stated in the final questionnaire that they do not heat their bedroom as they prefer a cooler bedroom due to their COPD.

[9] http://www.esru.strath.ac.uk/Documents/MSc_2011/Baster.pdf

3.12 Humidity

Living room

Tech Ref No.	Post install - 19th November 2016 - 1st April 2017				Post install - 1st November 2017 - 1st April 2018			
	6-10 pm Average humidity (RH%)	24 hours Average humidity (RH%)	24 hours Maximum humidity (RH%)	24 hours Minimum humidity (RH%)	6-10 pm Average humidity (RH%)	24 hours Average humidity (RH%)	24 hours Maximum humidity (RH%)	24 hours Minimum humidity (RH%)
T-51	-	-	-	-	49.5	48.4	87.5	24
T-10	50.9	51.3	63.5	27.0	50.7	51.5	65.5	28
T-20	51.0	50.0	67.5	33.0	40.0	40.0	57.5	24.5
T-27	38.0	37.0	61.5	22.5	36.7	35.9	53	22
T-06	49.2	49.1	61.5	38.5	-	-	-	-
T-18	51.1	50.0	67.0	24.5	49.3	46.9	68	27
Average	48.0	47.5			45.2	44.5		

Table 3.21 living room humidity levels post install

Humidity levels in 5 of the 6 properties were between the recommended 40%-60% rh range. T-27 was just below the recommended range, the humidity level in that property could be reduced by reducing the household temperature which averages around 22.5°C.

Bedroom

Tech Ref No.	Post install - 19th November 2016 - 1st April 2017				Post install - 1st November 2017 - 1st April 2018			
	6-10 pm Average humidity (RH%)	24 hours Average humidity (RH%)	24 hours Maximum humidity (RH%)	24 hours Minimum humidity (RH%)	6-10 pm Average humidity (RH%)	24 hours Average humidity (RH%)	24 hours Maximum humidity (RH%)	24 hours Minimum humidity (RH%)
T-51	65.9	64.5	78.5	50.5	-	-	-	-
T-10	55.6	57.2	72.0	38.5	51.8	54.4	71.5	38
T-20	-	-	-	-	50.3	50.5	67	32.5
T-27	43.7	44.0	60.0	30.0	52.6	52.4	82	33
T-06	51.8	53.2	66.0	44.5	55.2	56.6	70.5	42
T-18	51.5	52.5	72.0	38.5	45.4	45.7	67.5	31
Average	53.7	54.3			51.1	51.9		

Table 3.22 bedroom humidity levels post install

Humidity levels in 5 of the 6 properties were between the recommended 40%-60% rh range. T-51 was above the recommended range, it is not clear why the humidity levels in this property are above the recommended range.

3.13 Conclusions and recommendations

Conclusions

5 of the 6 residents saved money on their annual energy costs, 1 resident used to receive free coal so experienced an increase in costs whilst there was no data for the additional resident. Residents expressed increased satisfaction with how much control they had over their heating, the ease of use and how warm it gets when it is cold outside.

Residents rarely changed the pre-programmed settings of the heat pump, preferring to instead use the thermostat to alter temperatures. The temperatures experienced across the monitored periods and the preferred comfort periods did not fluctuate. It is unclear if the setback temperatures stated by the residents were in operation. If they were then it shows that the properties were retaining the heat provided by the heat pumps. Some residents cited an improvement in cardiovascular conditions after their solid fuel heating systems were removed. 1 resident noted that they had reduced the amount of times they visited their GP. Installing heat pumps alongside solar PV is a viable option in off-gas areas for those at risk of fuel poverty.

A comparison table that features key performance indicators for all the technologies trialled can be found in section 10.1.

Recommendations for potential future installations

Residents should be shown how to fully utilise the ASHP controls. 1 resident was turning up the thermostat to 26°C, an ASHP will operate more efficiently when heating the property at a lower temperature over an extended period. This resident experienced costs of around £1,700 per annum.

To improve the efficiency of the heat pump, consideration should be given to installing a PV diverter[10] that heats hot water using excess solar generation. This would take the emphasis off the heat pump to provide hot water and reduce use of an immersion heater.

Impact on fuel poverty

The solar PV reduces residents' electricity costs particularly over the spring/summer months. Unfortunately, the solar generation does not coincide with peak heating demand so cannot be used to operate the heat pump during those periods. It should allow residents to build up credit over the summer months which enables them to offset some of the heating costs in the winter, which given the low SCOP figures for the properties is likely to be much higher than in the summer.

Performance comparison against manufacturer's/manufacturers' claims

Providing hot water using an ASHP reduces the efficiency of the heat pump overall, all the properties experienced a low SCOP for the provision of hot water when compared against the provision of space heating.

[10] Eg - https://solarimmersion.co.uk/ or https://www.immersun.co.uk/ [Accessed 08/10/2018]

Economic business case for installation of measures

Installing an ASHP alongside solar PV has a high initial upfront cost, in this project the cost including install was £14,000 However, both elements are supported by separate subsidies, installing an ASHP and Solar PV enables the owner to receive Renewable Heat Incentive (RHI) payments and Feed-in Tariff (FIT) payments. This ensures that there is a return on the initial investment. The Feed-in Tariff payments will not be available from March 2019 which reduces the financial viability of installation.

The SAP rating increased in all the properties, 4 of the 6 properties moved up to a band C rated property after the measures were installed.

4.1 Hybrid ASHP

The initial proposal for this project was to use a heat pump and gas boiler in tandem to meet space heating demand at the most economical split between the two. Generally, hybrid systems consider the costs and efficiencies of a heat pump and alternative [more traditional] heating source (mains gas or oil) and operate one or the other independently, or a mix of the two. However, the selected system (Worcester Bosch boiler and Mitsubishi Ecodan ASHP) required a new [larger] hot water cylinder that could not be accommodated in the identified properties. The only viable solution was to change the way in which the system would operate. Project partners and manufacturers decided that the ASHP unit should provide all space heating whilst the gas boiler would provide hot water only. This is not a true hybrid system and likelihood of this set up being employed in the future is unlikely.

The properties were previously heated by gas boilers that were due for renewal.

4.2 Social evaluation and impacts

Qualitative feedback from initial questionnaire

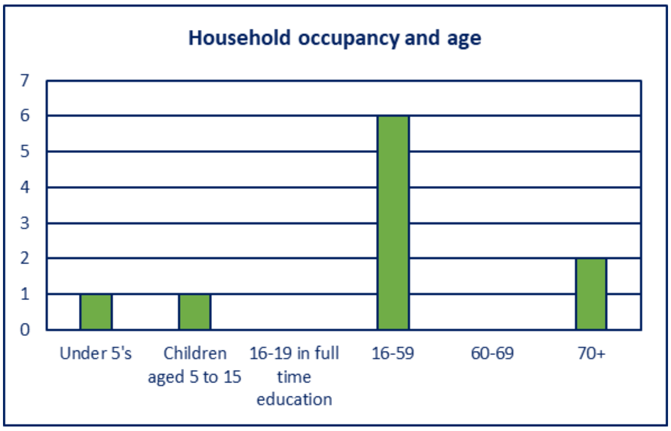


Figure 4.1 household occupancy

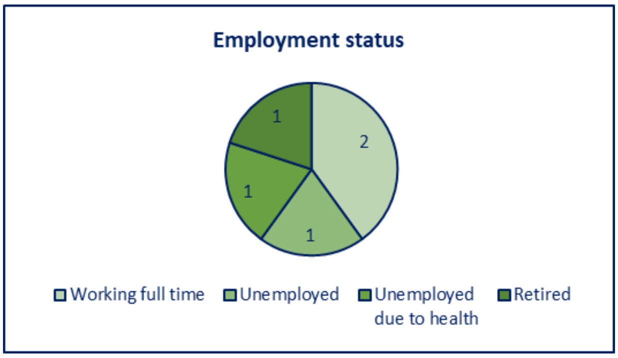


Figure 4.2 employment status

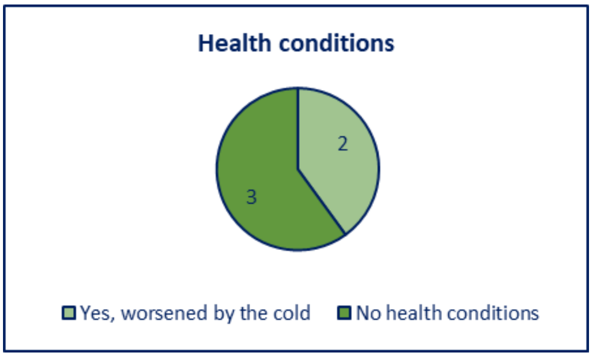


Figure 4.3 health conditions

6 households received a gas boiler and heat pump replacing their gas boiler. 1 resident dropped out of the study and none of the social analysis relates to this resident (T-03). Only a start and interim questionnaire was available for 1 resident (T-53) this questionnaire was used instead of a final questionnaire. Figure 4.1 shows that most residents were in the age range 16-59, there were 4 residents who were in age ranges that may mean they require more heat. There was a variety of employment statuses amongst the monitored group (figure 4.2). 2 of the 5 residents stated they had health issues worsened by the cold (figure 4.3). The health conditions experienced were arthritis, heart condition and narcolepsy.

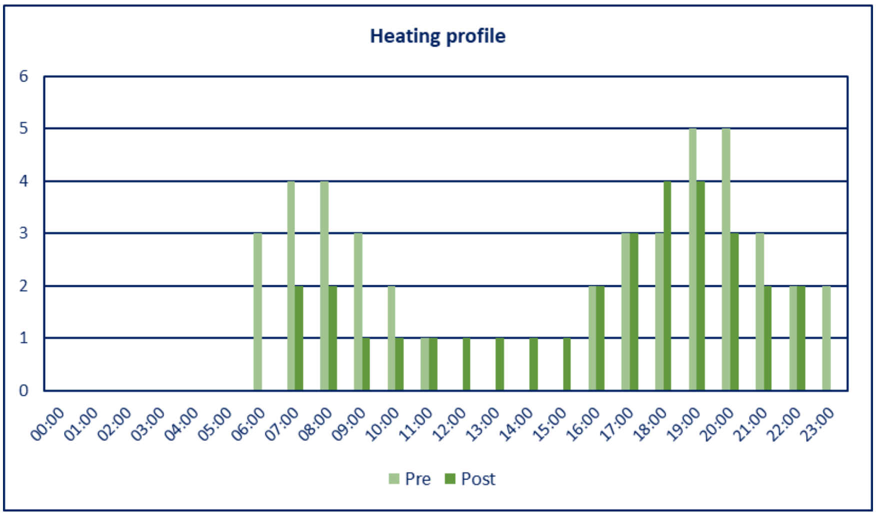


Figure 4.4 residents heating profile pre and post install

Residents were asked if there was a specific time of the day when they felt it was most important to have a warm home. This might be when they are least active e.g. sitting watching TV in the evening or when washing/dressing first thing in the morning. Residents were asked this in the questionnaire at the start of the project and then again at the end.

Figure 4.4 shows the results summed up across all respondents. There is a peak in demand for heating from residents between 5pm – 9 pm, this is particularly prevalent pre and post install questionnaires. There were some residents who wanted to be warm in the morning and 1 resident who wanted to be warm throughout the day, this is due to the varied occupancy and lifestyles of those involved in the study.

			Pre		Post	
Tech Ref	Size (m²)	House type	Rating	Band	Rating	Band
T-53	84	Semi-detached house	49	E	62	D
T-05	101	Semi-detached house	69	C	60	D
T-08	69	Semi-detached house	54	E	62	D
T-03	80	Semi-detached house	63	D	48	E
T-01	103	Semi-detached house	57	D	60	D
T-48	76	Semi-detached house	60	D	60	D

Table 4.5 property characteristics

As evidenced in table 4.5 all the properties were semi-detached, however they ranged in size 69m² to 103m² and were a mix of 2, 3 and 4-bedroom properties. The EPC ratings pre-install varied, ranging from 49 – 69. Post install they ranged from 48 – 62, indicating that there had been significant decreases for some properties. T-05 fell from a band C to a band D whilst T-03 experienced the most significant impact dropping from a rating of 63 to 48. 2 residents experienced a decrease in rating whilst 1 remained the same.

The EPC's incorrectly state that the gas boiler provides space heating alongside the ASHP. The reality is the ASHP is used for space heating only, and the gas boiler for hot water. The rdSAP software does not recognise a truly hybrid air source heat pump system. The technology must be entered as a gas boiler and an ASHP, this can lead to a reduction in SAP points particularly if the system is replacing a gas boiler.

There are other extenuating circumstances that impact the increase and decrease of the SAP ratings. T-03's pre-SAP assessment notes that there is 200mm of loft insulation however the post install SAP assessment assumes that there is no loft insulation. T-53 had cavity wall insulation put in place after the property's initial SAP assessment was carried out. This would have a significant impact on the SAP rating and should be borne in mind here.

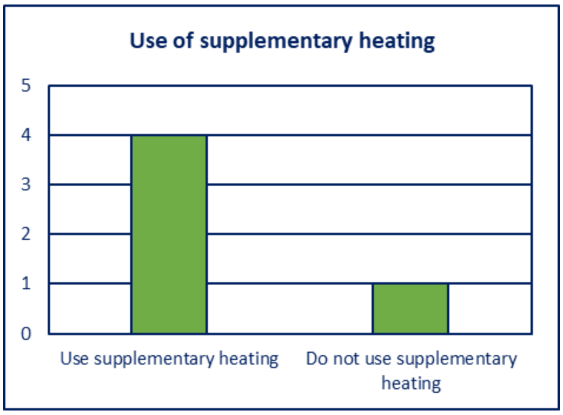


Figure 4.6 use of supplementary heating pre-install

5 residents stated that they used supplementary heating within the property prior to the hybrid system although 2 stated that they rarely used it (see figure 4.6). 3 residents would use their electric fires whilst the final resident used their gas room fire for 2 hours daily over the winter (T-08). In the final questionnaire the 4 residents that provided an answer stated that they did not use any supplementary heating.

4.3 Resident acceptance and satisfaction

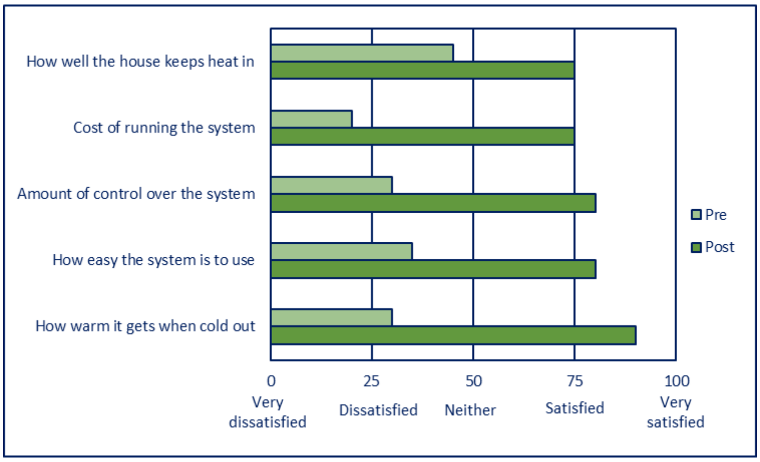


Figure 4.7 resident satisfaction with heating systems performance

There were significant improvements in resident satisfaction regarding the statements presented in figure 4.7. Post-install all the residents were either 'satisfied' or 'very satisfied' with all the statements presented to them. Prior to the install this was not the case with most residents were dissatisfied, they were least satisfied with the cost of running the system and how warm it got when it was cold outside. Both of which showed an improvement. Despite 2 residents noting that they were unable to use parts of the programmer this was not reflected in their satisfaction levels regarding the amount of control they had over the system and its ease of use.

4.4 Affordability of energy bills

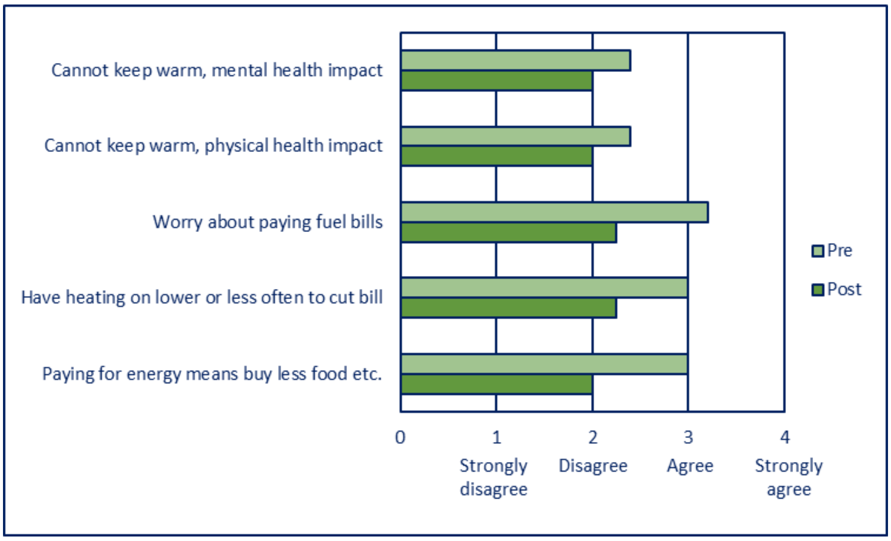


Figure 4.8 residents' level of agreement with energy affordability

One of the key worries of residents when using the old gas boiler system was paying the fuel bills. This reduced post install, however 1 resident noted that they still worried about paying the fuel bills.

4.5 Ease of use and reliability

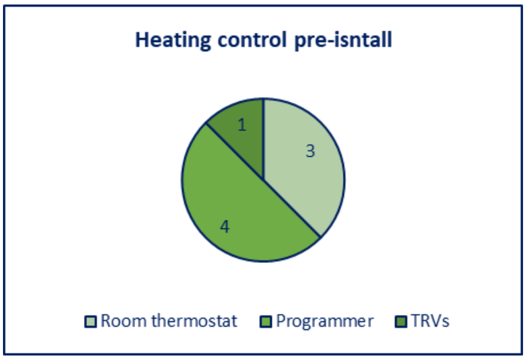


Figure 4.9 method of controlling heating pre-install

The most popular method of control of the heating system pre-install was the programmer, used alongside the room thermostat. This remained the case with the hybrid system however, some residents (T-48 & T-53) stated that they were unable to use the main controller or change their heating patterns.

4.6 Perceived comfort and benefits

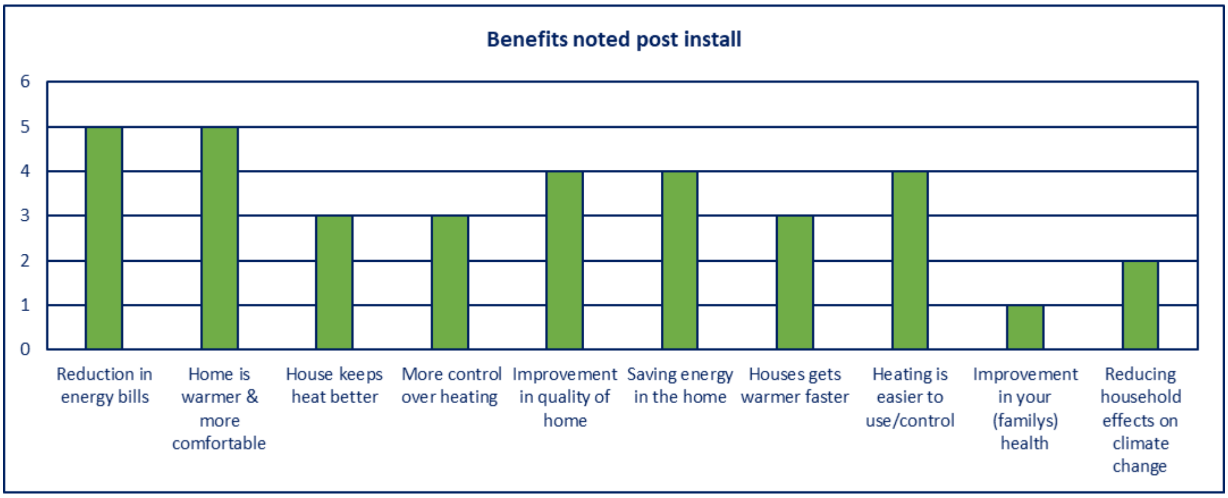


Figure 4.10 benefits noted by residents' post install

All the residents noted at least 2 benefits after the hybrid system was installed. The most selected were 'reduction in energy bills' and 'home is warmer and more comfortable. Only 1 resident experienced an improvement in their health however this had a significant impact on their work life. One of the residents at T-05 used to get regular colds, due to his work environment this meant he had to take 2-3 days off work around 5 times a year. With the new heating system, he has not had any time off work with colds. This has led to an increase in income and a better work record and relationship with the employer.

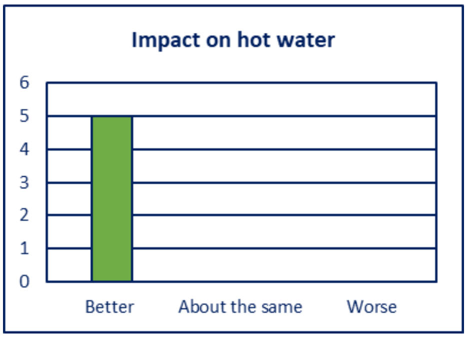


Figure 4.11 systems impact on use of hot water

One of the most important benefits of the hybrid system related to its impact on the provision of hot water. All 5 residents stated that the hot water was better post install, they cited the increased availability of hot water as one of the main reasons. This is due to the hot water demand being met by the gas boiler system.

4.7 Technical evaluation and results

Overview of technology

These properties received a Mitsubishi Ecodan ASHP alongside a Worcester Bosch Greenstar gas boiler. The intended use of this system was as follows. The hybrid system would determine which source of heating was most cost effective to meet heating demand at any given time. The selection of which heating element is used is based on factors such as external temperature, resident heating timings and the cost of gas and electricity. An ASHP works efficiently throughout most of the year however at low temperatures they cannot provide heat as efficiently. Installing a gas boiler or utilising an existing boiler to work alongside the heat pump means heating demand can be met during the coldest periods.

However, as explained earlier the system could not be installed as there was not enough space for the hot water cylinder to be installed.

4.8 Technical monitoring

- Lascar USB-2 thermal loggers were used to monitor the temperature and humidity within the living room and main bedrooms of the property.
- Tiny Tag View 2 current clamps were used to monitor the electricity used within the property.
- Heat meters alongside event loggers were installed to monitor the heat output of the heat pump and the output from the gas boiler – failed to record any data
- Watt hour meters alongside pulse loggers were fitted to monitor the electrical input into the heat pump.
- Gas meters were installed to monitor the input of gas to the boiler.

A full schematic of the technical monitoring is available in appendix 2.

4.9 Cost

There was no energy consumption data based on actual meter readings for the properties prior to the hybrid system being installed. The data that was obtained was inconsistent, some properties had electricity consumption data but no gas consumption or vice versa, whilst some properties did not have enough pre-install consumption data to make accurate assessments of energy cost. Additionally, some of the annual consumption that was available for the pre-install period was based on consumption figures that included estimated readings. There is data on the post installation energy costs which appear below.

"After" period							
Tech ref	Period	Days	Total Period (kWh)	Cost per 30 days	Degree days	kWh per Degree Days	Estimated annual cost
T-05	16/6/16 - 14/3/18	636	14,360	£108	4,272	3.4	£1,154
T-01	15/9/16 - 16/4/18	578	14,972	£124	4,481	3.3	£1,147
T-48	4/8/16 - 18/4/18	622	19,714	£152	4,545	4.3	£1,489
T-03	23/12/16 - 18/4/18	481	17,043	£170	3,722	4.6	£1,571
T-08	6/10/16 - 9/4/18	550	6,785	£59	4,349	1.6	£535
				£123		**3.4**	**£1,179**

Table 4.12 annual electricity costs post install

"After" period							
Tech ref	Period	Days	Total Period (kWh)	Cost per 30 days	Degree days	kWh per Degree Days	Estimated annual cost
T-05	13/5/17 - 14/3/18	305	1,952	£10	2,023	1.0	£104
T-01	15/9/16 - 16/4/18	578	3,377	£9	4,481	0.8	£81
T-48	23/8/16 - 18/4/18	603	3,804	£9	4,516	0.8	£90
T-03	18/10/16 - 18/4/18	547	8,876	£24	4,345	2.0	£219
T-08	6/10/16 - 26/2/18	508	2,379	£7	3,839	0.6	£66
				£12		**1.0**	**£112**

Table 4.13 annual gas costs post install

Combined		
Tech ref	Cost per 30 days	Estimated annual cost
T-05	£118	£1,257
T-01	£133	£1,227
T-48	£162	£1,579
T-03	£194	£1,790
T-08	£66	£601
	£135	**£1,291**

Table 4.14 combined energy costs post install

Residents total costs ranged from £601 per annum to £1,790 per annum. Most of the costs was related to the electricity usage as detailed in table 4.12. 2 properties had excessive total costs of £1,579 (T-48) and £1,790 (T-03). T-48 stated that they had noticed a reduction in energy bills however they also noted in the final questionnaire that they never check their energy bills/statements. T-03 pulled out of the study and thus there is no comment of energy costs.

Tech ref	Annual costs (electric)	% of cost (electric)	Annual costs (gas)	% of cost (gas)	Total cost
T-05	£1,154	92	£104	8	£1,257
T-01	£1,147	93	£81	7	£1,227
T-48	£1,489	94	£90	6	£1,579
T-03	£1,571	88	£219	12	£1,790
T-08	£535	89	£66	11	£601
Average	**£1,179**	**91**	**£112**	**9**	**£1,291**

Table 4.15 gas and electricity costs as a percentage of total costs

Table 4.15 shows the electric and gas usage as a proportion of cost. This refers to the total energy costs which includes space heating, water heating and remaining electrical demand i.e. lights and appliances. The heat meters failed to record the energy output on all the properties. Ideally the analysis would only factor in the space heating demand of the property.

On average the usage of gas made up 9% of the total energy costs. The highest proportion of total cost is T-03 who spent £219 on gas. This indicates that the ASHP was meeting most of the energy demand within the property. This is due to the system set up within the property, a truly hybrid system would lessen the demand on the hybrid system during the coldest months. Electricity costs of £1,571 per annum are excessive.

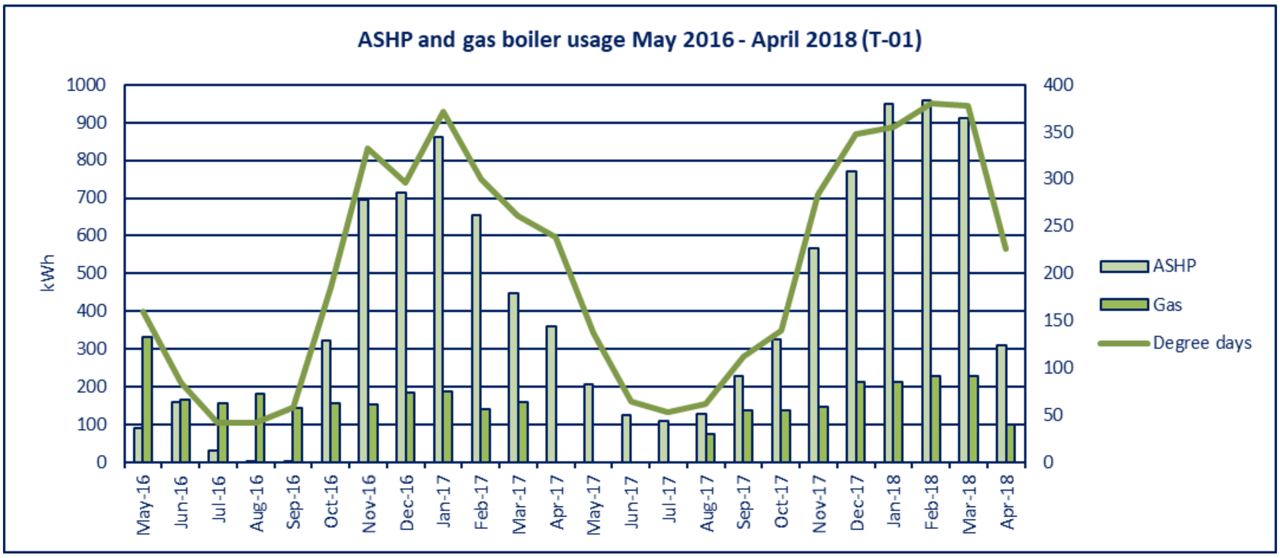


Figure 4.16 relationship between ASHP usage, gas boiler usage and changes in external temperature

Figure 4.16 shows the electrical input to the ASHP and the gas input to the boiler between May 2016 and April 2018 for T-01. Gas data is unavailable from the beginning of April 2017 until the beginning of August 2017 as the logger reached its memory capacity.

There is a clear correlation between the ASHP usage and the number of degree days, as the number of degree days increases the ASHP energy usage increases. The ASHP usage decreases over the spring/summer periods as the demand for space heating falls. The gas usage remains constant across the whole period and there is no clear relationship between the external temperature and gas usage. This is to be expected given that the gas boiler is only providing hot water to the properties.

Tech ref	Year	Total output	Total input	SCOP	Year	Total output	Total input	SCOP	Total output	Total input
T-05	2017	-	4655	-	2018	-	2785	-	-	7440
T-01	2017	-	4862	-	2018	-	3104	-	-	7966
T-48	2017	7312	3348	2.18	2018	7232	3437	2.10	14544	6785

Table 4.17 ASHP input and output figures

4.10 Temperature and thermal comfort

Living room

Tech Ref No.	Post install - 1st November 2016 -1st April 2017				Post install - 1st November 2017 - 1st April 2018			
	5-9 pm Average temperature (°C)	24 hours Average temperature (°C)	24 hours Maximum temperature (°C)	24 hours Minimum temperature (°C)	5-9 pm Average temperature (°C)	24 hours Average temperature (°C)	24 hours Maximum temperature (°C)	24 hours Minimum temperature (°C)
T-05	21.5	20.8	28.5	17.5	20.9	20.3	24.5	17.5
T-01	21.2	20.8	26.0	17.5	22.9	23.2	29	18.5
T-48	18.2	18.1	29.0	11.5	15.6	15.6	18.5	11.5
T-08	16.0	16.1	19.5	11.0	17.3	17.1	20.5	12.5
T-53	19.3	19.1	28.5	12.0	-	-	-	-
T-03	20.2	20.2	26.5	16.5	17.2	17.1	23.5	13.5
Average	19.4	19.2			18.8	18.7		

Table 4.18 living room temperatures post install

3 of the 7 properties failed to maintain a living room temperature between the recommended range of 18°C – 21°C over either one or both monitored periods. T-08 had the lowest expenditure of the monitored group therefore it is understandable that the temperature was lower than the other properties. T-03 and T-48 had the 2 highest costs yet also experienced some of the lowest temperatures. The average temperature in T-48 fell from 18.2°C in the first monitored period to 15.6°C in the second monitored period. The resident stated that the temperature was set at 21°C for the whole day and that the whole house was heated. The bedroom temperatures were significantly higher at 21.9°C and 21.4°C.

T-05 stated in their final questionnaire that the system was set up to heat the property to a temperature of 18°C between 7am and 10pm. The temperature data shows temperatures between

20°C and 21.5°C in the living room and 19°C and 20.5°C in the bedroom. T-01 had the same heating period of 7am to 10pm but at a higher temperature of 22°C. This temperature is achieved in the bedroom across the 2 monitored periods however in the living room the average temperature varies between 20.8°C and 23.2°C across the 2 periods.

Despite the different temperatures achieved T-05 and T-01 had similar post-install costs of £1,257 and £1,227 respectively. Both properties were of a similar size and construction and both around 100m² with 4 bedrooms. The electrical input into the ASHP was slightly higher in T-01 over the course of the monitored period as evidenced in table 4.17.

Bedroom

Tech Ref No.	Post install - 1st November 2016 -1st April 2017				Post install - 1st November 2017 - 1st April 2018			
	5-9 pm Average temperature (°C)	24 hours Average temperature (°C)	24 hours Maximum temperature (°C)	24 hours Minimum temperature (°C)	5-9 pm Average temperature (°C)	24 hours Average temperature (°C)	24 hours Maximum temperature (°C)	24 hours Minimum temperature (°C)
T-05	19.9	19.3	22.5	15.5	20.4	19.8	22	15.5
T-01	22.3	22.1	24.0	20.5	22.5	22.3	24.5	20
T-48	21.6	21.9	27.0	14.5	21.3	21.4	25.5	16
T-08	15.7	15.8	20.0	8.0	16.6	16.7	20.5	12
T-53	16.5	16.5	28.5	7.0	-	-	-	-
T-03	18.1	17.9	22.5	14.5	-	-	-	-
Average	19.0	18.9			20.2	20.1		

Table 4.19 bedroom temperatures post install

2 of the properties did not achieve a temperature between 18°C and 21°C (T-08 & T-53). Both residents selected temperatures lower than the other residents.

4.11 Humidity

Living room

Tech Ref No.	Post install - 1st November 2016 -1st April 2017				Post install - 1st November 2017 - 1st April 2018			
	5-9 pm Average humidity (RH%)	24 hours Average humidity (RH%)	24 hours Maximum humidity (RH%)	24 hours Minimum humidity (RH%)	5-9 pm Average humidity (RH%)	24 hours Average humidity (RH%)	24 hours Maximum humidity (RH%)	24 hours Minimum humidity (RH%)
T-05	52.3	50.3	69.0	29.5	50.7	47.9	69	28.5
T-01	49.0	46.4	59.5	33.5	63.7	62.6	76	35.5
T-48	48.3	47.8	66.5	28.0	47.6	47.3	65	33.5
T-08	60.3	60.4	77.5	30.5	56.5	55.5	75.5	33.5
T-53	47.2	46.4	85.0	26.0	-	-	-	-
T-03	55.9	54.6	72.0	35.5	56.4	55.8	79.5	37.5
Average	52.2	51.0			55.0	53.8		

Table 4.20 living room humidity levels post install

5 of the 6 properties maintained humidity levels between 40% - 60%rh, 1 resident maintained a level marginally above this (T-08). 3 properties experienced particularly high maximum humidity levels, the most significant was noted in T-53 at 85%rh. This property maintained a temperature of around 19°C however this property had the highest and lowest recorded temperature of 28.5°C and 7°C. This indicates that the property was intermittently heated which in part explains the variable humidity level.

Bedroom

Tech Ref No.	Post install - 1st November 2016 -1st April 2017				Post install - 1st November 2017 - 1st April 2018			
	5-9 pm Average humidity (RH%)	24 hours Average humidity (RH%)	24 hours Maximum humidity (RH%)	24 hours Minimum humidity (RH%)	5-9 pm Average humidity (RH%)	24 hours Average humidity (RH%)	24 hours Maximum humidity (RH%)	24 hours Minimum humidity (RH%)
T-05	56.9	55.3	71.0	43.5	50.9	48.8	67.5	36
T-01	48.0	48.9	63.5	38.5	45.5	46.5	59.5	33
T-48	41.4	41.2	58.0	25.5	45.8	46.5	65.5	28
T-08	61.7	63.2	85.5	40.0	58.5	59.6	75.5	40
T-53	59.8	61.8	87.0	29.5	-	-	-	-
T-03	65.6	67.4	80.5	55.0	-	-	-	-
Average	55.6	56.3			50.2	50.4		

Table 4.21 bedroom humidity levels post install

2 of the properties experienced humidity outside of the expected range of 40% - 60%rh. Temperatures in T-08 and T-53 were lower than in T-03. Despite this T-03 experienced the highest average humidity levels, additionally the humidity level never dropped below 55%rh. The increased humidity level was likely related to something other than the heating such as drying clothes within the bedroom.

4.12 Conclusions and recommendations

Conclusions

There was no pre-data available for any of the properties involved in the study. On average the energy cost post-install was close to £1,300. Only 10% of the energy costs were related to gas usage, the amount of gas that was used within the property did not vary much throughout the year as it was only providing hot water.

If the system was set up as initially proposed It would be expected that as the external temperature dropped the gas boiler would provide heat. The high electricity costs are likely related to the ASHP having to meet demand when external temperatures were lowest, it is likely that the gas boiler would have been more efficient during these periods.

Despite the issues experienced residents noted an increased satisfaction particularly in how warm the property gets when it is cold outside and the amount of control they have over their heating. 2 residents did however state that they were unsure on how to use the main element of the programmer, this would have allowed them to edit heating periods and temperatures.

A comparison table that features key performance indicators for all the technologies trialled can be found in section 10.1.

Recommendations for potential future installations

A hybrid system should not be configured in the same manner in future installations. The innovative element of this project was the ability to meet heating demand using two different sources simultaneously or individually based on external temperature and cost of fuel. Future installs should consider the viability of fitting a new hot water cylinder, heat battery[11], or using a hybrid heat pump that utilises a combination boiler.

Performance comparison against manufacturer's/manufacturers' claims

The configuration of the system means that it cannot be considered a hybrid system. It would therefore be unreasonable to compare the performance of the system against the manufacturers claims.

Economic business case for installation of measures

If the system was configured as intended RHI could be claimed. As there are 2 sources of heating and one is non-renewable a heat meter must be in place if RHI is to be claimed. The heat pump must have a SCOP of 2.5 or higher to be eligible for RHI. There was only 1 property with available data to determine the SCOP of the heat pump however this is irrelevant for claiming RHI given that the heat pump was the only source of heating.

The impact of the low SCOPs experienced by the properties with heat pumps and solar PVs was partly negated by the solar PV generation that helped reduce costs.

[11] For Example https://www.sunamp.com/ [Accessed 08/10/2018]

5.1 Gas and solar thermal

These properties received a Worcester Bosch Greenstar boiler with a Greenskies solar thermal system. The boilers replaced older boilers that were due for renewal, prior to the installs hot water demand was met solely by the gas boiler through a hot water cylinder.

5.2 Social evaluation and impacts

Qualitative feedback from initial questionnaire

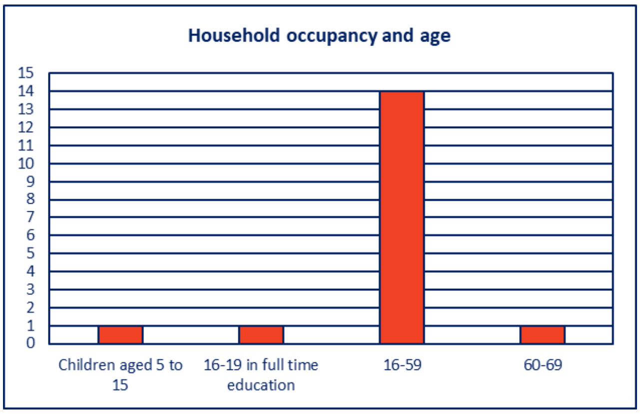


Figure 5.1 household occupancy

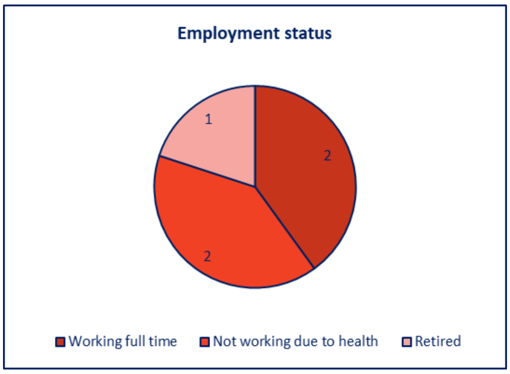


Figure 5.2 employment status

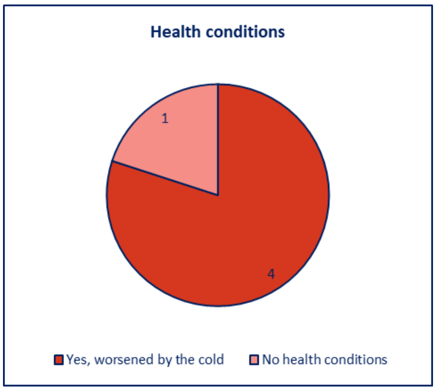


Figure 5.3 health conditions

5 households received a new gas boiler alongside a solar thermal array to meet some of their hot water demand. Figure 5.1 shows that most of the residents involved in the study were between the ages of 16 – 59, more vulnerable ages were underrepresented in this aspect of the project. 3 of the 5 properties had over 4 residents living within the property, increased occupancy is likely to mean higher hot water consumption. 4 of the residents stated that they had health conditions worsened by the cold (figure 5.3) and 2 of these residents stated that their health conditions prevented them from working. The conditions included; arthritis, ankylosing spondylitis, diabetes and depression.

All the residents stated in their start questionnaire that they had instantaneous electric showers installed. 1 of the residents stated that they had 2 electric showers. Electric showers cannot be supplied by the solar thermal array. Unless the residents are having regular baths, washing dishes regularly or have hot fill appliances they are unlikely to be taking full advantage of their solar thermal system.

			Pre		Post	
Tech Ref	Size (m^2)	House type	Rating	Band	Rating	Band
T-170	112	Semi-detached house	56	D	69	C
T-24	83	Semi-detached house	46	E	69	C
T-12	88	Semi-detached house	69	C	71	C
T-40	108	Semi-detached house	67	D	70	C
T-46	64	Semi-detached house	65	D	69	C

Table 5.4 property characteristics

All residents experienced an increase in their EPC rating, moving up to a band C. The properties were all semi-detached and varied in size from $64m^2$ to $112m^2$.

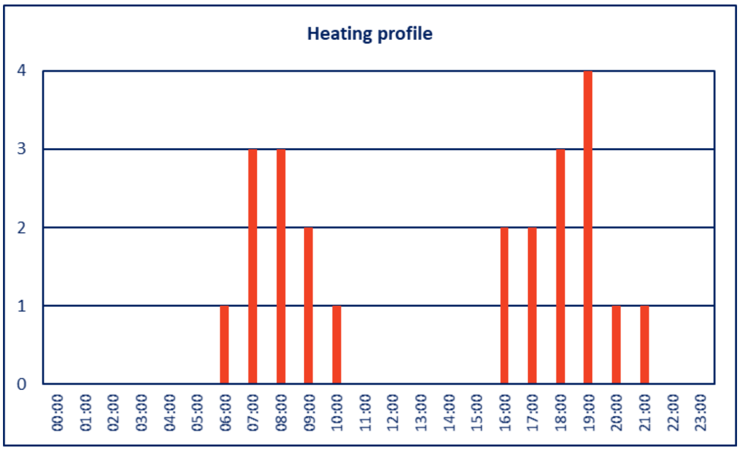


Figure 5.5 resident heating profile pre-install

There were 2 distinct heating periods noted by residents in the first questionnaire. There is an early morning heating period and then a secondary heating period in the evening from 4pm – 7pm.

5.3 Resident acceptance and satisfaction

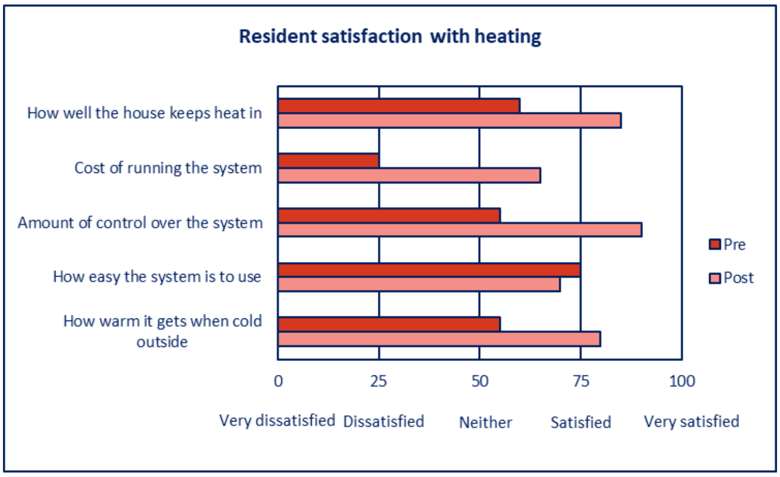


Figure 5.6 residents' level of satisfaction with the heating system

There was an increase in satisfaction regarding all the statements posed to residents as evidenced in figure 5.6. The most significant increase related to the cost of running the system, all residents were 'dissatisfied' with the cost of running their heating system prior to the new measures. One resident noted a decrease in satisfaction moving from 'dissatisfied' to 'very dissatisfied'. All the residents were either 'satisfied' or 'very satisfied' with how well the house keeps the heat in and the amount of control over the system.

5.4 Affordability of energy bills

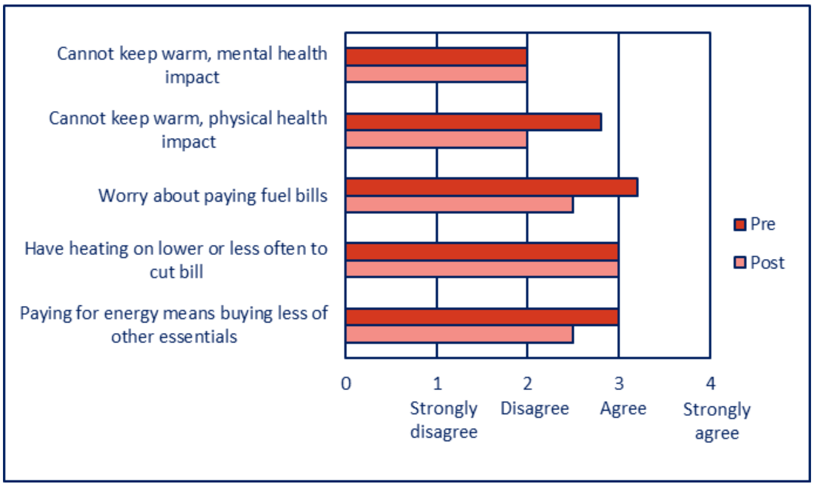


Figure 5.7 residents' level of agreement with affordability of energy

All residents continued to agree that they had the heating less often to lower or cut the fuel bill. 2 residents disagreed that paying for energy meant they bought less of other essentials, in the initial questionnaire 4 of the 5 residents 'agreed' or 'strongly agreed' with this statement.

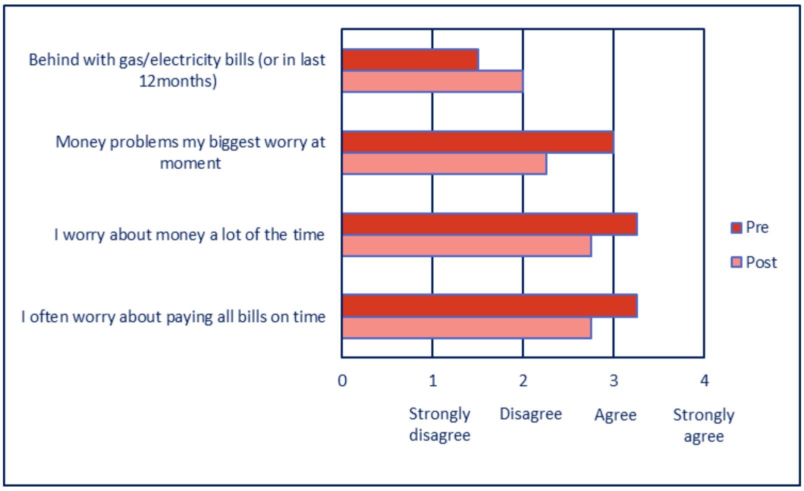


Figure 5.8 residents' level of agreement with financial issues

There were minor changes in agreement with the above statements relating to financial concerns. Paying bills and general money worries were high on the agenda for some of the residents.

5.5 Perceived comfort and benefits

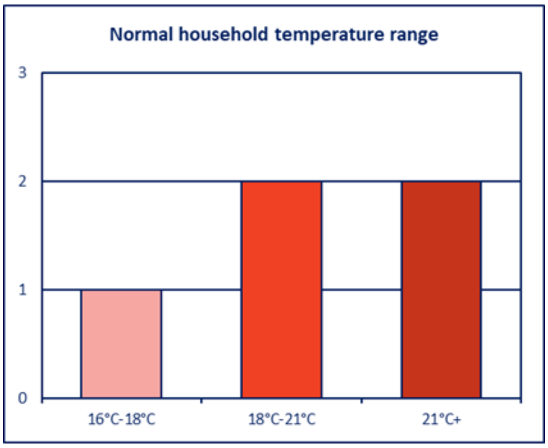


Figure 5.9 household temperature range prior to install

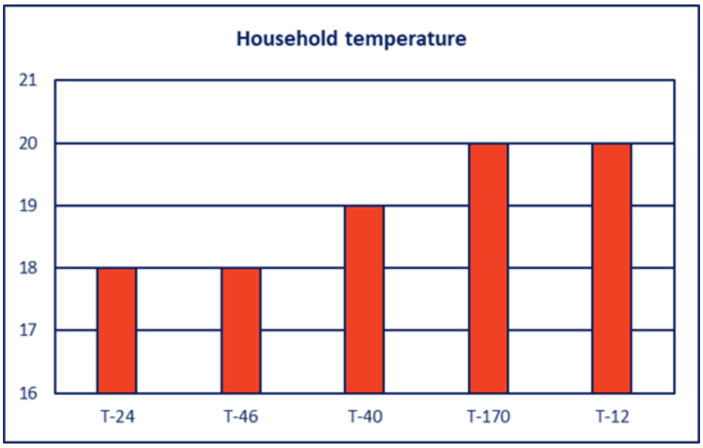


Figure 5.10 household temperature (°C) post install

In the final questionnaire the temperatures noted in each property by the residents were within the recommended 18°C – 21°C band (figure 5.10). Prior to the installs 2 residents had been heating their properties above 21°C and 1 within the 16°C – 18°C band (figure 5.9).

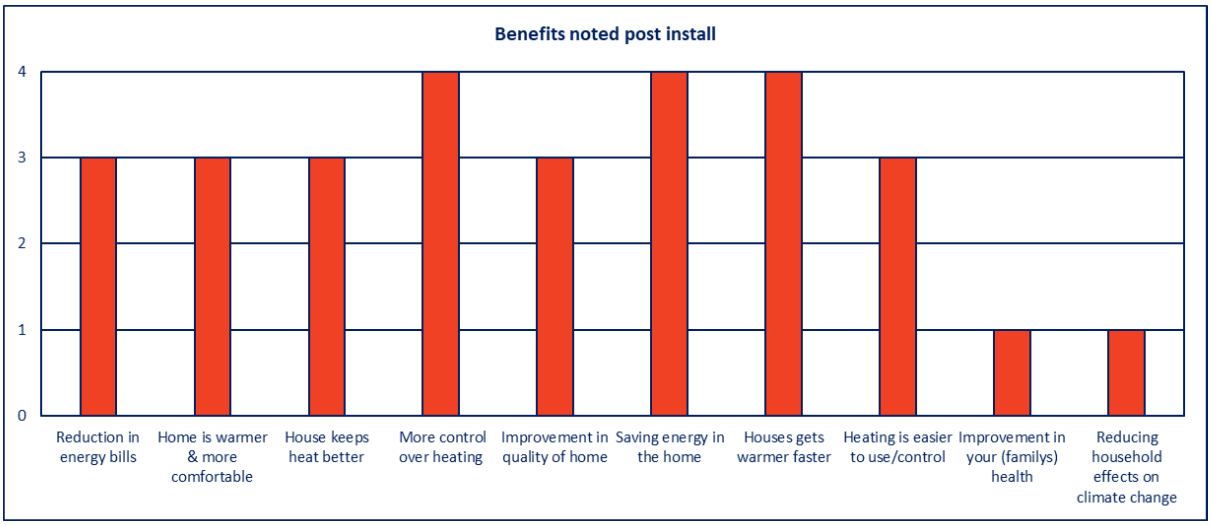


Figure 5.11 benefits noted by residents' post install

4 of the 5 residents noted benefits post install. The most noted benefits were 'more control over heating', 'saving energy in the home' and 'the house gets warmer faster'. 1 resident cited an improvement in their health as one of the benefits experienced. Stating that they get colds less often and when they do get them they do not last as long.

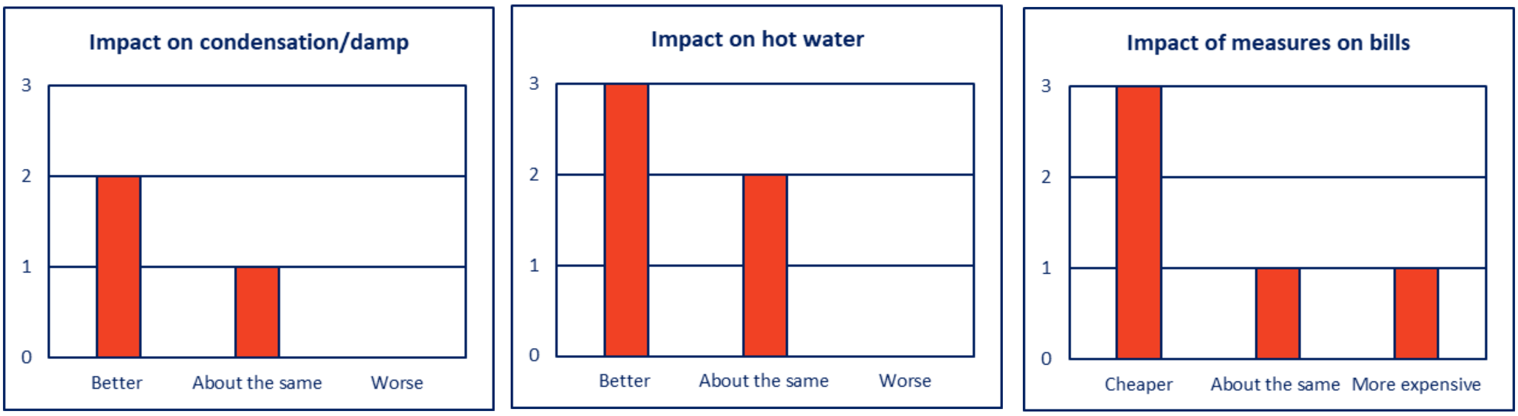


Figure 5.12 system impact (a) condensation (b) hot water (c) energy bills

3 of the residents noted an improvement in the use of their hot water (figure 5.12 b). 2 of those properties (T-24 & T-170) previously had hot water cylinders with no thermostatic control. 1 resident cited that the hot water was now available throughout the day (T-12).

3 Residents noted that the measures had made their bills cheaper (figure 5.12 c). T-170 & T-24 experienced decreases of 10% and 8% respectively whilst there was not enough pre-install data for T-46 to identify any change in annual costs. T-12 noted that their bills were about the same post install and the cost analysis shows there was no change in their annual costs.

5.6 Technical evaluation and results

Overview of technology

These properties received a Worcester Bosch Greenstar boiler with a Greenskies solar thermal system.

The use of solar thermal water heating is well established and is often used alongside traditional heating systems. Solar thermal can meet part of a properties hot water demand, especially during the summer months. However, a solar thermal system is unable to meet all hot water demand throughout the year; therefore, a boiler or immersion heater is required to meet demand when sun exposure is low and the winter months. To take full advantage of the system instant water heating appliances should not be in place i.e. electric showers. These appliances are not fed by the solar hot water system.

A larger hot water cylinder is required when installing a solar thermal system which may take up additional space in a property. The image below reveals an installation in one of the properties.

Figure 5.13 hot water cylinder for solar thermal hot water system

5.7 Technical monitoring

- Lascar USB-2 thermal loggers were used to monitor the temperature and humidity within the living room and main bedrooms of the property.
- Heat meters alongside event loggers were installed to monitor the heat output of the solar hot water system – these heat meters failed to record any data.

A full schematic of the technical monitoring is available in appendix 2.

5.8 Cost

Electric	"Before" period					"After" period							Comparison	
Tech ref	Period	Days	Total Period (kWh)	Cost per 30 days	Estimated annual cost	Period	Days	Total Period (kWh)	Cost per 30 days	Degree days	kWh per Degree Days	Estimated annual cost	Estimated saving (£)	Estimated saving (%)
T-46	-	-	-	-	-	1/4/17 - 1/4/18	365	3,446	£45	2,552	1.4	£463	-	-
T-40	10/12/14 - 12/7/16	580	13,251	£110	£1,049	22/10/16 - 27/9/17	340	7,802	£110	2,274	3.4	£1,178	-£129	-12%
T-12	22/1/16 - 19/8/16	210	1,302	£30	£323	4/9/16 - 13/8/17	565	3,628	£31	3,699	1.0	£337	-£14	-4%
T-170	12/9/14 - 20/4/16	586	7,212	£59	£549	6/10/16 - 2/4/18	543	8,308	£73	4,286	1.9	£665	-£116	-21%
T-24	4/9/14 - 4/2/16	518	1,814	£17	£169	2/10/16 - 27/3/18	541	1,888	£17	4,237	0.4	£153	£16	9%
				£54	**£522**				**£55**		**1.6**	**£559**	**-£61**	**-7%**

Table 5.14 annual electricity costs pre and post install

Gas	"Before" period							"After" period							Comparison	
Tech ref	Period	Days	Total Period (kWh)	Cost per 30 days	Degree days	kWh per Degree Days	Estimated annual cost	Period	Days	Total Period (kWh)	Cost per 30 days	Degree days	kWh per Degree Days	Estimated annual cost	Estimated saving (£)	Estimated saving (%)
T-46	-	-	-	-	-	-	-	1/4/17 - 1/4/18	365	10,713	£44	2,552	4.2	£450	-	-
T-40	10/12/14 - 12/7/16	580	10,413	£27	4,337	2.4	£258	22/10/16 - 27/9/17	340	4,129	£18	2,274	1.8	£195	£63	24%
T-12	22/1/16 - 19/8/16	210	8,146	£58	1,384	5.9	£631	4/9/16 - 13/8/17	343	13,353	£58	2,323	5.7	£616	£15	2%
T-170	12/9/14 - 20/4/16	586	29,443	£75	4,507	6.5	£701	6/10/16 - 2/4/18	543	18,278	£50	4,286	4.3	£457	£243	35%
T-24	4/9/14 - 31/3/16	574	20,983	£55	4,343	4.8	£518	2/10/16 - 27/3/18	541	18,828	£52	4,237	4.4	£477	£42	8%
				£54		**4.9**	**£527**				**£45**		**4.1**	**£439**	**£91**	**17%**

Table 5.15 annual gas costs pre and post install

	Combined				Comparison	
	Pre		Post			
Tech ref	Cost per 30 days	Estimated annual cost	Cost per 30 days	Estimated annual cost	Estimated saving (£)	Estimated saving (%)
T-46	-	-	£89	£914	-	-
T-40	£137	£1,306	£128	£1,372	-£66	-5%
T-12	£88	£954	£89	£953	£1	0.1%
T-170	£134	£1,250	£124	£1,123	£127	10%
T-24	£72	£687	£69	£630	£57	8%
Average	**£108**	**£1,049**	**£100**	**£998**	**£30**	**3%**

Table 5.16 annual energy costs compared pre and post install

2 of the residents experienced overall energy cost savings, T-170 saved 10% and T-24 saved 8%. 1 residents cost remained around the same post install (T-12).

1 resident's annual energy costs increased by £66 (T-40) their electricity costs increased by £129 whilst their gas costs reduced by £63. There were 5 people living at T-40 of which 3 were children, however, it is likely that hot water requirements for this family were not met solely by the solar thermal system - this resident had 2 electric showers. This may in part explain why they had a high annual electricity costs.

4 of the 5 residents made savings on their gas usage, this can be partially explained by the new higher efficiency boiler which replaced their previous boiler. Prior to the install all the residents heated their hot water using only the gas boiler system.

5.9 Temperature and thermal comfort

Living room

A standard gas boiler was installed at these properties therefore thermal logging was only carried out in the living room.

2 of the properties had average temperature below the recommended 18°C - 21°C range.

Tech Ref No.	Post install - 4th November 2016 -1st April 2017				Post install - 1st November 2017 - 1st April 2018			
	4-8pm Average temperature (°C)	24 hours Average temperature (°C)	24 hours Maximum temperature (°C)	24 hours Minimum temperature (°C)	4-8pm Average temperature (°C)	24 hours Average temperature (°C)	24 hours Maximum temperature (°C)	24 hours Minimum temperature (°C)
T-46	-	-	-	-	21.8	20.0	26	15
T-12	22.5	22.1	30.0	19.0	-	-	-	-
T-170	18.0	17.6	30.0	13.5	-	-	-	-
T-24	-	-	-	-	17.3	17.6	27.5	13.5
Average	**20.2**	**19.8**			**19.6**	**18.8**		

Table 5.17 living room temperatures post install

5.10 Humidity

Living room

Tech Ref No.	Post install - 4th November 2016 -1st April 2017				Post install - 1st November 2017 - 1st April 2018			
	4-8pm Average humidity (RH%)	24 hours Average humidity (RH%)	24 hours Maximum humidity (RH%)	24 hours Minimum humidity (RH%)	4-8pm Average humidity (RH%)	24 hours Average humidity (RH%)	24 hours Maximum humidity (RH%)	24 hours Minimum humidity (RH%)
T-46	-	-	-	-	51.7	52.8	72.5	31
T-12	51.2	50.2	67.0	32.5	-	-	-	-
T-170	53.9	54.2	66.5	32.0	-	-	-	-
T-24	-	-	-	-	47.2	46.7	61.5	28
Average	**52.5**	**52.2**			**49.5**	**49.8**		

Table 5.18 living room humidity levels post install

5.11 Conclusions and recommendations

Conclusions

2 of the residents made savings on their total energy consumption. 1 of these residents made savings on their gas consumption but increased their electricity consumption, it is unclear from the questionnaire data why this occurred. Despite the saving experienced the average temperature in the living room between November 2016 and April 2017 was only 17.6°C. Extensive thermal data was lacking for this subsection as the primary element of the install was the hot water provision by the solar thermal system.

A comparison table that features key performance indicators for all the technologies trialled can be found in section 10.1.

Recommendations for potential future installations

The number of instantaneous hot water fed appliances and other household demand for hot water should be considered before a solar thermal hot water system is installed. Concurrently, the electricity demand of the property should be considered as it may be more worthwhile installing a solar PV system if the electricity usage is high and hot water demand low.

Impact on fuel poverty

A solar thermal system has the potential to reduce the impact of fuel poverty if residents are high hot water users, and it is supplied from the hot water tank (i.e. not heated in an electric shower for example). As the specified heat meter did not register hot water supplied to the property it is not possible to determine how much hot water was used. However, the questionnaire data revealed that residents had electric showers and cold filled appliances. Additionally, 2 of the residents were high electricity users meaning it may have been more appropriate for these residents to have received a PV system with a diverter that heats their hot water with any excess PV generation. This would enable them to meet some of their electricity demand and still benefitting from [free] hot water if there was excess PV generation.

Performance comparison against manufacturer's/manufacturers' claims

Worcester Bosch cite an Energy Saving Trust report that shows solar hot water can meet up to 60% of hot water demand. It cannot be determined how much of hot water demand was met by the solar thermal hot water as the heat meters failed to record any of the solar thermals provision of hot water. It has been noted that there were appliances in these properties that required instantaneous hot water, thus reducing the hot water demand that could be provided by a solar thermal system.

Economic business case for installation of measures

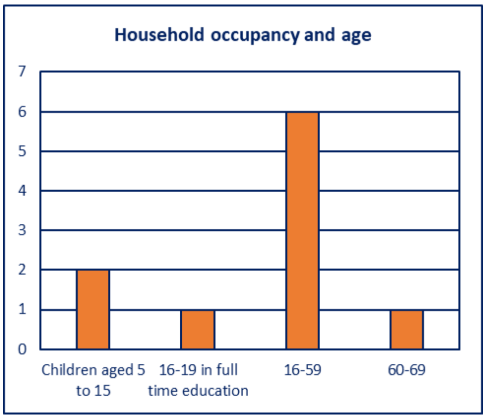
All properties increased their SAP rating, all moving up to band C. Solar thermal hot water systems are a well established renewable technology that can provide a significant uplift in SAP points. This is beneficial for landlords or owners who are attempting to bring their properties up to a band C. However this does not always coincide with an increase in comfort or decrease in costs.

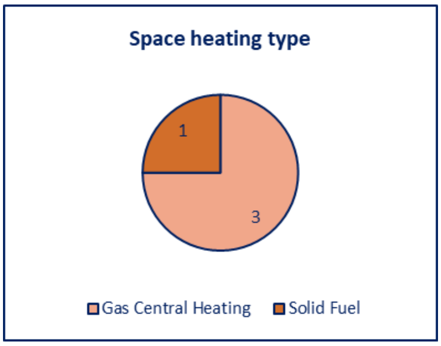
6.1 Gas (control group)

A Worcester Bosch Greenstar I ErP gas boiler was installed in 6 properties to offer a comparison against the other technologies installed. The boilers installed were replacing older inefficient gas boilers.

6.2 Social evaluation and impacts

Qualitative feedback from initial questionnaire





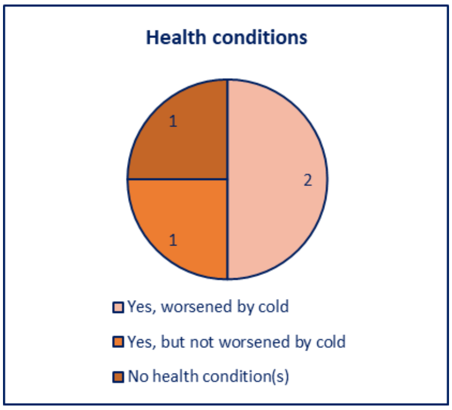


Figure 6.1 (a) household occupancy (b) previous heating system (c) health conditions

4 households had gas boilers installed. In 3 properties the gas boilers installed were replacing older, inefficient boilers and in 1 property the gas central heating replaced a solid fuel system. Figure 6.1 (a) shows that there was a range of ages within the properties, although there were no children under the age of 5 and no one over the age of 70. 2 residents cited health conditions that were worsened by the cold, these included asthma, arthritis and fibromyalgia.

			Pre		Post	
Tech Ref	Size (m^2)	House type	Rating	Band	Rating	Band
T-39	70	Semi-detached house	52	E	68	D
T-29	86	Semi-detached house	47	E	69	C
T-30	88	Semi-detached house	36	F	70	C
T-31	78	Semi-detached house	66	D	69	C

Table 6.2 property characteristics

All the properties SAP ratings improved after the measures were installed. Moving up from E's and an F to a D and C's. The biggest improvement seen was at T-30 which had the solid fuel central heating system replaced with a gas boiler.

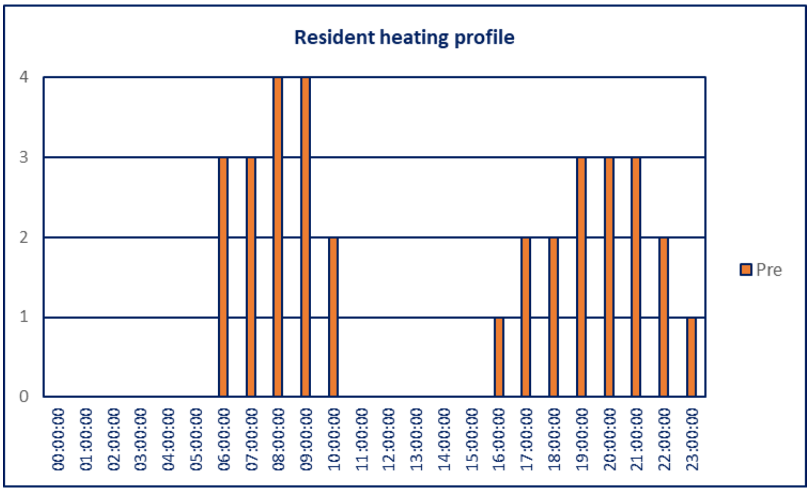


Figure 6.3 resident heating profile pre-install

Residents were asked if there was a specific time of the day when they felt it was most important to have a warm home. This might be when they are least active e.g. sitting watching TV in the evening or when washing/dressing first thing in the morning. Residents were asked this in the questionnaire at the start of the project and then again at the end.

Figure 6.3 shows the results summed up across all respondents. There are 2 clear periods when residents want to be warm within their homes, in the morning this was between 6am – 9am and then in the evening from 5pm – 10 pm. None of the residents stated that they wanted to be warm throughout the whole day

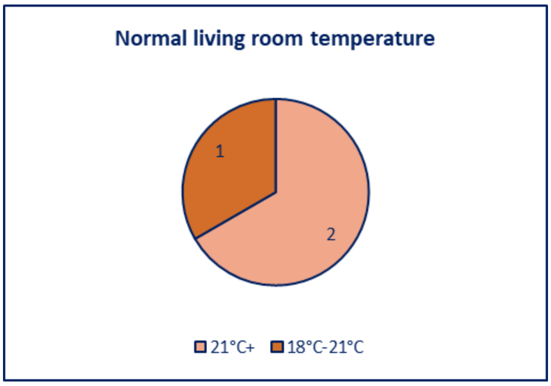


Figure 6.4 living room temperature ranges pre-install

2 of the residents stated that prior to the new system being installed their normal living room temperature was 21°C or higher (figure 6.4), the recommended temperature range is between 18°C – 21°C. In 1 property a temperature of 30°C (T-29) was noted by a PDC and in another it was set at 26°C, these are particularly high temperatures and it is unlikely that those temperatures were achieved in the properties. After the install T-29 reduced the thermostat to 20°C. 1 of the residents used a multi-fuel stove to keep warm in the evenings. The resident with the solid fuel system (T-30) had no thermostatic control over their system.

6.3 Resident acceptance and satisfaction

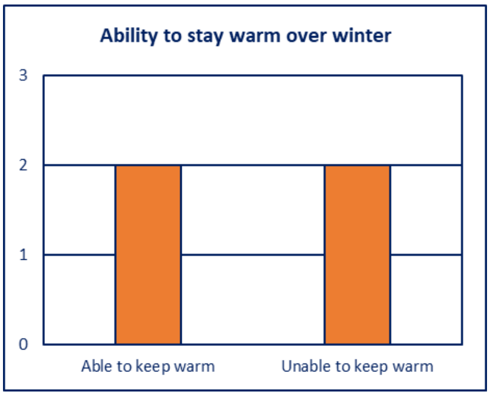


Figure 6.5 ability to stay warm over winter

Prior to the install of the gas boilers 2 residents felt they could not keep warm over winter. Both residents stated that it cost too much, and 1 resident stated that the system did not heat the property to a warm enough temperature (T-30).

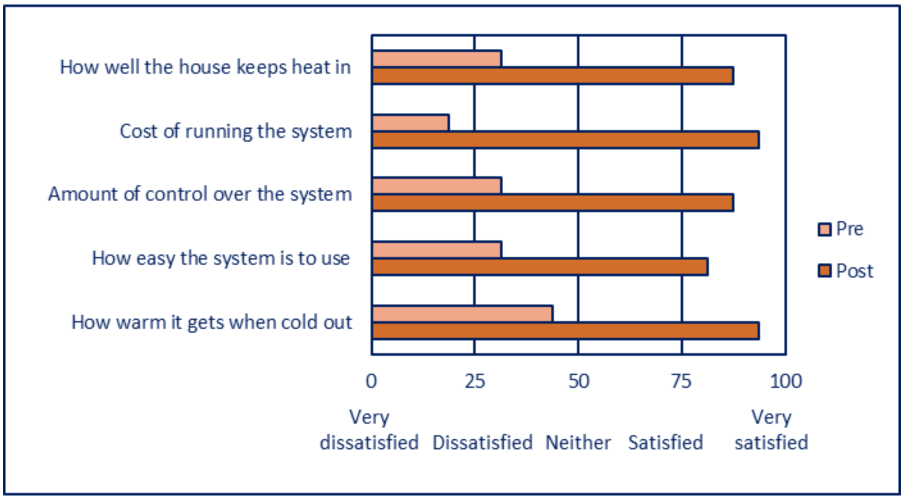


Figure 6.6 residents' level of satisfaction with the heating system

There was a significant improvement in residents' satisfaction with the heating system. The most important of which relates to the cost of the running system, prior to the install all residents were either 'very dissatisfied' or 'dissatisfied' with the statement. After install 3 of the 4 residents were 'very satisfied' with the cost of running the system.

6.4 Affordability of energy bills

The dissatisfaction with the cost of running the old system is reflected in figure 6.6 some residents that worried about paying the fuel bills, having the heating on less or lower and forgoing other essentials to pay for energy. 3 of the residents stated that the gas boiler helped reduce some of their money worries.

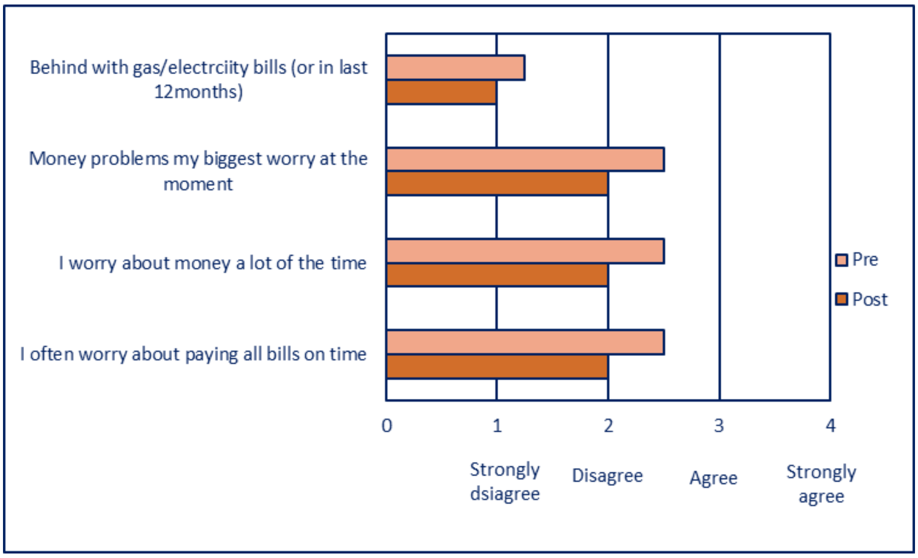


Figure 6.7 residents' level of agreement with energy affordability

All residents 'disagreed' with the statements found in figure 6.7, all the residents 'strongly disagreed' with the statement 'I am behind with gas/electricity bills or have been in the last 12 months'.

6.5 Perceived comfort and benefits

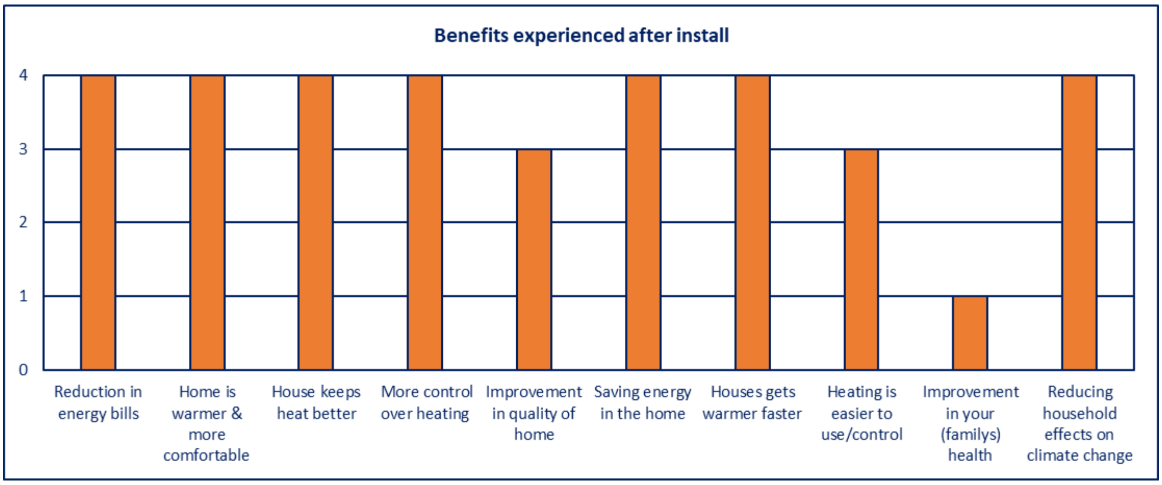


Figure 6.8 benefits noted by residents' post install

Residents noted several benefits after the gas boilers were installed. All the residents stated there was a reduction in their energy bills. T-30 said that the system had "made their lives so much easier".

6.6 Technical evaluation and results

Overview of technology

A Worcester Bosch Greenstar I ErP gas boiler was installed in 6 properties to offer a comparison against the other technologies installed.

6.7 Technical monitoring

- Lascar USB-2 thermal loggers were used to monitor the temperature and humidity within the living room and main bedrooms of the property.

6.8 Costs

Electric	"Before" period								"After" period								Comparison	
Tech Ref	Period	Days	Total Period (kWh)	Total cost	Cost per 30 days	Degree days	kWh per Degree Day	Estimated annual cost	Period	Days	Total Period (kWh)	Total Cost	Cost per 30 days	Degree days	kWh per Degree Day	Estimated annual cost	Estimated Saving (£)	Estimated Saving (%)
T-29	23/10/14 - 26/8/16	673	9,599	£1,536	£68	4,782	2.0	£833	14/10/16 - 31/3/18	533	6,595	£1,055	£59	4,210	1.6	£723	£110	13%
T-39	14/10/14 - 4/5/16	584	2,885	£462	£24	4,602	0.6	£289	7/9/16 - 18/4/18	588	2,783	£445	£23	4,499	0.6	£276	£12	4%
Average							1.3	£561							1.1	£500	£61	9%

Table 6.9 annual electricity costs pre and post install

Gas	"Before" period								"After" period								Comparison	
Tech Ref	Period	Days	Total Period (kWh)	Total cost	Cost per 30 days	Degree days	kWh per Degree Day	Estimated annual cost	Period	Days	Total Period (kWh)	Total cost	Cost per 30 days	Degree days	kWh per Degree Day	Estimated annual cost#	Estimated Saving (£)	Estimated Saving (%)
T-29	23/10/14 - 26/8/16	673	27,874	£1,394	£62	4,782	5.8	£625	14/10/16 - 31/3/18	533	17,213	£860	£48	4,210	4.1	£438	£187	30%
T-39	27/11/15 - 17/6/16	203	11,299	£567	£83	1,824	6.2	£664	7/9/16 - 18/4/18	588	19,255	£963	£49	4,499	4.3	£459	£205	31%
Average							6.0	£645							4.2	£449	£196	30%

Table 6.10 annual gas costs pre and post install

Combined	Before	After	Comparison	
Tech Ref	Combined costs	Combined costs	Saving (£)	Saving (%)
T-29	£1,458	£1,161	£297	20%
T-39	£953	£735	£217	23%
Average	£1,205	£948	£257	22%

Table 6.11 combined annual costs pre and post install

There is only pre and post data available for 2 of the 4 properties. 1 of the properties dropped out of the study after the interim questionnaire was carried out and the other resident previously used solid fuel to heat the property.

Both T-29 and T-39 experienced reductions in annual costs after the gas boiler was installed. (table 6.11) Overall T-29 reduced their annual costs from £1,458 to £1,161 whilst T-39 reduced their annual costs from £953 to £735. The biggest savings were seen on their gas usage which reduced in cost by 30%, it should be noted that a household member in T-29 moved out of the property and T-39 received double glazing. Both residents also experienced savings on their electricity costs although neither household noted that they had used electrically powered supplementary heating prior to the new system being installed.

6.9 Temperature and thermal comfort

Living room

Tech Ref No.	Post install - 4th November 2016 -1st April 2017				Post install - 1st November 2017 - 1st April 2018			
	6-10am Average temperature (°C)	24 hours Average temperature (°C)	24 hours Maximum temperature (°C)	24 hours Minimum temperature (°C)	6-10am Average temperature (°C)	24 hours Average temperature (°C)	24 hours Maximum temperature (°C)	24 hours Minimum temperature (°C)
T-29	22.4	23.3	29.5	17.0	23.0	23.8	29	18.5
T-39	18.0	19.4	40.0	13.0	18.7	19.7	36	13
T-31	20.6	22.5	29.5	17.5	-	-	-	-
T-30	20.9	21.1	24.0	18.0	21.1	21.2	27	15
Average	**20.5**	**21.6**			**21.0**	**21.6**		

Table 6.12 living room temperatures post install

There was no pre-install data for these properties. All the residents were able to maintain a temperature between 18°C and 21°C over both periods selected for analysis. T-39 had the lowest average temperatures in the living room whilst T-29 had the highest. T-30 experienced a temperature that did not deviate much from 21°C throughout the day and night. The temperature s achieved are within 1°C of their 22°C target temperature this was the case for the living room and bedroom.

Bedroom

Tech Ref No.	Post install - 4th November 2016 -1st April 2017				Post install - 1st November 2017 - 1st April 2018			
	6-10 am Average temperature (°C)	24 hours Average temperature (°C)	24 hours Maximum temperature (°C)	24 hours Minimum temperature (°C)	6-10 am Average temperature (°C)	24 hours Average temperature (°C)	24 hours Maximum temperature (°C)	24 hours Minimum temperature (°C)
T-29	21.0	21.5	26.0	16.0	21.1	21.4	24.5	18
T-39	21.2	21.8	27.5	16.0	21.0	21.3	25.5	15.5
T-31	18.6	19.1	22.0	16.0	-	-	-	-
T-30	21.6	22.3	27.0	13.5	20.2	19.9	32	12
Average	**20.6**	**21.2**			**20.8**	**20.9**		

Table 6.13 bedroom temperatures post install

All residents achieved temperatures between 18°C and 21°C in their bedrooms post install. The temperature in the bedroom of T-38 was warmer than in the living room. The resident at T-39 did spend most of their time in their bedroom.

6.10 Humidity

Living room

Tech Ref No.	Post install - 4th November 2016 -1st April 2017				Post install - 1st November 2017 - 1st April 2018			
	6-10am Average humidity (RH%)	24 hours Average humidity (RH%)	24 hours Maximum humidity (RH%)	24 hours Minimum humidity (RH%)	6-10 am Average humidity (RH%)	24 hours Average humidity (RH%)	24 hours Maximum humidity (RH%)	24 hours Minimum humidity (RH%)
T-29	39.5	39.5	64.5	26.5	37.7	37.8	54.5	24.5
T-39	48.3	46.3	69.0	16.0	44.1	42.7	59.5	18
T-31	42.6	42.0	62.5	28.0	-	-	-	-
T-30	46.8	46.9	54.0	38.5	42.5	43.5	67	30
Average	**44.3**	**43.7**			**41.4**	**41.3**		

Table 6.14 living room humidity levels post install

1 of the residents living rooms (T-29) fell marginally out of the recommended 40%rh - 60%rh range of humidity. All other properties maintained recommended humidity levels in the living rooms and bedrooms.

Bedroom

Tech Ref No.	Post install - 4th November 2016 -1st April 2017				Post install - 1st November 2017 - 1st April 2018			
	6-10 am Average humidity (RH%)	24 hours Average humidity (RH%)	24 hours Maximum humidity (RH%)	24 hours Minimum humidity (RH%)	6-10am Average humidity (RH%)	24 hours Average humidity (RH%)	24 hours Maximum humidity (RH%)	24 hours Minimum humidity (RH%)
T-29	46.0	45.5	68.0	33.0	45.4	44.8	60.5	32.5
T-39	41.6	41.3	51.5	32.5	39.3	39.1	49	30.5
T-31	52.4	50.6	60.0	38.0	-	-	-	-
T-30	41.2	40.0	56.5	27.5	49.9	48.8	74	26.5
Average	45.3	44.3			44.9	44.2		

Table 6.15 bedroom humidity levels post install

6.11 Conclusions and recommendations

Installing a gas connection or replacing a gas boiler with a more efficient model is a one of the most effective ways of reducing the risk of fuel poverty. Given the low cost of gas, its familiarity and established maintenance and replacement network, it is the benchmark that innovative technologies will continue to be compared against.

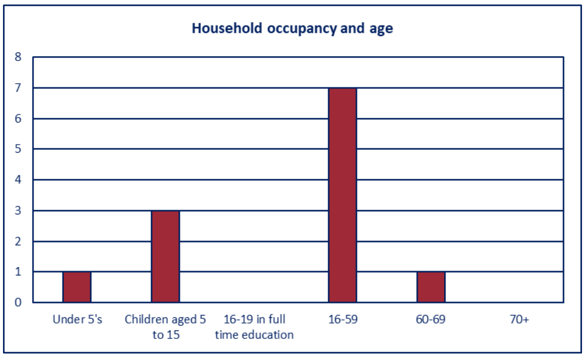
All the properties experienced an increase in their SAP rating, 3 of the 4 moved to a band C rating and the remaining property was 1 point off a band C rating. There were significant improvements in resident satisfaction with their heating system, particularly with the cost of running the system. There was only energy data available for 2 of the properties, both experienced around a 30% reduction in annual gas costs. T-29 had energy costs that reflected the higher temperatures in the property, although both were satisfied with the comfort provided.

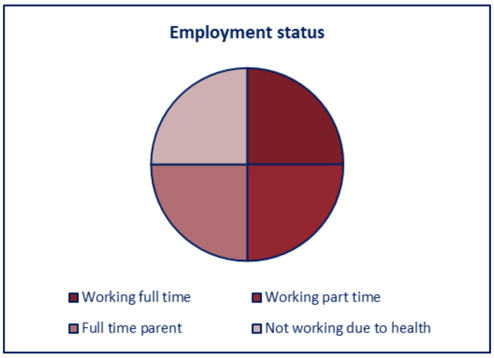
A comparison table that features key performance indicators for all the technologies trialled can be found in section 10.1.

7.1 Boiler with Smart Controls

Residents received a Worcester Bosch Greenstar i gas boiler alongside a smart thermostat and heat recovery unit.[12] The smart thermostat installed was the Worcester Wave, which features load compensation and weather compensation features. The advanced controls of the Wave thermostat such as setting heating schedules are only accessible via an app, for full operability the resident requires a smart phone or tablet to access the app. The residents previously had standard gas boilers in place.

7.2 Social evaluation and impacts





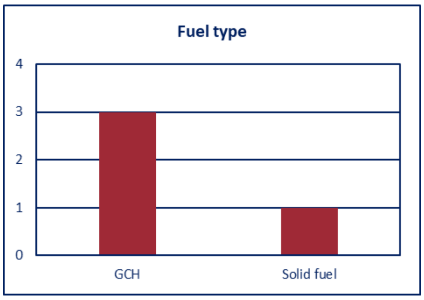


Figure 7.1 (a) household occupancy (b) employment status (c) previous heating system

4 properties received a gas boiler with a flue gas saver and weather compensator. 3 of the 4 residents previously had a gas boiler whilst 1 had a solid fuel central heating system (figure 7.1 c). The households were made up of a mixture of residents, with the majority between the ages of 16 – 59. In the property with the solid fuel system there were 4 children (WDH-14).

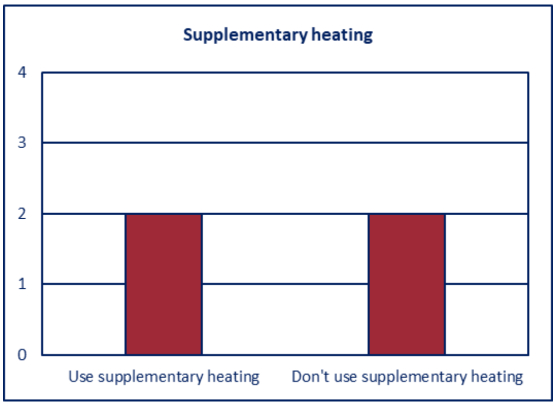


Figure 7.2 use of supplementary heating pre-install

2 residents stated that they used supplementary heating to keep warm at home prior to the new gas boiler system being put in place. 1 resident stated they used supplementary heating occasionally between December and March with the new system.

[12] https://www.worcester-bosch.co.uk/products/boiler-controls/wave

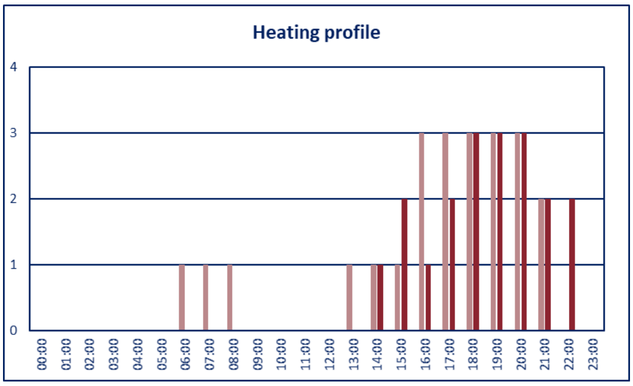


Figure 7.3 resident heating profile pre and post install

Residents were asked if there was a specific time of the day when they felt it was most important to have a warm home. This might be when they are least active e.g. sitting watching TV in the evening or when washing/dressing first thing in the morning. Residents were asked this in the questionnaire at the start of the project and then again at the end.

Figure 7.3 shows the results summed up across all respondents. The period that stands out is between 5pm – 8pm. None of the residents stated that they wanted to be warm throughout the whole day.

			Pre		Post	
Tech Ref	**Size (m²)**	**House type**	**Rating**	**Band**	**Rating**	**Band**
WDH-13	87	Semi-detached house	67	D	69	C
WDH-05	84	Semi-detached house	62	D	66	D
WDH-09	73	Semi-detached house	59	D	67	D
WDH-14	81	Semi-detached house	38	F	68	D

Table 7.4 property characteristics

All the properties increased their SAP points and all moved to either a high band D or a low band C.

7.3 Resident acceptance and satisfaction

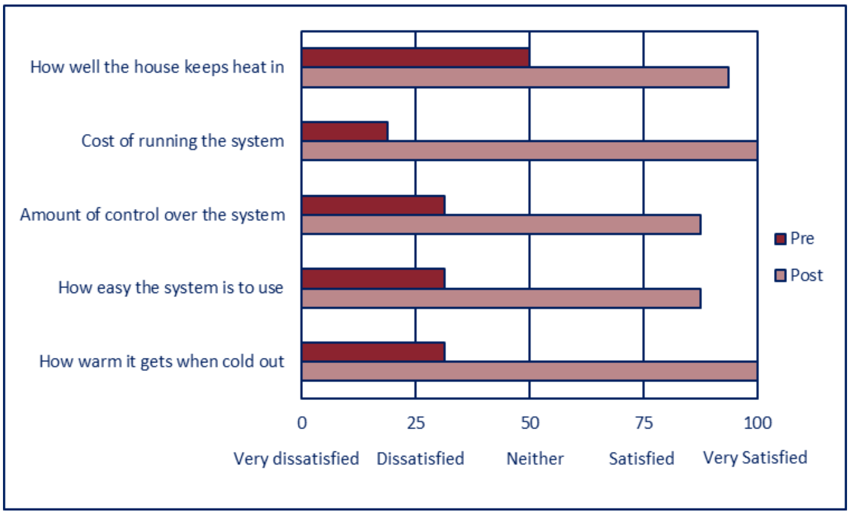


Figure 7.5 residents' level of satisfaction with the heating system

There were significant increases in satisfaction with the statements presented in figure 7.5. The 2 most significant increases relate to the "cost of running the system" and "how warm it gets when cold out". All residents stated they were very satisfied with these 2 statements. None of the residents were dissatisfied or very dissatisfied with the statements.

Whilst residents noted they felt they had more control over the system and it was easy to use they still expressed concerns regarding using the measures. 2 residents stated that they felt they didn't know how best to use the measures fitted and would like to know more and 1 resident stated that it had taken them time to learn how to use the system.

Residents also expressed that they did not have the Wave app or had forgotten their password. The Wave app increases the functionality of the system and without access they are unable to alter heating times and temperatures. It is imperative that residents can access the app as they cannot set the programmer without this.

7.4 Affordability of energy bills

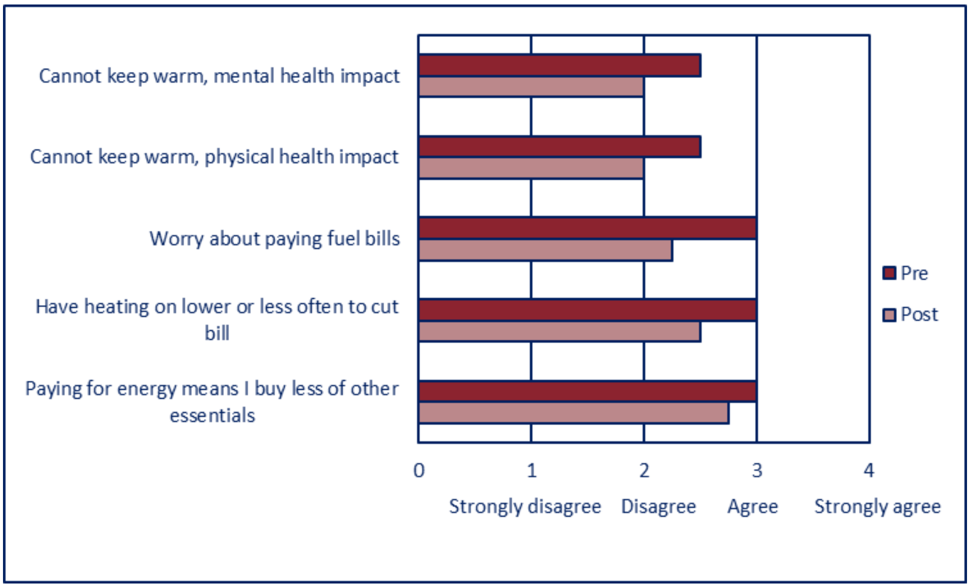


Figure 7.6 residents' level of agreement with energy affordability

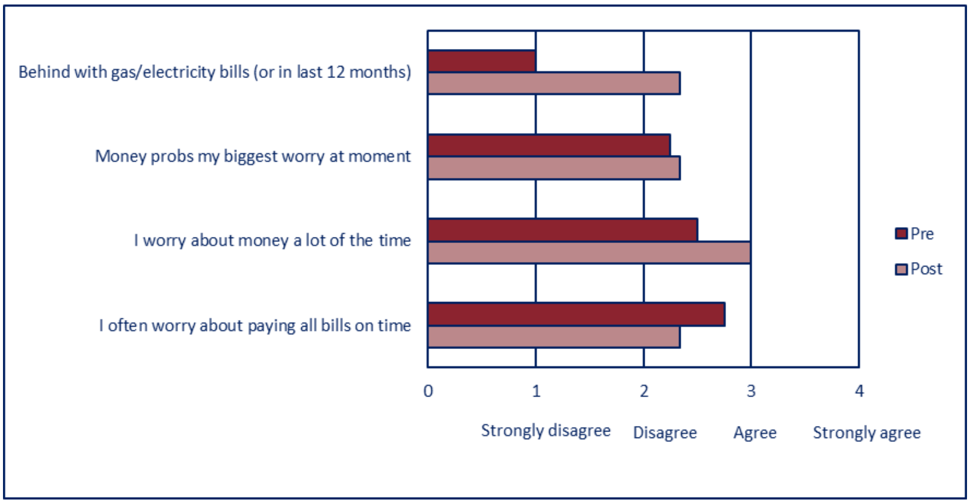


Figure 7.7 residents' level of agreement with money concerns

7.5 Perceived comfort and benefits

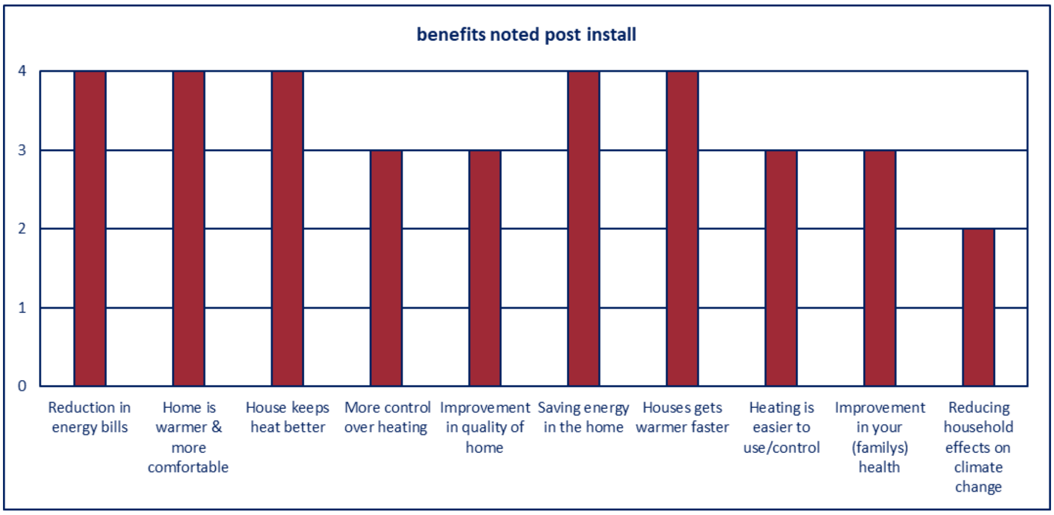


Figure 7.8 benefits noted by residents' post install

None of the residents stated in the initial questionnaire that they had any health conditions that were worsened by the cold. However, 2 residents noted they were getting fewer colds whilst 1 resident noted that their arthritis has improved.

7.6 Technical evaluation and results

Overview of technology

Residents received a Worcester Bosch Greenstar i gas boiler alongside a smart thermostat and heat recovery unit. The smart thermostat installed was the Worcester Wave, which features load compensation and weather compensation features.

7.7 Technical monitoring

- Lascar USB-2 thermal loggers were used to monitor the temperature and humidity within the living room and main bedrooms of the property.

7.7 Costs

Electric	"After" period			
Tech ref	Period	Days	Total Period (kWh)	Estimated annual cost
WDH-05	22/8/17 - 16/4/18	237	2,525	£622
WDH-14	1/4/17 - 1/4/18	365	7,390	£1,182
WDH-09	22/8/17 - 17/4/18	238	1,066	£262
Average				£689

Table 7.9 annual electricity costs post install

Gas	"After" period					
Tech ref	Period	Days	Total Period (kWh)	Degree days	kWh per Degree Days	Estimated annual cost
WDH-05	22/8/17 - 16/4/18	237	10,940	2,151	5.1	£546
WDH-14	1/4/17 - 1/4/18	365	15,830	2,552	6.2	£665
WDH-09	22/8/17 - 17/4/18	238	10,584	2,156	4.9	£527
Average					5.4	£579

Table 7.10 annual gas costs post install

Combined	
Tech ref	Estimated annual cost
WDH-05	£948
WDH-14	£1,659
WDH-09	£696
Average	£1,101

Table 7.11 combined annual energy costs post install

There was no pre-install data available for these residents. This was due to a combination of inconsistent readings or lack of enough pre-install consumption. Their annual costs varied between £696 and £1659 (table 7.11). 1 resident (WDH-14) was a high electricity user and unusually spent more on electricity than gas. The gas costs of all 3 properties were similar ranging from £527 to £665.

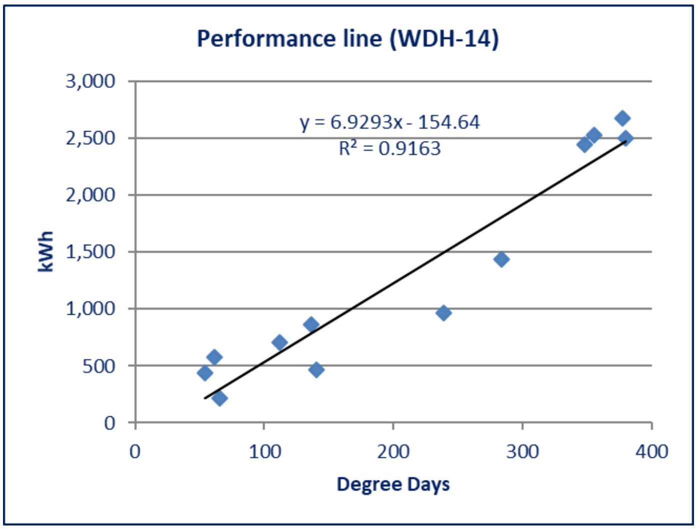


Figure 7.12 performance of heating system post install (WDH-14)

The above figure (7.12) reveals the relationship between external temperature and the amount of energy used to the heat the property. WDH-14 has a good correlation between degree days and energy consumption, this indicates that there is good control of the system. The Worcester Wave thermostat features a weather compensation aspect, this varies the flow of temperature leaving the boiler depending on the outside temperature of the property. The system determines how warm the radiators need to be to maintain comfort levels as the outdoor temperature rises and falls. This prevents the system from cycling on and off as happens with a room thermostat that tells the boiler to turn off when the set internal temperature is reached. This is an issue when a thermostat is placed in an area colder than the living areas i.e. a hallway, the living areas will have been overheated once the colder area has reached the set temperature.

7.8 Temperature and thermal comfort

Living room

Tech Ref No.	Post install - 15th November 2016 - 1st April 2017				Post install - 1st November 2017 - 1st March 2018			
	5-8 pm Average temperature (°C)	24 hours Average temperature (°C)	24 hours Maximum temperature (°C)	24 hours Minimum temperature (°C)	5-8 pm Average temperature (°C)	24 hours Average temperature (°C)	24 hours Maximum temperature (°C)	24 hours Minimum temperature (°C)
WDH-05	19.9	17.6	24.0	9.5	20.4	18.6	25.5	14.5
WDH-09	20.4	19.0	25.0	14.5	21.0	18.5	25	13
WDH-13	20.3	19.8	23.0	16.5	20.0	19.9	23.5	16
Average	20.2	18.8			20.5	19.0		

Table 7.13 living room temperatures post install

All the residents achieved temperatures between 18°C and 21°C between the preferred comfort period of 5-8pm. Temperatures were considerably higher during the 5-8pm period indicating that heating has been to set to come on at certain times or they use the thermostat to increase the temperature when they want it to be warmer. Temperature in the bedrooms of 1 property (WDH-05) fell outside of the 18°C - 21°C range. This resident stated that they kept the temperature at

15/16°C throughout the day and moved it up to 20°C for around 1 hour. All residents had TRVs installed and may have turned them down in rooms that were used less.

Bedroom

Tech Ref No.	Post install - 15th November 2016 -1st April 2017				Post install - 1st November 2017 - 1st March 2018			
	5-8 pm Average temperature (°C)	24 hours Average temperature (°C)	24 hours Maximum temperature (°C)	24 hours Minimum temperature (°C)	5-8 pm Average temperature (°C)	24 hours Average temperature (°C)	24 hours Maximum temperature (°C)	24 hours Minimum temperature (°C)
WDH-05	17.3	16.1	22.0	10.0	16.6	15.7	22	11
WDH-09	18.9	17.6	24.5	7.5	18.3	16.6	22.5	7.5
WDH-13	19.9	20.1	25.0	16.5	18.7	19.2	23.5	15
Average	18.7	17.9			17.9	17.2		

Table 7.14 bedroom temperatures post install

7.9 Humidity

Living room

Tech Ref No.	Post install - 15th November 2016 -1st April 2017				Post install - 1st November 2017 - 1st March 2018			
	5-8 pm Average humidity (RH%)	24 hours Average humidity (RH%)	24 hours Maximum humidity (RH%)	24 hours Minimum humidity (RH%)	5-8 pm Average humidity (RH%)	24 hours Average humidity (RH%)	24 hours Maximum humidity (RH%)	24 hours Minimum humidity (RH%)
WDH-05	53.4	53.1	81.5	38.0	49.7	49.3	71.0	28.0
WDH-09	48.9	49.8	69.5	31.5	48.8	51.3	70	30
WDH-13	54.2	52.7	70.5	30.5	54.4	52.4	73	31
Average	52.2	51.8			50.9	51.0		

Table 7.15 living room humidity levels post install

Table 7.15 and 7.16 show that average humidity levels were mostly within the expected 40%rh – 60%rh level. WDH-05 experienced slightly higher humidity levels in the bedroom than the other properties. None of the residents cited any issues with damp or condensation in the final questionnaire.

Bedroom

Tech Ref No.	Post install - 15th November 2016 -1st April 2017				Post install - 1st November 2017 - 1st March 2018			
	5-8 pm Average humidity (RH%)	24 hours Average humidity (RH%)	24 hours Maximum humidity (RH%)	24 hours Minimum humidity (RH%)	5-8 pm Average humidity (RH%)	24 hours Average humidity (RH%)	24 hours Maximum humidity (RH%)	24 hours Minimum humidity (RH%)
WDH-05	62.9	64.9	78.0	46.5	60.9	61.6	75.5	45.5
WDH-09	54.8	57.6	81.5	37.0	57.0	60.0	75.5	29.5
WDH-13	53.8	54.4	67.0	38.0	56.8	56.7	72	37.5
Average	57.2	59.0			58.2	59.4		

Table 7.16 bedroom humidity levels post install

7.10 Conclusions

The gas boiler with the enhanced controls performed in a similar manner to the standard gas boilers installed. All the properties experienced an increase in their SAP rating, 3 of the properties were all D rated prior to install whilst the solid fuel was F rated. 3 properties were then assessed to be high rated band D properties with 1 moving up to a band C.

There were significant improvements in resident satisfaction with their heating system, particularly with the cost of running the system and how warm it gets when it is cold outside. There was no pre-data available for these residents however gas costs were similar post install across the 3 properties, ranging from £527 to £665 per annum. Residents experienced higher temperatures in the preferred comfort period of 5-8pm which indicates that they had programmed the heating to be at a higher temperature during certain periods. The impact of the weather compensator element of the Wave can be seen on WDH-14, as this property demonstrated good level of control over their heating system.

Some of the residents did not have access to the related app. This was usually related to residents forgetting passwords or changing phones. If residents are to take advantage of the increased controllability of the Wave thermostat then they need to have access, some residents in fuel poverty may not have a suitable phone to access the app. Another area of concern relates to a change in home ownership, when a new resident moves in they will have to sign up to the app to programme the heating system.

A comparison table that features key performance indicators for all the technologies trialled can be found in section 10.1.

8.1 Dimplex Quantum high heat retention storage heaters

These storage heaters replaced older storage heaters that needed replacing. The Dimplex Quantum storage heaters[13] works on the same premise as traditional storage heaters i.e. utilising off-peak electricity tariffs to "charge" up ceramic bricks with heat and release it later to the room where it is installed. A common complaint around older systems is that heat "leaks" to the room when heat is not required and there is insufficient stored heat later in the day for release when heat is required (such as evenings). The Dimplex Quantum storage heaters work on the same principle as other [older] systems, with the added benefit of enhanced insulation for improved controllability of heat release at required times, an LCD display with a 7-day programmer. The storage heaters automatically adjust the energy required to heat the property according to changes in external weather. Manual controls are still available.

There is limited questionnaire data as 3 of the residents dropped out after the 1st year of monitoring. 1 of the 2 remaining residents was unavailable to carry out the final questionnaire.

			Pre		Post	
Tech Ref	Size (m²)	House type	Rating	Band	Rating	Band
WDH-45	83	Semi-detached house	49	E	64	D
WDH-10	50	Semi-detached bungalow	50	E	63	D
WDH-19	50	Semi-detached bungalow	54	E	62	D
WDH-08	50	Semi-detached bungalow	50	E	61	D
WDH-07	52	Semi-detached bungalow	49	E	63	D

Table 8.1 property characteristics

All the properties moved from band E rated properties to band D. All properties were of a similar rating pre and post install.

8.2 Cost

Electric	"Before" period							"After" period							Comparison	
Tech Ref	Period	Days	Total Period (kWh)	Total Cost	Degree days	kWh per degree day	Estimated annual cost	Period	Days	Total Period (kWh)	Total Cost	Degree days	kWh per degree day	Estimated annual cost	Estimated saving (£)	Estimated Saving (%)
WDH-07	26/2/15 - 1/3/16	369	12079	£1,273	2509	4.8	£1,088	25/8/16 - 15/8/17	355	12458	£1,244	2342	5.3	£1,139	-£51	-5%
WDH-45	13/9/14 - 15/8/16	702	23836	£2,705	4932	4.8	£1,177	13/1/17 - 18/4/18	460	17606	£1,951	3498	5.0	£1,196	-£19	-2%
WDH-10	23/2/15 - 27/2/16	369	10919	£880	2502	4.4	£754	1/9/16 - 15/8/17	348	9801	£795	2333	4.2	£731	£23	3%
WDH-19	-	-	-	-	-	-	-	1/12/16 - 20/7/17	231	9339	£881	1702	5.5	£1,111		
Average															-£16	-1%

Table 8.2 annual electricity costs pre and post install

Changes in annual costs experienced by residents were insignificant with an average increase in cost of £16. 2 of the residents increased their annual costs, WDH-07's annual costs increased by £51 and WDH-45's increased by £19. As there is no pre-install thermal data for the living room and bedrooms it is unclear if residents are achieving higher temperatures at around the same annual

13 https://www.dimplex.co.uk/product/quantum-heater

cost. The data from the post install temperatures show temperatures that are on average significantly higher than 21°C (table 8.4).

Tech ref	Pre		Post	
	On peak (%)	Off peak (%)	On peak (%)	Off peak (%)
WDH-07	32	68	27	73
WDH-45	40	60	37	63
WDH-10	10	90	10	90
WDH-19	-	-	22	78

Table 8.3 comparison of on and off-peak usage pre and post install

Table 8.3 shows the percentage of electricity used on and off-peak before and after the storage heaters were installed. All residents used most of their electricity on the off-peak rate, WDH-10 used 90% of their energy on the off-peak rate. 2 of the residents marginally increased the proportion of electricity used off-peak.

8.3 Temperature

Living room

Tech Ref No.	Post install - 15th November 2016 -1st April 2017				Post install - 1st November 2017 - 1st March 2018			
	5-9 pm Average temperature (°C)	24 hours Average temperature (°C)	24 hours Maximum temperature (°C)	24 hours Minimum temperature (°C)	5-9 pm Average temperature (°C)	24 hours Average temperature (°C)	24 hours Maximum temperature (°C)	24 hours Minimum temperature (°C)
WDH-07	24.0	23.3	27.5	17.0	22.2	21.3	26.5	13.0
WDH-45	22.7	22.0	27.5	16.5	22.3	21.7	24.0	19.0
WDH-10	22.7	22.5	26.0	18.5	-	-	-	-
WDH-19	25.0	24.1	29.5	17.5	-	-	-	-
WDH-08	19.0	18.6	21.5	15.5	-	-	-	-
Average	22.7	22.1			22.2	21.5		

Table 8.4 living room temperatures post install

4 of the 5 residents attained temperatures above the recommended range of 18°C – 21°C. WDH-19 experienced an average temperature of 24.1°C between the 15th November 2016 and the 1st April 2017. WDH-10 and WDH-45 maintained similar temperatures in the living room and main bedroom, WDH-45 spent £465 more per annum than WDH-10. However, WDH-45 is over 30m² larger than WDH-10.

WDH-07 is the same size as WDH-10 yet WDH-07 spent £408 per annum more (see table 8.2). This resident heated the property to excessive temperatures, this was particularly prevalent in the first monitored period where the temperature reached an average of 24°C between 5-9pm in the living room and 23.4°C in the bedroom. There appears to have been an adjustment made by the resident as these temperatures dropped to 22.2°C and 21.7°C respectively in the second monitored period. WDH-19 is another similarly sized property as WDH-07, they both experienced similar temperatures and costs.

The temperatures within the properties did not drop below 15.5°C within the living room during the 1st monitored period. This indicates that once the storage heaters have been turned on the properties are able to retain the heat throughout the heating season. The weather compensator enables the storage heaters to provide adequate heat to reach the residents desired temperatures as external temperature changes. This is evidenced in figure 8.5 below, this graph shows WDH-45 had a R^2 value of 0.94 indicating there was a positive relationship between degree days and energy usage. As the weather increased or decreased in temperature the storage heaters responded accordingly.

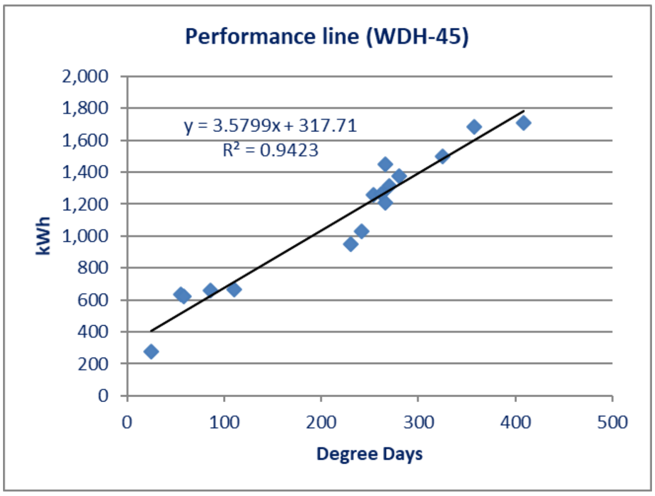


Figure 8.5 performance line of the Dimplex Quantum storage heaters

Bedroom

Tech Ref No.	Post install - 15th November 2016 -1st April 2017				Post install - 1st November 2017 - 1st March 2018			
	5-9 pm Average temperature (°C)	24 hours Average temperature (°C)	24 hours Maximum temperature (°C)	24 hours Minimum temperature (°C)	5-9 pm Average temperature (°C)	24 hours Average temperature (°C)	24 hours Maximum temperature (°C)	24 hours Minimum temperature (°C)
WDH-07	23.4	23.0	26.0	17.5	21.7	21.8	25.5	15
WDH-45	18.7	18.5	25.5	14.0	17.7	17.5	21.5	14.5
WDH-10	19.9	19.4	23.5	15.0	-	-	-	-
WDH-19	22.8	22.9	29.5	17.5	-	-	-	-
Average	21.2	20.9			19.7	19.7		

Table 8.6 bedroom temperatures post install

2 of the 4 properties with temperature data available attained temperatures between the recommended range of 18°C – 21°C. 2 properties exceed this with temperatures around 23°C.

8.4 Humidity

Living room

Tech Ref No.	Post install - 15th November 2016 -1st April 2017				Post install - 1st November 2017 - 1st March 2018			
	5-9 pm Average humidity (RH%)	24 hours Average humidity (RH%)	24 hours Maximum humidity (RH%)	24 hours Minimum humidity (RH%)	5-9 pm Average humidity (RH%)	24 hours Average humidity (RH%)	24 hours Maximum humidity (RH%)	24 hours Minimum humidity (RH%)
WDH-07	54.6	54.4	72.0	36.0	53.8	53.7	76.5	34.5
WDH-45	53.8	52.9	66.5	42.5	53.5	51.9	63.5	40.5
WDH-10	47.7	46.9	61.5	36.5	-	-	-	-
WDH-19	48.5	48.5	69.5	34	-	-	-	-
WDH-08	57.4	56.7	71.0	47.0	-	-	-	-
Average	52.4	51.9			53.6	52.8		

Table 8.7 living room humidity levels post install

Despite the high temperatures experienced in WDH-07 and WDH-19 the humidity levels remained within the 40%-60% range. This was the case in the living rooms and bedrooms (tables 8.7 & 8.8). This indicates that the properties are well insulated and ventilated.

Bedroom

Tech Ref No.	Post install - 15th November 2016 -1st April 2017				Post install - 1st November 2017 - 1st March 2018			
	5-9 pm Average humidity (RH%)	24 hours Average humidity (RH%)	24 hours Maximum humidity (RH%)	24 hours Minimum humidity (RH%)	5-9 pm Average humidity (RH%)	24 hours Average humidity (RH%)	24 hours Maximum humidity (RH%)	24 hours Minimum humidity (RH%)
WDH-07	54.3	56.7	69.5	34.0	56.5	58.3	77	34.5
WDH-45	55.0	53.4	70.0	36.5	55.4	53.1	72.5	35
WDH-10	55.2	55.7	67.0	44.0	-	-	-	-
WDH-19	51.5	53.2	67.5	32.5	-	-	-	-
Average	54.0	54.8			56.0	55.7		

Table 8.8 bedroom humidity levels post install

8.5 Conclusions

Electric storage heaters are the most common form of electric heating and are often found in high rise buildings and in off-gas areas. Storage heaters usually operate on economy 7 hours overnight and take advantage of cheaper electricity tariffs. The Dimplex Quantum's are high heat retention heaters with advanced controllability. A common complaint among residents with traditional storage heating is that their storage heaters release all their heat in the morning, leaving little for the evening. These residents living rooms had higher temperatures in their preferred comfort period of 5-8pm (a period when supplementary heating would be used) than their average temperatures across the monitored period. This indicates that residents were able to heat their properties later in the day and control the units effectively.

The costs remained largely the same after install, there were minor increases in cost and a minor decrease in cost. The proportion of energy used off-peak during the economy 7 hours increased marginally. 1 resident consumed 90% of their energy on the off-peak tariff. There is evidence of the Quantum's iQ controller responding to the external temperature.

A comparison table that features key performance indicators for all the technologies trialled can be found in section 10.1.

9.1 ASHP

A Mitsubishi Ecodan air source heat pump was installed to meet space heating and hot water heating, the heat pumps replaced solid fuel-based systems. The same air source heat pump was used in the ASHP & PV project (see 3.1) and the Hybrid project (4.1).

9.2 Social Evaluation

There were only 2 residents available to complete the questionnaire when the final visits took place. 1 of the residents had moved in after the ASHP was installed.

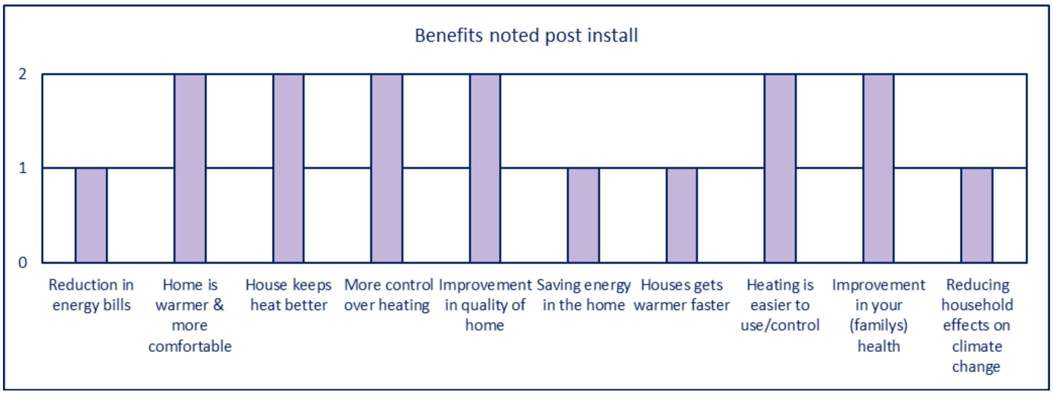


Figure 9.1 benefits noted by residents' post install

Both residents noted several benefits after the ASHP was installed as evidenced in figure 9.1. WDH-01 stated that they experienced fewer chest infections since the coal fire was removed, whilst also noting that costs were more manageable. They also found the system provided enough control and was easy to use. WDH-02 was very satisfied with how warm the property got when it was cold outside.

			Pre		Post	
Tech Ref	Size (m²)	House type	Rating	Band	Rating	Band
WDH-01	78	Semi-detached house	27	F	52	E
WDH-04	72	Semi-detached house	41	E	67	D
WDH-02	74	Semi-detached house	49	E	68	D
WDH-03	71	Mid-terrace house	45	E	55	D

Table 9.2 property characteristics

Table 9.2 shows that there was a significant uplift in the SAP ratings of the properties following installation of the ASHPs. 1 F property moved up to an E and the 3 E rated properties moved up to band D.

9.3 Cost

Electric	"After" period					
Tech ref	Period	Days	Total Period (kWh)	Degree days	kWh per Degree Day	Estimated annual cost (£)
WDH-01	18/11/16 - 16/4/18	514	9425	4076	2.3	£794
WDH-02	17/11/16 - 17/4/18	516	12202	4093	3.0	£1,023
WDH-04	27/10/16 - 8/5/18	558	14658	4391	3.3	£1,146
WDH-03	16/8/17 - 19/4/18	246	6910	2173	3.2	£1,091
Average					**3.0**	**£1,013**

Table 9.3 annual electricity costs post install

Tech Ref	2017			2018		
	Output	Input	SCOP	Output	Input	SCOP
WDH-02	7779	4043	1.9	4120	2077	2.0
WDH-01	7467	3173	2.4	4894	1953	2.5

Table 9.4 efficiency of the heat pumps

All properties were previously heated by solid fuel systems, therefore there is no accurate energy usage prior to the installation of the ASHP. Annual costs ranged from £794 to £1146 per annum.

At the final visit data on the input and output of the heat pumps was collected from the 2 residents that were available. WDH-01 had a SCOP of 2.5 however, this property was only heated to an average of 15°C. WDH-01 noted that the temperature was set at 18°C, keeping the temperature low and on regularly explains the higher SCOP. WDH-04 had the highest annual cost at £1146 yet they were able to keep the living room heated to 22°C and the bedroom at 20.5°C.

9.3 Temperature

Living room

Tech Ref No.	Post install - 15th November 2016 -1st April 2017				Post install - 1st November 2017 - 1st March 2018			
	5-9 pm Average temperature (°C)	24 hours Average temperature (°C)	24 hours Maximum temperature (°C)	24 hours Minimum temperature (°C)	5-9 pm Average temperature (°C)	24 hours Average temperature (°C)	24 hours Maximum temperature (°C)	24 hours Minimum temperature (°C)
WDH-01	14.9	15.2	25.5	10.0	-	-	-	-
WDH-02	20.6	20.7	23.0	14.5	21.3	21.7	28	15.5
WDH-04	21.7	21.9	25.0	19.5	21.7	21.7	23.5	15.5
WDH-03	20.8	20.6	24.5	16.0	-	-	-	-
Average	19.5	19.6			21.5	21.7		

Table 9.5 living room temperature post install

WDH-01 was the only property where the temperature was not between 18°C - 21°C. This property has the lowest annual cost, the lower temperature did not have an impact on the resident's view of the system. The temperature in the bedroom during the second monitored period was warmer, unfortunately the logger in the living room did not record any data. WDH-03 and WDH-04 maintained high temperatures in the living room and bedroom.

Bedroom

Tech Ref No.	Post install - 15th November 2016 -1st April 2017				Post install - 1st November 2017 - 1st March 2018			
	5-9 pm Average temperature (°C)	24 hours Average temperature (°C)	24 hours Maximum temperature (°C)	24 hours Minimum temperature (°C)	5-9 pm Average temperature (°C)	24 hours Average temperature (°C)	24 hours Maximum temperature (°C)	24 hours Minimum temperature (°C)
WDH-01	-	-	-	-	17.5	17.8	22.5	11.5
WDH-02	19.3	19.6	25.5	11.0	-	-	-	-
WDH-04	20.5	20.7	23.5	18.0	20.4	20.5	23	15
WDH-03	24.5	24.4	27.0	20.5	-	-	-	-
Average	21.5	21.6			19.0	19.1		

Table 9.6 bedroom temperature post install

9.4 Humidity

Living room

Tech Ref No.	Post install - 15th November 2016 -1st April 2017				Post install - 1st November 2017 - 1st March 2018			
	5-9 pm Average humidity (RH%)	24 hours Average humidity (RH%)	24 hours Maximum humidity (RH%)	24 hours Minimum humidity (RH%)	5-9 pm Average humidity (RH%)	24 hours Average humidity (RH%)	24 hours Maximum humidity (RH%)	24 hours Minimum humidity (RH%)
WDH-01	58.1	57.4	77.5	38.5	-	-	-	-
WDH-02	48.6	48.5	79	31.5	43.6	43.9	62.5	26.5
WDH-04	47.9	47.3	70.5	32.0	51.7	51.1	74.5	37
WDH-03	46.3	44.1	71.0	32.5	-	-	-	-
Average	50.2	49.3			47.6	47.5		

Table 9.7 living room humidity levels post install

Humidity levels within the living room were between the recommended range of 40%rh-60%rh. WDH-01 had the highest level of humidity although this does coincide with the property having the lowest temperatures. WDH-04 experienced the lowest levels of humidity particularly within the bedroom.

Bedroom

Tech Ref No.	Post install - 15th November 2016 -1st April 2017				Post install - 1st November 2017 - 1st March 2018			
	5-9 pm Average humidity (RH%)	24 hours Average humidity (RH%)	24 hours Maximum humidity (RH%)	24 hours Minimum humidity (RH%)	5-9 pm Average humidity (RH%)	24 hours Average humidity (RH%)	24 hours Maximum humidity (RH%)	24 hours Minimum humidity (RH%)
WDH-01	-	-	-	-	58.4	58.9	76	37.5
WDH-02	47.6	48.1	72.5	33.0	-	-	-	-
WDH-04	46.8	47.7	61.0	37.5	48.0	48.4	74.5	35
WDH-03	37.8	37.7	51.0	30.0	-	-	-	-
Average	44.1	44.5			53.2	53.6		

Table 9.8 bedroom humidity levels post install

9.5 Conclusions and recommendations

Conclusions

An ASHP is often installed in off-gas areas in place of oil or solid fuel heating systems, they are a well-established renewable heating technology. There was no accurate energy pre-install data for the residents as they were solid fuel heated properties. Post install the energy costs ranged from £794 to £1146 per annum. The cost and temperatures compare favourably with the ASHP systems that were installed with PV. The annual costs of two similarly sized properties with PV were similar to those without (c. £1000 per annum), however the temperatures in the dual system properties were slightly higher than those with just an ASHP.

The SAP rating increased in every property, 3 properties were rated at band D and 1 property was rated a band E property. ASHP installations benefit from receiving RHI payments, the payments are related to the annual heat demand figure that is listed on the EPC and factor in the seasonal performance factor (SPF). The SPF is taken from the MCs certification, to be eligible for Domestic RHI a heat pump must have a minimum SPF of 2.5. 1 property only had an SPF factor of 2 so would not be eligible if the payment for RHI was reliant on metering.

A comparison table that features key performance indicators for all the technologies trialled can be found in section 10.1.

10 Overall findings

10.1 Comparison tables

The following tables show some of the key performance indicators for each of the technologies. The tables are organised by property size, the following ranges were used:

- $50m^2$ - $69m^2$
- $70m^2$ - $79m^2$
- $80m^2$ - $89m^2$
- $90m^2$ +

Comparing properties of a similar size enables a fairer comparsion between technologies. The following tables should be read with caution as they do not take into account other household characteristics such as occupancy, lifestyle and number of rooms heated, which can have a significant effect on the average energy use in a small sample size.

Comparison of 50 – 69m^2 Properties

Properties					Pre		Post			Pre	Post	
Tech Ref	Previous heating system	Measure installed	Size (m^2)	House type	Rating	Band	Rating	Band	Change in SAP rating	Annual cost	Annual cost	Average living room temperature (°C)
WDH-10	Storage heaters	Dimplex Quantum	50	Semi-detached bungalow	50	E	63	D	+	£754	£731	22.5
WDH-19	Storage heaters	Dimplex Quantum	50	Semi-detached bungalow	54	E	62	D	+	-	£1,111	24.1
WDH-08	Storage heaters	Dimplex Quantum	50	Semi-detached bungalow	50	E	61	D	+	-	-	18.6
WDH-07	Storage heaters	Dimplex Quantum	52	Semi-detached bungalow	49	E	63	D	+	£1,088	£1,139	21.3
T-50	Storage heaters	Logicor	49	Top floor flat	66	D	59	D	-	£762	£1,554	21.6
T-66	Storage heaters	Logicor	67	Semi-detached house	55	D	50	E	-	£1,089	£1,558	17.1
T-46	Gas	Gas and solar thermal	64	Semi-detached house	65	D	69	C	+	-	£914	20

Table 10.1 property characteristics ($50m^2$ - $69m^2$)

Table 10.1 shows that the Dimplex system offered an increase in SAP points and a living room temperature within the 18°C – 21°C range. The 2 Logicor properties both achieved temperatures of 21°C but this was associated with high annual costs of over £1,500. Additionally the Logicor properties saw a reduction in SAP points as they are considered by the rdSAP software to be a “peak rate” electric heating system.

Comparison of 70 – 79m² Properties

Table 10.2 property characteristics (70m² - 79m²)

Properties					Pre		Post			Pre	Post	
Tech Ref	Previous heating system	Measure installed	Size (m²)	House type	Rating	Band	Rating	Band	Change in SAP rating	Annual cost	Annual cost	Average living room temperature (°C)
WDH-03	Solid fuel	ASHP	71	Mid-terrace house	45	E	55	D	+	-	£1,091	20.6
WDH-04	Solid fuel	ASHP	72	Semi-detached house	41	E	67	D	+	-	£1,146	21.7
WDH-02	Solid fuel	ASHP	74	Semi-detached house	49	E	68	D	+	-	£1,023	21.7
WDH-01	Solid fuel	ASHP	78	Semi-detached house	27	F	52	E	+	-	£794	15.2
T-10	Solid fuel	ASHP & PV	70	Semi-detatched House	34	F	74	C	+	£1,593	£1,011	23.2
T-18	Solid fuel	ASHP & PV	71	End-terrace House	60	D	63	D	+	£1,684	£1,036	21.5
T-06	Solid fuel	ASHP & PV	75	Semi-detatched House	-	-	74	C	-	£348	£489	18.5
WDH-09	Gas boiler	Gas boiler with controls	73	Semi-detached house	59	D	67	D	+	-	£696	19
T-39	Gas boiler	Gas boiler	70	Semi-detached house	52	E	68	D	+	£953	£735	19.4
T-48	Gas boiler	Hybrid	76	Semi-detached house	60	D	60	D	-	-	£1,579	18.1
T-34	Storage heaters	Logicor	70	Semi-detached house	57	D	46	E	-	£856	£1,007	19.4
T-33	Storage heaters	Logicor	71	Semi-detached house	59	D	49	E	-	£747	£1,015	19.7

Table 10.2 shows that all but one property (WDH-01) achieved a temperature within the range of 18°C – 21°C. Of these properties the lowest annual costs were experienced by the residents with gas central heating systems (WDH-09 & T-39). The Logicor systems achieved similar annual costs as 5 of the ASHP (including PV as well) properties however the ASHP properties mostly achieved higher temperatures.

Comparison of 80 – 89m² Properties

Properties					Pre		Post			Pre	Post	
Tech Ref	Previous heating system	Measure installed	Size (m²)	House type	Rating	Band	Rating	Band	Change in SAP rating	Annual cost	Annual cost	Average living room temperature (°C)
T-51	Solid fuel	ASHP & PV	89	Semi-detatched House	54	E	63	D	+	£1,860	£1,744	21.2
WDH-14	Gas boiler	Gas boiler with controls	81	Semi-detached house	38	F	68	D	+	-	£1,659	-
WDH-05	Gas boiler	Gas boiler with controls	84	Semi-detached house	62	D	66	D	+	-	£948	18.6
WDH-13	Gas boiler	Gas boiler with controls	87	Semi-detached house	67	D	69	C	+	-	-	19.9
WDH-45	Storage heaters	Dimplex Quantum	83	Semi-detached house	49	E	64	D	+	£1,177	£1,196	22.0
T-29	Gas boiler	Gas boiler	86	Semi-detached house	47	E	69	C	+	£1,458	£1,161	23.3
T-30	Gas boiler	Gas boiler	88	Semi-detached house	36	F	70	C	+	-	-	21.1
T-24	Gas boiler	Ga boiler and solar thermal	83	Semi-detached house	46	E	69	C	+	£687	£630	17.6
T-12	Gas boiler	Gas boiler and solar thermal	88	Semi-detached house	69	C	71	C	+	£954	£953	22.1
T-03	Gas boiler	Hybrid	80	Semi-detached house	63	D	48	E	-	-	£1,790	20.2
T-53	Gas boiler	Hybrid	84	Semi-detached house	49	E	62	D	+	-	-	19.1
T-45	Storage heaters	Logicor	87	Semi-detached house	62	D	52	E	-	-	£1,830	19.6

Table 10.3 property characteristics (80m² - 89m²)

T-03 and T-45 both experienced reductions in their SAP points, both moving from a D to E. This table has the highest costs of all the monitored properties, there is significant variation in cost and the temperatures achieved. The highest temperature achieved was by a gas heated property at a cost of £1,161 (T-29).

Comparison of 90 + m² Properties

Properties					Pre		Post			Pre	Post	
Tech Ref	Previous heating system	Measure installed	Size (m²)	House type	Rating	Band	Rating	Band	Change in SAP rating	Annual cost	Annual cost	Average living room temperature (°C)
T-27	Solid fuel	ASHP & PV	99	Semi-detatched House	56	D	81	C	+	£2,059	£1,148	22.4
T-20	Solid fuel	ASHP & PV	109	Semi-detatched House	53	E	77	C	+	-	-	20.5
T-05	Gas boiler	Hybrid	101	Semi-detached house	69	C	60	D	-	-	£1,257	20.8
T-01	Gas boiler	Hybrid	103	Semi-detached house	57	D	60	D	+	-	£1,227	20.8
T-170	Gas boiler	Gas boiler and solar thermal	112	Semi-detached house	56	D	69	C	+	£1,250	£1,123	17.6
T-40	Gas boiler	Gas boiler and solar thermal	108	Semi-detached house	67	D	70	C	+	£1,306	£1,372	-

Table 10.4 property characteristics (90m² +)

The annual costs post install for the properties in table 10.4 were similar as were the living room temperatures (T-170 was the exception). Only the 2 hybrid properties failed to move up to band C.

10.2 Key findings per technology

A brief overview of the key findings from each technology trialled in the properties. It should be noted that sample sizes were low, around 5-6 properties, and sometimes lower. The sample sizes were low due to the number of technologies trialled and the availability of resources for monitoring. These low sample sizes do not offer statistically significant findings and instead should be viewed as indicators of performance in specific households. Having a larger sample size would also reduce the impact of residents dropping out of the project or equipment failing as there would be a larger pool of data to draw on. It is recommended that larger sample groups of 30 + should be used in any future studies.

Logicor

- There was an increase in annual costs after the Logicor system was installed.
- Continual issues with the hot water system despite steps being taken to rectify the issue.
- The Logicor system was removed from 1 property, this household had continual issues with the system, they found the system unsuitable for their needs and expensive to run.

ASHP & PV

- There was a marked improvement in SAP points, 4 properties are now rated band C and 2 are rated as band D.
- There was an increase in resident satisfaction with the performance of the heating system, including control and ease of use.
- 4 of the 5 residents reduced their annual costs after install.
- All residents achieved an average living room temperature of 18°C – 21°C.
- There is a high upfront cost which is in part mitigated by FIT and RHI payments. The Feed-in Tariff will no longer be available in March 2019.
- Whilst having solar PV is an advantage and has an impact on cost peak supply (PV generation in the summer) does not coincide with peak demand (heat pump demand in the winter).
- 2 of the properties had SCOPs of less than 2.5, an SCOP of 2.5 is the minimum level of efficiency to be eligible for metered RHI payments.

Hybrid ASHP

- The system was not configured as intended therefore not operating as a recognised hybrid system.
- The performance of the system reflects its set up. Only 10% of energy costs were met by the gas boiler as it was only providing hot water.
- Electricity costs were high in 4 of the properties with an average electricity cost of £1340. The properties that received hybrids were larger than the other properties that received an ASHP which in part explains the higher annual costs of the hybrid properties. 1 of the other subgroups (ASHP & PV) also received solar PV generation which had an impact on their costs.

Gas boiler and solar thermal hot water system

- The hot water demand of the property and number of direct feed/instantaneous hot water appliances should be considered before installing a solar thermal system.
- These properties did not have a high hot water demand, and all had instantaneous electric showers.
- 2 of the residents reduced their annual energy costs.

Gas boiler (control)

- 3 of the properties were rated band C and 1 at band D post install.
- High levels of satisfaction regarding cost, ease of use and level of control.
- The temperature in the living room of all properties was between 18°C – 21°C.
- 2 of the residents reduced their annual costs after the new gas boiler was installed, the other 2 residents did not have enough consumption data to calculate any savings.

Gas boiler with smart controls

- High levels of satisfaction expressed by residents regarding cost, ease of use and level of control.
- Annual gas costs were low.
- There is evidence that the smart aspects of the Wave controller such as the weather compensation increased the level of control over the heating system.
- Residents had to have access to the Wave app to make changes to their heating schedule, this could not be done from the in-home display. Some residents noted that they did not have the app or had forgotten their password for it.

Dimplex Quantum high heat retention storage heaters

- Only minor increases or decreases in annual cost post install, 3 of the properties had post install costs of around £1,150.
- A high proportion of electricity was used on the cheaper economy 7 rate, this ranged from 63% - 90%.
- All residents achieved living room temperatures within or above 18°C – 21°C.
- There is some evidence that the Dimplex Quantum altered energy consumption according to changes in the external temperature.
- Some residents were overheating their properties, 2 heated their properties above 24°C.

ASHP

- A significant increase in SAP after moving from solid fuel, 3 properties moved up to band D and 1 to band E.
- There was an average annual electricity cost of £1,013 post install.
- 1 property had a SCOP of 2 whilst the other had an SCOP of 2.5. This is a measurement of the heat pumps efficiency. An SCOP of 2.5 is the minimum efficiency a heat pump can be to be eligible for RHI. However, this would not be the case if the property only used a heat pump to meet its heating demand.
- 3 of 4 residents had a living room temperature of 18°C – 21°C.

10.3 Overall observations

Standard Assessment Procedure

The most significant increases in SAP points were noted in properties where solid fuel had been replaced, ASHP systems and ASHP systems with PV were the technologies used to replace the solid fuel systems. Post install 4 of these properties were band C rated properties, 8 were band D rated properties and only 1 was in a band E although this property had the lowest SAP rating of all monitored properties pre-install, moving from 27 (F) to 52 (E).

Well established renewable technologies such as heat pumps and solar thermal hot water systems are well represented by the rdSAP software. Other technologies are newer to the market and the rdSAP software has not been adapted to accommodate for innovative systems. The hybrid system was not configured as intended on this project however if it had been then the Standard Assessment Procedure would not have represented it as a truly hybrid system. If innovative technologies are not accurately represented, then this will have an impact on future deployment of innovative measures as landlords and homeowners seek to increase their SAP rating.

Satisfaction levels with heating systems

Those residents that used gas as their main form of heating expressed the highest levels of satisfaction with the following statements; ‘cost of running the system’, ‘amount of control over the system’ and ‘how easy the system is to use’. All but 1 of these properties previously had gas boilers in place, this familiarity likely explains why residents were so satisfied with the above statements. Despite this it is still clear that gas boilers are considered simpler to use and the most affordable way in which to heat the home.

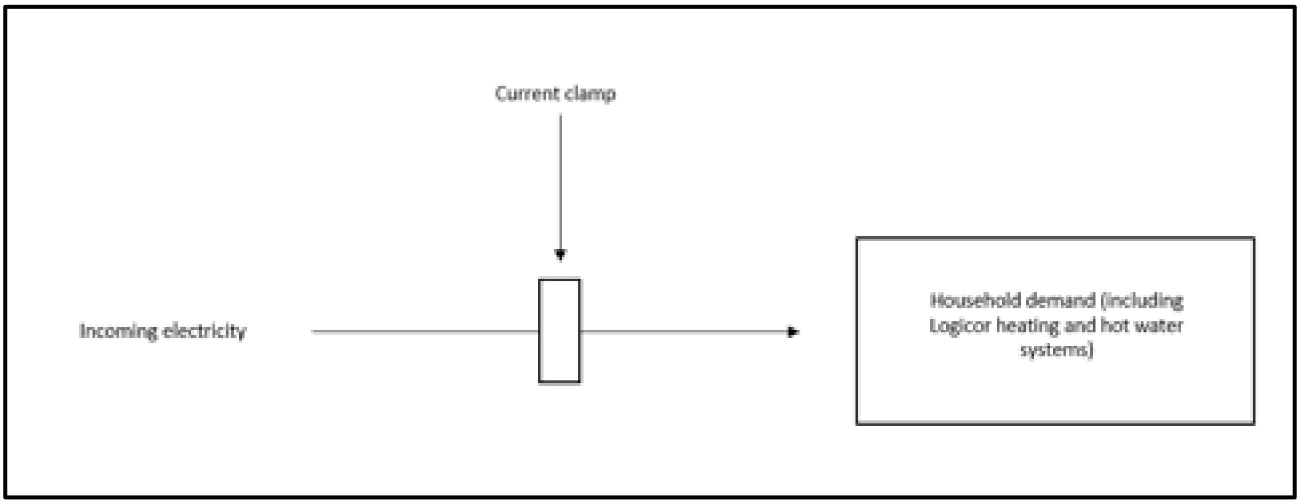
Gas systems will continue to be the benchmark against which innovative technologies are used. There is evidence that the more established renewable technologies are moving closer to this level of performance and acceptability. Those residents that received an ASHP alongside solar PV were satisfied with the amount of control they had and how easy the system was to use however satisfaction fell short regarding energy costs. Despite this the properties that had air source heat pumps installed experienced similar levels of satisfaction to gas heated properties. With further engagement and improvements in design specification these technologies will become easier to use and cost competitive. It should however be noted that these air source heat pumps replaced solid fuel heating systems that did not provide adequate heat and were expensive to run.

Appendix 1: Glossary of Terms

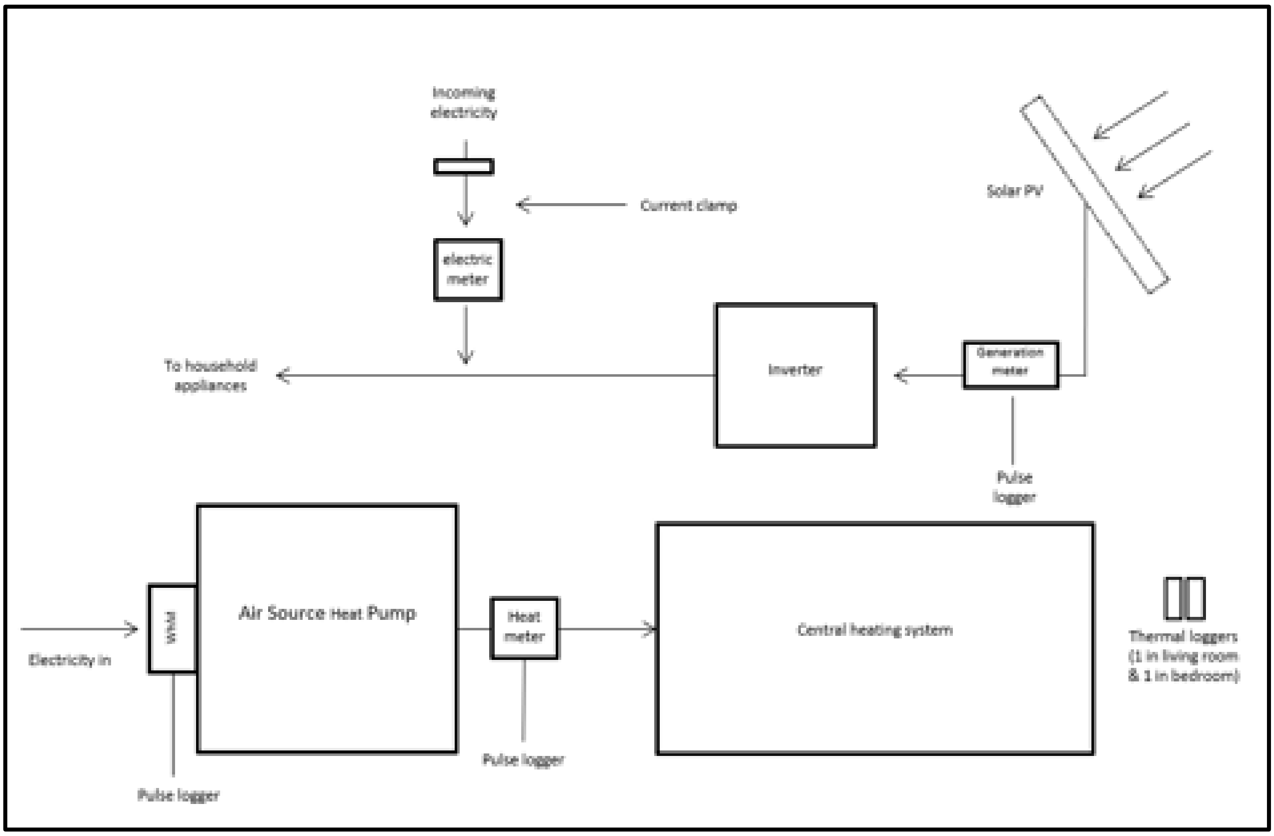
ASHP	*Air Source Heat Pump*
DD	*Degree Days*
EPC	*Energy Performance Certificate*
FIT	*Feed-in Tariff*
HIP	*Health and Innovation Programme*
NEA	*National Energy Action – the National Fuel Poverty Charity*
PV	*Photovoltaic*
RH	*Relative Humidity*
RHI	*Renewable Heat Incentive*
SAP	*Standard Assessment Procedure (for assessing home energy efficiency)*
TIF	*Technological Innovation Fund*
TRV	*Thermostatic Radiator Valve*

Appendix 2: Technical monitoring schematics

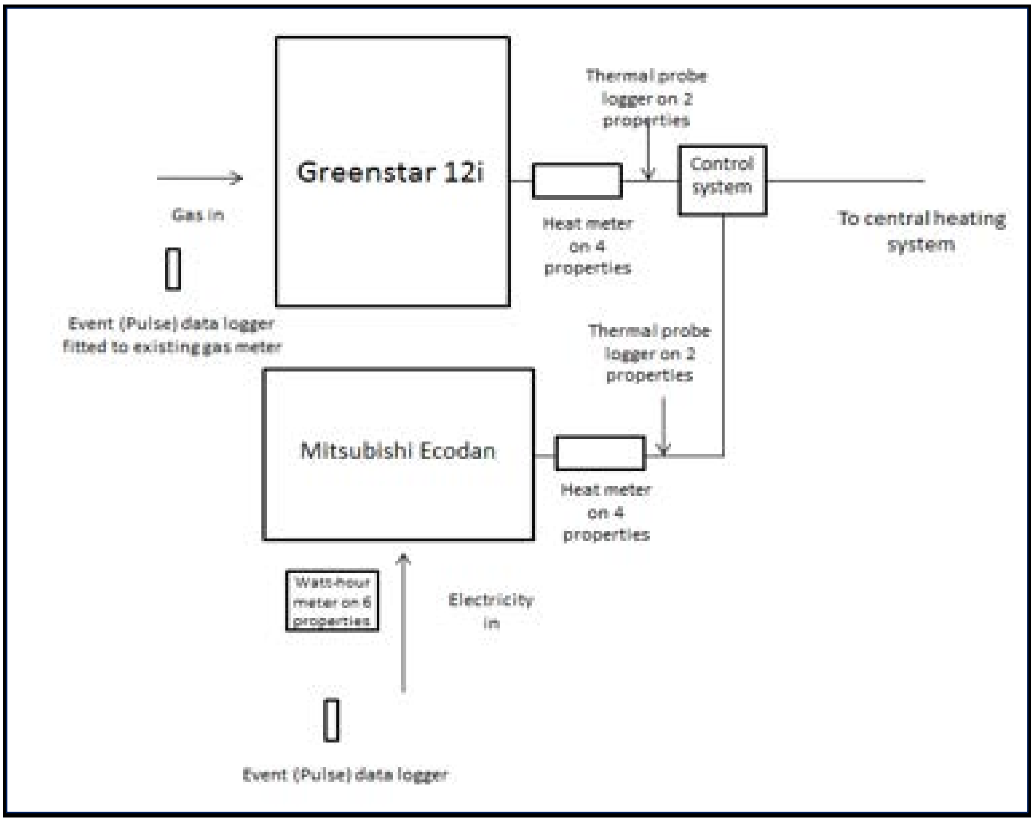
Logicor Heating system



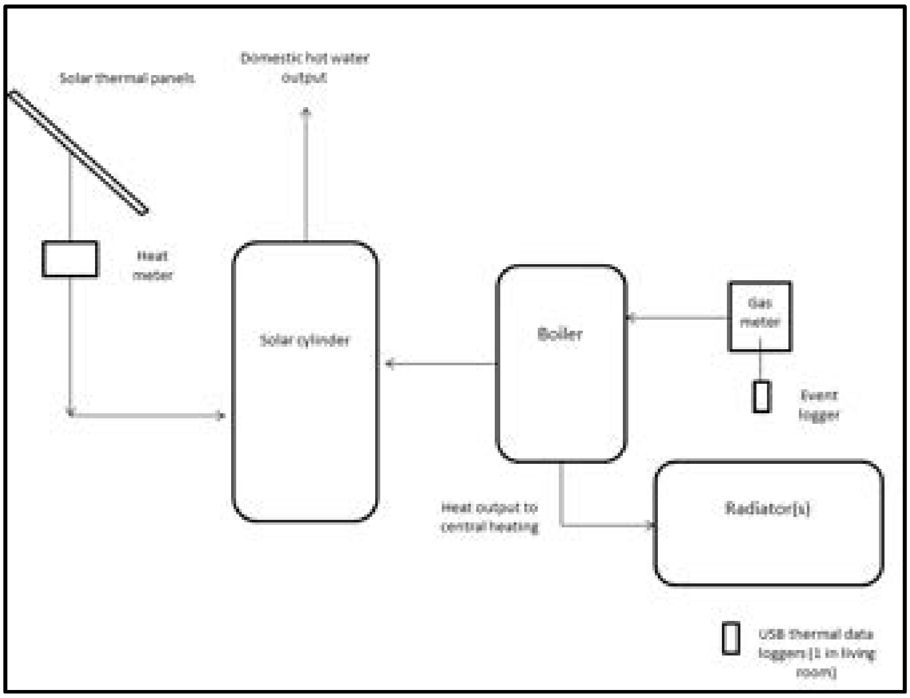
ASHP & Solar PV



Hybrid



Gas and Solar Thermal



Appendix 3: Case Study

Mrs M lives in a 3-bed, semi-detached house with her 19-year-old son and her husband. The family has suffered without hot water other than in the electric shower and from the kettle for more than four years as their heating had broken down. They were always cold and unable to heat their home to an acceptable standard. In the absence of a working central heating system they were using electric fan heaters, electric oil-filled radiators and a gas heater in various parts of the home to try to keep warm.

After receiving an installation of a new heating and hot water system the house has been transformed, resulting in many positive outcomes for the family. All members of the household are happier and interacting in a much more pleasant way. Mrs M works shifts and finds it easier to come home to a warm home after a night shift rather than shivering in the cold. In the past she sometimes found it easier to go out to work rather than spend time in her own home because of the cold.

There have been many positive impacts of the family's new heating system. The electricity bill has halved: they are using a prepayment meter and used to top it up with £20 per week in the winter months – this now lasts at least two weeks. The son suffers from bronchial asthma and used his inhaler daily during the winter. He is now only using the inhaler about once a month when he is spending time outside in the cold, when he is at home he doesn't need it at all. He thinks this is because you can no longer see your own breath when talking in the house. His health has improved a great deal which has been noticed at regular health check-ups by medical staff as his lung function is showing much better levels than in previous years.

The combined gas and electricity bill the previous Christmas/New Year for the family had been approximately £120 and after the intervention (during the same period 2016/17) the bill was no higher than £80.

The family has been able to have baths for the first time in years and the warmer home has resulted in much better personal hygiene for everyone because it feels much more comfortable to have a shower or a bath in a warm home. Even their dog has enjoyed a bath lately and is now much cleaner and happier!

Their son has the following to say about his new situation: "*It helps because the house is genuinely warmer. Before the heating [was installed] I just got so cold studying wasn't an option. I am currently studying for a degree in health and social care. With a warm room studying is so much easier. I don't feel as rushed, before I got done as quickly as possible as my hands were so cold I could not type. We live out of town so there are no library facilities I can use. After travelling an hour on the bus in the cold to arrive at a cold home and then studying in the cold was impossible. I now feel able to take my time over my studies".*

"Something that has really improved my personal hygiene is visits to the bathroom. It is so cool having warm water come out of the taps to wash and so much cleaner. I really appreciate being able to take my time over my studies and the improvements to our home as a result of the heating. We also don't have to boil the kettle 50 times a day".

Appendix 4: Health and Innovation Programme 2015 – 2017

The Health and Innovation Programme (HIP) was a £26.2 million programme to bring affordable warmth to fuel poor and vulnerable households in England, Scotland and Wales.
The programme launched in April 2015 and was designed and administered by fuel poverty charity National Energy Action as part of an agreement with Ofgem and energy companies to make redress for non-compliance of licence conditions/obligations. To date, it remains the biggest GB-wide programme implemented by a charity which puts fuel poverty alleviation at its heart.

The programme comprised 3 funds

- **Warm and Healthy Homes Fund (WHHF):** to provide heating, insulation and energy efficiency measures for households most at risk of fuel poverty or cold-related illness through health and housing partnerships and home improvement agencies

- **Technical Innovation Fund (TIF)**: to fund and investigate the impact on fuel poverty of a range of new technologies

- **Warm Zones Fund (WZF):** to install heating and insulation and provide an income maximisation service to households in or at risk of fuel poverty, delivered cost-effectively through partnership arrangements managed by NEA's not-for-profit subsidiary Warm Zones Community Interest Company

What it involved

- **Grant programmes** to facilitate the delivery of a range of heating and insulation measures and associated support. Grant recipients were encouraged to source match and/or gap funding to increase the number of households assisted and to enhance the support provided to them
- **Free training** to equip frontline workers with the skills needed to support clients in fuel poverty
- **Outreach work and community engagement** to provide direct advice to householders on how to manage their energy use and keep warm in their homes

In addition, we undertook substantial **monitoring and evaluation** work, to assess the effectiveness and measure the performance of the technologies, and to understand the social impacts of the programme. Our **communications programme** helped partners to promote their schemes locally as well as share best practice with others. The programme generated a considerable amount of **knowledge and insight** which will be made freely available to help support future policy and delivery.

Proper investment of advanced payments allowed us to generate interest which, along with efficiency savings, was reinvested back into the programme in the form of additional grants and support which helped us further exceed our targets.

For more information see www.nea.org.uk/hip

TECHNICAL INNOVATION FUND

NEA Technical
January 2019

NEA Action for Warm Homes