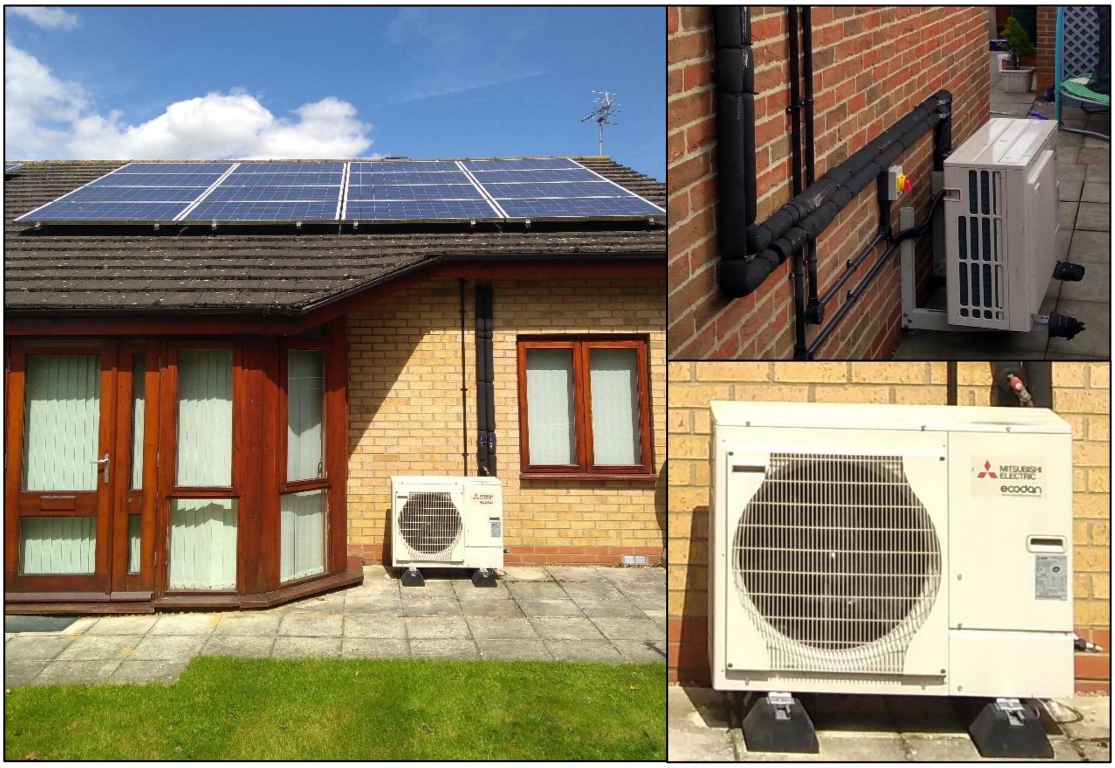
NEA Action for Warm Homes
TECHNICAL INNOVATION FUND

Project code CP786

Hybrid Air Source Heat Pump
(in conjunction with an existing oil-fired boiler)

Yorkshire Energy Services CIC
(Trading as YES Energy Solutions)

Technical Evaluation Report



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[1] 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 up to a maximum £7,400 per household, and a smaller measures programme funding measures 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.

[1] https://www.nea.org.uk/hip/ [Accessed 17/12/2018]

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.

Acknowledgements

With grateful thanks to our project partners:

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Executive summary

Project overview

The project involves the installation and monitoring of 5kW Mitsubishi Ecodan Hybrid Air Source Heat Pumps interfaced with existing oil boilers (Hybrid ASHP) into 10 properties. The Hybrid ASHP is designed to work with the existing oil-fired boiler currently used as the main source of space and water heating. The hybrid ASHP works in combination with the existing boiler, operating when the outside air temperature is above a pre-set level. Below this level the existing oil-fired boiler will heat the property to ensure that the ASHP operates at the optimum efficiency.

The project had the following aims:

- Fuel bill reductions
- Ease of use with on-demand heating
- Back-up system in case existing heat source (fuel oil) runs out
- Reduction in fuel poverty

Context

There are thousands of residents who struggle to keep on top of their fuel bills. Although oil fuel costs have dropped over the last 12 months, this is likely to be only a temporary reduction and the cost is still significantly higher than natural gas costs. LPG costs also remain significantly higher than the costs of natural gas.

This project took place in the villages of Leverton and Eastville, two areas amongst the 40% most deprived neighbourhoods in the country.

The technology

The project involves the installation and monitoring of 5kW Mitsubishi Ecodan hybrid air source heat pumps (Hybrid ASHP) into properties in Eastville and Leverton. The Hybrid ASHP is designed to work with the existing oil or LPG boilers currently used as the main source of space and water heating (oil-fired boilers in the case of this project).

The project

North Lincolnshire Council selected properties where space heating was provided by oil-fired boilers. These properties were all to have the Hybrid ASHP installed to provide space heating in conjunction with the existing oil-fired boiler. Further properties, where oil-fired boilers were providing space heating, would not have a hybrid ASHP and would be used as a control group for the purposes of this project.

Summary of findings

Due to the limited data available and diversity of operating modes used by trial householders, it proved challenging to provide some conclusions.

- The limited available data suggests that using the ASHP in conjunction with the oil boiler did provide cost reductions although this evidence is based on a very small number of properties which displayed different characteristics
- Usable data from the study properties was limited and represented different time periods.
- Residents were concerned about having to maintain a stock of fuel oil for the oil-fired boiler AND increase their spending (monthly payment) on electricity.
- Some residents used the ASHP in isolation (non-hybrid mode).
- Some residents continued to use the oil-fired boiler until the oil store was depleted, switching to ASHP mode at that point (non-hybrid mode).
- Residents maintained comfort levels before and after installation of the ASHP using either one or both heating systems.

Recommendations

Installation of this type of system should only be considered where:

- Residents are fully aware of the principle of the system.
- Residents are able to minimise bulk purchase of oil and spread the cost of that (or LPG) – ideally through one bill.
- Residents understand that in addition to oil (or LPG) they will see an increase in electricity bills but will use less oil than previously.

1 Project overview

1.1 Introduction

North Lincolnshire Council (NLC) has considerable experience in supporting, managing and delivering domestic energy efficiency projects. The project was led by Yorkshire Energy Services (YES) and involved the installation and subsequent evaluation of 5kW Mitsubishi Ecodan Hybrid Air Source Heat Pumps (Hybrid ASHP) in combination with an existing oil boiler and working in "hybrid" mode. Measures were installed into 10 properties. Originally the project was to install the systems into off gas main park homes, but on survey, the insulation levels in the properties were not adequate to support a [lower temperature] ASHP heating system. The Hybrid ASHP is designed to work with in combination with a secondary heating source (such as gas or oil) through a new or existing boiler. When air outside temperatures fall, ASHP efficiency decreases, and there is a point when it's more cost effective to use another source of heat. The hybrid system intelligently selects the most economical heat source depending on a variety of parameters.

NLC were responsible for engaging with residents and working with YES to set up initial introductions and discussions with residents and gain consent for participation. NLC led on setting up data-sharing agreements between partner organisations and residents.

YES Energy Solutions are experienced project managers of domestic energy efficiency schemes and are Microgeneration Certification Scheme[2] (MCS) accredited installers of this technology.

1.2 Aims

The technology deployed within this project is designed to complement the customer's existing heating system and maintain comfort levels in the property. In addition, the project will:

- Establish heating bill reductions
- Establish usability of the heating system
- Provide a back-up (secondary) heat source in case one fails
- Help address fuel poverty in rural off-gas situations

1.3 Context

There are 275,000[3] residents in Yorkshire who struggle to keep on top of their fuel bills and are defined as being in fuel poverty. Although oil fuel costs have dropped over the last 12 months, this is likely to be only a temporary reduction and the cost is still significantly higher than natural gas costs. LPG costs also remain significantly higher than the costs of natural gas.

The villages of Leverton and Eastville are in two areas amongst the 40% most deprived neighbourhoods in the country.

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[2] https://www.microgenerationcertification.org/ [Accessed 03/12/2018]
[3] https://www.gov.uk/government/statistics/sub-regional-fuel-poverty-data-2018 [Accessed 17/12/2018]

1.4 Project timeline

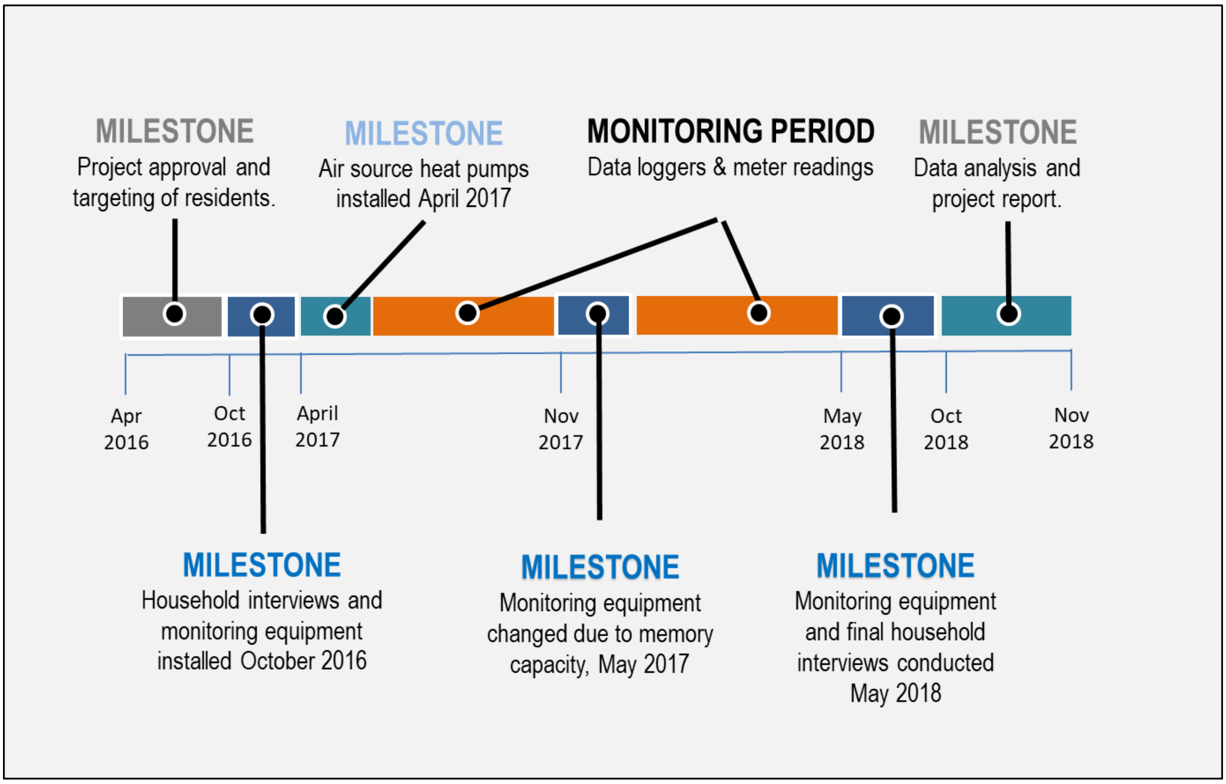

Figure 1.1 Project timeline

1.5 Attracting beneficiaries and establishing a monitored group

North Lincolnshire Council selected properties where space heating was provided by oil fired boilers; these properties were in the Eastville and Leverton areas of Yorkshire. These properties were all to have the Hybrid ASHPs installed to provide space heating in association with the existing oil-fired boiler. Properties in the Bishop Norton area, where oil fired boilers were providing space heating, were used as a control group for the purposes of comparing the hybrid group with an equivalent baseline on unimproved properties having an oil boiler. This was necessitated by the absence of any thermal or energy use data during a heating season, prior to the new systems being installed. Each property was given a unique technical reference number to enable comparisons to be made within this report but ensuring anonymity of the residents. This reference (Tech. Ref) is shown in Figure 1.2 with basic details of the property and any measures which were installed or whether it is a control (comparison) property.

Tech. Ref.	Area	House type	Measures/Control
T-01	Eastville	Semi-detached bungalow	Measures
T-03	Eastville	Semi-detached house	Measures
T-05	Eastville	Semi-detached bungalow	Measures
T-07	Bishop Norton	Mid-terrace house	Control
T-08	Eastville	Semi-detached bungalow	Measures
T-10	Eastville	Semi-detached bungalow	Measures
T-12	Leverton	Semi-detached house	Measures
T-14	Leverton	Semi-detached house	Measures
T-16	Leverton	Semi-detached house	Measures
T-19	Bishop Norton	Mid-terrace house	Control
T-21	Bishop Norton	End-terrace house	Control
T-23	Bishop Norton	Semi-detached house	Control
T-42	Eastville	Semi-detached bungalow	Measures
T-50	Eastville	Semi-detached house	Measures

Fig 1.2 Details of properties taking part in monitoring

1.6 Factors affecting the planned evaluation methodology

Issue	Description and mitigation
Project Scope	It was originally planned to trial the technology in park homes, but due to the poor thermal performance of the properties, Mitsubishi determined that it would not be sensible to deploy the ASHP based technology in these properties. Due to challenges in finding an alternative community and short timelines - bungalow type properties were found as an alternative.
Size of monitoring group	It was planned that 8 properties receiving measures would be monitored. Only one property was eventually found to be operating their heating in automatic "hybrid" mode. 4 control group properties were monitored, which restricted the available useful data for analysis.
Start of monitoring	NEA monitoring started in late October/early November 2016, however very little monitoring of oil usage could be achieved until the specialist oil meters were installed at the same time as the hybrid ASHP in March 2017 meaning that there was no "pre-install" oil usage data. Reliance on the "control group" was required for comparison during the active monitored period.
Monitored group	The monitoring group was significantly diminished due to a number of issues with either the installation of the hybrid ASHP or its configuration, monitoring equipment issues or the residents' manual intervention with the system.
Meter readings	Various installed meters were available to provide data for analysis. Where readings were available, these were used as part of the analysis. Solar PV generation meter data was generally not available as meters were located in the loft of the properties and not accessible. This means that analysis of energy consumption by the heat pump could not take account of any "free" electricity provided by the PV array. Analysis was mainly concentrated around a period of the day when PV generation was assumed to be negligible.
Monitoring equipment	A significant part of the specified monitoring equipment (mainly heat meters) were not installed by the Hybrid ASHP engineers as requested. Enhanced metering was only installed in one property. This had implications on the data for analysis.
Energy Performance Certificates	EPC performance, before and after the installation of the Hybrid ASHP, could not be performed due to anomalies following installation of the Hybrid ASHP. The EPC available on the Landmark Website showed the following issues. Certificates for properties in Eastville state that the main heating is provided by "Air source heat pump, radiators, electric" - this is incorrect. Certificates for properties in Leverton, state that the main heating is provided by "Boiler and radiators, oil" and "Air source heat pump, warm air, electric". This is also incorrect as the ASHP provides heat to the existing radiators connected to the oil boiler not via 'warm air'. This was only discovered at the analysis phase.

Tech. Ref.	Area	House type	Measures or Control	Factors affecting focussed analysis
T-01	Eastville	Semi-detached bungalow	Measures	Oil-fired boiler not used but sufficient data to analyse the Hybrid ASHP only
T-03	Eastville	Semi-detached house	Measures	Oil boiler manually turned on only when cold. Data unreliable for comparison
T-05	Eastville	Semi-detached bungalow	Measures	3 different tenants during the period of the project. Inconsistent data for analysis
T-07	Bishop Norton	Mid-terrace house	Control	Data limited to comfort levels only – no oil metering installed
T-08	Eastville	Semi-detached bungalow	Measures	The only property using the oil-fired boiler and the new Hybrid ASHP in the intended “hybrid” mode. Some operational data is available
T-10	Eastville	Semi-detached bungalow	Measures	Oil-fired boiler was not used as designed – resident manual intervention - therefore data unreliable
T-12	Leverton	Semi-detached house	Measures	ASHP turned off as resident continued to purchase oil. ASHP turned back on when oil stock depleted – unreliable and limited data
T-14	Leverton	Semi-detached house	Measures	Data limited to comfort levels only due to lost, misplaced, or faulty loggers
T-16	Leverton	Semi-detached house	Measures	Data limited to comfort levels only due to lost, misplaced, or faulty loggers
T-19	Bishop Norton	Mid-terrace house	Control	Critical lack of data
T-21	Bishop Norton	End-terrace house	Control	Sufficient data for analysis.
T-23	Bishop Norton	Semi-detached house	Control	Sufficient data for analysis.
T-42	Eastville	Semi-detached bungalow	Measures	Resident not available for questionnaires and installation of some monitoring equipment was removed for unexplained reasons – insufficient data for analysis
T-50	Eastville	Semi-detached house	Measures	Oil boiler not used due to faults but sufficient data to analyse the ASHP only.

Figure 1.3 Details of the properties and issues concerning analysis

2 Social evaluation and impacts

2.1 Qualitative feedback from initial questionnaire

During the initial visit by NEA staff in October/November 2016, residents were questioned through semi-structured interviews in their homes, to gauge their views and perceptions on a range of topics and issues. Figure 2.1 illustrates the age and gender of the respondents together with basic details of the property.

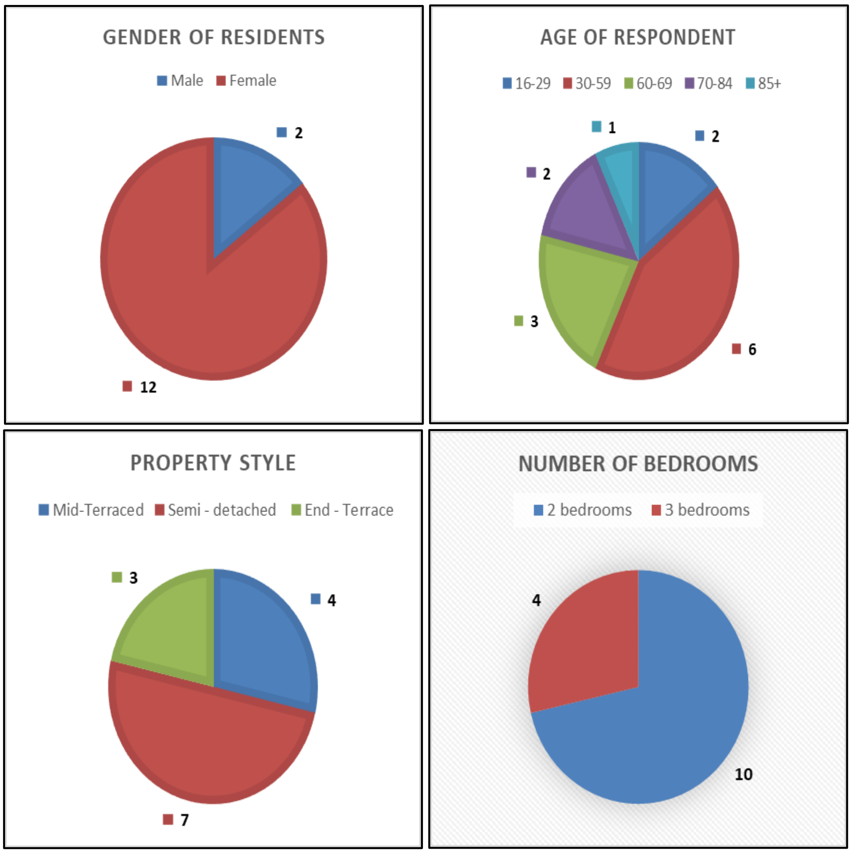

Figure 2.1 Gender and age of respondent, Property Style and number of bedrooms

Questions related to the age mix of all occupants of the properties and is shown in Figure 2.2

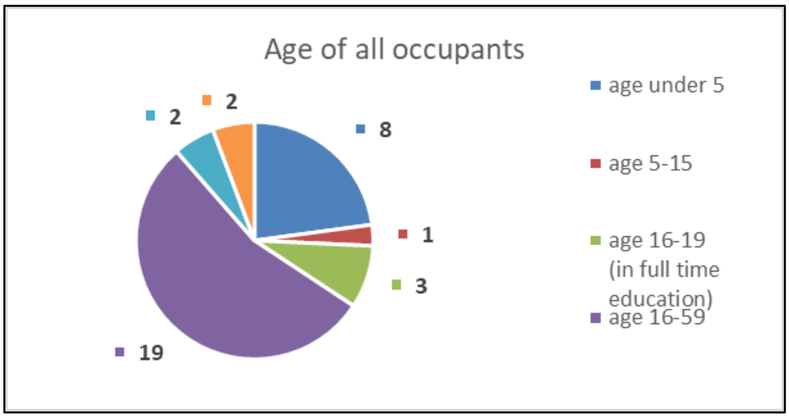

Figure 2.2 Age mix of all occupants in the monitored properties

Figure 2.3 Example of a property receiving an ASHP

During the questionnaires, residents were asked to state the times when it was important for them to have a warm home. These times will vary depending on their lifestyle and health requirements. The responses from 14 residents have been used to produce the chart in Figure 2.4.

As was expected a number of residents require their heating to be operational during the early morning but the majority expressed the importance of a warm home during the evening period. The graph indicates that 64% preferred heating starting at 17:00 hrs rising to 86% at 19:00 hrs and falling back to 64% at 20:00 hrs. Analysis in the following sections will therefore concentrate on the 4-hour period between 17:00 hrs and 21:00 hrs each day to evaluate heating system performance and resident acceptability of that heating system. There are a number of other reasons for selecting this period, but importantly, the properties had solar PV installed, and this generation of electricity by these panels reduces the electricity purchased from the resident’s electricity provider, skewing results. Concentrating on this period in the winter removes the contribution of “free” electricity from the PV panels to the ASHP. NEA was initially not made aware that the properties selected had Solar PV installed, hence no monitoring was installed to quantify generation and self-consumption within the property.

Where analysis is made over periods containing 24hr days, further clarification concerning the solar PV will be stated.

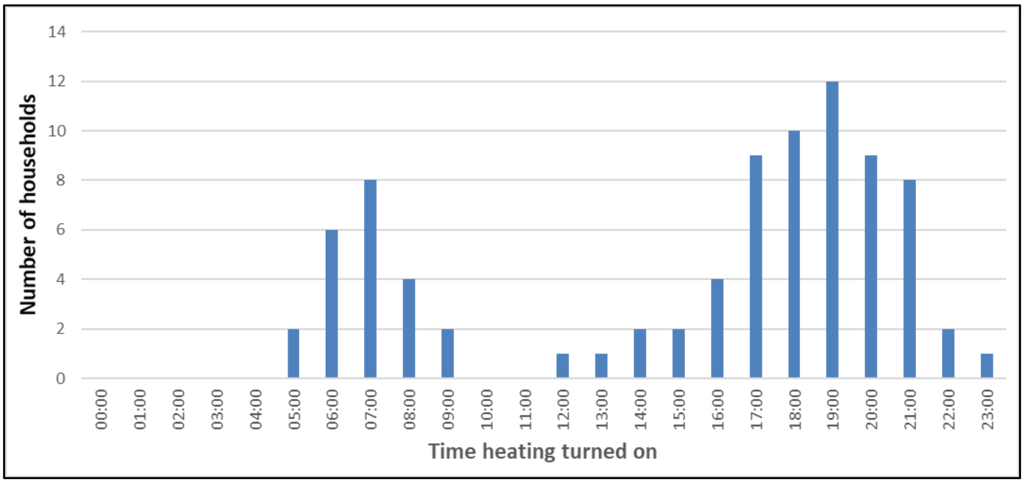

Figure 2.4 Times when residents stated it was important for them to have a warm home

2.2 Resident acceptance and satisfaction

In late 2016 or early 2017 during initial visits by NEA staff, residents were asked questions regarding their satisfaction with their current (oil-fired) heating system. The details and responses are shown in Figure 2.5. The majority of residents “disagreed” with all five questions presented, meaning they were not rationing energy to afford food etc. However, 4 respondents agreed with the statement “worrying about paying fuel bills”. These answers indicate that, in the majority of cases, there was a reasonable level of satisfaction with their financial situation and heating system.

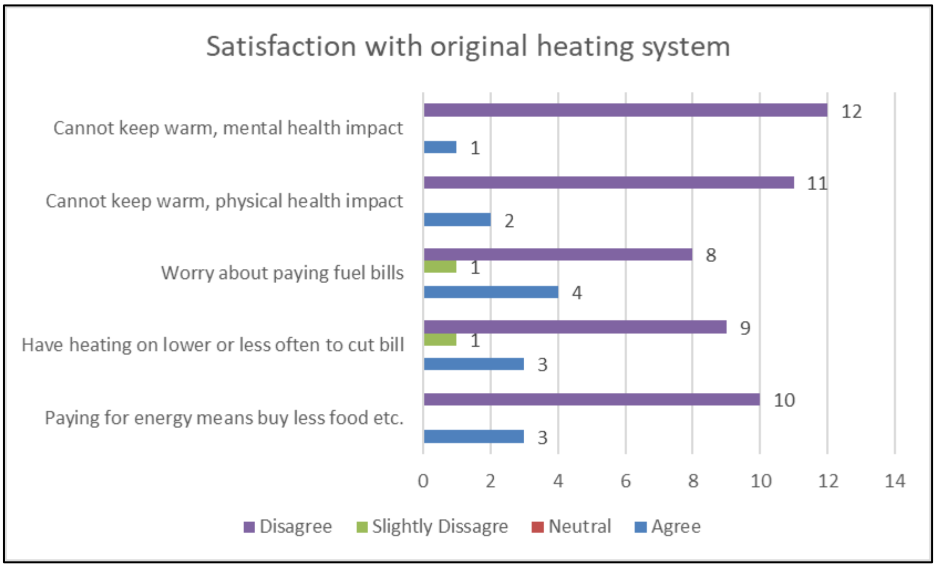

Figure 2.5 Satisfaction of residents with their heating system

During the initial and final interviews, residents were asked if they needed to wear additional items of clothing in order to keep warm during colder periods. Figure 2.6 shows the answers to this question (answers were not provided by all residents).

- Prior to installation of the Hybrid ASHP 5 of the 9 residents providing an answer **did wear additional clothing**
- Following installation of the Hybrid ASHP 2 of the 5 residents providing an answer did wear additional clothing
- Only 3 residents in the control group provided answers, 1 of which did wear additional clothing.

Additional clothing worn when cold	Properties receiving the ASHP		Control Group properties		All properties	
	Yes	No	Yes	No	Yes	No
Prior to installation of the ASHP	5	4	1	2	6	6
After installation of the ASHP	2	3	1*	2*	3	5

*Assumed to be as first visit

Figure 2.6, Is additional clothing worn to keep warm?

2.3 Perceived comfort and benefits

During the last project visit (May 2018), residents were asked to express their level of satisfaction with their heating system since the initial interview and installation of the technology. Only 5 residents provided answers which are summarised in Figures 2.7 & 2.8.

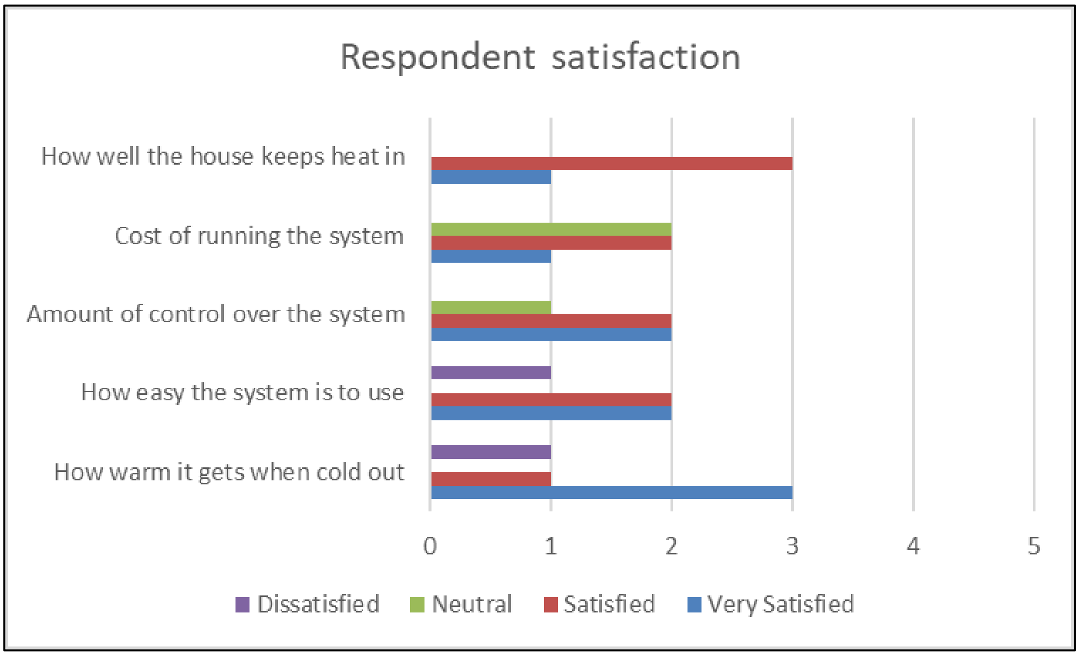

Figure 2.7 Number of households in the monitored group expressing level of satisfaction at the end of the project

Property Tech Ref	How warm it gets when cold out	How easy the system is to use	Amount of control over the system	Cost of running the system	How well the house keeps heat in	Comments
T-05	vs	vs	vs	n		ASHP *
T-03	s	s	s	n	s	ASHP only
T-14	vs	s	n	s	s	Oil & ASHP
T-08	vs	vs	vs	vs	vs	Oil & ASHP
T-50	d	d	s	s	s	ASHP only
	* Tenancy changed twice during project					

key	
vs	Very Satisfied
s	Satisfied
n	Neutral
d	Dissatisfied
vd	Very Dissatisfied

Figure 2.8 Property Ref analysis for answers shown in Figure 2.7

The data in Figure 2.8 clearly shows that the Property T-08, the only property using the Hybrid ASHP and oil-fired boiler as intended, was very satisfied with the system. T-50 was dissatisfied with how warm their home was and how easy the system was to use. All other responses were mainly “satisfied” with their heating system.
Note: Whilst T-14 appeared to use the system as a Hybrid, there was insufficient data to perform a detailed analysis. Property T-05 had 3 different tenants during the project and therefore the data recorded was unsuitable for comparisons to be made.

3 Technical evaluation and results

3.1 Overview of technology

The project involved the installation and monitoring of 5kW Mitsubishi Ecodan hybrid air source heat pumps (Hybrid ASHP), - Figure 3.1, into properties in Eastville and Leverton. The Hybrid ASHP was designed to work with existing boilers. In this project all were Thermecon wall-mounted oil-fired combi boilers.

Figure 3.1 Mitsubishi Ecodan hybrid air source heat pump and map showing property location including control group.

In addition, 8 properties of similar size and type were selected with similar oil-fired heating as a control group and provided comparison data to the group receiving interventions. The nearest properties were in the village of Bishop Norton (see Figure 3.1).

The hybrid ASHP system is designed to provide heat to the property through the ASHP, oil boiler or in a mode where both operate in conjunction with one another. When the outside air temperature is above a pre-set level, the ASHP would provide all of the heat (when it operates at higher efficiency). Below this level the existing (oil) boiler would heat the property, as it is cheaper to use oil. The system is pre-programmed with the energy costs from both systems and continually monitors both heat demand and outside temperatures, upon which its “decision” is made. A hybrid system allows heat pumps to deliver the heat requirement efficiently, and the oil-fired boiler to take over when the efficiency of the heat pump drops due to lower outside temperatures. There is an intermediate range where both systems may work simultaneously.

For every 1kW of input electrical energy, the Mitsubishi Hybrid ASHP harvests and upgrades “heat” from the outside air to provide the home with an average of at least 3.2kW of heat output. This figure is known as the “Seasonal Coefficient of Performance” (SCOP) and is generally calculated by dividing the heat output (kWh) of the ASHP by the electrical input (kWh). Therefore, based on the above Mitsubishi claim[4] where 1kW of electricity input provides 3.2kW of heat, the SCOP

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4 https://www.google.co.uk/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&ved=2ahUKEwjzr8vxpuDeAhWLD8AKHVpvAAsQFjAAegQIBBAC&url=https%3A%2F%2Flibrary.mitsubishielectric.co.uk%2Fpdf%2Fdownload_full%2F915&usg=AOvVaw0jsOYzYO8dii6w6bKl96Vs Accessed 19/11/18

would be 3.2. This figure will be compared to the data obtained during the monitoring of this project. An outdoor temperature switchover point is calculated and set by the installer, using manufacturers' guidelines. Outdoor temperature is automatically monitored. A typical schematic is shown in Figure 3.2.

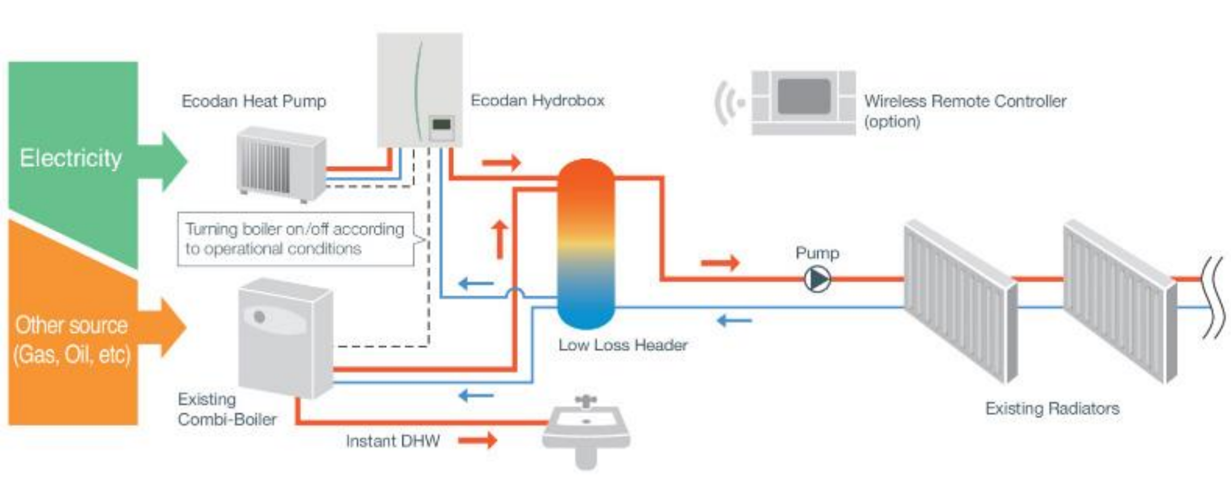


Figure 3.2 Schematic of typical installation (from Mitsubishi web site[5])

3.2 Technological monitoring

Two levels of monitoring were planned on this project: 'standard monitoring' and 'enhanced monitoring'. However, these specified monitoring scenarios were not implemented due to a number of factors, particularly the reduced number of specified heat meters which were not installed by the heating engineers.

'Standard Monitoring' was to consist of:

- 1 - energy clamp to measure ALL electricity used from the grid
- 1 - watt hour meter with pulse logger to measure electricity consumption of the ASHP
- 1 - oil meter with attached pulse logger to measure consumption of the oil-fired boiler
- 1 - heat meter with connected loggers to measure heat output from the ASHP
- 2 - thermal/humidity loggers to measure comfort levels in 2 rooms of the property.

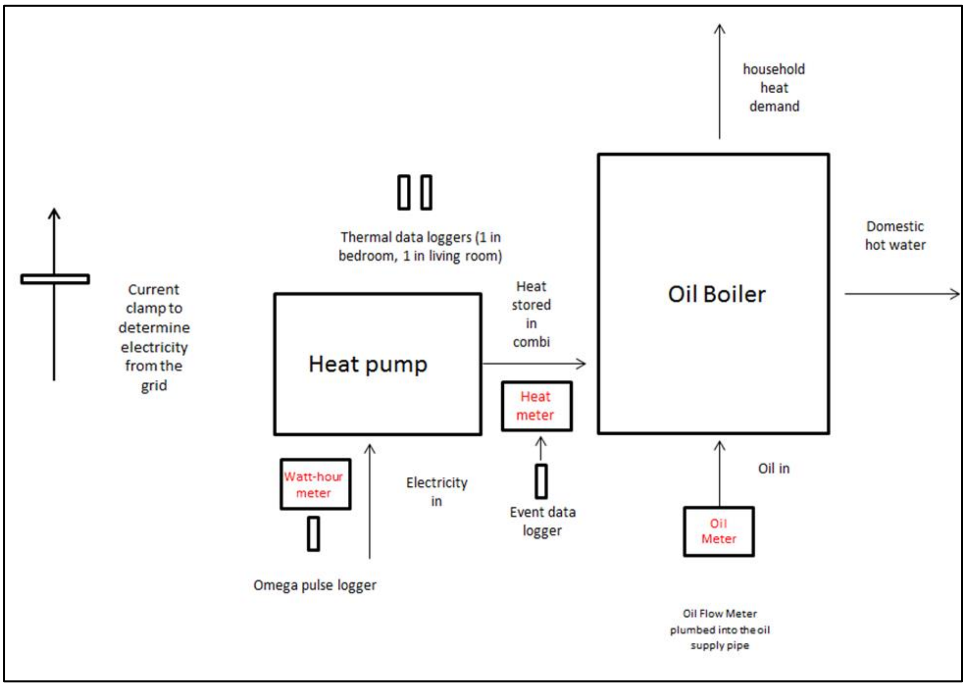
'Advanced Monitoring' was to consist:

- 1 - energy clamp to determine electricity used from the grid
- 1 - watt hour meter with pulse logger to measure electricity consumption of the ASHP
- 1 - oil meter with attached pulse logger to measure consumption of the oil-fired boiler
- 3 - heat meters with connected loggers to measure:
    - 1 to measure heat generated by the ASHP and passed to the oil-fired boiler
    - 1 to measure heat from the oil-fired boiler to the radiators
    - 1 to measure heat from the oil-fired boiler to domestic hot water

[5] https://www.google.co.uk/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&ved=2ahUKEwjzr8vxpuDeAhWLD8AKHVpvAAsQFjAAegQIBBAC&url=https%3A%2F%2Flibrary.mitsubishielectric.co.uk%2Fpdf%2Fdownload_full%2F915&usg=AOvVaw0jsOYzYO8dii6w6bKl96Vs Accessed 19/11/18

- 2 - thermal/Humidity loggers to measure comfort levels in 2 rooms of the property.
- 1 - pulse logger attached to existing Solar PV meter to measure electricity generated.

Schematic drawings of the two levels of monitoring are shown in Figures 3.3.



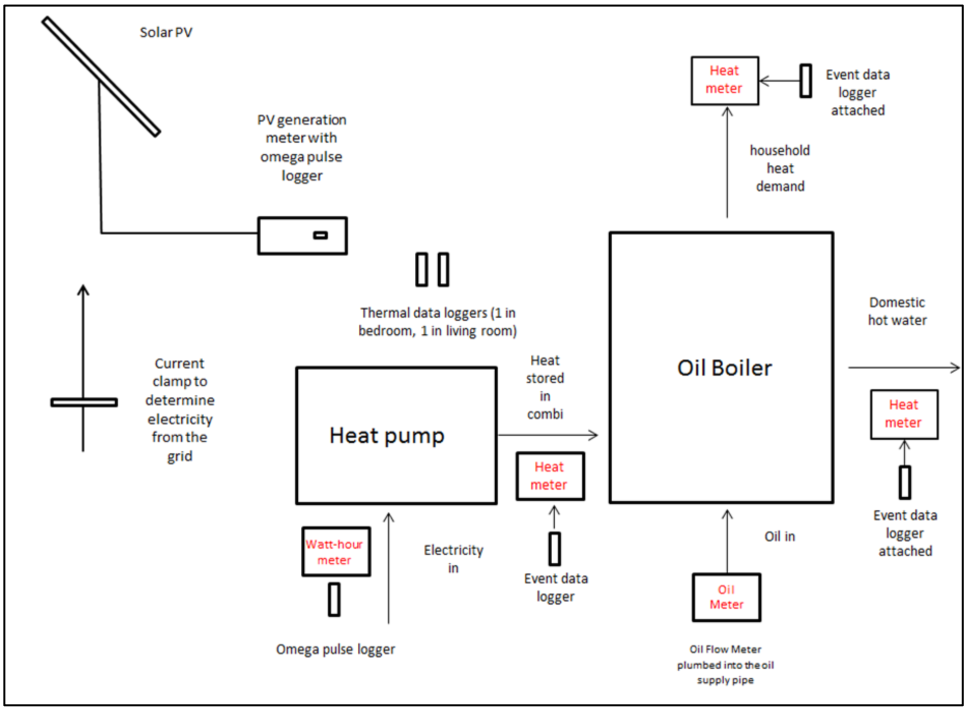


Figure 3.3 Schematics of proposed 'Standard' (top) and 'Advanced' (bottom) monitoring

However, for the reasons stated in section 1.6, all analysis is based on 'Standard Monitoring' as only one heat meter had been installed in each property. Also, there is no available data from the Solar PV generation meter.

3.3 Degree day data

To assist in analysis, it was important to use degree day data to allow for and indicate periods that were colder than others. Energy use data takes this into account for the period(s) to be analysed. These periods are based on the overall temperatures during the winter months of 2017/18.

Figure 3.4 shows degree days over a 9-month period, arranged as a ‘heat-map’ to illustrate the general temperatures recorded by a nearby weather station for the period. Warmer conditions are shown in light blue, progressing to darker blue for colder conditions. The number in each cell indicates the number of degree days for that day where 1-degree day equals 1°C below a 15.5°C baseline (14.5°C), 2-degree days equals 13.5°C, etc.

The heat-map shows that from 25th February 2018 to 3rd March 2018 was the coldest 7-day period with the 28th being the coldest day of the winter at 20.5-degree days (-5°C). This period contained a total of 120.3-degree days and will be used for various energy and comfort level analysis in the following sections of this report.

Day	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr
1	1.0	3.4	1.0	6.5	13.7	10.9	12.2	18.2	11.5
2	0.4	3.2	2.2	7.8	11.6	10.3	11.9	16.5	9.2
3	0.2	2.2	4.3	6.0	9.5	8.3	13.7	15.9	5.6
4	0.8	0.9	4.1	7.3	11.4	9.5	13.0	12.8	7.2
5	2.0	0.3	3.6	10.8	8.6	12.8	14.4	9.9	9.4
6	1.9	2.6	6.2	10.8	6.7	13.1	15.3	10.1	7.5
7	0.7	1.7	3.4	7.5	8.0	14.5	15.4	11.5	5.2
8	2.3	1.8	4.8	10.6	14.5	13.7	11.7	11.9	7.1
9	1.8	3.6	3.3	7.6	15.8	12.6	12.1	10.8	8.0
10	2.4	3.5	1.7	8.0	15.6	9.8	11.7	5.6	8.1
11	1.7	2.9	1.3	9.8	16.5	9.9	12.3	8.5	9.7
12	0.7	2.8	3.9	11.1	16.3	10.6	13.7	10.1	10.0
13	2.4	3.3	0.9	11.9	12.0	10.8	13.3	9.6	8.0
14	0.9	5.3	0.1	6.2	12.9	11.5	13.6	9.3	5.0
15	0.5	6.0	1.5	5.9	13.5	9.3	10.5	9.1	5.7
16	1.3	5.1	1.2	8.3	15.6	13.2	12.3	10.3	4.4
17	0.3	5.2	3.0	12.4	13.7	12.9	11.8	16.2	3.0
18	1.2	4.1	4.4	11.0	13.6	12.0	11.3	16.5	0.9
19	2.4	4.8	1.6	12.9	11.6	13.9	8.0	13.7	1.5
20	2.0	2.4	3.2	5.8	6.9	15.0	8.8	11.9	2.0
21	1.5	2.3	2.9	3.3	7.1	15.1	10.9	11.5	3.0
22	0.0	4.1	5.9	1.7	7.3	10.0	14.7	7.6	1.3
23	0.4	1.6	3.9	7.9	8.2	6.5	14.9	7.1	4.1
24	1.8	1.8	1.0	12.5	6.4	7.3	13.4	8.6	4.9
25	1.5	1.0	2.9	13.6	6.0	10.1	15.4	8.1	6.8
26	0.5	1.6	4.5	12.1	12.1	12.9	15.9	9.5	6.5
27	1.8	1.2	7.7	10.1	14.1	9.1	17.9	9.0	9.0
28	0.5	0.8	4.6	12.9	15.4	5.7	20.5	10.6	9.0
29	0.8	1.9	6.3	13.0	14.2	7.9		10.7	8.7
30	3.3	3.5	9.7	15.1	9.4	12.0		10.0	8.8
31	3.6		6.2		7.2	11.9		10.8	

Figure 3.4 Degree day heat-map for 2017/18 winter period

3.4 Energy Cost

The energy use (and associated cost) to residents was monitored in a number of ways using electricity and oil meter readings taken by NEA, partners, installers (on install day) and residents (using supplied logbooks). Residents were sent an SMS message on a weekly basis to remind them to record their meter reading in the logbook provided. Data from various loggers attached to meters and electricity cables, and residents supplied any utility bills they possessed. Degree-day data was also used to analyse energy use data and “corrected” for outside temperatures.

The following shows the details of where data was intended to be obtained from:

- Data logger attached to main electricity meter
- Periodic manual readings of the property main electricity meter
- Data loggers attached to pulse output of oil meter between oil tank and oil-fired boiler
- Periodic manual readings of the oil meter
- Resident supplied information on the purchase of oil
- Data logger attached to the electricity generation meter from the Solar PV
- Periodic manual reading of the generation meter
- Data loggers attached to heat meters installed in pipes of the heating system
- Periodic manual readings of heat meter display panel
- Periodic manual readings of the Hybrid ASHP integral display
- Thermal comfort

Data was not obtainable for many of the above sources for a number of reasons (see section 1.6), severely restricting the number of properties which provided sufficient data for analysis. The majority of analysis is therefore restricted to a limited number of properties. Where possible analysis is performed on three periods, where the majority of comparable data was available.

1st November 2016 to 31st March 2017;
1st November 2017 to 31st March 2018;
25th February 2018 to 3rd March 2018.

These periods are the same as those analysed in the next section on thermal comfort to allow correlation with energy consumption and comfort levels. In these cases, the 4-hour evening period will also be used, partly because this is when residents stated it was most important for them to be comfortably warm, and because PV generation is a minimum. In other cases, longer periods (multiple of 24 hours) will be used as the data would not allow for disaggregation to the hour. The properties with the most available data were:

T-08	**This is the only property that used both the original oil-fired boiler and the new Hybrid ASHP as intended and where sufficient data was available**.
T-01 & T-50	These two properties had Hybrid ASHP installed but the oil-fired boilers were not used.
T-21 & T-23	These two properties were part of the control group and therefore only used oil for heating.

3.5 Main electricity meter data (from data loggers)

Data loggers attached to the main electricity meter recorded the amount of energy used each hour during the project. Analysis was performed for various dates to allow comparison between properties. The 4-hour preferred heating period between 17:00hrs and 21:00hrs during the winter (see section 2.1 and Figure 2.3) has been selected for analysis in this section. This particular time period was selected for the following reasons:

1. Residents involved in the evaluation specified this as the most important time in the day for them to be warm and comfortable (preferred heating period).
2. The data loggers could not correctly record energy generated by the Solar PV. Data analysis for this ‘preferred heating period’ would more accurately reflect the amount of energy used as the PV would not be generating electricity during this period.

The dates selected reflect three distinct periods:

- 10th January to 31st March 2017, prior to installation of the Hybrid ASHP
- 1st November 2017 to 31st March 2018, after the installation of the Hybrid ASHP
- 25th February 2018 to 3rd March 2018, the coldest period of the 2017/18 winter

Figure 3.5 shows electricity consumption for 4 properties during the selected 4-hour timeslot within the defined date periods detailed above. Further supporting data appears in Appendix 1.

	Prior to installation of the ASHP			After installation of the ASHP			Coldest period	
Tech. Ref.	10/01/17 to 31/03/17 (80 days)		Heating system	01/11/17 to 31/03/18 (150 days) *		Heating system	25/02/18 to 03/03/18 (6 days) *	
	period	1 day		period	1 day		period	1 day
T-08	261.45	3.268	Oil boiler	922.18	6.148	Hybrid ASHP & Oil	22.46	3.743
T-01	740.88	9.261	Portable electric	820.67	5.471	ASHP Only	56.42	9.403
T-21	273.87	3.423	Oil boiler	540.73	3.605	Oil, control group	36.85	6.142
T-23	204.17	2.552	Oil boiler	387.95	2.586	Oil, control group	21.39	3.565
Degree Days	period	1 day		period	1 day		period	1 day
	769.4	9.618		1691.4	11.278		120.3	20.050

Figure 3.5 – Electricity consumption from data loggers (in kWh) for selected 4-hour periods within date range

Degree day data has been included to indicate that the period following installation of the Hybrid ASHP was slightly colder. This could not be adequately accounted for in the presented data through the degree day method of analysis[6] as this method utilises full days rather than periods within a 24-hour period. The degree day period provides an indication of the climatic conditions in the three periods. The average number of degree days increased from 9.618-degree days per day to 11.278-degree days per day representing a drop in average temperature of 1.7°C.

It should be noted that the degree day data is based on a daily figure for the three 'periods' and then averaged for the '1 day' period. This has been done for indicative use as the energy consumption is only based on the 'preferred heating period' of 17:00hrs to 21:00hrs each day.

The data indicates that:

- The 2 control group properties used a similar quantity of electricity for the 2 periods considering the colder weather during the 2017/18 winter.

- Property reference T-08, **the only property which used the Hybrid ASHP as intended**, used increased electricity (as would be expected) due to the change from oil to the (electrically powered) Hybrid ASHP. However, during the coldest period, the consumption per day reduced as the oil boiler provided heat during this colder period (as expected) due to the system switching to the oil system (the Hybrid ASHP would be less efficient in these colder temperatures).

- In comparison, property T-01 (which did not use the oil boiler) saw an increase in electricity consumption due to the lower efficiency of the [sole] ASHP heating system in these cold conditions.

[6] https://www.degreedays.net/introduction [Accessed 18/01/2019]

3.6 Main electricity meter readings

Meter readings taken by residents, NEA staff and project partner staff were analysed. However, due to the infrequent nature of the readings only 24-hour periods over several days can be analysed (unlike the previous section), but this does allow figures to be adjusted to take account of degree-day data. The winter periods of 2016/17 and 2017/18 are shown in Figure 3.6. An electricity cost of 16p/kWh is used across all TIF projects to allow comparisons to be made between them.

Analysis of this data alongside that obtained from the data loggers in the previous section was shown to be inconclusive due to:

- The previous section analysing data over the 4-hour 'preferred heating period'
- This section only analyses data for the 24-hour period
- Degree day data adjustment is only made within this section
- Property T-08 is the only property where both the oil boiler and the Hybrid ASHP were used.
- During colder weather conditions the Hybrid ASHP usage (of T-08) would reduce and the oil boiler output would increase
- Residents may have changed the periods when they used their heating system without reporting this

	Prior to installation of the ASHP							After installation of the ASHP						
Tech. Ref.	**Date range**	**Number of days**	**Heating system**	**Total kWh**	**Total Degree days**	**kWh / Degree day**	**30-day cost @ 16p/kWh ***	**Date range**	**Number of Days**	**Heating system**	**Total kWh**	**Total Degree day**	**kWh / Degree day**	**30-day cost @ 16p/kWh ***
T-08	04/01/17 to 03/04/17	89	Oil boiler	1,110	818.2	1.3566	£59.86	13/09/17 to 28/03/18	196	Hybrid ASHP & Oil	2,006	1,723.3	1.1640	£49.12
T-50	22/10/16 to 28/04/17	188	Oil boiler	1,581	1,655.4	0.9551	£40.37	21/10/17 to 09/05/18	200	ASHP only	4,007	1,873.3	2.1390	£96.17
T-21	31/10/16 to 03/04/17	154	Oil boiler	1,221	1,504.8	0.8114	£38.05	02/10/17 to 28/03/18	177	Oil boiler	1,495	1,759.6	0.8496	£40.54
T-23	22/11/16 to 26/03/17	124	Oil boiler	936	1,244.4	0.7522	£36.23	28/09/17 to 26/03/18	179	Oil boiler	1,329	1,748.3	0.7602	£35.64

*30-day cost based on total degree days for period ÷ number of days x 30 x kWh/Degree Day x £0.16

Figure 3.6 Electricity costs based on main meter reading

T-08 – The data in Figure 3.6 is somewhat contradictory – it suggests that, following the installation of the Hybrid ASHP, electricity consumption reduced from an average of £59.86 to £49.12 per average month. This is not what would be expected as the Hybrid ASHP uses more electricity than an oil boiler (including controls and pump). Questionnaires undertaken before and after the installation of the Hybrid ASHP suggest that the resident changed the heating pattern from 9 hours per day prior to the new system to 3 hours per day afterwards. However, analysis of comfort levels does not support this assertion.

T-50 – This property did not use the existing oil boiler following installation of the ASHP (and therefore is considered to be an ASHP rather than a Hybrid system). This resulted in over twice the amount of electricity being used. This figure is also approximately twice that of the control group properties where an oil boiler provides space and water heating, which is consistent with predictions.

T-21 and T-23 are both ‘Control’ properties and therefore an oil boiler provided space and water heating during the pre and post-install representative winter heating periods. Electricity consumption is roughly equal for both properties and both winter periods. Oil consumption data is analysed in the next section.

3.7 Heating oil use analysis

NEA specified the installation of oil meters onto the boilers’ oil supply pipe. Meters were supplied by NEA for installation into monitored and Control Group properties, along with diagrams and installation instructions. Data loggers were attached to each meter to count pulses from compatible meters. Energy use in kWhs were subsequently calculated using the conversion figure of 1 litre = 10.35kWh[7].

There were major challenges in obtaining oil metering data across the project, and no data was available relating to the oil consumption on those properties where the Hybrid ASHP were installed because either oil meters were not installed, or the data loggers were only able to capture data for a short period of time before the memory became fully utilised. For completeness, analysis of the data obtained is shown in Appendix 2.

3.8 Mitsubishi Energy Monitor

Air Source Heat Pumps use electrical energy and low-grade heat energy from the outdoor air and upgrade this energy to provide heat for water and space heating[8]. The ratio of the heat delivered to the power consumed represents the efficacy of the heat pump known as the Seasonal Coefficient of Performance or SCOP.

[7] https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/47732/7309-cca-draft-technical-guidance-app-b.xls [Accessed 18/01/2019] assuming 90% boiler efficiency
[8] https://www.evergreenenergy.co.uk/heat-pumps/how-does-a-heat-pump-work/ [Accessed 18/01/2019]

During the final monitoring visits, NEA staff were able to obtain details of the electricity consumed and the heat delivered by the heat pump for a number of the properties, from the Mitsubishi interface, installed with the ASHP system. An example of a typical energy monitor and data collected are shown in Figure 3.7.

Mitsubishi literature claims[9] an average SCOP of 3.2. Figure 3.8 indicates that the highest SCOP was 2.96 during the period of April – December 2017 and 3.13 for the period January to April 2018 (both for property T-05). This is approximately 5% below the claimed SCOP. However, the average across the 4 properties based on available data is, at best, 2.62 during the January to April winter months of 2018. This is approximately 18% below the claimed average SCOP. However, it must be stressed that this analysis is based on two dissimilar periods, rather than a prolonged period involving all seasons. The first period covers both winter and summer months and the second, mainly winter months. Further analysis is therefore needed before assuming these figures are representative across similar properties.

	April - December 2017			January - April 2018		
Property	Consumed electrical energy (kWh)	Produced heat energy (kWh)	CoP	Consumed electrical energy (kWh)	Produced heat energy (kWh)	CoP
T-08	2,123	5,502	2.59	1,237	3,370	2.72
T-03	1,023	1,899	1.86	1,261	3,341	2.65
T-05	1,910	5,663	2.96	1,409	4,409	3.13
T-50	1,542	2,592	1.68	1,865	3,657	1.96
Average	1,650	3,914	2.27	1,443	3,694	2.62
Minimum	1,023	1,899	1.68	1,237	3,341	1.96
Maximum	2,123	5,663	2.96	1,865	4,409	3.13

Figure 3.7, Mitsubishi energy monitor and data analysis

- T-08 – This property was the **only property where the Hybrid ASHP was used as designed**, in conjunction with the original oil-fired boiler. (average SCOP – 2.65)
- T-03 – The residents in this property **manually controlled the oil-fired boiler** when additional heat was required. (average SCOP – 2.26)
- T-05 – This property had three different tenants during the period of the project but achieved the greatest SCOP. (average SCOP – 3.04)
- T-50 – The oil-fired boiler in this property developed a fault and was not used during all the period of this project. (average SCOP – 1.82) – **ASHP Only**

3.9 Solar Photovoltaic generation meter data

The generation meters fitted with the solar photovoltaic (PV) panels prior to this project are installed in the loft of each property. NEA staff were not able to gain access to these meters for health and safety reasons. It was therefore not possible to take any generated electricity into account for this project.

It should also be noted that electricity generated through the PV system and exported to the grid (as against used within the property) would not be correctly recorded by data loggers attached to the main electricity meters, as loggers cannot differentiate between current flowing into or out of

[9] https://www.google.co.uk/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&ved=2ahUKEwjzr8vxpuDeAhWLD8AKHVpvAAsQFjAAegQIBBAC&url=https%3A%2F%2Flibrary.mitsubishielectric.co.uk%2Fpdf%2Fdownload_full%2F915&usg=AOvVaw0jsOYzYO8dii6w6bKl96Vs [Accessed 19/11/18]

the property and record it as energy "consumed". For this reason, the analysis of electricity from the grid was analysed for the evening period between 17:00hr and 21:00hrs. This was the period when residents indicated when heating was important but also, due to the chosen winter period, when no generation would occur from the solar PV panels.

3.10 Thermal comfort

Whilst analysis of energy data was not possible for all properties for the reasons previously discussed, temperature and comfort level data are available for a greater number of properties. The reason for this is that data was gathered by a simple temperature and humidity logger placed in each property by NEA at the time questionnaires were carried out. However, some data loggers became mislaid, moved, or lost during the 18 months of the project which resulted in some gaps in data.

All available data was analysed and included in Appendix 3, a summary is shown in Figures 3.9. The three periods have been selected to cover the 2016/17 winter, 2017/18 winter and the short coldest period of the 2017/18 winter; in all cases only the 17:00hrs to 21:00hrs period mentioned earlier in this report where residents expressed that it was important for their homes to be warm. No 'before' data is shown for the three control group properties as these properties did not have changes made to their heating system. Where data was not available for both 'before' and 'after' periods, those properties have been omitted from Figure 3.10 but are included in Appendix 3.

- Period #1. 1st November 2016 to 31st March 2017 – the winter period prior to the installation of the Hybrid ASHP
- Period #2. 1st November 2017 to 31st March 2018 – the winter period similar to period #1 but following the installation of the Hybrid ASHP
- Period #3. 25th February 2018 to 3rd March 2018 – the 7-day coldest period within Period #2

In addition to room temperature, relative humidity was also monitored. Water vapour contained in the air is referred to as relative humidity (RH), which changes with air temperature and represents the percentage of water vapour held by the air when compared to the maximum amount of water able to be supported by the air at the given temperature. It is not usually considered to be an indoor contaminant or a cause of health problems unless it exceeds certain values. In fact, some level of humidity is necessary for comfort and good health. 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. Figure 3.8 illustrates the optimum humidity levels as cited by Arundel et al[10]. The study concluded that maintaining relative humidity levels between 40% and 60% would minimise adverse health effects relating to relative humidity.

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[10] Anthony V. Arundel, Elia M. Sterling, Judith H. Biggin, and Theodor D. Sterling: Indirect Health Effects of Relative Humidity in Indoor Environments: available at http://www.ncbi.nlm.nih.gov/pmc/articles/PMC1474709/ [accessed 21/03/2017]

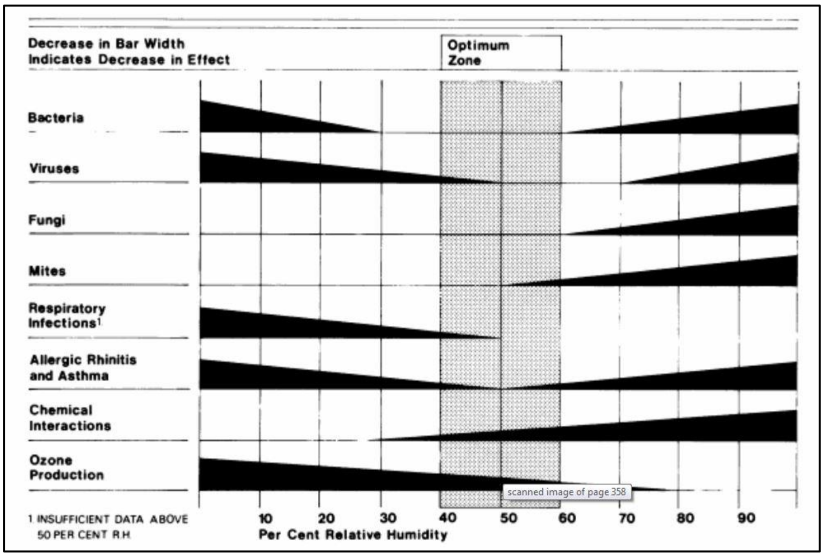

Figure 3.8 Optimum levels of relative humidity

	Summary of Comfort level analysis								
	Prior to installation of the ASHP 01/11/16 to 31/03/17 (4hr preferred heating period			After installation of the ASHP 01/11/17 to 31/03/18 (4hr preferred heating period			Coldest winter period 25/02/18 to 03/03/18 (4hr heating period)	
Tech Ref	**Heating system**	**Avg. Temp. (°C)**	**Avg. RH (%)**	**Heating system**	**Avg. Temp (°C)**	**Avg. RH (%)**	**Avg. Temp (°C)**	**Avg. RH (%)**
T-03	Oil boiler	20.02	48.64	Hybrid ASHP & Oil	19.89	49.71	20.09	40.87
T-08	Oil boiler	23.01	40.99	Hybrid ASP & Oil	23.64	37.46	24.64	26.04
T-10	Oil boiler	23.28	41.23	ASHP only	24.98	37.5	25.94	26.25
T-12	Oil boiler	21.08	49.80	Oil then ASHP	21.32	49.94	21.82	41.80
T-14	Oil boiler	20.78	54.43	Hybrid ASHP & Oil	15.49	66.68	16.57	55.17
T-16	Oil boiler	22.03	47.33	Hybrid ASHP & Oil	22.22	46.09	22.72	33.75
T-21	Oil boiler			Oil boiler	20.22	46.44	21.21	38.75
T-23	Oil boiler			Oil boiler	18.41	53.07	17.98	46.83
T-07	Oil boiler			Oil boiler	17.75	56.88	18.92	43.92

Figure 3.9 summary of comfort level analysis

Lounge temperatures slightly increased during the coldest week of the winter. However, during this one-week period average humidity levels for the properties where data was available dropped below the desired lower limit described in figure 3.8.

Property T-14 was the only property appreciably above the 40% lower level but this was probably due to the very low temperatures during this period.

The three control group properties were within the mid optimum range during the winter period but, as would be expected, dropped to the lower end of the optimum range during the 7-day cold period when room temperatures were slightly higher.

3.11 Summary of data analysis

T-08 was the only property, with sufficient data for analysis, where the Hybrid ASHP was installed and operated as intended, in conjunction with the existing oil-fired boiler.

- As would be expected electricity recorded by the main electricity meter increased when the Hybrid ASHP was installed. Unfortunately, there is no oil use data for the period following installation of the Hybrid ASHP severely limiting the conclusions which can be drawn.
- The Hybrid ASHP SCOP was 2.72, less than that expected but higher than T-50 where the oil-fired boiler was not used to provide heat during colder weather conditions.
- EPC rating increased from 68 (band D) to 84 (band C) following the installation of the ASHP.
- Average lounge temperatures remained the same before and after installation of the Hybrid ASHP but with an average 1°C increase during the 6-day coldest period of the 2017/18 winter.
- Humidity levels were at the lower end of normal (40.99%) prior to installation of the Hybrid ASHP and even lower (37.46%) following the installation but probably due to the slightly higher room temperatures (23.01°C to 23.64°C).

T-01 did not use the oil-fired boiler either before or after the ASHP was installed. Prior to the ASHP, portable electric heaters were used. The ASHP was the sole source of heating following its installation (therefore not considered a Hybrid).

- Electricity recorded by the loggers connected to the electricity meter reduced following installation of the ASHP as the portable electric heaters are not as efficient as an ASHP.
- Data was unavailable to calculate the ASHP SCOP.
- EPC rating increased from 78 (band C) to 88 (band B) following installation of the ASHP.
- Average lounge temperatures were unavailable for the period prior to the ASHP. Temperatures following installation of the ASHP were ‘normal’ including the 6-day coldest period of the 2017/18 winter.
- Humidity levels were within expected levels but slightly low during the 6-day coldest period.

T-50 used the oil-fired boiler prior to installation of the ASHP at which time the oil-fired boiler was not used. (The ASHP is therefore not considered a Hybrid)

- As expected electricity use recorded by the main meter increased following installation of the ASHP as this provided heating instead of the existing oil-fired boiler.
- The calculated SCOP for the ASHP was lower than expected at 1.96 for the period from January to April 2018 and also lower than property T-08 (2.72) which also used the original oil-fired boiler.
- Very little data was available on temperature and humidity although there was some for the 6-day coldest period which suggest both were slightly below the expected normal range.

T-21 is a control group property using an oil-fired boiler throughout the project.

- Electricity use recorded at the main meter was constant across the period of the project.
- The EPC rating was 82 (band B) which is comparable with the properties AFTER the ASHP had been installed. This indicates that there are other factors in these control group properties which contributed to this higher reading. This could be as the control group properties EPC were based on a 2-storey house instead of a bungalow for the ASHP group. The control group properties were also of slightly later construction and therefore improved construction detailing.
- Temperature and humidity levels are in the normal range and similar to properties where the ASHP had been installed

T-23 is a control group property using an oil-fired boiler throughout the project

- Electricity use recorded at the main meter was lower during the second winter of the project. The resident had reported that the heating (oil) was used all year during the first winter but only at certain times during the second winter. Whilst this would have most effect on the oil consumption, there would be an effect on electricity usage. There was no data for comfort levels during the first winter, but the second winter was on the lower side of those expected – see temperature and humidity below.
- No EPC was available for this property
- No temperature and humidity levels were available for the first winter but the figures for the second winter are 2-3°C below that of property T-21 which could explain the reduction in energy use recoded above.

4 Conclusions and recommendations

4.1 Conclusions

The aims of this project as stated in Section 1.2 were to quantify:

- Fuel bill reductions
- Ease of use with on-demand heating
- Back-up system in case existing heat source (fuel oil) runs out
- Reduction in fuel poverty

Due to the limited data available it is difficult to provide conclusions as to whether these aims have been met using this technology.

- The limited available data suggests that using the ASHP in conjunction with the oil boiler did provide cost reductions although this evidence is based on a very limited range of properties and date/time periods.
- Residents did complain, and acted, over the need to maintain both a stock of fuel oil for the oil-fired boiler AND increase their spending (monthly payment) on electricity.
- Several residents used the ASHP instead of the original oil-fired boiler
- Some residents continued to use the oil-fired boiler as they had recently purchased oil. When this stock was used, the ASHP was turned back on and the oil-fired boiler was not used at all.
- Residents maintained comfort levels before and after installation of the ASHP using either or both heating systems.

4.2 Recommendations for potential future installations

Installation of this type of system should only be considered where:

- Residents are fully aware of the principle of the system
- Residents are able to minimise bulk purchase of oil (or LPG) prior to install
- Residents understand that in addition to oil (or LPG) they will incur an increase in electricity bills but will use less oil than previously.

4.3 Impact on fuel poverty

Residents in fuel poverty are unable to afford to purchase two types of fuel prior to using it to heat their homes. Electricity used on a prepayment meter will be used more quickly; monthly payments, direct debits etc for the supply of electricity will increase. Many residents were buying oil in large consignments – smaller ‘top-ups’ would be more advantageous in these circumstances but could still be seen as ‘double purchasing’.

4.4 Performance comparison against manufacturer's/manufacturers' claims

Performance figures claimed by manufacturers were not met but this was probably due to the way residents used their heating systems as outlined in the previous sections.

4.5 Economic business case for installation of measures

It was not possible to provide evidence to substantiate an economic business case for the installation of the measures due to the issues raised in this project report. It is important to note that this does not mean there is no economic business case for this type of installation, just that further evidence, taking into account the conclusions and recommendations of this project, is needed.

Appendix 1: Electricity consumption data

This appendix shows analysis discussed in section 3.5

Figure A1.1 shows electricity use data for part of the 2016/17 winter period prior to the installation of the Hybrid ASHP. The 2 control group properties, T-21 and T-23, show similar consumption to propertyT-08 which will later have the Hybrid ASHP installed. Property T-01, which will also be receiving a Hybrid ASHP shows electricity consumption approximately three times greater than the other three. However, the resident reported that the oil-fired boiler was not used, and no oil fuel was bought during the last 4 years. Space heating was provided by varying types of electric portable heaters and would therefore result in greater electricity usage.

Energy Use Analysis Period #1	
Start Date	**10 January 2017**
End Date	**31 March 2017**
Number of Days	**80**
Start Time	**17:00:00**
End Time	**21:00:00**
Hours per day	**04:00:00**
Tech Ref	**Total Consumption (kWh)**
T-08	261.45
T-01	740.88
T-21	273.87
T-23	204.17
Count	4
Maximum	740.88
Minimum	204.17
Average	370.09
Std Dev	181.28

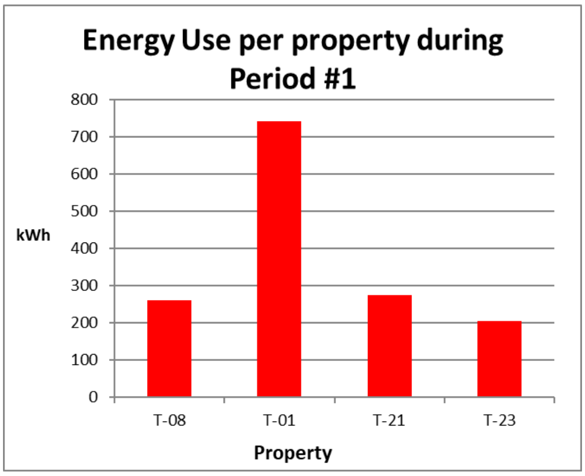

Figure A1.1, Energy consumption for the 2016/17 winter prior to the installation of the Hybrid ASHP

Figure A1.2 shows data for a slightly longer date range, and similar time period as 3.5 but during the 2017/18 winter period when the Hybrid ASHP had been installed (except the 2 Control Group properties, T-21 & T-23). A combination of the longer date period and colder weather conditions will result in increased energy use where electricity is used for heating. The difference is 1,614.4-degree days compared to 741.5-degree days in previous winter period; representing 217.7% increase in the number of degree days (colder temperatures). The 2 control group properties which used oil as the main heating fuel increased they electricity usage (adjusted) by 100.4% and 47.4% respectively.

Property T-01 which now uses the Hybrid ASHP instead of portable electric heating only used 10.76% extra electricity (adjusted for date period and degree days) indicating a large saving when compared to an expected increase in electricity use of 217.7% if portable electric heaters had been used in this period.

Property T-08 which now uses the Hybrid ASHP in addition to the existing oil-fired boiler had an increase in electricity energy use of 252.7% (adjusted for date period and degree days). This is higher than the calculated 217.7% but could be explained by the fact that the Hybrid ASHP is now used as the main source of heating with the oil-fired boiler only used during colder weather (automatic switch over).

Energy Use Analysis Period #2	
Start Date	**01 November 2017**
End Date	**31 March 2018**
Number of Days	**150**
Start Time	**17:00:00**
End Time	**21:00:00**
Hours per day	**04:00:00**
Tech Ref	**Total Consumption (kWh)**
T-08	922.18
T-01	820.67
T-21	540.73
T-23	387.95
Count	4
Maximum	922.18
Minimum	387.95
Average	667.88
Std Dev	291.09

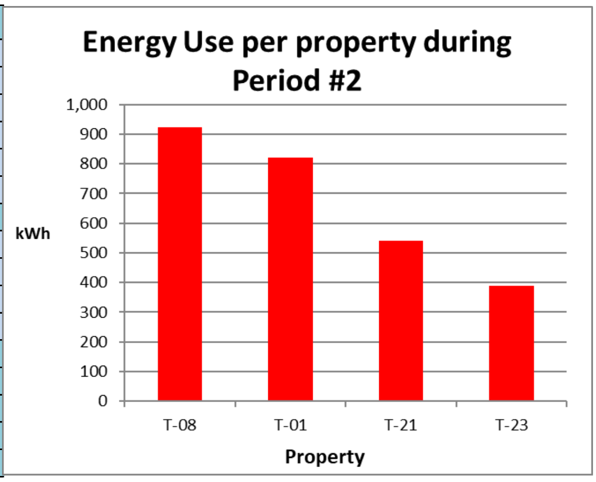

Figure A1.2, Energy consumption for the 2017/18 winter following the installation of the Hybrid ASHP.

Figure A1.3 shows data for the 6-day coldest period between 25th February 2018 to 3rd March 2018. The figures show that electricity consumption by property T-08 is lower than that of T-01. Property T-01 does not use the oil boiler and therefore all heating is provided by the ASHP. Property T-08 is lower as, during lower temperatures, the oil-fired boiler predominately provides space heating.

Energy Use Analysis Period #3	
Start Date	**25 February 2018**
End Date	**03 March 2018**
Number of Days	**6**
Start Time	**17:00:00**
End Time	**21:00:00**
Hours per day	**04:00:00**
Tech Ref	**Total Consumption (kWh)**
T-08	22.46
T-01	56.42
T-21	36.85
T-23	21.39
Count	4
Maximum	56.42
Minimum	21.39
Average	34.28
Std Dev	15.50

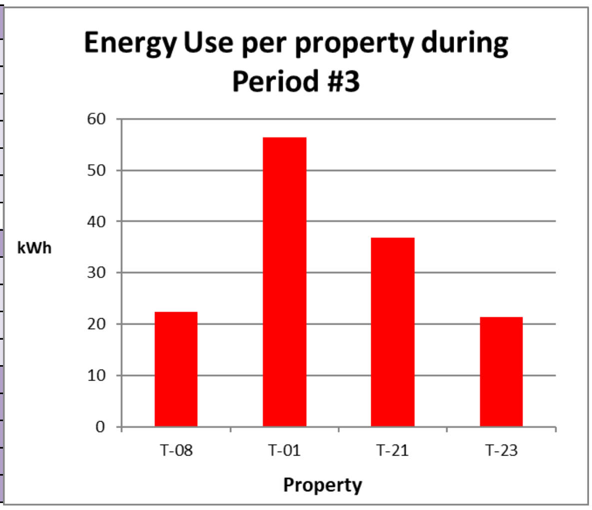

Figure A1.3, Energy consumption for the coldest 6 days during the 2017/18 winter.

Appendix 2: Oil consumption data

This appendix shows analysis discussed in section 3.7

Analysis of the data is shown in Figure A2.1 covering part of the 2016/17 winter. Properties T-08 and T-10 are properties receiving the Hybrid ASHP. T-07 and T-21 are control group properties and therefore only using oil to heat their homes.

Analysis Period #1	
Start Date	**08 March 2017**
End Date	**18 April 2017**
Number of Days	**41**
Start Time	**00:00:00**
End Time	**23:59:59**
Hours per day	**23:59:59**
Property	**Total kWh**
T-07	1076.77
T-08	393.80
T-10	345.63
T-21	621.35
Count	4
Maximum	1076.77
Minimum	345.63
Average	609.39

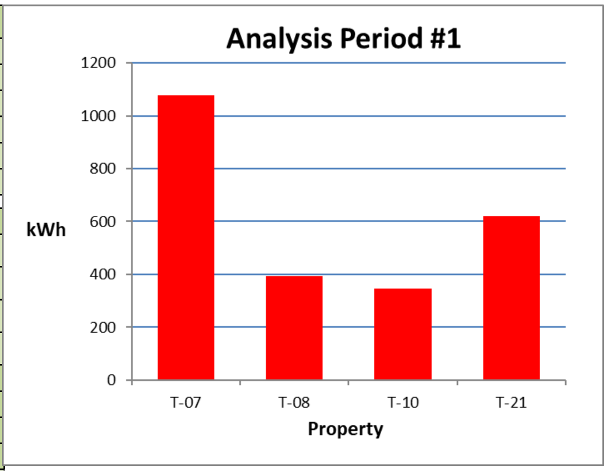

Figure A2.1, Heating oil consumption (kWh), 2016/17 winter

Figure A2.2 shows analysis for the same date range but only for the 4-hr ‘preferred’ evening heating period.

Analysis Period #2	
Start Date	**08 March 2017**
End Date	**18 April 2017**
Number of Days	**41**
Start Time	**17:00:00**
End Time	**21:00:00**
Hours per day	**04:00:00**
Property	**Total kWh**
T-07	286.63
T-08	52.19
T-10	59.21
T-21	128.74
Count	4
Maximum	286.63
Minimum	52.19
Average	131.69

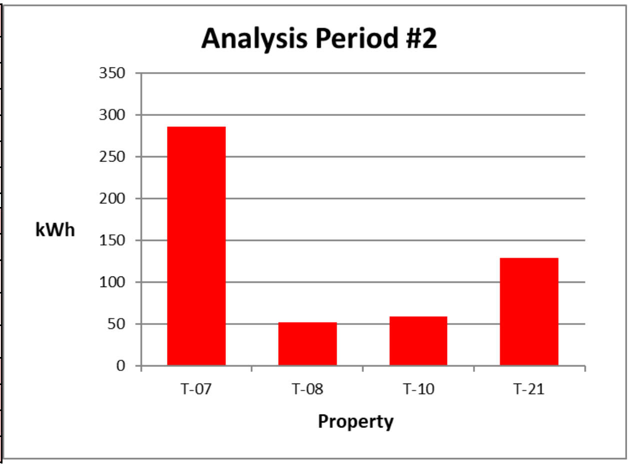

Figure A2.2, Heating oil consumption (kWh), 4hr preferred heating period

Figure A2.3 shows data for the 2017/18 winter. These are all control group properties and the only properties with data of oil consumption for this period.

Analysis Period #3	
Start Date	**25 October 2017**
End Date	**30 October 2017**
Number of Days	**5**
Start Time	**17:00:00**
End Time	**21:00:00**
Hours per day	**04:00:00**
Property	**Total kWh**
Tech Ref-07	3.99
Tech Ref-21	15.55
Tech Ref-23	16.22
Count	3
Maximum	16.22
Minimum	3.99
Average	11.92

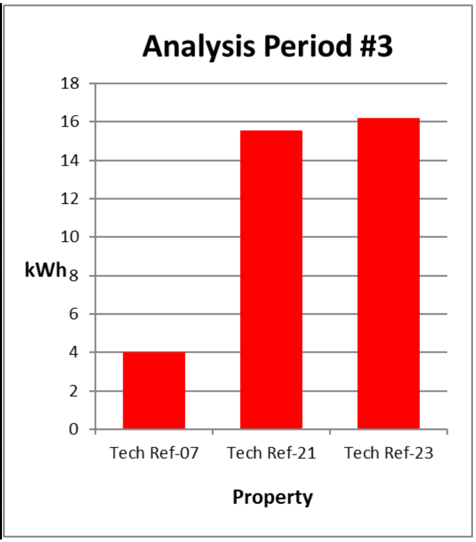

Figure A2.3, Heating oil consumption (kWhs) 2017/18 winter – all Control Group properties

Appendix 3: Comfort level data

This appendix shows analysis discussed in section 3.10

All the data that was available was analysed and is shown in Figures A3.1, A3.2, and A3.3. The three periods have been selected to cover the 2016/17 winter, 2017/18 winter and the short coldest period of the 2017/18 winter. In all cases only the 17:00hrs to 21:00hrs period mentioned earlier in this report where residents expressed that it was important for their homes to be warm.

This analysis is from data downloaded from loggers placed in the lounge of monitored properties where a Hybrid ASHP had been installed (control group properties are analysed separately). However please refer to sections in the main report which analyses data for a reduced number of properties due to either installation issues or the householder's intervention on how the new system was used.

- Period #1. 1st November 2016 to 31st March 2017 – the winter period prior to the installation of the Hybrid ASHP
- Period #2. 1st November 2017 to 31st March 2018 – the winter period similar to period #1. But following the installation of the Hybrid ASHP
- Period #3. 25th February 2018 to 3rd March 2018 – the 7-day coldest period within Period #2

Comfort Level Analysis Period #1			
Start Date	01 November 2016	Start Time	17:00:00
End Date	31 March 2017	End Time	21:00:00
Number of Days	150	Hours per day	04:00:00
Property	Average Temperature		Average Humidity
T-03	20.02		48.64
T-05	25.77		35.94
T-08	23.01		40.99
T-10	23.28		41.23
T-12	21.08		49.80
T-14	20.78		54.43
T-16	22.03		47.33
Count	7		7
Maximum	25.77		54.43
Minimum	20.02		35.94
Average	22.28		45.48
Median	22.03		47.33
Std Dev	1.94		6.34

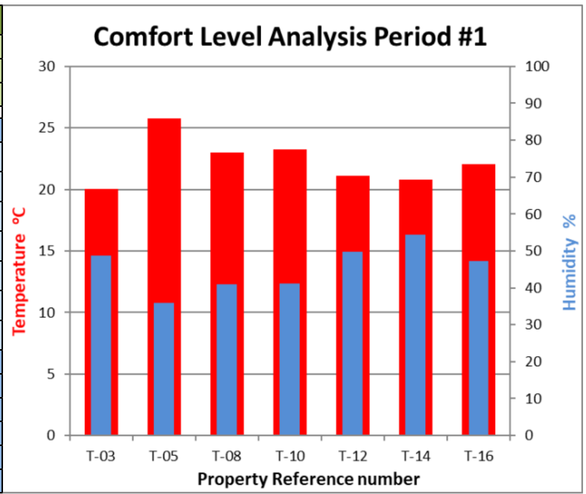

Figure A3.1 Comfort levels prior to the installation of the Hybrid ASHP

Comfort Level Analysis Period #2			
Start Date	01 November 2017	Start Time	17:00:00
End Date	31 March 2018	End Time	21:00:00
Number of Days	150	Hours per day	04:00:00
Property	Average Temperature		Average Humidity
T-01	20.52		45.50
T-03	19.89		49.71
T-08	23.64		37.46
T-10	24.98		37.50
T-12	21.32		49.94
T-14	15.49		66.68
T-16	22.22		46.09
Count	9		9
Maximum	24.98		66.68
Minimum	15.49		37.31
Average	21.21		46.25
Median	21.32		46.09
Std Dev	2.65		9.20

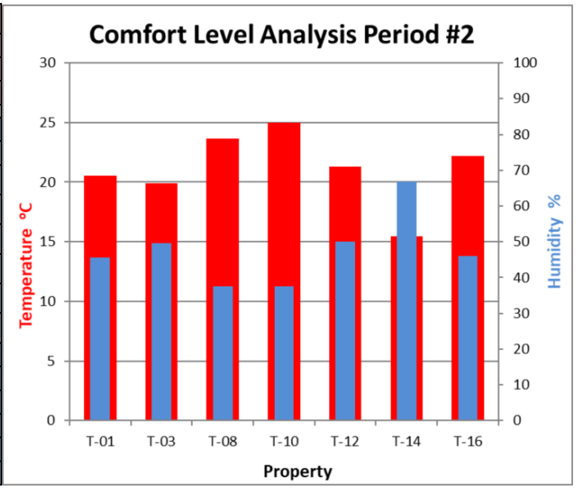

Figure A3.2 Comfort levels following the installation of the Hybrid ASHP

Comfort Level Analysis Period #3			
Start Date	25 February 2018	Start Time	17:00:00
End Date	03 March 2018	End Time	21:00:00
Number of Days	6	Hours per day	04:00:00
Property	Average Temperature		Average Humidity
T-01	20.55		36.79
T-03	20.09		40.87
T-08	24.64		26.04
T-10	25.94		26.25
T-12	21.82		41.80
T-14	16.57		55.17
T-16	22.72		33.75
T-50	19.57		30.42
Count	8		8
Maximum	25.94		55.17
Minimum	16.57		26.04
Average	21.49		36.39
Median	21.18		35.27
Std Dev	2.98		9.67

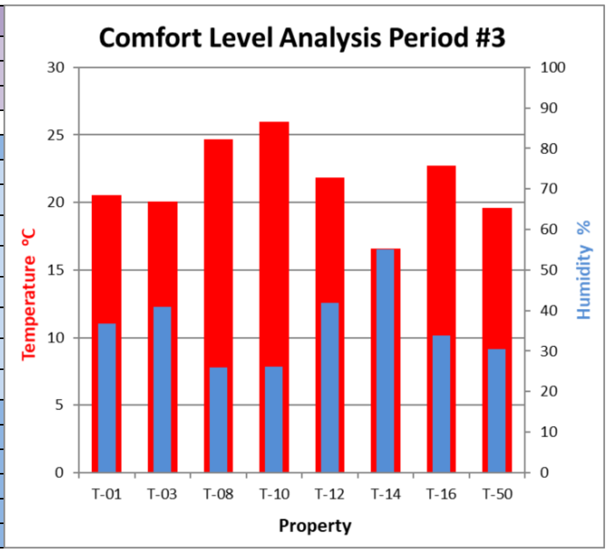

Figure A3.3 Comfort levels during the 7-day coldest period following the installation of the Hybrid ASHP

Comparison of the above three analysed periods show that following the installation of the Hybrid ASHP average room temperatures during the 4-hour period reduced by approximately 1°C compared to the pre-installation winter period. The drop in the minimum, temperature appears to be the main reason for the average reduction.

Similar comfort level analysis was made on three control group properties that had not received any alteration to their heating system and continued to use oil as their main source of fuel for space heating.

Periods #2 and #3 were used as there is insufficient data for the 2016/17 winter period. However, this does allow for direct comparison between monitored properties that had received a hybrid ASHP one operating in hybrid mode and one as an ASHP and the control group that had not. Details are shown in Figures A3.4 and A3.5.

Comfort Level Analysis Period #2			
Start Date	01 November 2017	Start Time	17:00:00
End Date	31 March 2018	End Time	21:00:00
Number of Days	150	Hours per day	04:00:00
Property	**Average Temperature**		**Average Humidity**
T-07	17.75		56.88
T-21	20.22		46.44
T-23	18.41		53.07
Count	3		3
Maximum	20.22		56.88
Minimum	17.75		46.44
Average	18.80		52.13
Median	18.41		53.07
Std Dev	1.28		5.28

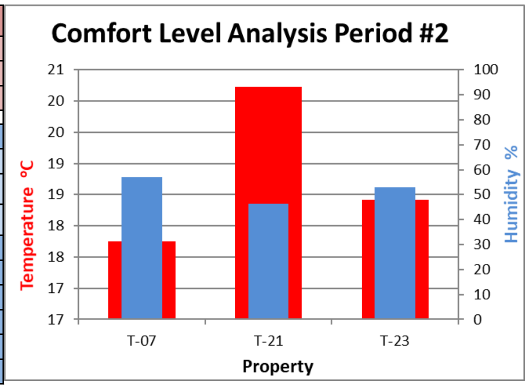

Figure A3.4, Comfort levels of the Control Group properties

Comfort Level Analysis Period #3			
Start Date	25 February 2018	Start Time	17:00:00
End Date	03 March 2018	End Time	21:00:00
Number of Days	6	Hours per day	04:00:00
Property	**Average Temperature**		**Average Humidity**
T-07	18.92		43.92
T-21	21.21		38.75
T-23	17.98		46.83
Count	3		3
Maximum	21.21		46.83
Minimum	17.98		38.75
Average	19.37		43.17
Median	18.92		43.92
Std Dev	1.66		4.09

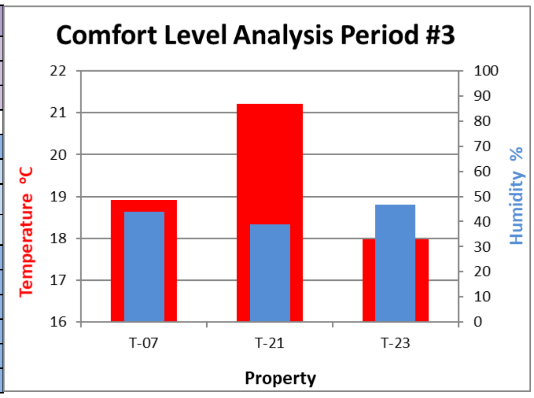

Figure A3.5, Comfort levels of the Control Group properties during the 7-day coldest period

The data for the control group properties show that average temperatures for these properties were on average lower than those of the monitored group with the Hybrid ASHP. T-07 and T-23 in particular were heating their property to a lower level than T-21. These temperatures were broadly similar or slightly higher during the 7-day coldest period.

Appendix 4: Glossary of Terms

ASHP	Air Source Heat Pump
Hybrid ASHP	Hybrid Air Source Heat Pump
SCOP	Seasonal Coefficient of Performance
EPC	Energy Performance Certificate
kWh	Kilowatt hour
LPG	Liquefied Petroleum Gas
MCS	Microgeneration Certification Scheme
NEA	National Energy Action – the National fuel poverty charity
NLC	North Lincolnshire Council
RH	Relative Humidity
SAP	Standard Assessment Procedure (for assessing home energy efficiency)
Solar PV	Solar PhotoVoltaic
TIF	Technical Innovation Fund
YES	Yorkshire Energy Services

Appendix 5: 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

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Action for Warm Homes