Daikin Altherma hybrid heat pumps, Copeland and South Tyneside

Technical Evaluation Report

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September 2017

CP747
Daikin Altherma hybrid heat pumps, Copeland and South Tyneside, Home Group

Number of households assisted	24
Number of households monitored	8

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 EAS in Scotland, 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.

Acknowledgements

Project partners
Home Group

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Fuel Poverty Gas Network Extension Scheme administered by Northern Gas Networks

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Executive summary

Project overview

This project was delivered by housing association Home Group, who installed 24 Daikin hybrid heat pumps in properties that were also being connected to the mains gas network. It had the following aims;

- To establish the running costs of the 5kWh Daikin Altherma hybrid heat pump compared to the previous electric heating systems (6kWh storage 2kWh on peak).
- To examine the impact of installing the Daikin Altherma hybrid heat pump on residents' comfort and satisfaction levels.
- To help inform Home Group and other interested parties as to whether hybrid heating systems are a viable alternative to electric storage heaters.

Context

Around 1.7m households in GB use electric storage heating systems, which allow households to use cheaper electricity at night to charge the heating system and release heat during the day. Electric storage heating systems are commonly used in homes which do not have access to the gas network, and these households tend to have higher running costs and be on lower incomes[1].

Achieving thermal comfort levels via storage heaters can be challenging. Users need to pre-set controls in advance of the day's heating requirement, which involves trying to predict heat need and outside temperature. A common complaint is that the heat dissipates throughout the day and there is insufficient heat in the evening.

Daikin Altherma hybrid heat pump

The Daikin Altherma hybrid heat pump combines a high efficiency combi boiler with an air-to-water heat pump. Using smart hybrid logic, the system automatically selects the most cost-effective and efficient heating mode, based on external and internal temperatures, the heat and hot water demand, and the cost of gas and electricity as determined by the selected energy tariff. The gas combi boiler provides hot water and heating while the heat pump provides heating only. When the external temperature drops and the heat pump efficiency drops, then the gas boiler is utilised. When the external temperature drops further the gas boiler will work in isolation

The project

[1] Insights paper on households with electric and other non-gas heating, Ofgem, 2015, accessed 31 July 2015 https://www.ofgem.gov.uk/ofgem-publications/98027/insightspaperonhouseholdswithelectricandothernon-gasheating-pdf

This project involved installing Daikin Altherma hybrid heat pumps in 24 properties between January and February 2016. It also required connection to the gas grid which was funded separately via the Fuel Poor Network Extension Scheme (FPNES) through Northern Gas Networks, which incentivises the regulated gas network companies to connect low-income households and communities to the mains gas network.

The heat pumps were installed in properties in Gosforth in Copeland; and South Shields in South Tyneside. The properties in Gosforth were within a carbon saving communities (CSCO)-eligible rural area. Those located in South Shields were within a Lower Super Output Area (LSOA) ranked within the top 10% most deprived areas in England. Of these, 8 were initially selected for monitoring purposes. This was later reduced to 7 properties when one of the residents moved home, however their responses were still included in the social evaluation.

The majority of monitored properties had electric storage heaters prior to the installation, and all properties had energy efficiency (EPC) ratings of D or E. All residents were aged over 60 and most were retired. Based on the self-reported costs, the residents in the study were paying on average £860 per annum for their electricity. There was however significant variation in how much residents were paying, one resident paid £1081 per annum whilst another paid £ 517 per annum.

Summary of findings

Resident satisfaction

- Residents' satisfaction increased significantly after the installation of their new heating system (how well the house keeps the heat in, cost of running the system, amount of control over the system, how easy the system is to use and how warm it gets when cold outside).

- 4 of the residents commented on being able to heat additional rooms after the installation of the hybrid system, and all of the residents stated they did not have to use additional supplementary heating devices (or "on-peak boost" built into traditional storage heating systems).

Energy savings and thermal comfort

- There was an average estimated annual saving of 20.4% in Gosforth and a 31.36% saving in South Shields, however there was variability in the amount of savings with 1 resident saving 15% and another saving 41%. 1 household saw an increase in annual cost of around 8%.

- After the installation, the average temperatures between 5pm-9pm in the living rooms were 22.3°C in Gosforth and 22.7°C in South Shields. There were some significant increases in several properties however some properties reduced the temperature in the living room as they were able to set a thermostat with the hybrid system.

- Some of the properties saw significant increases in their bedroom temperatures, although some residents did not heat their bedrooms.

- Whilst most of the residents stated they had more control they were unable to access the timer/programmer element of the hybrid system.

- In Gosforth the average Seasonal Coefficient of Performance (SCoP) was lower than in South Shields, and on average they used a higher percentage of gas to run their heating system due to prevailing climatic conditions or housing standard or both.

Conclusions and recommendations

The hybrid system was successful in reducing heating costs in 6 out of the 7 properties, and all residents noted improvements in their comfort stating they were 'very satisfied' with how warm their property got when it was cold outside, and this was confirmed by temperatures of around 22°C monitored in their living rooms. This was despite none of the residents being able to set their own heating times within the hybrid system.

There was significant disruption to the residents during the process of installing the gas connection and the hybrid system. In spite of this the residents stated that receiving the new system was worth the disruption.

A larger study that includes more properties with electric storage heaters will be required to determine if the savings are as significant as those highlighted in this study. Installing remotely-accessible data monitoring would increase the quality and availability of data and allow for early identification of system problems or data-gathering issues.

There is a higher capital cost associated with the hybrid system when compared to traditional heating systems such as a gas boiler. A hybrid system may be cheaper over the lifetime of the system as potentially there are lower running costs, Renewable Heat Incentive (RHI) payments and a longer operating lifetime. However, to procure and install this system would require a significant upfront capital investment, which a resident in fuel poverty is unlikely to have. It would be more viable for a housing association to meet the upfront cost particularly as they would gain a return in investment through RHI payments and would not have to replace the heating system as often.

The hybrid system may not be future-proof as the UK looks to transition to a low carbon economy, however it does have the potential to be a low-carbon bridge when phasing out the use of fossil fuels.

1. Project overview

1.1 Introduction

This project was delivered by Home Group. It involved installing Diakin Altherma hybrid heat pumps in 24 properties in Gosforth, Copeland; and South Shields, South Tyneside.

The technology combines a high efficiency combi boiler with an air-to-water heat pump. Using smart hybrid logic the system automatically selects the most cost-effective and efficient heating mode. The system determines the most cost effective approach based on the following: the external and internal temperatures, the heat and hot water demand and the cost of gas and electricity as determined by the selected energy tariff.

The gas combi boiler provides hot water and heating whilst the heat pump provides heating only. The system has 1 of 4 modes of operation and switches between these modes to ensure the most efficient and economical mode is selected. The operating modes are as follows:

1. Heat pump only – used in mild temperatures when the heat pump capacity and efficiency can satisfy the heating demand efficiently.
2. First hybrid mode – when the external temperature drops the boiler provides some additional heat.
3. Second hybrid mode – when the temperature drops below another threshold level (as determined by the algorithm and the factors mentioned above), the heat pump's efficiency reduces the flow control that regulates the variable speed pump to slow the flow rate. This raises the heat pump's efficiency
4. Boiler only – when the temperature is very low and temperature demand is heightened the boiler operates on its own.

To determine the effectiveness of the hybrid system there were several elements to be monitored:

- Annual cost – how much it costs to heat the property and provide hot water over a year.
- Comfort levels – the temperature and humidity levels before and after the heating system was installed.
- Coefficient of Performance (CoP) – how efficient the heat pump is at providing heat.
- Proportion of energy provided by electric compared to gas.

1.2 Aims

- To establish the running costs of the 5kW Daikin Altherma hybrid heat pump compared to previous heating systems.

- To examine the impact of installing the Daikin Altherma hybrid heat pump on residents' comfort and satisfaction levels.

- To help inform Home Group and other interested parties whether hybrid heating systems are a viable alternative to electric storage heaters.

1.3 Context

Around 1.7m households in GB use electric storage heating systems, which allow households to use cheaper electricity at night to charge the heating system and release heat during the day. Electric storage heating systems are commonly used in homes which do not have access to the mains gas network, and these households tend to have higher running costs and be on lower incomes which make them more likely to be in, or at risk of, fuel poverty[2].

Achieving thermal comfort via storage heaters can be challenging. Users need to pre-set controls in advance of the forthcoming day's heating requirements, which involves trying to predict heat need and outside temperature. A common complaint is that the heat dissipates throughout the day and there is insufficient heat in the evening.

1.4 Project timeline

Figure 1.1 below summarises the main milestones in the project.

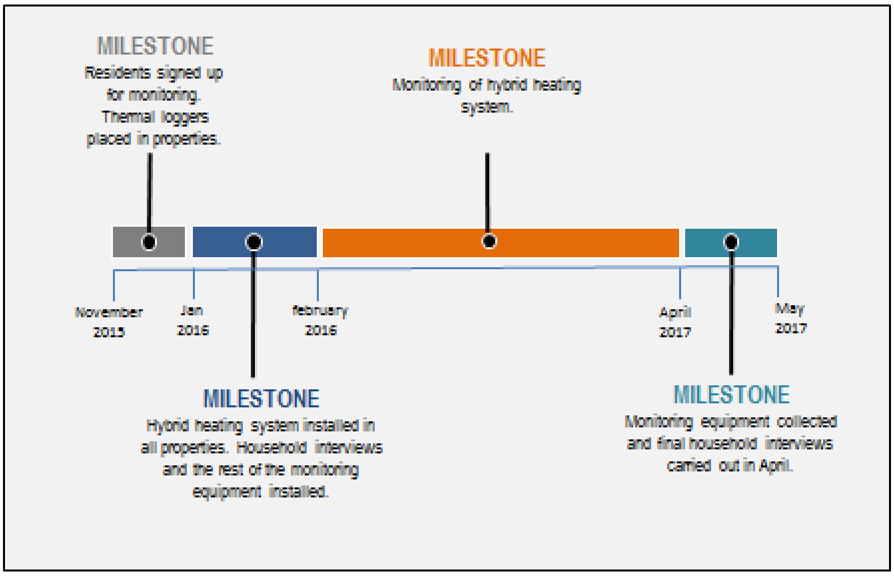

Figure 1.1 project overview

[2] Insights paper on households with electric and other non-gas heating, Ofgem, 2015, accessed 31 July 2015 https://www.ofgem.gov.uk/ofgem-publications/98027/insightspaperonhouseholdswithelectricandothernon-gasheating-pdf

After the system was installed in January/February 2016, a full winter monitoring period was planned. This enabled any issues with system performance to be resolved and it gave residents a chance to understand the new system and controls.

1.5 Attracting beneficiaries and establishing the monitored group

Home Group own properties in South Shields (Tyne & Wear) and Gosforth (Copeland in Cumbria) that were eligible to receive a mains gas connection through the Fuel Poor Network Extension Scheme which incentivises gas distribution network companies to connect low income and disadvantaged households and communities to the mains gas network[3].

Home Group consulted with 24 of their tenants receiving a new gas connection to establish if they were willing to receive a hybrid heat pump system. Home Group visited each property to explain the heating system and the project to the residents. Residents were also informed that they may be monitored by NEA and it was explained to them what this would entail. All 24 of the residents agreed to receive the new system and signed a consent form agreeing to be part of a monitored group. For reasons of cost effectiveness, only 8 were selected to be part of this monitored group.

All properties at both locations had a pre-installation EPC rating of D or E. In Gosforth the lowest EPC SAP rating was 48, the highest was 66 and the average was 55. In South Shields 1 property was rated an E at SAP 46, whilst the rest fell within band D. The highest rating was 66 and the average was 63. The area where the properties were located in South Shields is within a lower upper output area of deprivation (LSOA) ranked in the top 10% most deprived areas in England, with 9.3% of households estimated to be in fuel poverty. In previous studies only a small number of properties that had received a hybrid heat pump had residents living in (or at risk of) fuel poverty.

8 properties were selected for monitoring, 4 were in South Shields and 4 were in Gosforth. 2 of the properties in Gosforth were part of Sustainable Home's National Energy Study 2[4] and therefore energy consumption from the previous winter was readily available.

[3] Madhura, R. (2015). The findings of our review of the Fuel Poor Network Extension Scheme. Ofgem. Available at: https://www.ofgem.gov.uk/sites/default/files/docs/2015/03/the_findings_of_our_review_of_fuel_poor_network_extension_scheme_26_march_2015_0.pdf [Accessed 19 Jun. 2017].

[4] http://www.sustainablehomes.co.uk/research-project/national-energy-study-two/ [Accessed 07/08/17]

2. Technical evaluation methodology

2.1 Introduction

8 properties underwent technical monitoring, 1 resident dropped out of the study as they left the property. All of the properties were 2-bedroom bungalows of a similar size. 6 of the residents had electric storage heaters and 2 had electric on-peak heating. In order to protect the privacy of residents the data in the study has been anonymised, each property has been allocated a unique identification number.

Interviews were conducted during the installation period by one of NEA's project development co-ordinators (PDCs). The PDC conducted interviews with households at the start of the monitoring period in January/February 2016, soon after installation of the hybrid system, and at the end of the monitoring period in March/April 2017. This enabled NEA to capture data over a year to establish the effectiveness of the hybrid system and record any changes to participating householders' comfort and energy expenditure.

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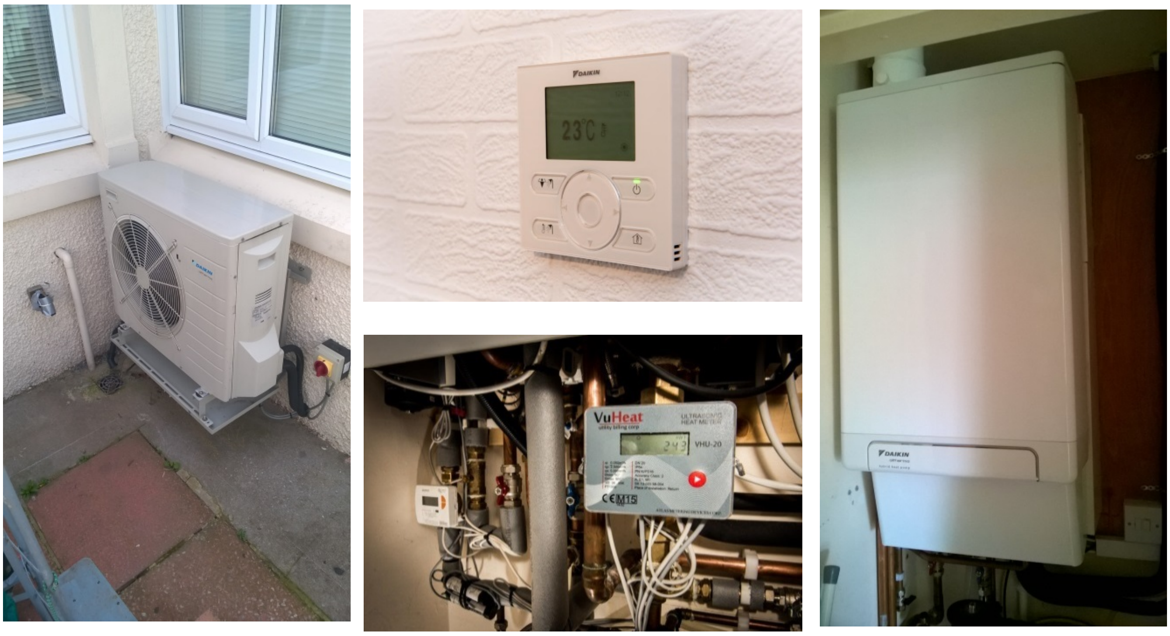


Figure 2.1 Daikin Altherma hybrid heat pump

Tech Ref. No.	SAP rating	EPC rating	Floor Area	Previous Heating System	Property Type	Property Location
T-14	60	D	$62m^2$	Electric storage heaters	Bungalow	End terrace
T-13	48	E	$62m^2$	Electric storage heaters	Bungalow	Mid terrace
T-12	60	D	$62m^2$	On peak electric	Bungalow	End terrace
T-15	52	E	$62m^2$	Electric storage heaters	Bungalow	End terrace
T-10	65	D	$54m^2$	Electric storage heaters	Bungalow	Mid-terrace
T-05	46	E	$54m^2$	On peak electric	Bungalow	Mid-terrace
T-07	64	D	$54m^2$	Electric storage heaters	Bungalow	Mid-terrace
T-02	65	D	$54m^2$	Electric storage heaters	Bungalow	Mid-terrace

Table 2.2 details of the properties in the study prior to the hybrid heat pump

- Properties in Gosforth

- **Properties in South Shields**

2.2 Technical monitoring

All of the technical monitoring equipment was installed before or during the install of the hybrid system. The thermal and humidity loggers were placed in all monitored properties prior to the installation of the hybrid system. These measured the temperature and humidity levels in the living room and main bedroom.

Heat metering was used to determine the heat output from the system. 1 heat meter was installed to monitor the heat output of the whole system (this heat meter failed to provide accurate readings), 1 heat meter was installed to measure the heat output of the heat pump only and a final heat meter was installed to monitor the heat output to domestic hot water.

A watt hour meter was fitted to all 8 properties to measure the electricity consumption of the heat pump over the project duration.

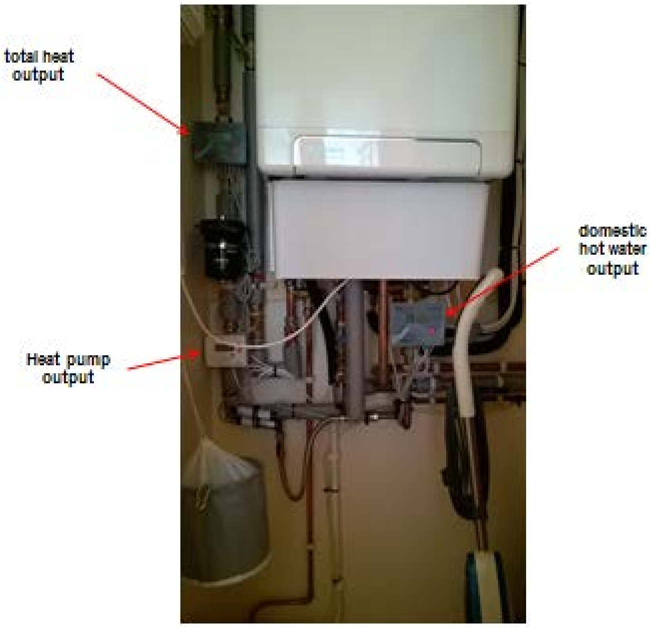


Figure 2.3 heat meter locations

Monitoring equipment

The following monitoring equipment was used on the project.

Thermal data loggers

Lascar USB2 data loggers were used to record the temperature and humidity inside the property every hour[5]. 2 thermal loggers were installed in each of the monitored homes, with 1 placed in the living room and 1 in the main bedroom.

Electricity consumption meters

Standard electricity consumption or watt hour meters were fitted on 1 of the wires to the heat pump to record the total electricity consumption in kWh. These were fitted on 8 of the heat pumps.

Heat meters

Vu Heat DN-20 ultrasonic heat meters were fitted to determine the heat output from the ASHP, heat out to hot water and heat out to the central heating. These meters were compliant with current OFGEM requirements for RHI payments[6].

Event loggers

Lascar USB5 event loggers were attached to the heat meters to record each time an event occurred[7].

[5] https://www.lascarelectronics.com/media/1572/easylog-data-logger_el-usb-2.pdf
[6] https://www.bellflowsystems.co.uk/files/attachments/544/VHU20%20Datasheet.pdf
[7] https://www.lascarelectronics.com/media/2941/easylog-data-logger-el-usb-5.pdf

Figure 2.4 heat meter

Tech Ref. No.	Monitoring	USB-2 living room	USB-2 bedroom	Watt hour meter	Heat meter - ASHP	Heat meter - DHW	Heat meter - Total	Gas meter
T-14	Standard	•	•	•	•			
T-13	Standard	•	•	•	•			
T-12	Advanced	•	•	•	•	•	•	
T-15	Standard	•	•	•	•			
T-10	Standard	•	•	•	•			
T-05	Advanced	•	•	•	•	•	•	•
T-07	Advanced	•	•	•	•	•	•	
T-02	Standard	•	•	•	•			

Table 2.5 summary of monitoring equipment

In the agreed monitoring evaluation only 2 properties were originally intended to receive advanced monitoring however a third property was selected due to a fault with the monitoring equipment in 1 of the originally selected properties. Figures 2.6 and 2.7 illustrate the planned deployment of monitoring across the 2 levels of monitoring (standard and advanced) planned across the project.

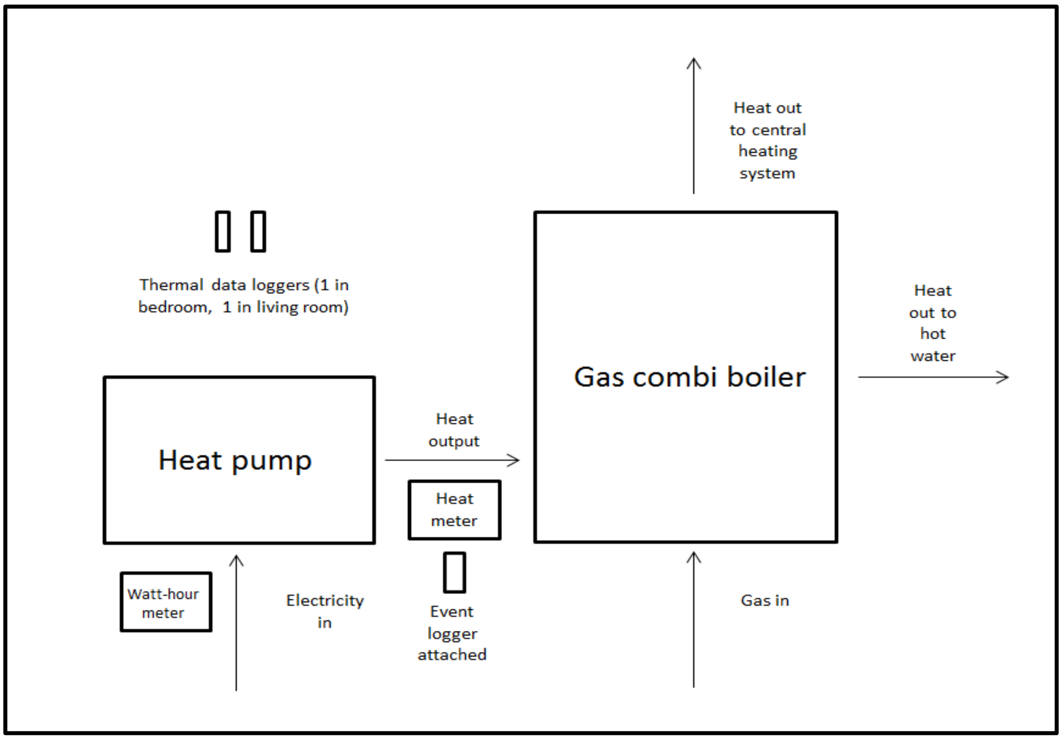


Figure 2.6 standard monitoring schematic

The rationale for the 2 levels of monitoring was primarily cost reduction, enabling more funding to be used on measures installed in properties.

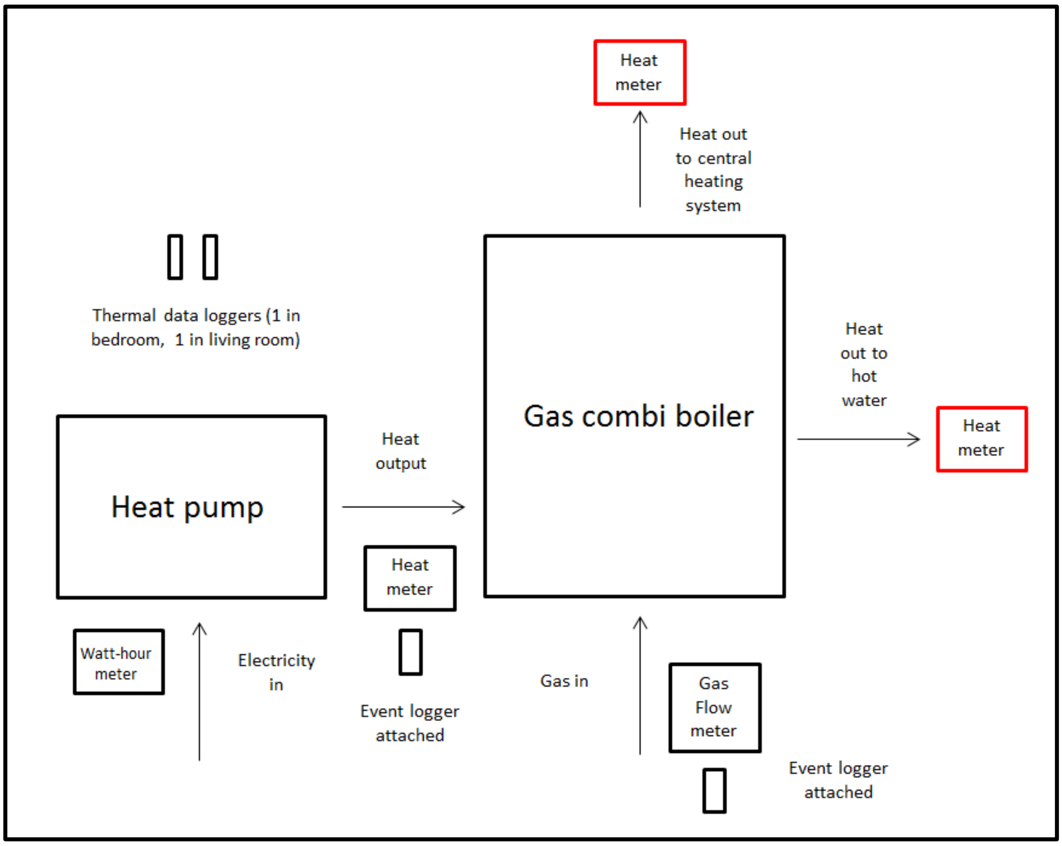


Figure 2.7 advanced monitoring schematic

2.3 Factors affecting the evaluation methodology

Issue	Description and mitigation
Size of monitored group	The monitored group was reduced from 8 properties to 7 properties as 1 of the residents moved out in October 2016. Their responses have been included in the social evaluation aspect of this report. 2 properties were selected for additional monitoring (1 in each locality). There were concerns about the compatibility between the heat meter probes and the hybrids sensor pockets in 1 property therefore a third property had additional monitoring equipment installed whilst the issue was resolved.
Start of monitoring	7 of the 8 residents received thermal and humidity loggers in late October 2015. 1 of the residents did not receive the loggers until January 2016. This meant that there was no thermal and humidity data for that property prior to the install of the hybrid system.
Control group	No control group was required for this project as there was mostly sufficient energy consumption data and thermal data for the properties pre and post install.
System Performance	There have been 2 gas valve failures in Gosforth, both within the same property (but not part of the monitored group in this study). A large number of systems failed in South Shields due to the circulation pumps seizing up. 3 of the monitored properties reported this issue but stated that it was resolved quickly. Water analysis was conducted by Daikin and they determined that there was an issue with the alkalinity of the water in the heating system. This was attributed to inadequate flushing meaning cleansing agents remained in the system. The systems were power-flushed and the pumps replaced and there were no issues thereafter.
Meter readings	Most of the residents took regular gas and electric meter readings. Some questionnaires were carried out over the phone as some of the residents were not available at the time of the home visit; this made it difficult to consider past bills and meter readings from residents. Some properties also had fewer historical meter readings available from their energy supplier than others.
Failure of equipment	NEA specified the location and purpose of the monitoring equipment but on collection of the logging equipment 1 heat meter measuring the total heat output did not present useable data.
Unforeseen problems	1 of the specified heat meters between the heat pump and the domestic heating circuit was physically too large to be installed. The alternative meter (of smaller physical size) could not provide a pulse output to log heat by time, hence limited data was only

available through manual meter readings at periodic intervals.

2.4 Social impacts

Unfortunately, 1 of the residents dropped out of the study as they moved out of the property in October 2016. Their questionnaire responses are used for some aspects of the social evaluation in the "pre-install" period.

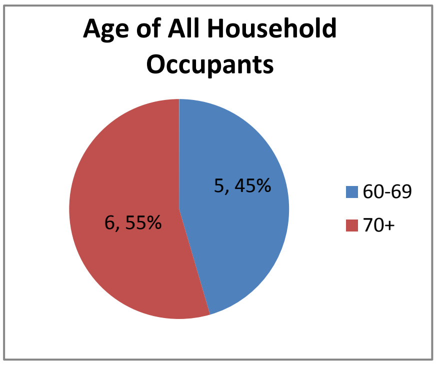
1 questionnaire was incomplete as the resident stated she had no working heating system prior to the install of the hybrid system however she remained part of the study and her responses are included in the evaluation where appropriate.

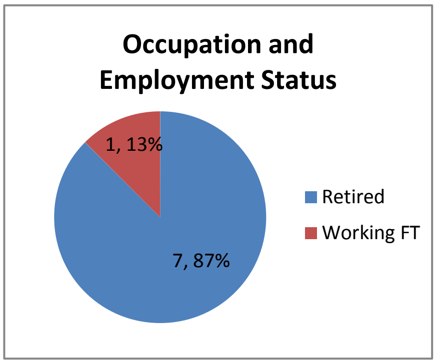
Householder demographic details

The number and age range of the residents who took part in the study is shown in Figure 2.8 (a). There were 8 households involved and there were 11 residents living in those properties. All 11 residents were above the age of 60, 6 of the residents were in the age range 60-69 and 5 residents were in the age range 70-84. The occupation and employment status of the main bill-payer(s) in this study group is detailed in Figure 2.8 (b); this chart shows that only 1 resident worked full time and the rest were retired.

Figure 2.8c shows that 6 of the residents had electric storage heaters prior to the install of the hybrid system; 2 of the residents were using on-peak electric heaters. 1 of the 2 residents replaced the storage heaters upon moving into the property as they did not like the system. The other resident had been told that a new system was being installed and decided to use oil-filled electric radiators until the new system was installed.

The 8 properties were split over 2 localities. 4 of the properties were located in South Shields, South Tyneside and the other 4 were located in Gosforth, Copeland. All of the properties in the study were of a similar size and style; all were single-storey bungalows with 2 bedrooms. The properties in Gosforth were marginally bigger and had a floor area of 62m² compared to a floor area of 54m² in South Shields. 3 of the properties in Gosforth were end-of-terraces whilst all of the properties in South Shields were mid-terraces and therefore potentially less heat-loss through external walls.





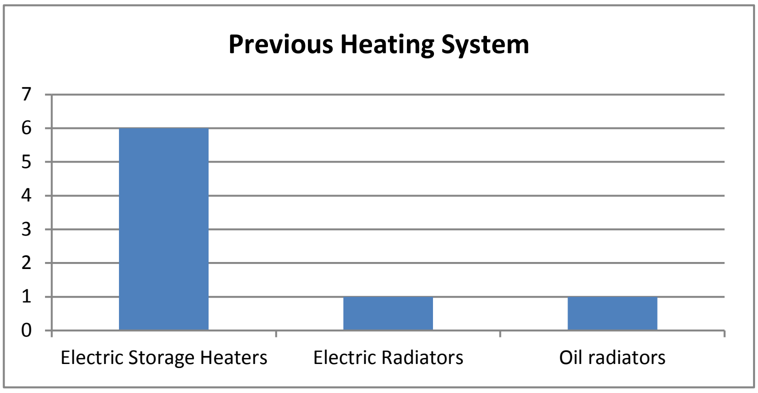


Figure 2.8 (a) Household age (b) Occupation (c) Previous heating system

Qualitative feedback given pre-installation of the hybrid heat pump

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. Only the final questionnaire has been used to determine the resident heating profile. In the first questionnaire there is no data for T-12 and T-02 dropped out of the study, therefore it was more appropriate to use the final questionnaire where all the residents who took part had provided information.

Figure 2.9 shows the results summed up across all respondents. There is a peak in demand for heating between 5pm-9pm. The majority of the residents in this study were retired or not working. It was therefore not unusual to see heating patterns continuing through much of the day.

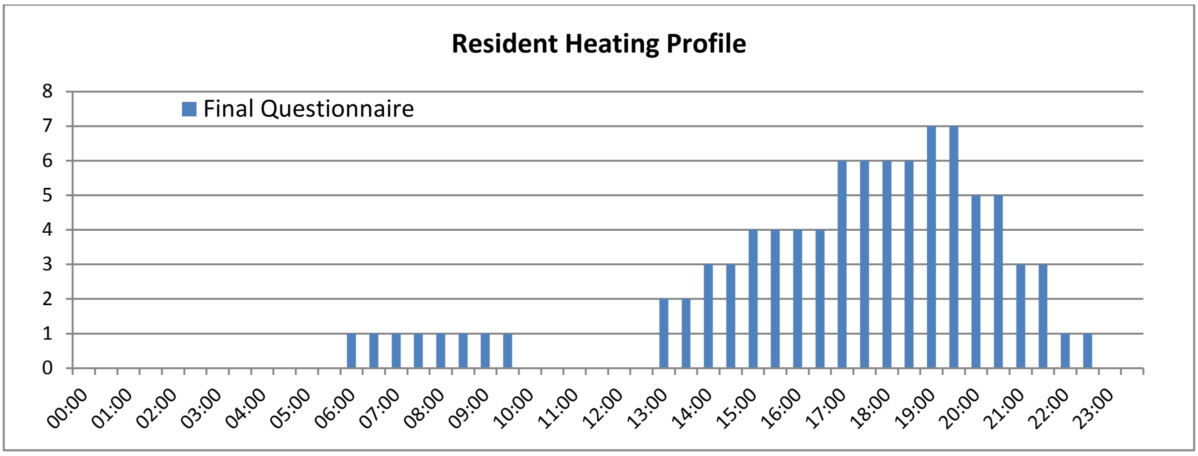


Figure 2.9 times when it was important for the residents to have a warm home

Qualitative feedback given post-installation of the hybrid heat pump

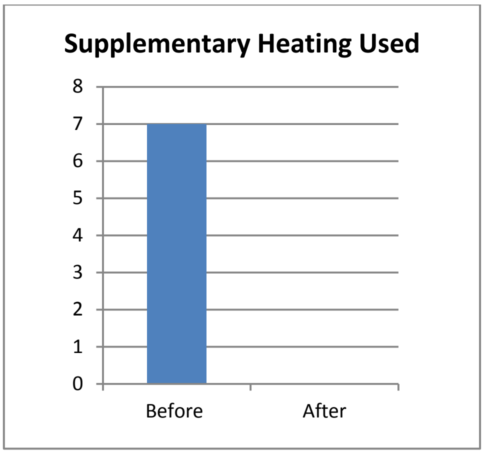


Figure 2.10 using supplementary heating

Prior to the installation of the hybrid heat pump, 7 out of the 8 residents used supplementary heating (as seen in Figure 2.10). After the measures were installed none of the residents used supplementary heating. 5 of the 7 residents were able to heat or use more rooms. Previously they did not have storage heaters within every room or they found it too expensive to heat the rooms that did have storage heaters.

The chart in Figure 2.11 reveals what residents used to do if they came home and their home was too cold. After the hybrid system was installed the residents had 3 ways of controlling their heating system; adjusting the thermostat, adjusting the programmer/overriding it and adjusting the TRVs. Before the hybrid system was installed the majority of residents would turn on supplementary heating to heat their home; 2 residents stated that the storage heaters did not adequately heat their homes and used supplementary heating; 3 of the residents noted that they would put on a jumper or a leave a coat on if they came home and it was too cold and 2 of those residents stated they would also put on supplementary heating. After the hybrid system was installed nobody used supplementary heating and only 1 person would put on an extra jumper or leave a coat on. The 1 resident that stated they would put on a jumper or leave a coat on also stated they would adjust the thermostat. All of the residents were therefore able to warm their home using just the hybrid system if they came in and it was too cold. 5 of the residents stated that they would adjust the room thermostat if it was too cold which they could not do when they had storage heaters. The 2 residents that noted they would adjust the thermostat prior to the new system are referring to the output control on the storage heaters. However none of the residents said they would adjust/override the programmer to control the temperature as these had been pre-programmed and could not be changed.

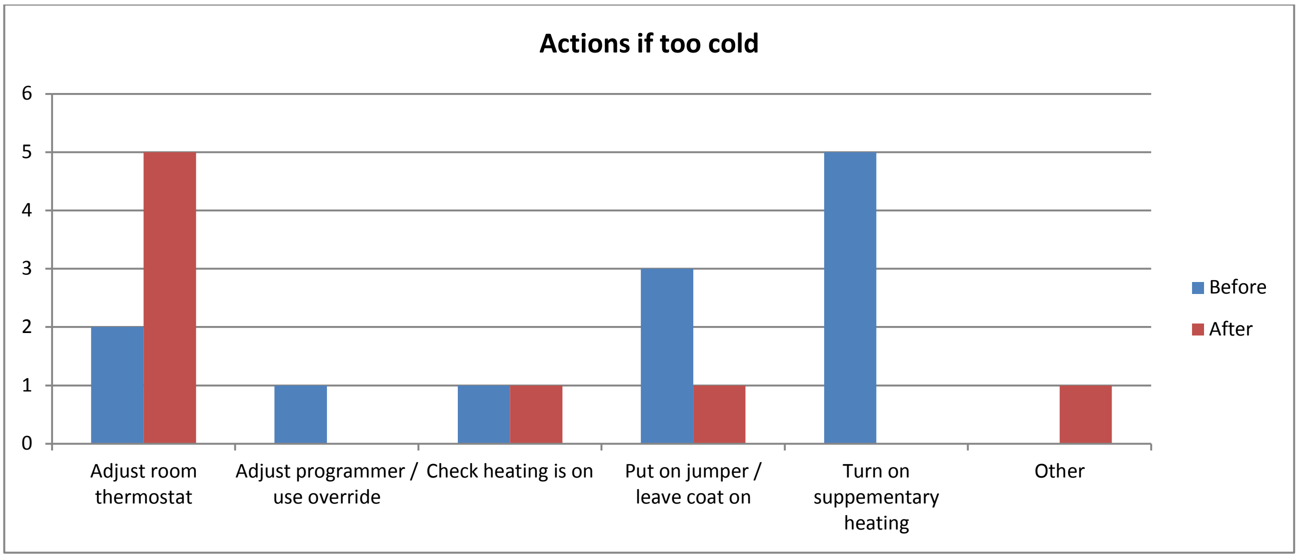


Figure 2.11 actions taken if property is too cold when residents come home

Figure 2.12 shows that before the hybrid system was installed 5 of the residents were wearing extra warm clothing at home. Extra warm clothing refers to wearing more clothing than they normally would if the property was warm e.g. wearing an additional jumper or wearing a blanket/coat/dressing gown over their clothes. After the hybrid system was installed only 1 resident (T-13) wore extra warm clothing at home. Despite wearing extra warm clothing the resident was very satisfied with how warm her house got when it was cold outside and was able to keep her property comfortably warm over the winter period.

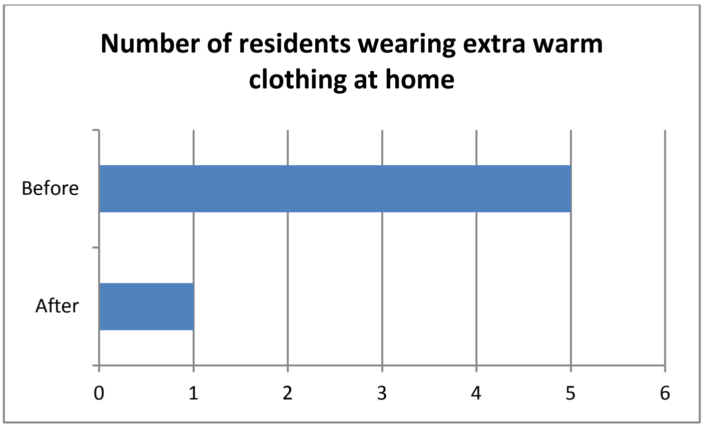


Figure 2.12 wearing extra warm clothing

Resident acceptance and satisfaction

Residents were asked to rate satisfaction with their heating system using 1 of the following responses: 'very dissatisfied', 'dissatisfied', 'neither', 'satisfied' or 'very satisfied'. Each response was assigned a score where 'very dissatisfied' scored 0 and 'very satisfied' scored 100. An average (mean) score of between 0 and 100 was then calculated across the sample. It was possible to determine the satisfaction with the heating system before and after the installation of the hybrid heat pump.

Figure 2.13 shows that there was a marked improvement in all areas of resident satisfaction after the hybrid system was installed. The largest increase related to how satisfied they were with how warm their homes got when it was cold outside, all the residents were 'very satisfied' after the hybrid system was installed.

There was also an increase in satisfaction regarding how well the house kept the heat in; this is despite the fact that no changes were made to the insulation in the property as part of the project or separate to it. This may relate to the fact that the residents can now keep their heating system running for longer than they could with the storage heaters.

There was only a slight increase in satisfaction regarding the cost of running the system. 2 of the residents noted that they were unsure about the cost of heating as they had not looked at their statements in enough detail.

Residents were also markedly more satisfied with the amount of control they had over the system and the ease of using the system. All of the residents knew how to use their thermostats however Figure 2.14 shows that only 2 of the residents knew how to use their programmers. None of the residents had access to the programmer as it was password protected. The heating times were programmed in at the beginning of the project and residents could not change them. Residents were still able to turn the heating system on/off at thermostat. Despite being unable to use the programmer the majority of residents are still satisfied with how much control they have over the hybrid system compared to the storage heaters.

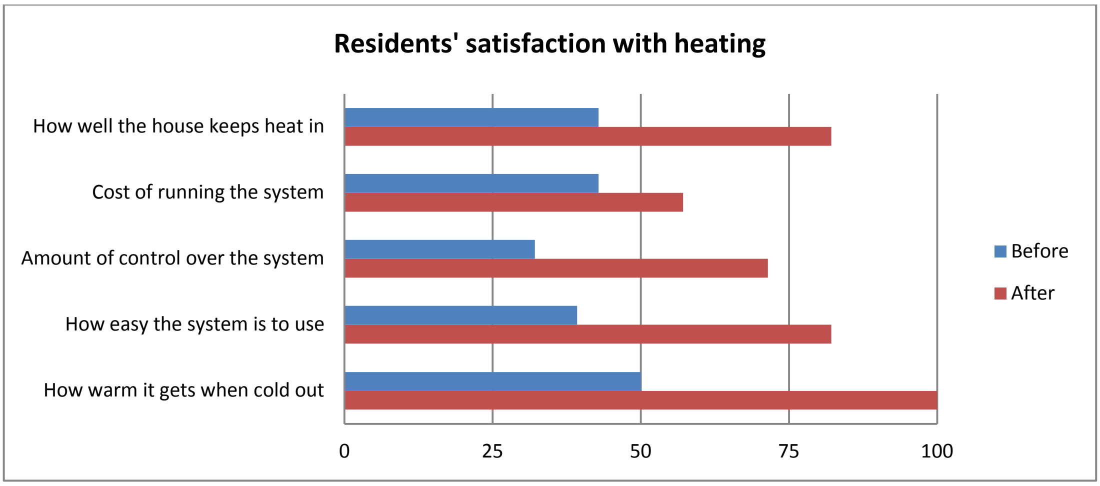


Figure 2.13 residents' satisfaction with their heating system

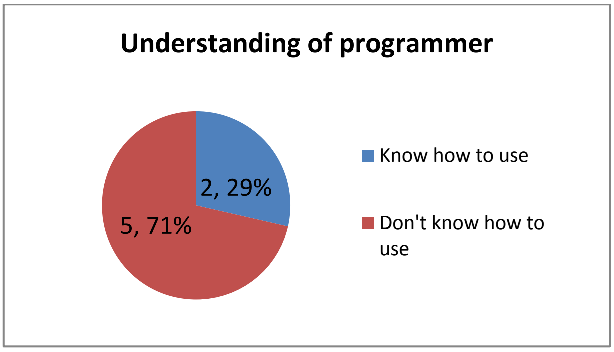


Figure 2.14 Residents' understanding of their programmer

Perceived cost

Residents were asked to rate their agreement with a series of statements about their heating system. Their responses: 'strongly disagree', 'disagree', 'agree' or 'strongly disagree' were each assigned a score where 'strongly disagree' scored 1 and 'strongly agree' scored 4. An average (mean) score of between 1 and 4 was then calculated across the sample. The level of agreement with the statements was determined from residents' answers before and after the installation of the hybrid system.

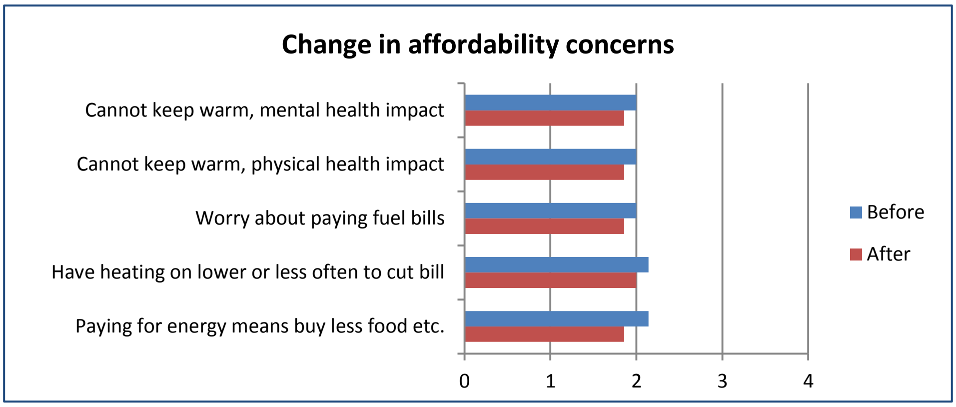


Figure 2.15 residents' concerns about affordability

The chart in Figure 2.15 reveals that residents were not overly concerned with the affordability of their storage heaters. There is a slight decrease in concern for each of the statements. Only 1 of the residents (T-07) agreed with each of the statements and strongly agreed with the statement "I have the heating on lower or less often to cut the bill". All of the residents disagreed with all of the statements after the hybrid system was installed.

Perceived comfort and benefits

Figure 2.16 shows that all of the residents noted at least 3 benefits after the hybrid system was installed. All 7 of the residents noted that their homes were warmer and more comfortable whilst 6 of the residents noted that they had more control over their heating.

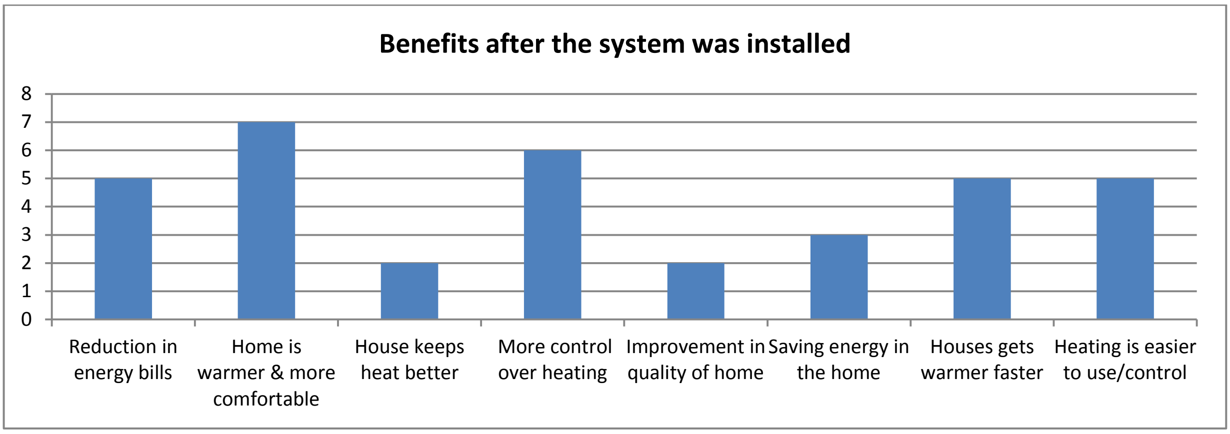


Figure 2.16 Benefits experienced by residents after installation of their hybrid heat pump

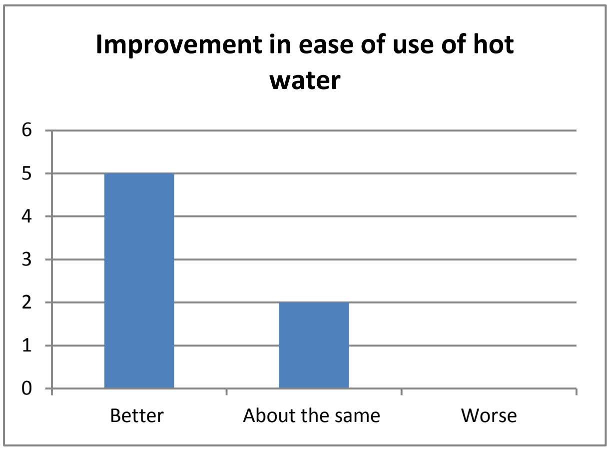


Figure 2.17 improvements in use of hot water

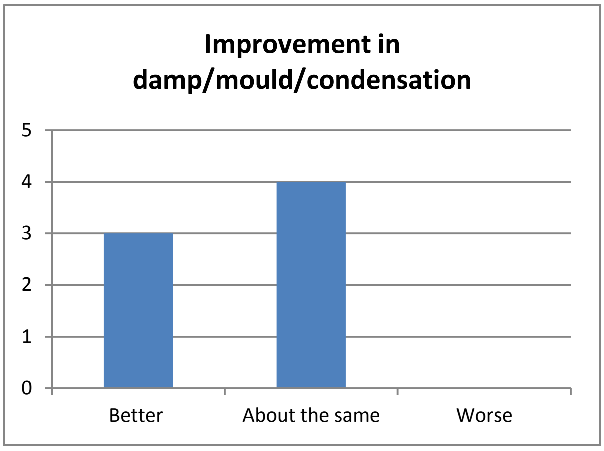


Figure 2.18 improvements in damp/mould/condensation

5 of the residents noted an improvement in the ease of use of the hot water system as shown in Figure 2.17. Residents' comments about the system related to the instant delivery of hot water, the temperature and the cost. 1 resident noted that they no longer had to heat a full tank of water and could use only what they needed, whilst another resident had previously used the boost capability for his immersion heater as he was at work all day and would not benefit from the Economy 7 hours. 3 of the residents noted an improvement in the level of damp/mould/condensation within the properties as shown in Figure 2.18. 2 of the residents stated that the improvements were in rooms located on the exterior of the property with exposed walls and that these improvements were due to a radiator being placed in those rooms.

3 Technical evaluation

3.1 Cost

Analysis using electricity meter readings and energy bills

Gas and electricity meter readings were recorded by households during the study. Consumption data prior to the installation of the hybrid heat pump was obtained through various means. Home Group obtained readings periodically when visiting the properties; there was also data available from the Sustainable Homes National Energy Study for 2 of the properties in Gosforth. Additional data was obtained from resident bills and contacting their energy suppliers. This enabled the consumption of the properties to be compared before and after the installation of the hybrid systems. Most of the properties had storage heaters and were on an Economy 7 tariff. The period selected for analysis before the installation was between January 2015 and February 2016. The period selected for analysis after the installation was between February 2016 and April 2017. These 2 similar time periods were selected to accurately compare before and after costs.

In order to properly analyse energy use for space heating, account must be taken of the weather. For example, 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. 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, for example. 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 taking into account the outside temperature for those different periods.

As the project was split over 2 different areas, 2 different sets of degree day data had to be used. The degree day data for Gosforth was obtained from the weather station at St. Bee's Head as this was close to Gosforth and had good quality data over a long period of time. The degree day data for South Shields was obtained from the weather station at Boulmer, Northumberland; this weather station is located north of South Shields and is located on the coast the same as South Shields whereas other stations that were closer were not coastal. 20-year average degree day values were available only on a regional basis, so the Borders region was used for the South Shields properties and the North Western region for the Gosforth properties.

In Table 3.1 meter readings and bill data were used to obtain the gas and electricity consumption in kWh for the 'before' and 'after' periods. For the before period the consumption over the period was converted into a cost. The properties were on an Economy 7 tariff and therefore paid a higher rate for electricity consumed during the day (on-peak) and a lower rate over the Economy 7 hours at night (off-peak). A standardised price of 18p for the on-peak hours and 7p for the off-peak hours was selected; these were then multiplied by the on-peak consumption and off-peak consumption respectively. The estimated annual electricity cost was calculated by dividing the cost over the period by the number of degree days for that period and multiplying that figure by the average annual number of degree days in the appropriate area.

For the period after the installation the figure of kWh per degree day was calculated by dividing the electricity consumption by the number of degree days for the same period and doing the same for the gas consumption. These 2 figures were then added together. The estimated electricity cost for the sites was obtained by multiplying the unit electricity cost by the number of kWh per degree day for the property and the 20-year average annual number of degree days in the South of England.

Gosforth, Cumbria

	"Before" period								"After" period								Comparison
Tech Ref	Period	Days	Total Period (kWh)	Cost over period	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
T-14	26/1/15-2/2/16	372	7,816.0	£645.68	£52.07	2,376.00	3.290	£646.90	29/02/16 - 27/3/17	392	7,537.8	£55.56	2,456.00	3.069	£703.60	-8.77%
T-13	26/1/15-2/2/16	372	10,282.0	£984.73	£79.41	2,376.00	4.327	£986.59	5/3/16 - 2/4/17	394	7,170.1	£63.45	2,447.70	2.929	£810.38	17.86%
T-12*	5/8/15 - 2/2/16	181	2,929.0	£468.64	£77.68	1,031.80	2.839	£1,081.21	24/2/16 -24/3/17	398	9,399.0	£67.98	2,529.40	3.716	£848.72	21.50%
T-15	5/8/15 - 2/2/16	181	2,102.0	£224.14	£37.15	1,031.80	2.037	£517.12	1/10/16 - 1/4/17	182	2,332.0	£47.05	1,584.90	1.471	£428.74	17.09%
Average**								£861.64							£696	18.82%

Table 3.1 analysis of energy costs before and after installation of the hybrid system

* T-12 had electric on-peak meters before the hybrid system was installed. The residents believed that they were on a single-rate tariff but were actually still on the Economy 7 rate. However, the daytime readings were being used to calculate the night- time consumption. As they had on-peak electric heaters they were using most of the energy during the day on the low off-peak rate. For the purpose of the analysis the total consumption has been used and a standard tariff of 16p per unit.

** The averages do not include T-14 due to its low SCoP (explained below)

T-12 saw an increase in the number of kWh per degree day from 2.839 to 3.716 which is an increase of 30.89%. However, the estimated annual cost shows a saving of 21.5%. The savings over a year were related to the difference in price per kWh that the resident is now paying. Prior to the install the resident would be paying for on-peak electric usage (16p per unit) and after the install they were still paying for on-peak electricity however a proportion of their energy needs is now provided by gas (5p per unit). The difference between the 2 savings figures (annual cost and kwh per degree day) is considerable and is likely to be related to the fact that 58.2% of the energy consumed between 24th February 2016 and 24 March 2017 was provided by the gas boiler (see Table 3.1) and therefore at a cheaper rate. T-12 saw considerable increases in temperature in the living room and bedroom after the installation of the hybrid system. Figure 3.12 shows that after the hybrid system was installed the average temperature of the property between 5-9pm in the living room increased from 20.3°C to 23°C. In the bedroom the temperature also increased by around 3°C.

T-14 saw an increase of 8.77% in their estimated annual cost from £646.90 to £703.60. T-14 had the lowest Seasonal Coefficient of Performance (SCoP)[8] of any of the properties at 2.38 (a measure of efficiency used with heat pump technology). A low SCoP usually equates to higher operating costs and lower efficiency. Daikin has visited the property to try and resolve the issue but they have been unsuccessful in doing so. The resident subsequently has the highest gas usage as a proportion of the energy consumed at 57.9%. The resident saw significant improvements in comfort despite the rise in cost. The temperature in the living room increased by around 2°C (see

[8] https://www.daikin.eu/en_us/faq/what-is-a-heat-pump-.html [Accessed 22/6/2017]

Table 3.6). The resident also heated the kitchen and hallway which they had not done previously.

T-13 and T-15 saw similar estimated savings when comparing the estimated annual cost pre and post the hybrid installation. T-13 achieved savings of 17.86% and T-15 achieved 17.09%. When looking at the cost per 30 days T-15 notes a 26.65% increase in the cost per 30 days. This figure does not take into account the degree days over the period; there were over 500 more degree days over the period that was chosen to analyse the consumption of the heating after the hybrid was installed. In T-13 and T-15 the temperatures remained largely the same after the installation of the hybrid system. In T-13 the temperature dropped from 22.9°C to 22.1°C in the living room between 5-9pm after the hybrid system was installed. In T-15 the temperature within the living room stayed the same at 19.8°C (see Figure 3.12).

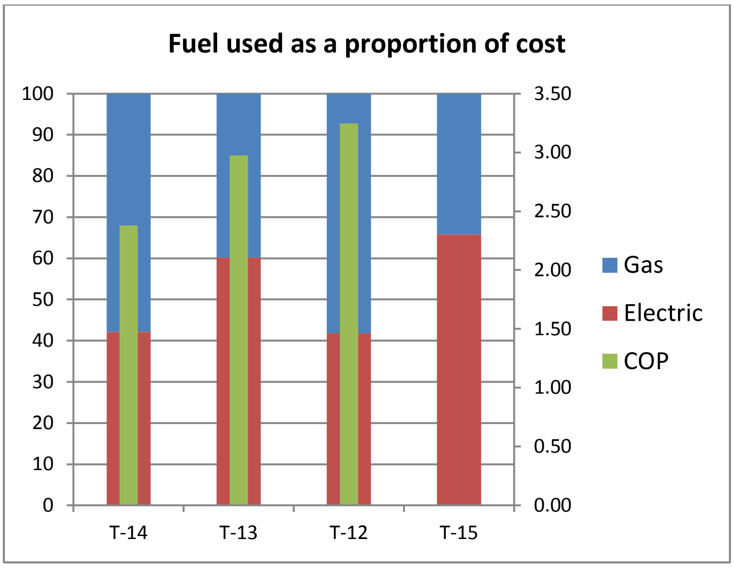


Figure 3.2 fuel type used as a proportion of cost (gas/electric) and COP

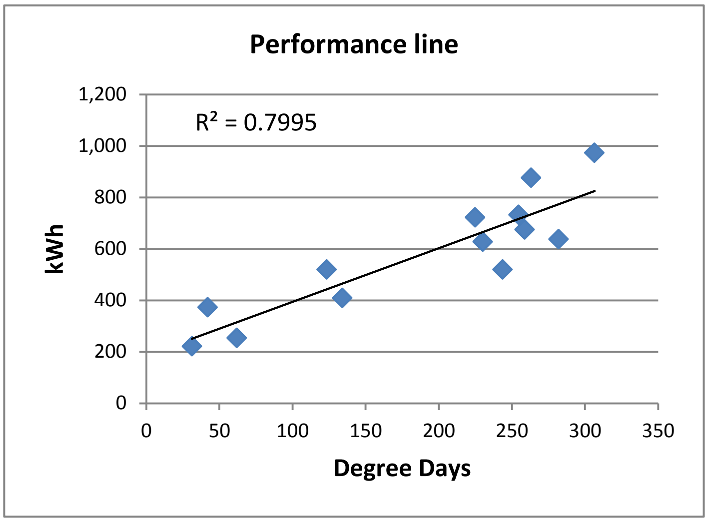


Figure 3.3a T-14 heated by storage heaters

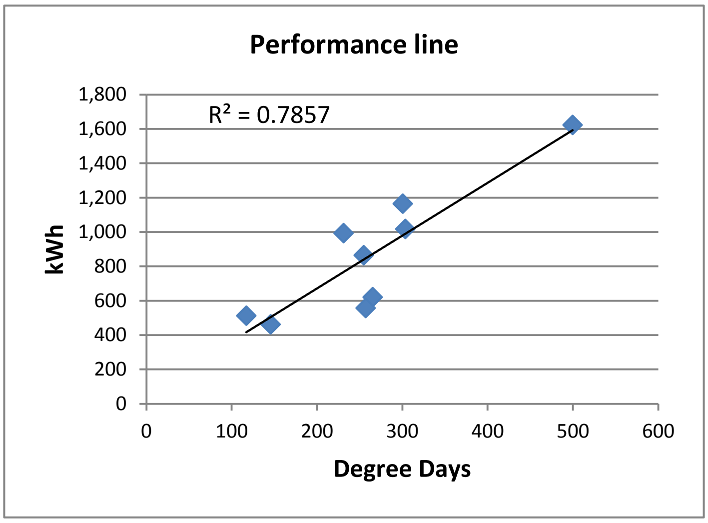


Figure 3.3b T-14 heated by hybrid system

Figures 3.3a and 3.3b show that for T-14 there was an increase in the gradient, indicating an increase in energy use for a given number of degree days (outside temperature) compared to the storage heaters. This change in performance is mainly related to the low SCoP (as detailed above) which impaired the efficiency of the heat pump aspect of the system. As noted above the resident experienced significant improvements to thermal comfort in the living room and bedroom and was also heating additional areas of the house. The resident also stated that the heating was on all day every day.

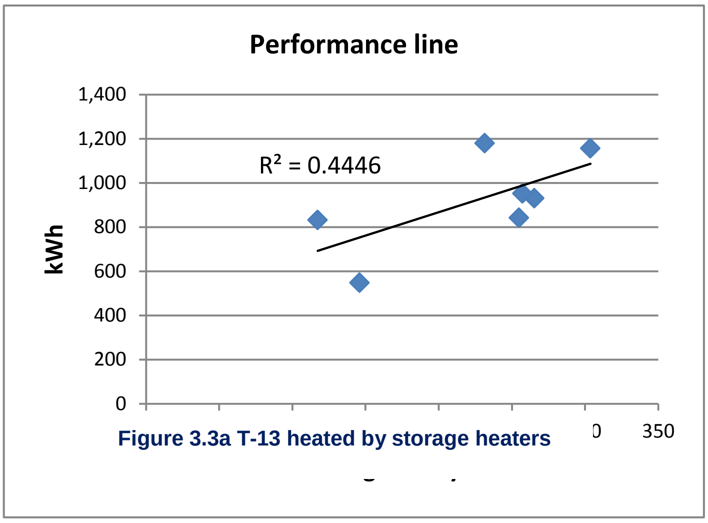


Figure 3.3a T-13 heated by storage heaters

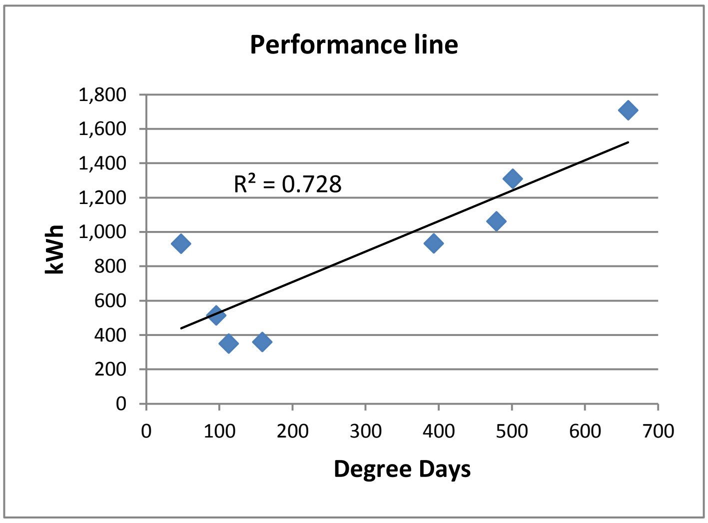


Figure 3.3b T-13 heated by hybrid system

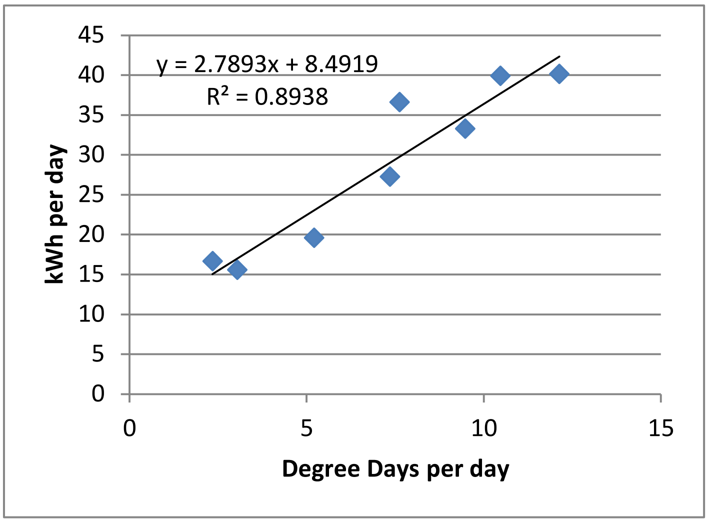


Figure 3.4c T-13 heated by storage heaters

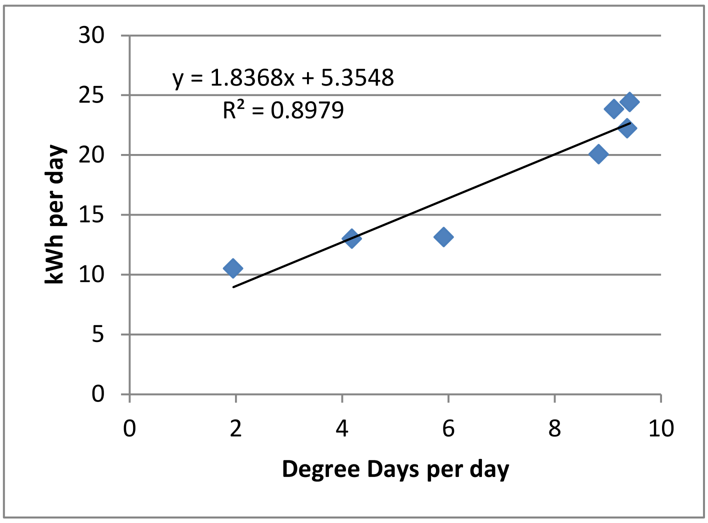


Figure 3.4d T-13 heated by hybrid system

Figures 3.4a and 3.4b above show the correlation of energy use against degree days (best-fit) for T-13 pre and post the installation. The R^2 value relates to how good the correlation is between degree days and energy consumption, an R^2 value of 0.75 or above indicates a reasonable correlation between energy consumption and degree days. Figure 3.4a is particularly low which may indicate poor control or an error in the methodology. If the meter reading interval is inconsistent the R^2 value is not as useful an indicator of correlation and the gradient of the line of best fit cannot be used with accuracy. To rectify this it is possible to look at the correlation between degree days per day and energy consumption per day. Figure 3.4c reveals that T-13 had good control when using the storage heaters and this level of control was maintained using the hybrid system (see Figure 3.4d). The gradient of the line of best fit decreased after the installation of the hybrid system indicating a decrease in the energy required as degree days increased.

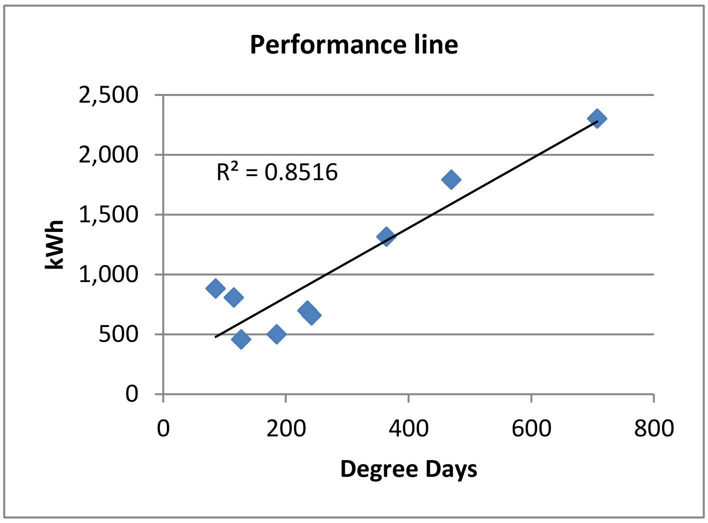


Figure 3.5a T-12 heated by hybrid system

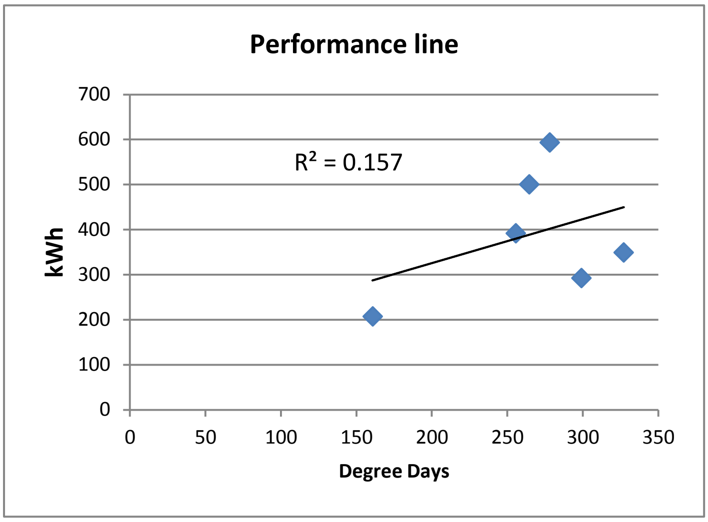


Figure 3.5b T-15 heated by hybrid system

The R^2 value in Figure 3.5a shows that T-12 had a good level of control over the hybrid heating system. There was not enough energy consumption data for the property pre installation of the hybrid system. T-15 had particularly poor control over the heating system and this did not improve when changes were made to the methodology such as increasing the baseline temperature or looking at energy consumption per day. T-15 was the only resident in full-time work and subsequently only turned on the heating system in the evening when he arrived back from work, thus explaining the scatter on Figure 3.5b. Despite this the resident still saw an estimated saving of 17.09%.

South Shields

	"Before" period								"After" period								Comparison
Tech Ref	Period	Days	Total Period (kWh)	Cost over period	Cost over 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
T-10	8/1/15-11/1/16	368	10,108.0	£793.69	£64.70	2,323.50	4.350	£773.02	18/3/16-4/3/17	351	3,749.4	£36.20	2,131.80	1.759	£449.60		41.84%
T-05	5/2/15 - 11/1/1	339	5,843.0	£934.88	£82.73	1,983.20	2.946	£1,066.78	15/2/16-4/3/17	383	7,290.2	£78.12	2,489.70	2.928	£906.53		15.02%
T-07	15/10/15-11/1/	88	2,700.0	£263.91	£89.97	630.40	4.283	£947.38	1/3/16-1/3/17	365	4,627.4	£49.19	2,277.30	2.032	£594.68		37.23%
Average								**£929.06**							**£650.27**		**31.36%**

Table 3.6 analysis of energy costs before and after installation of the hybrid system

Similar to T-12, T-05 also had on-peak electric heating. T-05 saw an estimated saving of 15.02% when comparing the estimated annual cost pre and post the hybrid installation. There was only a slight estimated saving when comparing the kWh required per degree day before and after the hybrid system was installed, this figure fell from 2.946 kWh per degree day to 2.926 kWh. The savings over a year were related to the difference in price per kWh that the resident is now paying. Prior to the install the resident would be paying for on-peak electric usage (16p per unit) and after the install they were still paying for on-peak electricity however a proportion of their energy needs is now provided by gas (5p per unit). The resident also saw increases in their living room and bedroom temperatures, the living room between 5-9 pm increased from 20.5°C to 22.5°C and the bedroom between 5-9pm increased from 18.4°C to 22.9°C (see Figure 3.12).

Figure 3.6 shows that the 2 properties that moved from Economy 7 to the hybrid system saw the greatest savings. T-10 saw the greatest saving of 41.84% when comparing the estimated annual cost pre and post the hybrid installation. The average temperature between 5-9pm in the living room when the resident had electric storage heaters was 24.6°C. The resident stated that they used a fan heater in the evening during the winter to achieve warmth. After the hybrid system was installed the temperature dropped to 22.1°C (see Figure 3.12) which is still an appropriate temperature. The resident had the programmer set to 22°C and therefore the heating system was able to achieve this. The temperature also decreased in the main bedroom from 24.4°C to 22.3°C (see Figure 3.13). The resident also stated they can now heat their spare bedroom.

T-07 saw an estimated saving of 37.23% when comparing the estimated annual cost pre and post the hybrid installation. T-07 maintained similar temperatures in the living room and bedroom after the installation of the hybrid system. In the living room the temperature stayed just over 23°C and in the bedroom it fell marginally from around 19°C to just over 17°C (see Figures 3.12 and 3.13). The residents stated that they also have the option to heat more rooms which they could not do when they had storage heaters.

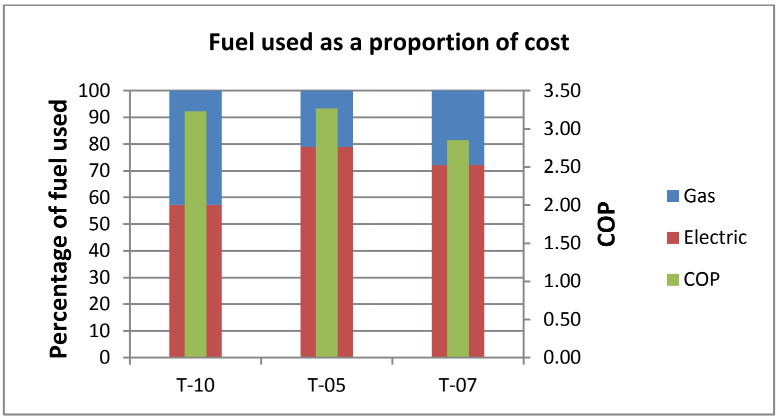


Figure 3.7 fuel type used as a proportion of cost (gas/electric) and COP

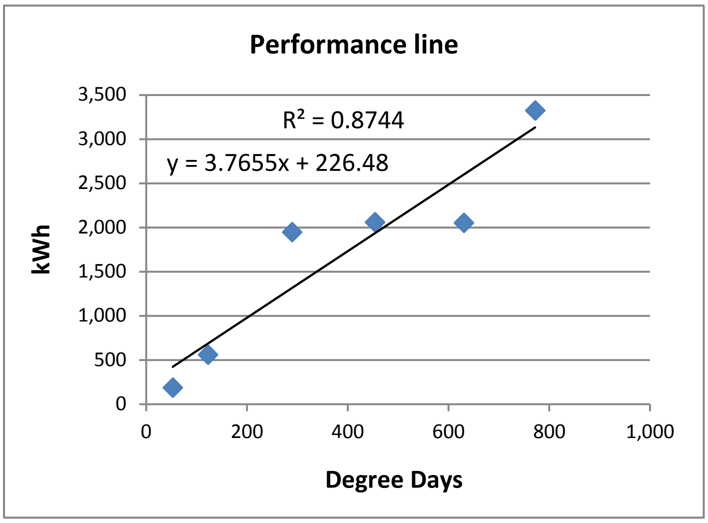


Figure 3.8a T-10 heated by storage heaters

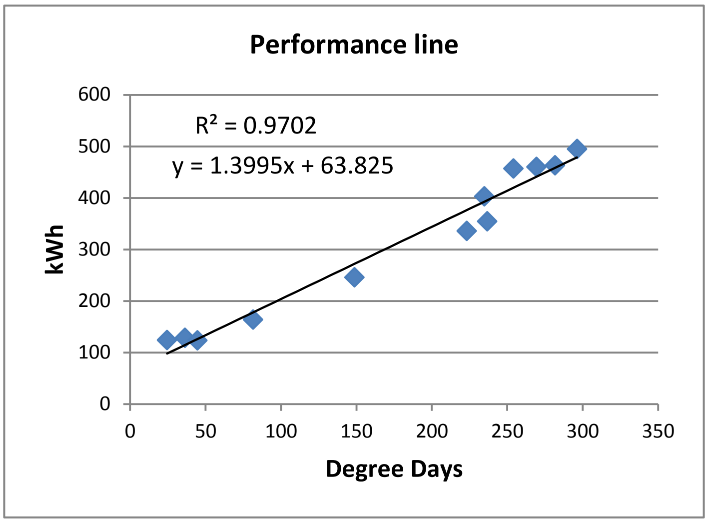


Figure 3.8b T-10 heated by hybrid system

Figures 3.8a and 3.8b show how the consumption per degree day decreased from 3.97 to 1.96 for property T-10 after replacing the electric convector heaters with the ASHP. With both graphs there was a strong correlation between electricity consumption and number of degree days, indicating that the resident in property T-10 was able to maintain fairly good temperature control with the electric storage heaters however control with the hybrid heat pump is much improved. Both the slope of the line (the kWh per degree day), and the intersect point (the baseload consumption per day) have also decreased, indicating better heating control.

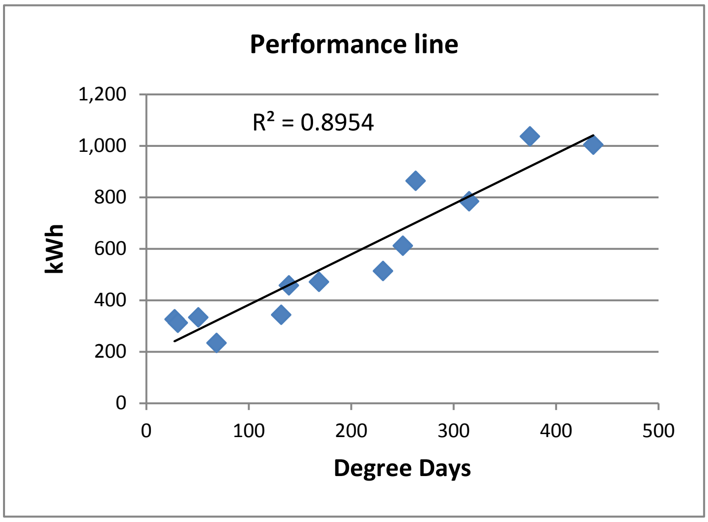


Figure 3.9a T-05 heated by hybrid system

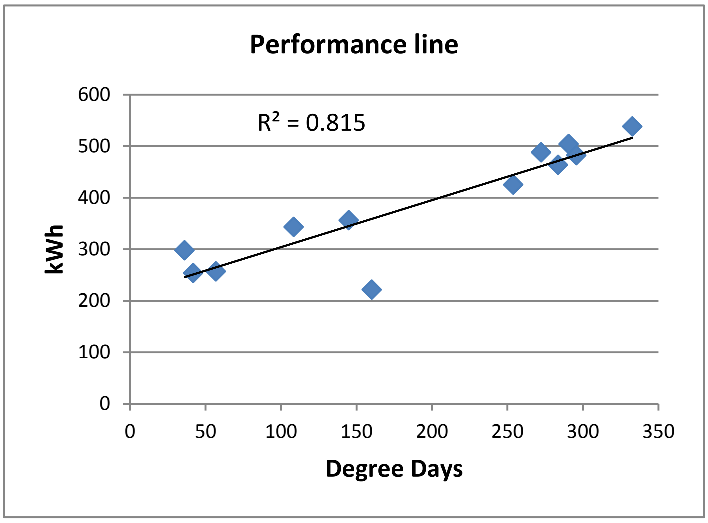


Figure 3.9b T-07 heated by hybrid system

T-05 and T-07 do not have enough meter readings prior to the installation of the hybrid heat pump to prepare a graph. The graphs in figures 3.9a and 3.9b show good control after the installation of the hybrid system as both have a good best-fit line. Both T-05 and T-07 had similar heating patterns, T-05's heating came on at 6am at 22°C and switched to 18°C at 9pm whilst T-07's heating came on at 8:30am at 21°C and stayed on until 9pm.

3.2 Coefficient of Performance (SCoP)

The seasonal coefficient of performance of a heat pump is a ratio of how much heat is provided compared to electrical input where the source temperature varies over the period monitored and hence output will vary. Each property had a dedicated watt hour meter to measure the electrical input into the ASHP and a dedicated heat meter to monitor the heat output of the ASHP. The output can then be divided by the input to determine an indicative SCoP. The quoted SCoP in technical specifications of heat pumps is a specialised measurement obtained through controlled testing under specific conditions. The values obtained in this study are simple calculations to test whether there are any differences in performance across the sample.

$$Seasonal\ Coefficient\ of\ Performance = \frac{Heating\ Ouput\ (W)}{Total\ Power\ input\ over\ the\ season\ (W)}$$

Figure 3.10 shows the SCoP of 6 of the monitored properties where there was adequate data. The lowest SCoP was T-14 at 2.38, this is particularly low considering typical CoP for a typical heat pump is between 3 and 4 and a heat pump must have a minimum value of 2.5 to be eligible for RHI payments. 3 of the 7 properties failed to reach a SCoP of 3 over the monitoring period.

The hybrid systems were designed to different temperature outputs to match the property types and locations. The Gosforth systems had an output temperature of 50°C and the South Shields systems had an output temperature of 45°C. The lower the output temperature to the radiators, the higher the SCoP should be. In the Gosforth properties (see Figure 3.10) T-14 and T-13 failed to reach a SCoP of 3 over the monitored period whilst 1 property in South Shields also failed to reach a SCoP of 3. On average the properties in South Shields used less gas as a proportion of their fuel costs than in Gosforth (see Figures 3.2 & 3.7). On average the properties in South Shields used gas for 30% of their energy requirements whilst in Gosforth the average usage was 50%. It appears that as the external temperature dropped the heat pump in the Gosforth properties could not provide enough heat to match the required output of 50°C. The gas boiler needed to work alongside the heat pump to provide the additional heat required.

Figure 3.10 SCoP of each property over the duration of the study

Temperature and thermal comfort

Figure 3.11 thermal logger in property

Temperature and humidity loggers were placed in all 8 properties during the study. One was placed in the main living room and a second was placed in the main bedroom. The loggers were installed in all of the properties in late October 2015 before the hybrid system was installed. The loggers were removed in May 2017. The data selected to be analysed was over a 30-day period before the hybrid systems were installed and a 30-day period after the hybrid systems were installed. The residents' heating profile as shown in Figure 2.9 was used to determine between which times the data was monitored, the figure shows that the majority of residents thought it was important to be warm between 5pm-9pm. The 24-hour average, maximum and minimum temperatures were also selected for analysis.

The 30-day period before the measure and the 30-day period after the measure had to have a similar amount of degree days. This meant that the 2 periods selected experienced similar weather conditions. In Gosforth the period before the installation was between 15th November 2015 and 15th December 2015 and there were 242.1 degree days during this period. The period after the installation was between 22nd October 2016 and 21st November 2016; there were 240 degree days during this period. In South Shields the period before the installation was between 15th November 2015 and 15th December 2015 and there were 256.9 degree days during this period. The period after the installation was between 22nd November 2016 and 21st December 2016; there were 266.6 degree days during this period.

Table 3.12 shows that all of the properties maintained temperatures that were either between the recommended range for comfort and good health of 18-21°C or above it in the period before and the period after the measures were installed. Prior to the installation of the hybrid system all of the properties except T-05 used supplementary heating to achieve the temperatures in their living rooms. After the installation none of the properties required supplementary heating and the living rooms were on average 0.9°C warmer in the Gosforth properties rising to 22.3°C (in the preferred comfort heating period 5-9pm). In South Shields the properties maintained similar levels of thermal comfort at 22.7°C in the living room.

Gosforth	Living Room pre measure - 15/11/15 - 15/12/15				Living Room post measure - 22/10/16 - 21/11/16			
	5-9pm	24 hours	24 hours	24 hours	5-9pm	24 hours	24 hours	24 hours
Tech Ref. No.	Average Temp (°C)	Average Temp (°C)	Maximum Temp (°C)	Minimum Temp (°C)	Average Temp (°C)	Average Temp (°C)	Maximum Temp (°C)	Minimum Temp (°C)
T-14	22.6	22.7	25.5	20	24.3	22.3	25.5	17.5
T-13	22.9	21.9	25	17.5	22.1	19.9	25.5	15.5
T-12	20.3	19.5	26.5	14.5	23.0	21.7	28.0	16.5
T-15	19.8	19.6	23.5	15	19.8	19.1	23.5	14.0
Average	21.4	20.9	25.1	16.8	22.3	20.7	25.6	15.9
Degree days	242.1				240.0			
South Shields	Living Room pre measure 15/11/15 - 15/12/15				Living Room post measure 22/11/16 - 21/12/16			
	5-9pm	24 hours	24 hours	24 hours	5-9pm	24 hours	24 hours	24 hours
Tech Ref. No.	Average Temp (°C)	Average Temp (°C)	Maximum Temp (°C)	Minimum Temp (°C)	Average Temp (°C)	Average Temp (°C)	Maximum Temp (°C)	Minimum Temp (°C)
T-10	24.6	24.5	27.5	21.5	22.1	21.1	24.5	17.0
T-05	20.5	20.4	24	16.5	22.5	22.3	25.5	19.5
T-07	23.8	21.2	27	16	23.6	21.3	26	15.5
Average	23	22	26.2	18	22.7	21.6	25.3	17.3
Degree days	256.9				266.6			

Table 3.12 Temperatures in the living room of the monitored properties before and after the hybrid system was installed

Table 3.13 shows that the temperature in the bedrooms of all the Gosforth properties increased during the preferred time for warmth. 1 properties bedroom (T-13) was not heated to the recommended level of 18°C; the remaining properties all reached or exceeded this temperature. T-13 stated that they did not heat their bedroom as they preferred a cold bedroom. In South Shields T-10 reduced the average bedroom temperature to within a healthy range and T-05 saw bedroom temperatures increase to 22°C, T-07 only had the bedroom radiator on occasionally and the temperature was therefore around 17°C.

Gosforth	Bedroom pre measure 15/11/15 - 15/12/15				Bedroom post measure 22/10/16 - 21/11/16			
	5-9pm	24 hours	24 hours	24 hours	5-9pm	24 hours	24 hours	24 hours
Tech Ref. No.	Average Temp (°C)	Average Temp (°C)	Maximum Temp (°C)	Minimum Temp (°C)	Average Temp (°C)	Average Temp (°C)	Maximum Temp (°C)	Minimum Temp (°C)
T-14	15.7	15.7	18	14	18.0	17.7	19.5	16.0
T-13	16.5	17.1	20.5	14.5	17.0	17.1	19.5	14.0
T-12	15.2	15.4	17.5	13.5	18.4	18.2	20.5	16.0
T-15	19.9	19.6	25.5	14	19.1	18.8	22.5	14.5
Average	16.8	17.0	20.4	14.0	18.1	18.0	20.5	15.1
Degree days	242.1				240.0			
South Shields	Bedroom pre measure 15/11/15 - 15/12/15				Bedroom post measure 22/11/16 - 21/12/16			
	5-9pm	24 hours	24 hours	24 hours	5-9pm	24 hours	24 hours	24 hours
Tech Ref. No.	Average Temp (°C)	Average Temp (°C)	Maximum Temp (°C)	Minimum Temp (°C)	Average Temp (°C)	Average Temp (°C)	Maximum Temp (°C)	Minimum Temp (°C)
T-10	24.4	24.4	27	21	22.3	21.6	25.5	18.0
T-05	18.4	18.4	22	16	22.9	22.4	26.0	19.5
T-07	18.8	19.2	22	16.5	17.4	17.5	20.0	15.0
Average	20.5	20.7	23.7	17.8	20.9	20.5	23.8	19
Degree days	256.9				266.6			

Table 3.13 temperatures in the main bedrooms of the monitored properties before and after the hybrid system was installed

Humidity

Water vapour, usually measured as relative humidity or the percentage of water vapour held by the air compared to the saturation level, 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. On the other hand, 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.

A study by Arundel et al. concludes that maintaining relative humidity levels between 40% and 60% would minimise adverse health effects relating to relative humidity[9]. The indirect health effects of relative humidity may be growing in importance as a result of the continuing construction of energy efficient sealed buildings with low fresh air ventilation rates, but this subject is outside of the scope of this study.

The automated data-loggers record both temperature and relative humidity (RH) at regular intervals across the study properties. Relative humidity 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 the health problems associated with this high humidity. From the Building regulations part F[10]; the suggested average monthly maximum humidity levels for domestic dwellings during the heating season is 65%.

Table 3.14 shows that the average humidity levels in the living rooms of the monitored properties before the hybrid heat pump was installed were between 41% and 68% over a 24-hour period. After the system was installed the average humidity levels in the living rooms fell to within the recommended 40-60% range. The 2 properties that saw the greatest reduction in humidity levels were T-12 and T-15, T-12 saw a decrease from 66% to 58% during 5-9pm. The maximum level of humidity also dropped from 80% to 72%. The reduction in humidity was accompanied by a 2.7°C increase in temperature between 5-9pm.

	Living Room pre measure - 15/11/15 - 15/12/15				Living Room post measure - 22/10/16 - 21/11/16			
Gosforth	5-9pm	24 hours	24 hours	24 hours	5-9pm	24 hours	24 hours	24 hours
Tech Ref. No.	Average Humidity	Average Humidity	Maximum Humidity	Minimum Humidity	Average Humidity	Average Humidity	Maximum Humidity	Minimum Humidity
T-14	49%	48%	54%	41%	46%	48%	61%	37%
T-13	46%	47%	55%	39%	52%	52%	62%	44%
T-12	66%	67%	80%	54%	58%	60%	72%	43%
T-15	67%	68%	76%	39%	58%	59%	68%	49%

[9] 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]
[10] Available from https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/468871/ADF_LOCKED.pdf [Accessed 21/03/2017]

Average	57%	57%	66%	43%	53%	55%	66%	43%
South Shields	Living Room pre measure - 15/11/15 - 15/12/15				Living Room post measure - 22/11/16 - 21/12/16			
	5-9pm	24 hours	24 hours	24 hours	5-9pm	24 hours	24 hours	24 hours
Tech Ref. No.	Average Humidity	Average Humidity	Maximum Humidity	Minimum Humidity	Average Humidity	Average Humidity	Maximum Humidity	Minimum Humidity
T-10	41%	41%	50%	35%	48%	49%	56%	43%
T-05	54%	52%	67%	42%	52%	50%	62%	40%
T-07	56%	58%	70%	48%	58%	58%	66%	48%
Average	50%	50%	62%	42%	53%	52%	61%	44%

Table 3.14 humidity in the living rooms of the monitored properties before and after the hybrid system was installed

Table 3.15 shows that the average humidity between 5-9pm and over a 24-hour period in the main bedroom in the Gosforth properties fell after the installation of the hybrid systems. The average humidity over a 24-hour period fell from 69.8% to 64.5%. All of the properties were over the 65% average maximum humidity mark as suggested by the building regulations and T-12 rises the highest of all the properties to 81%. T-12 and T-14 still saw decreases in humidity despite both stating they did not have the heating on in their bedrooms all the time. The properties in South Shields did not have the same issues with humidity as 2 of the properties (T-10 and T-07) had 5-9pm average temperatures hovering around the 22°C mark.

Gosforth	Bedroom pre measure - 15/11/15 - 15/12/15				Bedroom post measure - 22/10/16 - 21/11/16			
	5-9pm	24 hours	24 hours	24 hours	5-9pm	24 hours	24 hours	24 hours
Tech Ref. No.	Average Humidity	Average Humidity	Maximum Humidity	Minimum Humidity	Average Humidity	Average Humidity	Maximum Humidity	Minimum Humidity
T-14	69.8%	70.4%	83.0%	63.5%	59.9%	60.5%	68.0%	54.0%
T-13	56.6%	57.0%	68.5%	44.5%	56.7%	58.0%	67.0%	45.5%
T-12	82.4%	84.0%	90.0%	73.0%	71.0%	73.5%	81.0%	62.5%
T-15	66.7%	67.6%	76.0%	37.5%	64.6%	66.1%	73.0%	56.0%
Average	68.9%	69.8%	79.4%	54.6%	63.1%	64.5%	72.3%	54.5%
South Shields	Bedroom pre measure - 15/11/15 - 15/12/15				Bedroom post measure - 22/11/16 - 21/12/16			
	5-9pm	24 hours	24 hours	24 hours	5-9pm	24 hours	24 hours	24 hours
Tech Ref. No.	Average Humidity	Average Humidity	Maximum Humidity	Minimum Humidity	Average Humidity	Average Humidity	Maximum Humidity	Minimum Humidity
T-10	40.8%	40.9%	49.5%	34.5%	48.3%	48.9%	56.0%	42.5%
T-05	53.5%	51.9%	67.0%	42.0%	51.5%	50.3%	61.5%	39.5%
T-07	56.5%	57.8%	69.5%	48.0%	58.0%	58.0%	66.0%	48.0%
Average	50.3%	50.2%	62%	41.5%	52.6%	52.4%	61.2%	43.3%

Table 3.15 humidity in the main bedrooms of the monitored properties before and after the hybrid system was installed

Installation and service

All of the residents experienced some form of disruption as the gas connection was installed and the hybrid system was installed. All of the residents agreed that the installers were respectful and careful when in their homes; 4 of the 7 residents ‘strongly agreed’ with this statement.

3 of the 7 residents noted that they had a system breakdown however they all stated that these issues were resolved quickly. Those residents said they had to contact a central Home Group switchboard to request someone to come out to the property, 1 issue that arose was the staffs' unfamiliarity with the hybrid system and 1 resident had 2 engineers out who could not diagnose or fix the problem with the hybrid system.

4. Conclusions and recommendations

4.1 Conclusions

The original aims of the project were as follows

- To establish the running costs of the 5kWh Daikin Altherma hybrid heat pump compared to previous heating systems.

- To examine the impact of installing the Daikin Altherma hybrid heat pump on residents' comfort and satisfaction levels.

- To help inform Home Group and other interested parties whether hybrid heating systems are a viable alternative to electric storage heaters.

Running costs

- On average the residents in Gosforth saved 20.4% (excluding T-14) on their annual fuel cost when using the 20-year degree day average days per year. This was a reduction in their energy bill from £861.64 a year to £679 a year. There was an increase in the annual fuel bill for T-14 however the COP for this property was particularly low and Daikin has made repeated visits to try and resolve this issue without success. The other 3 properties had savings between 17% - 26%. On average the properties (excluding T-14) used electricity 58% of the time and gas 42% of the time.
- On average the residents in South Shields saved 31.36% on their annual fuel cost when using the 20-year degree day average days per year. This was a reduction in their energy bill from £929.06 a year to £650.27 a year. There was a greater variation in how much the residents saved, ranging from 15% - 42%. On average the properties used electricity 69% of the time and gas 31% of the time.

Thermal comfort and satisfaction

- Residents' satisfaction with their heating increased in each category (how well the house keeps the heat in, cost of running the system, amount of control over the system, how easy the system is to use and how warm it gets when cold out). All 7 residents claimed they were 'very satisfied' with how warm their home gets when it's cold outside. After the installation of the hybrid system none of the residents used supplementary heating and only 1 resident wore extra warm clothing.

- Only 2 residents knew how to use the programmer of the hybrid system, none of the residents had access to this to change the settings. Despite this 5 residents stated that they 'had more control over their heating'. The residents still had some level of control as they could change the thermostat settings and certainly more control over when they wanted their property to be warm compared to the storage heaters.

- There was a slight decrease in affordability concerns however the residents were not particularly concerned about these issues when they had the storage heaters, possibly as a result of living in relatively small/appropriately sized accommodation with average/above average energy efficiency levels.

- On average the properties in South Shields had a higher SCoP (3.12) and more control over their heating system as there was a strong relationship between energy consumption and degree days.

- On average the living room temperature increased after the installation of the hybrid system in Gosforth from 21.4°C to 22.3°C during the residents' preferred heating period of 5-9pm. The bedroom temperature also increased from 16.8°C to 17.1°C. In South Shields, the average living room temperature decreased after the installation of the hybrid system from 23°C to 22.7°C during the residents' preferred heating period of 5-9pm. The bedroom temperature increased significantly in 2 of the properties.

- The increases in temperature in the Gosforth properties may partly explain why the savings in the Gosforth properties were less than the savings in South Shields.

- Prior to the hybrid system the average humidity levels in living rooms was between 41%-68% and after the installation the average humidity levels fell to between the healthy band of 40% - 60%.

Overall the residents, who were all aged 60 or older, made significant savings on their energy bills whilst maintaining a comfort level of around 22°C and also heating more rooms than they had done with the storage heaters. They also had more control over when their heating system delivered heat however they did not have full programmability of the hybrid system.

4.2 Recommendations for potential future installations

- A larger study would confirm whether the savings made stated by our small sample are representative across the wider programme.
- A larger scale study is need to confirm if the savings indicated in this study could be replicated across appropriate numbers of properties of similar construction, size, and occupancy etc.

- Installing remote monitoring to determine real-time usage of the hybrid system and check that the monitoring equipment is monitoring the correct input or output.
- Residents should be provided with access to the programming element of the hybrid system and the training required in its use.

4.3 Viability of replacing storage heaters with hybrid heat pumps

All of the residents preferred the hybrid system over their storage heaters, and 6 of the 7 residents saved money and all noted an improvement in how warm and comfortable their home was. However, there are several issues that impact on the systems' effectiveness at combatting fuel poverty.

There is a higher capital cost associated with the hybrid system when compared to traditional heating systems such as a gas boiler. A hybrid system may be cheaper over the lifetime of the system as potentially there are lower running costs, RHI payments and a longer operating lifetime. However to procure and install this system would require a significant upfront capital investment; a resident in fuel poverty is highly unlikely to have this level of resource. It is a more viable option for a housing association who can meet the upfront cost particularly as they would gain a return on investment through RHI payments and would not have to replace the heating system as often.

None of the residents had access to the programmer next to the gas-combi boiler. The programmer enables residents to set the schedule of the time their heating turns on/off, set the temperature and change the energy prices. The unit takes into account the price of gas and electricity when determining the most efficient method of heating the property; it is therefore important to have the ability to change that setting when residents switch tariffs or suppliers. If the residents want anything changed then someone has to come out and re-programme the system. Despite this, 5 out of 7 residents were satisfied with the amount of control they had over the system.

A new gas connection would be required if replacing storage heaters with a hybrid system. Installing a new gas connection can be time-consuming, expensive and disrupting to residents, however all of the residents within the study stated that the interruptions and early teething problems were worth it for the new system. The hybrid system may not be future-proof as the UK looks to transition to a low carbon economy however it does have the potential to be a low carbon bridge when phasing out the use of fossil fuels.
It is also beneficial as connecting off-gas communities to the grid is currently one of the most effective ways of combatting fuel poverty and reducing the fuel poverty gap. The Fuel Poor Network Extension Scheme (FPNES)[11] address this particular issue.

4.4 Comparison with manufacturer claims

"Independent analysis by the Centre for the Built Environment of Leeds Beckett University showed the Daikin Altherma hybrid heat pump had Primary Energy efficiencies of more than 100% and Seasonal Performance Factors of between 3 and 4. Results demonstrate that hybrid systems can be far more efficient than traditional fossil-fuel boilers, particularly when the heat pump provides a significant proportion of the space heating. Calculations carried out by Daikin UK indicate that by installing these systems to replace electric storage heaters or fossil fuel boilers, homeowners and

[11] https://www.ofgem.gov.uk/system/files/docs/2017/03/fpnes_eco_change_of_eligibility_criteria_letter_final_1.pdf

tenants can save an average of £272 a year, or 22%, on fuel bills, compared with running a gas boiler alone"[12].

The study by Leeds Beckett University looks at the savings compared to electric storage heaters. The study showed a 19.1% saving in cost between 1st April 2014 and 31st March 2015; this is based on an average heat pump efficiency of 340% and 63% of the heating demand being covered by the heat pump[13]. This study shows an average saving across 6 properties of 25.9% (see Figure 3.1 and 3.6). The average efficiency of the heat pumps in 5 of those properties was significantly lower at 311% efficiency. There is insufficient data to monitor how much of the heating demand was covered by the heat pump however on average the heat pump provided 63.8% of total energy demand.

[12] Daikin Altherma Hybrid Heat Pump Research Report. (n.d.). [PDF] Daikin. Available at: http://www.daikin.co.uk/binaries/Daikin%20Altherma%20Hybrid%20Heat%20Pump%20Research%20Report_tcm511-421946.pdf [Accessed 20 Jun. 2017].

[13] Fuel poverty and renewable technology Innovative approaches to balancing sustainability and cost. (n.d.). [PDF] Daikin. Available at: http://www.daikin.co.uk/binaries/Green%20Housing%20Forum%20November%202015%20whitepaper_tcm511-419207.pdf [Accessed 20 Jun. 2017].

Appendix 1: Glossary of terms

ASHP	Air Source Heat Pump
CoP	Coefficient of Performance
CSCO	Carbon Savings Community Obligation
DD	Degree Days
EPC	Energy Performance Certificate
FPNES	Fuel Poor Network Extension Scheme
GCH	Gas Central Heating
HDD	Heating Degree Days
LSOA	Lower Layer Super Output Area
NEA	National Energy Action – the National Fuel Poverty Charity
RH	Relative Humidity
RHI	Renewable Heat Incentive
SAP	Standard Assessment Procedure (for assessing home energy efficiency)
SCoP	Seasonal Coefficient of Performance

Appendix 2: 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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