CP759

Replacing gas boilers with Daikin Altherma hybrid heat pumps
Home Group

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 along with the Warm Zone Fund and Warm and Healthy Homes Fund.

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

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and around 70 products (although this number reduced slightly as some products proved not to be suitable and were withdrawn).

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

Technical monitoring and evaluation

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

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

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

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

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

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

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

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Craig Kaminsky, Home Group

NEA team:

Josh Sawyer, Project Development Coordinator
Michael Hamer, Technical Development Manager

Prepared by NEA, with contributions from Home Group
Month/Year of Publication
National Energy Action
Level 6 (Elswick)
West One
Forth Banks
Newcastle upon Tyne
NE1 3PA
www.nea.org.uk

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Executive summary

Project overview

After the successful delivery of a project that replaced electric storage heaters with hybrid heat pumps Home Group were invited to run an additional hybrid heat pump project. This project replaced gas boilers that were due for renewal with Daikin Altherma Hybrid heat pumps. The hybrid system combines an air-to-water heat pump alongside a condensing combination gas boiler to provide heating and hot water. The system can automatically select the most cost-effective and efficient heating mode based on external and internal temperatures, the space heating and hot water demand, and the current cost of gas and electricity. Home Group led on identifying suitable properties to install the hybrid systems, organising the installation and ensuring residents were able to use the new systems.

The project had the following aims:

- To establish the running costs of the Daikin Altherma hybrid heat pump and compare them against the running costs of the replaced gas boilers.
- To examine the impact of the new heating system on residents' comfort levels.
- To examine whether residents can control the system effectively.
- To establish how the performance of the system is affected when retaining the existing radiators. Primarily, how this impacts the Seasonal Coefficient of Performance (SCOP) and ratio of heat provided by the gas boiler and ASHP.
- To determine if a hybrid heating system is a cost effective replacement for housing associations when carrying out boiler renewals.

Context

In the UK heat accounts for nearly a quarter of all carbon emissions and 82% of energy use in the home relates to heating and hot water.[1] 90% of today's homes will still be in use in 2050, a major retrofit will be required to decarbonise heat and meet climate targets. New heating technologies are emerging to help make this a reality whilst also maintaining thermal comfort and affordability. Home Group had previously installed Daikin hybrid heat pumps as part of a separate Technical Innovation Fund (TIF) project. This project reviewed the hybrid system in properties with electric storage heaters that would need replacing. Testing the system in this scenario meant that any detrimental impact to running costs and comfort would be limited. This report is available on NEA's website.[2] Following on from the success of that project the CP759 project looked to test the technology in properties with poor performing end of life gas boilers. This would allow an assessment of the technology in homes where it is likely to be deployed in the future, where gas boiler assets and systems can be utilised in the transition to low carbon fuel sources.

The Daikin Altherma hybrid heat pump is a combination of an air-to-water heat pump and

[1] Energy Consumption in the UK data (2017) published by BEIS available at https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/633503/ECUK_2017.pdf

[2] http://www.nea.org.uk/hip/hybrid-daikin-altherma-heat-pumps-north-east-north-west-england/

condensing gas combination boiler. Heat pumps have been used across the UK to provide heating to off-gas areas and reduce carbon emissions. Heat pumps are most effective in milder climates and often struggle to provide adequate heat at an affordable price when the outdoor temperature drops to lower levels. The operating mode is chosen based on energy tariffs, heating demand and external temperature. A combination of both systems should enable the property to be heated to the desired level, even in cold temperatures, whilst also reducing carbon emissions.

Most domestic properties have gas heating systems with high temperature emitting radiators. Typically, they are configured to provide flow temperatures of 80°C, whilst the maximum output temperature of a heat pump is closer to 55°C. Heat pumps therefore usually require new oversized low temperature emitting radiators. Replacing the radiators adds to the upfront cost of installation and disrupts the residents. The inclusion of a gas boiler means that low temperature emitting radiators may not be a necessity as the gas boiler can boost the heat delivered. The project will investigate this and associated impacts on performance and cost.

The technology

Daikin Altherma Hybrid heat pump

The Daikin Altherma combines two established technologies, a condensing combination boiler and air-to-water heat pump, to provide heating and hot water. The system utilises smart hybrid logic to determine whether the gas boiler, ASHP or a combination of both should be used to meet the household heating demand. Essentially as the external temperature drops the heat pump becomes less efficient and the boiler begins to provide some of the heat demand. When the external temperature drops further the gas boiler will work in isolation. The hot water demand is met solely by the gas boiler.

The project

As part of this project 12 properties spread across North Newcastle and Gateshead received Daikin Altherma hybrid heat pumps to replace gas combination boilers that were coming to the end of their lifecycle. The properties involved in the project were a mix of solid brick and cavity wall construction. The 8 properties monitored were band D-rated and were terraced houses of solid brick construction. The monitored properties were within a neighbourhood that ranks in the top 20% most deprived areas in England. There was a mix of tenants within the monitored group, with the majority working full time. The size of the project reduced from an initial proposal of 24 installs to 12 installations. This did not initially impact the monitored group size of 8 although subsequently one resident did drop out due to personal circumstances.

4 of the monitored properties had new central heating systems including replacement low temperature radiators, whilst the other 4 properties retained their existing system. The 4 properties retained their high temperature radiators although some radiators were resized as they were not suitably sized for the existing gas boiler system. The hybrid system enables the existing radiators to be kept in place as the gas boiler can meet the higher flow temperatures required by the existing radiators. The ASHPs in both subsets were set at an output temperature of 55°C. This is the upper temperature flow for an ASHP, this temperature was selected as the properties were solid brick construction and subject to high heat loss. Additionally, the previous hybrid project tested the ASHP

at 45°C and 50°C flow temperatures. The ASHPs in the properties that retained the radiators would provide a flow temperature of up to 55°C at which point the system switches to gas boiler only mode to provide the flow temperature required. The two subsets will be compared throughout the report to determine the difference in SCOP and percentage of heating demand met by the ASHP. This will determine whether retaining the existing central heating system is a viable option.

The hybrid systems were installed in October 2016 and were monitored over 2 winter periods to determine if the residents had saved money and if their comfort levels had improved or worsened alongside any other issues relating to controllability and performance. The success of this project has primarily been assessed through analysis of annual heating costs and perceived comfort levels. These two key factors have been selected as this project was replacing a well-established technology (gas boilers), with a newer technology, largely untested in homes which are at risk of fuel poverty. To measure this, the energy consumption of each property was monitored before and after the installation of the hybrid heat pumps. Heat meters were connected to monitor the efficiencies of the system. Thermal loggers were used to record the temperature and humidity in the living room and bedroom. A questionnaire was used to collect qualitative data on comfort levels, residents' attitudes to the system and controllability of the system.

Summary of findings

Energy costs

- To establish the running costs of the Daikin Altherma hybrid heat pump and compare them against the running costs of the gas boilers.

Table 1.1 shows that 6 of the 8 residents monitored reduced their annual costs. 1 resident increased their annual costs by 1% however they were a very low energy user. The final resident had no pre-install consumption data as they had only just moved into the property before the system was installed. This resident had the highest costs after install and had experienced repeated reliability issues with the hybrid system.

Tech Ref	Before		After		Comparison	
	Cost per 30 days	Estimated annual cost	Cost per 30 days	Estimated annual cost	Estimated Saving (%)	Estimated Saving (£)
Existing radiators						
T-02	£65	£773	£59	£621	20%	£152
T-18	£99	£1,153	£86	£1,050	9%	£104
T-01	£83	£982	£80	£847	14%	£135
T-20*	£19	£276	£27	£280	-1%	-£4
Average	**£82**	**£969**	**£75**	**£839**		**£130**
New radiators						
T-07	£91	£1,122	£91	£954	15%	£168
T-06	£101	£1,189	£86	£851	28%	£339
T-08	£46	£552	£50	£539	2%	£13
T-10**	-	-	£122	£1,255	-	-
Average	**£79**	**£954**	**£87**	**£781**		**£173**

Table 1.1 Annual costs pre & post install

Table 1.1 shows that there was no noticeable difference in cost savings between those who received the low temperature emitters and those who did not. Savings on annual energy costs across both groups ranged from 2% to 28%. Those with the new radiators met a higher proportion of their heat demand using the ASHP than those with the existing high temperature emitting radiators. This meant the annual cost of their electricity usage increased whilst their annual cost of gas usage decreased. The hybrid system determines which element of the system is most cost effective to meet heat demand. This in part explains why both subsets made savings on their annual costs. The residents with the existing system made savings despite meeting most of their heating demand with gas. The system determined that it was more efficient to meet demand using the gas boiler, additionally the boiler they received was more efficient than their previous boiler.

Tech ref	Estimated Saving per year (£)	Estimated saving (%)	RHI over lifetime	Hybrid install costs	Install costs after RHI payments	Payback (years)	SCOP	Daikin RHI calculator
Existing radiators								
T-02	£152	20%	£754	£7,145	£6,391	35	2.06	£1,004
T-18	£104	9%	£853	£7,209	£6,356	54	-	£1,238
T-01	£135	14%	£1,107	£6,982	£5,875	36	2.16	£1,004
	£130		**£905**	**£7,112**	**£6,207**			**£1,082**
New radiators								
T-07	£168	15%	£3,471	£8,194	£4,723	21	2.68	£3,101
T-06	£339	28%	£2,988	£8,485	£5,497	9	2.86	£3,101
T-08	£13	2%	£1,782	£8,194	£6,412	481	2.29	£2,503
	£173		**£2,747**	**£8,291**	**£5,544**			**£2,902**

Table 1.2 Renewable Heat Incentive payment calculation and payback periods

The table above details the expected Renewable Heat Incentive (RHI) payments for each property. Table 1.2 shows that for the properties that retained their radiators the RHI payments over the lifetime of the project were low at an average of £905 over the 7 years that RHI can be claimed. 2 of the properties would have been unable to claim RHI as they achieved SCOPs under the 2.5 threshold required to claim RHI. At the current level the payback would be between 35 – 54 years. Retaining the radiators enables a saving of around £1200 on the installation costs but on average there is an £1800 difference over the amount of RHI that can be claimed over the 7 years. Installing hybrid systems and retaining the radiators in this case would not be a cost-effective method as RHI could not be claimed and the payback would be reliant on annual cost savings.

For the properties that had new low temperature emitting radiators installed, the average RHI payment is £2747 over the 7 years, the RHI payment alongside the annual savings made significantly lessens the payback period. T-06 made the most significant annual cost saving and had the second highest level of RHI payments. At the current output and level of savings achieved T-06 would require 9 years to make a return on the investment made.

Seasonal Coefficient of Performance

The properties with the new radiators in place had the highest Seasonal Co-efficient of Performance (SCOP) figures of all the properties, the higher SCOP figures indicate a greater efficiency of the heat pump; this meant that the heat pump offered a cost per unit that was comparable to the cost per unit provided by gas. Table 1.3 shows that the 2 properties with the lowest SCOP were those with the existing radiators still in place. The properties were largely dependent on the gas boiler, this meant that the low SCOP did not have a significant impact on heating costs.

Tech ref	ASHP output	ASHP input	COP
Existing radiators			
T-02	1485	721	2.06
T-01	2180	1008	2.16
Average			**2.11**
New radiators			
T-07	6992	2607	2.68
T-06	6156	2152	2.86
T-08	3603	1570	2.29
T-10	6130	2060	2.98
Average			**2.70**

Table 1.3 Seasonal Coefficient of Performance of ASHP

Thermal comfort and satisfaction

- To examine the impact of the new heating system on residents' comfort levels.

This project followed on from the CP747 hybrid heat pump trial which was awarded funding in the first round of applications. The start of this project was later in the year which meant there was no pre-install period during a winter where indoor temperatures could be monitored. The control group did not offer a fair comparison as they had insulated cavity walls and their old inefficient boilers were replaced with a new boiler after they signed up to the project. The initial intention was to measure the impact on comfort from the pre-install level temperatures.

Post-install 4 of the 7 residents experienced temperatures in their living room within the recommended range of 18°C – 21°C. Those that did not still noted their satisfaction with the temperatures that they now experienced with the new system. Despite not all residents achieving the recommended temperatures most were satisfied. Particularly with how warm their home got when it was cold outside and how well the house kept the heat in. 6 of the 7 residents were now able to keep warm at home however 4 residents stated that they still needed to wear warm clothing indoors to maintain comfort.

Controllability

- To examine whether residents can operate and control the system effectively.

Only 1 of the 7 residents felt that they were unable to control the hybrid system adequately, however residents did raise issues regarding more advanced control of the heating system.
All 7 residents knew how to use the thermostat element of the programmer. The simplified thermostat allowed the residents to increase or decrease the temperature daily (eventually reverting to original settings). Only 2 of the 7 felt they knew how to change the settings on the more advanced element of the programmer. The programmer is where heating patterns and temperatures are selected. These were selected upon set-up by the residents and programmed in by the installer. Residents were unable to set their own heating periods and temperatures; therefore, they were unable to change their settings if their circumstances changed without

contacting the installer or housing association. This is reflected in the satisfaction level residents noted regarding the "amount of control over the system" which fell slightly after install. Several residents expressed that they wanted to be able to have more control over the system i.e. set the heat timings. Home Group state that residents were able to specify the timings when they received training on the system. Despite the lack of control that residents felt they had over timings and other more advanced aspects there was an increase in their satisfaction regarding "how easy the system is to use".

Residents primarily used the thermostat to control their heating system, changing the temperature daily in cold temperatures. Some residents were increasing the temperatures past 21°C up to 25 °C (T-10) & 26°C (T-18) (see chart 2.5). It is also noticeable that 3 of the residents turned their thermostat up to 30°C when using their previous gas boiler system, as they felt that the gas boilers did not provide enough warmth at lower temperatures. Moving to a system that provides a more continuous heat at a lower temperature meant a significant behaviour change for these residents, which may explain why they were turning up the temperature to unsuitable levels. If the heat pump attempted to provide higher temperatures over short periods, then there would be a significant drop in efficiency. ASHPs operate most efficiently when providing a lower level of heat over a longer period. Increasing the room temperature to above 25°C would likely be met by the gas boiler thus reducing the amount provided by the ASHP. T-18 met the lowest amount of space heating using the ASHP at 12%. Some residents also stated that the heating came on at the wrong time or they could not remember their heating schedules (T-06 & T-18).

Reliability

6 of the 7 residents noted that they had some form of reliability or breakdown issue. These included system issues and parts failures. The following were some of the issues cited by residents: boiler pressure dropping, timer for heating to come on and off not working and heating not coming on at the correct time.

Additionally, there have been some parts failures across the installs which have added to the disturbance experienced by residents. The 2 key issues relate to gas valve failures and circulation pump failures. There were issues with the original gas valves fitted at the manufacturing stage which Daikin rectified by redesigning the valve. Regarding the circulation pumps, Daikin's original approved flushing methodology identified a hot and cold-water flush as an approved methodology for flushing cleansing agents and debris from completed heating systems. Both Daikin hybrid heat pump projects encountered multiple failures of the hybrid boiler integral heating system circulation pump. Water analysis indicated that residual system cleanser was corroding and seizing up the pump impeller. As a result, the approved flushing methodology has been amended to require power flushing of all completed systems. In all instances where this was an issue, subsequent power flushing of the system resolved the issue.

MCS conflict

The gas boiler market is well supported in the UK with over 26 million gas boilers installed.[3] Gas boiler suppliers have well-established customer service procedures and support. The ASHP market is smaller than the gas boiler market and the market for hybrid systems even smaller.

[3] http://hvpmag.co.uk/news/fullstory.php/aid/5003/Global_boiler_market_heats_up_as_the_UK_is_no_longer_the_largest_market.html

ASHP servicing providers are limited in supply due to skills shortages and a lower market share of the heating replacement market. Home Group ensured that they selected a utilised and experienced installer that was registered as an approved Daikin installer to protect the integrity of the install.

Home Group reported a conflict between the installer MCS warranty process and manufacturer parts warranty with there being a risk that installers attending faults cite the failure as being parts-related, therefore requiring a subsequent Daikin service engineer to attend the fault. This is not reflective of a 1 visit fix mentality and can result in the customers experiencing multiple visits before a fault is repaired. This could potentially be resolved by Daikin developing a pre-agreed/prepayment approval servicing agreement with approved installers during the MCS warranty period, towards fixing systems on a 1st-time basis. Approved installers could carry a stock of key parts to facilitate. Both CP747 and CP759 identified quality implications in respect of commissioning of hybrid systems.

Only a small number of properties across Home Group's housing stock have had hybrid systems installed. The lack of knowledge or awareness of the system has compounded some of the issues experienced by certain residents. 2 of the 7 residents felt that they did not know who to contact for issues with the system, the same 2 residents also disagreed that they were given prompt follow-up support. When raising issues residents do not always make it clear that they have a hybrid system. Whilst all hybrid installs are flagged on Home Group's systems there is evidence from residents that engineers without knowledge of, or training on, the hybrid system were being sent out. T-06 and T-07 stated in the final questionnaire that the wrong person was sent out or the person did not know how to fix the issue.

Conclusions and recommendations

Overall 6 of the 8 residents made savings on their annual energy costs whilst remaining warm in their homes. There were no significant cost differences between those who received the new radiators and those who did not. Savings on annual energy costs across both groups ranged from 2% to 28%. The levelling of these costs shows that the hybrid system is determining which fuel is most cost effective for those properties under changing circumstances. This is despite differences in the performance of the two subsets. Those that had the radiators replaced with low temperature emitters met more of the demand and had higher SCOPs than those that retained the existing system. These differences do not appear to have had an impact on residents' cost or comfort, however there is an impact on the financial viability of installing a hybrid system. The availability of RHI payments helps to offset some of the upfront cost, allowing housing associations to see a return on their investment. To be eligible for RHI payments the SCOP of the heat pump must be 2.5 or above, the properties that retained their previous radiators did not achieve a high enough SCOP and therefore would not be eligible.

Residents felt that the system was easy to use however some residents did express that they would like more control over setting their own heating periods. The system settings were locked but residents were able to change the temperature and turn the system on and off, additionally they could contact Home Group to change their heating profile.

The issues regarding parts failures and system breakdowns had a negative impact on how residents viewed aspects of the project. The success of the project and positive impact on residents' annual costs was diminished by these issues. Home Group took steps to eliminate any installation or performance issues by using an experienced installer, however the MCS conflict noted by Home Group led to delays in residents receiving the support that they required to enable their system to operate effectively.

This project has shown that transitioning to low carbon heating systems need not have an impact on residents' cost and comfort levels. Residents saved on their annual heating costs however given some of the issues associated with the hybrid this was not always realised or reflected by resident views.

Recommendations

- Replacement of all radiators with low temperature emitting radiators. This would optimise the SCOP and enable RHI payments to be claimed.
- Residents were impacted by the MCS conflict noted by Home Group. With there being a conflict between the installer MCS warranty process and manufacturer parts warranty there was a risk that installers attending faults cite the failure as being parts-related, therefore requiring a subsequent Daikin service engineer to attend the fault. This is not reflective of a 1-visit fix mentality and can result in the customers experiencing multiple visits before a fault is repaired. This could potentially be resolved by Daikin developing a pre-agreed/prepayment approval servicing agreement with approved installers during the MCS warranty period, towards fixing systems on a 1st time basis. Approved installers could carry a stock of key parts to facilitate.
- Remote cloud-based monitoring would enable accurate monitoring of the system performance and would enable adjustments to be made to residents heating systems remotely. It could also be used to identify more significant faults with a system i.e. COP falling significantly thus spotting issues before they have a chance to worsen.
- At present the residents are constrained by their lack of control over the system. Whilst they can change their settings using the room thermostat element of the programmer, residents require more control over the more advanced heating system settings.
- An ASHP operates more efficiently when providing heat continuously at a lower temperature which should be reflected in the programming of the system.
- ASHP systems perform better in well insulated properties, these properties would have benefited from external wall insulation however this is an expensive solution.

1. Project overview

1.1 Introduction

Home Group replaced gas boilers, which were due for renewal, with Daikin Altherma hybrid heat pumps in 12 properties. 6 of those properties had a full central heating system replacement and in the remaining 6 the hybrid system was connected to the existing radiators and pipework. The Daikin Altherma utilises an air-to-water heat pump alongside a condensing gas combination boiler to meet household heating and hot water demands.

The Altherma unit automatically selects the most cost effective and efficient heating mode based on the following criteria: external and internal temperatures, heat and hot water demand and the users' costs of gas and electricity. The heat pump works in conjunction with the gas boiler to meet the household heating demand whilst the household water demand is met solely by the gas boiler.

This proposal followed on from a previous Technical Innovation Fund (TIF) project with Home Group that replaced storage heaters with Daikin Altherma hybrid heat pumps after connecting the properties to the gas grid. This report is available on NEA's website.[4]

1.2 Aims

The project had the following aims:

- To establish the running costs of the Daikin Altherma hybrid heat pump and compare them against the running costs of the replaced gas boilers
- To examine the impact of the new heating system on residents' comfort levels
- To examine whether residents can control the system effectively
- To establish how the performance of the system is affected when retaining the existing radiators. Primarily, how this impacts the Seasonal Coefficient of Performance (SCOP) and ratio of heat provided by the gas boiler and ASHP
- To determine if a hybrid heating system is a cost effective replacement for housing associations when carrying out boiler renewals.

1.3 Context

In the UK heat accounts for nearly a quarter of all carbon emissions and 82% of energy use in the home relates to heating and hot water.[5] 90% of today's homes will still be in use in 2050, a major retrofit will be required to decarbonise heat and meet climate targets. New heating technologies are emerging to help make this a reality whilst also maintaining thermal comfort and affordability. Home Group had previously installed Daikin hybrid heat pumps as part of a separate Technical Innovation Fund (TIF) project. This project reviewed the hybrid system in properties with electric storage heaters that would need replacing, testing the system in this scenario meant that any detrimental impact to running costs and comfort would be limited.

[4] http://www.nea.org.uk/hip/hybrid-daikin-altherma-heat-pumps-north-east-north-west-england/

[5] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/633503/ECUK_2017.pdf

Every year housing associations replace aged or faulty boilers that are no longer as efficient at providing heating and hot water. These boilers are typically replaced with more efficient gas boilers that will likely be replaced after 10 years of use depending on maintenance and amount of usage. Installing a new gas boiler is usually the easiest and lowest cost option for housing associations as the technology is well known and there are procedures in place to service and maintain them. However, at the same time, housing associations are looking to future-proof their properties and reduce carbon emissions whilst maintaining resident comfort levels and keeping resident heating costs low.

Heat pumps are likely to play a key role in decarbonising the UK's domestic heating and helping to meet long-term climate change targets. Heat pumps are classed as a renewable technology as they extract heat from the air and pass it through a heat exchanger to be utilised at a higher temperature. This process still requires some input from non-renewable sources. A criticism of heat pumps is that they are not as efficient over particularly cold periods; a hybrid heat pump system which includes a gas boiler alongside an ASHP should allay some of these concerns. The boiler would operate when the external temperature fell below a certain threshold for the ASHP to operate efficiently. Tenants, particularly vulnerable tenants, often find ASHPs difficult to operate,[6] the inclusion of a gas boiler may provide a level of familiarity to hybrid system users.

1.4 Property characteristics

The properties and residents monitored were in a Lower Layer Super Output Area (LSOA) that ranks as one of the 20% most deprived neighbourhoods in England. All the properties that were selected for installation of the new heating system had older gas boilers that were due for replacement. The monitored properties were all terraced properties built at the turn of the 20th century and all are solid brick-walled with no internal or external wall insulation. Table 1.4 shows that all properties prior to the installation of the new heating systems were rated Band D.

Property characteristics									
Tech ref	System	Location	Walls	Floor area	Bedrooms	EPC pre	Band	EPC post	Band
T-02	Existing	Mid	Solid brick	65m²	3	57	D	47	E
T-18	Existing	End	Solid brick	64m²	-	55	D	-	-
T-20	Existing	Mid	Solid brick	60m²	-	64	D	47	E
T-01	Existing	Mid	Solid brick	66m²	2	64	D	50	E
T-07	New	End	Solid brick	89m²	2	58	D	31	F
T-06	New	End	Solid brick	66m²	2	61	D	-	-
T-08	New	Mid	Solid brick	69m²	2	62	D	50	E
T-10	New	Mid	Solid brick	71m²	3	62	D	-	-

Table 1.4 Property characteristics and pre-install SAP rating

After the measures were installed a follow-up Energy Performance Certificate (EPC) assessment was carried out.[7] Table 1.4 shows that for those properties assessed the ratings fell from a band D to a band E and in one case a band F. The issue here lies with the assessment procedure rather than the performance of the technology. The Standard Assessment Procedure (SAP) software is used to produce an EPC and is not capable of recording a hybrid system, and thus must be

[6] http://www.nea.org.uk/wp-content/uploads/2017/02/NG-AWS-Rural-Comparison-REPORT-v12.pdf

[7] https://www.gov.uk/buy-sell-your-home/energy-performance-certificates

entered as 2 separate units, a gas boiler and ASHP.[8] The methodology has the potential to cause problems for future installations. By 2030 the government wants all fuel poor homes to be upgraded to a band C.[9] Housing associations and private landlords must raise the EPC ratings of their properties to meet this government target. They may look to employ innovative technologies to do so. If the EPC rating is affected in an adverse manner by the hybrid heat pump, then the uptake of this innovative option will be de-incentivised.

1.5 Project timeline

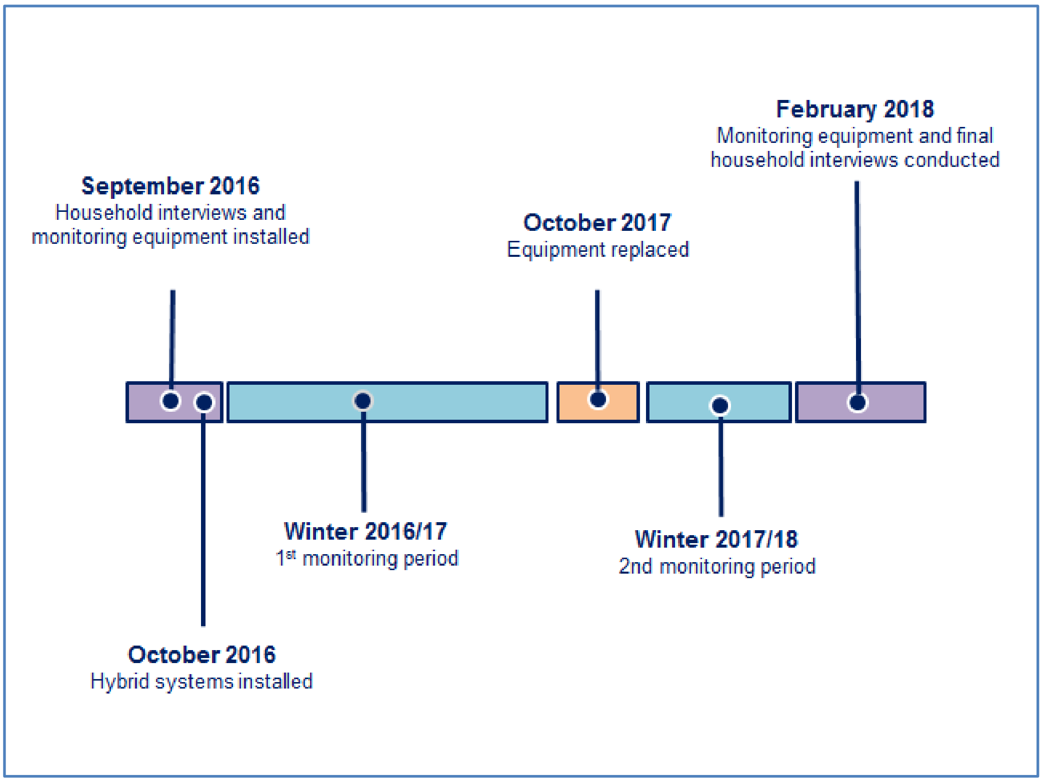

Figure 1.5 Project timeline

1.6 Attracting beneficiaries and establishing a monitored group

Home Group used their database of properties to identify properties that would require their existing gas boiler to be replaced in the near future. Once the properties were identified surveys took place to determine if a hybrid install was suitable for the property and the installation would satisfy any planning/building regulations.

Problems were found at certain properties and particular types of properties.

- There was no consistency in the rear yard layouts across one of the proposed streets. This meant that the condenser units could not be placed in a manner that would satisfy the

[8] http://www.elmhurstenergy.co.uk/uploads/TB24_All_RdSAP_Conventions_Final_Aug_2016.pdf
[9] https://www.gov.uk/government/publications/clean-growth-strategy/clean-growth-strategy-executive-summary

G.2.e permitted development planning requirements.[10]

- The noise limit as set out in the MCS permitted development standard would likely be breached due to the closeness of the habitable rooms in the neighboring properties. Installs would not have been classed as permitted development and would have required planning permission which would have delayed the project.
- The boilers were positioned within cupboards that created difficulties for flue and refrigerant pipework installations.
- The sub-mains cables coming out of the substation were at maximum capacity and would have required reinforcement. They projected that it would be more than 12 months for these works to be facilitated. This prevented more systems being installed.

This reduced the number of proposed installs down to 12 units; 8 of these properties were then selected for monitoring. 4 of those monitored retained the existing radiators and the other 4 had the whole central heating system replaced with low temperature emitting radiators.

No thermal pre-data is available for any of the properties as there was no pre-install winter monitoring period. Most of the equipment had to be fitted when the Altherma systems were installed as it was only applicable to the hybrid system. Due to the later start initial face-to-face questionnaires were carried out with residents around a month after the installations took place. The monitoring equipment was replaced prior to the start of the 2nd winter monitoring period. This was primarily due to battery and memory running out but also to check that the equipment was recording, and the systems were fully operational. A final face-to-face questionnaire was carried out with all residents in February 2018 and all monitoring equipment was collected.

Historical meter readings were required to compare the cost of using the system before and after the hybrid heat pump install. This also enabled a comparison between the properties that retained their existing radiators and those that received the new low temperature radiators.

To protect the privacy of residents the data in the study has been anonymised; each property has been allocated a unique identification number e.g. T-01.

[10] http://www.legislation.gov.uk/uksi/2015/596/pdfs/uksi_20150596_en.pdf

1.7 Factors affecting the planned evaluation methodology

Issue	Description and mitigation
Size of monitoring group	12 properties received the hybrid heat pump system of which 8 received monitoring. Due to a small sample size of 8 properties all 8 received advanced monitoring. This included heat metering to measure system outputs and dedicated watt hour meters and gas meters to measure system inputs.
Identification of the monitored group and control group	Residents were invited by letter to be part of a control group for the second winter of monitoring. Properties of a comparable size were selected for the control group, but the only responses came from residents living in more modern housing. The properties were selected due to them having old boilers that needed replacing. Unfortunately, during the monitoring period these boilers were replaced.
Start of monitoring	Monitoring equipment was installed at the same time as the installations took place as the project was an additional project to the TIF programme. This meant that no pre-thermal and humidity data was available. However, the comfort levels could still be compared against the 2 different groups (full heating system group and existing radiators group). This was partially mitigated by the inclusion of 2 control properties, unfortunately these properties were of cavity wall construction as opposed to the solid brick found at the properties that received the hybrid system.
Monitored group	One resident dropped out of the social aspects of the study early on due to personal circumstances. This left only 3 properties with existing radiators to be monitored.
System performance	• There were gas valve failures at 2 properties. This was also an issue on the CP747 hybrid TIF project, but Daikin replaced the gas valves on each property. The issues with the valves was rectified and redesigned valves are fitted on new manufactured units. • There were circulation pump failures at 2 properties and 1 of these properties experienced 2 circulation pump failures. This also occurred on the other hybrid project. The issue concerned the Daikin flushing methodology utilised by the installer. Daikin's approved flushing methodology recommends a hot and cold flush however this was found to be unsuitable. The pump in the hybrid system requires a fine tolerance in relation to water quality and a power flush of the system is now required. • 3 residents raised concerns about the pressure dropping on the boilers. 2 of the residents that experienced these issues

	retained the existing radiators. • 1 resident had recurrent issues with the system and was unable to heat the property with the hybrid system. The resident was provided with electric fans including over a 3-week period.
Meter readings	Extensive meter reading data was available for some residents as they had either prepayment meters or smart meters installed. Some residents had hard-to-reach household gas and electric meters and therefore regular readings were unavailable. Meter readings from the other meters (heat meters and watt hour meters) were taken intermittently. Pulse loggers attached to watt hour meters often came loose and did not record accurately.
Monitoring equipment	Some of the heat meter displays were unreadable once installed on the pipework. This meant no monthly data could be read from them. The event logger attached to the heat meter monitoring the ASHP output failed to record events which meant only monthly data was available on how much heat the ASHP produced. In addition, the heat meter monitoring total heat output did not provide accurate figures. Several of the residents moved the thermal loggers in their properties over the course of the 1st winter of monitoring; this was mitigated by ensuring they were in place over the 2nd winter monitoring period.

2. Social evaluation and impacts

2.1 Qualitative feedback from initial questionnaire

6 of the 8 residents completed questionnaires at the start of the project and 7 of the 8 completed questionnaires at the end of the project. 1 resident (T-20) did not wish to take part in the social evaluation aspect of the project.

There was a mixture of single occupancy and multiple occupancy homes. Within the project the ages ranged from under 5 years old up to 70 years old. The majority of residents were working full time whilst 2 of the residents were retired. The variation in ages and employment seen in charts (a) & (b) is reflected in the varied heating demands and patterns of each household. Figure (c) shows that 3 of the residents had a health condition that was worsened by living in cold conditions. The conditions cited included the following: arthiritis, angina, asthma and emphysema.

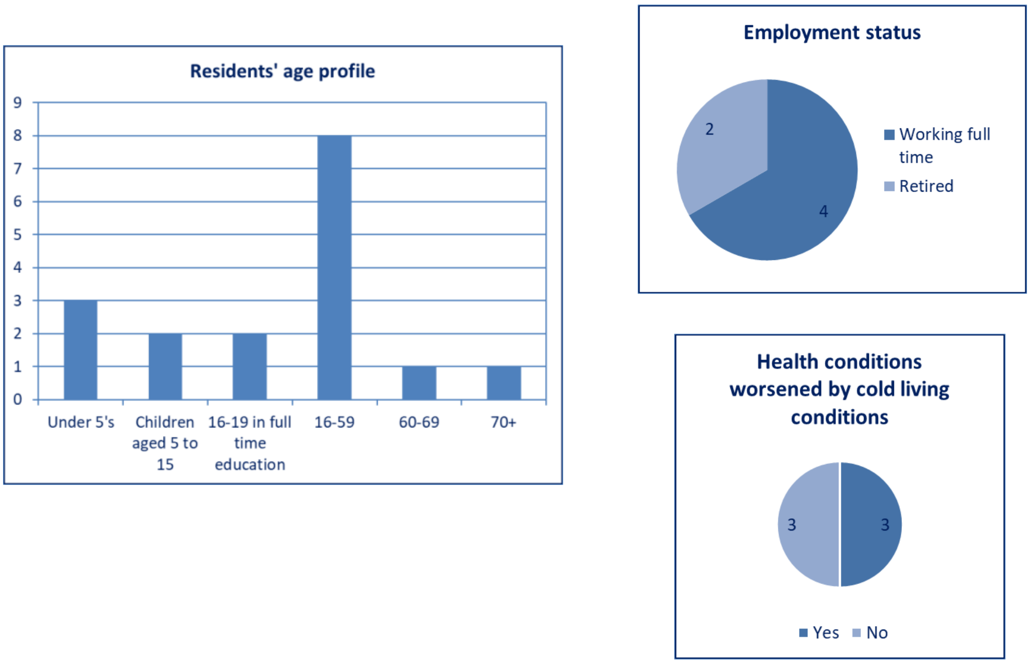

Chart 2.1 (a) Household age (b) Occupation (c) Health conditions

2.2 Heating patterns and temperatures

All the residents had gas combination boilers that were due for renewal. Prior to the installation of the new system 3 of the residents used supplementary heating alongside their gas boiler to keep warm in the home (see chart 2.2). All 3 residents stated that they used supplementary heating as the property was cold in the evenings, this is despite 2 of those residents having their thermostat set at 30°C (T-10 & T-02). 1 resident continued to use supplementary heating after the installation of the new system albeit less frequently than before. An additional resident started to use supplementary heating (T-18). There were also instances where residents had to use supplementary heating on a temporary basis if the heating system had stopped working.

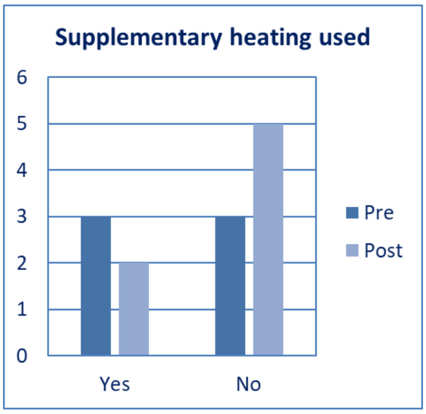

Chart 2.2 Number of residents using supplementary heating pre and post install

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

Chart 2.3 shows the results summed up across all respondents. There are 2 peaks in demand for heating both before and after the new heating system was installed. The first is in the morning between 6am – 10am and the second more prevalent period is in the evening between 6pm – 10pm. Chart 2.4 shows that residents primarily used their heating in the morning and in the evening, chart 2.3 provides evidence of the variation around those 2 primary periods, some choosing to be warmer earlier in the morning or later in the evening. Not all residents would fit into the heating patterns selected, for instance a retired resident may spend more time in the home during the day and therefore want to be warm throughout the day.

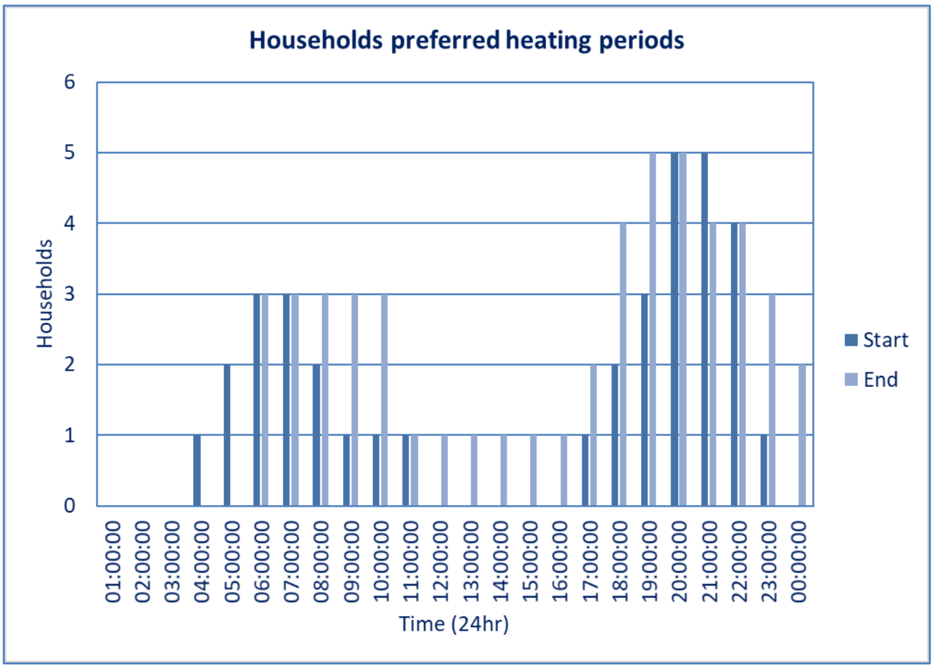

Chart 2.3 Times when residents stated it was important for them to have a warm home

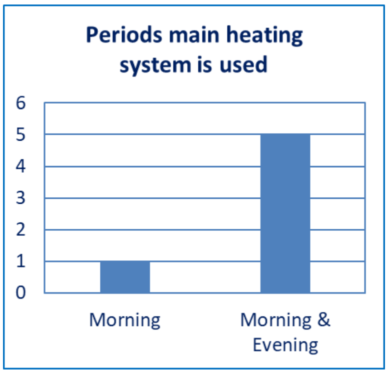

Chart 2.4 When residents stated they used the main heating system

Residents could set their temperature using a thermostat with their original gas boiler and with the hybrid system. A healthy living room temperature is usually within the range of 18°C – 21°C, chart 2.5 reveals that 3 residents set their thermostats at 30°C. Even at this temperature the residents reported that the temperature did not reach their desired comfort level.

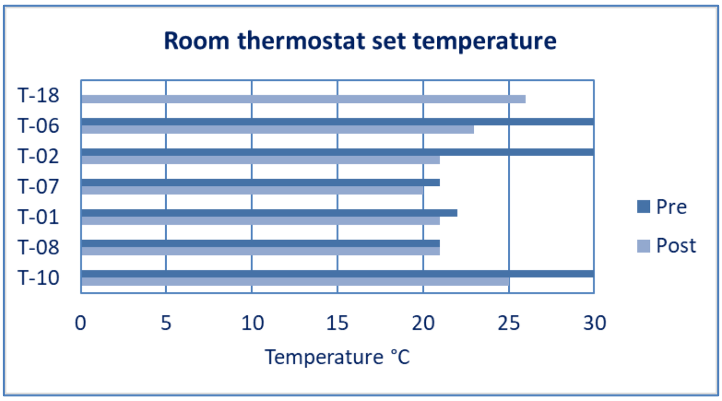

Chart 2.5 Thermostat set points for each property

2.3 Affordability of energy bills

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 heating system.

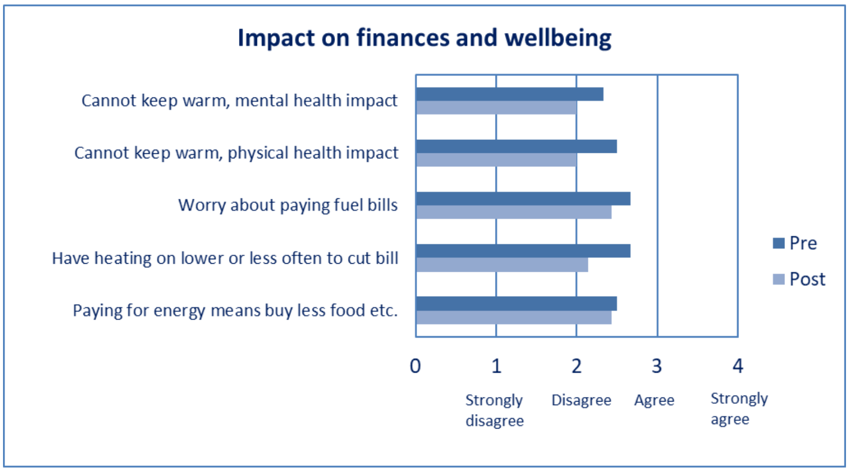

Chart 2.6 Impact of heating on residents' finances and wellbeing

Chart 2.6 shows that on average there has been an improvement in the situation regarding each statement presented to residents. All the residents disagreed with the statements 'I cannot keep warm at home and this affects my physical health' and 'I cannot keep warm at home and this affects my mental health'. Some residents remain concerned about paying their fuel bills and that paying for energy means they buy less food or other essentials.

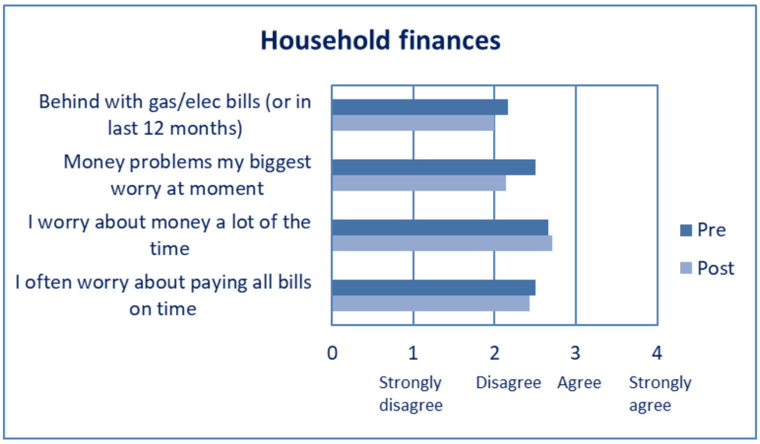

Chart 2.7 Residents' financial concerns

It is clear in chart 2.7 that for many of the residents, money was something that they worried about a lot of the time both before and after the measures were installed. 3 residents noted that after the measures were installed they felt their bills were cheaper as evidenced by chart 2.8, this was offset as 2 residents felt that their bills were now more expensive. According to the cost analysis all but 1 resident (T-20 low user with a negligible 1% increase) saved money on their total energy costs. 1 of the residents did not have any pre install consumption data but was calculated to be spending £1255 per annum (T-10).

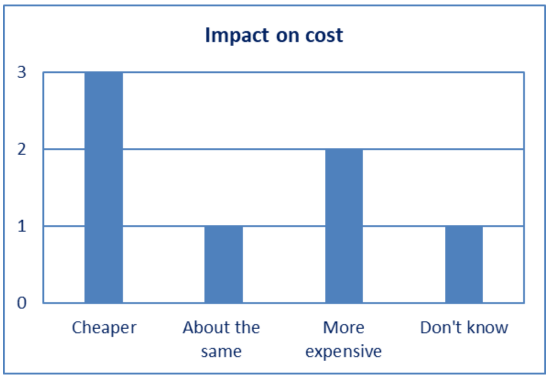

Chart 2.8 Impact of heating on residents' energy costs

Residents were asked what impact the system had on their energy costs, chart 2.8 shows that 3 residents found their energy costs cheaper post install. Charts 2.8 & 2.9 show that for some of the residents there was a link between how much they pay for their energy costs and how much they worry about money issues. However, for some residents the amount they pay for their energy is just one of a multitude of concerns.

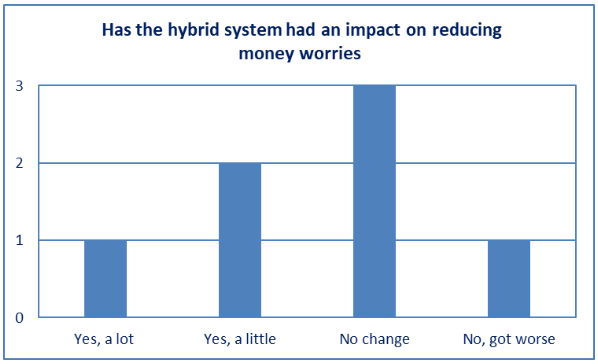

Chart 2.9 Impact of heating on residents' finances and wellbeing

2.4 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 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 heating system.

Chart 2.10 shows that there was an improvement in all aspects except in the amount of control residents had over the system. The major improvements were related to 'how well the house keeps the heat in' and 'how warm it [the house] gets when cold outside'. The average response was closer to satisfied after the new system was installed. The level of insulation remained the same throughout the duration of the project and no draught proofing was carried out. Residents may be noting that the new system is more responsive and is still able to provide warmth later in the day even when it was cold outside.

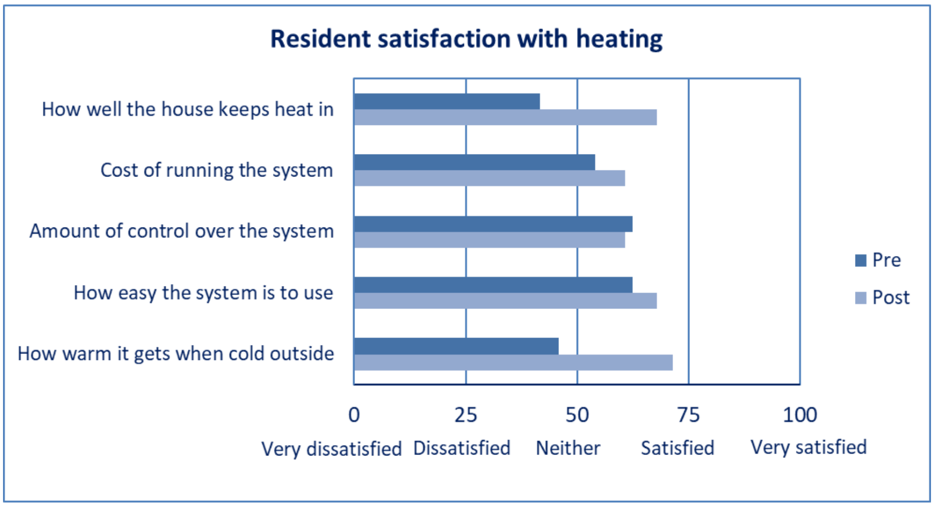

Chart 2.10 Satisfaction of residents with their heating system

There was a significant increase in the number of residents who were able to keep warm at home as noted in chart 2.11. Only 1 resident stated that they were unable to keep warm at home after the hybrid system was installed. The issues that some residents had with the system are reflected in chart 2.12 which shows that 4 residents were still wearing additional warm clothing to keep warm in their homes.

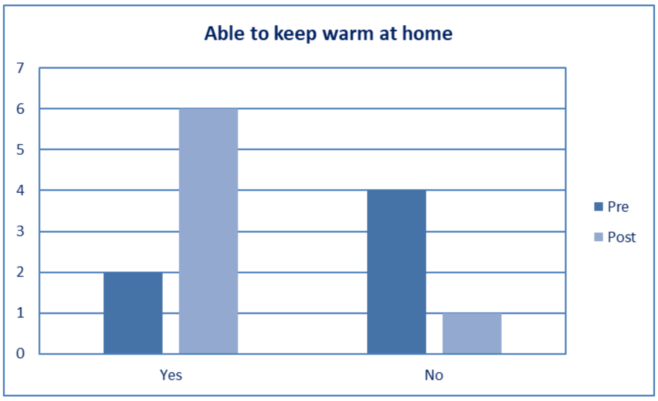

Chart 2.11 Number of residents able to keep warm at home

Chart 2.12 Number of residents who wear extra warm clothing at home

Residents were offered the opportunity to provide general feedback on the heating system and project generally. Opinions on the system and its performance were mixed. For some residents the system fitted their needs and heating requirements. Some residents were not satisfied due to their circumstances changing but the heating patterns remaining the same, the lack of control over their settings or recurrent system and parts failures. Of the 3 residents that had the most pressing concerns 2 had the replacement central heating system installed alongside the hybrid system. The remaining resident retained the existing radiators.

2.5 Ease of use and controllability

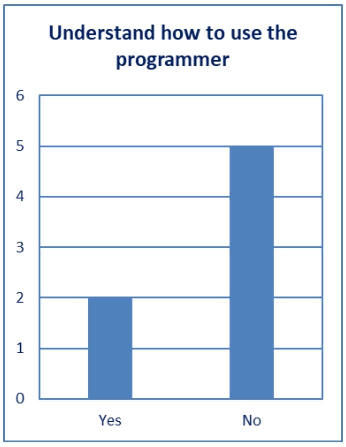

Chart 2.13 Number of residents that stated they knew how to use the programmer

Residents were provided with training on how to use the system at different points over the duration of the project. The contractors had demonstrable experience in the field and were approved Daikin installers. They provided training after the initial installation of the hybrid system. Residents were offered additional training from Home Group and the installers. 3 of the residents stated that they were not sufficiently shown how to use the system although 1 of these residents was on holiday when the initial training was provided.

6 of the 7 residents felt that they were able to control the hybrid system adequately, however residents did raise issues regarding more advanced control of the heating system.
All 7 residents knew how to use the thermostat element of the programmer. The simplified thermostat allows the occupier to increase or decrease the temperature daily (eventually reverting to original settings). Only 2 of the 7 felt they knew how to change the settings on the more advanced element of the programmer. The programmer is where heating patterns and temperatures are selected. These were selected upon set-up by the residents and programmed in by the installer. Residents were unable to set their own heating periods and temperatures; therefore, they were unable to change their settings if their circumstances changed without contacting the installer or housing association. This is reflected in the satisfaction level residents noted regarding the "amount of control over the system" which fell slightly after install. Several residents expressed that they wanted to be able to have more control over the system i.e. set the time when their heating came on and went off. Home Group state that residents were able to specify the timings when they received training on the system. Despite the lack of control that

residents felt they had over timings and other more advanced aspects there was an increase in their satisfaction regarding “how easy the system is to use”.

The decision-making process (software) of the hybrid unit is influenced in part by the residents’ unit costs for gas and electricity. The smart control will determine which is more cost effective to meet space heating demands. This could be detrimental if the resident is moved from a fixed-term tariff to a standard tariff and the prices increase.

Residents primarily used the thermostat to control their heating system, changing the temperature daily in cold temperatures. Some residents were increasing the temperatures past 21°C up to 25 °C (T-10) & 26°C (T-18) (see chart 2.5). It is also noticeable that 3 of the residents turned their thermostat up to 30°C when they had their gas boilers installed, as they felt that the gas boilers did not work at lower temperatures. Moving to a system that provides a more continuous heat at a lower temperature meant a significant behaviour change for these residents, which may explain why they were turning up the temperature to unsuitable levels. If the heat pump attempted to provide higher temperatures over short periods, then there would be a significant drop in efficiency. ASHPs operate most efficiently when providing a lower level of heat over a longer period. Increasing the room temperature to above 25°C would likely be met by the gas boiler thus reducing the amount provided by the ASHP. T-18 met the lowest amount of space heating using the ASHP at 12%. Some residents also stated that the heating came on at the wrong time or they could not remember their heating schedules (T-06 & T-18).

Reliability and system breakdown

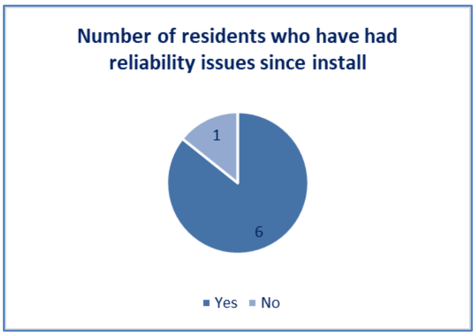

Chart 2.14 Number of residents who have had reliability issues

Chart 2.14 shows that 6 of the 7 residents noted that they had some form of reliability or breakdown issue. These included system issues and parts failures. The following were some of the issues cited by residents: boiler pressure dropping, timer for heating to come on and off not working and heating not coming on at the correct time.

Additionally, there have been some parts failures across the installs which have added to the disturbance experienced by residents. The 2 key issues relate to gas valve failures and circulation pump failures. There were issues with the original gas valves fitted at the manufacturing stage which Daikin rectified by redesigning the valve. Regarding the circulation pumps, Daikin’s original approved flushing methodology identified a hot and cold-water flush as an approved methodology for flushing cleansing agents and debris from completed heating systems. Both Daikin hybrid heat pump projects encountered multiple failures of the hybrid boiler integral heating system circulation pump. Water analysis indicated that residual system cleanser was corroding and seizing up the pump impeller. As a result, the approved flushing methodology has been amended to require power flushing of all completed systems. In all instances where this was an issue, subsequent power flushing of the system resolved the issue.

MCS conflict

The gas boiler market is well established in the UK with over 26 million gas boilers installed. Gas boiler suppliers and installers have well-established customer service procedures and support. ASHP servicing providers are limited in supply due to skills shortages and a lower market share of the heating replacement market.

Home Group reported a conflict between the installer MCS warranty process and manufacturer parts warranty with there being a risk that installers attending faults cite the failure as being parts related, therefore requiring a subsequent Daikin service engineer to attend the fault. This is not reflective of a 1 visit fix mentality and can result in the customers experiencing multiple visits before a fault is repaired. This could potentially be resolved by Daikin developing a pre-agreed/pre-payment approval servicing agreement with approved installers during the MCS warranty period, towards fixing systems on a 1st-time basis. Approved installers could carry a stock of key parts to facilitate. Both CP747 and CP759 identified quality implications with respect commissioning of hybrid systems.

Perhaps the skills shortage and commissioning impacts could be addressed by Daikin offering and providing a commissioning service to confirm the system has been installed to manufacturers required. This could provide a commercial opportunity to Daikin for further revenue and could be incentivised by reducing the cost of an extended parts warranty or by offering a free extension to the parts warranty, after all if the quality of install is right, Daikin should have confidence in the performance of the parts and this should reduce reactive warranty call-out costs. The parts failures and system breakdowns, alongside the controllability issues mentioned had a noteworthy impact on some of the residents' views of the hybrid system. This is despite 6 of the 7 residents saving on their annual costs.

In some circumstances residents were left without a main heating system and were provided with fan heaters whilst the issue was corrected. 1 resident has experienced significant disruption since the installation of the hybrid system (T-10). The resident remarked in the final questionnaire that the system had stopped working over a 3-week period during Christmas and they were reliant on fan heaters. The use of fan heaters may in part explain their excessive annual electricity cost of £820. The property had the most efficient heat pump with an SCOP of 2.98, indicating that when the system worked it was performing well. This resident cited in the final questionnaire that their "money problems had worsened" due to using the electric fan heaters when the system was not working. For 3 of the residents the boiler pressure has regularly dropped, 1 resident (T-18) stated that they have had the installer out 12-14 times to correct the issue.

Only a small number of properties across Home Group's housing stock have had hybrid systems installed. The lack of knowledge or awareness of the system has compounded some of the issues experienced by certain residents. 2 of the 7 residents felt that they did not know who to contact for issues with the system, the same 2 residents also disagreed that they were given prompt follow-up support. When raising issues residents do not always make it clear that they have a hybrid system. Whilst all hybrid installs are flagged on Home Group's systems there is evidence from residents that engineers without knowledge of, or training on, the hybrid system being sent out. T-06 and T-07 stated in the final questionnaire that the wrong person was sent out or the person did not know how to fix the issue.

2.6 Perceived comfort and benefits

Chart 2.15 shows the benefits selected by 4 of the residents. 3 of the 7 residents stated that they had noticed no benefits since the heating system was installed (T-10, T-06 & T-18). The 4 that noted benefits selected that their homes were warmer and more comfortable. 3 of those residents also noted a reduction in their energy bills. Increased control was also referred to in chart 2.15, this is despite residents being unable to change their heating schedule. 2 residents (T-01 & T-08) stated that they now felt they had more control over the system than previously. T-08 stated that they left the system to operate on its original settings and did not use the room thermostat to change the temperature. T-01 had the existing radiators in place.

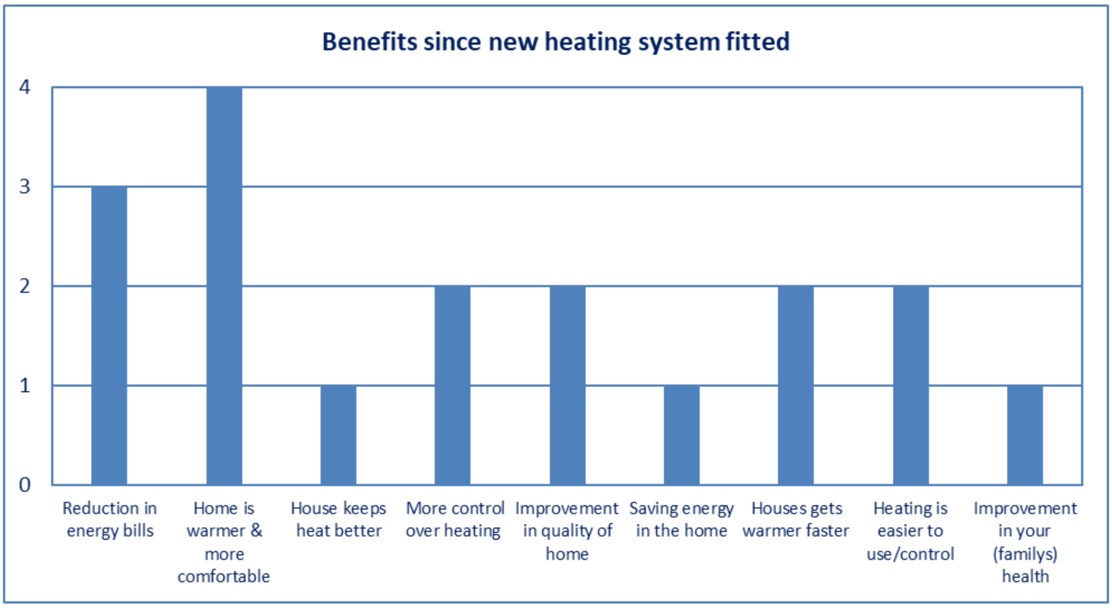

Chart 2.15 Benefits perceived by residents after installation of the hybrid system

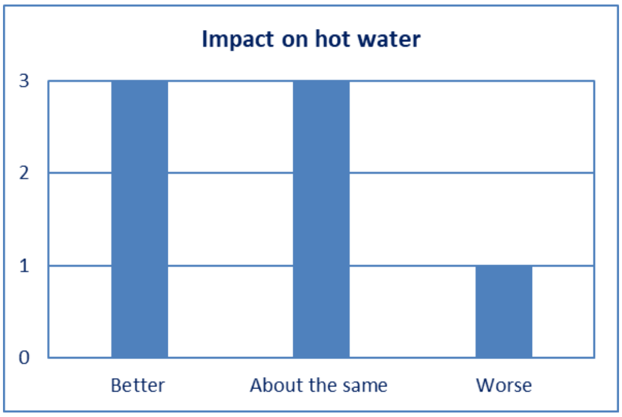

Chart 2.16 Impact the new heating system had on the hot water

Chart 2.16 shows that 3 residents stated their hot water provision was better after the hybrid system was installed. With one resident indicating that they found it worse than previously. Hot water was provided solely by the gas boiler.

3. Technical evaluation and results

3.1 Overview of technology

The Daikin Altherma hybrid system combines a high efficiency combination 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 system has 1 of 4 modes of operation and switches between these modes to ensure the most efficient and cost-effective 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.

Additionally, the domestic hot water is provided solely by the gas boiler.

Figure 3.1 Internal unit

Figure 3.2 External condensing unit

When installing a heat pump system, it is often necessary to replace the existing radiators with ‘oversized’ radiators (see figure 3.3). A heat pump operates most efficiently when providing water to the system at 40°C – 55°C, therefore the radiators need to have a large enough surface area to radiate the heat out at this lower temperature. 4 of the monitored properties retained their existing radiators as this project sought to determine the impact that retaining the existing radiators had on the efficiency of the hybrid system.

Figure 3.3 Oversized radiators

Daikin have since started to install heat pump systems with the R32 refrigerant that is more efficient and environmentally friendly than existing refrigerants. Whilst R32 refrigerants impact on global warming less than other refrigerants currently used, it also improves the COP of heat pumps.

The indoor unit is about the same dimension as a condensing combination boiler. The addition of the external fan unit complicates the installation as this must satisfy various planning standards such as the MCS Planning Standard and the Town and Country Planning Act. One of the key issues for this project was the potential noise levels emitted by the ASHP, if they don’t pass the noise assessment then planning consent would be required which delays the project.

3.2 Technical monitoring

The same monitoring setup was installed in each monitored property. 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.[11] 2 thermal loggers were installed in each of the monitored homes, 1 placed in the living room and 1 in the main bedroom.

Watt Hour Meters

Watt hour meters were fitted to determine the electricity demand of the ASHP unit. These were fitted on all 8 monitored properties.

Heat meters

VuHeat DN-20[12] ultrasonic heat meters were fitted to determine the heat output to hot water and heat output to the central heating system. The VuHeat heat meters were not suitable for the monitoring of the ASHP output. The Sontex Superstatic 440 with the Sontex Supercal 531 integrator was selected to monitor the ASHP output. These meters are compliant with OFGEM requirements for Renewable Heat Incentive (RHI) payments.[13]

Gas meters

A dedicated gas meter was installed to measure the gas usage of just the boiler, this was necessary as the property also used gas for cooking.

Event loggers

Lascar USB5 event loggers were attached to the heat meters and gas meters to record each time an event occurred i.e. unit of gas or electricity consumed.[14] Omega 101 loggers were attached to the dedicated ASHP watt hour meters.

[11] https://www.lascarelectronics.com/easylog-data-logger-el-usb-2/

[12] https://www.bellflowsystems.co.uk/vuheat-dn20-compact-ultrasonic-heat-meter-qp-2-5-3-4-reducing-connections-included-.html

[13] https://www.ofgem.gov.uk/environmental-programmes/domestic-rhi/about-domestic-rhi

[14] https://www.lascarelectronics.com/easylog-data-logger-el-usb-5/

Figure 3.4 heat metering and gas metering installed on the hybrid system pipework

Residents were also asked to record their meter readings every 2 weeks. The resident's energy supplier was contacted to obtain meter readings both pre and post installation. The frequency of this data depended on the type of metering installed within the property, it ranged from half-hourly readings for those that had smart metering to biannual readings for those with credit meters.

3.3 Cost

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 and historical meter reads were obtained from residents' bills. Where these were not available their energy supplier was contacted to provide any actual meter readings. This enabled the energy consumption of the properties to be compared before and after the installation of the hybrid systems. Where possible the period selected for analysis before the installation was usually over the course of two winter periods. The period selected for analysis after the installation was also preferably over two winter periods.

In order to analyse energy use for space heating, the impact of the external temperature must be considered. 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.[15] When the average outside temperature drops to 14.5°C, this is classed as 1 degree-day. Degree days are added together for the required period to give the total number of degree days for the period. Different periods can then be compared for their energy consumption and the results used to predict energy consumption on a normalised basis considering the outside temperature for those different periods.

The degree day data for the area was obtained from the weather station at Newcastle Airport, which is located around 5 miles away from the project area. The degree day data is reliable and available over an extended period. 20-year average degree day values are only available on a regional basis, so the Borders region was selected.

Tables 3.5 & 3.6 note the gas and electricity consumption in kWh for the 'before' and 'after' periods, this was from a combination of meter readings and resident bills. For the 'before' period the consumption over the period was converted into a cost. Prior to the installation of the hybrid system the properties were heated solely by gas unless residents used supplementary heating such as electric fan heaters. A standardised price of 5p per kWh of gas was used for each property. The estimated annual gas cost was calculated by dividing the total cost over the period by the number of degree days for that same period and then multiplying that figure by the 20 year average annual number of degree days in the region. The annual electricity usage was not weather dependent so was not calculated using degree days.

With the hybrid system installed the properties were heated by electricity (ASHP) and gas (Boiler). The annual cost of gas over the 'after' period was calculated in the same manner as previously explained. Post install the amount of electricity consumed was related to the external temperature therefore the annual electricity consumption was calculated in the same manner, corrected for degree day differences, as for gas except a standardised figure of 16p per kWh was used to represent the electricity costs. The gas and electricity costs were then combined for pre and post install periods (see table 3.7) to give an overall view of total energy costs.

[15] http://www.degreedays.net/

Electric	"Before" period						"After" period							Comparison
Tech Ref	Period	Days	Total Usage (kWh)	Cost over 30 days	Total Cost	Estimated annual cost	Period	Days	Total Period (kWh)	Cost per 30 days	Degree days	kWh per Degree Days	Estimated annual cost	Estimated Saving
Existing radiators														
T-02	4/2/15-14/9/16	686	4,234	£30	£677	£360	17/7/16-27/2/18	225	1,255	£27	1,621	0.8	£283	21%
T-18	12/2/15-20/5/16	463	5,491	£57	£879	£692	17/10/16-26/10/17	374	4,101	£53	2,333	1.8	£643	7%
T-01	1/10/15-1/9/16	336	3,267	£47	£523	£568	1/10/16-1/3/16	516	5,477	£51	3,814	1.4	£525	8%
T-20*	13/5/16-19/8/16	98	318	£16	£51	£190	26/9/16-22/2/18	514	1,051	£10	3,726	0.3	£103	46%
Average				**£44**		**£540**				**£43**		**1.3**	**£484**	
New radiators														
T-07	4/2/15-14/9/16	588	3,585	£29	£574	£356	30/9/16-21/2/18	509	6,346	£60	3,703	1.7	£626	-76%
T-06	14/4/15-20/5/16	402	3,429	£41	£549	£498	17/10/16-27/4/18	557	5,203	£45	4,278	1.2	£445	11%
T-08	1/9/14-19/8/16	718	2,923	£20	£468	£238	14/9/16-21/2/18	525	3,364	£31	3,741	0.9	£329	-38%
T-10	-	-	-	-	-	-	2/11/16-21/2/18	476	7,873	£79	3,511	2.2	£820	-
Average				**£30**		**£364**				**£54**		**1.5**	**£555**	

Table 3.5 Electricity costs before and after hybrid heat pump installed

Gas	"Before" period								"After" period							Comparison
Tech Ref	Period	Days	Total Usage (kWh)	Cost over 30 days	Total Cost	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
Existing radiators																
T-02	14/9/14-16/9/16	733	17,123	£35	£856	4,748	3.6	£412	17/7/17-27/2/18	225	4,791	£32	1,621	3.0	£338	18%
T-18	12/2/15-20/5/16	463	13,060	£42	£653	3,238	4.0	£461	17/10/16-26/10/17	374	8,314	£33	2,333	3.6	£407	12%
T-01	1/10/15-1/9/16	336	8,126	£36	£406	2,242	3.6	£414	1/4/17-1/4/18	365	6,974	£29	2,476	2.8	£322	22%
T-20*	13/5/16-19/8/16	98	202	£3	£10	267	0.8	£86	22/9/16-22/2/18	514	5,767	£17	3,726	1.5	£177	-105%
Average				**£38**			**3.8**	**£429**				**£31**		**3.1**	**£356**	
New radiators																
T-07	4/2/15-14/9/16	588	24,113	£62	£1,206	3,598	6.7	£766	30/9/16-21/2/18	509	10,603	£31	3,703	2.9	£327	57%
T-06	18/9/15-20/5/16	402	16,046	£60	£802	2,651	6.1	£691	17/10/16-27/4/18	557	15,204	£41	4,278	3.6	£406	41%
T-08	30/1/15-19/8/16	567	10,031	£27	£502	3,644	2.8	£315	14/9/16-21/2/18	525	6,889	£20	3,741	1.8	£210	33%
T-10	-	-	-	-	-	-	-	-	2/11/16-21/2/18	476	13,375	£42	3,511	3.8	£435	
Average				**£49**			**5.2**	**£590**				**£34**		**3.0**	**£345**	

Table 3.6 Gas costs before and after hybrid heat pump installed

Tech Ref	Before		After		Comparison	
	Cost per 30 days	Estimated annual cost	Cost per 30 days	Estimated annual cost	Estimated Saving (%)	Estimated Saving (£)
Existing radiators						
T-02	£65	£773	£59	£621	20%	£152
T-18	£99	£1,153	£86	£1,050	9%	£104
T-01	£83	£982	£80	£847	14%	£135
T-20*	£19	£276	£27	£280	-1%	-£4
Average	**£82**	**£969**	**£75**	**£839**		**£130**
New radiators						
T-07	£91	£1,122	£91	£954	15%	£168
T-06	£101	£1,189	£86	£851	28%	£339
T-08	£46	£552	£50	£539	2%	£13
T-10**	-	-	£122	£1,255	-	
Average	**£79**	**£954**	**£87**	**£781**		**£173**

Table 3.7 Combined costs before and after install

* T-20 is excluded from the average figures. This resident was a low energy user and only had 98 days of pre install consumption data available.
** T-10 is excluded from the average figures as there is no pre data available for the resident.

When the annual gas and electricity costs are combined, 6 households saw reductions in their annual cost. On average the total annual costs in properties with the existing central heating system reduced from £969 per annum to £839. Those with the new system installed experienced a slightly more significant reduction from £954 per annum to £781 per annum. These are the properties where the residents met a higher proportion of their heating demand using the ASHP. T-08 saw the lowest amount saved per annum, T-08's combined costs were already low at £552 per annum. Whilst they did use the heat pump to meet 45% of their heating demand they had a low heating demand. Additionally, the ASHP provided 3000 kWh less than the other properties that retained their heating systems.

1 household (T-20) saw a negligible increase of 1% however as explained above they have been excluded from the average figures. The 1 remaining resident (T-10) had only recently moved in when the hybrid system was installed. This meant there was no pre-install consumption data. This resident had the highest annual cost of all the properties monitored and significant issues with the running of the system. T-10 used an excessive amount of electricity despite having the highest SCOP of all the properties.

Similar savings were experienced across both install types. Those residents who had the system connected to existing radiators still experienced savings on their annual costs. Their heating demand was mostly met by the gas boiler element of the hybrid unit (see table 3.11), the new boiler was more efficient than the boilers they replaced. Those properties all experienced reductions in their electricity usage despite having the ASHP installed. 1 of the residents no longer had to use electric oil-filled radiators in the evening. This in part reduced their electricity consumption by 21% (T-02). On average the ASHP was only meeting the heating demand 16% of the time therefore it was rarely used which in part explains the low electricity usage.[16] The way the residents operated the heating may also have had an impact on the electricity costs. T-02's annual electricity cost fell the most (21%). This resident often turned the system on in the evening when they returned home from work. This instant demand for heat would have primarily been met by the gas boiler and T-02 had the lowest ASHP usage out of all the properties across the projects.

[16] As there is no data of the total heat output of the system an assumed boiler efficiency has been used. More detail on this can be found in the cost modelling section of the report.

Reductions in gas usage were also seen in the households that still had the existing central heating system installed. These reductions were not as pronounced as those with the new system.

Those households that had a new central heating system installed saw higher savings on their annual gas costs than those without (see table 3.6). The ASHP operating on a new radiator system and at a flow temperature of 55°C reduced demand on the gas boiler, subsequently this meant that electricity costs increased in 2 of the 3 properties (see table 3.5). T-06 experienced a saving on their electricity costs but has already noted they had a low heat demand.

The property that made the greatest saving was T-06 (28%) as their annual cost reduced from £1189 to £851. The resident maintained temperatures of around 21°C in the living room and main bedroom. The resident experienced this saving despite spending the most on their space heating across all the properties over the duration of the project (see table 3.11). The Seasonal Coefficient of Performance (SCOP) of the property was 2.86 and this level of efficiency would have had a positive impact on the cost of heating provided by the ASHP. T-10 had the highest SCOP of all the properties (see chart 3.8) and spent less on space heating over the same period as T-06. Despite this the resident experienced the highest annual costs of all the properties. The resident stated that there were periods when they had to use supplementary heating as the heating was not working. This explains the disparity in costs between space heating and total costs of the system.

Renewable Heat Incentive

Tech ref	Estimated Saving per year (£)	RHI over lifetime	Hybrid install costs	Install costs after RHI payments	Payback (years)	SCOP	Daikin RHI calculator
T-02	£152	£754	£7,145	£6,391	35	2.06	£1,004
T-18	£104	£853	£7,209	£6,356	54	-	£1,238
T-01	£135	£1,107	£6,982	£5,875	36	2.16	£1,004
	£130	**£905**	**£7,112**	**£6,207**			**£1,082**
T-07	£168	£3,471	£8,194	£4,723	21	2.68	£3,101
T-06	£339	£2,988	£8,485	£5,497	9	2.86	£3,101
T-08	£13	£1,782	£8,194	£6,412	481	2.29	£2,503
	£173	**£2,747**	**£8,291**	**£5,544**			**£2,902**

Table 3.8 RHI payments and payback periods

Claiming the Renewable Heat Incentive (RHI) can help offset the high upfront costs associated with installing heat pumps. Table 3.8 shows that for the properties that retained their radiators the RHI payments over the lifetime of the project were low at an average of £905 over the 7 years that RHI can be claimed. 2 of the properties would have been unable to claim RHI as they achieved SCOPs under the 2.5 threshold required to claim RHI. In the 2 properties the amount of heat produced by the ASHP was low, on average it was 16%. At the current level the payback would be anywhere between 35 – 54 years. Retaining the radiators enables a saving of around £1200 on the installation costs but on average there is an £1800 difference over the amount of RHI that can be claimed over the 7 years. Installing hybrid systems and retaining the radiators in this case would not be a cost-effective method as RHI could not be claimed and the payback would be reliant on annual cost savings.

The ASHPs in the properties that had new low temperature radiators provided on average 41% of space heating demand which increases the amount of RHI paid over the 7 years. 1 of the properties would have been unable to claim RHI (T-08) as it had a SCOP of 2.29. At 40% the average RHI payment is £2747 over the 7 years which alongside annual savings made can lessen the payback period. T-06 made the most significant annual cost saving and had the second highest level of RHI payments. At the current level T-06 would require 9 years to return on the investment made.

To claim RHI on a hybrid installation metering must be installed to take into account the non-renewable output of the system.[17] The RHI payments were calculated using the data from the heat meter monitoring the output of the ASHP. The Daikin RHI calculator was used to verify that these figures were accurate, an example of a Daikin-generated report can be found in appendix 3.[18]

3.4 Heating performance

The Seasonal Coefficient of Performance (SCOP) of a heat pump is an average measurement of how effective a heat pump is on an annual basis.[19] The efficiency of a heat pump varies across the seasons, in the winter when the temperature is colder the ASHP will require more electrical input to reach internal target temperatures. The SCOP provides a fairer assessment of a heat pumps long term performance than just calculating the Coefficient of Performance (COP) as this figure only applies to a particular outdoor and flow temperature. The higher SCOP the more efficient the heat pump is operating. A SCOP of around 3 is respectable for a heat pump.[20]

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 COP 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.

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

Chart 3.8 shows the Seasonal Coefficient of Performance (SCOP) of the ASHP in 6 of the properties. Those properties that had the existing central heating system in place recorded the lowest SCOP (T-01 & T-02). The properties with the replaced radiators achieved higher SCOPs. 1 property's SCOP was significantly lower than the others (T-08), this resident did not heat their property during milder weather when the heat pump would have operated at its most efficient.

[17] https://www.ofgem.gov.uk/ofgem-publications/121703

[18] https://www.daikin.co.uk/en_gb/installers/support/rhi/rhi-estimator.html

[19] https://www.bre.co.uk/heatpumpefficiency/background

[20] https://www.thegreenage.co.uk/coefficient-of-performance-seasonal-performance-factor/

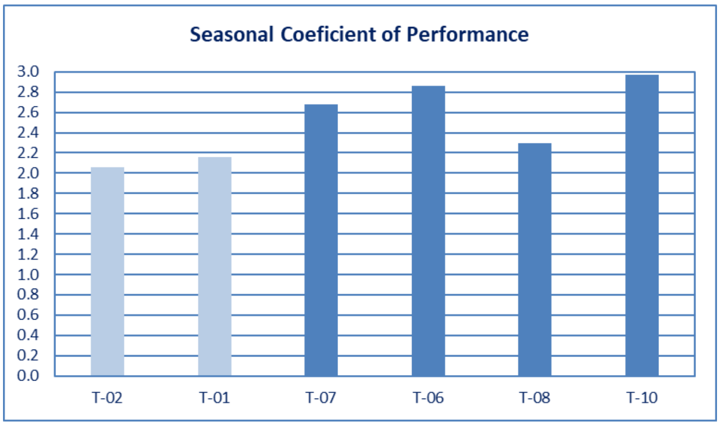

Chart 3.9 Seasonal Coefficient of Performance of the heat pumps in each property

For an ASHP system to be eligible for RHI payments then the Seasonal Performance Factor (SPF) must be over 2.5.[21] Chart 3.9 shows that 3 of the 6 properties would not be eligible for RHI payments. The lack of RHI payments would have a significant impact on offsetting the upfront capital costs.

3.5 Cost modelling

Hybrid costs						Gas boiler						
Tech ref	Gas usage (kWh)	Cost (£)	ASHP electricity usage (kWh)	Cost (£)	Total cost	Gas usage (kWh)	ASHP heat output (kWh)	output @ 80% efficiency	Total space heating (kWh)	Total cost	Saving	COP
T-02	7907	£395	721	£115	£511	7907	1485	1856	9763	£488	4%	2.06
T-01	10341	£517	1008	£161	£678	10341	2180	2725	13066	£653	4%	2.16
Average					£595					£571		
T-07	8793	£440	2607	£417	£857	8793	6992	8740	17533	£877	-2%	2.68
T-06	13304	£665	2152	£344	£1,010	13304	6525	8156	21460	£1,073	-6%	2.86
T-08	4911	£246	1570	£251	£497	4911	3603	4504	9415	£471	5%	2.29
T-10	11486	£574	2060	£330	£904	11486	6130	7663	19149	£957	-6%	2.98
Average					£817					£844		

Table 3.10 Space heating cost comparison of hybrid system and gas only system

Modelling has been carried out to show how much residents have spent on their space heating since the start of the project. The modelling considers 2 different scenarios for comparison.

1st scenario – A combination of the gas boiler and ASHP meets space heating demand.

2nd scenario – Gas boiler meets space heating demand solely.

Heat metering was in place to monitor the ASHP output, Domestic Hot Water (DHW) output and Total Heat output. The metering on the Total Heat output failed to record accurate readings due to

21 https://www.ofgem.gov.uk/environmental-programmes/domestic-rhi/applicants/eligible-heating-systems

installation issues relating to the heat probes. To circumvent this issue the total gas consumption from a dedicated gas meter was converted to kWh. This assumes the boiler is 80% efficient. The boilers that were in place before were Ravenheat CSI 85 boilers that had an efficiency of 90%. Boiler efficiency varies with age and use, a DECC report noted that boilers with a 90% efficiency operated at 80% efficiency.[22] The DHW output (at 80%) was subtracted from the total gas usage in kWh to provide a figure for the energy relating to space heating.

Table 3.10 shows that those properties with the lowest SCOPs would have been marginally better off in terms of cost if they had an 80% efficient boiler installed. The 2 properties with the lowest SCOP were those with the existing radiators still in place, and highest pre-set target temperatures. The properties were largely dependent on the gas boiler, T-02 & T-01 used the gas boiler to meet 82% and 83%, respectively, of their heating demand. The inefficient nature of the ASHP in those properties meant using it was not cost effective. The properties with the higher SCOPs would have been worse off in terms of cost if a gas boiler was installed. The higher SCOP figures indicate a greater efficiency of the heat pump and therefore offer a cost per unit that is comparable to heat provided by gas.

The following table (3.11) notes the full life time costs of a hybrid system and a gas boiler only system. This table is taken from Daikin's hybrid heat pump home heating brochure.[23] It shows that over the lifetime cost of a gas boiler and hybrid system there is the potential to save £5674. Daikin specify in their modelling that 75% of the heating demand should be met by the ASHP at an output temperature of 50°C. The highest percentage of demand met by the heat pump in any of the properties was 47% whilst the output temperature was set at 55°C.

	Initial capital cost	Life time running cost	7 year RHI income	10-15 year replacement cost	Total life time cost	Saving
Scenario 1 – Boiler	£3,000	£16,770 (Annual £1,118)	-	£3,000	£22,770	-
Scenario 2 – Hybrid	£8,780	£14,490 (Annual £966)	£6,174	-	£17,096	£5,674

Table 3.11 full life costs of a hybrid system compared to a gas boiler

[22] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/180950/In-situ_monitoring_of_condensing_boilers_final_report.pdf

[23] https://www.daikin.co.uk/content/dam/dauk/document-library/Brochures/Heating/Heating%20Homeowner%20brochures/Daikin%20Altherma%20Hybrid%20Heat%20Pump_homeowner_brochure_English.pdf

3.6 Space heating demand

Space Heating								
Tech ref	Period	Days	Gas output *	Gas (%)	ASHP output (kWh)	ASHP (%)	Total (kWh)	% saved
Existing radiators								
T-02	28/9/16 - 22/2/18	512	7116	83	1485	17	8601	20%
T-18	30/9/16 - 15/5/18	592	12887	87	1942	13	14829	9%
T-01	28/9/16 - 22/2/18	512	9307	81	2180	19	11487	14%
Average				84		16		
New radiators								
T-07	15/9/16 - 21/2/18	524	7914	53	6992	47	14906	15%
T-06	6/10/16 - 27/4/18	568	11973	65	6525	35	18498	28%
T-08	13/9/16 - 21/2/18	526	4420	55	3603	45	8023	2%
T-10	11/10/16 - 21/2/18	498	10338	63	6130	37	16468	-
Average				59		41		

Table 3.12 Percentage of use and cost of space heating over the projects duration

The total space heating demand varies across the households from 8023 kWh up to 18498 kWh. The above table (3.12) shows the percentage of heating demand met by the ASHP and boiler. Alongside this are the total space heating costs for each property. The calculations assume a price of 5p per kWh of gas and 16p per kWh of electricity. As referenced in the cost modelling section the total heat output was unavailable so an assumed boiler efficiency of 80% was used to calculate how much gas was used to meet the hot water demand. This could then be subtracted from the total gas usage in kWh (taken from the dedicated gas meter) giving the total space heating usage.

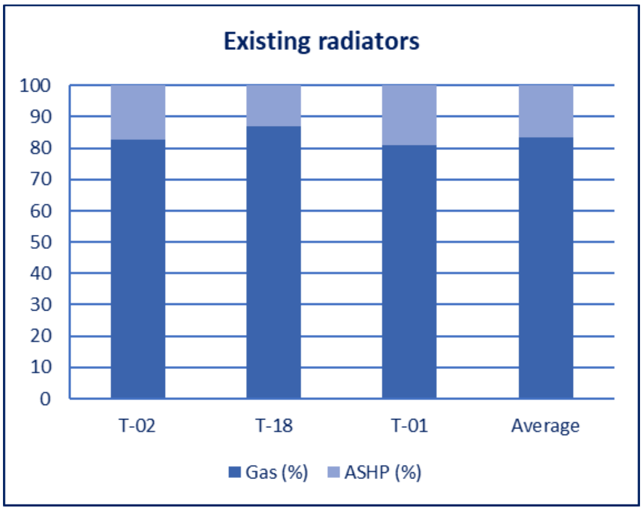

Chart 3.13 Proportion of space heating demand met by the gas boiler and heat pump in properties with existing radiators

Chart 3.13 reveals that the properties that retained the existing radiators used a higher proportion of gas to meet space heating demands, an average of 84% of the heating demand was met by gas. Those that had new oversized (low temperature) still primarily utilised gas whilst the ASHP met on average 41% of space heating demand (chart 3.14).

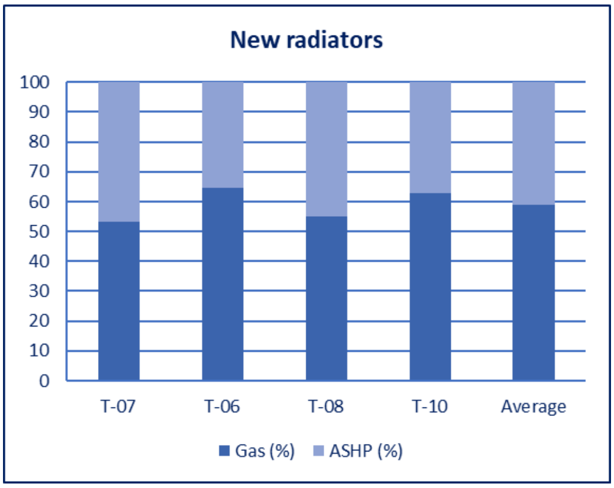

Chart 3.14 Proportion of space heating demand met by the gas boiler and heat pump in properties with new radiators

Air Source Heat Pumps operate more efficiently at lower flow temperatures. In this group, the existing radiators were replaced with oversized radiators and a flow temperature was set at 55°C. Aside from the replacement of radiators, there are several factors as to why the gas boiler was the most prevalent source of heating in each property:

- All properties had solid walls with no internal or external insulation.
- A heat pump operating on its own would not be able to satisfy heat demand and maintain requested temperatures, particularly in cold weather. This is due to the existing radiators being designed to operate at higher flow temperatures of around 70°C – 80°C. The smart control system understands this and switches to boiler only demand to increase flow to meet space heating demand.
- The pattern of heating within the property also determines which fuel source is used. In the UK it is widely assumed that households usually favour a twice daily heating schedule e.g. heating comes on in the morning for several hours and then goes off before coming back on in the evening. However, some residents were operating the system out of these periods by changing the thermostat.[24] If the hybrid system was operated like this then the property would need to be brought back up to temperature. Leaving the heating on or with a setback temperature of 18°C would likely increase the ASHP usage.
- 3 of the properties were end of terrace properties with additional exposed walls.
- The Altherma unit determines which source of energy should be used to heat the home based on external temperature and the input price of gas and electric. If a resident was on a competitively low tariff for gas, the system may determine that using gas is the most economical option. NEA was unable to verify the pre-set details programmed into the heat pumps which is used by the software to determine how the system operates.

[24] https://www.sciencedirect.com/science/article/pii/S0360132313002540 [Accessed 10 Jul. 2018].

There is evidence that a lower proportion of annual heat demand is met by the heat pump through this twice a day heating schedule, which has an impact on any carbon and cost savings realised.[25] This may account for why some of the properties meet such a low proportion of their heat demand using the heat pump. A twice-a-day heating schedule is not the optimal way to use heat pumps. Heat pumps are most efficient when operating continuously at low temperatures.

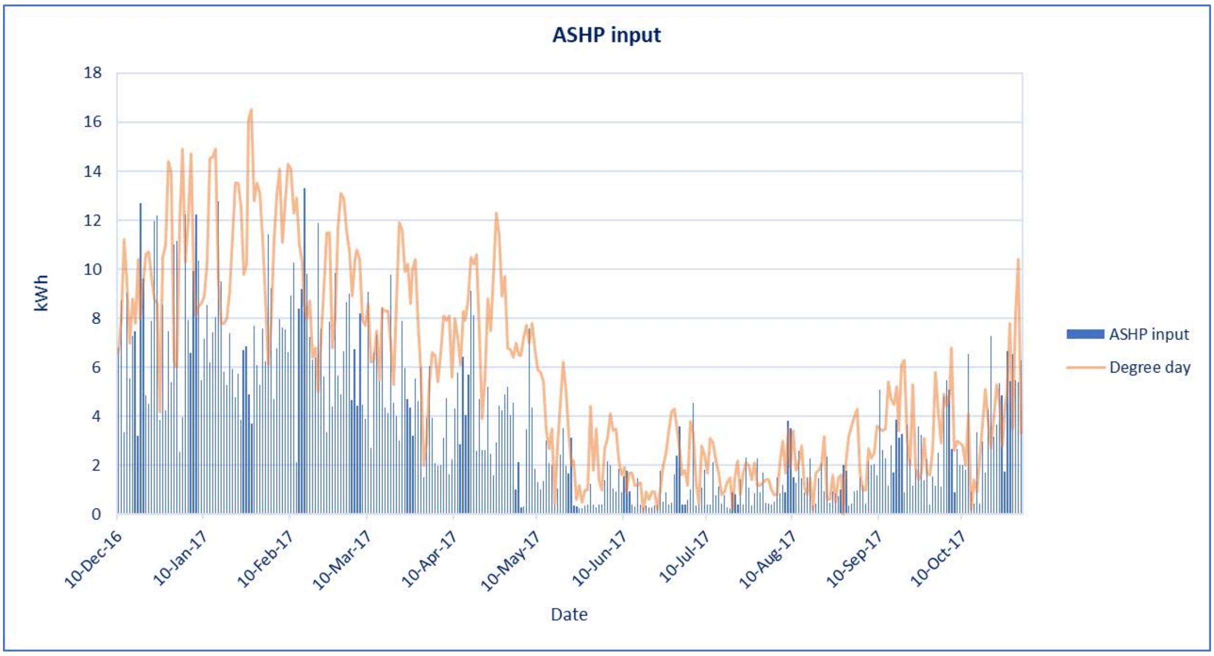

Chart 3.15 Relationship between ASHP usage and degree days (T-06)

Chart 3.15 shows the power used by the ASHP recorded by a watt hour meter in T-06. The chart tracks the ASHP usage against the number of degree days per day between 10th December 2016 and 1st November 2017. One of the advantages of the hybrid unit is its ability to respond to changes to the external temperature and provide enough energy to maintain comfort levels in the property. There are certain points where the relationship does not correlate well with outside temperature, this is particularly visible over the winter period and indicates when the external temperature drops too low for the heat pump to meet as much of the heating demand. This leads to the gas boiler meeting the heat demand.

[25] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/700572/Hybrid_heat_pumps_Final_report-.pdf

3.8 Temperature and thermal comfort

Temperature and humidity loggers were placed in 7 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 the properties in late September and October 2016 as the hybrid systems were being installed. The loggers were replaced before the start of the 2nd winter heating period and were then removed between February and May 2018. The residents' preferred heating periods as shown in chart 2.3 were used to determine between which period would be selected for analysis, the figure shows that the main comfort period was in the evening from 6pm to 10 pm. The 24-hour average, maximum and minimum temperatures were also selected for analysis.

2 periods have been selected for analysis. Both periods are after the installation of the hybrid systems and cover the same period of winter in 16/17 and 17/18. The first period covers November 2016 – February 2016 in which there were 977 degree days. The second period covers November 2017 – February 2018 in which there were 991 degree days. There was roughly the same number of degree days in both periods, indicating that the external temperatures were similar. The selected periods also cover months when the heating system was likely to have been in use.

Living room

Tech Ref No.	Post install November 2016 - February 2017				Post install November 2017 - February 2018			
	6-10 pm Average temperature (°C)	24 hours Average temperature (°C)	24 hours Maximum temperature (°C)	24 hours Minimum temperature (°C)	6-10 pm Average temperature (°C)	24 hours Average temperature (°C)	24 hours Maximum temperature (°C)	24 hours Minimum temperature (°C)
Existing								
T-02	16.3	17.0	23.0	12.0	16.8	16.9	28	10.5
T-18	-	-	-	-	20.3	19.4	28	13.5
T-01	21.1	19.8	24.5	16.5	21.2	19.3	24	15
Average	18.7	18.4			19.5	18.5		
New								
T-07	16.7	15.8	19.0	12.0	16.5	15.9	21	12
T-06	-	-	-	-	21.4	21.1	29.5	12
T-08	17.9	17.7	20.0	13.5	16.6	16.4	19.5	11
T-10	18.4	18.2	24.5	10.0	22.0	21.2	27.5	15.5
Average	17.7	17.2			19.1	18.7		
Degree days	977				991			

Table 3.16 Average living room temperatures in properties post hybrid install

Tech Ref No.	Control - 31/10/17 - 24/4/18			
	6-10 pm Average temperature (°C)	24 hours Average temperature (°C)	24 hours Maximum temperature (°C)	24 hours Minimum temperature (°C)
C-99	22.4	20.4	28.5	14.0
C-101	20.1	19.2	25.5	14.0
Average	21.2	19.8		
Degree days	1896			

Table 3.17 Average living room temperatures in control properties

There is data available for 5 of the 7 residents over the course of the first winter monitoring period. Across the period 2 residents were within the 18°C – 21°C range that is specified for a healthy indoor temperature. There is data available for the other 2 properties over the second winter monitoring period, both properties were within the 18°C – 21°C range. In the second monitoring period 4 of the 7 residents experienced average temperatures between the 18°C – 21°C range.

All but one property experienced higher average temperatures in the 6-10 pm period than they did over the 24 hour period. T-07, T-02 and T-08 all experienced temperatures below the healthy range of 18°C – 21°c however these residents were all satisfied with the level of comfort provided by the system and the cost of the system. T-08 preferred a colder home and used their heating sparingly. The monthly values for heat output revealed that from the end of March this resident's usage dropped significantly and they did not ramp up usage until the December.

T-02 did not use the heating system as originally set up, due to the residents working pattern they switched the unit on when they came in from work in the evening this may also help explain the low SCOP of the heat pump. T-07 has the lowest average temperatures across the 24 hour period and the 2nd lowest of the 6-10pm average. This indicates that the residents' preferred comfort period was at a different time in the day.

Those who experienced higher temperatures were less impressed with either the cost, level of control provided or the performance of the system. T-18, T-06 and T-10. T-18 and T-06 both experienced reductions in their annual costs of 9% and 28% respectively but had concerns related to the level of control they had to set heating times. T-18's annual costs were higher than T-06's at £1050, T-06 had the existing radiators replaced and had a SCOP of over 2.8 whilst T-18 only used the heat pump to meet 12% of the household heating demand. T-10 had significant issues with the heating system and whilst they achieved the highest average temperatures (21.2°C) they also spent the most heating their home at £1255 per annum. A considerable proportion of this increase was related to the resident's use of supplementary heating when the system did not work.

Whilst not directly comparable the 2 control properties (tables 3.17 & 3.19) maintained temperatures between the 18°C – 21°C across a considerably colder period in both the living room and bedroom. In the period monitored there were 1896 degree days. Both properties saw increased average temperatures between 6-10pm, periods when they wanted to be warm. As noted earlier these properties were insulated and had new boilers installed not long after monitoring began.

Bedroom

Tech Ref No.	Post install November 2016 - February 2017				Post install November 2017 - February 2018			
	6-10 pm Average temperature (°C)	24 hours Average temperature (°C)	24 hours Maximum temperature (°C)	24 hours Minimum temperature (°C)	6-10 pm Average temperature (°C)	24 hours Average temperature (°C)	24 hours Maximum temperature (°C)	24 hours Minimum temperature (°C)
Existing								
T-02	14.8	15.5	22.0	9.0	14.6	14.9	21.5	9
T-18	-	-	-	-	17.6	17.4	23	13
T-01	19.5	19.1	23.0	16.5	17.7	17.4	23.5	13
Average	17.1	17.3			16.7	16.6		
New								
T-07	18.1	17.8	21.0	12.0	17.5	17.7	22.5	13.5
T-06	-	-	-	-	21.0	21.2	25	13.5
T-08	15.8	15.9	17.5	14.0	18.1	17.1	22	12.5
T-10	18.2	18.1	24.5	10.5	20.6	20.5	31.5	13
Average	17.4	17.3			19.3	19.2		
Degree days	977				991			

Table 3.18 Average bedroom temperatures in properties post hybrid installs

Tech Ref No.	Control - 31/10/17 - 24/4/18			
	6-10 pm Average temperature (°C)	24 hours Average temperature (°C)	24 hours Maximum temperature (°C)	24 hours Minimum temperature (°C)
C-99	21.1	19.9	27.0	13.0
C-101	21.3	20.7	24.5	16.5
Average	21.2	20.3		
Degree days	1896			

Table 3.19 Average bedroom temperatures in control properties

Average temperature levels are below the 18°C recommended for bedrooms in 5 of the 7 properties. However, in 4 of those properties the temperature averages around the 17°C mark. This alongside the maximum temperatures indicate that these bedrooms are being heated and they may be warmer at night or early in the morning when residents require a warm bedroom. 1 of the 2 residents that experienced the highest average temperatures in the bedrooms also had the highest annual cost (T-10). It may be that this resident needs the heating patterns and temperatures altered to reduce their costs. The maximum temperature is particularly high in that property, 27.5°C in the living room and 31.5°C. This resident set the thermostat at 25°C and had to use supplementary heating for extended periods of time, both are possible reasons for the high maximum temperatures.

3.9 Humidity

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

The automated data-loggers used in this project record both temperature and relative humidity (RH) at pre-determined intervals across the study properties. RH is a ratio (expressed as a percentage) of the amount of moisture present in the air at each logging point, relative to the amount that would be present if the air were saturated. Since the latter amount is dependent on temperature, relative humidity is a function of both moisture content and temperature. Relative Humidity is derived from the associated Temperature and Dew Point for the indicated sample. The higher the value of RH, the more water vapour is contained in the air. High values are problematic, and can cause damage to building fabric and furnishings, and can cause mould growth and cause health problems associated with this high humidity. From the Building regulations part F; the suggested average monthly maximum humidity levels for domestic dwellings during the heating season is 65%.[26]

Living room

Tech Ref No.	Post install November 2016 - February 2017				Post install November 2017 - February 2018			
	6-10 pm Average humidity (%rh)	24 hours Average humidity (%rh)	24 hours Maximum humidity (%rh)	24 hours Minimum humidity (%rh)	6-10 pm Average humidity (%rh)	24 hours Average humidity (%rh)	24 hours Maximum humidity (%rh)	24 hours Minimum humidity (%rh)
Existing								
T-02	59.0	58.5	76.5	41.0	59.3	58.1	79.5	43.5
T-18	-	-	-	-	51.9	54.6	79	37
T-01	59.3	58.3	78.5	39.0	63.1	60.0	78	46
Average	59.2	58.4			58.1	57.5		
New								
T-07	68.2	66.5	89.5	48.0	70.5	68.1	88	52.5
T-06	-	-	-	-	48.1	48.2	92	30.5
T-08	51.9	51.1	69.0	37.0	54.9	56.0	79	37
T-10	55.8	54.9	72.5	40.0	43.6	44.0	64.5	26.5
Average	58.6	57.5			54.3	54.1		

Table 3.20 Average living room humidity levels in properties post hybrid install

[26] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/468871/ADF_LOCKED.pdf

Tech Ref No.	Control - 31/10/17 - 24/4/18			
	6-10 pm Average humidity (%rh)	24 hours Average humidity (%rh)	24 hours Maximum humidity (%rh)	24 hours Minimum humidity (%rh)
C-99	48.4	47.0	79.0	27.0
C-101	44.3	44.3	70.0	26.5
Average	46.3	45.7		

Table 3.21 Average living room humidity levels in control properties

Table 3.20 shows that average humidity levels in the properties ranged from 44%rh (T-10) up to 68%rh (T-07). There is data available for each property during the 2nd period of monitoring between November 2017 and February 2018. During this period 6 of the 7 properties humidity levels were within the recommended range of 40%rh – 60%rh, T-07 had a high levels of humidity in the property over both periods of analysis. This resident had complained about issues of damp and mould prior to the install and the continued low temperatures experienced would have continued to maintain this issue. T-06 has a wide range between the maximum and mininmum humidity levels across the 2nd monitoring period. A level of 92%rh indicates that something is releasing excessive moisture, this resident often dried their washing in the living room.

Table 3.21 shows that the control properties also maintained humidity levels between 40%rh – 60%rh. These figures are two of the lowest experienced by residents in the study however they are both cavity wall construction which is more likely to facilitate ideal indoor air conditions.[27]

Bedroom

Tech Ref No.	Post install November 2016 - February 2017				Post install November 2017 - February 2018			
	6-10 pm Average humidity (%rh)	24 hours Average humidity (%rh)	24 hours Maximum humidity (%rh)	24 hours Minimum humidity (%rh)	6-10 pm Average humidity (%rh)	24 hours Average humidity (%rh)	24 hours Maximum humidity (%rh)	24 hours Minimum humidity (%rh)
Existing								
T-02	66.7	66.3	89.0	42.5	61.3	61.9	76	48.5
T-18	-	-	-	-	56.4	56.1	72	42
T-01	63.1	64.3	84.5	43.0	63.7	65.2	80.5	46
Average	64.9	65.3			60.5	61.1		
New								
T-07	52.6	53.3	68.0	41.0	54.4	54.9	70	40.5
T-06	-	-	-	-	46.4	47.4	62	37.5
T-08	57.3	58.0	71.5	46.5	50.7	50.6	75	35
T-10	56.3	55.3	72.5	40.5	45.5	45.5	63.5	29.5
Average	55.4	55.5			49.3	49.6		

Table 3.22 Average bedroom humidity levels in properties post hybrid install

Tech Ref No.	Control - 31/10/17 - 24/4/18			
	6-10 pm Average humidity (%rh)	24 hours Average humidity (%rh)	24 hours Maximum humidity (%rh)	24 hours Minimum humidity (%rh)
C-99	54.3	52.0	78.5	35.5
C-101	48.3	50.7	68.0	34.5
Average	51.3	51.4		

Table 3.23 Average bedroom humidity levels in properties post hybrid install

Table 3.22 shows that 2 properties (T-02 and T-01) experienced humidity levels just above the upper end of the 40%th – 60%rh range. They also had the highest maximum humidity levels. T-02 experienced a drop in humidity levels in the second monitoring period. The temperatures in both properties were below the recommended 18°C – 21°C, T-02 experienced an average temperature of 14.9°C in the second post install period.

4. Conclusions and recommendations

4.1 Conclusions

The following section provides comments and conclusions on the project's aims:

- **To establish the running costs of the Daikin Altherma hybrid heat pump and compare them against the running costs of the gas boilers**

6 of the 8 residents monitored reduced their annual costs. 1 resident increased their annual costs by 1% however they were a very low energy user. The final resident had no pre-install consumption data as they had only just moved in before the system was installed. This resident had the highest costs after install and had experienced repeated issues with the hybrid system's performance.

There were no significant cost differences between those who received the new radiators and those who did not. Savings on annual energy costs across both groups ranged from 2% to 28%. The levelling of these costs shows that the hybrid system is determining which fuel is most cost effective for those properties under changing circumstances. Those with the new system met a higher proportion of their heat demand via the ASHP than those with the existing central heating system. This meant the annual cost of their electricity usage increased whilst their annual cost of gas usage decreased e.g. T-07 experienced a 76% increase in electricity costs and a 57% saving on gas costs.

Those residents who kept the existing radiators also experienced savings. In some cases, they saw savings on both their gas and electricity usage (T-02, T-18 & T-01). The household that experienced the greatest saving (T-01) no longer used their electric oil filled radiator to heat their home. Alongside the ASHP the residents received a new combination boiler as part of the hybrid system, this replaced the old inefficient boiler. A boiler's efficiency reduces as it is used especially if it has not been properly maintained. The condensing combination Altherma boiler is rated at 89.1% efficiency and undoubtedly offered an improvement on the previous system which had an efficiency of 90.1% but was prone to failure. Unfortunately, the control group selected for comparison also received a replacement gas condensing boiler removing the project's ability to establish previous energy and thermal baseline beyond historical energy billing information.

The cost modelling carried out showed that those properties with the lowest SCOPs would have been marginally better off in terms of cost if they had an 80% efficient boiler installed instead of the hybrid system. The 2 properties with the lowest SCOP were those with the existing radiators still in place, and highest pre-set target temperatures. The properties were largely dependent on the gas boiler. The inefficient nature of the ASHP in those properties meant using it was not cost effective. The properties with the higher SCOPs would have been worse off in terms of cost if a gas boiler was installed. The higher SCOP figures indicates a greater efficiency of the heat pump and therefore offer a cost per unit that is comparable to heat provided by gas.

- **To examine the impact of the new heating system on residents' comfort levels**

This project was part of a second round of TIF projects therefore installations began at the start of the winter monitoring period. This meant there was no opportunity to capture pre-install temperatures within a heating period (cold weather). The control group did not offer a fair comparison as they had insulated cavity walls and their old inefficient boilers were replaced with new boilers shortly after they were recruited to the project.

4 of the 7 residents experienced temperatures in their living room within the recommended range of 18°C – 21°C. Those that did not still noted their satisfaction with the temperatures that they received. Despite not all residents achieving the recommended temperatures most were satisfied, particularly with how warm their home got when it was cold outside and how well the house kept the heat in. 6 of the 7 residents were now able to keep warm at home however 4 residents stated that they were still wearing extra warm clothing to keep warm.

- **To examine whether residents can operate and control the system effectively**

Residents were provided with training on how to use the system at different points over the duration of the project. The contractors had demonstrable experience in the field and were approved Daikin installers. They provided training after the initial installation of the hybrid system. Residents were offered additional training from Home Group and the installer. 3 of the residents stated in the final questionnaire that they did not feel they were sufficiently shown how to use the system although 1 of these residents was on holiday when the initial training was provided.

6 of the 7 residents felt that they able to control the hybrid system adequately, however residents did raise issues regarding more advanced control of the heating system. All 7 residents knew how to use the thermostat element of the programmer. The simplified thermostat allows the occupier to increase or decrease the temperature daily (eventually reverting to original settings). Only 2 of the 7 felt they knew how to change the settings on the more advanced element of the programmer. The programmer is where heating patterns and temperatures are selected. These were selected upon set-up by the residents and programmed in by the installer. Residents were unable to set their own heating periods and temperatures; therefore, they were unable to change their settings if their circumstances changed without contacting the installer or housing association. This is reflected in the satisfaction level residents noted regarding the "amount of control over the system" which fell slightly after install. Several residents expressed that they wanted to be able to have more control over the system i.e. set the heat timings. Home Group state that residents were able to specify the timings when they received training on the system. Despite the lack of control that residents felt they had over timings and other more advanced aspects there was an increase in their satisfaction regarding "how easy the system is to use".

Residents primarily used the thermostat to control their heating system, changing the temperature daily in cold temperatures. Some residents were increasing the temperatures past 21°C up to 25 °C (T-10) & 26°C (T-18) (see chart 2.5). It is also noticeable that 3 of the residents turned their thermostat up to 30°C when they had their gas boilers installed, as they felt that the gas boilers did not work at lower temperatures. Moving to a system that provides a more continuous heat at a lower temperature meant a significant behaviour change for these residents, which may explain why they were turning up the temperature to unsuitable levels.

- **To determine if using the existing radiators impacts the performance of the hybrid heating system**

Those properties with the existing radiators and central heating system in place used the gas boiler to meet around 85% of their space heating demands. The low SCOP figures of the 2 properties with existing radiators also means that they would not be eligible the 7-year Renewable Heat Incentive (RHI) payments. RHI payments currently make ASHP systems such as this one viable and without them the payback period is considerably longer. The necessary data to calculate the SCOP from the other 2 properties was unavailable to due to the inaccessibility of the meters.

For the properties that retained their radiators the RHI payments over the lifetime of the project were low at an average of £905 over the 7 years that RHI can be claimed. At the current level the payback would be between 35 – 54 years. Retaining the radiators enables a saving of around £1200 on the installation costs but on average there is an £1800 difference over the amount of RHI that can be claimed over the 7 years. Installing hybrid systems and retaining the radiators in this case would not be a cost-effective method as RHI could not be claimed and the payback would be reliant on annual cost savings.

For the properties that had new low temperature emitting radiators installed the average RHI payment is £2747 over the 7 years, the RHI payment alongside the annual savings made the payback period significantly less. T-06 made the most significant annual cost saving and had the second highest level of RHI payments. At the current output and level of savings achieved T-06 would require 9 years to return on the investment made.

The low proportion of heat delivered by the ASHP aspect of the system did not impact the residents too greatly, the gas boiler aspect of the system was able to meet their heating demands in a cost-effective manner.

Even those with the low temperature radiators in place met most of their heating demand through the gas boiler. The calculations are based on a boiler efficiency rating of 80% as there was no data from the heat meters to determine total heat supplied. The actual efficiency may vary from the 80% stated and would likely differ from property to property. Using the assumed efficiency, on average the ASHP provided 41% of the space heating demand. The highest proportion was 47%. The low proportion of heating demand met by the ASHP may have been influenced by several factors:

- All properties in the study have uninsulated solid walls.
- The output temperatures were set at 55°C to accommodate the high heat loss of the properties

- Residents did not always follow the heating schedules that were set up for them when the system was installed. Some residents manually altered the thermostat or only heated the property when they came in from work.
- Set up as a two phase heating schedule as per customer requests. Whereas an ASHP operates more efficiently when providing heat continuously at a lower temperature.

- **To determine if a hybrid heating system is a cost effective replacement for housing associations when carrying out boiler renewals**

Installing a hybrid system has a higher upfront cost than just installing a gas boiler or ASHP. Figure 4.1 below shows the average costs of installing the different systems in a typical semi-detached house.[28] Installing a 5KW hybrid heat pump (base case in figure 4.1) system costs over 4x the amount it costs to install a gas boiler. This is without replacing the radiators in the property, if this was also done the cost would increase and be over 5x more expensive than installing a gas boiler. The average costs of the complete installation of the hybrid system were £7112 when the radiators weren't replaced and £8291 when the low temperature radiators were installed.

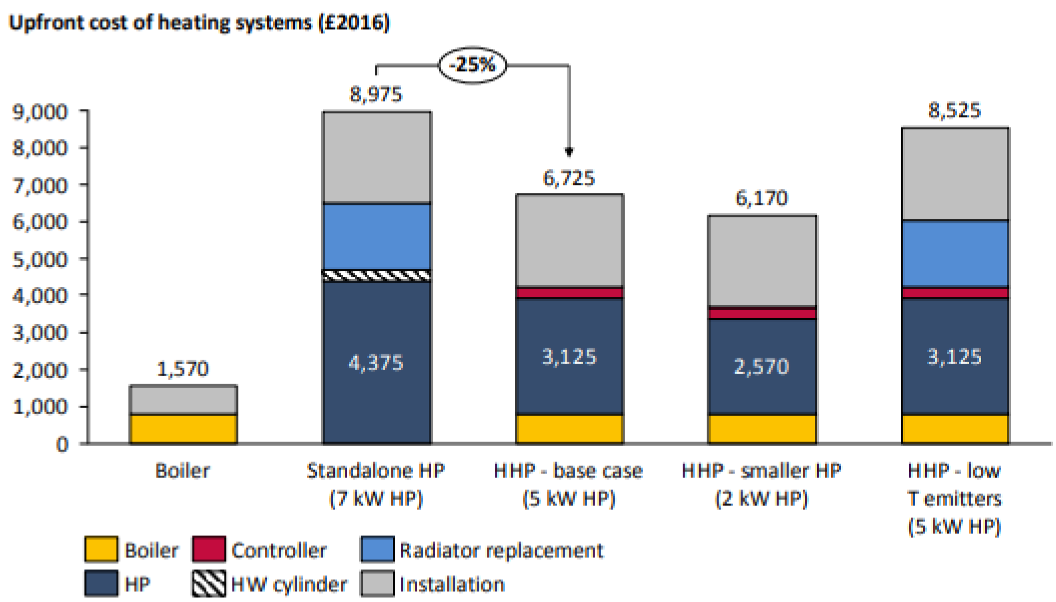

Figure 4.1 upfront costs of gas boilers, heat pumps and hybrid heat pumps

The results from this study indicate that fitting the hybrid system to pre-existing radiators is not a viable option. Whilst the costs did not vary significantly between those with new low temperature radiators and pre-existing radiators there was a significant impact on the SCOP. The results showed that the SCOP of those properties with the existing radiators was below the threshold to claim RHI. The RHI payments make a significant contribution in reducing the payback period and currently make heat pumps a viable option. Replacing all the radiators adds to the cost and to the level of disruption experienced by the residents. Although this could be partially negated by only replacing the important radiators i.e. living room radiators with low temperature emitters.

28 https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/700572/Hybrid_heat_pumps_Final_report-.pdf

The upfront cost can be negated in part by claiming the RHI payments for 7 years however, in this study 2 of the properties would be ineligible. An additional saving may be recognised if the lifetime of the system is more than that of a standard gas boiler system. As there are 2 units sharing the household heat demand they should both last longer. However, 6 of the 7 properties experienced some form of repair or maintenance issue throughout the duration of the project. For some the issues and disruptions were continual. Issues such as this should be ironed out as the system matures and procedures for repairs and maintenance advance. However, having 2 complex heating systems that operate together in a property may well lead to issues with at least one element.

4.2 Additional findings

Reliability and parts failure

6 of the 7 residents noted that they had some form of reliability or breakdown issue. These included system issues and parts failures. The following were some of the issues cited by residents; boiler pressure dropping, timer for heating to come on and off not working and heating not coming on at the correct time.

Additionally, there have been some parts failures across the installs which have added to the disturbance experienced by residents. The 2 key issues relate to gas valve failures and circulation pump failures. There were issues with the original gas valves fitted at the manufacturing stage which Daikin rectified by redesigning the valve. Regarding the circulation pumps, Daikin's original approved flushing methodology identified a hot and cold-water flush as an approved methodology for flushing cleansing agents and debris from completed heating systems. Both Daikin hybrid heat pump projects encountered multiple failures of the hybrid boiler integral heating system circulation pump. Water analysis indicated that residual system cleanser was corroding and seizing up the pump impeller. As a result the approved flushing methodology has been amended to require power flushing of all completed systems. In all instances where this was an issue, subsequent power flushing of the system resolved the issue.

Impact on EPC

All the properties with pre and post-install EPCs experienced a reduction in SAP points, prior to the install all properties were a band D but fell to bands E and F post install. At present the rdSAP is not able to record a hybrid system as the main heat source. The procedure fails to consider the smart control of the ASHP alongside the gas boiler.

EPCs are the main way that improvements to housing stock are measured. The Clean Growth Strategy announced a target of EPC Band C by 2030 for all housing. The inflexibility of SAP will likely have an impact on the implementation of innovative heating and energy technologies in the future.

4.3 Recommendations for potential future installations

- Replacement of all radiators with low temperature emitting radiators. This would optimise the SCOP and enable RHI payments to be claimed.
- Residents were impacted by the MCS conflict noted by Home Group. With there being a conflict between the installer MCS warranty process and manufacturer parts warranty there was a risk that installers attending faults cite the failure as being parts related, therefore requiring a subsequent Daikin service engineer to attend the fault. This is not reflective of a 1 visit fix mentality and can result in the customers experiencing multiple visits before a fault is repaired. This could potentially be resolved by Daikin developing a pre-agreed/pre-payment approval servicing agreement with approved installers during the MCS warranty period, towards fixing systems on a 1st time basis. Approved installers could carry a stock of key parts to facilitate.
- Learning from this project has shown that a full power flush of the system should be carried out.
- Remote cloud-based monitoring would enable accurate monitoring of the system performance and would enable adjustments to be made to residents heating systems remotely. It could also be used to identify more significant faults with a system i.e. COP falling significantly thus spotting issues before they have a chance to worsen.
- At present the residents are constrained by their lack of control over the system. Whilst they can change their settings using the room thermostat element of the programmer, residents require more control over the more advanced heating system settings.
- An ASHP operates more efficiently when providing heat continuously at a lower temperature which should be reflected in the programming of the system.
- ASHP systems perform better in well insulated properties, these properties would have benefitted from external wall insulation however this is an expensive solution.

4.4 Impact on fuel poverty

This project has shown that transitioning to low carbon heating systems need not have an impact on residents' cost and comfort levels. Residents saved on their annual heating costs although this was not always reflected in the residents' views. Residents disliked the fact that they could not set their own heating patterns without contacting Home Group or the installer. Enabling residents to use this element of programmer likely requires the provision of significant resources to help residents understand and operate the system in a manner that allows the system to perform at its optimum level.

The install and parts issues noted in this study could have a significant impact on those at risk of fuel poverty. At various times throughout the project T-10 was reliant on expensive supplementary heating to stay warm when the main heating system failed. This household had the highest annual costs and a portion of that was related to non ASHP electricity usage.

There are high upfront costs associated with the purchase and installation of a hybrid system. Figure 4.1 shows the upfront cost difference between purchasing and installing a gas boiler and a hybrid heat pump. The availability of the Renewable Heat Incentive (RHI) helps to offset some of the upfront cost, allowing housing associations to see a return on investment.

4.5 Performance comparison against manufacturers' claims

An accurate performance comparison against Daikin's claims is not possible. This is primarily due to the low proportion of heating demand that was met by the ASHP. Daikin specify in their modelling that 75% of the heating demand should be met by the ASHP at an output temperature of 50°C. The highest percentage of demand met by the heat pump in any of the properties was 47% whilst the output temperature was set at 55°C.

Appendix 1: Glossary of Terms

ASHP	*Air Source Heat Pump*
COP	*Coefficient of Performance*
DD	*Degree Days*
EPC	*Energy Performance Certificate (uses rdSAP software)*
HIP	*Health and innovation Programme*
HDD	*Heating Degree Days*
NEA	*National Energy Action – the National Fuel Poverty Charity*
rdSAP	*Reduced Data Standard Assessment Procedure*
RH	*Relative Humidity*
RHI	*Renewable Heat Incentive*
SAP	*Standard Assessment Procedure (for assessing home energy efficiency)*
SCOP	*Seasonal Coefficient of Performance*
SPF	*Seasonal Performance Factor*
TIF	*Technological Innovation Fund*

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

Appendix 3: Daikin RHI estimation

DAIKIN

dRHI ESTIMATION
Daikin Airconditioning UK Ltd

Project Reference	NEA-01				
Property Location	England & Wales		DECC Heat Loss Estimate	16,299 kWh	
Property Age	Pre 1930	Property Type	End-terrace	Bedrooms	
Design Flow Temperature	55°C	Model Selected	EVLQ05 - EHYHBH05	SCOP	3.23

Estimated return (Tariff 10.49p)	ANNUAL dRHI £ 180	7 YEARS dRHI £ 1,238

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Action for Warm Homes