NEA
Action for Warm Homes
TECHNICAL INNOVATION FUND

Project code CP780
Various heating solutions for social housing in North Lincolnshire
Ongo Homes

Technical Evaluation Report






Tom Shepherd
(August 2018)

Background

About National Energy Action

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

About the Technical Innovation Fund

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

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

TIF facilitated a number of trials to identify the suitability of a range of technologies in different household and property types and had two strands: a large measures programme to fund (or part fund) the installation and evaluation of technologies costing up to an average of £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 were selected for monitoring purposes. Participation was entirely voluntary, and householders were free to withdraw from the study 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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Tom Shepherd - Independent Energy Consultant

NEA team:
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Table of contents

Executive summary

Project overview

Ongo Homes installed 3 different types of innovative full heating systems into 30 properties from their social housing stock. Existing heating was removed and replaced with one of the 3 technologies: 14 Logicor infrared radiator systems, 10 Daikin Altherma hybrid heat pumps and 6 Sunamp heat batteries. 18 of the 30 properties with new heating systems were monitored, as well as 5 control properties for comparison. The heating was installed into a range of different property types, with different tenant profiles. Householders were asked to record their energy usage and this combined with the readings from the monitoring equipment has enabled analysis of the technologies and assessment of their running costs and suitability for social housing.

The project had the following aims;

- To assess the suitability of the 3 types of heating for social housing tenants
- To evaluate the running costs and energy use of the 3 heating systems
- To trial the Sunamp heat batteries with different off-peak electricity tariffs
- To assess tenants' views of the heating systems
- To evaluate the heating performance in terms of thermal comfort

Context

Just over 4 million households in Great Britain do not have access to mains gas for heating[1]. Heat pumps are a relatively cheap method of heating homes in areas off the gas network and are the heating of choice for many social landlords in off-gas areas, including Ongo Homes. Over 150 air source heat pumps (ASHPs) are installed in Ongo Homes' off-gas housing stock. However, Ongo wanted to research some alternatives for off-gas areas for those properties which were using either storage heaters or solid fuel heating and where ASHP installations were difficult or costly, and to trial the introduction of hybrid heat pumps into gas areas.

As increasing numbers of heat pumps are installed to replace more traditional heating systems such as solid fuel, oil, lpg and storage heaters, more electrical load is being added to the distribution network at peak times. When a number of heat pumps are installed in a small area, electrical upgrades could be required to reinforce the electrical distribution network. These are expensive and can take time to implement.

1.6 million households in Great Britain use electric storage heaters to heat their home[1]. These use off-peak electricity to heat homes and are a common heating source in many off-gas properties. They are not very controllable and often run out of heat in the evening. This uncontrollability can mean either that electricity is wasted or the home is not warm enough. Households with storage heaters are more likely than the average to be in fuel poverty[1].

200,000 GB households use solid fuel as their main heating[1]. These can also be costly to use and

[1] Ofgem - Insights paper on households with electric and other non-gas heating December 2015

require coal to be ordered and supplied in a timely manner. Appliances are laborious to maintain and require the fuel to be carried into the home, and ash to be removed, which is often difficult for elderly or vulnerable householders.

The National Grid “Future Energy Scenarios 2015” report forecasts that about 1.2m to 7.5m households could be served by heat pumps in 2030[2]. This could mean a move away from gas central heating towards ASHPs. Hybrid heat pumps are a transition technology combining the best features of gas combi boilers with the best features of ASHPs.

The 3 technologies used on this project offer ways of either shifting electrical load to off-peak periods and tariffs, reducing electrical loads of heat pumps on the network when demand is high or by reducing their use when their performance is low (during particularly cold weather), or reducing total electrical input by accurate control of heat. As well as relieving stress on the electrical network, shifting the load to an off-peak period can cut costs for householders.

The technology

Logicor Infrared Radiators

This is an electric on-peak heater that the manufacturer claims cuts heating costs by emitting only radiant heat, meaning that it uses less energy than alternative on peak systems because it stores heat in physical objects rather than the air, providing a more even heat distribution within a room[3]. Each heater has its own thermostat meaning that the temperature for each room can be set independently from a central controller.

Logicor heaters are an all-electric phased radiant heating system. The heaters have a very thin carbon heating elements sandwiched between two sheets of toughened glass with a mica insert to minimise heat loss from the rear of the appliance.

Daikin Hybrid Heat Pump

This is an air source heat pump combined with a condensing gas combination boiler. It is the first of its kind on the UK market, and is a development that makes best use of both heat pump and condensing gas boiler technology. It can be installed either in properties with mains gas, or with lpg. The properties in this project were all connected to mains gas.

The hybrid heat pump incorporates a number of technical innovations, so that the system runs as efficiently as possible. The gas boiler provides all the hot water and there are three operating modes for space heating.

1. At higher external temperatures, when the coefficient of performance (COP) of the heat pump is at its highest, the heat pump operates alone.

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[2] Future Energy Scenarios – National Grid July 2017

[3] Heating reimagined. Clear Heater System. Logicor 2014

2. When the external temperature falls and the heat pump cannot provide sufficient heat to the property, the gas boiler turns on and works in tandem with the heat pump, with the heat pump preheating the water into the boiler.
3. When the external temperature drops even further and the COP (efficiency) of the heat pump drops, such that it is more economic to use the boiler, the boiler does all of the work.

The set points at which the unit changes its mode of operation are calculated by the hybrid’s internal controller based on gas and electricity prices, and the heat load of the property, ensuring that the cheapest and most efficient use is made of electricity and gas.

Sunamp Heat Battery

The Sunamp Heat Battery shifts the heat load to an off-peak time, meaning reduced running costs for the householders and reduced stress on the electrical network. The heat battery is a heat storage system using phase change materials (PCMs) to store a concentrated amount of heat in a relatively small space. A high temperature heat pump runs on an off-peak electricity tariff to “charge” the heat store using low cost electricity. The store then discharges its heat when required via a radiator circuit at a flow temperature of 55 ^{0}C. The only energy that is used during on peak times is the central heating pump to circulate water round the radiators. During off-peak times, when the system charges up, not only does the customer get the benefit of a low electricity tariff, but they also get the benefits of the heat pump extracting renewable energy from the outside air.

If the heat battery runs out of charge because there has been extra demand on the heating or hot water, then the heat pump can directly supply the heating circuit at a flow temperature of 55 ^{0}C.

The project

The Infrared radiators were installed in 14 properties. They were targeted at smaller properties, mostly bungalows and flats, although 2 houses also had this system installed. 7 of the 14 properties were selected for monitoring, representing a cross section of those in the trial. The systems replaced in the monitored properties were 1 solid fuel, 1 on-peak electric heaters and 5 storage heaters. Of the 7 monitored properties, there was a change of household at 1 property part way through the project and 1 other household where limited information was provided.

The hybrid heat pumps were initially targeted at properties which were on the gas network, but without a gas connection. However, it proved difficult to persuade people who had consistently refused a new gas central heating system in the past to take part in the trial of a new heating system. Due to the difficulties in recruiting households to the trial, it was only possible to install dataloggers and so monitor 1 property before the installation of the new systems. The remainder were recruited to the project when their existing gas boiler failed. The hybrid heat pumps at these homes were installed at short notice and there was no time to do any “before” monitoring. 5 of the 10 properties with hybrid heat pumps were monitored. This included the one property with solid fuel heating, and 4 properties which had a standard gas combi boiler.

The Sunamp heat batteries were all installed into houses which previously had solid fuel heating systems. The large physical size of the heat batteries suited the solid fuel properties, as they were able to be installed into the coal stores which were no longer required. All 6 properties were monitored. There was a change of tenant at one property at the end of the first year's monitoring.

Six households were recruited as control properties. These represented a variety of properties and heating systems. However, the data obtained from them was of limited value because there were too many variables to provide any significance to the results, or to be able to compare the controls with the properties with new heating systems.

During the project, Ongo Homes had a PV installation programme, and several of the monitored properties received new PV arrays in the first year. This complicated the monitoring and invalidated some of the electrical measurements because the current clamps used are not designed to differentiate between import and export of electricity, or record "self consumption" of the free PV generated electricity.

Summary of findings

Energy costs

Monitoring results showed that the infrared radiators were

- more expensive to run than the storage heaters at 4 properties where they were replaced
- cheaper to run than the on-peak electric panel heaters at 1 property where they were replaced
- likely to be cheaper than the solid fuel heating system they replaced

Monitoring results showed that the hybrid heating systems were

- likely to be significantly cheaper to run than the 1 solid fuel heating system they replaced

There was insufficient data to reach any conclusions about the change in costs where the hybrid heat pumps replaced gas boilers. It was only possible to compare costs at two properties, one of which was more expensive with the hybrid heat pump and one which was cheaper to run.

Monitoring results showed that the heat batteries were

- cheaper to run than the solid fuel heating systems they replaced, providing the customers switched to a time of use tariff e.g. Economy 10 or Economy 7.
- The one customer who was unable to switch to an E-10 tariff had an increase in heating costs.

Thermal comfort

- On average, internal temperatures at the properties which moved from an electric heating system to infrared radiators changed very little.
- The internal temperatures at the property that switched from solid fuel to infrared heating reduced by about 2 ^{0}C.
- There was insufficient data from before the installation to reach any conclusions about the effect of the hybrid heating system on internal temperatures.

- Average internal temperatures at the properties that had heat batteries installed reduced by approximately 0.6 ^{0}C after the new heating was installed.

Damp and humidity

- Relative humidity (RH) increased in the living room at properties that previously had solid fuel heating systems. This is likely to be due to decreased ventilation in these rooms, following removal of open flues.
- On average the RH at the properties which had infrared radiators installed remained unchanged (after the one property that had solid fuel system had been removed from the calculation).
- One property showed signs of mould growth – this property had high RH levels before and after the installation of their infrared radiators with the average temperature in the living room and the bedroom at about 17 ^{0}C before and at about 18 ^{0}C after the change of heating.
- There was insufficient data from before the installation to reach any conclusions about the effect of the hybrid heating system on RH levels.

Resident satisfaction

- Satisfaction levels among tenants with the new heating systems was generally high, with most households responding that they were satisfied or very satisfied with the warmth, cost, controllability, and ease of use of their new heating.
- Four out of 6 of the households with the infrared heating were positive about its attributes, but 2 consistently marked it down. The cost of running the system meant that these 2 households didn't heat their homes to the temperature they would want and they said that their homes didn't warm up quickly or maintain the heat.
- Only 1 out of 5 households with the hybrid heat pump said they saw a reduction in their energy bills, but all 5 of them said they had a warmer and more comfortable home. 4 out of 5 of the hybrid households thought that their home gets warmer faster and keeps the heat better, that they have more control over their heating and that it is easier to use.
- The 4 heat battery customers who answered the questionnaire were very positive about all aspects of the heating system, giving it a higher satisfaction level than the other two technologies.

Conclusions and recommendations

- Households with all technologies were generally very happy with the performance of their heating systems, and their ability to keep their homes warm when they wanted them warm.
- Although they gave better controllability, 4 out of 6 of the infrared heating systems were more expensive than the heating systems they replaced.
- There is insufficient data on the hybrid heat pumps to give an accurate assessment of running costs compared to previous heating systems. However, all households said that their homes were warmer and more comfortable.
- Where customers had been able to switch to Economy 10 or Economy 7 tariffs the heat batteries were cheaper to run than the previous solid fuel heating. They were also popular with householders.

- Installation costs for the hybrid heat pump and the heat battery would need to be reduced to make them economic to install. Alternatively, RHI payments could help pay back the increased capital investment of the hybrid heat pump.
- Improved insulation of the heat batteries could reduce their heat loss.

1. Project overview

1.1 Introduction

Ongo Homes installed 3 different types of innovative full heating systems into 30 properties from their social housing stock. Existing heating was removed and replaced with one of the 3 technologies: 14 Logicor infrared radiator systems, 10 Daikin Altherma hybrid heat pumps and 6 Sunamp heat batteries. 18 of the 30 properties with new heating systems were monitored, as well as 5 control properties. The heating was installed into a range of different property types, with different tenant profiles. Householders were asked to record their energy usage and this combined with the readings from the monitoring equipment has enabled analysis of the technologies, to evaluate their running cost and suitability for social housing.

1.2 Aims

The project had the following aims;

- To assess the suitability of the 3 types of heating for social housing tenants
- To evaluate the running costs and energy use of the 3 heating systems
- To trial the Sunamp heat batteries with different off-peak electricity tariffs
- To assess tenants' views of the heating systems
- To evaluate the heating performance in terms of comfort

1.3 Context

Just over 4 million households in Great Britain do not use mains gas for heating[4]. Heat pumps are a relatively cheap method of heating homes in areas off the gas network and are the heating of choice for many social landlords in off-gas areas, including Ongo Homes. There are over 150 air source heat pumps (ASHPs) in Ongo Homes' off-gas housing stock.

Ongo Homes wanted to research some alternatives for off-gas areas, for properties where ASHP installations were difficult or costly to install, and to trial the introduction of hybrid heat pumps into gas areas.

1.6 million households in Great Britain use electric storage heaters to heat their home[4]. These use off-peak electricity to heat homes and are a common heating source in many off-gas properties. They are not very controllable and often run out of heat in the evening, when it is cold outside. The

[4] Ofgem - Insights paper on households with electric and other non-gas heating December 2015

uncontrollability can mean either that electricity is wasted by opening windows if it is warmer than expected, or the home is not warm enough in the evening and the heating may need to be topped up using more expensive on-peak electricity. Households with storage heaters are more likely than the average to be in fuel poverty[5]. Alternatives for off-gas properties that save on electricity use and cut costs could help reduce fuel poverty.

As increasing numbers of heat pumps are installed to replace more traditional heating systems such as solid fuel, oil, lpg and storage heaters, more electrical load is being added to the distribution network at peak times. Off peak electricity tariffs such as Economy 7 (E-7) and Economy 10 (E-10) are designed to encourage people to shift their electricity usage to off-peak times when less electricity is used and generation costs are lower. The Sunamp heat battery enables householders to shift their electricity usage to off-peak times by storing heat. This means that as well as having a heat pump that provides heat at a coefficient of performance (COP) of up to 3, the heat pump can also use E-7 or E-10 electricity rates of about half the price of standard electricity. In theory, this will provide extremely cheap heating at the same time as benefiting the electricity network.

When they are well designed, ASHPs will cost marginally more to run than a well-designed new A rated gas boiler[6]. The COP (efficiency) of a heat pump falls as the external temperature falls, so the colder it is outside, the more it costs to run a heat pump. In addition, the colder it is outside, the higher the demand on the electrical network. Shifting the heating load from electric to gas at colder temperatures with a hybrid heat pump can therefore solve two issues – it can improve the average performance of the ASHP by operating it only in its most efficient range and it can load shift from a heavily loaded electricity network.

The National Grid "Future Energy Scenarios 2015" report forecasts that about 1.2m to 7.5m households could be served by heat pumps in 2030[7]. This could mean a move away from gas central heating towards ASHPs. Hybrid heat pumps are a transition technology combining the best features of gas combi boilers with the best features of ASHPs.

1.4 Project timeline

Ongo Homes[8] is a housing association with 10,000 homes for rent throughout North Lincolnshire, with a few properties in South Yorkshire and in Lincolnshire.

The main contractor selected for the installations was Ongo Homes' heating contractor, Aqua Interiors. They had already been trained by Logicor and had installed a few of the infrared heating systems. Aqua Interiors had also installed a number of the standard Daikin split system air source heat pumps for Ongo Homes. For the project they were given additional training from Daikin on

[5] Ofgem - Insights paper on households with electric and other non-gas heating December 2015

[6] http://www.energysavingtrust.org.uk/renewable-energy/heat/air-source-heat-pumps

[7] Future Energy Scenarios – National Grid July 2017

[8] http://ongo.co.uk/corporate-information/our-group/about-ongo-homes/

installation of the hybrid pump. Daikin provided a service engineer to complete the refrigeration connection between the internal and external units and to commission all the hybrid heat pumps.

Sunamp[9] installed their heat batteries and provided onsite training to installers - Aqua interiors on the connection of the heat batteries to the heating system. Daikin provided a service engineer to complete the refrigeration connection and commissioning of the high temperature heat pumps.

Tom Shepherd, an independent energy consultant, helped to set up the project, work with tenants and provide technical support throughout the project.

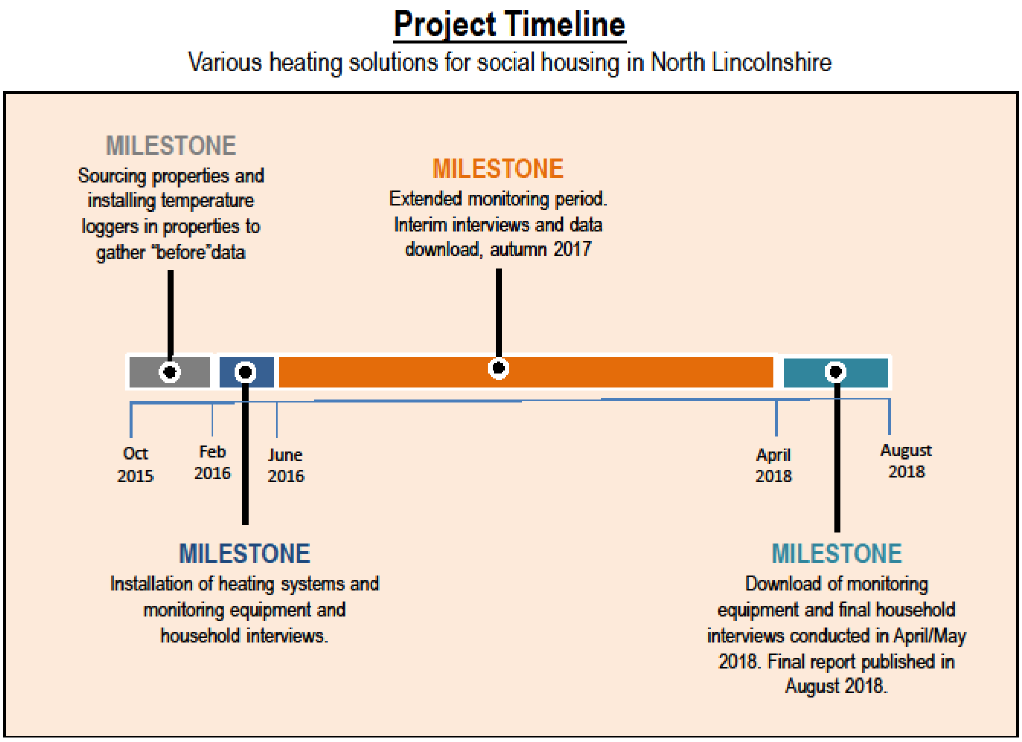


Figure 1.1 Project timeline

Unfortunately, Aqua Interiors ceased trading half way through the project, which caused a delay to completion of the installation of the Sunamp heat batteries and the hybrid heat pumps. Most of the systems had been installed, but the monitoring equipment still needed to be commissioned, and some snagging work was delayed until May and June 2016.

When the project started, the intention was to monitor existing internal temperatures and utility bills for a short period before installation of the new heating system and then to carry out a years' monitoring with the new heating system installed. Initial monitoring pointed to worse performance

[9] https://www.sunamp.com/

than would be expected for the Sunamp heat batteries, so Sunamp investigated and made some alterations to the systems. Alterations made included:

- reducing the heat pump ΔT (the difference between flow and return temperature) from 10 ^{0}C to 5 ^{0}C, to reduce heat pump cycling
- cleaning the heat pump filters which were blocked with debris, and restricting flow
- Moving some of the heat pumps further from the external walls of the properties to improve air flow
- Swapping the flow and return pipes from the heat pump to the heat battery at property T-17. These had inadvertently been swapped over when the heat meters had been installed, meaning that the battery at this property would not fully charge.
- Setting the pumps on the heat pump to modulate, rather than run at full power.
- Removing the transport brackets from the heat pump compressors.

A second year of monitoring was then agreed to see whether the changes would make any difference to the results.

1.5 Attracting beneficiaries and establishing a monitored group

- Ongo Homes contacted tenants living in areas off the gas network via email and a mail shot
- Properties targeted had solid fuel heating, storage heaters, or on-peak electric heating
- Properties in gas areas but without gas central heating were also targeted
- Those who expressed interest in an alternative heating system received a visit from Ongo and Tom Shepherd in October and November 2015.
- During the home visit, the aims of the project and technology types were explained to tenants, the suitability of the property was assessed and a decision made on the most suitable new heating technology for the property.
- At the home visit temperature loggers were installed in a selection of suitable properties and utility meters readings were recorded.
- Properties selected for the infrared radiators were mostly smaller properties off the gas network, although 2 houses were included.
- The hybrid heat pump was targeted at households who lived on the gas network but were without gas heating. Ongo Homes had already had a number of drives to convert tenants to gas central heating where there is gas mains, and those targeted for this scheme had mostly already refused gas central heating. Only one household was recruited through this method, and one was recruited following a change in tenancy.
- An alternative approach was needed for the remaining 8 properties for a new hybrid heat pump. These were taken from the replacement boiler list, following the failure of an existing boiler. Unfortunately, this meant that for the hybrids there was only one property that was able to have a “before and after” assessment of internal temperatures and energy use.
- Properties selected for the Sunamp heat battery were larger properties off the gas network which had previously been heated with solid fuel. The coal stores were able to be used for housing the large heat battery and the heat pump hydrobox.
- Ongo Homes, as lead partner, provided project management, access to their properties for trials and used their framework contractors for the installations.

- Tom Shepherd worked on tenant liaison, checking that installations and monitoring equipment had been installed to manufacturer's recommendations and taking periodic readings from the monitoring equipment to check performance.
- NEA conducted householder interviews at the start, mid-way through and at the end of the project, gathering detailed information about demographics, householder heating and energy use and their thoughts on the heating.
- Heating systems were programmed for installation between the end of January 2016 and end of April 2016.
- Control properties were recruited in the autumn of 2016 to provide a comparison against the properties which received measures (due to lack of pre-install data). Six households were interviewed and temperature loggers left at their properties.

Properties selected for Logicor infrared radiators

Infrared radiators were installed in a range of properties, 14 in total, which had previously been heated either with solid fuel, storage heaters, or in one case on-peak electric heaters. Of these, 7 were selected for monitoring.

Details of properties selected for Logicor infrared radiator systems are listed in table 1.2a below.

Property monitoring reference	Property type	Old heating system	SAP rating	Floor area (m^2)	EPC annual space & water heating demand (kWh)
T-4	Ground floor flat (2 bed)	Storage heaters	46	70	
T-5	First floor flat (2 bed)	Storage heaters	74	63	
T-10	Bungalow detached (1 bed)	Solid fuel	55	43	8,277
T-11	Bungalow end terr (1 bed)	On peak electric	59	43	7,377
T-12	Ground floor flat (2 bed)	Storage heaters	No EPC		
T-22	House semi det (3 bed)	Storage heaters	54	83	8,746
T-119	Bungalow end terr (1 bed)	Storage heaters	64	51	9,148
Not monitored	First floor flat (2 bed)	Storage heaters	41	56	13,198
Not monitored	Bungalow semi det (1 bed)	Solid fuel	59	42	
Not monitored	Bungalow semi det (1 bed)	Solid fuel	52	42	
Not monitored	Bungalow end terr (1 bed)	Storage heaters	58	44	
Not monitored	Bungalow semi det (1 bed)	Storage heaters	39	63	
Not monitored	Bungalow semi det (2 bed)	Storage heaters	37	55	
Not monitored	House mid terrace (2 bed)	Solid fuel	64	75	9,481

Table 1.2a Details of properties taking part in the study receiving the infrared radiators

Where there is no recorded space and water heating demand shown in the table above, this is because the EPC was completed in 2010 or earlier when EPCs did not record this information.

Properties selected for Daikin hybrid heat pumps

The hybrid heat pumps were all installed in houses. In total, 10 were selected of which 5 were monitored. One had previously been heated either with solid fuel, one with storage heaters, and the remaining had been heated with a standard gas combi boiler. Tenants at one additional property (T-84) responded to the questionnaire, although the property wasn't formally monitored.

Details of properties selected for new Daikin hybrid heat pump systems are listed in table 1.2b below.

Property reference	Property type	Old heating system	SAP rating	Floor area (m^2)	EPC annual space and water heating demand (kWh)
T-20	House semi det (3 bed)	Solid fuel	39	88	17,366
T-50	House semi det (3 bed)	Gas boiler	58	86	11,891
T-52	House semi det (3 bed)	Gas boiler	72	88	9,470
T-73	House semi det (3 bed)	Gas boiler	60	90	15,943
T-83	House end ter (3 bed)	Gas boiler	65	81	10,269
T-84	House end ter (3 bed)	Gas boiler	52	79	15,584
Not monitored	House mid ter (3 bed)	Gas boiler	61	91	13,770
Not monitored	House end terr (3 bed)	Gas boiler	71	96	9,378
Not monitored	House semi det (3 bed)	Storage heaters	58	86	10,566
Not monitored	House semi det (3 bed)	Gas boiler	64	70	9,121

Table 1.2b Details of properties taking part in the study receiving the hybrid heat pump

Properties selected for Sunamp heat batteries

The Sunamp heat batteries and Daikin high temperature heat pumps were all installed in houses. The 6 selected were all monitored. They had all previously been heated with solid fuel, and consequently had large coal stores which could be used for the heat battery and heat pump hydrobox.

Details of the properties selected for new Sunamp heat batteries are listed in table 1.2c below.

Property reference	Property type	Old heating system	SAP rating	Floor area (m^2)	EPC annual space and water heating demand (kWH)
T-8	House semi det (3 bed)	Solid fuel	57	87	11,860
T-9	House semi det (2 bed)	Solid fuel	64	71	9,113
T-13	House mid terr (2 bed)	Solid fuel	No EPC		
T-16	House mid terr (2 bed)	Solid fuel	64	77	9,153
T-17	House semi det (3 bed)	Solid fuel	47	78	
T-23	House semi det (3 bed)	Solid fuel	51	93	14,136

Table 1.2c Details of properties taking part in the study receiving the Sunamp heat battery

Properties selected as controls

A mixture of properties with different heating systems were chosen as control properties. Information is given in table 1.2d below.

Property reference	Property type	Heating system	SAP rating	Floor area (m^2)	EPC annual space and water heating demand (kWH)
C-1	Semi detached bungalow (2 bed)	Storage heaters	55	59	9,535
C-82	Mid terrace bungalow (1 bed)	Storage heaters	No EPC		
C-127	Semi detached house (3 bed)	Solid fuel boiler	37	77	17,151
C-129	Semi detached house (3 bed)	Gas boiler	70	82	9,502
C-131	Semi detached house (3 bed)	Gas boiler	62	113	18,621
C-135	End terrace bungalow (1 bed)	Storage heaters	55	48	8,413

Table 1.2d Details of control properties taking part in the study

Location of properties

Properties were all owned by Ongo Homes and located within North Lincolnshire. The Sunamp heat batteries and most of the Logicor infrared radiators were located in off-gas rural areas. The hybrid heat pumps were installed in properties on the mains gas network, which meant that they were installed in towns or urban areas. The plans below show the spread of properties across the region.

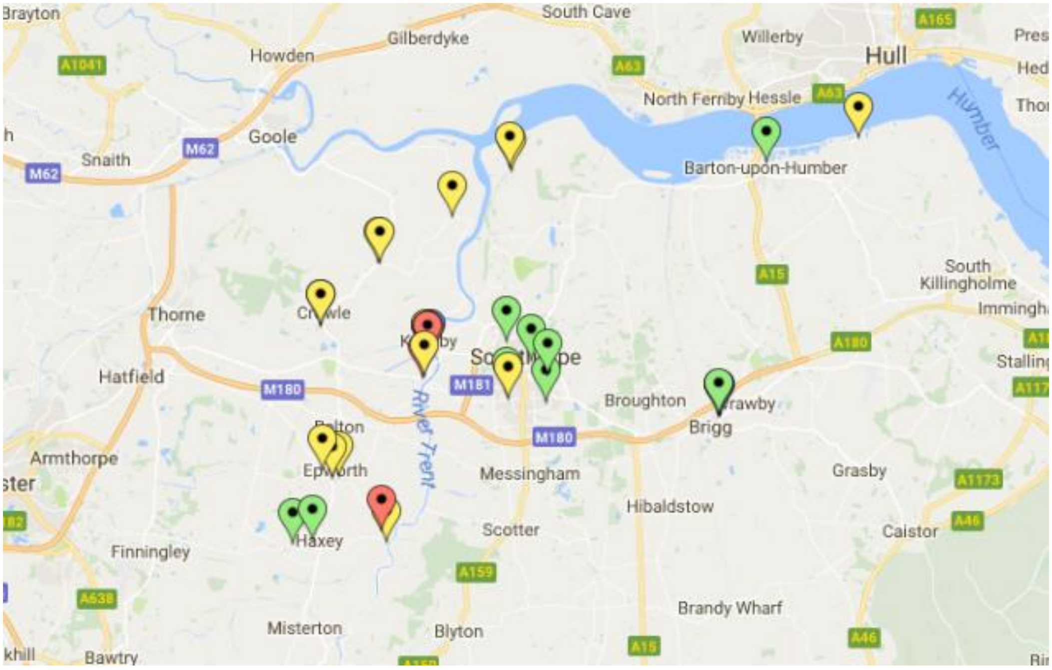


Figure 1.3a Location of heating installations in North Lincolnshire

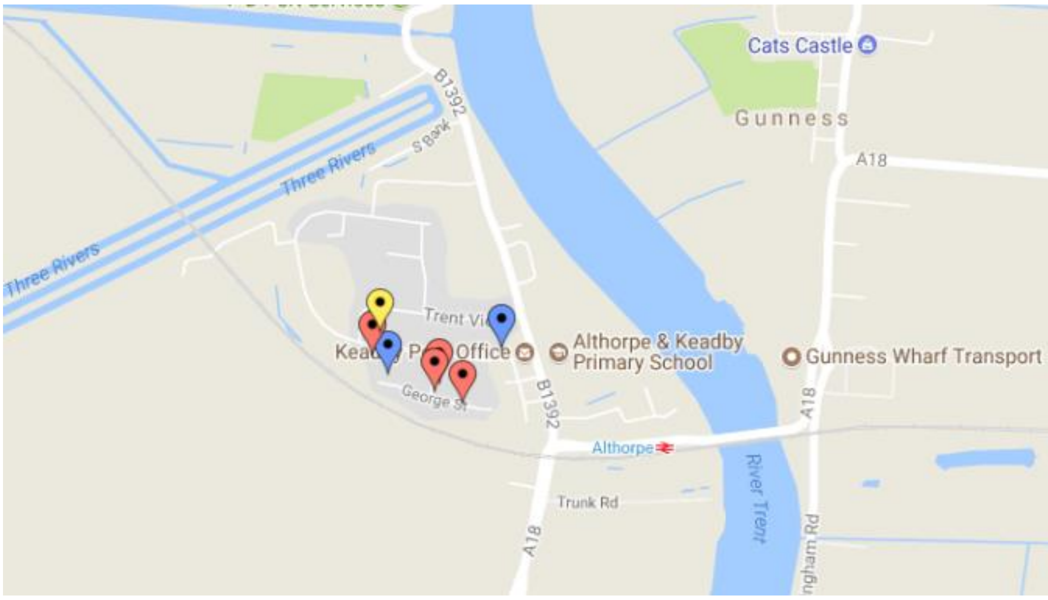


Figure 1.3b location of heating installations: closer view on Keadby

Key: Heat battery Hybrid Infrared Control

1.6 Factors affecting the planned evaluation methodology

Issue	Description and mitigation
Monitoring equipment	Some of the heat meters were installed on the wrong pipes, so had to be moved before monitoring could begin. Fortunately, this was discovered during snagging and was able to be rectified before the start of the heating season.
Monitoring equipment	Some of the Opti-pulse loggers did not stick well to the face of the Watt hour meters and became detached. Most of these were discovered on interim site visits and were able to be secured by other methods.
Monitoring equipment	Several pieces of monitoring equipment did not record data, including heat meters, current clamps, gas meter loggers. A second winter of recording meant that there is a good data set for the properties, although not always over the same time period.
Location of temperature loggers	Two of the control group (C-1 and C-82) had to be dropped from the project because on the return visit to the properties, the temperature loggers were found to have been moved and were not in locations where they would measure representative room temperatures. Temperature loggers at some other properties were also lost because they were displaced by tenants.
Monitored group	There was a change of tenancy at property T-16 (heat battery) during the summer of 2017. The original temperature loggers were lost, so no internal temperatures were able to be assessed for the first year. There was also a change of tenancy at property T-11 (infrared radiators) during the summer of 2017.
Meter readings	Some of the tenants were very diligent about recording their meter readings. Two in particular T-8 and T-22 took meter readings at the same time every day. This enabled very good analysis and provided a good check on the accuracy of the opti-pulse loggers fitted to the electricity meter and the data from other loggers.
Solar PV systems	Solar PV systems were installed at 6 properties during the project. This affected the readings from current clamps at 3 properties. Current clamps are not able to differentiate between import and export of electricity, so it was not possible to determine how much electricity was used in the property.

2. Social evaluation and impacts

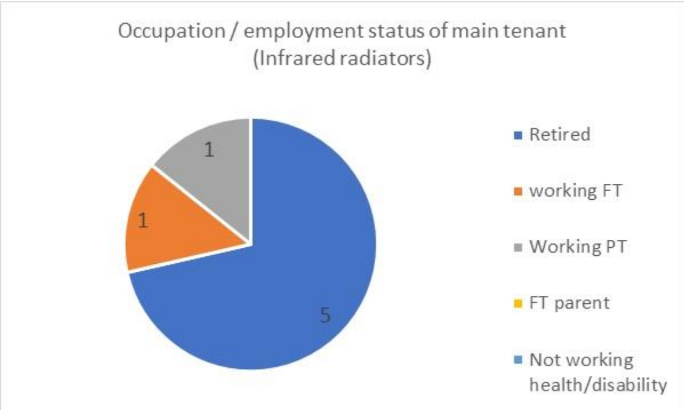
2.1 Qualitative feedback from questionnaires

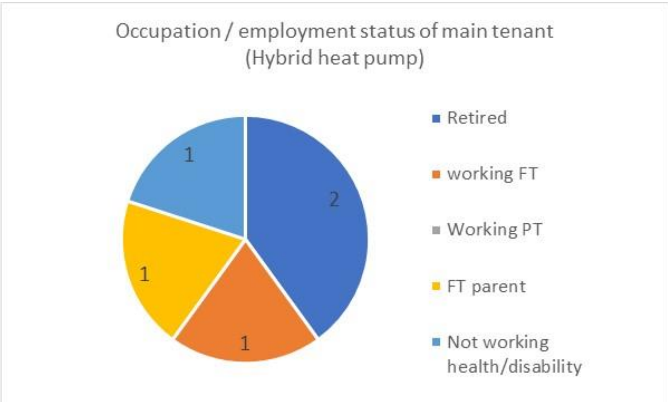
At the start of the project households received a number of home visits from people involved in the project.

- A recruitment visit to let households know about the project and explain the technology to them. At this visit it was decided which properties would be monitored. Temperature loggers were left in properties in which households agreed to monitoring at this visit. All participants in the project were given energy efficiency advice at this visit.
- Survey from the installer
- Installation, which took from a couple of days to a week, including a run through of the controls from the installer
- Snagging visit for all properties and check on any metering equipment installed
- Initial questionnaire visit from NEA, during which a comprehensive semi structured questionnaire was undertaken with monitored households. The questionnaire covered household demographics, existing heating system, heat requirements, use and control of existing heating, existing running costs, using and saving energy in the home.
- Monitored properties then received several other visits to read monitoring equipment and utility meters over the course of the project.
- Two further data gathering visits from NEA to ask about customer experience of the new heating system in comparison to the old, and dataloggers were replaced.

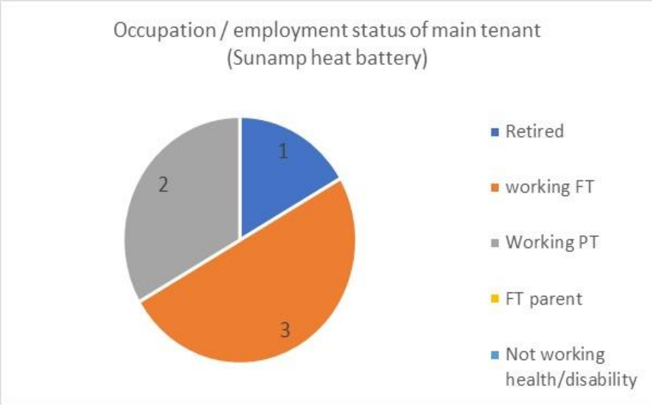
This section includes information and graphs showing detail of the responses the monitored households gave to questions at the start and the end of the project.

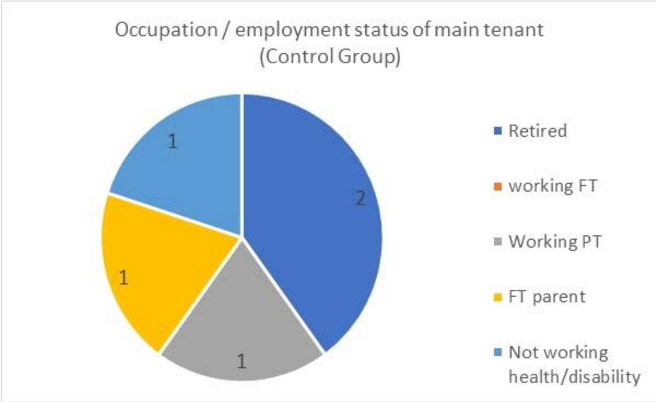
Occupation





Graph 2.1 Occupation / Employment status of main tenant (a) Infrared radiators, (b)Hybrid heat pump

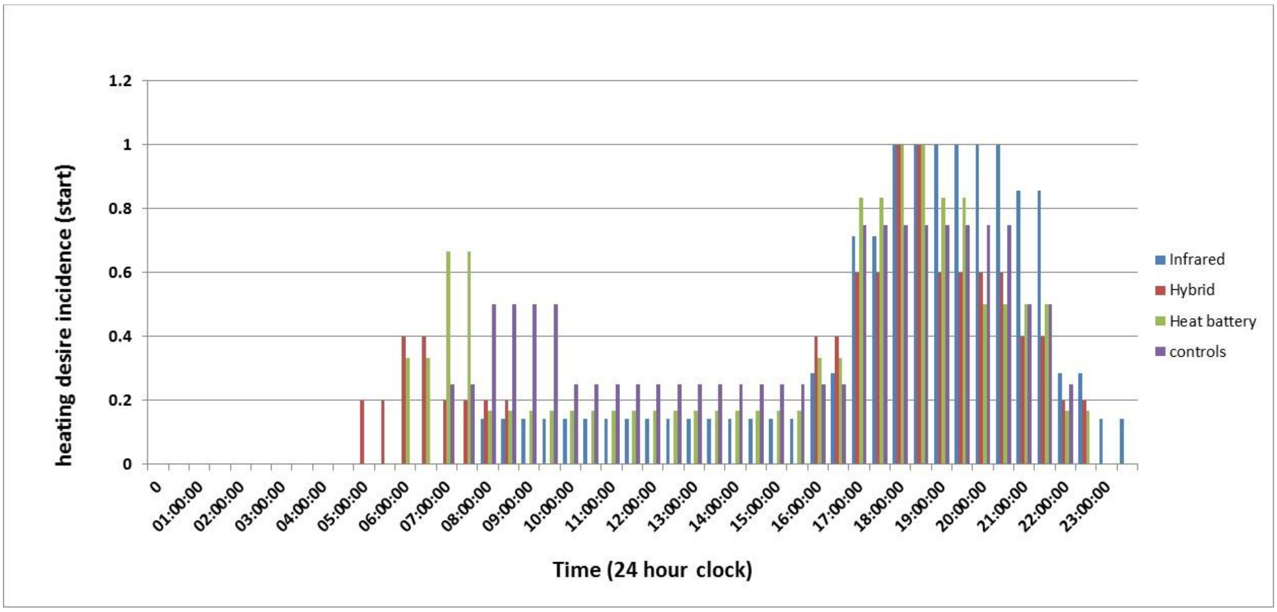




Graph 2.1 Occupation / Employment status of main tenant (c) Sunamp heat battery, (d) Control group

From Figure 2.1 above it can be seen that there is a difference in occupation and employment status between the households who had each heating technology installed. 5 of the 6 who had the Sunamp heat battery installed were working either full or part time, whereas 5 out of 7 of those who had the infrared radiators installed were retired. This is reflected in the property types and ages of the households. Hybrid heat pump properties were either 2 or 3-bedroom houses, while the infrared radiators were installed mostly in 1 or 2-bedroom bungalows and flats (see tables 1.2 above).

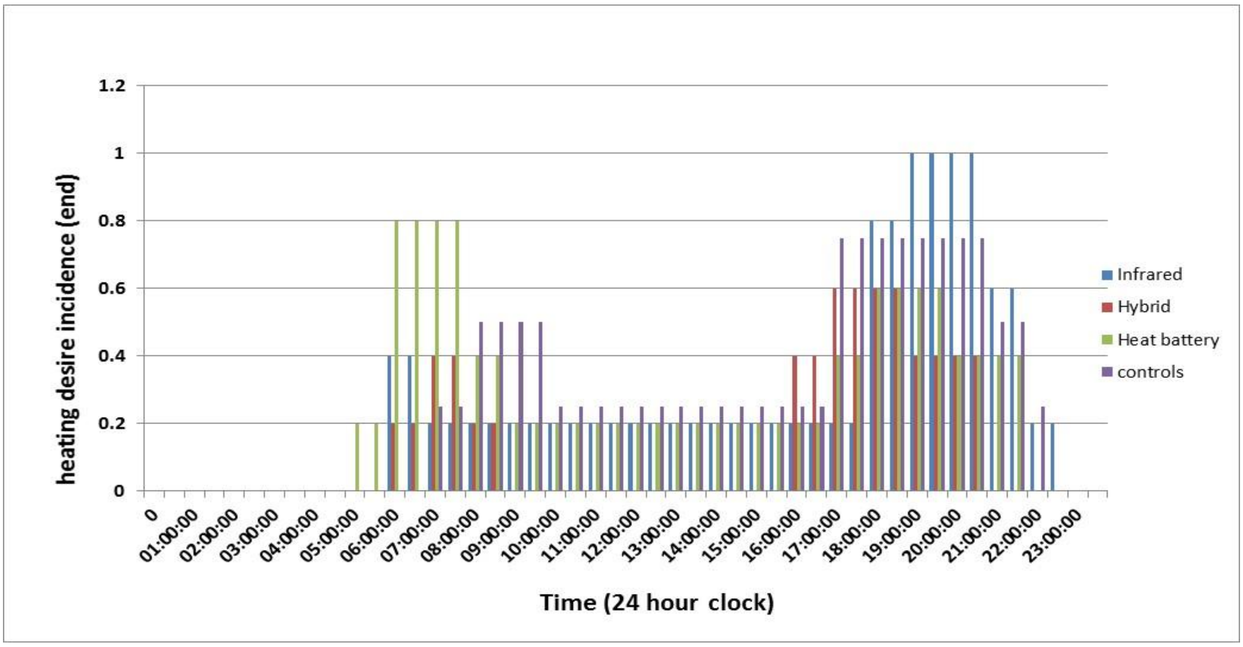
The hybrid heat pump and control groups were more mixed in property type and household occupation.



Graph 2.2 Times when residents stated it was important for them to have a warm home at the start of the project

Households were asked when it was important to them that their home was warm. They were asked this question either just before or just after their new heating system was installed, and again at the end of the project after they had had the new heating for 2 years. The time when most households indicated that they wanted a warm home was in the evening between 5 and 9 pm, with a second peak in the early morning. A few households also wanted heating on during the day.

Those who wanted their heating on during the day were older households and those at home all day. Nobody said that they wanted heating all through the night.



Graph 2.3 Times when residents stated it was important for them to have a warm home at the end of the project

Comparing the responses from the start of the project and 2 years later, shows little change. There is a marginal increase in desire for heat in the early morning, and marginal decrease in requirement for the evening. One property with a heat battery had a change in tenancy, resulting in different times for desired heat. There were also fewer respondents (20 compared to 24 at the start).

2.2 Affordability of energy bills

Electricity tariff

The importance of selecting the correct electricity and gas tariff was explained to all households. This was particularly important for customers who had Sunamp heat batteries and Logicor Infrared radiators installed. The Sunamp heat batteries are designed specifically to run on off-peak electricity, and the infrared radiators which run on a standard electricity tariff mostly replaced storage heaters which run on Economy 7 (E-7)

People who had Logicor infrared radiators installed and who had previously had storage heaters were advised to switch from E-7 to a single rate tariff. They were helped by an advisor from the infrared radiator supplier to switch to very low fixed term tariffs.

Examples of low tariffs tenants were helped to switch to include:

- 8.34 p/kWh + 23.82p/day standing charge with Xtra Energy
- 9.525 p/kWh + 22.602 p/day standing charge with Cooperative Energy (Fixed April 2017 DD)
- 10.395 p/kWh + 20.024 p/day standing charge with nPower (online fix April 2017 DD)

All the above prices include VAT.

These tariffs ran out after a year and the tenants then had to change their tariff themselves. Some were able to do this, but others were not. The fixed rate deals at the end of the first year were not as good as those which had been available at the time of the change of heating system, so even those who were able to switch to another fixed term tariff were not able to get as good a deal. For example, the nPower on line fixed changed to 12.768 p/kWh + 21.42 p/day standing charge in April 2017, representing a 23% increase on the rate per kWh.

Householders who had the Sunamp heat battery installed were encouraged to switch to an Economy 10 tariff (E-10) - the electricity tariff recommended by Sunamp. E-10 allows the battery to charge during three separate off-peak periods per day (midnight to 5 am; 1 pm to 4 pm and 8 pm to 10 pm). (Some E-10 meters are set at GMT and do not change during the summer, others switch to BST). Switching to E-10 can be a difficult process. Not all electricity suppliers offer an E-10 tariff, and those that do will only offer it to existing customers. If your supplier does not offer E-10, you therefore have to switch supplier, wait for 28 days, until you are classed as an existing customer, then contact your supplier again and request an E-10 meter. The supplier will then send out an engineer to change the meter. Three of the six Sunamp heat battery customers managed to switch to E-10 at the beginning of the project, one decided to switch to an E-7 tariff because they wanted to stay with their existing supplier who did not, do E-10. Two customers did not switch to either E-7 or E-10: one thought they had switched, but on investigation it was found they were still on a single rate tariff. PV panels were fitted to this property in the winter of 2017 and the customers decided that they would stay on a single rate tariff. The Sunamp timer was altered to charge the system during daylight hours. The final customer managed to switch supplier, but had two missed appointments for meter changes, and at the end of the project had still not switched to E-10.

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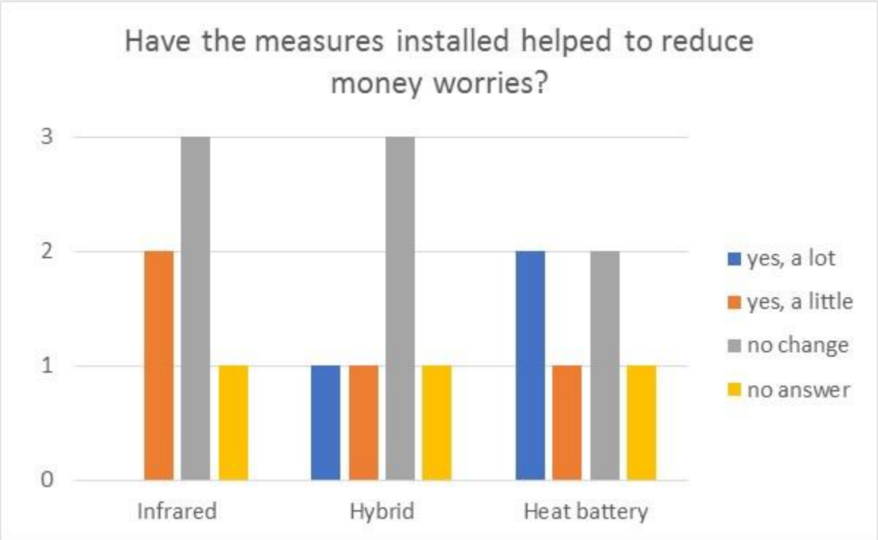
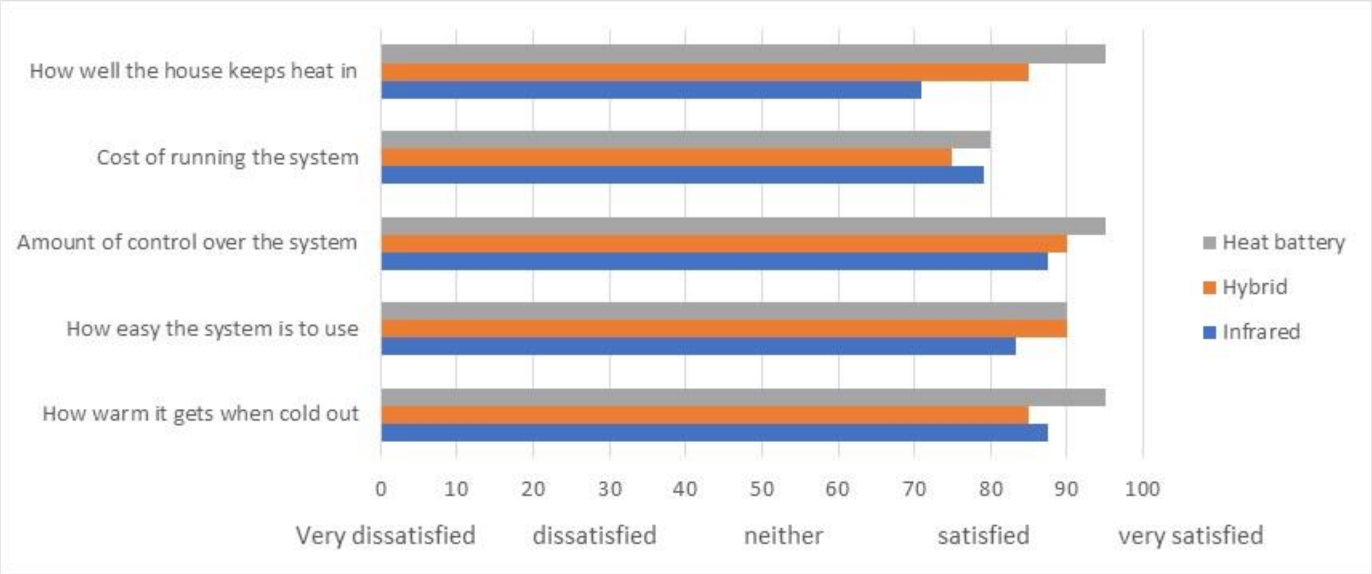
15 out of 16 households said they had changed either their supplier or tariff as a result of the project.

At the end of the project households were asked whether the new heating system had helped to reduce their money worries. The most positive response was from heat battery customers, 3 out of the 5 who answered the question answered yes, while 2 out of 5 of the infrared radiator and 2 out of 5 hybrid customers answered yes. These results are shown in Graph 2.4 below.



Graph 2.4 Customer response about money worries at the end of the project

2.3 Resident acceptance and satisfaction



Graph 2.5 Satisfaction of residents with their new heating system

During the final interviews, householders were asked about their satisfaction with various aspects of their new heating system. The responses were either ‘very dissatisfied’, ‘dissatisfied’, ‘neither’, ‘satisfied’ or ‘very satisfied’. Each of the responses was assigned a score where ‘very dissatisfied’ scored 0, and ‘very satisfied’ scored 100. An average (mean) score of between 0 and 100 was calculated for each question for each type of heating system. Graph 2.5 above shows a chart with the response scores to the statements.

Satisfaction levels with the new heating systems was generally high, with most households responding that they were satisfied or very satisfied with the warmth, cost, controllability, and ease of use. The heat battery scored best in all of the categories. Lowest satisfaction ratings were for how well the home keeps the heat in with the infrared system.

2.4 Ease of use and reliability

There were 6 reliability issues which were brought up during the interviews at the end of the project, as follows:

Infrared radiators:

In one property, one heater was not added to the control panel at commissioning, one heater had an overcurrent error and had switched off to protect itself, meaning that 2 rooms were without heat for a prolonged period.

Hybrid heat pumps:

At one property the boiler failed for 10 days due to problems with the thermostat.

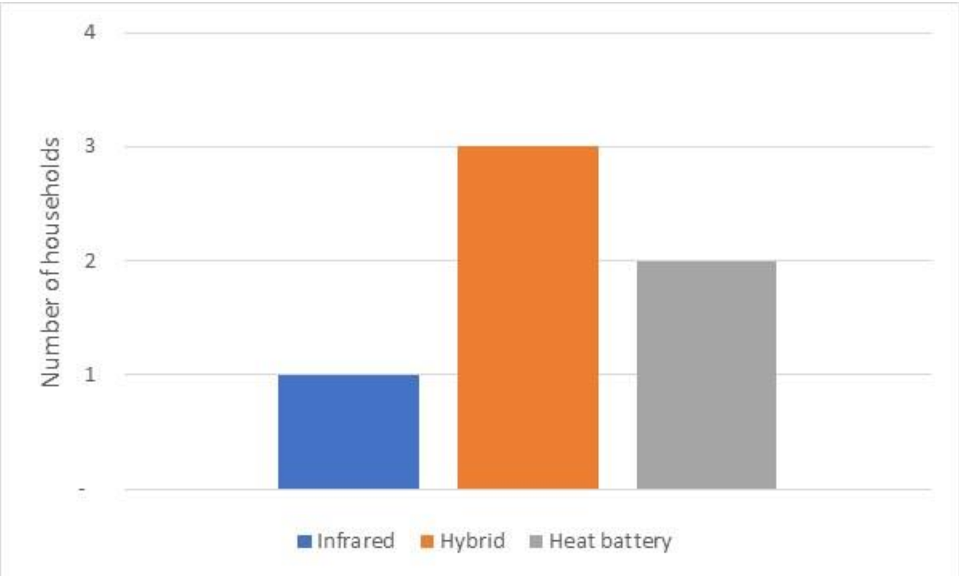
At another property, the system also failed for 10 days due to what was identified as a defective valve in the boiler so that the boiler would not operate.

The third failure with a hybrid system was due to a burst pipe, which was fixed the following day.

Two failures with the hybrid heat pumps took 10 days to resolve, one in the middle of winter. It appears that there was confusion about responsibility, which will have been exacerbated by the fact that the installation contractor had ceased trading, so there was no warranty agreement in place. Ongo Homes maintenance contractor was called out but had not been trained in servicing of the equipment. Daikin were then called, but the call out and subsequent ordering of spare parts took additional time.

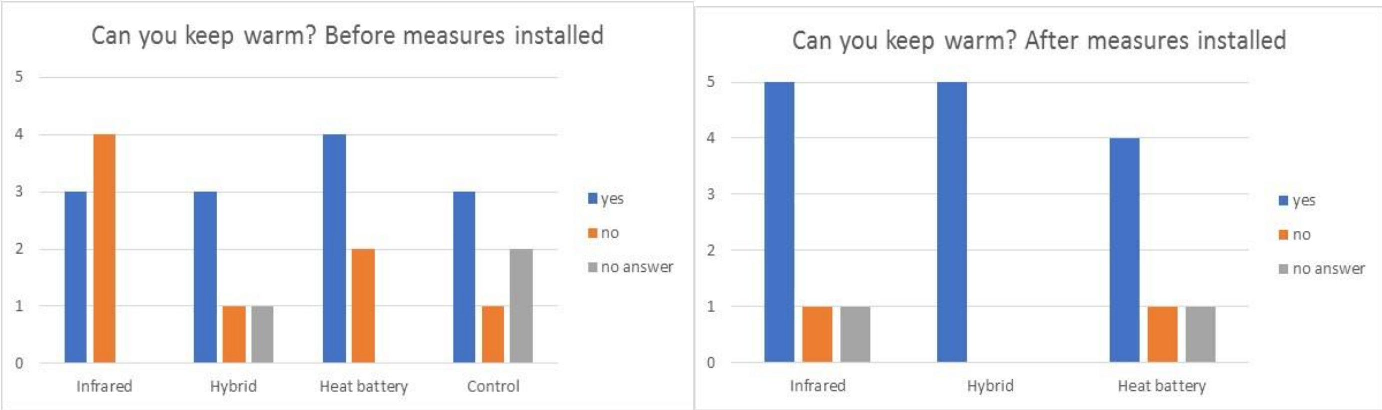
Sunamp heat battery

Two failures were reported, and both related to the system not being set up properly. The first problem was resolved when Sunamp came to put the problem right. The second problem took a long time to identify and resolve. It turned out that the heat battery had been incorrectly installed, but it was only when the weather turned cold and the heat pump was not able to heat the property that it was reported to Sunamp. There were a number of issues at this property, the most significant of which were that the heat pump flow and return pipes had been swapped around while heat meters had been installed. This had a dramatic effect of the operation of the system as the Sunamp Battery was only able to store a small amount of energy.



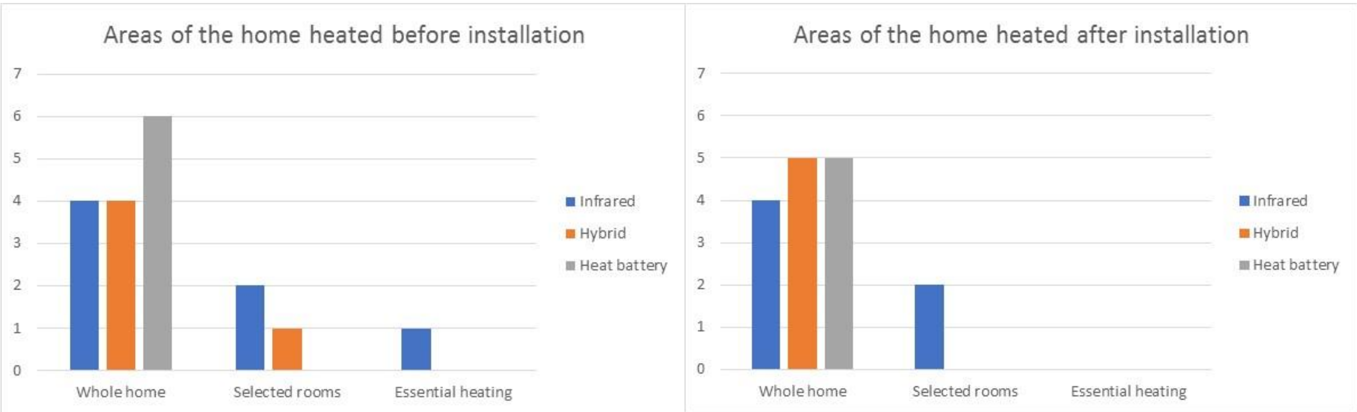
Graph 2.6 Number of households in the monitored group who had reliability issues or breakdown of their heating

2.5 Perceived comfort and benefits



Graph 2.7 Before and after responses to the question "Can you keep warm?"

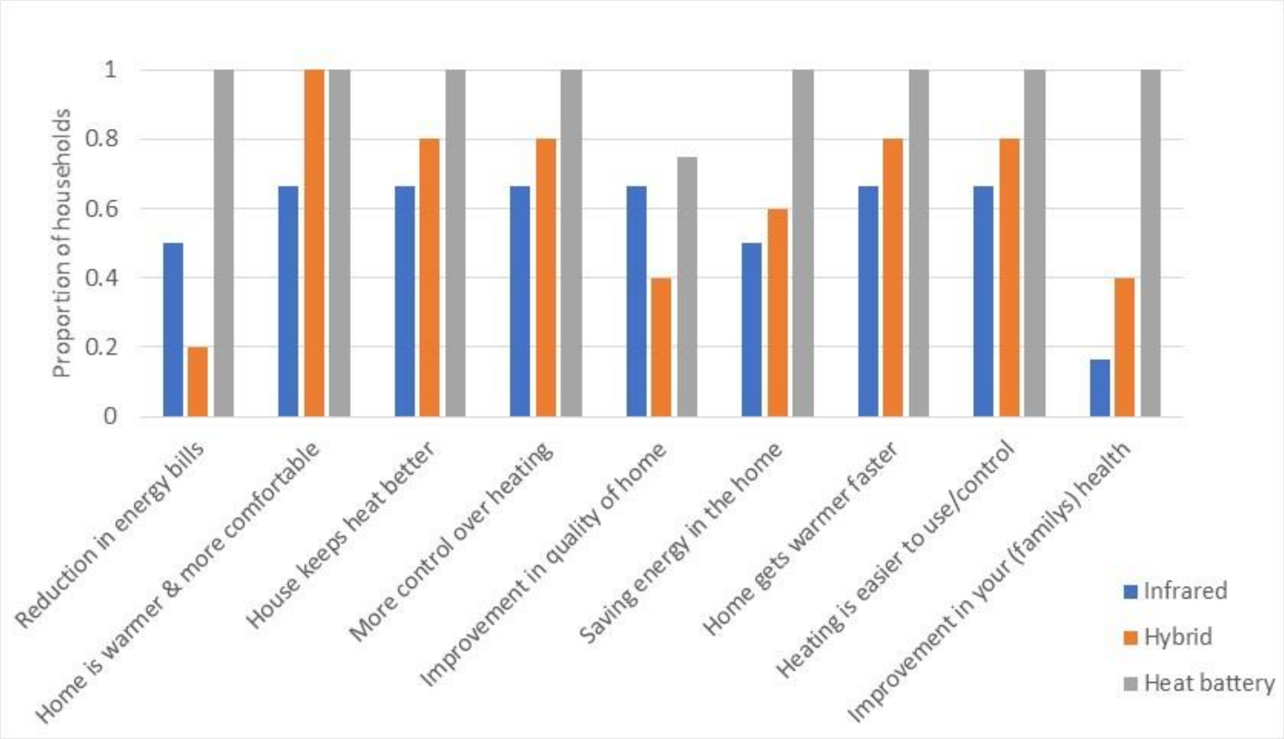
There was an increase in both infrared radiator and hybrid heat pump customers who said that they could keep warm in their homes after the installation of the new heating systems. One of the heat battery customers changed from not being able to keep warm with their old heating system to feeling warm with the new system. There was a move in the opposite direction for one heat battery property, but this is the one where there was a change in tenancy, so the household may have had different expectations. One infrared radiator customer was unable to keep warm.



Graph 2.8 Before and after responses to a question about the areas of the home that were heated

For hybrid and heat battery there was an increase in the number of rooms that were heated following installation of the new heating system, so that all households with these two heating systems felt able to heat the whole home following the change. This included the households who had previously only heated part of their property. There was no increase in whole home heating for the infrared group.

Householders were asked a series of questions about the perceived benefits of their new heating system. The questions were completed by 6 infrared, 5 hybrid and 4 heat battery customers The other 2 Sunamp customers didn't comment (one moved in mid-way through the project, and the other didn't complete the questionnaire).



Graph 2.9 questionnaire responses for attributes of new heating system shown as those who agreed with the statement as a proportion of the total.

The customer perception shows the Sunamp heat battery as the favourite among those questioned, with 4 out of 4 giving a positive response to all questions except 1.

Reduction in Energy Bills

All 4 of the heat battery households thought that their bills had reduced. 3 of the infrared customers thought that their bills had reduced, but only 1 hybrid customer thought they were paying less.

Warmer and more comfortable?

4 heat battery customers, 5 hybrid customers and 4 out of 6 infrared customers thought that their home was warmer and more comfortable. Hybrid customers may have taken savings as improved heat, rather than reduced cost. An increase in internal temperature and the fact that more of the rooms are heated may mean that the bills have not decreased.

Ease of use

4 out of 6 infrared customers thought the system was easier to use. This is again likely to be due to the automated controller.

4 out of 5 hybrid customers thought the system easier to use than their old system. The Daikin simplified room thermostat was specified to control the heating and help to reduce the complexity of control, and this may have been a contributing factor.

4 heat battery customers thought the system was easier to use and they had more control over it. This is not surprising, as their previous heating system was solid fuel, which takes a lot of maintenance, and they have moved to a fully automated system with pre-set times and temperatures on the room thermostat.

Speed to heat up

4 out of 6 infrared radiator customers, 4 out of 5 hybrid customers and all 4 heat battery customers thought that their home heats up faster than with their old heating system.

Ease of use of hot water system

Half of the 6 infrared customers thought that the hot water was easier to use, and 3 about the same

The results from hybrid customers was mixed with 2 saying that they thought it easier to use 1 about the same and 2 not as easy to use. The 2 households who said it wasn't as easy to use said that it took a long time for the hot water to get through to the taps.

This attribute is not shown on the graph. 4 heat battery customers thought the hot water system was easier to use. As with the heating, this is likely to be because they are moving from solid fuel to an automated system.

Summary

Four out of 6 of the households with the infrared heating were positive about its attributes, but 2 consistently marked it down. The cost of running the system meant that these 2 households didn't heat their homes to the temperature they would want and they said that their homes didn't warm up quickly or maintain the heat.

Only 1 out of 5 households with the hybrid heat pump saw a reduction in their energy bills, but all 5 of them said they had a warmer and more comfortable home. 4 out of 5 of the hybrid households thought that their home gets warmer faster and keeps the heat better, that they have more control over their heating and that it is easier to use.

The 4 heat battery customers who answered the questionnaire were very positive about the heating system, giving it a better response rate than the other two technologies.

3. Technical evaluation and results

3.1 Overview of technology

Logicor Infrared Radiators

This is an electric on-peak heater that the manufacturer says gives out radiant heat, meaning that it uses less energy than alternative on peak systems because it stores heat in physical objects, and not the air, providing a more even heat throughout the room. Each heater has its own thermostat meaning that the temperature for each room can be set independently from a central controller. 0.82 kW and 0.43 kW models are available. (Product references**:** GH-518R (820 W), GH518B (430 W)) See figure 3.1 below.

The number and size of heaters are selected based on the floor area of the room. The manufacturer claims that a large heater can cover up to 12 m^2 and a small heater up to 6 m^2 of floor area.

The heaters have a very thin carbon heating element sandwiched between two sheets of toughened glass with a mica insert to minimise rear facing heat loss. Manufacturer's recommendations are that the radiators should be installed on internal walls. More information can be found on the Logicor website http://www.clear-heater.co.uk/clear-heater-system.html

Figure 3.1   Showing GH-518R (left) and GH518B (right) as installed.

The system comes with a wireless controller which communicates with each radiator. The desired time and temperature for each room is set up on the controller. Each radiator has a sensor which records the room temperature so the system knows whether the room is at the desired temperature. If a room is below temperature, then the controller sends a signal to the corresponding radiator to turn it on. The controller has a number of menus, including temperature settings, electricity used, and running costs (current and historic).

Figure 3.2 showing the screen of the wireless controller on the desired temperature page.

In line with manufacturer's instructions, size and number of radiators was determined by the floor area. This meant one infrared radiator was installed in most rooms with two in living rooms. The systems run on a standard electricity tariff. Radiators were set by the installers using the controller on a fixed temperature for each room, so that they run continuously with the same temperature day and night. Some customers left the radiators at the temperature they had been set at, some changed the settings via the controller, while others turned them on / off by the switches on the wall to control the heating.

Daikin Hybrid Heat Pump

This is an air source heat pump combined with a condensing gas combination boiler. It is the first of its kind on the UK market, and is a development that makes best use of both heat pump and condensing gas boiler technology. It can be installed either in properties with mains gas, or with lpg. There are two models of the Daikin hybrid: one with a 5 kW heat pump and one with an 8 kW heat pump: product references: UK.HYBRID.05B33 (5 kW model) UK.HYBRID.08B33 (8 kW model). Both use the same combi gas boiler which provides 33 kW of heat to domestic hot water and 27 kW of heat to the heating circuit. The properties in this project were all connected to mains gas. More information can be found on the Daikin website:
https://www.daikin.co.uk/en_gb/product-group/hybrid-heat-pump.html

Figure 3.3 external heat pump installed on feet with drip tray

Figure 3.4 Boiler / hydrobox installed in an airing cupboard

The hybrid heat pump incorporates a number of technical innovations, so that the system runs as efficiently as possible. The gas boiler provides all the hot water as a combi, with no ned for a water tank. There are three operating modes for space heating.

1. At higher external temperatures, when the coefficient of performance (COP) of the heat pump is at its highest, the heat pump operates alone.
2. When the external temperature drops and the heat pump cannot provide sufficient heat to the property, the gas boiler turns on and works in tandem with the heat pump, with the heat pump preheating the water into the boiler.
3. When the external temperature drops even further and the COP of the heat pump drops, such that it is more economic to use the boiler, the boiler does all of the work.

The set points at which the unit changes its mode of operation are calculated based on gas and electricity prices, and the heat load of the property, ensuring that the cheapest and most efficient use is made of electricity and gas.

The Daikin hybrid heat pump systems were designed with radiator circuits with a flow temperature of 55 ^{0}C and the controls were set with weather compensation varying between 40 ^{0}C at an external temp of 15 ^{0}C, and 55 ^{0}C at -3 ^{0}C outside. The heat pump was therefore designed to work for the majority of the time, and the gas boiler tops up the heat when it is cold outside and heat pump performance is lower.

The internal calculator in the heat pump controller uses gas and electric prices, together with its known COP and the measured external temperature to decide whether to use the ASHP, boiler or both. For this project the gas price was set at 4p/kWh and electricity was set at 12p/kWh at all properties

Sunamp Heat Battery

This is a heat storage system using phase change materials (PCMs) to store a concentrated amount of heat in a relatively small space. The Sunamp Battery shifts the heat load to an off-peak electricity time, meaning reduced running costs for the householders and reduced stress on the electrical network.

A high temperature heat pump charges the heat battery during off-peak periods on an Economy 7 or Economy 10 electricity tariff. The store then discharges its heat when required via a radiator circuit at a flow temperature of 55 ^{0}C. The only energy that is used during on-peak times is the central heating pump to circulate water round the radiators. During off-peak times, when the system charges up, not only does the customer get the benefit of a low electricity tariff, but they also get the benefits of the heat pump extracting renewable energy from the air.

If the Sunamp Battery runs out of charge because there has been extra demand on the heating or hot water, then the heat pump can directly supply the heating circuit during on-peak tariff periods at a flow temperature of 55 ^{0}C.

The 11 kW high temperature Daikin heat pump (ERSQ011AV1) provides heat to the system. This is a split system heat pump with an external unit linked to a hydrobox by refrigerant pipes. It extracts heat from the outside air in the same way as any other air source heat pump, except that it has a second compressor in the hydrobox which can raise the flow temperature up to 80 ^{0}C. When coupled to the Sunamp Battery the flow temperature is set to 71 ^{0}C. This is sufficient to enable a full melt of the PCM within the battery which melts at 56 ^{0}C. A Sunamp control box has a timer which calls for heat from the heat pump to charge the battery at times of off-peak electricity rate. This can be set to match Economy 7, Economy 10, or any other required times, e.g. daylight hours if a property has a PV system.

The battery has 18 cells of PCM and a plate heat exchanger linked together see figure 3.7 below, giving a total heat storage capacity of 40 kWh. A room thermostat in the property calls for heat from the battery and can be set by the householder. This is completely independent from the charging times, so heat is called for when needed in the home. Domestic hot water is supplied directly via a plate heat exchanger at the top of the battery. If the battery is depleted of heat and there is a call for heat from the room thermostat, the heat pump is turned on and supplies heat directly to the heating circuit without charging the battery. This means that heat may be supplied directly during times of peak electricity cost.

Figure 3.5 Sunamp heat battery and hydrobox

Figure 3.6 Daikin external high temp heat pump unit

The battery itself is 1900 x 950 x 750 mm. The Daikin high temperature hydrobox is 705 x 600 x 695 mm.

Figure 3.7 Sunamp heat battery with the cover removed showing the cells of PCM and plate heat exchanger at the top.

3.2 Technological monitoring

All properties

Temperature and humidity in the monitored properties were recorded every hour using a Lascar EL-USB-2 temperature and humidity logger[10]. These were placed in the living rooms and the bedrooms at a location that would provide a representative temperature for the room. This was away from windows and external walls away from any heat sources, away from the sun, and somewhere that it would not be dislodged easily.

External temperature was also logged at two site locations.

Households taking part in the study were asked to regularly record gas and electricity meter readings in a simple log book. Recent and historic meter readings were obtained from energy bills and by contacting their energy supplier. These were used to assess the electricity and, where appropriate, gas consumption before and after the installation of the new heating system.

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[10] Lascar EL-USB-2 datasheet https://www.lascarelectronics.com/media/2925/easylog-data-logger_el-usb-2.pdf (Accessed 12 May 2017)

Monitoring of infrared radiators

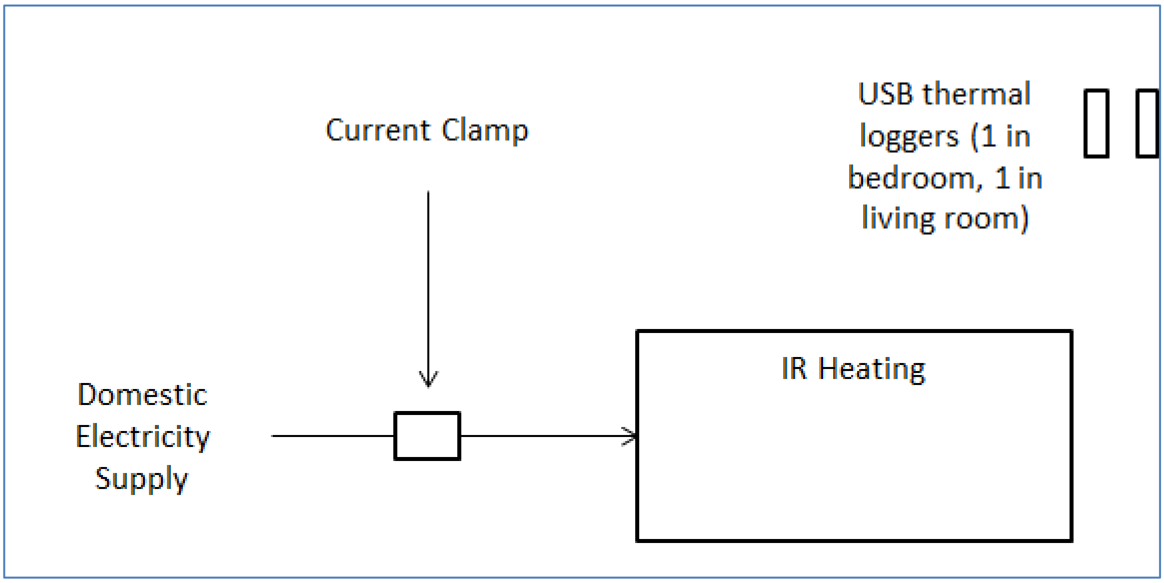


Figure 3.8 – Schematic diagram of monitoring equipment placed in properties receiving infrared radiators,

Properties with infrared radiators that were selected for monitoring had 1 or 2 current clamps with data loggers installed. In some properties a single current clamp was installed, and in others two current clamps were fitted. The first current clamp was fitted on the main incoming electrical cable. If a second was fitted, this was on the supply to the heating circuit.

Figure 3.9 showing two current clamps installed on the neutral cable to the heating consumer unit and on the neutral cable to the main consumer unit.

Monitoring of hybrid heat pumps

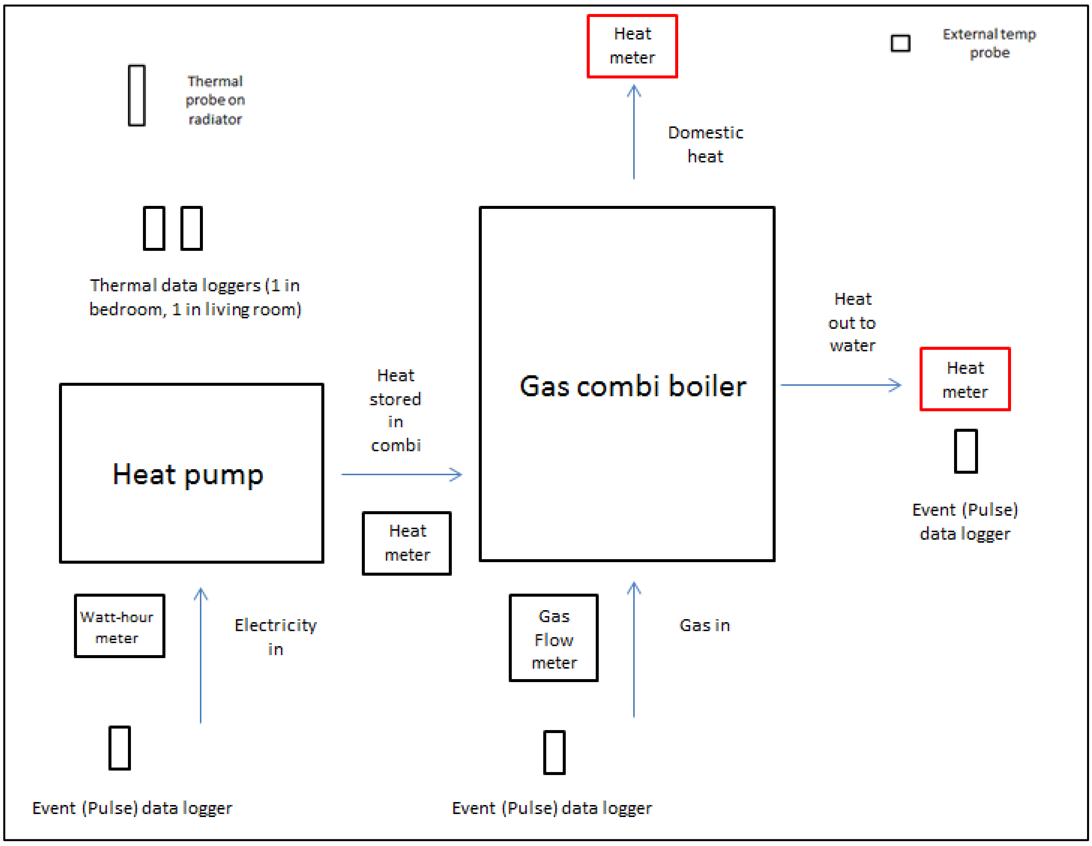


Figure 3.10 – Schematic diagram of monitoring equipment placed in properties receiving hybrid heat pumps,

A Watt hour meter, three heat meters and a gas meter were installed on 6 of the Daikin hybrid systems. The Wh meter measured electrical input to the heat pump with a pulse logger measuring the number of Wh of electricity every 5 minutes. The gas meter measured gas input to the gas boiler. The heat meters measure:

1. heat output from the heat pump before it goes into the central heating circuit of the gas boiler
2. heat output from the gas boiler into the central heating circuit. (this heat meter included a pulse logger measuring each kWh of heat generated.)
3. heat output from the gas boiler into domestic hot water. (this heat meter included a pulse logger measuring each kWh of heat generated.)

The measured data from these enabled a calculation of:

- the heat input to the central heating circuit by the gas boiler by subtracting 1 above from 2 above;
- the SCOP (Seasonal coefficient of performance) of the heat pump, by dividing 1 above by the output from the Wh meter;
- the efficiency of the gas boiler calculated from ((2 above – 1 above) + 3 above)/ gas input to boiler.

In addition, the surface temperature at the bypass radiator was recorded at 30-minute intervals.

Figure 3.11 picture of pipework, and monitoring equipment below a boiler / hydrobox, showing gas meter and 3 heat meters.

Monitoring of Sunamp heat batteries

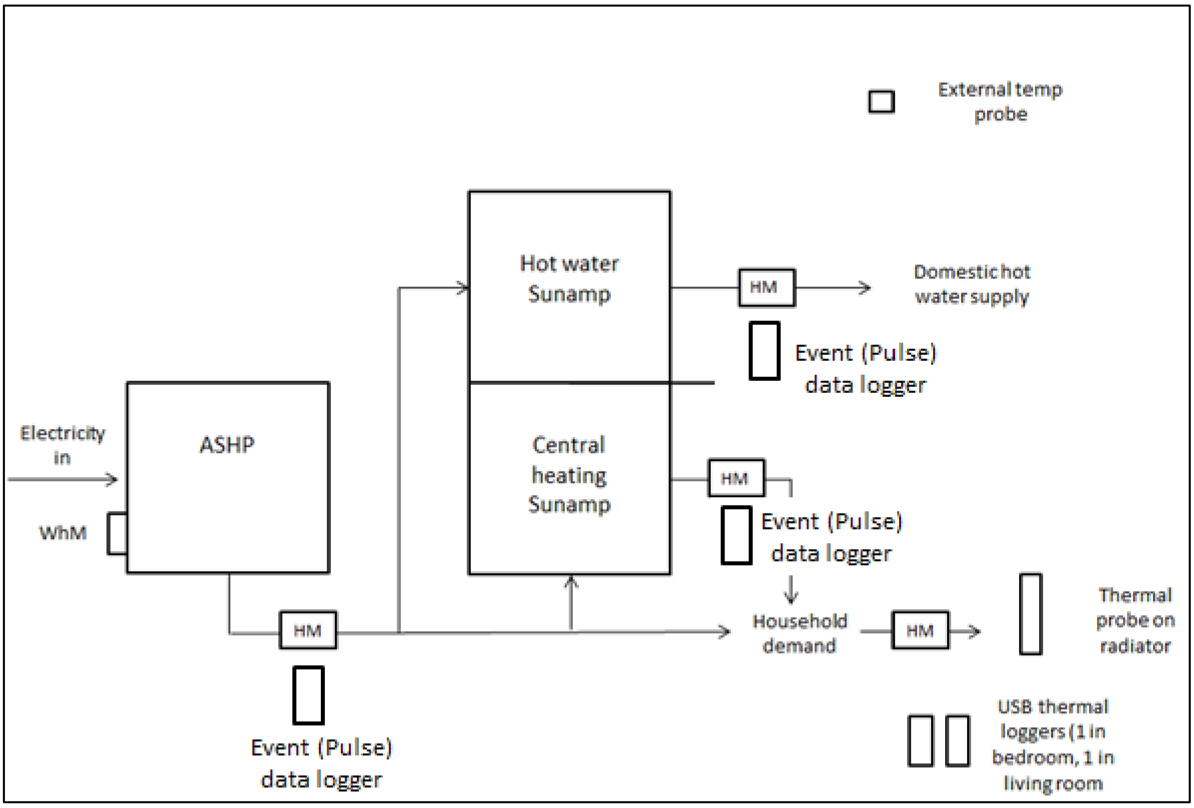


Figure 3.12 – Schematic diagrams of monitoring equipment placed in properties receiving Sunamp heat batteries,

A Watt hour meter and three heat meters were installed on each Sunamp system.

The Wh meter measured electrical input to the heat pump, with a pulse logger recording the number of Wh pulses of electrical input to the system every 5 minutes.

The heat meters included a pulse logger recording every kWh of heat measured:

- heat output from the heat pump / input to the heat battery
- heat output from the heat battery into the central heating circuit
- heat output from the heat battery into domestic hot water

The measured data from these enabled calculation of the SCOP of the heat pump, and the proportion of heat lost from the heat battery and inefficiencies in the system.

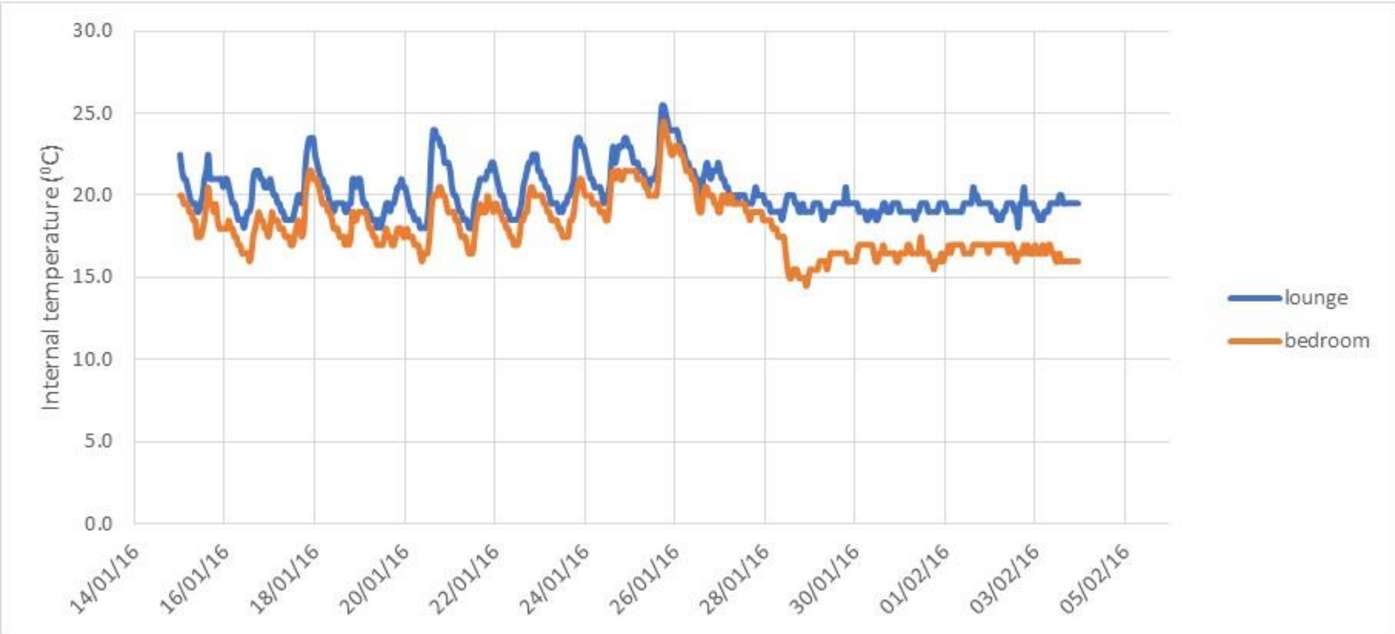
In addition, the surface temperature at the bypass radiator was recorded at 30-minute intervals.

3.3 Results from monitoring equipment

Logicor Infrared radiators

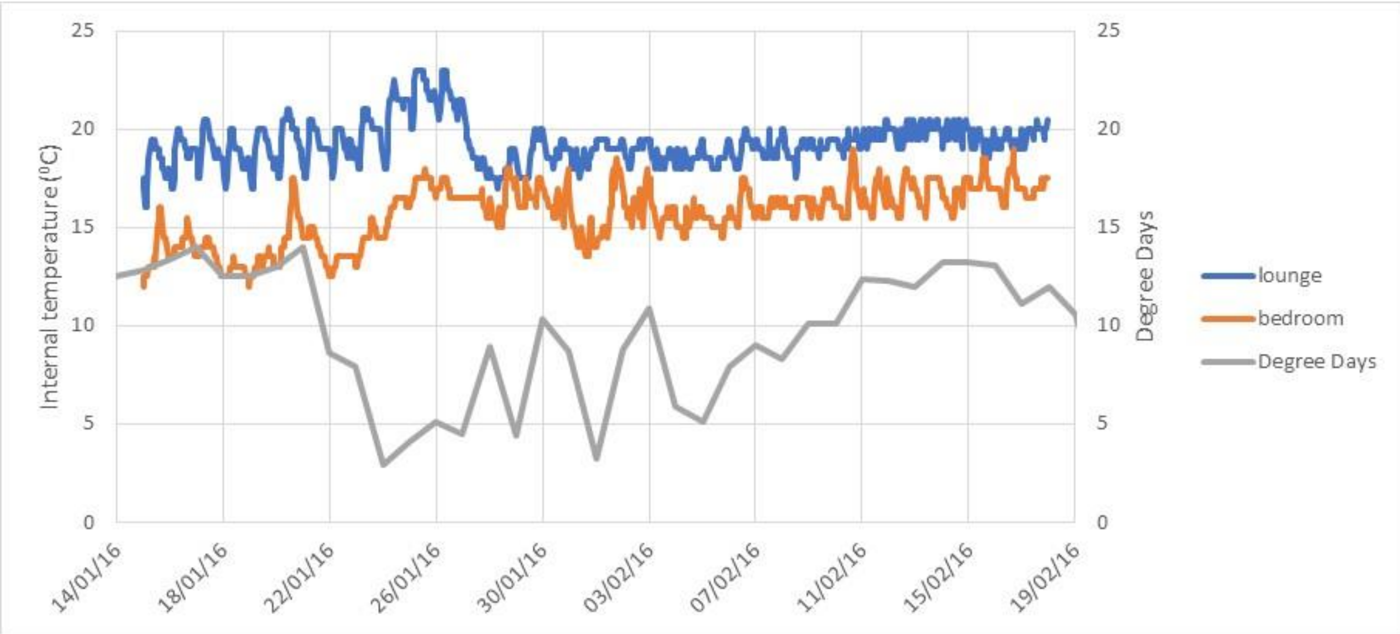
Internal temperatures

Looking at the recorded temperatures in properties that had infrared radiators installed, in most properties a stabilisation of temperature is observed, with much less variability from day to night. Four examples are shown below.



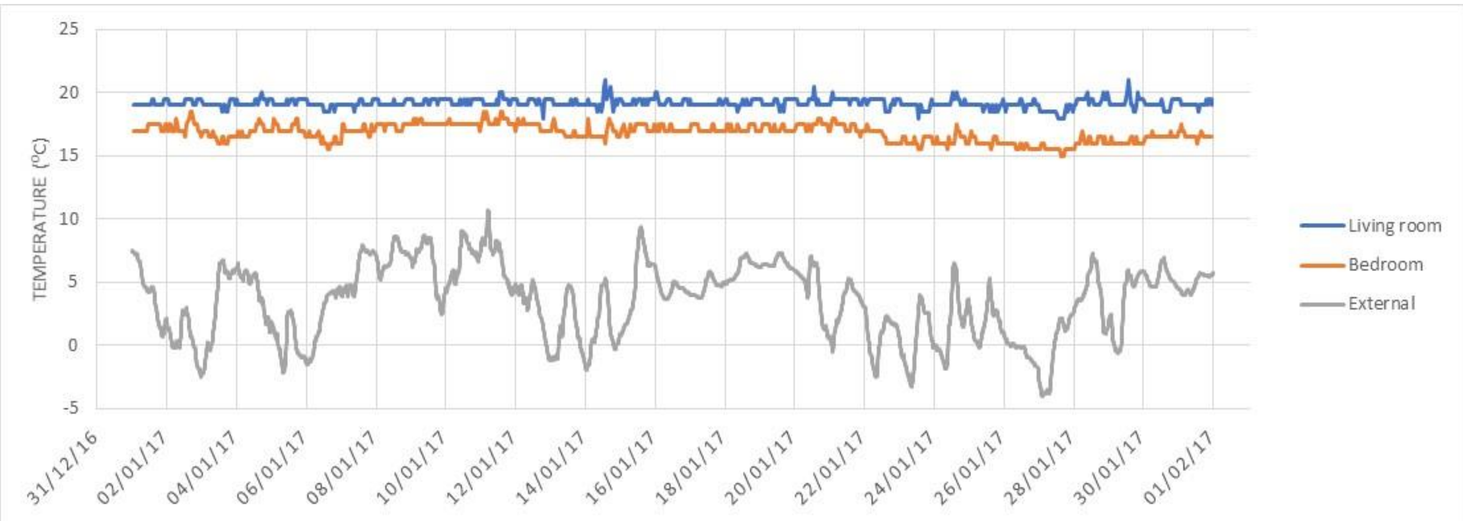
Graph 3.3.1 Property T-10 internal temperatures 15 Jan 16 to 4 Feb 16

The infrared radiators were installed at property T-10 on 28 and 29 Jan. Graph 3.3.1 above shows the internal temperatures at this property before and after the installation date. The difference between the variable temperatures resulting from the solid fuel heating before and the infrared radiators afterwards can be clearly seen.



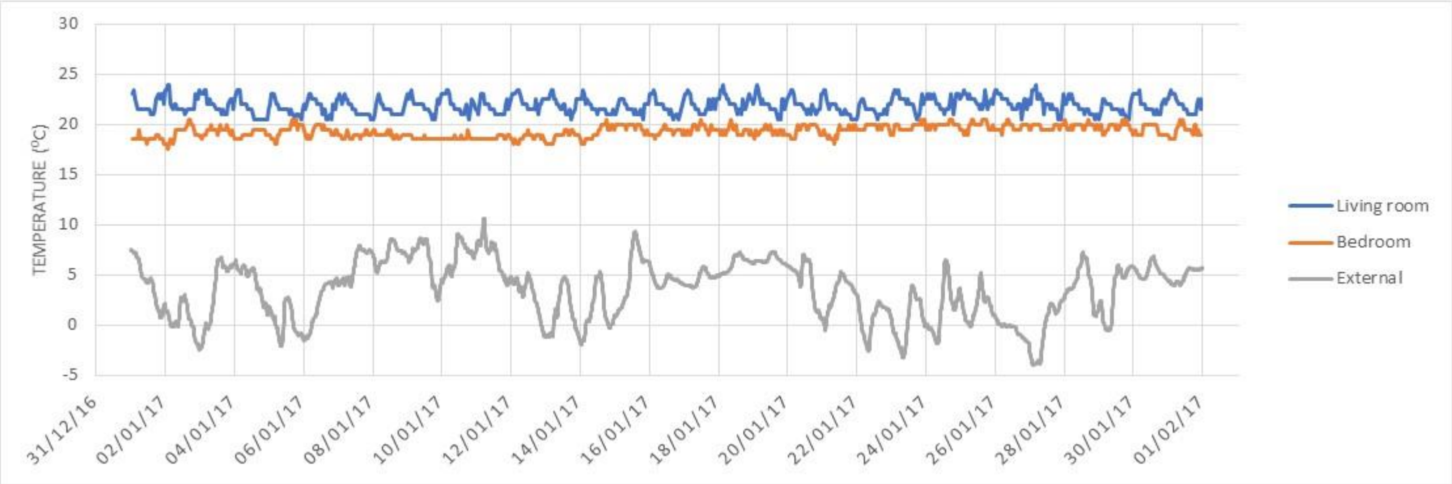
Graph 3.3.2 Property T-5 internal temperatures and degree days 15 Jan to 15 Feb 2016

The infrared radiators at property T-5 were installed on 28 and 29 Jan. Graph 3.3.2 above gives a time before and after installation and again shows a stabilisation of temperatures following installation of the infrared radiators. The difference between the variable heating of the storage heaters before and the infrared radiators afterwards can be seen. This time a degree day line has been added to the graph. This shows that during the period when the storage heaters where heating the property, as the weather gets warmer illustrated by lower DD values (23 to 27 Jan), the internal temperature increases. Storage heaters are not easy to control and so internal temperature often tracks external temperature.



Graph 3.3.3 Property T-10 internal and external temperatures 1 Jan to 31 Jan 2016

The consistent internal temperature in the living room and bedroom in property T-10 resulting from the infrared radiators can be seen in graph 3.3.3 above despite a variable external temperature.

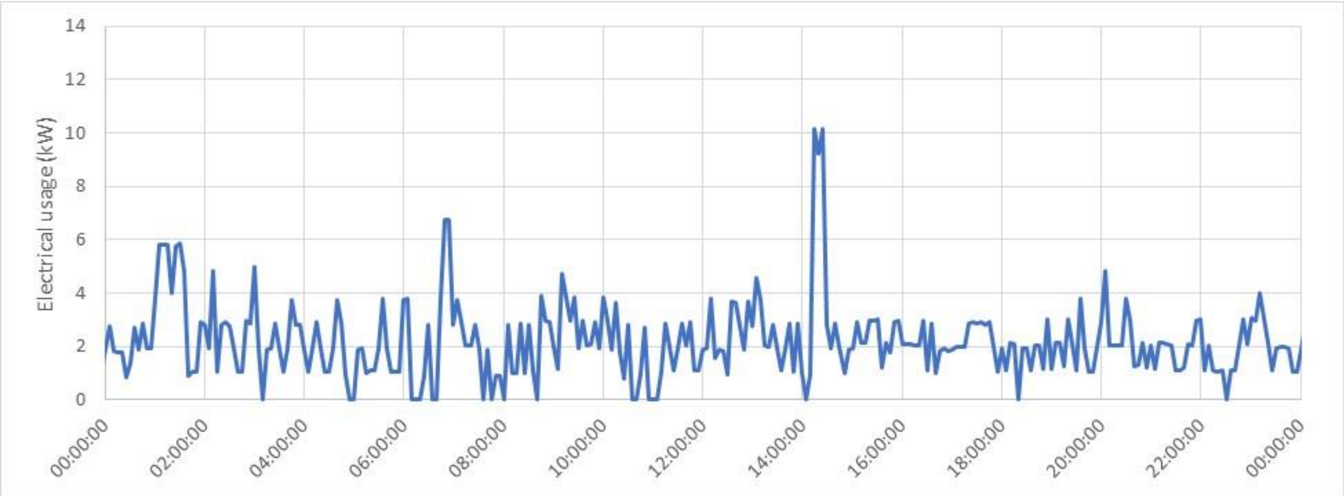


Graph 3.3.4 Property T-22 internal and external temperatures 1 Jan to 31 Jan 2016

Graph 3.3.4 above gives another example of internal temperatures during January 2017. There is more variability in the living room temperature, but the bedroom temperature is more consistent.

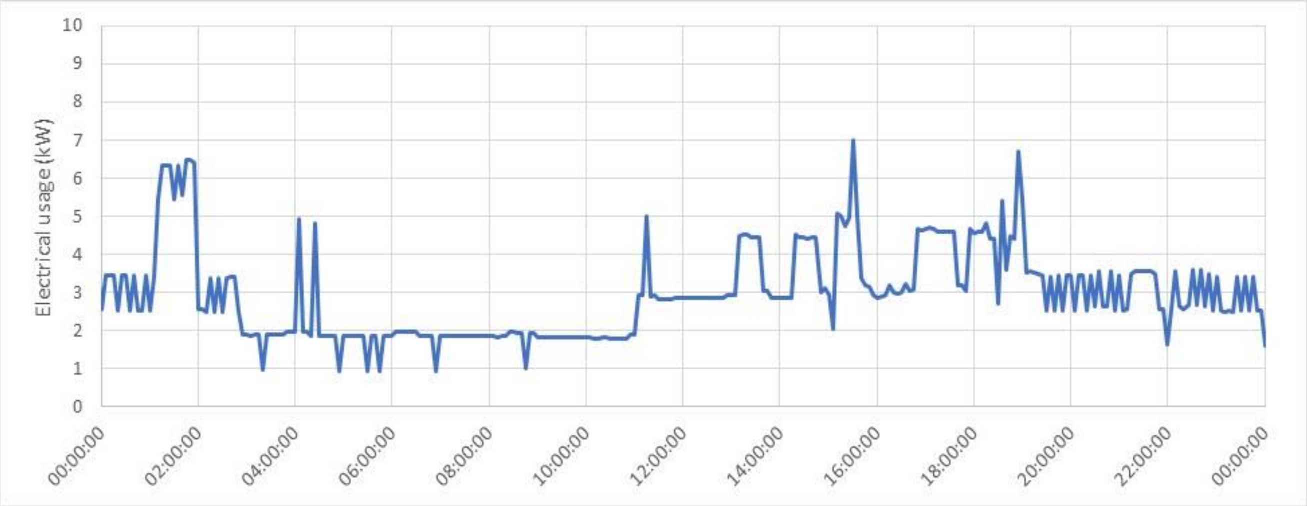
Electrical usage over time

The current clamps measure the average current passing through an electric cable. Readings were taken every 5 minutes and recorded in a data logger. From the current readings, and assuming a voltage of 230 V, the average power passing through the cable can be calculated every 5 minutes.



Graph 3.3.5 Property T-12 total property electrical usage 21 Jan 2018

Graph 3.3.5 above shows an example of the readings from a current clamp. This one is in property T-12 and shows the total electrical usage at the property for 21 Jan 2018. The electricity usage is fairly consistent throughout the period, with only short peaks. Average electrical power over 24 hours = 2.18 kW, giving a total usage of 52.2 kWh for the day.

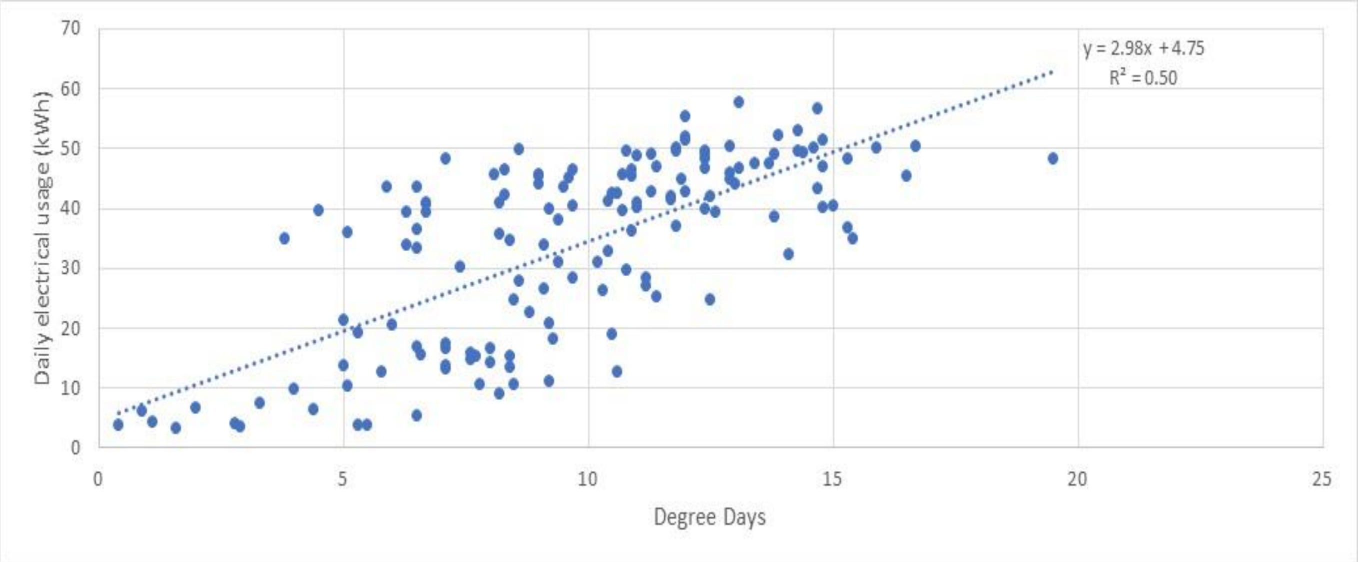


Graph 3.3.6 Property T-22 total property electrical usage 21 Jan 2018

Graph 3.3.6 above shows another example of total property electrical usage. This time from the current clamp at property T-22.

Average electrical power over 24 hours = 2.22 kW, giving a total usage of 53.2 kWh for the day.

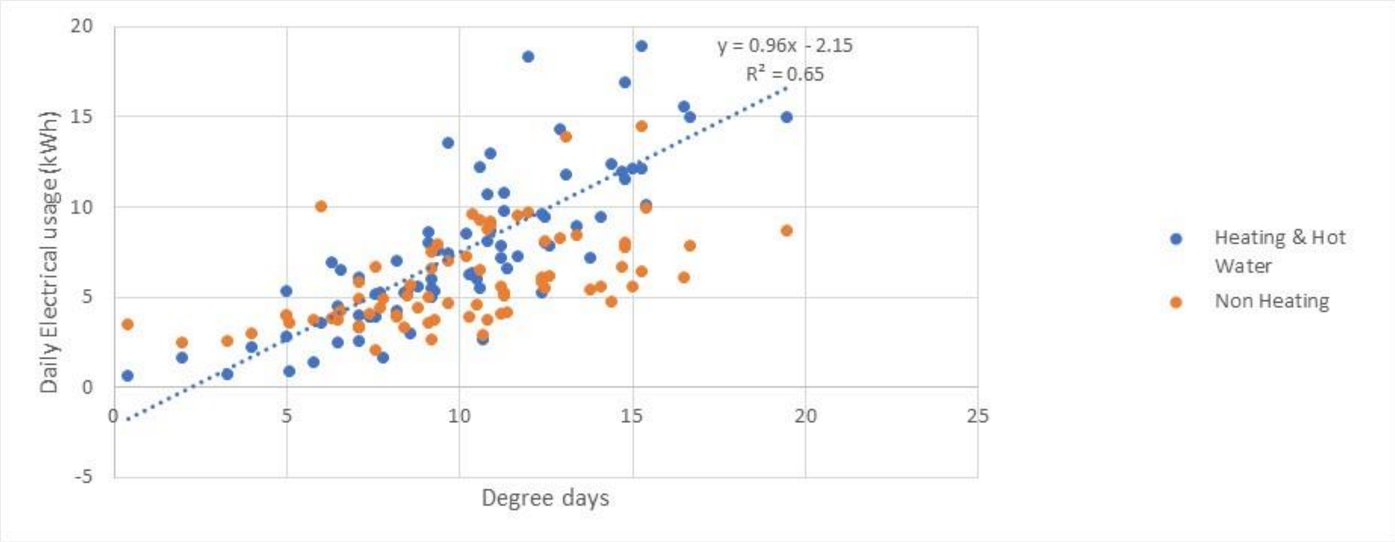
When compared to readings taken from the electrical utility meter, this current clamp records with an error rate of 6.1%. Over the period 7 December 2017 to 2 February 2018 (58 days), the current clamp recorded 3,028 kWh, while the electric meter changed by 3,226 kWh.



Graph 3.3.7 Property T-12 total daily electrical usage against degree days for 6 Dec 2017 to 1 May 2018

Plotting the total daily electrical usage against degree days shows how the electrical usage varies compared with external temperature as demonstrated in Graph 3.3.7 above.

The total readings from the current clamp of 4,926 kWh at property T-12 compared well with electric meter readings for the same time period of 5,095 (3.3% difference). Over this time period average internal temperatures were 19.78 ^{0}C in the living room and 17.48 ^{0}C in the bedroom.

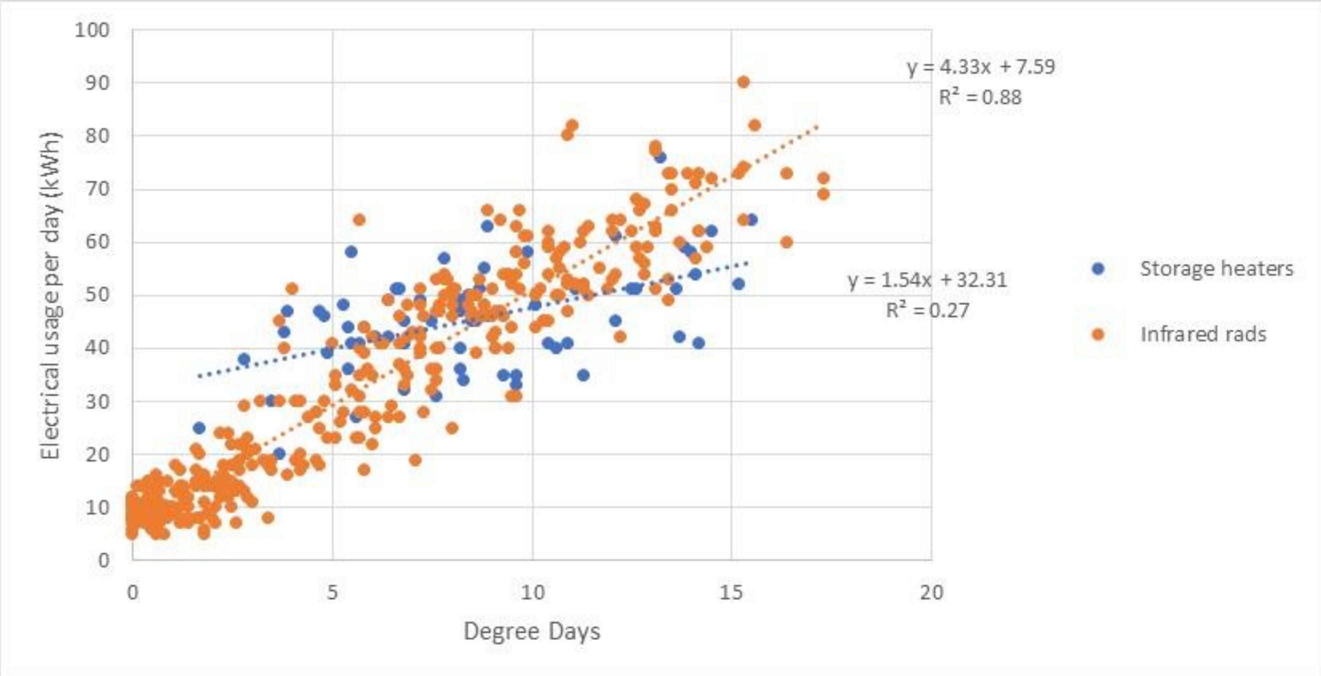


Graph 3.3.8 Property T-4 daily electrical usage against degree days for 3 Feb to 19 April 2018

Graph 3.3.8 shows data from a property where two current clamps were used: one on the cable to the consumer unit supplying the infrared radiators and hot water cylinder, the other on the main consumer unit which included everything else in the property including an electric fan heater in the bathroom (there is no infrared radiator in the bathroom).

The readings from these current clamps do not appear to be very accurate. When compared against readings taken from the electric meter, there is a discrepancy of 28%. For the period in the graph above, the current clamps showed total electricity consumption for heating & hot water was 443 kWh, while other electrical usage in the property was 552 kWh (total = 995 kWh). Between these two dates, the difference in electric meter readings for the property was 1,355 kWh.

The readings give an indication of what is happening in the property, but not with acceptable confidence. It is not known whether one or both of the current clamps have been reading inaccurately, (it is unlikely that the utility electric meter is inaccurate). It can be seen that there is a correlation between the electrical input to heating & hot water and degree day data. This property was not particularly warm, with an average temperature over the above measurement period of 18.6 ^{0}C in the living room and 18.1 ^{0}C in the bedroom. Current clamps are dependent on careful installation with jaws fully closed, and free from other close proximity magnetic interference.



Graph 3.3.9 Property T-22 total daily electrical usage against degree days for 19 Nov 2015 to 10 April 2018

The householder at property T-22 kept a daily log of electricity usage, which meant that the cost of running the system could be represented graphically against degree day data. The graph above shows the total daily electricity use against degree days for this property which had storage heaters replaced by infrared radiators. The graph covers a period of 10 (winter) weeks with the storage heaters and two full years with new infrared radiators. It can be seen that there is a linear relationship (R^2 = 0.88) between the amount of electricity used by the infrared radiators and daily external temperature. The electricity use for the old storage heat system shows lower correlation (R^2 = 0.27), showing the difficulty of controlling this type of heating.

Properties T-5, T-10 and T-119 had solar PV panels installed part way through the project. Current clamps are not able to differentiate between electricity being imported or exported from a property. The readings from the current clamps at these three properties were therefore not able to be used for analysis.

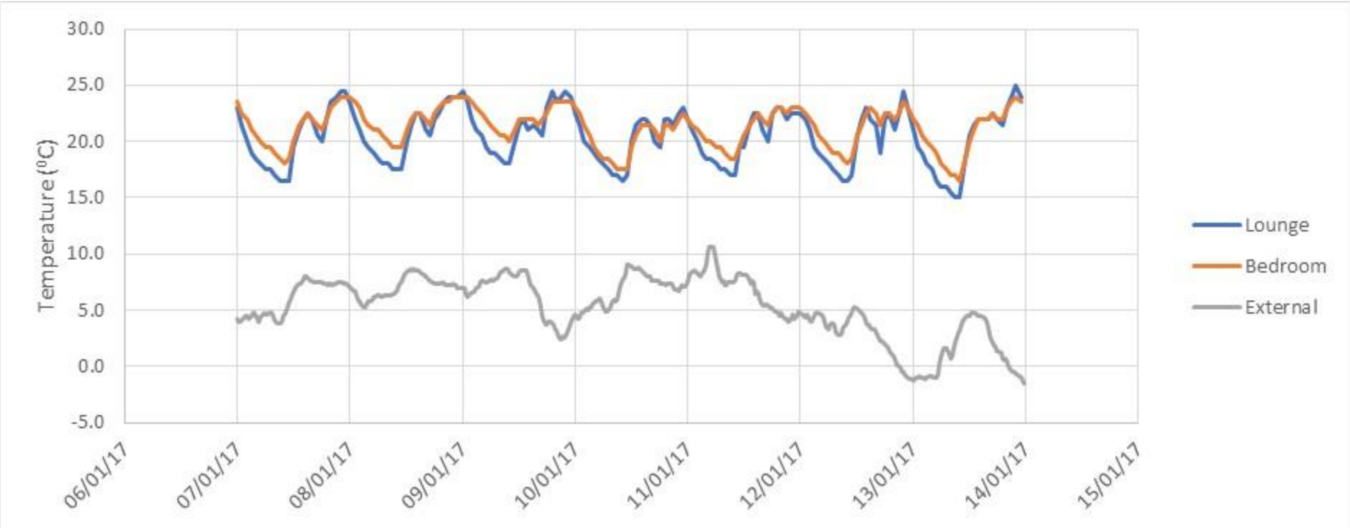
Daikin hybrid heat pump

Internal temperatures

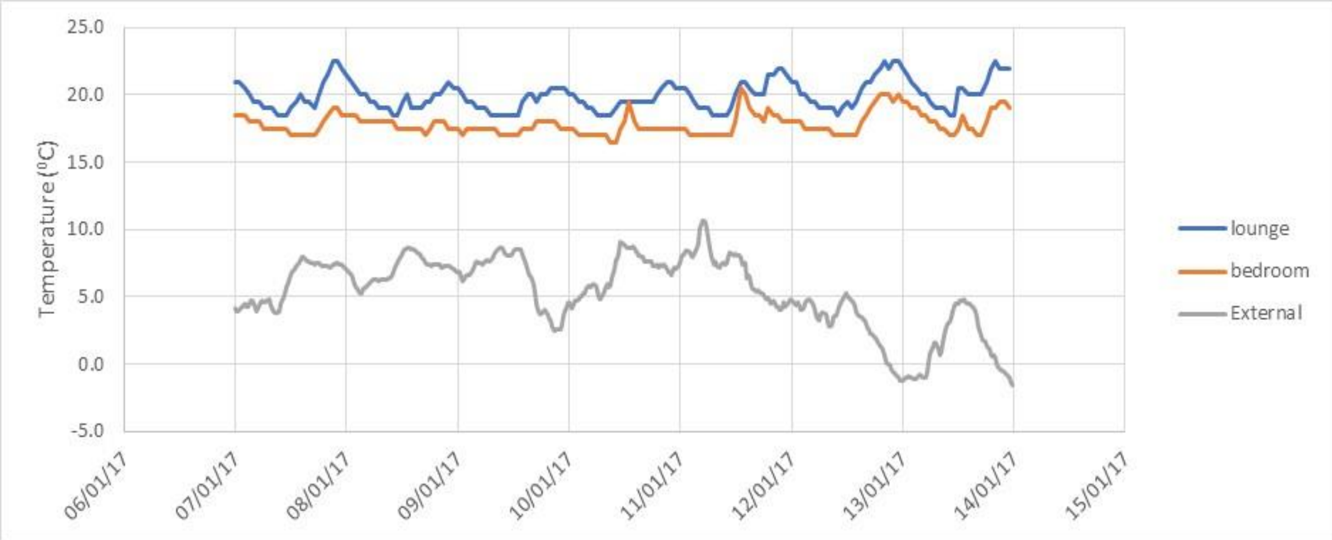
Only one of the hybrid properties had internal temperature monitoring equipment placed before the installation of the new heating. This was property T-20, which had a solid fuel fire with back boiler.

Graph 3.3.10 Property T-20 internal temperatures 13 to 20 Dec 2015

Before and after temperature graphs for property T-20 show that with the solid fuel heating, the lounge temperature was more variable than the bedroom and there was one heating cycle per day (Graph 3.3.10 above) After installation of the hybrid heat pump both the lounge and bedroom varied by more than 5 ^{0}C per day, with two heating cycles per day (Graph 3.3.11 below).



Graph 3.3.11 Property T-20 internal and external temperatures 7 to 14 Jan 2017



Graph 3.3.12 Property T-73 internal and external temperatures 7 to 14 Jan 2017

Graph 3.3.12 gives another example of internal and external temperatures at a property with a hybrid heat pump.

Gas and electrical inputs and heat outputs

The following graphs show examples of data taken from the gas meter logger measuring gas input to the boiler, heat meter to the heating circuit, heat meter to the domestic hot water circuit (DHW) and Wh meter pulse logger measuring electrical input to the heat pump. The third heat meter that was installed to measure the heat output from the heat pump before it goes into the gas boiler did not have an electronic or digital output, so it cannot be used in this analysis. Readings were taken from this heat meter screen at every home visit to enable SCOP values for the ASHP and boiler efficiencies to be calculated.

The heat meter measures every kWh of heat which passes through the meter, so the points on the graph are the time at which the next full kWh has been registered.

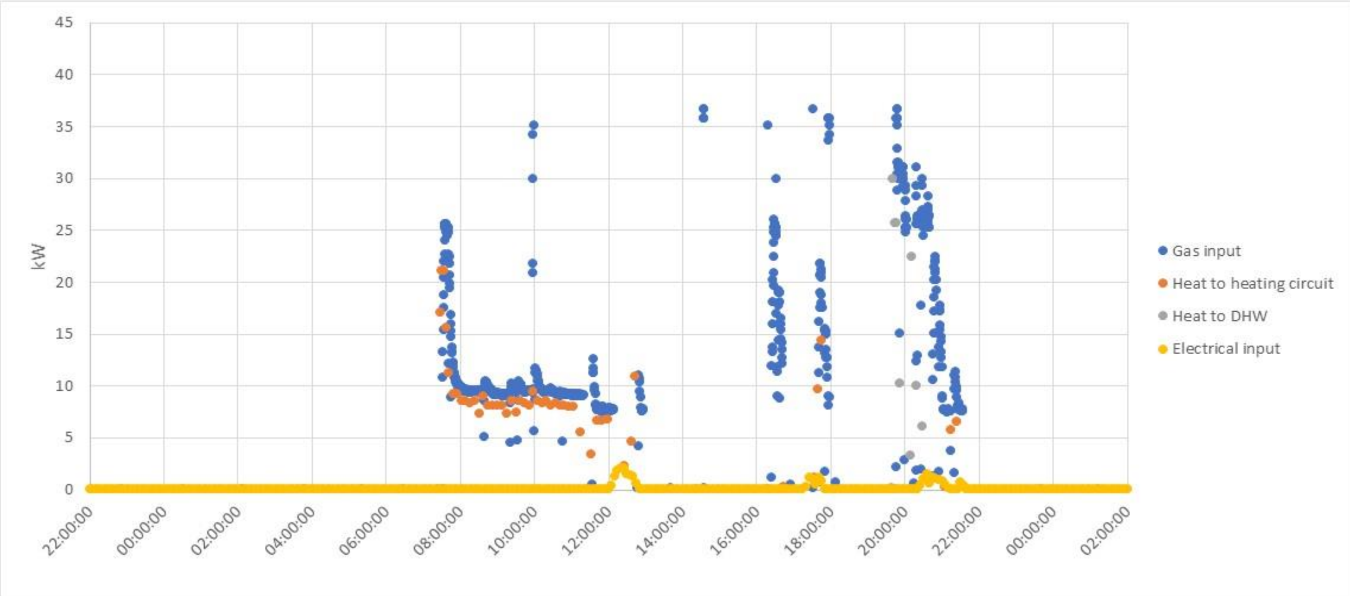
The Watt hour meters log every Wh of electrical input to the heat pump with the logger recording the number of pulses in every 5-minute period, so give a far more accurate picture of when the heat pump is using energy.

The gas meters measure every 1/100 m^3 of gas, which equates to 0.112 kWh. Every 9 events (represented by 9 dots on the graph) recorded by the gas meter equals approximately 1 kWh, The difference in resolution means that often the electrical input to the heat pump appears to come on before any heat is registered from the heat pump into the heating circuit.

The energy vectors are the areas under each set of dots on the graph.

When the boiler is providing heat to the heating circuit, the blue dots (gas input) are slightly above the orange dots of heat output, showing the inefficiency of the gas boiler.

High outputs from the boiler, often of short duration are mostly heat to DHW. Often no DHW flow is shown because the resolution of the heat meter is a ninth of that of the gas meter and the heat meter on the DHW circuit has not passed the next kWh.

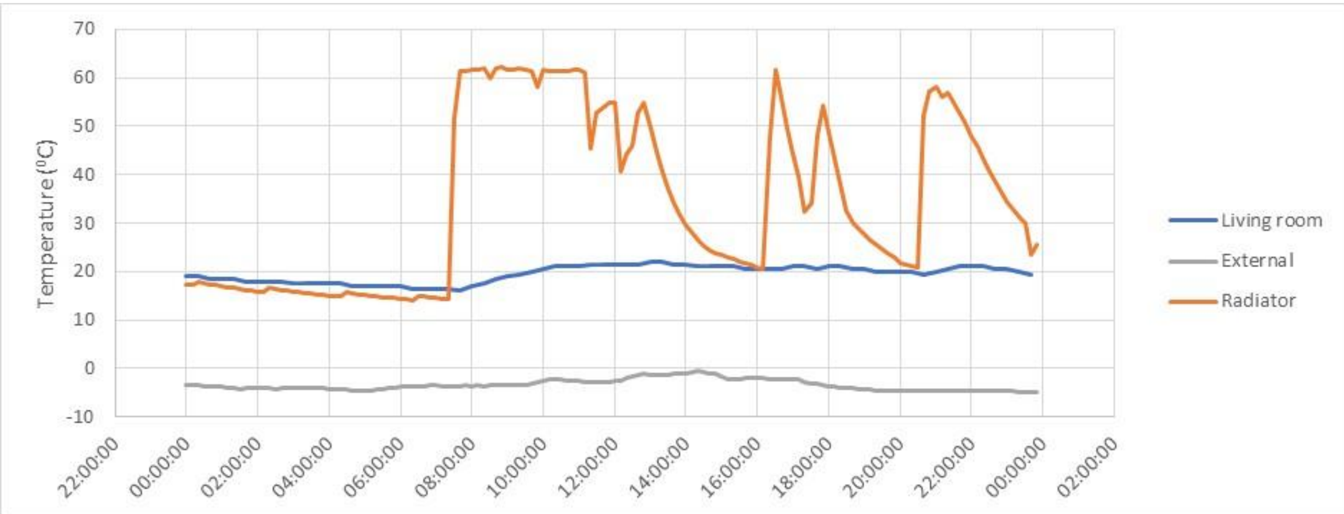


Graph 3.3.13 Property T-73 gas and electrical input to hybrid and heat output for 28 Feb 2018

Graph 3.3.13 above shows readings taken from property T-73 for gas and electrical input to the hybrid heat pump and heat flow to DHW and heating circuit for 28 Feb 2018. This was a very cold day with recorded Degree Days of 19.5, meaning an average external temperature of -4 ^{0}C.

The heating comes on at 7 am, and after an initial spike in heat output from the gas boiler, the system modulates and reduces to an input of about 10 kW, and output of 8 to 9 kW. In the afternoon / evening there are short term, high gas input events providing energy to both heating and DHW.

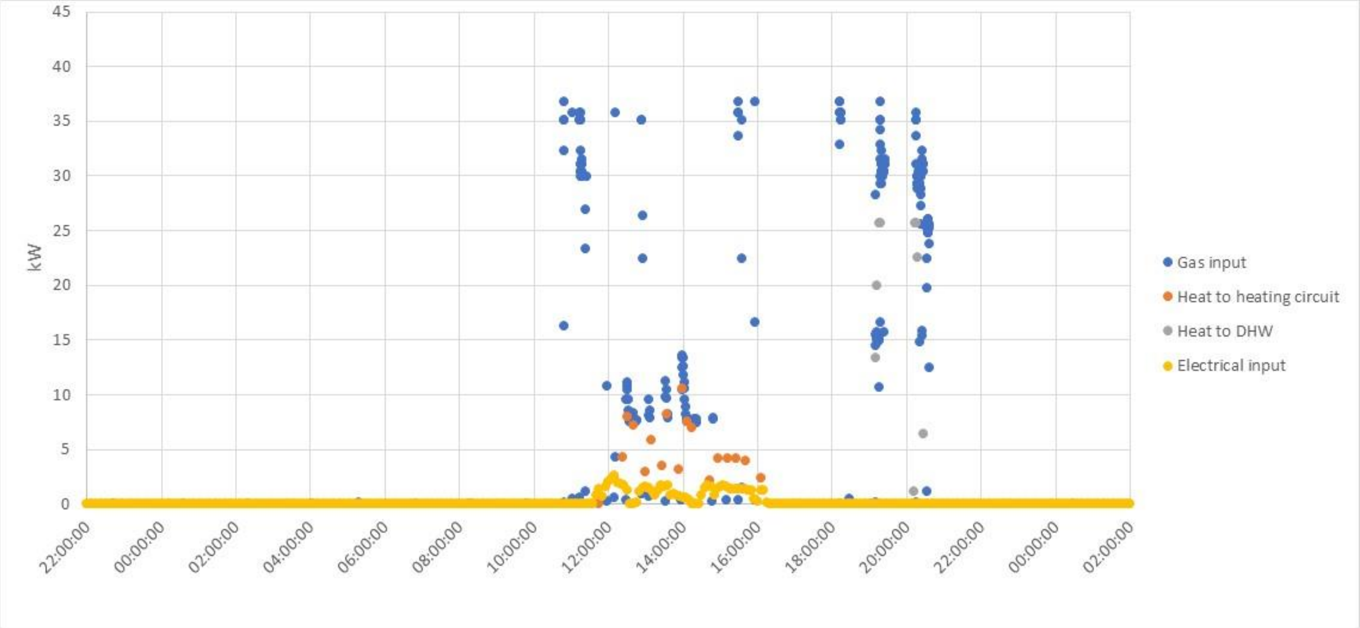
The heat pump only comes on for very short periods. The COP of the heat pump will be poor in the cold external temperature, so the heat pump controller's internal calculator will have worked out that it is cheaper to use the boiler for most of the heat demand.



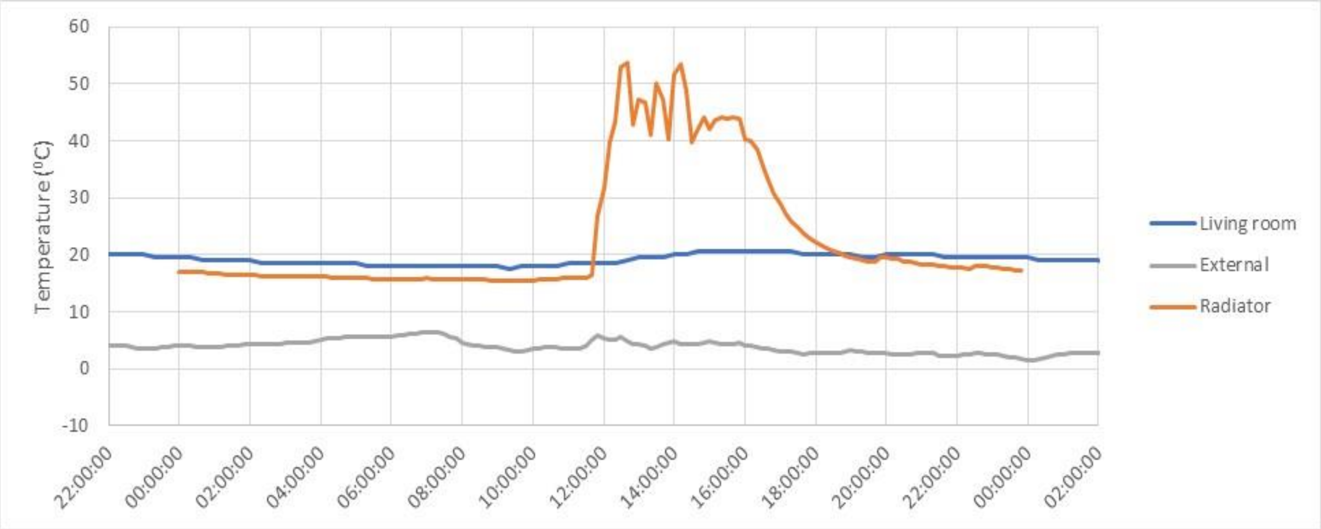
Graph 3.3.14 Property T-73 internal, external and radiator temperatures for 28 Feb 2018

Graph 3.3.14 above shows measured temperatures at property T-73 for the same date as the monitoring data in graph 3.3.13. The radiator temperature shows more clearly the times when the heating is on, with a radiator temperature of about 60 ^{0}C.

This shows that the internal temperature begins to rise a bit before 8 am and continues to rise until about 11 am from which time the heating cycles on and off maintaining a fairly constant internal temperature.

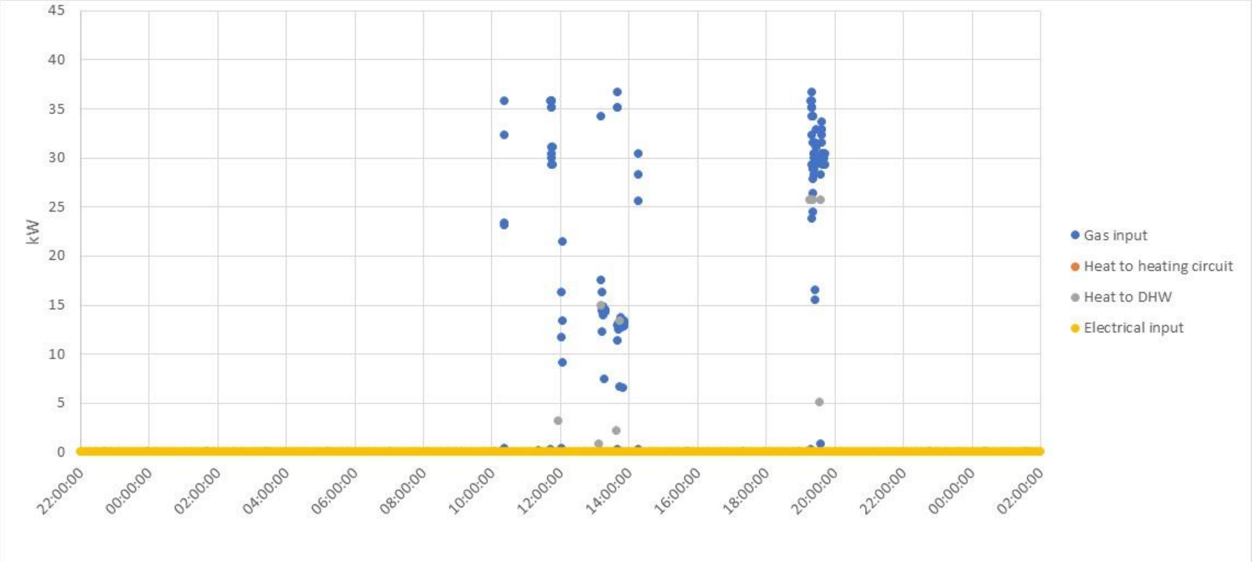


Graph 3.3.15 Property T-73 gas and electrical input to hybrid and heat output for 31 Jan 2018

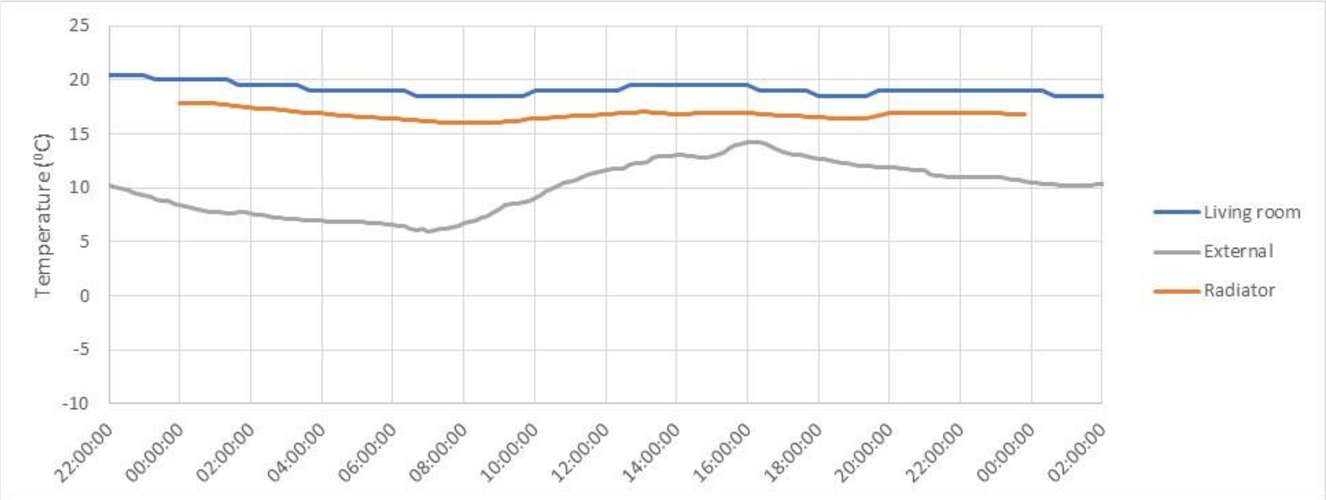


Graph 3.3.16 Property T-73 internal, external and radiator temperatures for 31 Jan 2018

Graphs 3.3.15 and 3.3.16 above show monitoring outputs for property T-73 on 31 Jan 2018. This is a warmer day than 28 Feb, with a degree day of 10.7. On this day, the heat pump operates in two modes. Firstly between 11:30 and 2:30 as a preheat to the gas boiler, when the heating flow temperature peaks at 55 ^{0}C. Between 2:30 and 4 the heat pump operates on its own, with a flow temperature of about 43 ^{0}C. Afternoon and evening output from the boiler is to DHW.



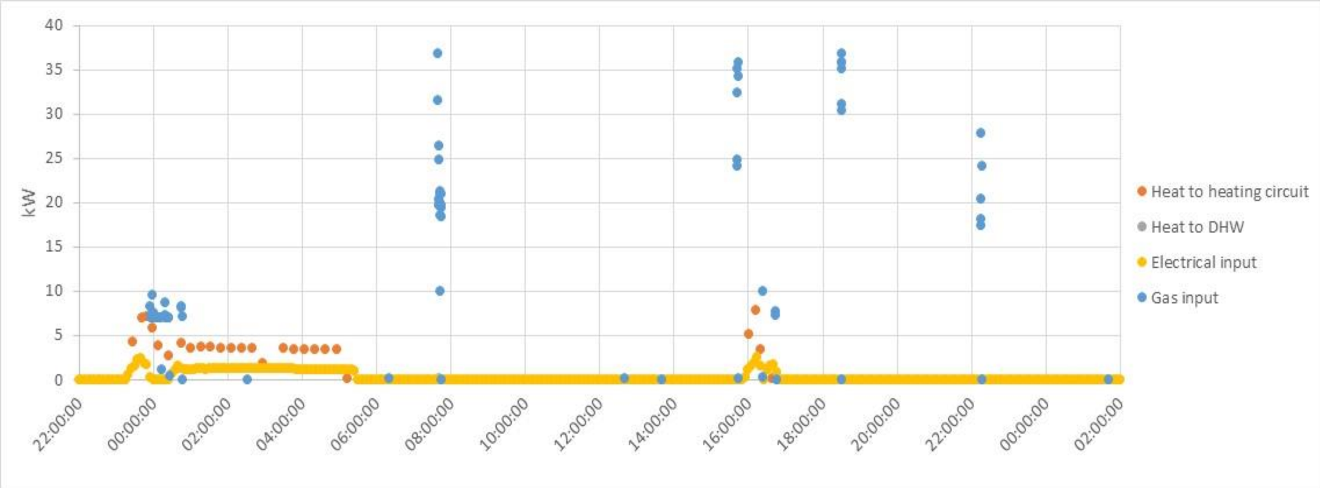
Graph 3.3.17 Property T-73 gas and electrical input to hybrid and heat output for 28 Jan 2018



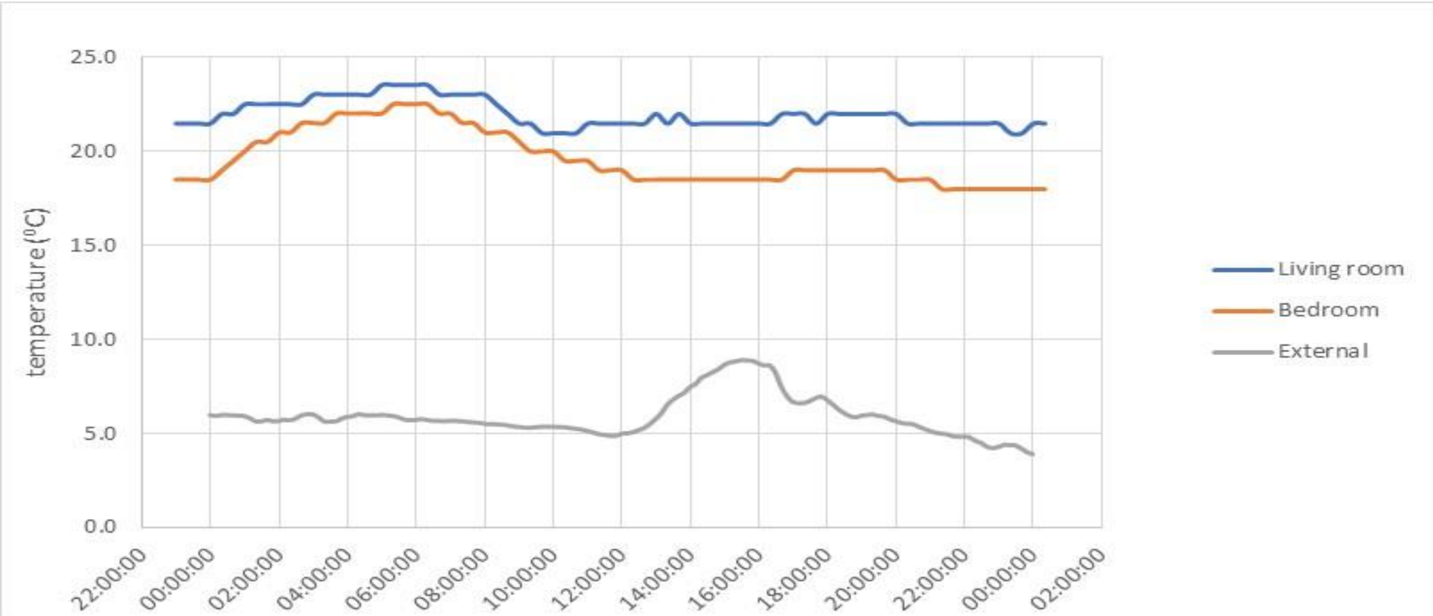
Graph 3.3.18 Property T-73 internal, external and radiator temperatures for 28 Jan 2018

Graphs 3.3.17 and 3.3.17 above show monitoring outputs for a third day type for property T-73. 28 January 2018 was relatively warm for mid-winter. A degree day value of 3.8 meant that there was no call for heating on this day. The heat pump did not turn on, and the boiler only operated to provide DHW.

The external temperature rises to almost 15 ^{0}C. The internal temperature in the living room ranges between 18 and 20 ^{0}C. The radiator does not come on, as it is stable at the hall temperature of 16 to 18 ^{0}C.



Graph 3.3.19 Property T-83 gas and electrical input to hybrid and heat output for 4 Jan 2018



Graph 3.3.20 Property T-83 internal and external temperatures for 4 Jan 2018

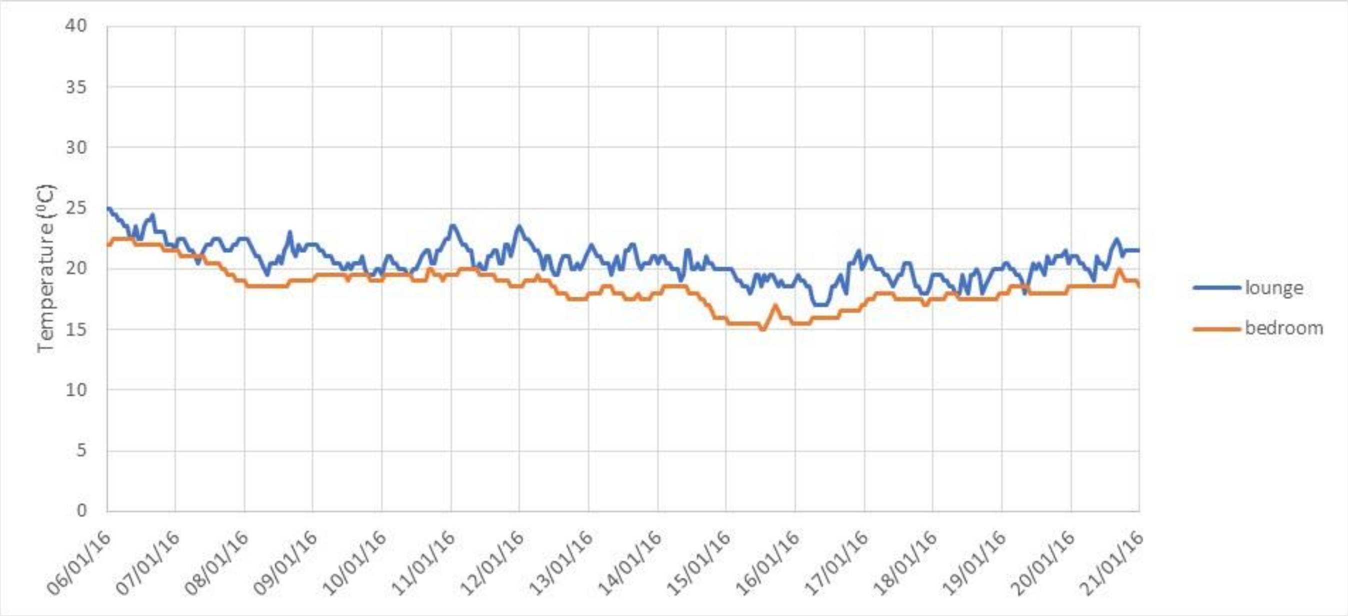
Graphs 3.3.19 and 3.3.20 above show operation of the hybrid heat pump at property T-83 on 4 Jan 2018 with degree day of 8.3.

There is an unusual heating pattern at this property. Initially when the heating is turned on at about 11pm on the 3rd, it is powered by both the heat pump and boiler. It then stabilises overnight when it is powered by the heat pump only. There is a spike in gas usage early morning, for DHW. The heating is on briefly in the afternoon, powered by the heat pump and boiler. In the afternoon there are 2 short draw-off periods of DHW.

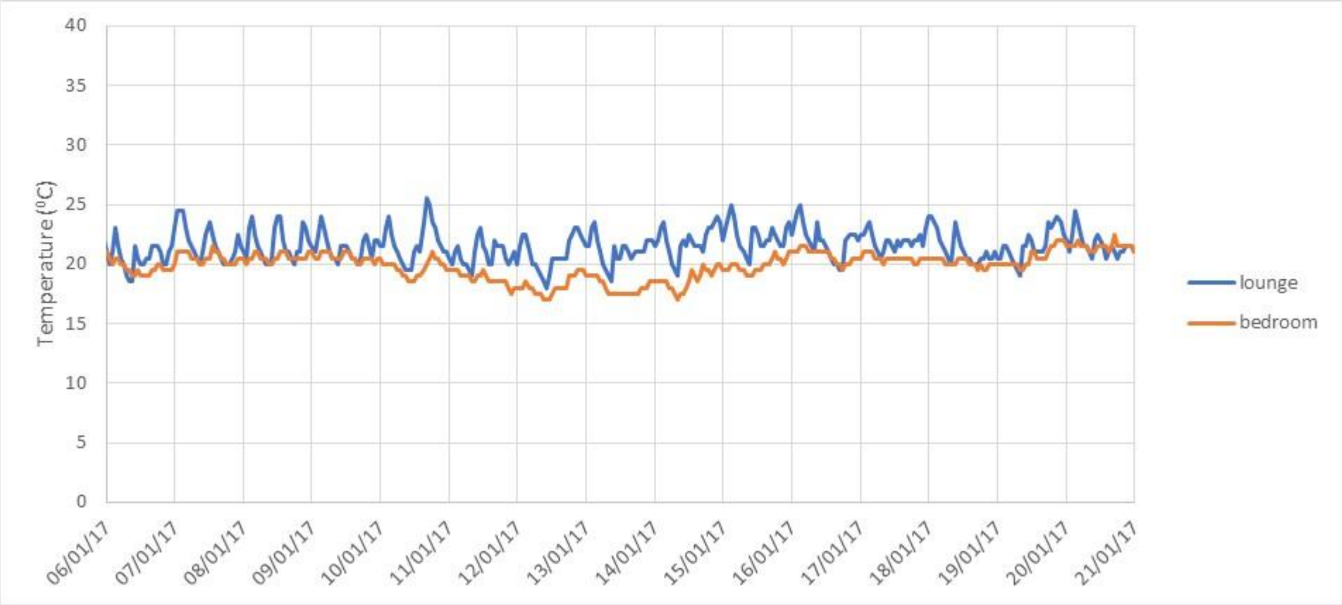
There was no temperature probe measuring radiator temperature at this property, but the effects of the heating coming on can be seen as the internal temperature in both the living room and bedroom can be seen to begin to rise at midnight, not long after the heating has been turned on.

Sunamp heat battery

Internal temperatures



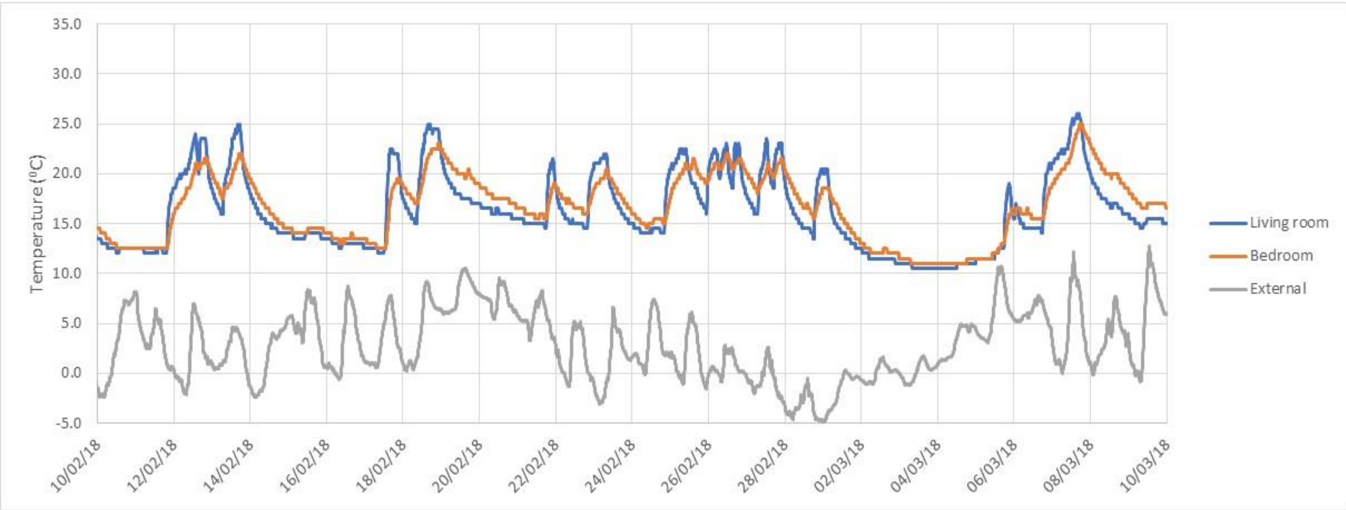
Graph 3.3.21 Property T-8 internal temperatures 6 to 21 Jan 2016



Graph 3.3.22 Property T-8 internal temperatures for 6 to 21 Jan 2017

Graphs 3.3.21 above shows internal temperatures at property T-8 with the existing solid fuel heating and 3.3.22 shows the internal temperatures at the same property a year later after the Sunamp heat battery was installed.

For this property there is not much difference in variability of room temperature over time.



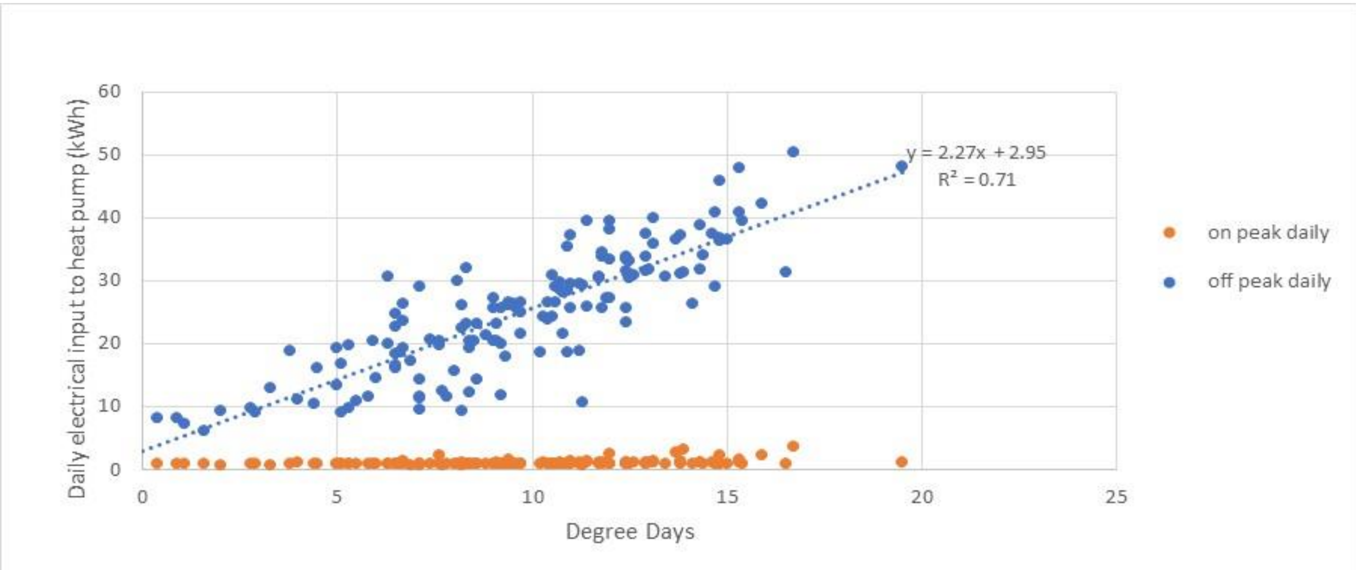
Graph 3.3.23 Property T-13 internal and external temperatures for 10 Feb to 9 Mar 2018

Graph 3.3.23 above shows the recorded internal and external temperatures for property T-13. This property has much more variable internal temperatures than all the others, and there are times even in the middle of winter when the heating appears to have been turned off for several days in a row.

On-peak and off-peak electricity use

The heat batteries are designed to shift heat load to off-peak electricity periods when electricity costs are cheaper. 3 of the 6 households on the scheme switched to E-10, one to E-7, and one with a solar PV system moved the charging period to the middle of the day (10 am to 3 pm GMT) when there was maximum chance for using the electricity generated by the pv system to power the heat pump. 1 household stayed on a standard electric tariff for the duration of the project.

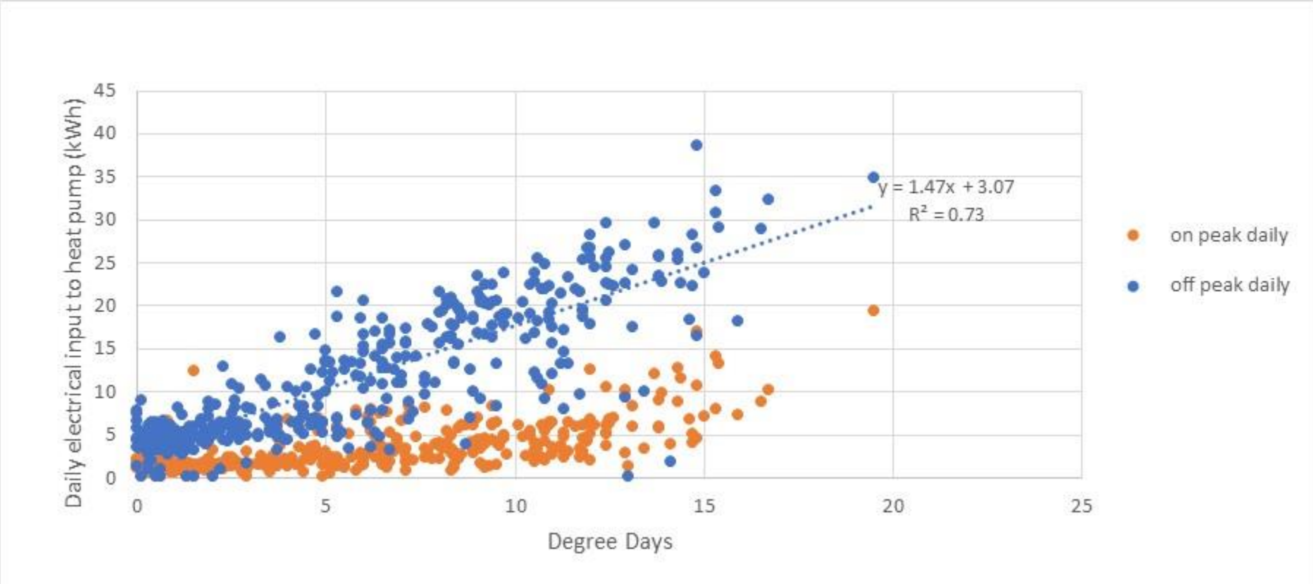
The pulse loggers which measured the electricity running to the heat pump through the Wh meters recorded the amount of energy used over time. Matching the electricity used against time, it is possible to see how well the system did at switching heat load to off-peak times. The following graphs show the division of electricity usage between off-peak and on-peak electricity periods.



Graph 3.3.24 Property T-16 daily electrical input to heat pump against degree days - 5 Dec 2017 to 28 Apr 2018

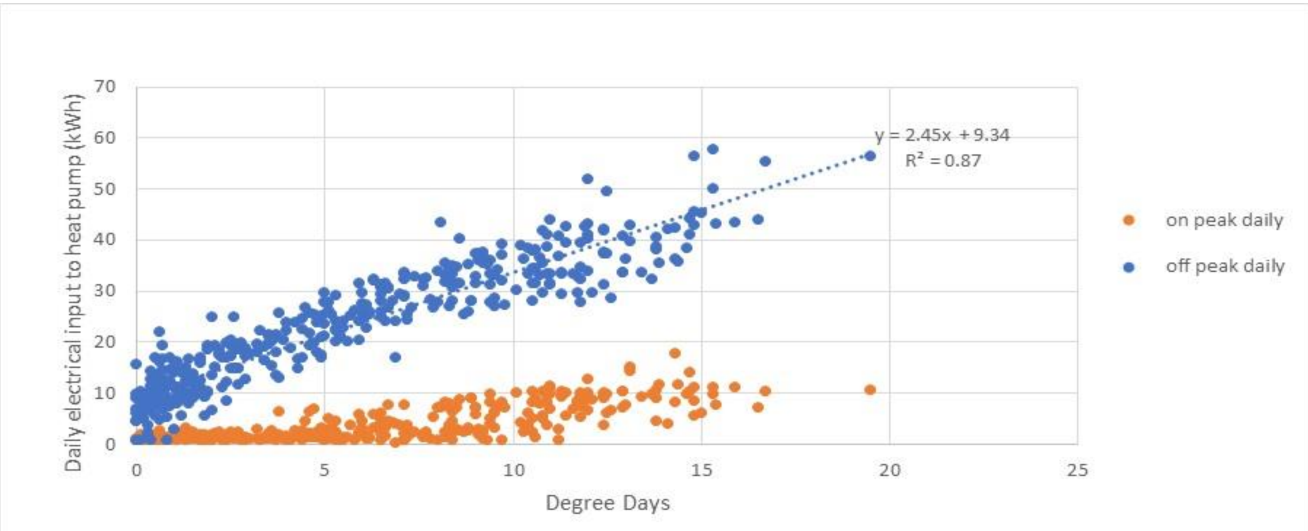
Graph 3.3.24 above shows that for property T-16 almost all electrical input to the heat pump over the winter 2017/18 was during periods of off-peak tariff. Even on the coldest days hardly any on-peak electricity was used.

This property used E-10 electricity, and there is a good correlation between DD and electricity usage for off-peak electricity ($R^2 = 0.71$).



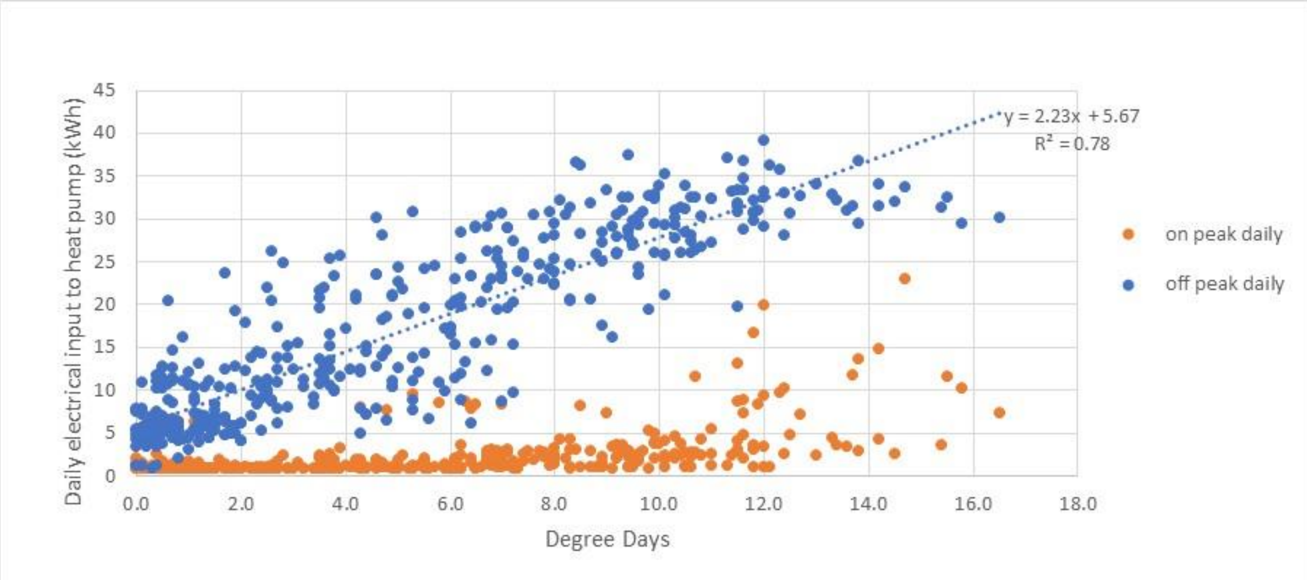
Graph 3.3.25 Property T-17 daily electrical input to heat pump against degree days - 19 Mar 2017 to 29 Apr 2018

The Sunamp time clock for property T-17 was set to E-10 times, and the graph above shows that the correlation of off-peak electricity usage against DD was good ($R^2 = 0.73$). At this property there was some on-peak usage even on warmer days. The tenants at this property did not change their electricity tariff, so did not take advantage of the savings that would have been made.



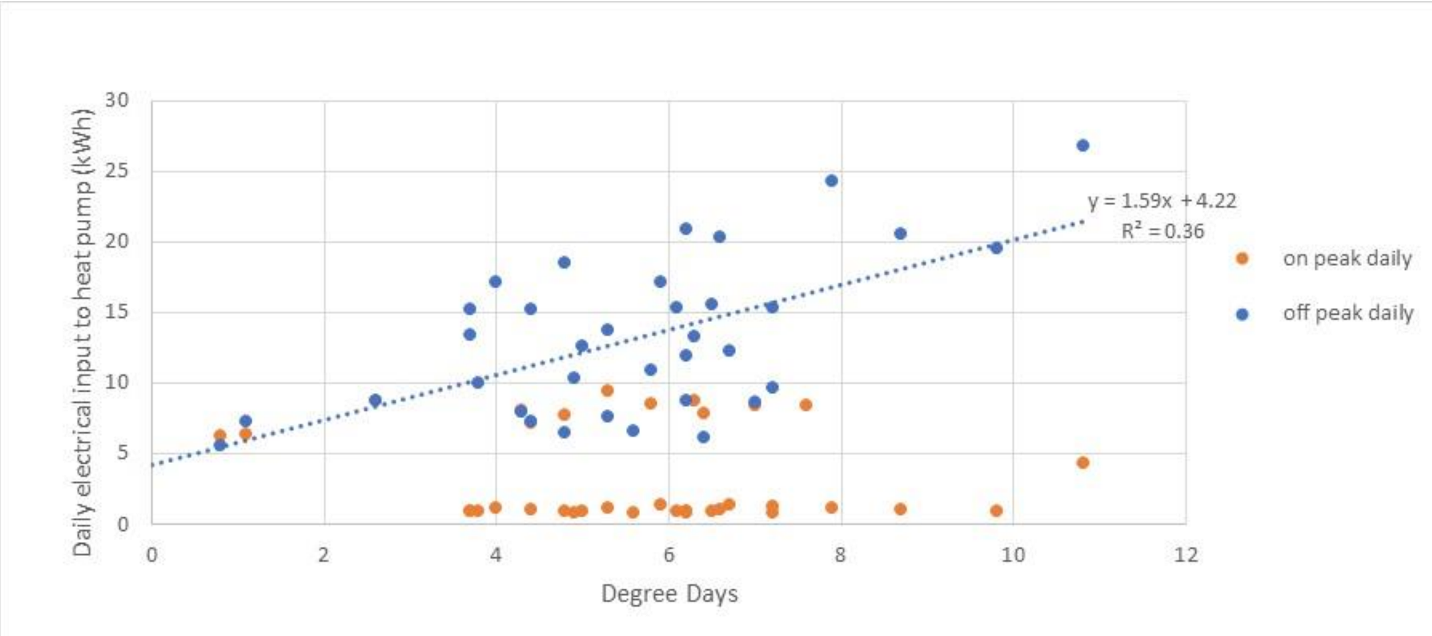
Graph 3.3.26 Property T-23 daily electrical input to heat pump against degree days – 8 Apr 2017 to 28 Apr 2018

Graph 3.3.26 shows the electrical input to the heat pump for another property using E-10 electricity. The house was kept at a higher temperature than the others. The result of this is a steeper increase in electricity use against DD, and higher on-peak electricity use from about DD >8. A larger battery, of say 50 kWh instead of 40 kWh, would have enabled shifting of almost all the on-peak electricity usage to off-peak charge time.



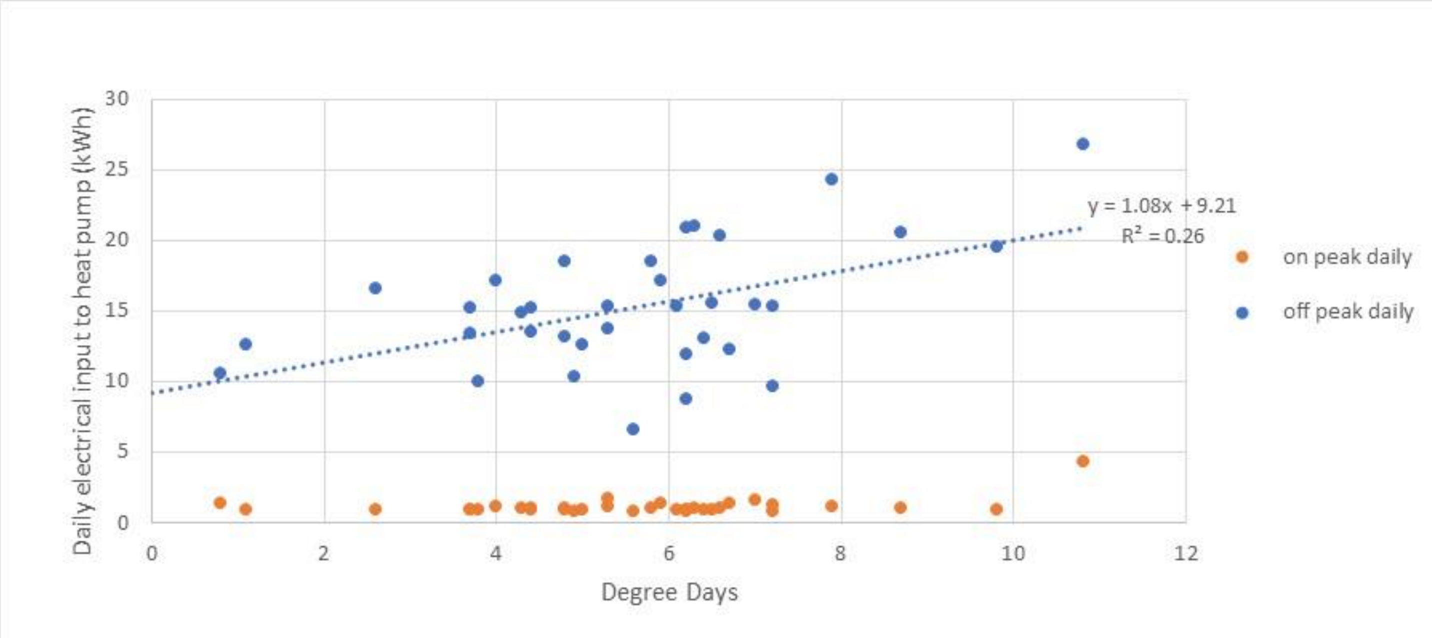
Graph 3.3.27 Property T-8 daily electrical input to heat pump against degree days - 28 Oct 2016 to 6 Dec 2017

For property T-8, which used E-10, there is good correlation between the off-peak electricity usage and degree days (R^2 = 0.78). In general, on-peak electricity usage for the heat pump is only used when it is colder outside (DD>10). However, there are several relatively warm days (dd < 8) where there was a significant amount of on-peak electricity usage, these all occurred during late March and early April 2017. This period is shown in graph 3.3.28 below.



Graph 3.3.28 Property T-8 daily electrical input to heat pump against degree days – 26 Mar to 30 Apr 2017

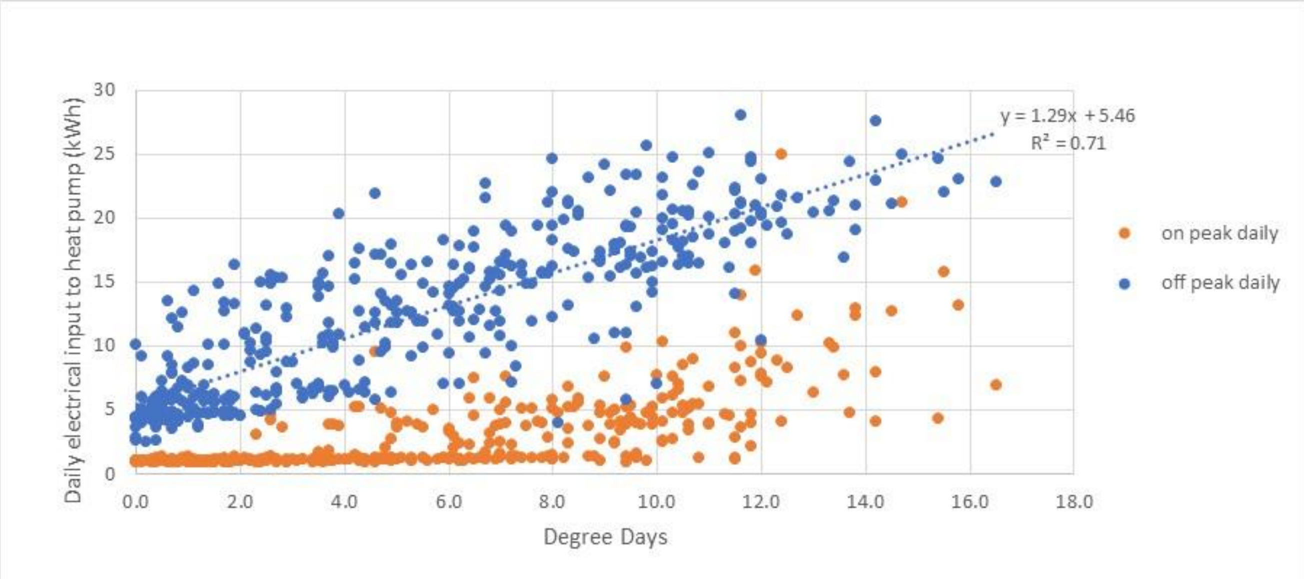
The clocks moved forward an hour at 2 am on Sunday 26 March. The timer on the Sunamp battery was set to change to BST, which meant that it shifted forward by an hour to coincide with the change in time. However, the E-10 utility meter did not change and is set permanently to GMT. The heat pump was being timed to come on an hour before the start of the off-peak period and was therefore starting its charge cycle using on-peak electricity. After a few days, the customer noticed that the electricity costs had increased, and the clock on the Sunamp controller was rectified on 6 April to match the E-10 clock.



Graph 3.3.29 Property T-8 predicted daily electrical input to heat pump against degree days without timeclock error – 26 Mar to 30 Apr 2017

Graph 3.3.29 above shows how the data from the period 26 March to 30 April 2017 would have looked if the time on the Sunamp timer had not been shifted forward by an hour for 26 March to 6 April 2017.

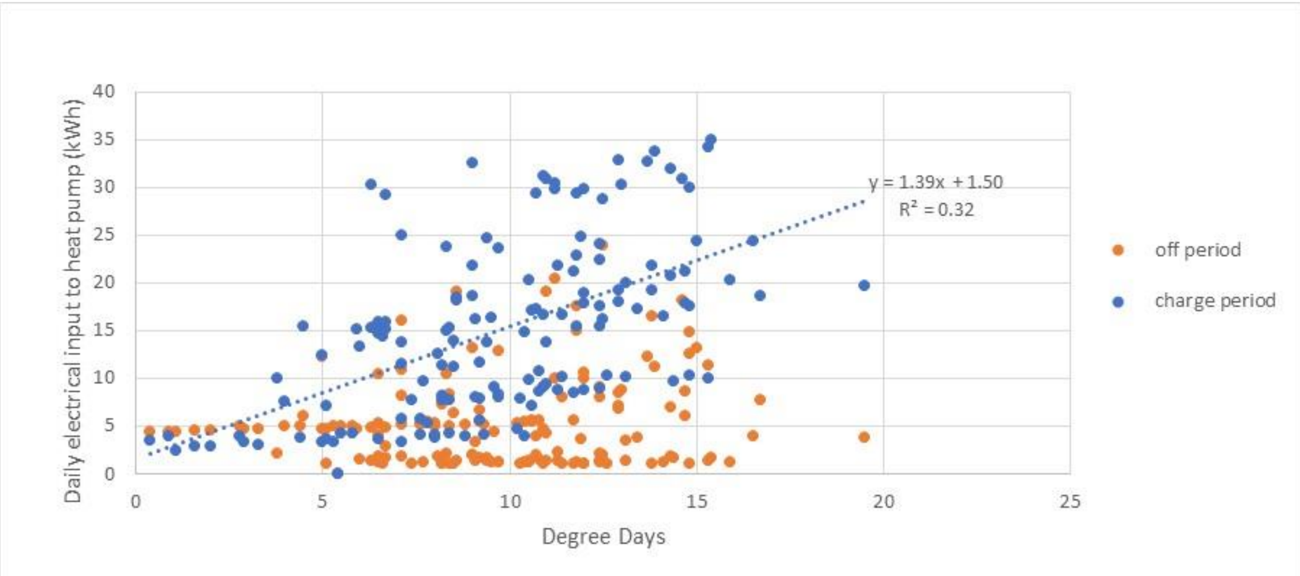
The cost of this error over 12 days was about £8, so over a year could make a difference in running cost to the tenant of £250. This demonstrates the importance of synchronising the time clock on the Sunamp heat battery with the electricity meter.



Graph 3.3.30 Property T-9 daily electrical input to heat pump against degree days – 28 Oct 2016 to 4 Dec 2017

Graph 3.3.30 above relates to property T-9 which used an E-7 electricity tariff. There is good correlation between off-peak electricity usage and DD ($R^2 = 0.71$), but it can be seen that there is significantly more on-peak usage than with the properties using E-10. Whereas an E-10 tariff has three off-peak periods, an E-7 tariff only has one, so the heat in the battery is more likely to be used up before it can be recharged at low cost.

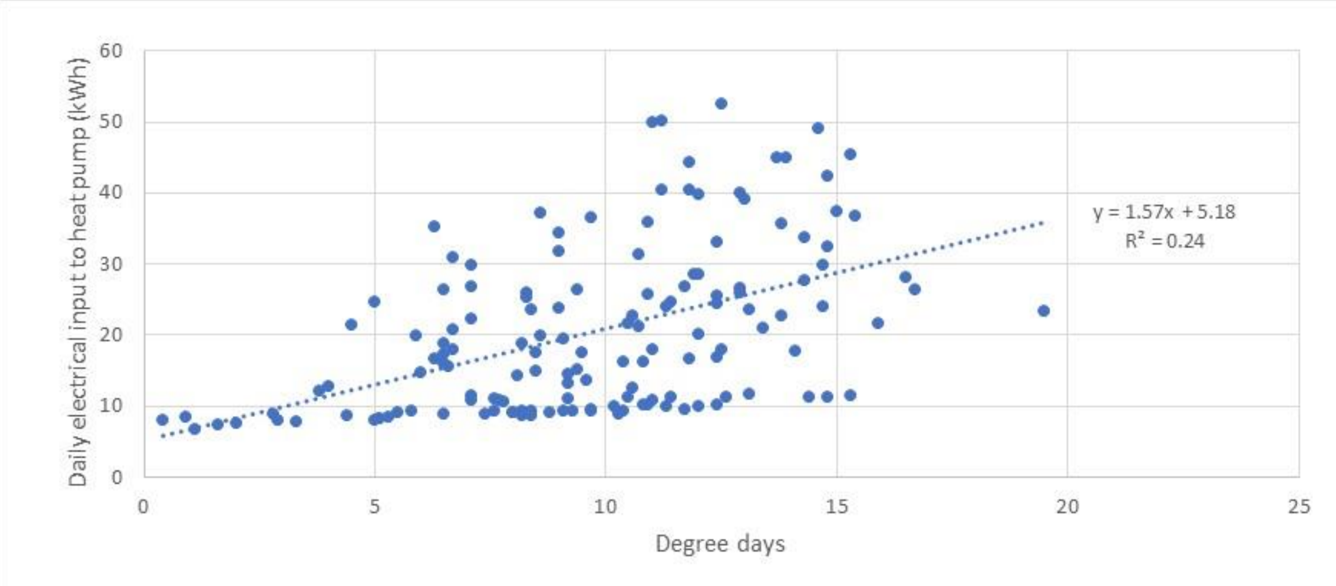
The cost of off-peak E-7 at 4.68 p/kWh that this customer was able to obtain was significantly lower than the E-10 tariffs of 6.07 p/kWh and 9.52 p/kWh that were available. This lower off-peak rate cancelled out the higher amount of on-peak usage at this property.



Graph 3.3.31 Property T-13 daily electrical input to heat pump against degree days - 7 Dec 2017 to 1 May 2018

Graph 3,3,31 relates to property T-13 which is the house which had a standard electricity tariff and a pv system. Charge times were set for the times most likely to see peak solar generation i.e. 10 am to 3pm (GMT). The period labelled “off period” is any time outside this.

There is poor correlation between the designated charge period and DD (R^2 = 0.32), and a significant amount of electricity usage outside the designated charge time. There is also poor correlation between the total daily electrical input to the heat pump against degree day (R^2 = 0.24) – see graph 3.3.32 below. This is likely to be because of a variable heating regime. On some days, even in the middle of winter, the heating was not turned on, see graph 3.3.23 above.

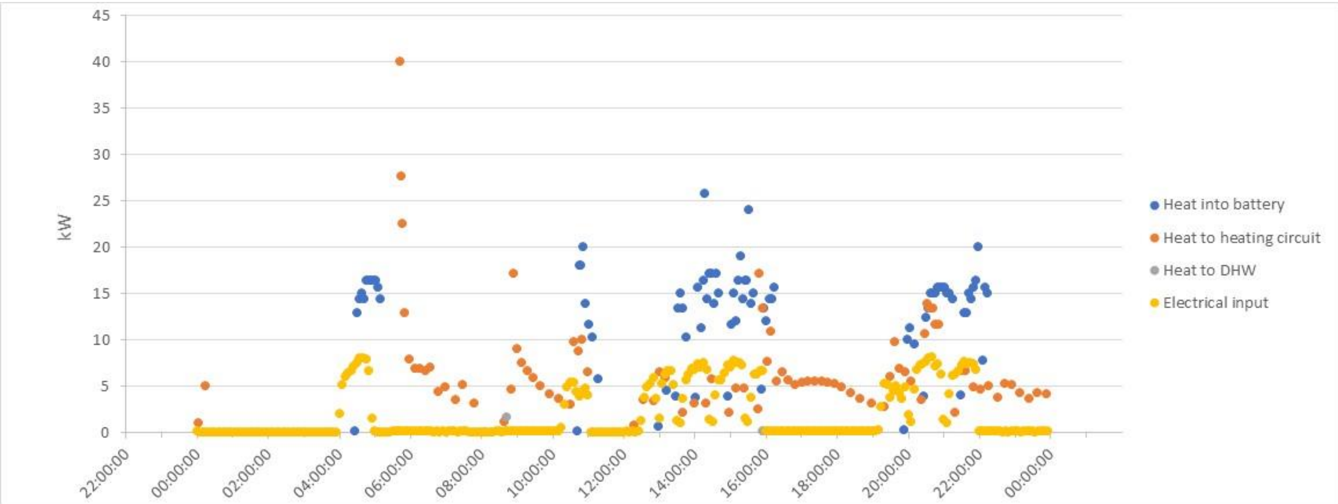


Graph 3.3.32 Property T-13 total daily electrical input to heat pump against degree days - 7 Dec 2017 to 1 May 2018

Heat meter analysis

The following graphs show the outputs from the three heat meters installed in the heat battery heating systems at various times for different properties. The loggers attached to the heat meters measure every kWh, so the points on the graph are the time at which the next full kWh has been registered. The heat to the heating circuit reaches very high outputs because when the battery is fully charged it pumps heat round the heating circuit at a temperature of 56 ^{0}C. At the start of a heating cycle, the return heating pipe is below 20 ^{0}C. When the return pipe gets up to temperature the heat output rapidly reduces to a value more equal to the heat load of the property.

The loggers attached to the Watt hour meters log the number of Wh pulses of electrical input to the heat pump every 5 minutes, so give a far more accurate picture of when the heat pump is using energy than the heat meter recordings. The difference in resolution means that often the electrical input to the heat pump appears to come on before any heat is registered from the heat pump into the battery. The energy is the area under the graph.



Graph 3.3.33 Property T-8 electrical input and heat outputs for 26 Jan 2017

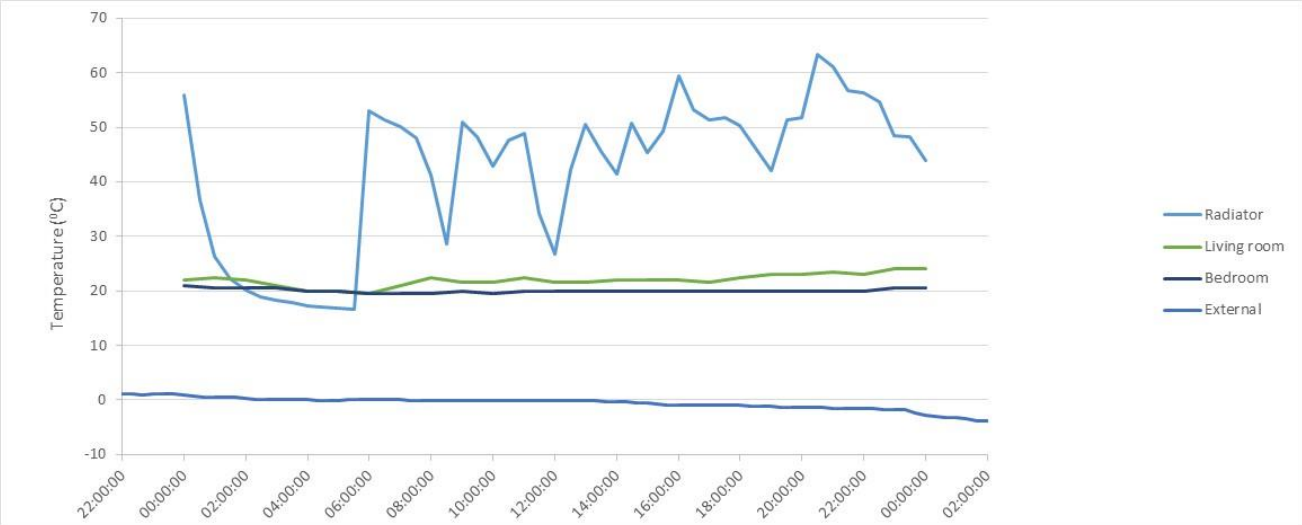
26 January 2017 was a cold day with average external temperature =0.0 ^{0}C. (DD = 15.5)

Over the 24-hour period, the monitoring equipment at property T-8 recorded the following:

(a) Electrical input = 44.1 kWh
(b) Heat to battery = 84 kWh
(c) Heat to heating circuit = 89 kWh
(d) Heat to DHW = 3 kWh

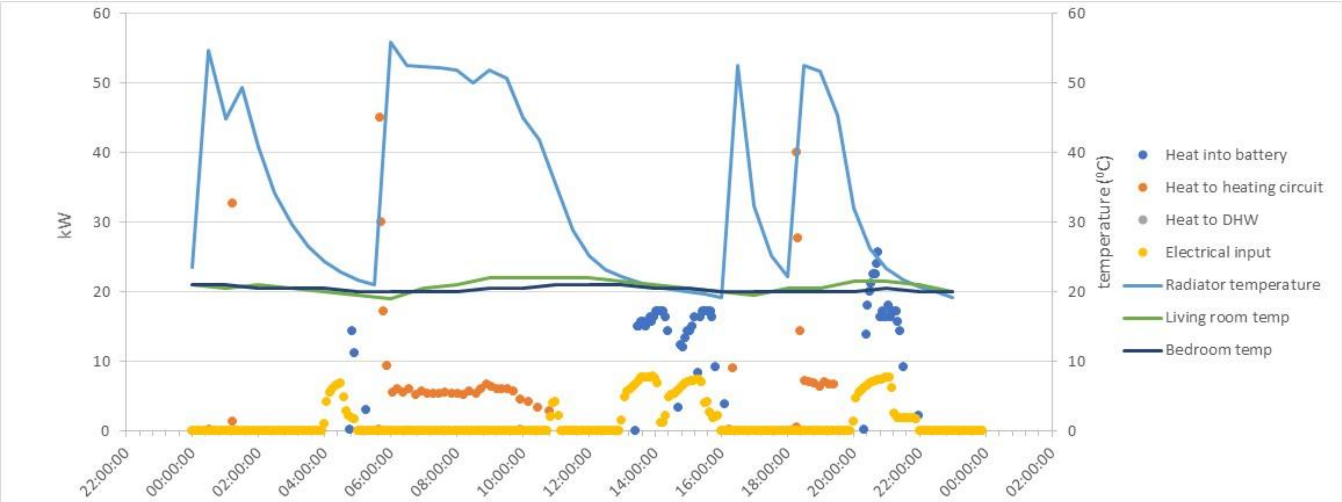
From these the following can be calculated:
Coefficient of performance of the heat pump (COP) = b/a = 1.90

Over this 24-hour period more heat was taken out of the battery than was put in. The heat battery is almost fully charged overnight but comes on at 4 am to top up. The heating comes on at 6 am and goes off just before 8. The heating comes on again at about 9am, and by 10: 30, the heat battery is depleted, so the heat pump turns on to give heat directly to the property. Note that the electrical input to the heat pump stabilises at about 5 kW, rather than the usual 7 kW. This is because the heat pump is running at the lower flow temperature of 55 ^{0}C, rather than 71 ^{0}C when it tops up the battery. After an hour or so of operation, the heat pump turns off again until the next charging cycle is due at 1pm. The heating is the on all afternoon and evening, with the heat pump topping up the heat battery only during the off-peak electrical periods.



Graph 3.3.34 Property T-8 internal, external and radiator temperatures for 26 Jan 2017

From graph 3.3.34 above, it can be seen from the radiator temperature probe that the heating was cycling on and off for the majority of the day. The radiator temperature peaks at about 65 ^{0}C, when the heat pump is charging the battery at 71 ^{0}C and also providing heat to the heating circuit.



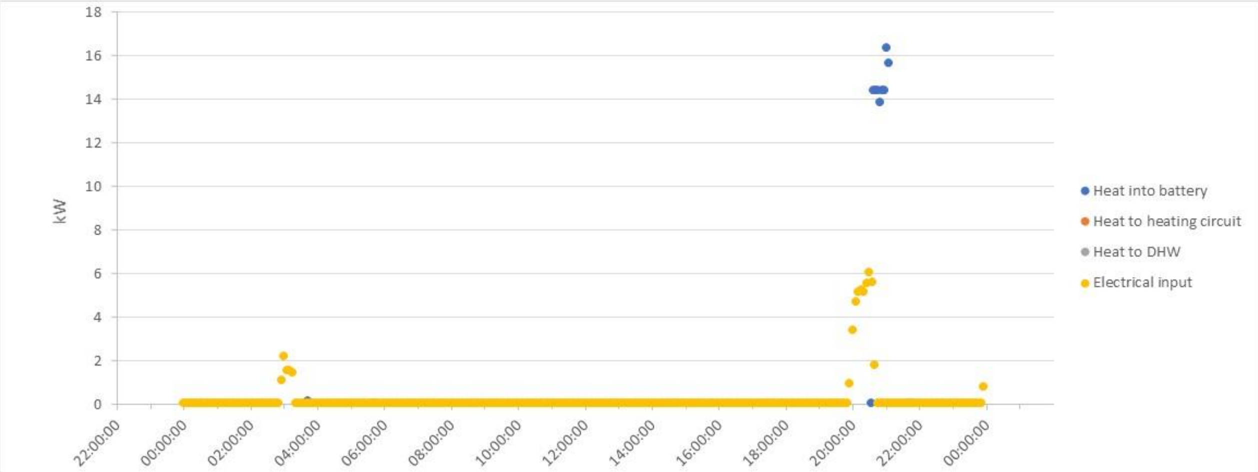
Graph 3.3.35 Property T-8 combined graph showing temperatures and energy flows for 21 Jan 2017

Over the 24-hour period for 21 Jan 2017, when DD =12, the monitoring equipment recorded the following:

(a) Electrical input = 32.6 kWh
(b) Heat to battery = 62 kWh
(c) Heat to heating circuit = 47 kWh
(d) Heat to DHW = 3 kWh

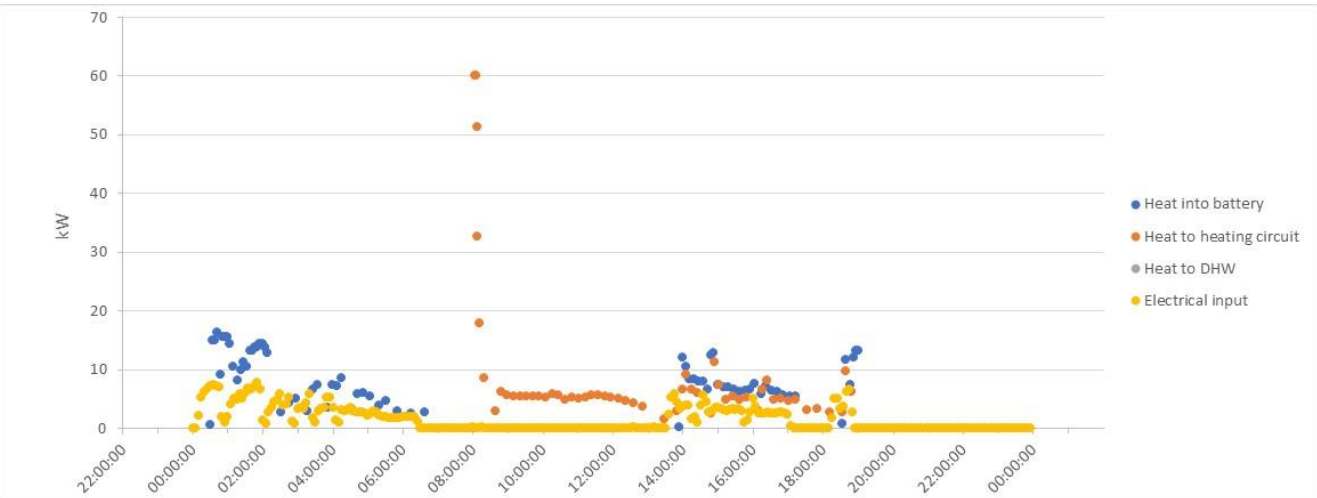
From these the following can be calculated:
Coefficient of performance of the heat pump (COP) = b/a = 1.90

Apart from a small top up from the heat pump at about 11:00, after the heating has been on all morning, the heat battery provides all heat to the heating circuit. This graph also shows the recorded temperatures at the hall radiator, and the ambient temperature in the living room and main bedroom. It can be seen that the maximum radiator temperature achieved is about 55 ^{0}C. The phase change material in the heat battery solidifies at 56 ^{0}C, so flow out of the battery is at 56 ^{0}C. After a short period the radiator temperature stabilises at about 52 ^{0}C.



Graph 3.3.36 Property T-8 electrical input and heat output for 15 Jun 2017

On 15 June 2017, when the Degree Day was 0.3 no heating was required at property T-8 and no hot water was drawn off. However, it can be seen that the heat pump still came on twice to top up the heat in the battery. In this case, the total electrical input was 5.64 kWh, with approx. 10 kWh input to the heat battery.



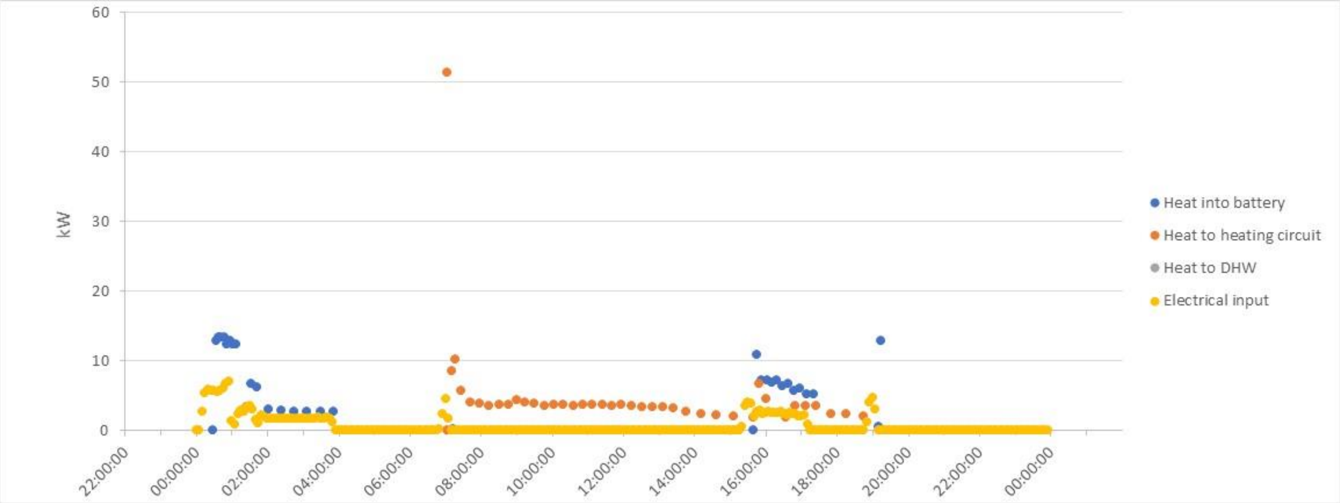
Graph 3.3.37 Property T-9 electrical input and heat output for 26 Jan 2017

Over the 24-hour period in graph 3.3.37 above, the monitoring equipment recorded the following:

(a) Electrical input = 37.6 kWh
(b) Heat to battery = 72 kWh
(c) Heat to heating circuit = 56 kWh
(d) Heat to DHW = 0 kWh

From these the COP = b/a = 1.91

This graph shows the main overnight charging period during the E-7 off peak time, heating coming on at 8 am and the heat pump coming on at 1:30 pm, once the heat battery has been depleted to provide direct heat until 7pm. Electrical input to the heat pump is lower during the on-peak charging period, than the off-peak charge period.



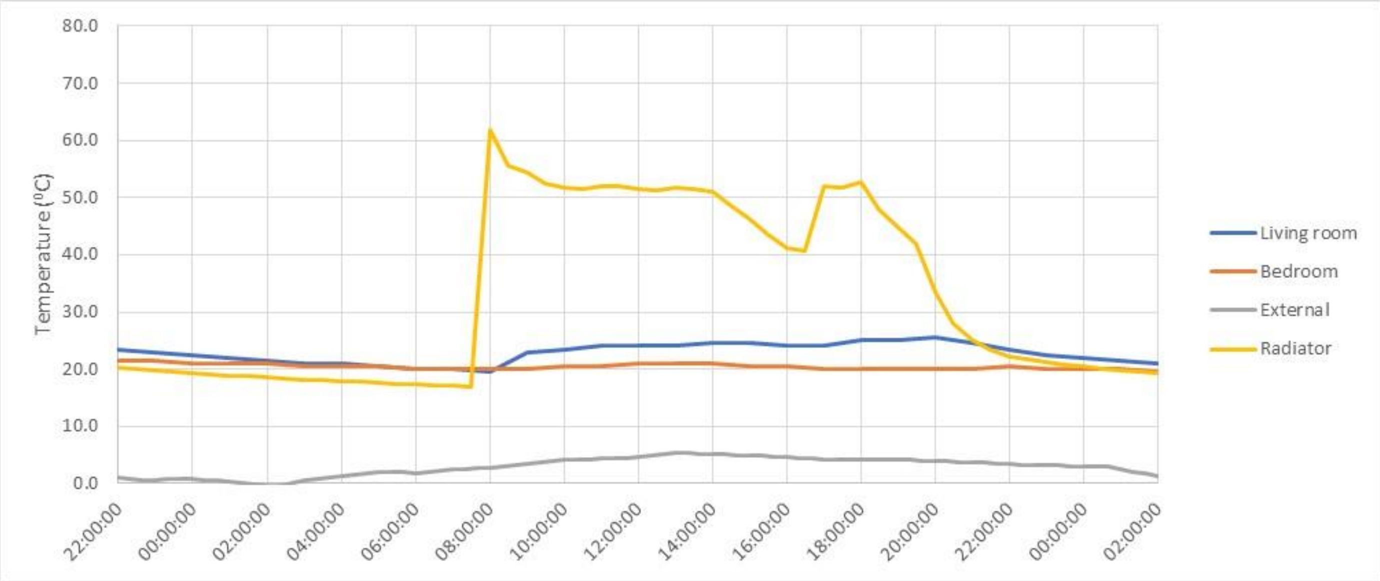
Graph 3.3.38 Property T-9 electrical input and heat output for 21 Jan 2017

Over the 24-hour period, shown in graph 3.3.38 above, the monitoring equipment recorded the following:

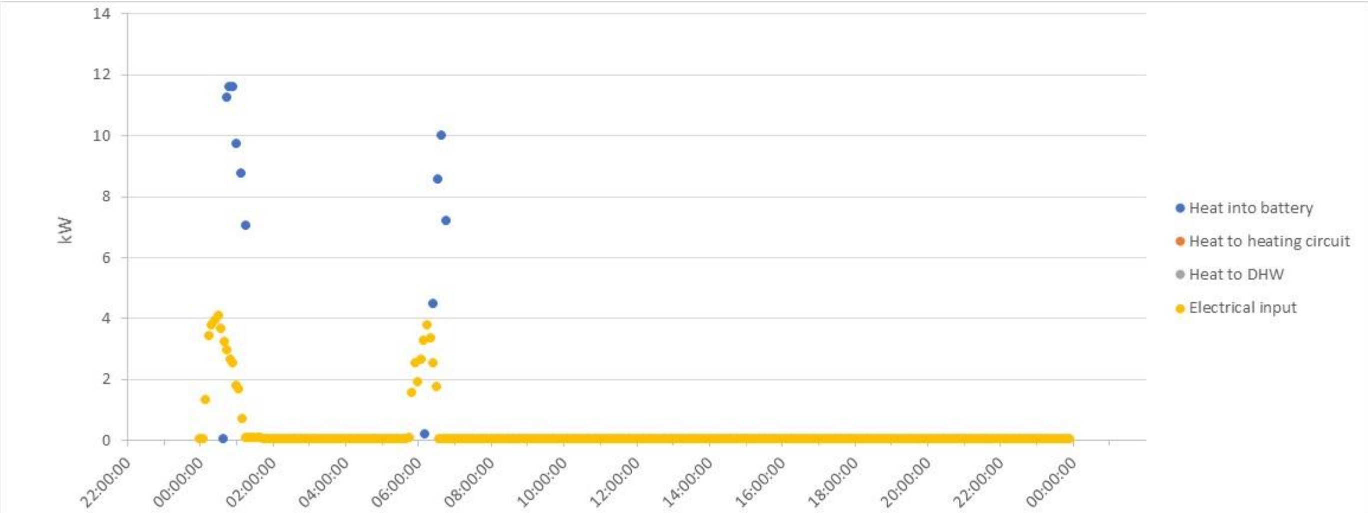
(a) Electrical input = 18.3 kWh
(b) Heat to battery = 33 kWh
(c) Heat to heating circuit = 41 kWh
(d) Heat to DHW = 0 kWh

From these the COP = b/a = 1.80

There is a 2 hour top up of heat in the afternoon, when the heating has been on all day (see Graph 3.3.39 below for recorded temperatures for the same day.



Graph 3.3.39 Property T-13 internal, external and radiator temperatures for 21 Jan 2017



Graph 3.3.40 Property T-9 electrical input and heat output for 15 Jun 2017

Over the 24-hour period shown in Graph 3.3.40 above when the DD = 0.3, the monitoring equipment recorded the following:

(a) Electrical input = 6.25 kWh
(b) Heat to battery = 12 kWh
(c) Heat to heating circuit = 0 kWh
(d) Heat to DHW = 0 kWh

From these the COP = b/a = 1.92

Graph 3.3.40 shows no heat output to either central heating or DHW. Despite not having a heat requirement, there is still an energy input to the heat battery. This is the heat loss from the battery.

3.4 Performance against manufacturer's claims

Infrared radiators

The manufacturers do not claim very much about their product. They say:

> *"Radiant Heat is multidirectional and a much more efficient way of heating an indoor space. Where traditional convection heat can lead to an uneven temperature within a room, radiant heating stores energy in physical objects instead of air, leading to a temperature difference of 0.2 degrees centigrade in a room, as opposed to 2-5 degrees centigrade that convection achieves[11]."*

and

> *"Through an advanced control panel unit and existing building electrical wiring, the Logicor Clear Heater System responds to the user's command and input. Set a temperature and energy is used only when necessary to constantly keep spaces at a comfort level that the user specifies."*

The evidence gathered shows that the internal temperatures are consistent over time, irrespective of the external temperature and that the daily electricity use for heating is directly proportional to Degree Days.

The manufacturers claim their product is "efficient", but don't say anything about running costs. Comparison at the properties which previously had electric heating systems (storage heaters or on-peak electric) shows, on average, a very small reduction in electricity usage and an average increase in costs of over £200 pa. All properties which previously used storage heaters showed an increase in running costs.

Hybrid heat pump

The gas boiler efficiency for the Daikin hybrid recorded on the Product Characteristics Database[12] (PCDB) is 89.1%.
The SCOP listed on the MCS website for the Daikin hybrid[13] at a flow temperature of 55 ^{0}C is 3.16.
The boiler efficiencies and heat pump SCOP for each property have been calculated and are shown in table 3.4.1.

The heat meter which measured the heat output from the heat pump before it went into the gas boiler had no digital output, so recordings were taken from the meter output screen at each site visit. The Daikin controller also has its own internal calculator which takes readings from its electrical input and heat output. These two are compared for 5 of the properties with hybrid heat pumps. It was also possible to calculate boiler efficiencies by dividing the known heat output from the gas boiler by the known input to the gas boiler through the gas meter. The output from the gas boiler is the total heat measured into the DHW plus total heat into the heating circuit minus the heat output from the heat pump.

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[11] Heating reimagined – Clear Heater System, Logicor 2014

[12] http://www.ncm-pcdb.org.uk/sap/pcdbsearch.jsp?pid=26

[13] http://www.microgenerationcertification.org/consumers/product-search?product_type_id=4694

Property reference	Heat pump SCOP from installed metering equipment	Heat pump SCOP from Daikin controller	Boiler efficiency	Proportion of space heating provided by heat pump
T-20	2.73	2.72	61%	59%
T-50	2.59	2.92	58%	56%
T-52	2.64	2.88	59%	61%
T-73	2.31	2.72	59%	58%
T-83	2.48	2.47	62%	51%
Average	2.55	2.74	60%	57%

Table 3.4.1 SCOP and boiler efficiency as measured

The gas boiler efficiencies look low compared with the 89.1 % recorded on the PCDB. This may be partly due to the way the monitoring equipment recorded hot water input and draw-off. A small water draw-off may have input of gas, which heats water within the gas boiler, that then does not fully leave the boiler into the DHW pipework.

The SCOPs from the monitoring equipment compare well with the SCOPs from the Daikin controller for two of the properties. However, there is a significant difference in readings at properties T-50, T-52 and T-73. The measured SCOPs are not as good as the 3.16 listed on the MCS website for a flow temperature of 55 ^{0}C. This will be under ideal lab test conditions and lab test results will include for a lower minimum flow temperature on the radiator circuit which will improve the SCOP. However, the gas boiler of the installed systems operates at lower external temperatures, reducing operation of the heat pump when its performance is not so good. This would tend to improve the SCOP of the system on site.

Two householders (T-73 and T-83) use the on/off button to control their heating. It has been explained to them that this is not the most efficient way of controlling their heating and that they should adjust the room thermostat up and down, but they do not want to change the way that they control their heating. These are the two properties with the lowest SCOP. Householders at property T-50 were using the on/off button early in the project, but after a visit at the end of October 2016, where they had the controls explained again, they then left the controller on a standard day time temperature with a night time setback. This improved the recorded SCOP at this property from 2.47 to 2.59.

NEA project CP747 monitored Daikin hybrid heat pumps in two areas in Northern England[14]. These tested the hybrid system at different flow temperatures, with the following results:

Average SCOP with a flow temperature of 45 ^{0}C = 3.12

Average SCOP with a flow temperature of 50 ^{0}C = 2.87

For this project in North Lincolnshire the Average SCOP with a flow temperature of 55 ^{0}C = 2.55

The above clearly shows the reduction in heat pump performance as the flow temperature increases. It should be noted that the hybrid heat pump is an intermediate technology, which can be installed in properties which previously had gas boilers, requiring limited internal works. The lower the flow temperature in the heating circuit, the more efficient the heat pump, but maintaining

[14] Daikin Altherma hybrid heat pumps, Copeland and South Tyneside. Technical Evaluation Report Sept 2017

a higher flow temperature may mean that the hybrid heat pump can be installed instead of a standard gas boiler with limited radiator changes, so reducing install costs.

Heat Battery

At the design flow temperature for the system of 71 ^{0}C, the coefficient of performance (COP) of the Daikin high temp heat pump can be calculated as in the table below:

External temp	-2	+2	+7	+12	+15
COP	2.16	2.32	2.83	3.06	3.19

Table 3.4.2 COP of Daikin 11 kW high temperature heat pump at various external temperatures and 71 ^{0}C

From this it would be expected that the average COP over the heating season or seasonal COP (SCOP) would be in the region of 2.6.

SCOPs recorded in the first year at each property, taken by dividing the heat pump heat meter reading by the Watt hour meter reading are shown in the table below:

Property	T-8	T-9	T-13	T-16	T-17	T-23	Average
Average SCOP Yr 1	2.07	1.92	1.87	1.91	1.84	2.25	1.98
Dates	12.8.16 – 24.4.17	24.6.16 – 24.4.17	18.7.16 – 24.4.17	27.10.16 – 5.5.17	3.11.16 – 24.4.17	18.5.16 – 24.4.17	
Days	255	304	280	190	172	341	
Degree days	1854	1899	1868	1714	1612	1983	

Table 3.4.3 SCOP of Daikin heat pump as measured in the first winter

SCOPs for the second year are shown in Table 3.4.4

Property	T-8	T-9	T-13	T-16	T-17	T-23	Average
Average SCOP Yr 2	2.10	1.90	1.96	1.95	1.96	2.19	2.01
Dates	24.4.17 – 12.4.18	24.4.17 – 12.4.18	24.4.17 – 13.4.18	5.5.17 – 11.4.18	24.4.17 – 12.4.18	24.4.17 – 11.4.18	
Days	353	353	354	341	353	352	
Degree days	2226	2226	2233	2148	2226	2216	

Table 3.4.4 SCOP of Daikin heat pump as measured in the second winter

The performance shown by the heat pumps is not as good as would have been expected. It would be difficult to achieve the figure of 2.6 which will have been in perfect conditions of a test laboratory, but only one of the heat pumps has approached a reasonable SCOP.

The largest change in SCOP between year 1 and 2 is at property T-17 where Sunamp found several faults, which they rectified in March 2017.

Loss from the heat battery

Using the three heat meters, the amount of heat energy that is lost from the heat battery can be calculated. The heat meter on the output of the heat pump measures the heat input to the heat battery. Adding the flow from the heat meters on the heating circuit and the domestic hot water circuit gives the total heat output from the heat battery.

The figures in the table below are averages taken from Summer 2016 until mid-April 2018. Further examination of the readings, (not shown here), indicates that there are greater losses from the heat battery in colder weather.

Property	T-8	T-9	T-13	T-16	T-17	T-23	Average
Heat from ASHP / day (kWh/day)	47.6	31.0	32.9	38.0	31.9	58.2	39.9
Heat to space heating circuit / day (kWh/day)	28.7	18.7	17.1	15.2	16.6	35.9	22.0
Heat to DHW / day (kWh/day)	2.3	0.5	1.2	2.4	0.5	3.1	1.7
Loss from heat battery (Diff heat in – heat out) / day (kWh/day)	16.6	11.9	14.6	20.4	14.8	19.2	16.3

Table 3.4.5 Calculated losses from the heat battery

An average of about 16 kWh per day is a lot of heat loss from the heat battery. Over a year this will equate to about 6,000 kWh, which on an off-peak tariff of 6p/ kWh and with a COP of 2 will cost about £180. Some customers are paying over 9p/kWh for off-peak electricity, so costs for them will be higher. These losses are a significant cost to the householders.

Sunamp are continuing to develop their products, making improvements to the performance and insulation of their heat batteries.

Solar PV systems

During the course of the project 6 properties had 3 kWp solar PV systems installed on their roofs, as follows:

Property ref	Technology	Date of PV installation	Approximate orientation	Notes
T-5	Infrared radiators	13/3/17	180^0	
T-10	Infrared radiators	Spring 2016	185^0	Some shading to the South
T-119	Infrared radiators	Winter 2015/16	210^0	Before new heating system installed
T-52	Hybrid heat pump	Winter 2015/16	180^0	Before new heating system installed
T-8	Heat battery	Spring 2016	240^0	Before new heating system installed
T-13	Heat battery	3/11/16	185^0	

Table 3.4.6 PV systems installed

These systems generate electricity during daylight hours. Any electricity that is generated can be used in the property, with any that is not used at the property being exported to the grid for use elsewhere. There was no battery storage associated with these PV systems, so to use the electricity generated it needed to be used at the time of generation.

PV systems generate only in daylight hours, with generation increasing with less cloud, no shade, and with angle of incidence on the panels. There is far higher generation during the summer than during the winter, and electric heating systems use more electricity during the winter when it is colder.

The installation of PV panels was not anticipated at the start of this project, and the monitoring was therefore not designed to measure the PV generation and how it affected the running costs of the heating systems installed. The daily PV generation for each property has been kindly provided by Empower Community LLP. Without knowing how much of the generation has been used in the home and how much has been exported to the grid, the benefits for the householders can only be estimated.

The tables below summarise the average generation during the winter and summer quarters, showing the generation, the measured average daily electricity use by the heating system (where available) and the recorded daily increase in the utility electricity meter. With the exception of property T-13, which had a smart meter, any electricity generated and used in the home is not recorded on the utility meter, so it is not known how much the electricity bills have decreased because of the PV, nor how much it contributes to the heating. However, as during the winter period the amounts of generation are low (between 1.4 and 4.7 kWh per day) and the electricity usage for the infrared radiators and heat battery is high, the proportion of the total heating load provided by the PV system will be low.

Property ref	Dates Winter quarter	Average daily generation (kWh)	Average daily electricity consumption of heating system (kWh)	Average daily increase in electricity meter for period (kWh)
T-5	8/12/17 to 2/3/18	4.4		12.4
T-10	5/12/17 to 18/2/18	1.4		36.6
T-119	24/12/17 to 19/2/18	2.9		46.6
T-52	7/12/17 to 11/4/18	4.7	4.9	14.9
T-8	1/12/16 to 28/2/17	1.4	33.3	43.0
T-13	3/11/17 to 2/2/18	2.3	24.8	27.9

Table 3.4.6 Average winter PV generation and electricity usage

Property ref	Dates Summer quarter	Average daily generation (kWh)	Average daily electricity consumption of heating system (kWh)	Average daily increase in electricity meter for period (kWh)
T-5	31/5/17 to 30/8/17	13.4		3.4
T-10	22/5/17 to 12/8/17	9.7		6.6
T-119	5/5/17 to 8/8/17	11.3		10.5
T-52	1/6/17 to 31/8/17	12.0	0.6	
T-8	1/6/17 to 31/8/17	5.8	7.1	14.3
T-13	1/6/17 to 31/8/17	9.6		

Table 3.4.7 Average summer PV generation and electricity usage

Property T-13 which had a heat battery timed to come on during daylight hours had a smart meter which recorded the export of electricity to the grid. Readings from this meter showed that for the period 24 April 2017 to 13 April 2018 1,091 kWh was exported to the electricity grid. Over the same time period the PV system generated a total generation of 2,165 kWh, meaning that 1,074 kWh (or

49.6%) of the electricity generated was used in the home. At this customer's tariff of 13.73 p/kWh, this represented a saving of £147.46, or an annual saving of approximately £150. It is not known how much of this contributed to the heating system and how much to the general electricity use in the property.

3.5 Cost

Where possible, the cost of running the existing heating system has been calculated and compared with the cost of running the new heating. The electricity usage is taken either from customer bills with "actual" readings or recorded electric meter readings from site visits or customer log books.

Notes to tables in the following section:

- Internal temperatures are shown so that it can be seen whether a change in internal temperature is likely to have had an effect on the cost.

- The living room and bedroom temperatures shown are for winter periods only and do not include times when the heating would not expect to be used.
- The following tariffs have been used to calculate the heating costs, not the actual tariffs obtained by customers:

Standard rate electricity:	15 p/kWh
Standard rate gas	5 p/kWh
E-7 on peak rate	7 p/kWh
E-7 off peak rate	18 p/kWh
E-10 on-peak rate	7 p/kWh
E10 off-peak rate	16 p/kWh

- Costs for standing charge have not been included because the meters are not exclusively used for heating.

Infrared radiators

	"Before" period											
Tech Ref	Start	End	Days	Total Period peak electricity (kWh)	Total Period off-peak electricity (kWh)	Peak electricity background usage (kWh/day)	Off-peak electricity background usage (kWh/day)	Degree days	kWh per Degree Day	Estimated Annual heating Cost	Average lounge temp over period (^{0}C)	Average bedroom temp over period (^{0}C)
T-4	18/01/15	28/01/16	375	1,936	1,600	4	3	2,043	0.45	£117.29	17.16	17.18
T-5	15/04/15	29/01/16	289	621	402	1	1	1,223	0.36	£118.67	19.70	16.34
T-10	22/10/15	25/02/16	126	1,654	coal at £32/week	7		926	n/a	£1,153.84	20.76	19.05
T-11	05/11/15	28/01/16	84	4,054		13		590	5.02	£1,615.07	20.96	21.05
T-12	19/01/15	17/01/16	363	1,459	5,936	4	1	1,930	2.89	£434.91		19.54
T-22	16/02/15	28/01/16	346	3,786	8,984	5	2	1,695	6.11	£1,202.70	19.23	18.29

	"After" period with infrared heaters											
Tech Ref	Start	End	Days	Total Period electricity (kWh)	N/A	Background electricity usage (kWh/day)	N/A	Degree days	kWh per Degree Day	Estimated Annual Heating Cost	Average lounge temp over period (^{0}C)	Average bedroom temp over period (^{0}C)
T-4	28/10/16	20/03/17	143	2,707		7		1,266	1.35	£ 433.51	18.17	18.40
T-5	22/03/16	22/03/17	365	3,164		2		1,970	1.24	£ 397.48	17.50	15.07
T-10	06/11/16	03/11/17	362	7,067		7		1,800	2.52	£ 810.16	19.08	17.49
T-11	03/11/16	07/12/17	399	11,718		13		2,106	3.10	£ 997.65	20.11	21.30
T-12	31/03/17	02/04/18	367	7,910		5		2,041	2.98	£ 957.55	20.05	17.75
T-22	27/10/16	27/10/17	365	12,313		7		1,818	5.37	£ 1,726.73	21.72	19.09

	Savings			
Tech Ref	Annual cost Saving	% Saving	Change in lounge temp (^{0}C)	Change in bedroom temp (^{0}C)
T-4	-£316.22	-269.6%	1.01	1.22
T-5	-£278.81	-234.9%	-2.20	-1.27
T-10	£343.68	29.8%	-1.68	-1.56
T-11	£617.42	38.2%	-0.85	0.25
T-12	-£522.64	-120.2%	n/a	-1.79
T-22	-£524.03	-43.6%	2.49	0.80

Table 3.5.1 Comparison of costs "before" with "after" for infrared radiators

Notes to table 3.5.1

Background usage has been estimated from the recorded electrical use in mid-summer when the heating system was not being used.

The amount of coal used at property T-10 was based on a customer estimated value of 2 bags a week at £16 per bag, rather than actual recorded expenditure on coal. The results for this property will therefore be less accurate than the others, so are highlighted in orange to indicate their uncertainty.

The 20-year average annual degree-day value for East Pennines = 2145 degree days per year has been used to normalise the data to estimate the annual cost for a standard year.

Summary of results

Of the 6 properties to have infrared heating installed, the 4 which previously had storage heaters have had an increase in heating costs, the property which previously had solid fuel heating appears to have had a reduction, but for reasons explained in the notes above, this is a less accurate calculation. The property which previously had an on-peak electric heating system has had a decrease in costs.

Some properties were warmer, others cooler on average than with their previous heating over the measurement periods.

Hybrid heat pumps

	"Before" period												
Tech Ref	Start	End	Days	Total Period electricity (kWh)	Other fuel costs	N/A	N/A	Electricity background usage (kWh/day)	Gas background usage (kWh/day)	Degree days	kWh per Degree Day	Estimated Annual heating Cost	Average lounge temp over period (^{0}C)	Average bedroom temp over period (^{0}C)
T-20	22/10/15	01/04/16	162	1,002	coal @ £16/bag (3 - 4 bags/wk in winter)			5	N/A	1,274	n/a	£1,504.48	21.17	21.64
T-50	27/05/15	13/05/16	352	3722	gas (14,172)			9	0.5	1902	7.66	£886.42		
T-52	no before data													
T-73	01/04/15	02/03/16	336	6051	gas (6,385)			19	3.4	1632	2.95	£258.14		
T-83	no before data													

	"After" period with hybrid heat pumps													
Tech Ref	Start	End	days	Total Period electricity (kWh) from electric meter	Total Period gas (kWh) from gas meter	Total Period electricity (kWh) into hybrid	Total Period gas (kWh) into hybrid	Electricity background usage (kWh/day)	Gas background usage (kWh/day)	Degree days	kWh per degree day	Annual Heating and hot water Cost	Average lounge temp over period (^{0}C)	Average bedroom temp over period (^{0}C)
T-20	28/10/16	03/11/17	371	4,265	7,350	2,557	7,583	5	0.0	1,854	5.34	£868.80	18.95	21.44
T-50	28/10/16	10/11/17	378	5,895	7,552	2,513	7,371	9	0.5	1,906	5.19	£838.89	*20.77	19.34
T-52	31/03/17	11/04/18	376	4,137	6,059	906	5,093	9	2.6	2,104	2.85	£398.10	20.98	18.59
T-73	27/10/16	10/11/17	379	7,917	6,991	594	5,713	19	3.4	1,909	3.30	£421.02	19.82	17.61
T-83	31/03/17	02/05/18	397	11,238	4,956	1,374	5,153	25	0.0	2,206	2.87	£441.29	21.39	19.22

	Savings			
Tech Ref	Annual cost saving	% saving	Change in lounge temp (^{0}C)	Change in bedroom temp (^{0}C)
T-20	£622.17	41%	-2.22	-0.20
T-50	£47.53	5%		
T-52				
T-73	-£162.88	-63%		
T-83				

Table 3.5.2 Comparison of costs "before" with "after" for hybrid heat pumps

Notes to table 3.5.2

Background electricity usage has been calculated as the amount of electricity recorded from the utility meter minus the electricity use recorded by the Wh meter recording electrical input to the hybrid heat pump.

Background gas usage has been calculated as the amount of gas recorded from the utility meter minus the gas use recorded by the gas meter recording gas input to the boiler. The gas meter installed measuring the gas input to the boiler at properties T-20 and T-83 both read marginally more than the utility gas meters. This meant that the background gas reading calculates as negative. This is clearly not the case, so the background gas usage for these two properties has been set as 0.

The amount of coal used at property T-20 was based on a customer estimated value of 3 to 4 bags a week at £16 per bag, rather than actual recorded expenditure on coal. The results for this property will therefore be less accurate than the others, so are highlighted in orange to indicate their uncertainty.

Only one property (T-20) had temperature loggers installed for the before period, so it is not possible to evaluate the change in temperatures at other properties.

Unfortunately, no before gas and electricity readings were available for 2 of the properties.

The “after” living room temperature at T-50 was recorded over a winter 2017/18, rather than the period of 2016/17 when the gas and electric meter readings were recorded.

The 20-year average annual degree-day value for East Pennines = 2145 degree days per year has been used to normalise the data to estimate the annual cost for a standard year.

Summary of results

The property which previously used coal as its main heating source appears to have had a large reduction in heating costs. However, this is subject to uncertainty, as indicated in the notes above. This is also accompanied by a reduction in average living room temperature of 2 ^{0}C.

Only two other sample properties are able to have their before and after costs compared: one has an increase in costs, and the other a decrease. Both these properties had gas central heating before heating system replacements occurred.

Heat battery

	"Before" period													
Tech Ref	Start	End	Days	Total Period electricity (kWh)	Other fuel costs			Electricity background usage (kWh/day)		Degree days	kWh per Degree Day	Estimated Annual heating and hot water Cost	Average lounge temp over period (°C)	Average bedroom temp over period (°C)
T-8	04/11/15	28/03/16	145	1,728	£432.61			7.9		1,173	n/a	£900.21	21.92	20.15
T-9	22/10/15	26/04/16	187	1,863	£414.30			7.8		1,462	n/a	£678.54	21.51	20.16
T-13	no before data													
T-16	05/11/15	06/05/16	183	1,591	£370.00			10.8		1,468	n/a	£540.56	18.45	no data
T-17	29/10/15	15/04/16	169	2,612	£404.38			13.8		1,335	n/a	£684.24	20.95	20.49
T-23	22/10/15	21/04/16	182	1,592	£750.93			6.9		1,420	n/a	£1,200.62	25.52	24.61

	"After" period with Sunamp heat battery installed													
Tech Ref	Start	End	Days	Total Period peak electricity (kWh)	Total Period off-peak electricity (kWh)	Total Period peak electricity into heat pump (kWh)	Total Period off-peak electricity into heat pump (kWh)	Peak electricity background usage (kWh/day)	Off-peak electricity background usage (kWh/day)	Degree days	kWh per degree day	Annual Heating and hot water Cost	Average lounge temp over period (°C)	Average bedroom temp over period (°C)
T-8	28/10/16	03/11/17	371	2,839	7,204	884	6,239	5	2.6	1,854	3.84	£668.82	21.19	20.21
T-9	28/10/16	03/11/17	371	3,258	4,995	960	4,410	6	1.6	1,854	2.90	£557.00	22.58	20.21
T-13	02/02/18	13/04/18	70	1,331		332	943	0.8		741	1.72	£553.54	16.59	17.29
T-16	05/12/17	11/04/18	127	1,071	3,862	130	3,426	7	3.4	1,362	2.61	£410.39	18.10	17.19
T-17	24/04/17	12/04/18	353	11,099		1,084	5,146	13.8		1,983	3.14	£1,010.70	19.58	19.03
T-23	24/04/17	11/04/18	352	3,063	8,773	1,293	8,100	5	1.9	1,974	4.76	£840.80	24.76	23.67

	Savings			
Tech Ref	Annual cost saving	% saving	Change in lounge temp (°C)	Change in bedroom temp (°C)
T-8	£231.38	26%	-0.73	0.06
T-9	£121.54	18%	1.07	0.05
T-13	no data			
T-16	£130.17	24%	-0.35	no data
T-17	-£326.46	-48%	-1.37	-1.46
T-23	£359.82	30%	-0.76	-0.94

Table 3.5.3 Comparison of costs "before" with "after" for heat battery

Notes on Table 3.5.3

The cells in orange are less accurate because they are based on estimates. Only the tenant at property T-16 recorded the amount of coal used every week during the "before" period. Coal use and costs at the other properties have been estimated based on the usage at T-16 and adjusted for the energy requirement listed in the EPC. These cost estimates are highlighted in yellow to indicate that they will be less accurate than the others.

The 20-year average annual degree-day value for East Pennines = 2145 degree days per year has been used to normalise the data to estimate the annual cost for a standard year.

T-13 is the property which didn't switch electric tariff but had a PV system installed and had the timer altered to coincide heat battery charging with daylight hours. The costs shown in table 3.5.3 above are the costs of electricity used by the heating system, and do not include any reduction in costs by using free electricity generated at the home.

T-17 is the property where the tenants didn't switch their electricity tariffs to either E-7 or E-10.

Summary of results

Four out of the 6 properties appear to be cheaper to run with the Sunamp heat battery than they were with their solid fuel heating system, however 3 out of 4 of these costs are not accurate due to the estimates of coal purchased explained in the notes above.

One property had an increase in costs: T-17 where the heat pump was run on standard electricity.

For one property (T-13) there was insufficient information to determine any change in costs.

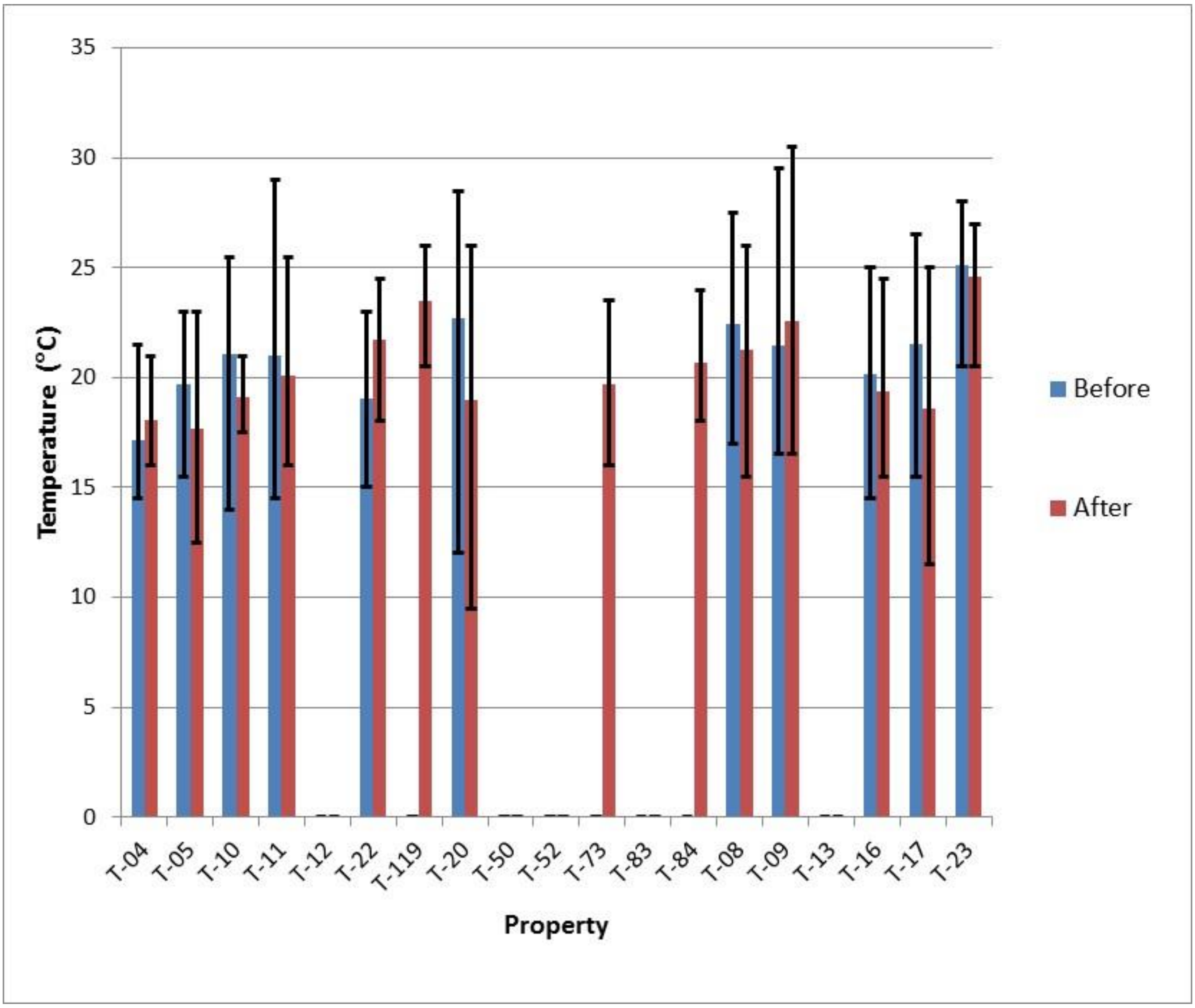
3.6 Temperature and thermal comfort

		Living room temperatures 6 November 2015 to 28 January 2016				Living room temperatures 6 November 2016 to 31 March 2017			
Measure	Tech Ref	Average Temp (°C) 24 hours	Maximum Temp (°C) 24 hours	Minimum Temp (°C) 24 hours	Average Temp (°C) 5pm-9pm	Average Temp (°C) 24 hours	Maximum Temp (°C) 24 hours	Minimum Temp (°C) 24 hours	Average Temp (°C) 5pm-9pm
Infra Red radiators	T-04	17.1	21.5	14.5	17.3	18.1	21.0	16.0	18.3
	T-05	19.7	23.0	15.5	19.6	17.7	23.0	12.5	18.6
	T-10	21.1	25.5	14.0	21.3	19.1	21.0	17.5	19.2
	T-11	21.0	29.0	14.5	21.7	20.1	25.5	16.0	19.9
	T-12								
	T-22	19.0	23.0	15.0	18.5	21.7	24.5	18.0	21.4
	T-119					23.5	26.0	20.5	23.5
	Maximum	21.1	29.0	15.5	21.7	23.5	26.0	20.5	23.5
	Minimum	17.1	21.5	14.0	17.3	17.7	21.0	12.5	18.3
	Average	19.6	24.4	14.7	19.7	20.0	23.5	16.8	20.1
Hybrid heat pump	T-20	22.7	28.5	12.0	23.7	19.0	26.0	9.5	20.3
	T-50								
	T-52								
	T-73					19.7	23.5	16.0	20.3
	T-83					20.7	24.0	18.0	20.5
	T-84					24.3	30.5	17.0	24.0
	Maximum					24.3	30.5	18.0	24.0
	Minimum					19.0	23.5	9.5	20.3
	Average					20.9	26.0	15.1	21.3
Heat battery	T-08	22.4	27.5	17.0	22.5	21.2	26.0	15.5	21.2
	T-09	21.5	29.5	16.5	22.7	22.6	30.5	16.5	23.8
	T-13								
	T-16	20.2	25.0	14.5	20.1	19.3	24.5	15.5	20.0
	T-17	21.5	26.5	15.5	21.9	18.6	25.0	11.5	18.4
	T-23	25.1	28.0	20.5	25.0	24.6	27.0	20.5	25.2
	Maximum	25.1	29.5	20.5	25.0	24.6	30.5	20.5	25.2
	Minimum	20.2	25.0	14.5	20.1	18.6	24.5	11.5	18.4
	Average	22.1	27.3	16.8	22.4	21.3	26.6	15.9	21.7

Fig 3.6.1 Table showing living room temperature before and after installation of new heating systems

Table 3.6.1 above shows the living room temperatures in the period monitored before and after the heating measures were installed. The average temperatures for the infrared radiators and the heat battery have not changed much following the new heating measure. There is a slight reduction in the average maximum and a slight increase in the average minimum temperature for the infrared and heat battery properties. This suggests that the two technologies are more controllable than the previous heating systems. As only one of the hybrid heat pumps had monitoring equipment installed before the new heating was installed a meaningful average comparison cannot be done between before and after. There is a low minimum in the living room of property T-20. This coincides with a period of a few days when the system was turned off, and there was no heat input to the property.

DD period before = 596 DD period after = 1287.



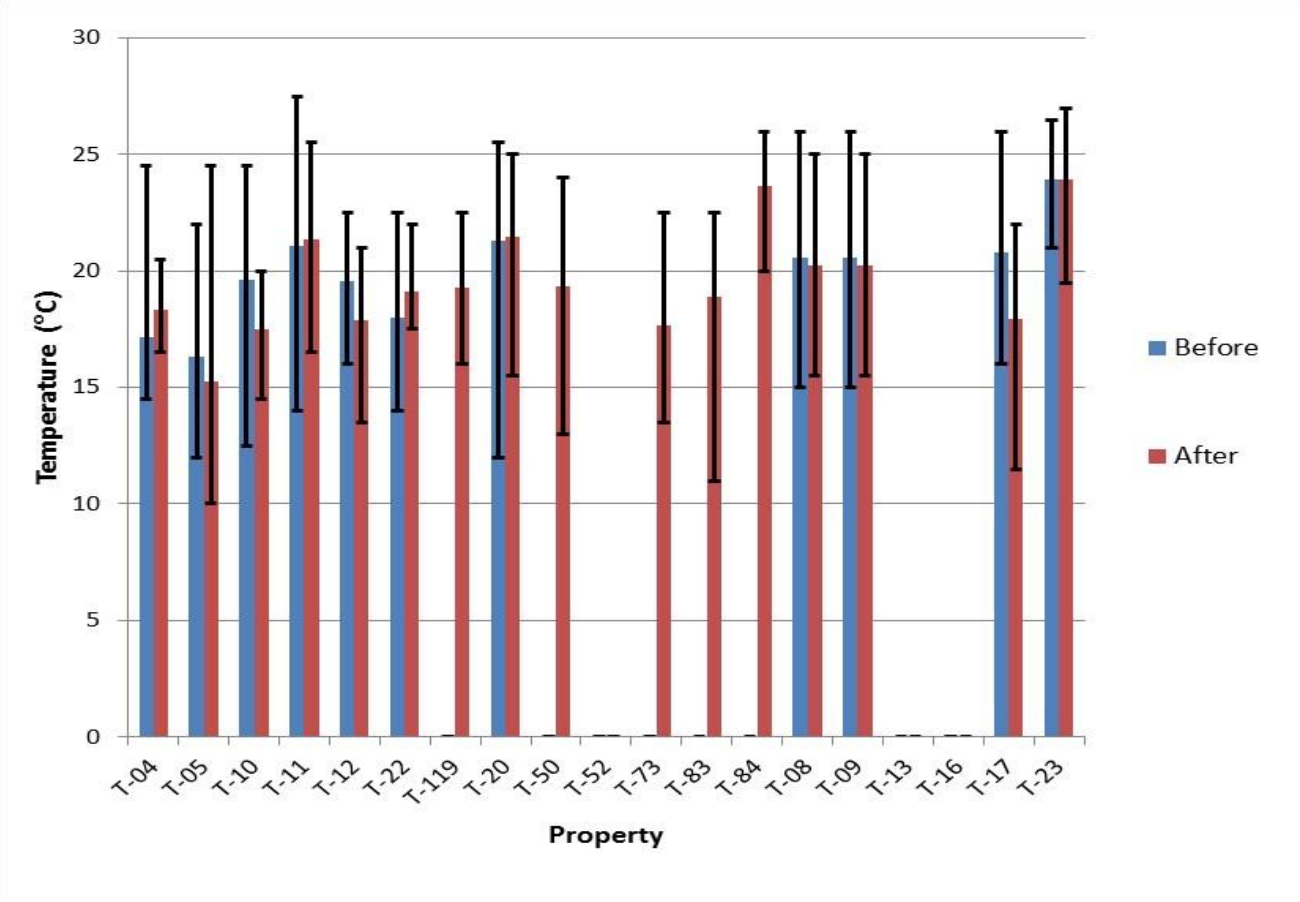
Graph 3.6.2 Living room temperature before and after installation of new heating systems, with max/min bars

Graph 3.6.2 gives a graphical representation of the before and after temperatures given in table 3.6.1 for living rooms before (from 6 November 2015 to 28 January 2016) and after (6 November 2016 to 31 March 2017).

		Bedroom temperatures 6 November 2015 to 28 January 2016				Bedroom temperatures 6 November 2016 to 31 March 2017			
Measure	Tech Ref	Average Temp (°C) 24 hours	Maximum Temp (°C) 24 hours	Minimum Temp (°C) 24 hours	Average Temp (°C) 5pm-9pm	Average Temp (°C) 24 hours	Maximum Temp (°C) 24 hours	Minimum Temp (°C) 24 hours	Average Temp (°C) 5pm-9pm
Infra Red radiators	T-04	17.2	24.5	14.5	17.1	18.3	20.5	16.5	18.3
	T-05	16.3	22.0	12.0	16.4	15.3	24.5	10.0	15.2
	T-10	19.6	24.5	12.5	19.6	17.5	20.0	14.5	17.5
	T-11	21.1	27.5	14.0	20.8	21.3	25.5	16.5	21.2
	T-12	19.6	22.5	16.0	19.4	17.9	21.0	13.5	17.9
	T-22	18.0	22.5	14.0	18.0	19.1	22.0	17.5	19.3
	T-119					19.3	22.5	16.0	19.6
	Maximum	21.1	27.5	16.0	20.8	21.3	25.5	17.5	21.2
	Minimum	16.3	22.0	12.0	16.4	15.3	20.0	10.0	15.2
	Average	18.6	23.9	13.8	18.5	18.4	22.3	14.9	18.4
Hybrid heat pump	T-20	21.3	25.5	12.0	21.8	21.4	25.0	15.5	22.6
	T-50					19.4	24.0	13.0	19.8
	T-52								
	T-73					17.6	22.5	13.5	18.2
	T-83					18.9	22.5	11.0	18.4
	T-84					23.7	26.0	20.0	24.1
	Maximum					23.7	26.0	20.0	24.1
	Minimum					17.6	22.5	11.0	18.2
	Average					20.2	24.0	14.6	20.6
Heat battery	T-08	20.6	26.0	15.0	20.5	20.3	25.0	15.5	20.4
	T-09	20.6	26.0	15.0	20.5	20.3	25.0	15.5	20.4
	T-13								
	T-16								
	T-17	20.8	26.0	16.0	20.5	17.9	22.0	11.5	17.4
	T-23	23.9	26.5	21.0	23.7	24.0	27.0	19.5	24.5
	Maximum	23.9	26.5	21.0	23.7	24.0	27.0	19.5	24.5
	Minimum	20.6	26.0	15.0	20.5	17.9	22.0	11.5	17.4
	Average	21.5	26.1	16.8	21.3	20.6	24.8	15.5	20.6

Table 3.6.3 Table showing bedroom temperature before and after installation of new heating systems

Table 3.6.3 shows similar temperature readings for the bedrooms. On average, bedroom temperatures are lower than living room temperatures, but again on average readings are not much changed following the installation of new heating. As with the living rooms, the variation between maximum and minimum for infrared and heat battery properties has reduced, suggesting more controllability of heating.



Graph 3.6.4 Bedroom temperatures before and after installation of new heating systems, with max/min bars

Graph 3.6.4 shows the same information before (6 November 2015 to 28 January 2016) and after (6 November 2016 to 31 March 2017) installation of a new heating system.

3.7 Humidity

Water vapour in the air, usually referred to as relative humidity (RH), 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). RH 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.

Figure 3.7 illustrates the optimum humidity levels as cited by Arundel et al[15]. The study concluded that maintaining relative humidity levels between 40% and 60% would minimise adverse health effects relating to relative humidity.

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

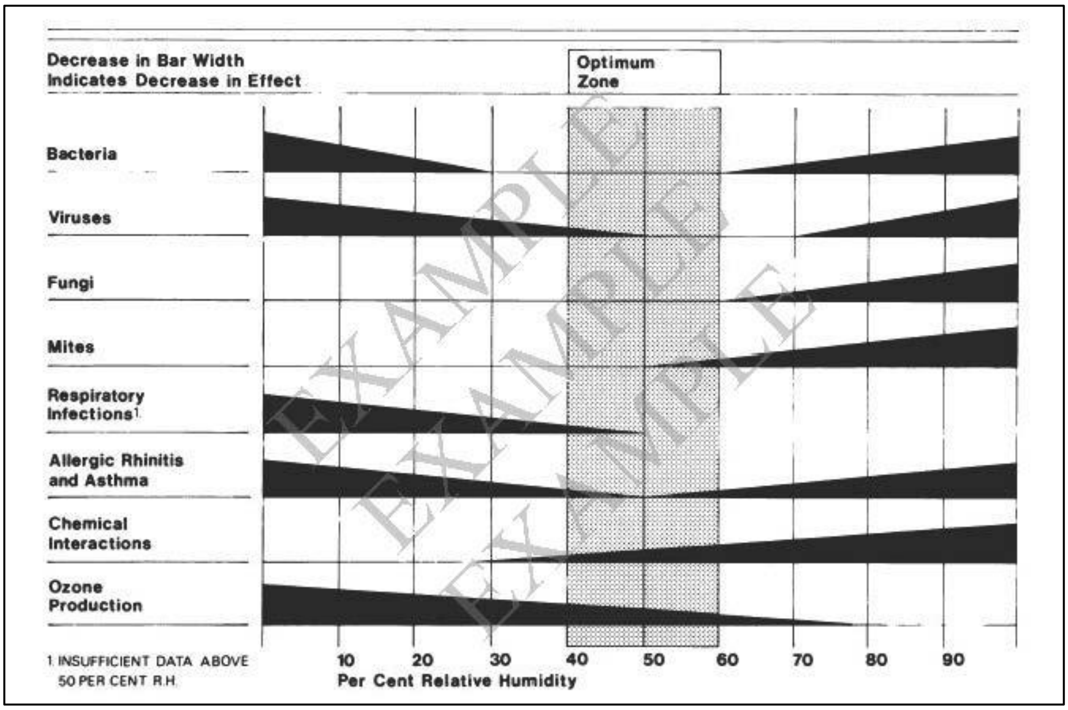


Figure 3.7.1 Optimum humidity levels to reduce indirect effects from pathogenic organisms or chemicals

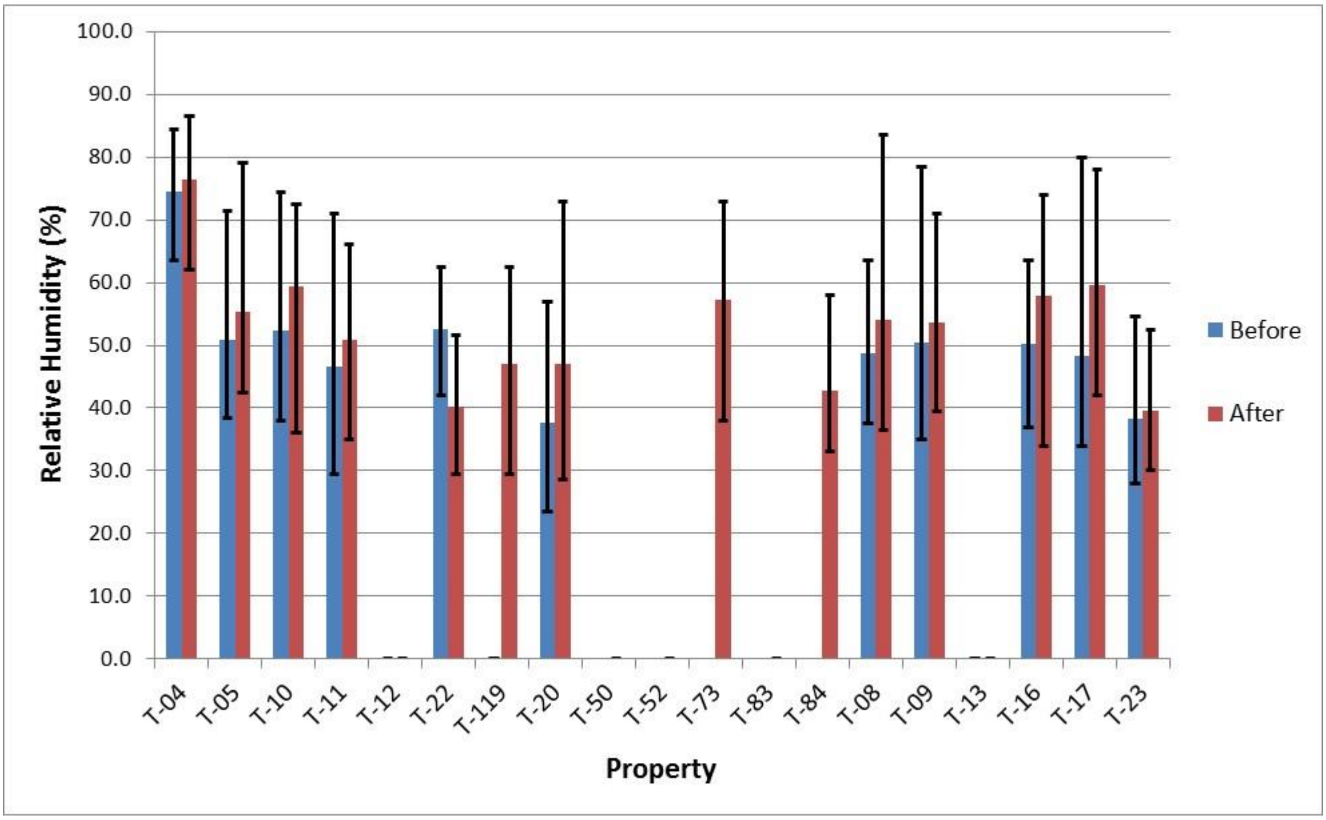
The automated data-loggers used in this project record both temperature and relative humidity (RH) at pre-determined intervals across the study properties. RH is a ratio (expressed as a percentage) of the amount of moisture present in the air at each logging point, relative to the amount that would be 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 Approved Document F to the Building regulations[16]; the suggested average monthly maximum humidity levels for domestic dwellings during the heating season is 65%.

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

		Living room humidities 6 November 2015 to 28 January 2016				Living room humidities 6 November 2016 to 31 March 2017			
Measure	Tech Ref	Average Humidity (% RH) 24 hours	Maximum Humidity (% RH) 24 hours	Minimum Humidity (% RH) 24 hours	Average Humidity (% RH) 5pm-9pm	Average Humidity (% RH) 24 hours	Maximum Humidity (% RH) 24 hours	Minimum Humidity (% RH) 24 hours	Average Humidity (% RH) 5pm-9pm
Infra Red radiators	T-04	74.5	84.5	63.5	74.8	76.3	86.5	62.0	76.1
	T-05	50.8	71.5	38.5	51.7	55.4	79.0	42.5	54.5
	T-10	52.4	74.5	38.0	52.8	59.4	72.5	36.0	59.2
	T-11	46.6	71.0	29.5	46.4	50.8	66.0	35.0	50.7
	T-12								
	T-22	52.6	62.5	42.0	53.5	40.2	51.5	29.5	40.8
	T-119					47.0	62.5	29.5	46.9
	Maximum	74.5	84.5	63.5	74.8	76.3	86.5	62.0	76.1
	Minimum	46.6	62.5	29.5	46.4	40.2	51.5	29.5	40.8
	Average (Mean)	55.4	72.8	42.3	55.8	54.8	69.7	39.1	54.7
Hybrid heat pump	T-20	37.6	57.0	23.5	37.6	47.0	73.0	28.5	46.6
	T-50								
	T-52								
	T-73					57.2	73.0	38.0	58.7
	T-83								
	T-84					42.8	58.0	33.0	43.1
	Maximum					57.2	73.0	38.0	58.7
	Minimum					42.8	58.0	28.5	43.1
	Average (Mean)					49.0	68.0	33.2	49.5
Heat battery	T-08	48.8	63.5	37.5	50.2	54.1	83.5	36.5	55.0
	T-09	50.4	78.5	35.0	51.4	53.6	71.0	39.5	53.9
	T-13								
	T-16	50.3	63.5	37.0	50.9	57.9	74.0	34.0	57.9
	T-17	48.4	80.0	34.0	48.6	59.6	78.0	42.0	60.2
	T-23	38.3	54.5	28.0	39.3	39.6	52.5	30.0	39.9
	Maximum	50.4	80.0	37.5	51.4	59.6	83.5	42.0	60.2
	Minimum	38.3	54.5	28.0	39.3	39.6	52.5	30.0	39.9
	Average (Mean)	47.2	68.0	34.3	48.1	53.0	71.8	36.4	53.4

Fig 3.7.2 Living room RH before and after installation of new heating systems

Levels of humidity at property T-4 were very high, with an average of 74.5 % in the living room before the infrared radiators were installed and 76.3 % afterwards. This property showed signs of mould growth in the bathroom.



Graph 3.7.3 Living room RH before and after installation of new heating systems, with max/min bars

Graph 3.7.3 above shows the relative humidity in living rooms before (from 6 November 2015 to 28 January 2016) and after (6 November 2016 to 31 March 2017) the new heating systems were installed.

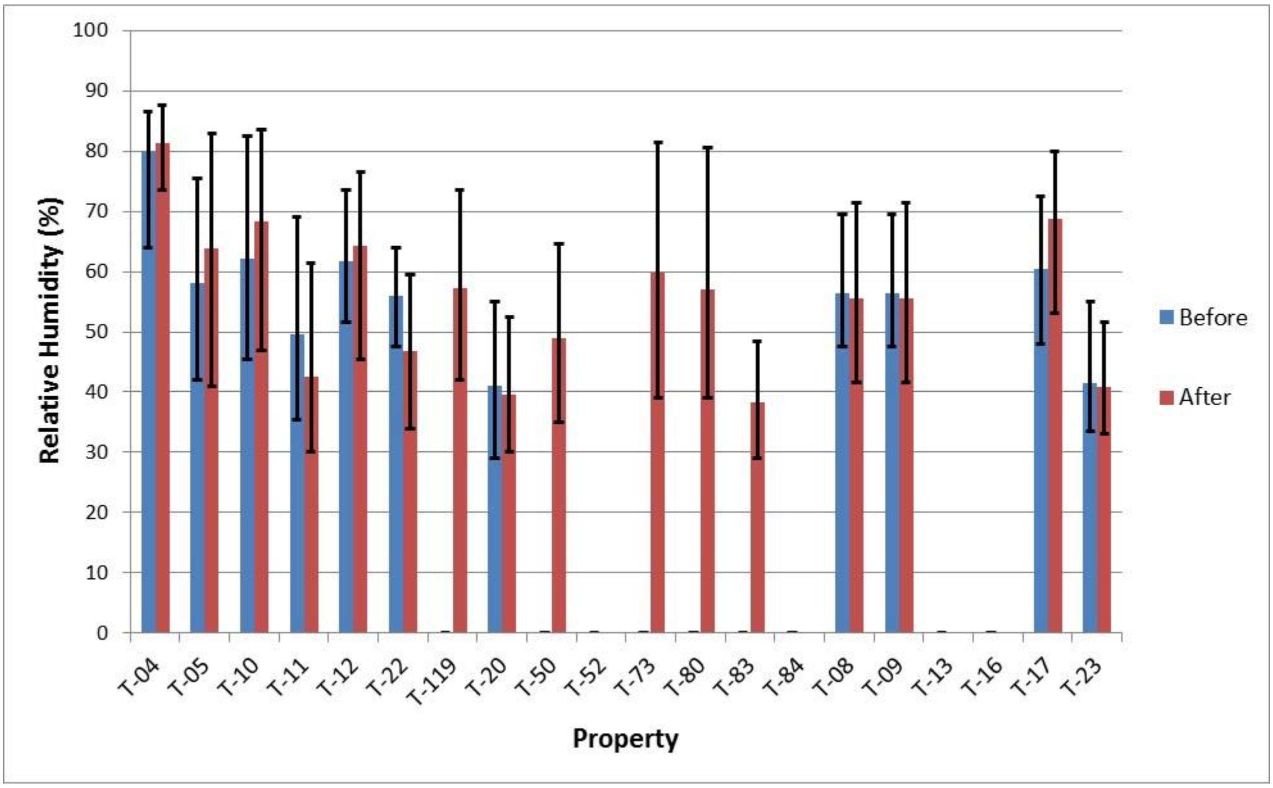
Table 3.7.2 and graph 3.7.3 above show that following installation of the new heating systems, on average, there was a slight decrease in RH in properties with infrared radiators and an increase in internal RH for heat batteries for which there is an increase in minimum, maximum and average RH over 24 hour periods and between 5 and 9 pm.

Only one property with a hybrid heat pump had RH measured before, and this property had a solid fuel heating appliance, whereas the other properties had gas combi boilers. This property, which showed an increase in RH, may not be representative of the sample which had hybrid heat pumps installed.

All the properties which had the heat batteries installed, as well as one hybrid heat pump property (T-20) and one infrared radiator property (T-10) previously had solid fuel heating systems. Open flued solid fuel heating requires a high amount of ventilation to enable complete combustion of the fuel and ensure safe evacuation of combustion gases. Higher ventilation rates with the solid fuel heating are likely to have lowered RH in these properties. When solid fuel heaters were removed, there will have been a significant drop in ventilation due to closure of the flue and sealing of air bricks. This could well be the cause of increased humidity, despite little change in internal temperature.

		Bedroom humidities 6 November 2015 to 28 January 2016				Bedroom humidities 6 November 2016 to 31 March 2017			
Measure	Tech Ref	Average Humidity (% RH) 24 hours	Maximum Humidity (% RH) 24 hours	Minimum Humidity (% RH) 24 hours	Average Humidity (% RH) 5pm-9pm	Average Humidity (% RH) 24 hours	Maximum Humidity (% RH) 24 hours	Minimum Humidity (% RH) 24 hours	Average Humidity (% RH) 5pm-9pm
Infra Red radiators	T-04	80.0	86.5	64.0	79.2	81.3	87.5	73.5	80.7
	T-05	58.2	75.5	42.0	57.0	63.7	83.0	41.0	62.7
	T-10	62.2	82.5	45.5	61.2	68.3	83.5	47.0	67.2
	T-11	49.6	69.0	35.5	49.8	42.5	61.5	30.0	43.1
	T-12	61.7	73.5	51.5	61.3	64.3	76.5	45.5	63.5
	T-22	55.9	64.0	47.5	55.5	46.8	59.5	34.0	46.4
	T-119					57.4	73.5	42.0	57.6
	Maximum	80.0	86.5	64.0	79.2	81.3	87.5	73.5	80.7
	Minimum	49.6	64.0	35.5	49.8	42.5	59.5	30.0	43.1
	Average (Mean)	61.2	75.2	47.7	60.7	60.6	75.0	44.7	60.2
Hybrid heat pump	T-20	41.0	55.0	29.0	41.2	39.6	52.5	30.0	39.4
	T-50					49.0	64.5	35.0	47.9
	T-52								
	T-73					59.7	81.5	39.0	60.7
	T-83					57.0	80.5	39.0	53.0
	T-84					38.4	48.5	29.0	
	Maximum					59.7	81.5	39.0	60.7
	Minimum					38.4	48.5	29.0	39.4
	Average (Mean)					48.8	65.5	34.4	50.2
Heat battery	T-08	56.4	69.5	47.5	55.3	55.5	71.5	41.5	54.7
	T-09	56.4	69.5	47.5	55.3	55.5	71.5	41.5	54.7
	T-13								
	T-16								
	T-17	60.4	72.5	48.0	59.1	68.8	80.0	53.0	68.0
	T-23	41.4	55.0	33.5	41.4	40.9	51.5	33.0	40.5
	Maximum	60.4	72.5	48.0	59.1	68.8	80.0	53.0	68.0
	Minimum	41.4	55.0	33.5	41.4	40.9	51.5	33.0	40.5
	Average (Mean)	53.7	66.6	44.1	52.8	55.2	68.6	42.3	54.5

Fig 3.7.4 Bedroom RH before and after installation of new heating systems



Graph 3.7.5 Bedroom RH before and after installation of new heating systems, with max/min bars

The changes in RH in the bedrooms are similar to those in the living room although less marked. Property T-20, which had previously had a solid fuel heating system and where there had been an increase in living room RH showed a decrease in bedroom RH. This is likely to be because the main change in ventilation in the property was in the living room where the open fire was located. The bedroom ventilation rate would probably be unchanged.

4. Conclusions and recommendations

4.1 Conclusions

This project has demonstrated three different heating systems:

- infrared radiators with the temperature in each room set on a central controller, which then controls when each radiator comes on to provide heat as required to each room
- a hybrid heat pump running on gas and electricity, with the central controller deciding whether to use gas or electricity depending on which is cheaper at the time, determined by external temperatures and performance parameters of the heat pump
- a heat battery using a high temperature heat pump to run during off-peak electricity periods to melt a phase change material and store the heat until required in the home

A total of 18 of the heating systems were monitored to evaluate the energy used by the systems and to assess their performance. Customers with monitoring equipment in their homes were also asked a number of questions before and after installation to gauge their view on the systems.

Customer satisfaction

- Satisfaction levels among tenants with the new heating systems was generally high, with most households responding that they were satisfied or very satisfied with the warmth, cost, controllability, and ease of use of their new heating.
- Four out of 6 of the households with the infrared heating were positive about its attributes, but 2 consistently marked it down. The cost of running the system meant that these 2 households didn't heat their homes to the temperature they would want and they said that their homes didn't warm up quickly or maintain the heat.
- Only 1 out of 5 households with the hybrid heat pump said they had seen a reduction in their energy bills, but all 5 of them said they had a warmer and more comfortable home. 4 out of 5 of the hybrid households thought that their home gets warmer faster and keeps the heat better, that they have more control over their heating and that it is easier to use.
- The 4 heat battery customers who answered the questionnaire were very positive about all aspects of the heating system, giving it a better response rate than the other two technologies.

Costs

Monitoring results showed that the infrared radiators were

- more expensive to run than the storage heaters at 4 properties where they were replaced
- cheaper to run than the on-peak electric panel heaters at 1 property where they were replaced
- likely to be cheaper than the solid fuel heating system they replaced

Monitoring results showed that the hybrid heating systems were

- likely to be significantly cheaper to run than the solid fuel heating system they replaced
- There was insufficient data to reach any conclusions about the change in costs when hybrid heat pumps replaced gas boilers. It was only possible to compare costs at 2 properties, one of which was more expensive with the hybrid heat pump and one was cheaper to run.

Monitoring results showed that the heat batteries were

- cheaper to run than the solid fuel heating systems they replaced, providing the customers switched to a time of use tariff e.g. Economy 10 or Economy 7.
- The customer who was not able to switch to an E-10 tariff had an increase in heating costs.

Performance and Controllability

Households were generally very happy with the performance of their heating systems, and their ability to keep their homes warm when they wanted them warm. Graphs in Section 3 show that all 3 heating systems provide good controllability. The infrared radiators were left on a constant setting and provided even internal temperatures whatever the external temperature. The hybrid heat pumps and heat batteries were either set with a day time temperature and a night time set back, or with two heating cycles. These gave a more variable internal temperature than the infrared radiators but provided comfortable heat at times needed by the householders.

4.2 Recommendations for potential future installations

- Due to their increased running costs, infrared radiators are not recommended for future heating installations in social housing
- Where possible reduce the flow temperature of the hybrid heat pump as this will improve the SCOP of the heating system, increasing the use of the heat pump and lowering overall running costs.
- Hybrid heat pumps may be worth investment where the RHI can be claimed against the increased capital cost of installation.
- Improve the insulation of the heat batteries to reduce losses from the system
- Continued development of heat batteries, which proved popular with households.

4.3 Impact on fuel poverty

The infrared radiators have increased the heating cost for customers who had previously had storage heaters, so this has had a negative effect on the affordability of their heating.

The hybrid heat pumps have not been shown to be cheaper to run than the gas boilers that they replaced, but householders reported that they were happy with the system and on average they heated more of their home than previously. The customer who previously had a solid fuel heating system had significantly reduced heating costs.

The heat batteries were cheaper to run than the solid fuel systems they replaced. Reducing the heat loss from the heat battery could save customers up to an additional £180 per year on their fuel bills.

4.4 Performance comparison against manufacturers' claims

The infrared radiators provide consistent heat, which is accurately controlled by the appliance thermostats, so they do not waste heat by overheating the property. However, because they are on-peak electric heating systems they are not cheap to run.

The hybrid gas boiler efficiencies at an average of 60% are low compared with the reported efficiency of 89.1 % as recorded on the Product Characteristics Database (PCDB)[17]. This may be partly due to short draw-off periods for hot water.

The measured SCOPs for the hybrid heat pump are not as good as might be expected. The SCOP listed on the MCS website[18] for this product at a flow temperature of 55 ^{0}C is 3.16, whereas average site measurements were 2.55, and the average from the Daikin controller was 2.74.

The SCOP of one property was improved by changing the way the system was controlled. It was increased from 2.47 when it was controlled by the on/off switch to 2.59 when it was controlled by the room thermostat. The two lowest SCOPs were from another two customers who didn't control their heating with the room thermostat.

Heat losses from the heat battery need to be addressed. A significant amount of heat is being lost from the batteries and heat pump hydroboxes, which reduces the savings made by using an off-peak electricity tariff. The losses could amount to costs of £180 or more a year.

The measured SCOPs of the high temperature heat pumps (average 2) were not as high as in manufacturer's literature (2.6) for the same temperature conditions. Improvements in performance here, would reduce costs for the households.

4.5 Economic business case for installation of measures

Infrared radiators

Although the infrared radiators showed improved performance, through better controllability and reduced electricity consumption, the cost of running the system was more expensive than the storage heaters that 4 customers had used previously. The infrared system was cheaper to run for the 1 customer who had on-peak electric panel heaters, and estimated to be cheaper than the solid fuel system of 1 customer. However, the cost of installation and the fact that most customers are paying more for their heat means that installation of these systems shouldn't be recommended.

[17] http://www.ncm-pcdb.org.uk/sap/pcdbsearch.jsp?pid=26

[18] http://www.microgenerationcertification.org/consumers/product-search?product_type_id=4694

Hybrid heat pump

The hybrid heat pump is more expensive to purchase and install than a standard gas combi boiler. It has received good reports from customers, who report better control over their heating and more rooms heated, insufficient data on running costs before have been gathered to demonstrate any significant cost savings for customers moving from a standard gas boiler to the hybrid.

Renewable Heat Incentive payments would be able to be claimed on any renewable heat generated by the heat pump which would help to mitigate the additional cost of installation.

Heat battery

The Sunamp heat battery has proven to be popular with tenants and is a very good way of shifting electrical load to off-peak times. It has been cheaper to run than solid fuel heating systems for customers who switched to E-10 or E-7 tariffs. However, the heat battery combined with a high temperature heat pump was a very expensive heating option, costing over £15,000 per installation. The Sunamp heat battery is at the early stages of commercialisation with only a handful of units installed to date. Increased numbers in manufacturing is likely to reduce costs in the future which will make its installation more attractive. Sunamp are continuing to develop their heat batteries, with improved insulation and wider range of products.

Changes to time of use tariffs in the future which could mean lower electricity costs at certain times and could also mean that with a more flexible control system running costs could be reduced further.

Appendix 1: Glossary of Terms

ASHP	*Air Source Heat Pump*
BST	*British Summer Time*
COP	*Coefficient of Performance*
DD	*Degree Days*
DHW	*Domestic hot water*
E-7	*Economy 7 electricity tariff*
E-10	*Economy 10 electricity tariff*
EPC	*Energy Performance Certificate*
EWI	*External Wall Insulation*
GMT	*Greenwich Mean Time*
HIP	*Health and innovation Programme*
kWh	*Kilowatt Hour*
NEA	*National Energy Action – the National Fuel Poverty Charity*
PCDB	*Product Characteristics Database: database of products which have been tested for input into SAP or RdSAP calculations. This gives product performance.*
PCM	*Phase change material*
PV	*Photovoltaic*
RH	*Relative Humidity*
RHI	*Renewable Heat Incentive*
SAP	*Standard Assessment Procedure (for assessing home energy efficiency)*
SCOP	*Seasonal Coefficient of Performance*
TIF	*Technological Innovation Fund*
TRV	*Thermostatic Radiator Valve*
Wh	*Watt hour – unit of electrical energy (1/1000 of a kWh)*

Appendix 2: Health and Innovation Programme 2015 – 2017

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

The programme comprised 3 funds

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

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

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

What it involved

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

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

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

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

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