TECHNICAL INNOVATION FUND

NEA Action for Warm Homes

CP752
Air-source heat pumps with solar PV-T panels
Optivo

Technical Evaluation Report




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October 2018

Background

About National Energy Action

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

About the Technical Innovation Fund

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

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

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

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

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

Technical monitoring and evaluation

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

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

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

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

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

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

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

Acknowledgements

With grateful thanks to our project partners:

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Executive summary

Project overview

This project installed a hybrid combination of a Mitsubishi air-source heat pump (ASHP) with novel Solar Angel PV-T (PV and thermal) solar panels in 21 homes, to provide a "whole house" approach, in rural properties not connected to mains gas in Norton, Kent and Iden, East Sussex. The properties were owned by Optivo, a housing association providing homes and services to communities across London, Kent and Sussex. The monitored properties were 2 or 3-bedroom semi-detached houses of a range of types, occupancy levels and age ranges of occupant, most of which had previously been treated with loft and cavity wall insulation and had double-glazed windows.

The project had the following aims, to:

- Replace the existing heating system with a Mitsubishi ASHP system coupled with solar PV-T panels, to provide renewable heating, hot water and electricity for the households,
- Assess any change in residents' comfort – both reported in questionnaires, and measured using temperature and humidity monitors – after the new heating, and solar PV-T system,
- Quantify any change in electricity use and costs for heating, and general household use, following the measures, compared to the period prior to installation,
- Quantify flows of renewable electricity and heat generated to determine effectiveness,
- Report any change in ease of use of the heating system with the new measures fitted,
- Determine the effectiveness and cost-effectiveness of these measures to reduce fuel poverty in rural off-gas properties - information relevant to many social housing (and private) owners.

Context

In the area of Norton, near Faversham in Kent, 67.7% of homes are not connected to mains gas, with 11% fuel poverty[1]. This lower super-output area (LSOA) - the smallest area for which robust statistics are available, is in the 40% most deprived in the country[2]. Iden, near Rye in East Sussex, has 95% of homes with no mains gas connection (the majority being >2km from a gas main), also suffering 11% fuel poverty[1] and this area is within the top 20% most deprived in the country.

In Great Britain, it is estimated that around 10% (4 million) of households do not have a mains gas connection, with just over half of these using electricity as their primary heating source[3]. Given the distance from gas mains, this proportion is much higher in rural areas. Dwellings with electric heating systems tend to have lower energy efficiency ratings, partly reflecting higher running costs and lower levels of heating controllability. Due to their higher heating costs, these households are more likely to be fuel poor.

Optivo chose to test this approach, to help determine the most suitable methods to achieve the government's requirement to achieve EPC band C standard by 2030, for their rural "off gas" properties. This solution could be scaleable to their other 600 rural off-gas properties in the South-East of England, as well as being relevant to other housing providers in the UK. "Off-gas grid" properties invariably pay more for fuel, often live in inefficient properties and are less protected from bad pricing regimes (such as purchasing oil), due to little regulation in this sector.

[1] Non-gas map, www.nongasmap.org.uk [Accessed 6/9/2018]

[2] Indices of Deprivation 2015 explorer, dclgapps.communities.gov.uk/imd/idmap.html [Accessed 6/9/2018]

[3] Insights paper on households with electric and other non-gas heating, ofgem.gov.uk/ofgem-publications/98027/insightspaperonhouseholdswithelectricandothernon-gasheating-pdf [Accessed 6/9/2018]

The technology: ASHP and PV-T

Mitsubishi Ecodan ASHPs have been installed successfully in many homes across the country. These provided central heating and domestic hot water. The innovation of this project was its combination with novel solar PV-T panels which produce both electricity and domestic hot water (mainly in summer), so providing renewable energy towards all elements of domestic energy needs throughout the year.

The project

Optivo had already identified 25 suitable properties to improve in 2 locations. 8 of these properties' residents were willing to be part of the monitoring, 4 in Norton, Kent, and 4 in Iden, Rye. All the monitored properties were 2- or 3-bedroom semi-detached properties. 3 of the 4 properties in Norton had solid fuel fires with back boilers, and one (where the fire had previously broken down and been removed) had a fully electric boiler system. All 4 properties monitored in Iden had electric storage heating. All the properties used electric immersion heaters for hot water. Attention was paid to insulation and air tightness to ensure the new systems operated as efficiently as possible. Optivo would fund air tightness, insulation and lighting measures for each property where required prior to fitting of the ASHP system, to reduce heat losses.

Energise Sussex Coast - Optivo's trusted energy advice partner in Sussex - provided expert energy efficiency advice to residents on how to use the controls of their new renewable heating systems. They also gave additional advice on energy tariff switching, energy and water efficiency.

All properties were monitored for temperature and humidity, and a datalogger was fitted to monitor household electricity use. All had a solar generation meter fitted. 4 of the properties (2 in each location willing to have more invasive monitoring) had watt-hour meters fitted to monitor energy used by the heat pump and immersion tank, with LED pulse sensors to monitor usage by time. These homes also had a thermal probe fitted on the main radiator – usually the living room – and heat meters fitted to monitor the heat input to domestic hot water (DHW) from the solar thermal, the ASHP input to DHW, and the ASHP heat usage for central heating. All households were asked to record their electricity meter readings every 2 weeks for the duration of the study, and to provide bills detailing previous consumption. Pre-installation questionnaires were carried out with residents in February 2016 to gather information on household occupancy, energy using behaviours and costs, and satisfaction with the existing heating and insulation.

Installation of the ASHPs took place between February and March 2016, then the solar panels were commissioned in May 2016. However, the first recorded heat output from the solar hot water was measured in July 2016 – it is not known whether the hot water element of the PV-T panels was connected after the solar PV element, or whether the heat meters were only fitted later, after its install. Properties with heat meters fitted were visited in October 2016 to check these, at which point the data loggers connected to these were exchanged. Interim questionnaires were carried out with householders in December 2017 when all monitoring equipment was exchanged. Monitoring then continued until July 2018 when all removable equipment was collected, and a final questionnaire was carried out to gauge resident satisfaction with their heating, hot water and electricity usage now they had experienced a whole winter with the measures fitted.

Summary of findings:

Energy use and costs

Taking into account electricity use only (kWh):

- Properties saw an average saving of 18.1 % per year on electricity use (kWh), but within this previously electric storage heated (ESH) homes saved 43.4 % (reducing from 7.7 down to 4.3 kWh/degree day (dd)) after installation of the new heating measures. Household T-10, which previously had an electric boiler saved 11.9 % (8.65 down to 7.6 kWh/dd). homes which previously used solid fuels, expectedly, increased their electricity consumption by 13.7 % (from 4.48 to 5.1 kWh/dd), as they used more electricity for heating.
- In cost terms – due to assumed changes in electricity tariff - this equated to 28.45 % savings (£621 per year) on average for previously storage heated homes. Household T-10 which used an electric boiler saved 10.3%. Electricity costs for homes which previously used solid fuels went up by 42.6% (£459 per year) on average due to change of energy source.

Taking all fuel consumption into account, including estimates of solid fuel volumes and costs, added inaccuracies and gave unusual results as some households in these rural areas were able to obtain logs for free due to working in / connections with forestry activity:

- The average saving in total fuel usage (kWh) was 50.9 % (down from 12.0 to 5.0 kWh/dd). With a standard deviation (σ) of 21 %, the savings are significant to a 2σ, or 95.4% confidence level. If property T-10 - which suffered many issues and made lowest savings, probably as a result - is excluded, total fuel savings averaged 56.4 % (from 12.5 down to 4.7 kWh/dd), with a σ of 15 %, so savings are significant to 3σ or 99.6%.
- Breaking this down by previous heating type, average savings in all energy use (kWh) were 64.1 % for previously solid fuel heated homes (17.4 down to 5.1 kWh/dd). With a standard deviation of 20.6 % this is significant to 3σ or 99.6%. Previously ESH-heated homes saw an average saving of 50.7 % (down from 8.8 to 4.3 kWh/dd), with a standard deviation of 8.1 %, this is also significant to 3σ or 99.6%.
- In cost terms, savings depended significantly on whether households were previously able to obtain solid fuel (logs) for free. Savings varied from 0.12 % - 53 %, averaging 18.4 % (£472 per year down from £2,134 to £1,662) for previously solid fuel-heated homes, and 28.5 % (£621, £2,031 down to £1,410) for previously ESH-heated homes. However, with a standard deviation of 21.8 %, only this latter was statistically significant to 1σ or 68.2 %.
- ASHP electricity usage was skewed by one high user (T-10) but median usage was 9.1 kWh per day or 2.23 kWh/dd, and a median cost of £727 per year. The ASHP made up 30 - 66 % of household energy bills, median 56 % based on degree day cost analysis, lower than the 82% of energy use for heating and hot water in the average home (DECC figures).
- Current clamp monitoring of electricity consumption indicated a relatively strong relationship between electricity use and degree days of heating need. Baseline usage in this sample averaged 22.3 kWh/day, and an increase in usage with heating need of 1.44 kWh/dd.

Thermal comfort

- For the 2 homes where monitoring was installed before the ASHP was fitted, temperatures evened out between a warm living room with multi-fuel stove and cold (14°C) bedroom in one property (T-05) to 19-20°C, and temperatures increased in both living and bedroom from 16°C to 18-20°C in the other property (T-02), after install.

- Properties were generally able to achieve the recommended range of 18-21°C during the evening period. Those with elderly residents or young children tended to heat the home higher than this. Average temperatures in property T-03 decreased below 18°C during the study which is of concern. This house had its loft insulated recently, but still reported draughty doors. On average minimum temperatures increased, and temperature was more stable+.

Damp and humidity

- For the 2 properties monitored prior to ASHP installation, humidity levels in the cold bedroom of T-05 were above the recommended 40-60% range but decreased to within this range after the new heating system was fitted. Humidity in property T-02 was within the 40-60% range.
- Humidity levels for most properties fell within the recommended range. One property which was heated to the highest temperatures (T-09) previously had humidity levels below the recommended minimum of 40%, but this has now increased to within the 40-60% range.

Resident satisfaction and comfort

- Residents' feedback indicated a marked improvement in comfort, with numbers saying they could keep comfortably warm at home increasing from 3 up to 7 out of 8 (the final household could get warm but had problems of control so now often found it too hot). Numbers reporting that they had to wear additional warm clothes in the home to keep warm enough decreased from all 8 households to only 2 (2 others said it was needed only in extreme cold weather). 6 of the 8 said they could now use [more of] the home more comfortably.
- Satisfaction with all aspects of the heating and insulation improved – particularly large improvements were seen in satisfaction with the cost of running the heating system, how warm it gets in the home when it’s cold out, and the amount of control over the system. 4 households loved the system and thought that everyone in areas without gas should have one.
- Supplementary heating use decreased from 6 households to 3 of the 8 questioned, and these used it only for short periods and/or when it was particularly cold.
- Benefits identified included: 7 of 8 had lower energy bills, more control over the heating, and felt it was reducing their climate impact, 6 felt the home was warmer or more comfortable, and they were saving energy in the home, and 5 felt the heating was easier to use or control.
- Other positives included no longer needing to carry heavy solid fuels, or to have a cold house in the mornings until a fire was lit, that it was easier to achieve the desired temperature, and that the new radiators looked nicer than old storage heaters, and the house was cleaner.
- 6 of the 8 householders also said their hot water, and its ease of use, was better than before, and 3 households said there had been an improvement in damp issues.
- Householders were very satisfied with the installation of the measures, giving the installers glowing reviews, saying how good, friendly, patient and clean they were.
- In terms of affordability perception, residents estimated that they paid £1,820 on average previously: an average of £2,025 for those on ESH; and £1,800 for electricity plus £400-£1,800 solid fuel costs for those who previously had solid fuel heating. This reduced to £1,144 on average with the new heating system, if property T-10 with high hot water usage and the solar hot water turned off is excluded. 7 of 8 residents felt that their bills were cheaper.
- Previously, significant concerns about affording (energy) bills and rationing strategies were seen: most respondents agreed that paying for energy meant they had to buy less of other essentials e.g. food, they had the heating on lower / less often than desired to keep the energy bill down, and they couldn’t keep warm at home which impacted on residents’ physical health.

After the new heating, on average all these were no longer the case. Residents said they had seen savings and felt more in control of their energy bills. General money worries had also reduced. By the end of the study, 4 of 7 respondents said the measures had helped to reduce money worries a little, and another said they'd saved on bills but hadn't had money worries.

- Many felt it was easier to use than their old system, however 2-3 felt it was more difficult to use than their previous system. Some were unsure that they knew how best to use the measures which had been fitted, particularly mentioning that the controller was not intuitive, and the manual was too complicated / not written in user friendly terms for residents to understand. 7 of 8 said they knew how to use the thermostat of the system, but only 3 of 8 knew how to use the timer and a few households asked for support on how to do this, or get it set up for them.
- 4 of the 8 properties had suffered reliability issues with the measures, and whilst 2 of these had been fixed quickly, the other 2 had suffered leaks, and one had to wait 2 weeks in winter for a repair (without affordable alternative heating). Worryingly, 2 households' solar hot water systems were turned off – steps must be put in place both to explain to tenants what systems and their controls do, which should be left on, and switches appropriately labelled. Also, ensure that contractors always leave systems turned on after visits and provide support if they find such equipment turned off. One household also had cloudy hot water which was causing them concern.
- 2 of the 8 properties were still found to be on Economy 7 tariffs at the end of the study (one further had been switched back to E7 by a new supplier, which the residents were not aware of). One had requested to switch to a flat rate, but this had not been actioned by the supplier, the other was not confident enough to ask her energy company for any change. Additional support to ensure residents manage to switch is required. However, both residents actually spent slightly less on E7 compared to their supplier's flat rate tariff, highlighting the need for in depth analysis of situations before offering advice. Advice to switch to a flat rate if an ASHP is fitted may not always be correct if combined with PV(-T) that reduces daytime electricity use, depending on how much residents can make use of off-peak times (e.g. EDF's, 2hrs evening then 5hrs in morning in SE-region).

For those 4 properties which agreed to took part in the enhanced monitoring only:

Thermal probe data

- Thermal probe data could not provide a comparison with radiator temperature attained with the previous heating system but did verify that the 4-8pm heating period analysed recorded the highest radiator temperatures, except for property T-03 where heating was now higher between 8pm-midnight. As expected, maximum radiator temperatures were lower than for non-ASHP systems, but room temperatures achieved were safe and comfortable.

Heat metering and sub-metering

- Heat metering provided detailed indications of the different elements of home heating and DHW provision in this ASHP and PV-T system throughout the monitoring period. Whist some concerns are raised about absolute magnitudes of values recorded (whether heat meter temperature sensors were fitted correctly), patterns of consumption over the year(s) are clearly visible. Median heat pump increase in usage with heating need was 2.45 kWh/dd – similar to that calculated from ASHP usage sub-meter readings above.
- Other sub-meters and pulse sensor data allowed detailed monitoring of patterns of use over time and plotting of performance lines. Pulse logger data showed baseline ASHP usage of 3.93 kWh/day in home T 02 plus 1.5 kWh/dd of heating. Home T-04 had baseline usage of 1.8

kWh/day plus 1.11 kWh/dd. From ASHP sub-meter readings, slopes were 1.56 and 1.67 kWh/dd for homes T-01 and T-04, 2.48 and 2.46 kWh/dd for T-02 and T-03 (less accurate).

- Calculations of (seasonal) performance resulted in values of 0.6, 3.92, 1.91 and 2.14 for the 4 properties. The latter two are reasonable but the first is much too low and the second too high, suggesting incorrect fitting of temperature sensors on heat meters.

EPCs / SAP values

- SAP values of properties varied widely, and not all properties had prior EPC assessments, but averaged 40 (E) prior to improvements and this increased by an average of 15.5 SAP points to 55 (D) after the new ASHP heating and solar PV-T system was fitted.

Conclusions and recommendations

- Installation of a combination of ASHP and solar PV-T significantly reduced household energy use and resulted in large savings in homes where all fuels previously used were paid-for.
- Even in cases where households did not make a significant saving, satisfaction with heating generally improved: homes were warmer and more comfortable, the temperature was easier to control, and the install process itself was liked by residents. Many other benefits were also identified, and general money worries decreased.
- Electricity use for heating showed a strong relationship with heating need, and safe and comfortable temperatures were achieved in the monitored properties.
- Due to the more complex nature of this combination of technologies, some issues were seen with reliability / faults, and residents knowing how to use the system. The controller and manual are quite complicated. Greater follow-up support to troubleshoot faults and ensure residents know how to use the system is suggested - or redesigns of controls and manual to improve simplicity / usability, or creation of a summary “Quick-start guide” – as well as assistance for residents to switch tariff. However, further investigation is needed as to whether the recommendation of a flat-rate is suitable for ASHP when combined with PV-T (and in this location/Economy 7 tariff times).
- Two properties were found with their solar hot water systems turned off, so greater awareness of residents, and training for contractors, is needed to ensure such energy saving systems are never left turned off after any maintenance. Remote monitoring of the status of systems could be developed to alert housing associations to any issues.
- These measures therefore seem to effectively help address fuel poverty and have a simple payback of 12.6 (ESH) – 16.6 (solid fuel) years depending on previous heating fuel type.
- PV-T requires unshaded south-facing roof space, an airing cupboard for the hot water tank, and ASHPs require properties to be well-sealed to work cost effectively, plus space to locate them outside. For greatest resident comfort, energy saving, and to minimise tenant disruption in any roll-out of these measures, they should be part of wider property thermal improvement, addressing as many heat-loss issues as possible at once, before fitting of the ASHP and PV-T.
- Fitting of mains showers (in place of electric ones) to ensure residents can make most use of the solar heated hot water is recommended
- Provision of advice to residents - at the time of installation - on the most effective and efficient use of energy in the home is always advised; as well as how to time their use to make best use of their new technology installed; to ensure residents are on the best energy tariff for their use; and that they are claiming all benefits for which they are eligible.

1. Project overview

1.1 Introduction

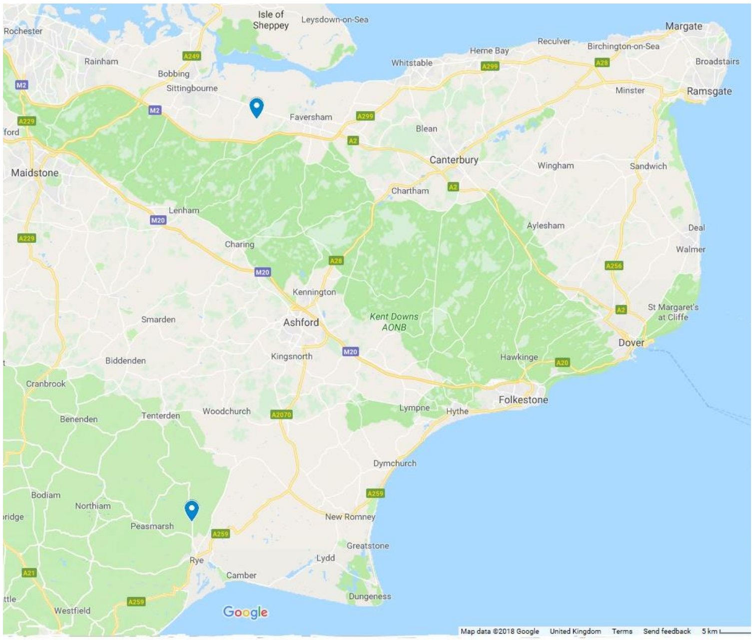
This project undertook the installation of a Mitsubishi air-source heat pump (ASHP) with novel Solar Angel PV-T (PV and thermal) solar panels, to provide a "whole house" approach, in rural properties not connected to mains gas in Norton, Kent and Iden, East Sussex. (Heat pumps with heat recovery units were installed in a further 4 homes which were unsuitable for PV-T, these were not part of the monitored group due to the reduced levels of innovation.) The properties were owned by Optivo (previously known as Amicus Horizon), a registered social landlord (RSL). All monitored properties were 2- or 3-bedroomed semi-detached houses.

1.2 Aims

The project had the following aims, to:

- Replace the existing heating system with a Mitsubishi ASHP system coupled with solar PV-T panels, to provide renewable heating, hot water and electricity for the households,
- Assess any change in residents' comfort – both reported in questionnaires, and measured using temperature and humidity monitors – after the new heating, and solar PV-T system,
- Quantify any change in electricity use for heating, and general household use, following the measures, compared to the period prior to installation,
- Quantify flows of renewable electricity and heat generated by the system,
- Report any change in ease of use of the heating system with the new measures fitted,
- Determine the effectiveness and cost-effectiveness of these measures to reduce fuel poverty in rural off-gas properties - information relevant to many social housing (and private) owners.

1.3 Context



In the area around the monitored properties in Norton, near Faversham in Kent, 67.7% of homes are not connected to mains gas, with 11% fuel poverty[4]. This lower super-output area (LSOA, the smallest area for which statistics are available) is in the 40% most deprived in the country[5]. Iden, near Rye in East Sussex, has 95% of homes with no mains gas connection (the majority being >2km from a gas main), also suffering 11% fuel poverty[1] and this area is within the top 20% most deprived in the country. Both LSOAs are in the 10% most deprived in the country for barriers to housing and services.

Figure 1.1 Map showing locations of the 2 clusters of monitored properties, in Iden, near Rye, E. Sussex, and Norton, near Faversham, Kent

[4] Non-gas map, www.nongasmap.org.uk [Accessed 6/9/2018]

[5] Indices of Deprivation 2015 explorer, dclgapps.communities.gov.uk/imd/idmap.html [Accessed 6/9/2018]

In Great Britain, it is estimated that around 10% of (i.e. 4 million) households do not have a mains gas connection, with just over half of these using electricity as their primary heating source[6]. Given the distance from gas main infrastructure, this proportion is much higher in rural areas. Dwellings with electric heating systems tend to have lower energy efficiency ratings, partly reflecting higher running costs as well as their lower level of heating controllability. Due to their higher heating costs, these households are more likely to be fuel poor.

Optivo chose to test this approach, to measure the most cost-effective methods to achieve the government's requirement of all homes meeting EPC band C standard by 2030, for their rural properties not connected to mains gas. This solution could be scaleable to their other 600 rural off-gas properties in the South-East of England, as well as being relevant to other housing providers in the UK. "Off-gas grid" properties will invariably pay more for fuel, often live in inefficient properties and are less protected from bad pricing regimes (such as purchasing oil), due to little regulation or competition in this sector.

Optivo state that they funded improvements to airtightness, insulation and lighting in the properties prior to fitting of the ASHP system, to improve energy efficiency / reduce heat loss so the systems installed could run most effectively.

1.4 Project timeline

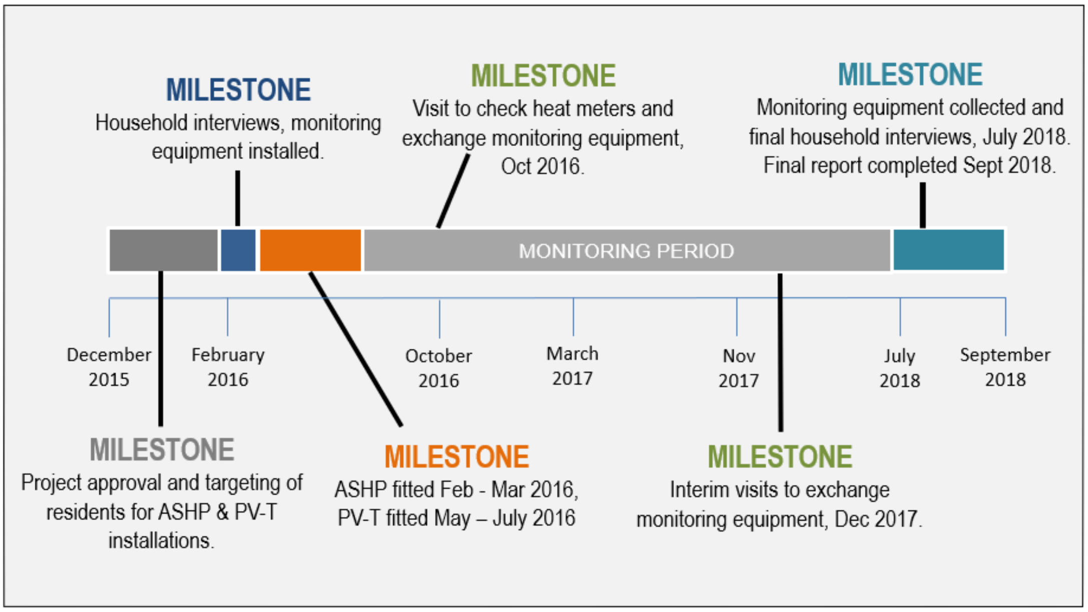


Figure 1.2 Project timeline

This project was agreed in December 2015, and Optivo had already identified suitable properties they owned for improvement. They contacted their tenants to inform them of the works which would be carried out and requesting participation in the monitoring. Installation of the ASHPs was carried out first in February 2016 for the properties in Norton, Kent, and in March for the properties in Iden, E. Sussex. NEA's visits to install data loggers and carry out initial questionnaires was during the ASHP installation period for the properties in Norton (Feb 2016). Installations of the PV-T panels were carried out in May 2016, however the first heat meter readings for the solar hot water were recorded in July 2016 (we do not know the reason for this). 25 households received measures, 8 of which were monitored, 4 in greater detail.

[6] Insights paper on households with electric and other non-gas heating, ofgem.gov.uk/ofgem-publications/98027/insightspaperonhouseholdswithelectricandothernon-gasheating-pdf [Accessed 6/9/2018]

1.5 Attracting beneficiaries and establishing a monitored group

Initial engagement with householders was done by Optivo:

- Identifying suitable off-gas properties indicative of significant numbers of their stock
- Contacting residents to inform them of the works which would be carried out, to bring their home up to a higher energy efficiency standard. Engaging with residents early in the project to try to reduce drop out. In the event of resident drop out, they had several hundred other eligible properties in the areas to replace participants if necessary. Carrying out initial visits to gauge residents' interests and support them through the process.
- Introducing NEA and inviting participation in the monitoring element of the study. Optivo staff accompanied NEA on initial visits to introduce them to householders (and contractors) to complete resident questionnaires and install monitoring equipment.
- Optivo supported NEA with contacting residents after initial interviews to gather any missed information, and assisted members of the technical team to check that all monitoring equipment had been installed by the contractors correctly and to NEA requirements.
- Energise Sussex Coast provided energy advice and support in using the new technology to each household via home visits. Both Energise Sussex Coast and Optivo staff were trained by the systems' manufacturers in their use, to train residents and provide ongoing support.
- The project had its own resident liaison officer to answer any customer questions and deal with any complaints regarding the installation process. Optivo also has a robust and award-winning complaints management process to deal with any complex complaints.

25 households were identified to receive the measures and from this sample, tenants of 8 homes were willing to receive monitoring equipment and record meter readings. These were 2- and 3-bedroom semi-detached houses. Details of the properties monitored are shown in Table 1.3, and example photographs of property types treated are shown on the front cover of this report.

EPCs were carried out for most properties prior to installation of the measures in March and/or October 2015. The SAP values of the monitored properties varied from 17 (G) to 56 (D), with an average value of 40 (E), before the measures were installed. EPCs were repeated for all properties in July - September 2016, following installation of the measures, and the results are shown in Figure 1.3, with the improvement in SAP value calculated for those homes where EPCs were available prior to the works. The average improvement was 15 SAP points. This is likely to be heavily skewed by one property with a very low SAP rating - if this is excluded, an average improvement of 12 SAP points was seen. These EPCs also highlight that some properties still did not have loft or cavity wall insulation in place, or low energy lighting, after the installation of the ASHP and PV-T panels.

Properties in Iden have 6 PV-T panels, those in Norton have 8 panels each. Solar Angel quote output of per panel of 250 Wp[7], this equates to a maximum electricity output of 1.5 kWp to Iden homes and of 2 kWp for Norton homes, plus solar hot water. The difference in PV output between properties in the two areas must be considered when determining savings in electricity use / costs.

Since the PV-T system was only installed in May-July 2016, after the end of the winter heating period, it was decided to extend the monitoring over a further winter in order to gain better quality data over a longer period. NEA wrote to all monitored properties explaining this and visited during

[7] Northburn Solar website, www.northburnsolar.co.uk/solarpanels/solarPV-T/solarPV-T.html [Accessed 7/9/2018]

December 2017 to exchange the data loggers. Residents of all properties were content to continue to be part of the extended monitoring, which ended in July 2018.

In order to maintain anonymity for study participants, all properties are reported using allocated Technical reference numbers, as shown in Figure 1.3.

Ref.	Location	Bedrooms	Floor area (m^2)	Previous heating	Previous EPC	EPC after measures	Improvement
T-01	Kent	3	85	Solid fuel	E (51)	D (64)	13
T-03	Kent	3	85	Solid fuel	F (26)	E (40)	14
T-09	Kent	3	85	Solid fuel	D (56)	D (65)	9
T-10	Kent	3	85	Electric boiler	G (17)	E (50)	33
T-02	E. Sussex	2	73	Storage heating	-	D (57)	N/A
T-04	E. Sussex	3	87	Storage heating	E (48)	D (61)	13
T-05	E. Sussex	3	70	Storage heating	E (43)	E (54)	11
T-12	E. Sussex	2	73	Storage heating	-	E (49)	N/A

Table 1.3 – Type and size details of monitored properties

All monitored participants completed an initial questionnaire at the outset of the project – before (or during) installation of the ASHPs – about their household occupancy, energy-using behaviours, and experiences of heating their home: their costs and satisfaction with their heating, insulation, and comfort. A short intermediate questionnaire was carried out at the visits in December 2017, to ask about the installation process of the measures and initial feedback. Final questionnaires were carried out for all properties in July 2018 at the final visit to collect all the removeable data loggers.

1.6 Factors affecting the planned evaluation methodology

Issue	Description and mitigation
Monitoring period	Monitoring equipment was placed in all properties in Feb 2016, which was during the ASHP installation period in Kent properties. (Some monitoring equipment required wiring / plumbing in, so was fitted at the same time as the piece of equipment it monitored.) This meant no pre-ASHP-installation monitoring was possible in the Kent properties, and there was only a short monitoring period before ASHPs were fitted in the East Sussex properties in March 2016. Heat meter installation was checked, and data loggers exchanged, in enhanced monitoring properties in Oct 2016. Interim visits, when data loggers were exchanged in all properties, were in Dec 2017, and all loggers were collected in July 2018.
Issues with the measures	One property (T-04) had problems with their heating system, and the residents report that their data loggers were removed (because of this), so no temperature data is available until after Dec 2017. One household (T-10) had a leak / depressurisation of the heating system resulting in it not working – this was fixed in Dec 2017. At final visits, 2 homes (T-10, T-12) were found to have their solar thermal systems switched off. This was explained to the resident, and the switch turned on, but it is unknown how long the household had not been benefiting from free solar hot water.
Meter readings	Meter readings could be obtained for all properties from energy log books, bills or energy company records for the period prior to and after install, aided by the fact that many residents used prepayment meters which record an automated meter reading at every top-up.
Solid fuel use recollection	3 of the properties previously used solid fuel. Costs and usage of fuels other than electricity were not asked about at the initial interview, so details were requested during the interim and final questionnaire sessions. Residents found it difficult to estimate their usage of solid fuels, especially if they were able to obtain logs for free – so these estimates will be less accurate but are included to give an indication of energy and cost savings / changes, since electricity was not previously their main heating fuel.
Monitoring equipment	Residents of one property (T-04) reported that their monitoring equipment was removed, and another (T-12) had a young child who liked to put things in the bin, hence initial loggers were lost. Initially properties were fitted with Enica Opti-pulse LED pulse sensors on household meters where relevant, and any sub-meters fitted. These recorded no data, for unknown reasons. They were replaced in Dec 2017 with Omega Pulse 101 LED pulse sensors which had a higher (but not 100%) success rate. In some cases, we had to rely on the householder taking regular meter readings (which most did not do for sub-meters), the readings taken at our 3-4 visits to the properties and obtaining readings from the energy supplier (for a main household meter).
Previous heating systems	The monitored group contains properties which previously used 2 different heating types: those in Norton, Kent used solid fuel heating (except for one with an electric boiler), and those in East Sussex had storage heating. These should be considered as different sub-groups when analysing cost and energy savings, and questionnaire feedback about the measures, due to the different costs and nature of use of these previous heating systems.

Table 1.5 - Issues experienced which may affect the monitoring and evaluation of this project

2. Social evaluation and impacts

2.1 Qualitative feedback from initial – pre-installation – questionnaire

All 8 monitored householders were interviewed at the start of the monitoring period; completed a short interim questionnaire in the middle of the study (Dec 2017, after the measures had been in place for 1 winter); and were interviewed at the end of the project in July 2018. These interviews identified key aspects of the property's type, occupancy and resident behaviour which could affect energy use, and captured experiences of using their heating; and to identify any changes, benefits and other effects at the middle and end of the project. It must be highlighted that questionnaire responses are resident opinions, so are not necessarily factually correct, but this also highlights levels of resident knowledge about their home. This section sets out the questionnaire results regarding the residents' views, acceptance of the technology etc. and any immediate findings.

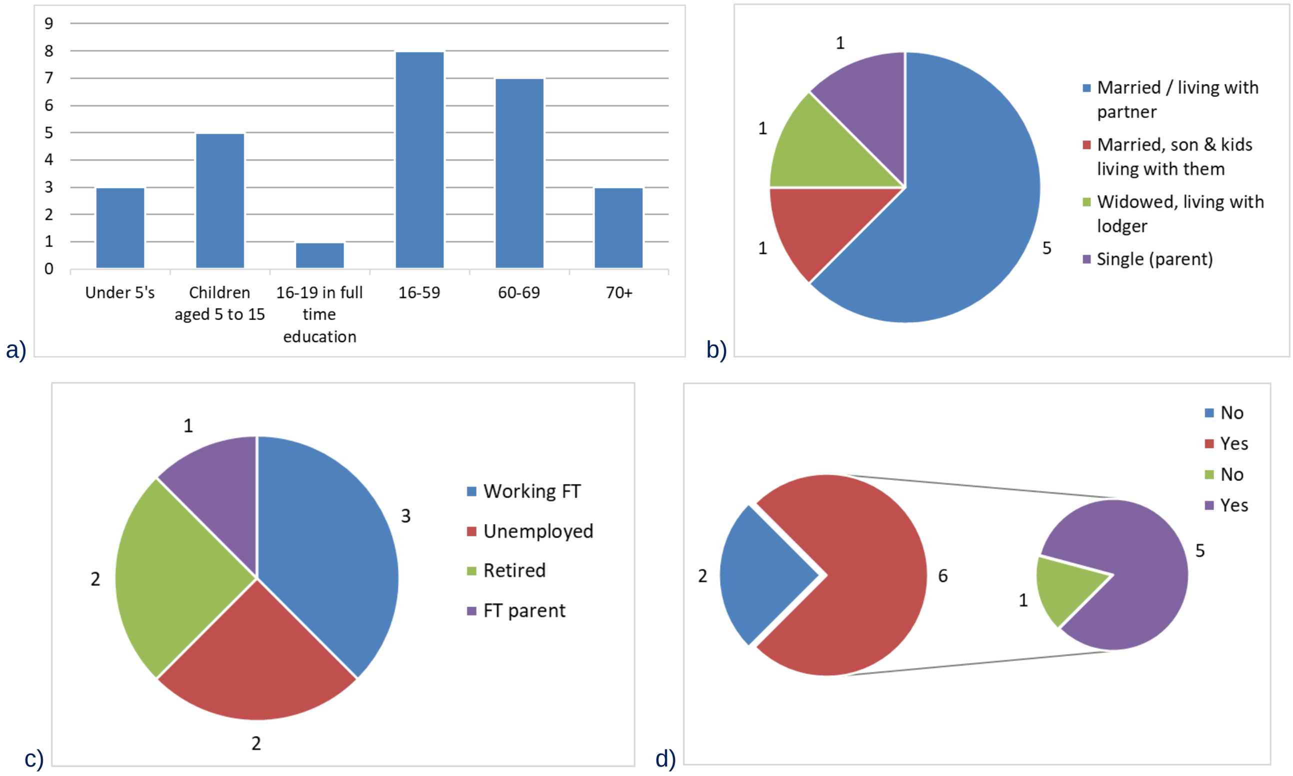
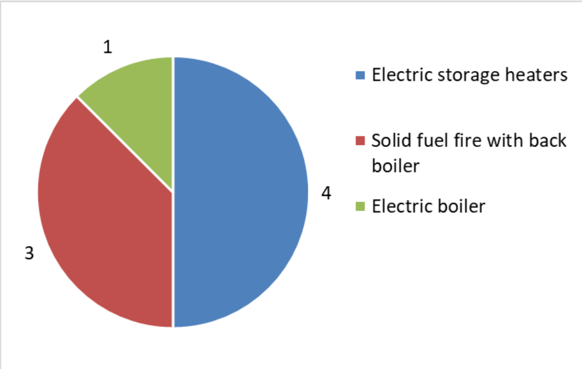


Figure 2.1 (a) Household age distribution, (b) Living situation, (c) Occupation, (d) Health conditions (impacted by cold)

Figure 2.1(a) shows that there was a wide distribution of resident ages in the monitored properties – the majority were of working age, but there were a significant number of children (though fewer of these were in full-time education) and also older people. Whether householders are able to share responsibility for energy bills can be a useful guide to vulnerability to high energy costs. Figure 2.1(b) shows that residents in 7 of the 8 households were able to share energy costs with (an)other adult household member(s) – only 1 householder had to singularly manage their bills. Fig 3.1(c) shows that 3 of the 8 households reported that the main bill payer was working full-time, whereas 2 were unemployed, 2 were retired and 1 was a full-time parent, 5 of the 8 may therefore have a more limited income. Figure 2.1(d) shows that 6 of the 8 households contained at least one resident with health issues, 5 of which were reported to be made worse by living in a cold home (so for best health they needed to keep the home warm). Health issues present included lupus, diabetes, rheumatism, arthritis, multiple sclerosis, back problems, muscle problems, joint replacements, and a heart condition.

As shown in Figure 1.3 (page 13), 2 of the properties had 2-bedrooms, and the remaining 6 were 3-bedroom homes – all were semi-detached. Before the new heating was fitted, Figure 2.2(a) shows that the 4 properties in East Sussex were heated by electric storage radiators, 3 in Kent used solid fuel fires with a back boiler (it was unclear whether this heated radiators, hot water, or both), and one – whose fire had previously broken and been removed - had a fully electric boiler system. Those who used storage heaters reported knowing how to use the controls, whereas those with solid fuel fires had to control it via the amount of fuel added, and the regulator. Only the household with the electric boiler controlled it using a thermostat. All had electric immersion tanks to heat their hot water (again, it is unclear if the solid fuel back boiler system contributed to this).



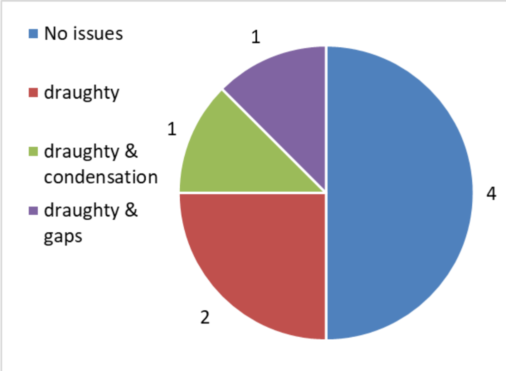
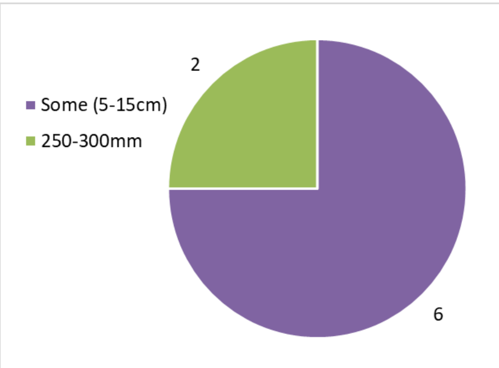


Figure 2.2 (a) Previous heating type, (b) Glazing issues.

All properties had double glazing, but as shown in Figure 2.2(b), 2 found them draughty, one reported they were draughty and also suffered condensation, and another reported they were draughty with gaps. One householder also reported draughty doors. Household knowledge of loft insulation levels was poor – as shown in Figure 2.3(a), 6 thought they had a little, but only 2 thought they had the recommended standard of 250-300mm insulation installed.



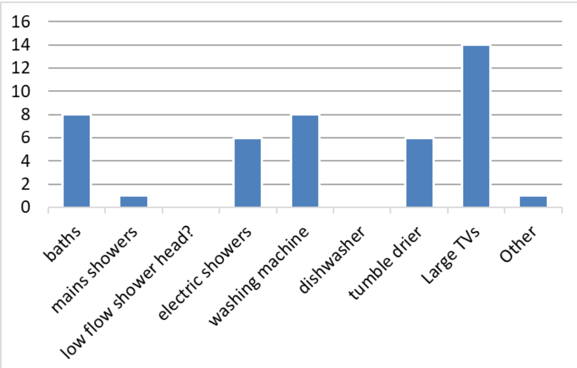


Figure 2.3 (a) Loft insulation (b) Energy using appliances present

The energy-using appliances present in the 8 households are shown in Figure 2.3(b) – as seen, all had a washing machine and bath fitted, and all but one had a shower, mostly electric. 6 had a tumble drier present, but none had a dishwasher. The "other" item identified was an unheated fish tank (with pump). The most frequent appliances were large TVs, with an average of 1.75 per property – those with elderly residents often had only one in the main living room, the properties which had more were those with teenage children in the home. Normal room temperatures were not known since only the household with the electric boiler system had a thermostat fitted.

Residents were asked what time(s) of day it was important for them to have a warm home, at both the start and end of the project. The resulting "heating desire profile", as shown in Figure 2.4, was created over a 24hr time period in which heating need was divided into half-hour periods starting at the time shown, was used in the technical monitoring to assess whether homes achieved warm and safe temperatures during the required time period(s), in this case deemed to be 4-8pm.

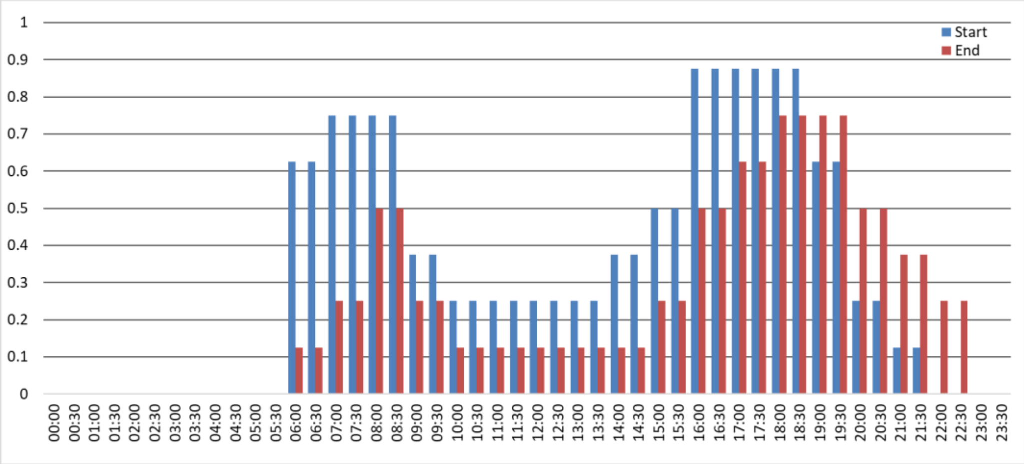


Figure 2.4 Times when residents stated it was important for them to have a warm home

2.2 Affordability of energy bills

At each interview, residents were asked to estimate how much they paid for energy, and how often. This was used to estimate an annual total. Whilst this method is not accurate (due to incorrect recollection, rounding, accounts in debt/credit, delays in energy suppliers amending direct debits) it is useful as a measure of residents' perception of their heating costs. Initially, the 8 residents reported their payments averaging at £1,820 per year, varying between a minimum of £1,040 and a maximum of £2,600. Separating out the two heating types, for those using electric storage heaters the average was £2,025 per year; and for those using solid fuel, £1,800 per year for electricity, plus solid fuel costs. Solid fuel costs varied widely, estimated at between £400-£1,820 per year. Since this was a rural area, some residents were able to obtain logs for free. At the interim questionnaire, reported costs had dropped to an average of £1,319, varying from £910 to £1,560 – a clear perceived reduction on the previous year. By the end of the study, payments reported averaged £1,326 per year, varying between £780-£2,600. Energy price rises occurred during the study period which will confound estimates, and winter 2017-18 was particularly cold, so more heating was required, which may explain an increase for some. The property reporting the highest electricity use (T-10) is a high hot water user and was found not to have its solar hot water system turned on, which may explain the high level of cost even during the summer months. Excluding this property, costs averaged £1,144, and the maximum cost was £1,456.

We also asked residents whether their energy bills had reduced or not, as shown in Figure 2.5. At the interim questionnaire (Dec 2017), 6 of the 8 respondents felt that their bills were cheaper. One did not know, and another – T-10, whose system was not working properly – was finding it more expensive as they had to use their electric room fire instead. However, by the end of the study (July 2018), of the 8 respondents, 7 felt that their bills were cheaper, and one household felt that they were paying about the same as they had previously. Again, this was property T-10 where the solar hot water was turned off, so they may save more money on energy now this has been turned on again. Two did comment that they were now in credit with their electricity, another mentioned that their electricity bills had gone up a bit because they were using less coal. One household reported that they'd previously been "throwing money at the meter" and still always running out of electricity – after the measures were installed their energy company had sent out a meter reader to check the meter was working correctly as their electricity use had dropped so much.

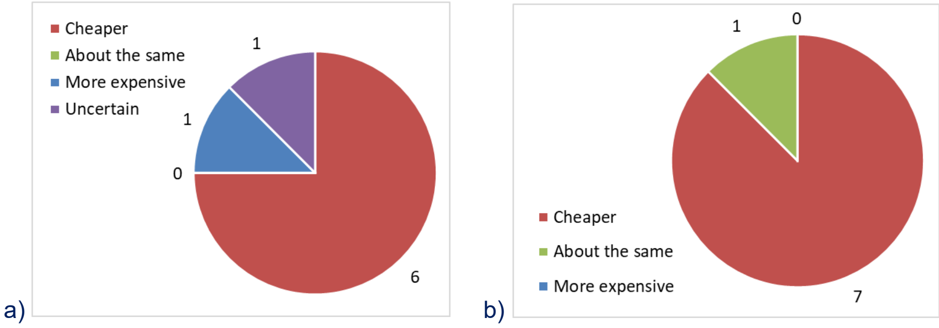


Figure 2.5 Reported effect of measures on heating bills (a) at interim questionnaire, (b) at end of monitoring period.

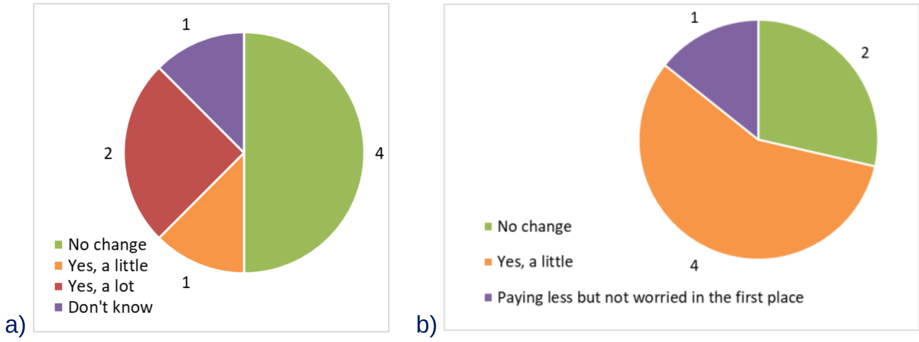


Figure 2.6 Reported effect of measures on money worries (a) at interim questionnaire, (b) at end of monitoring period.

Figure 2.6 shows residents' views on whether the measures had reduced any money worries they had. At the interim visit, 4 of the 8 residents felt that their money worries hadn't changed, one respondent reported that the measures had reduced their money worries a little and 2 felt they'd helped a lot (one was unsure), however by the end, of 7 respondents, 2 felt the measures had not changed their money worries, and 4 felt the measures had reduced their money worries a little, and one said that they were paying less on their bills but had not been worried about money previously.

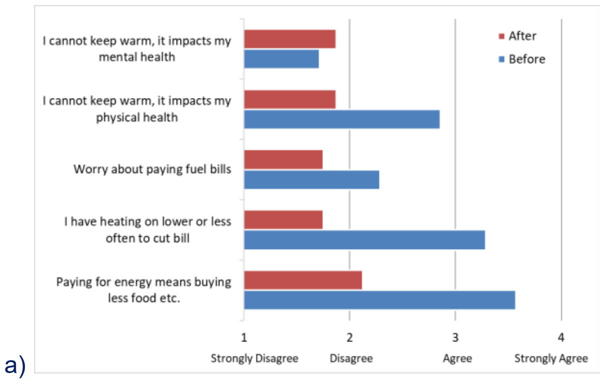
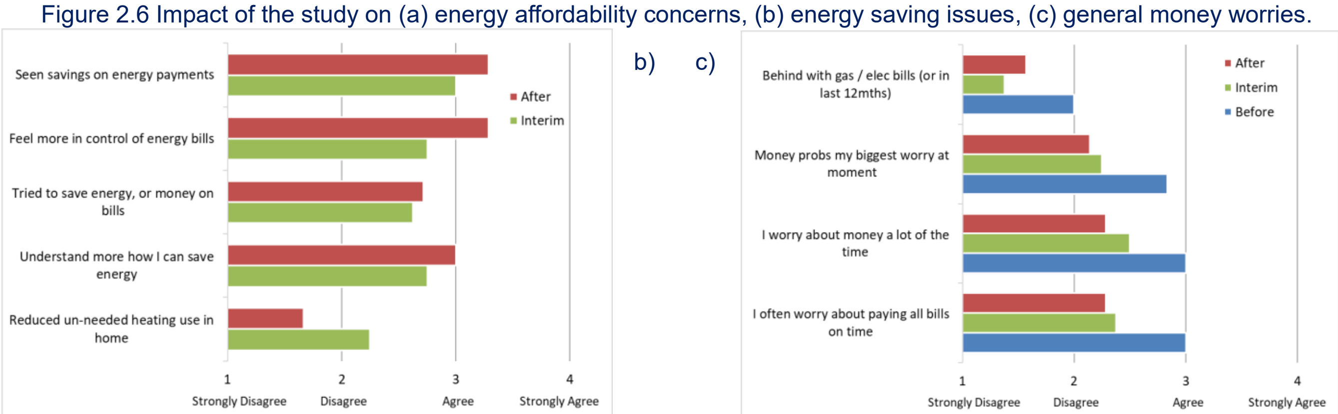


Figure 2.6 Impact of the study on (a) energy affordability concerns, (b) energy saving issues, (c) general money worries.



Respondents were asked how much they agreed or disagreed with a series of statements relating to energy affordability issues, feelings of control over energy bills, and money concerns in general. Responses were allocated a score of 1 for strongly disagree, 2 for disagree, 3 for agree and 4 for strongly agree. Scores were then averaged across all respondents for each questionnaire period so any change in opinions over time can be seen – results are displayed in Figure 2.6. Statements in (a) and (c) were negatively phrased, so a lower score is better in fuel poverty terms, whereas in (b) the statements were positively phrased, so a higher score shows feelings of greater control.

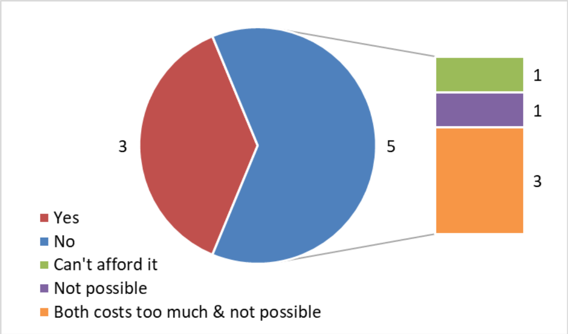
Fig 2.6 (a) shows that there were significant concerns and coping actions to afford energy bills prior to installation of the new measures, whilst numbers of those reporting mental health impacts from a cold home was low and did not change, all other coping strategies, worries and physical health impacts have reportedly reduced from initially high incidence rates.

There was little change in respondents' views on the impact of the measures or their behaviour over their energy bills between the interim and end questionnaires, Fig 2.6 (b). Residents felt that they had seen savings on their energy bills, felt more in control of their energy bills and understood more about how to save energy. Householders were unsure whether they had tried to save (money on) energy more or not, and most said they had not reduced unneeded heating in the home - many felt there was no unneeded heating previously to reduce.

General affordability issues, Fig 2.6 (c) showed that residents had concerns around money worries and paying all bills on time before the new measures were fitted, and these were reduced after the new heating system and PV-T was fitted. There was general disagreement with the idea of being behind with energy bills – many residents used prepayment meters, so this was not possible.

2.3 Perceived comfort and benefits

Participants were asked about their comfort with their existing heating & insulation, before the measures were installed, and again in the final questionnaire, to see whether there had been any improvement. Figure 2.7 shows whether respondents felt they could mostly keep comfortably warm at home, both (a) before and (b) after receiving the new measures. Only 3 of the 8 householders felt they could mostly keep warm enough before the measures. The breakdown bar indicates that most felt that this was due to both physical issues with the property as well as their ability to afford enough heating. After install, 7 of the 8 respondents said they could now keep warm enough in the home – a notable improvement in comfort.

a)


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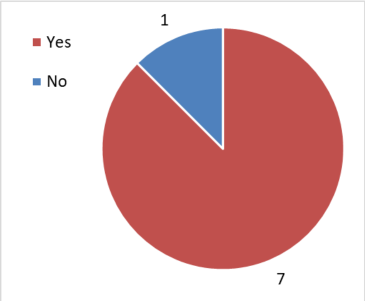


Figure 2.7 Whether householders could mostly keep comfortably warm at home in winter / when it's cold outside, (a) before, with breakdown of reasons why if it was not possible to keep warm enough on right hand side of chart and (b) after installation of the ASHP and PV-T system.

The one household where the residents were uncomfortable had problems with (understanding the) controls of the system – they stated that whilst they could get heat when they needed it, due to manual control they ended up either over- or under-heating the house rather than attaining a comfortable medium. This was reported to the housing association to assist them to programme the heating on a timer, to set different temperatures for different times of day - so manual change would not normally be needed – to limit residents turning the heating up too high to “make it work”.

Respondents were asked if they ever needed to wear additional warm clothes in the home e.g. coat, dressing gown, or multiple jumpers over clothes, blankets etc., to keep warm. All 8 respondents reported that they needed to wear extra clothing to keep warm enough prior to installation of the new ASHP and PV-T systems. Figure 2.8 shows that by the end of the study only 2 of the 8 reported needing to wear extra warm clothes indoors to keep warm, the remaining 4 no longer needed to do this, and 2 reported that they had to do so only in very cold weather (this study ran over the very cold winter of 2017-18) but felt that they would not need to do so in a “normal winter”.

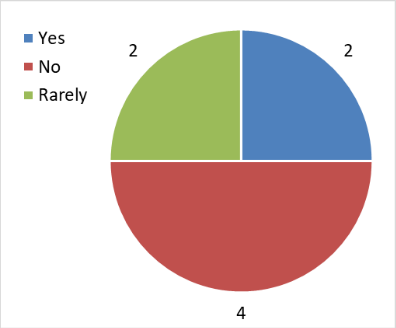
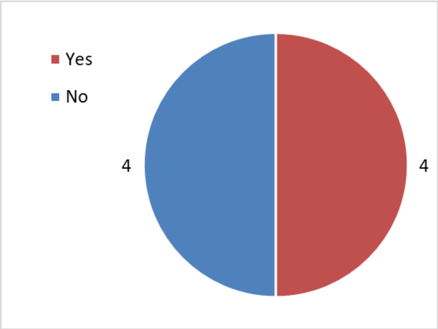


Figure 2.8 Need to wear extra warm clothes in the home after measures

6 households reported needing to use supplementary heating at the start of the study: 4 used electric heaters (fan heaters or bar-fires) especially in rooms where no storage heater was fitted; 3 used solid fuel, either open fires or a multi-fuel stove often / daily in winter, especially the evenings (one household used both types of extra heating). After installation of the measures, at the interim visits, only 3 households reported using supplementary heating (electric heating and one also used an LPG/Calor gas heater) but only one used it regularly – this was the household, T-10, whose heating was not functioning properly. By the end of the study the same 3 households reported using supplementary heating but most only for short periods and/or when it was particularly cold.

Residents were also asked whether they felt they could heat or comfortably use more rooms since the measures were fitted, at both the intermediate and end questionnaires, shown in Figure 2.9.

a)



b)

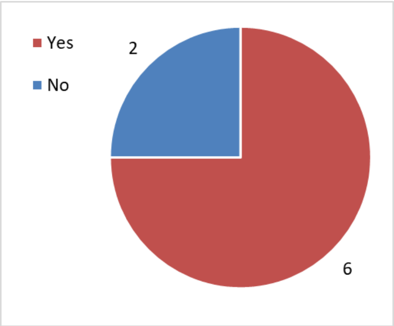


Figure 2.9 Householders reporting that they could heat or comfortably use more rooms at (a) the intermediate and (b) the final questionnaire

6 of the 8 householders said that they could now use the home more comfortably, either being able to heat more rooms than previously, or use the same number of rooms as before but being more comfortable in them. Those who noticed no improvement in comfort were those who had solid-fuel fires & back boilers previously. These had other negative aspects covered below.

Figure 2.10 shows the number of householders identifying benefits following installation of the measures in the intermediate and final questionnaires (both had 8 respondents). In the final questionnaire, 7 stated that their energy bills had reduced, they had more control over their heating, and they felt they were reducing their household’s impacts on climate change. 6 felt their home was now warmer and more comfortable, the were saving energy in the home, and 5 felt their heating was easier to use or control. 4 felt their home gets warmer faster.

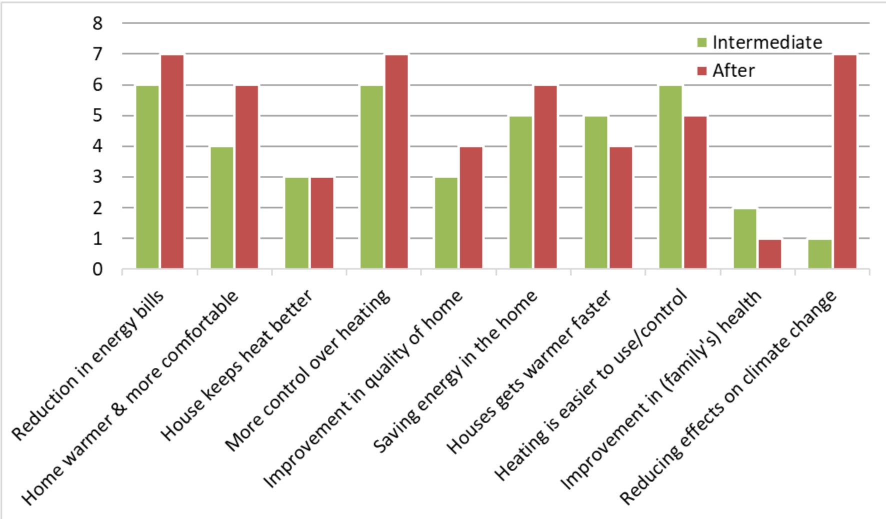


Figure 2.10 Benefits perceived by residents after installation of the ASHP system and PV-T panels

Other comments made about benefits included two households stating they no longer needed to physically lug coal and wood, one mentioned that it was no longer cold in the mornings until the fire was lit, and that it was much easier to use than a coal fire (for those who previously had solid fuel fires), and that once storage heaters were on, they were on, even if you were too hot, so the new system was much easier to control comfortably. Two mentioned that the radiators looked a lot nicer / cleaner than their old storage heaters. On mentioning noise, only one person stated that there was not much noise from the ASHP and they did not notice it, so this did not appear to be an issue.

Other benefits identified related to hot water and its ease of use. In both the intermediate and final questionnaire, 6 of the 8 respondents reported that their hot water was better than previously, with 2 stating it was the same as before.

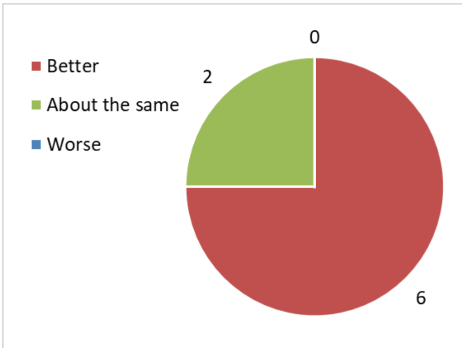


Figure 2.11 Impact of the measures on the hot water (ease of use & heat)

The impact on damp, condensation and mould in the home was asked about, if this was present. 4 or 5 properties felt that this was not an issue previously, 3 households said there had been an improvement with reduced damp, mould or condensation seen. However, by the time of the final visit, one property appeared to have had a leak above / in their spare bedroom, resulting in damp mould patches on the walls as shown in Figure 2.12. It is unknown whether this was linked to the new heating & PV-T system or not. This was reported to the housing association to verify that the leak was fixed, and the householder was recommended to air their fitted wardrobes by leaving them, and the window, open on warm days (the final visit was during the summer).

Figure 2.12 Mould issues in property T-01 where a leak (unknown cause) had resulted in mould patches on ceiling near eaves, patches / spots on walls, and damp in backs of fitted wardrobes (against external wall).

2.4 Resident acceptance and satisfaction

Residents were asked about their satisfaction levels with different aspects of their home heating and insulation in the start, interim and end questionnaires. As for those questions where residents were asked how much they agreed or disagreed with statements, a response of very satisfied was allocated a value of 100, satisfied with 75, neither satisfied nor dissatisfied with 50, dissatisfied with 25, and very dissatisfied was valued at zero. These values could then be averaged across all respondents for each questionnaire, to see whether overall opinions changed during the study. Results are displayed in Figure 2.13.

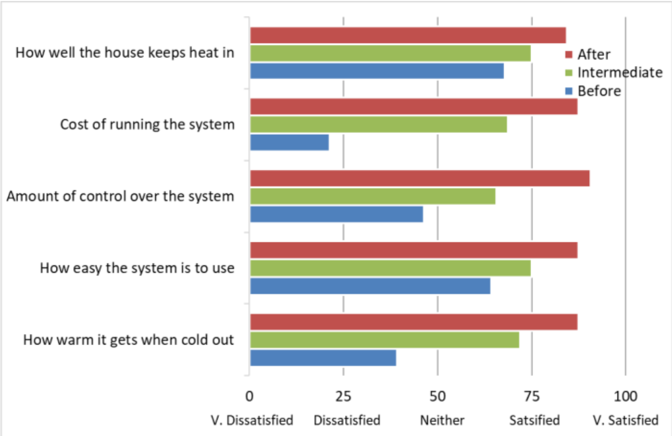


Figure 2.13 Resident satisfaction with aspects of their heating system & insulation

This shows that satisfaction improved in all aspects. Least change was seen in satisfaction with how well homes kept the heat in (unsurprising as insulation levels had not changed), which was already relatively good. Greatest improvement was seen in satisfaction with the cost of running the heating system, with residents dissatisfied with their old heating system but on average satisfied to very satisfied with their heating costs using the new measures. Marked improvements were also seen in satisfaction with how warm the home got when it's cold outside and the amount of control over the system, and a small improvement in satisfaction with the ease of use of the heating.

Resident comments about their satisfaction included four households which loved the heating, one calling it "heavenly", another saying it was luxury compared to their old (storage) system. One householder reported that the system was "brilliant", two reported that it was cleaner than coal.

From comments made, the interviewer was asked to rank each respondent's feelings out of 5 (with 1 being very negative, 3 being indifferent, and 5 being very positive) and their involvement / engagement with their new heating system, presented in Figure 2.14.

4 of the 8 respondents' comments suggested that they felt very positive about using their heating since the new measures were fitted, one was mildly positive at the interim visit. One who felt that it was ok but not as warm as her previous coal fire was rather indifferent. Two properties found the heating was not working very well, T-10 and T-04, so felt negatively about it. All issues were reported to the housing association, so by the final visit only one household still felt indifferent about the new heating, and those where issues had been resolved now felt positive about it.

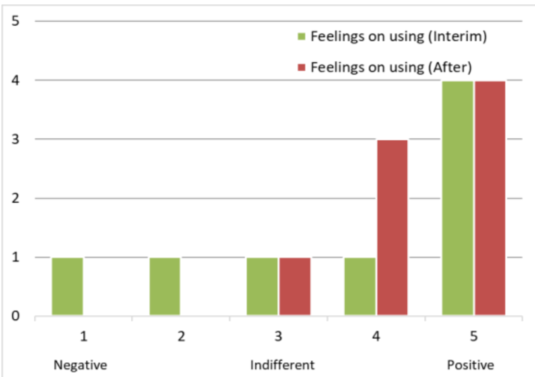


Figure 2.14 Ranking of householders' feelings about using their new measures

2.5 Ease of use and reliability

As with all new systems, especially those which are relatively complicated like this one, it must be ensured that residents know how to use / control it, otherwise they may inadvertently misuse it and/or find that they cannot make work to it heat their home as desired. This can clearly result in dissatisfaction with the measures.

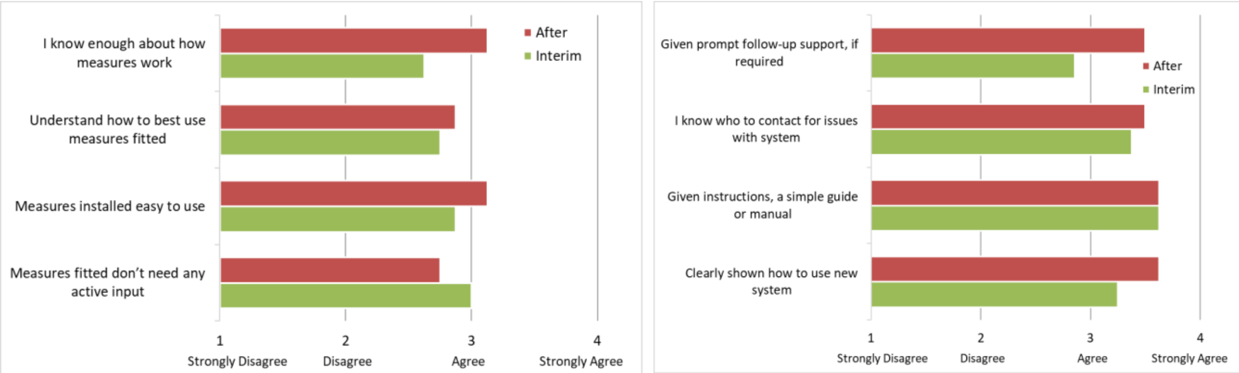


Figure 2.15 Resident (a) understanding and use of their new system, and (b) the support they received to use it

At both the interim and final questionnaires, participants were asked about how they used the system and whether they felt they had received sufficient support to use it. As previously described, responses were allocated a numerical value so that they could be averaged across the sample, with results displayed in Figures 2.15 (a) and (b).

Many householders felt that the heating system was easier to use than their old system, Fig 2.15(a), not requiring too much active input from them to work - these were both those who had storage heating previously, and those who had solid fuel fires. However, over the whole sample, agreement with these statements varied between the interim and final questionnaires, often falling in the "unsure" area between "agree" and "disagree", though closer to the former. Residents remained unsure that they knew how best to use the measures fitted, though most felt that they knew "enough about how (to make) the measures work as they needed to know".

However, a few residents felt the new heating and hot water system was more difficult to use than the old system, often requesting assistance / more support to use it at visits: Many said they had been told how to use the system, see Figure 2.15(b), but they had since forgotten. They mentioned that they did not find the controller intuitive to use and, whilst they had been given a manual - and a few had also received a DVD about the system - the manual was very detailed, in technical language, and not user-friendly, see Figure 2.16. Some residents did not have a DVD player, so a DVD was not useful. So, despite Figure 2.15(b) showing a relatively positive picture, some lack of knowledge and dissatisfaction remained. Residents would have benefited from very simple instructions or a "Quick-start guide" to refer to as a reminder.

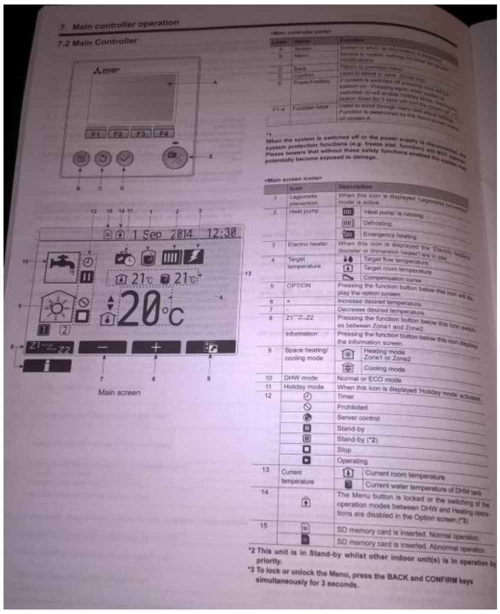


Figure 2.16 ASHP heating and hot water system controller (above) and manual (left)

Some were also hesitant to phone Optivo to request support, though if call-outs were requested, most reported that they received prompt follow-up support. Feedback on speed and effectiveness of support was higher after the interim visits at which some support was requested via NEA staff.

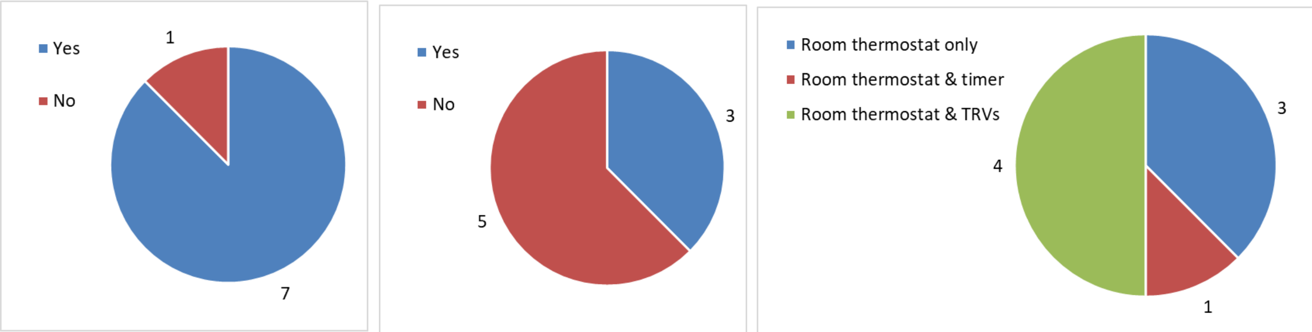


Figure 2.17 Resident knowledge of (a) how to use the room thermostat (b) how to use the programmer / timer and (c) main methods of controlling the new heating system

Knowledge of how to use the controls was reasonable, see Figure 2.17– 7 of the 8 respondents said they knew how to use the room thermostat, the remaining household was T-04 who said it wasn't working for them, being either too hot or too cold, so didn't feel they knew how to control it sufficiently. However, only 3 of the 8 households knew how to use the programmer / timer. Two were happy to use the room thermostat to manually control the heating, and one household had the timer pre-set for them by the installers so hadn't needed to change it (simply turning the desired room temperature down during the summer), but others expressed a desire to either know how to set the timer themselves so that the heating could turn on e.g. in advance of them coming home from work, or to have it set up for them e.g. property T-04 to eliminate their need to fiddle with the thermostat to prevent over- and under-heating resulting in extra costs and discomfort.

One issue found on the final visits was that 2 homes' solar hot water systems were turned off at the switch, see Figure 2.18 (a). It is unknown how long these had been off, as these controls had not been inspected previously. Residents need to be made aware of what the switch is for, that they should not turn it off as it will save them money, and to check that the system is turned back on after any maintenance visits by contractors. However, not all householders will be this engaged, hence the utmost importance of ensuring that any contractors who visit turn the system back on after any maintenance, and if they find it turned off on arrival, to explain to the householder what it does and why they should leave it turned on. Data from these 2 properties, T-10 and T-12, will be analysed as for the others, but this will be noted as a possible reason if their savings are lower than expected.

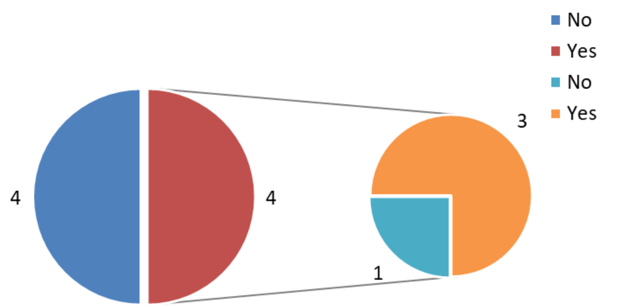


Figure 2.18 (a) Solar hot water controls: display & switch, (b) breakdowns / reliability issues with the system and whether resolved quickly (c) cloudy hot water

Figure 2.18 (b) shows whether residents suffered reliability issues or breakdowns of the measures. Worryingly, half had suffered issues: two reported that an unknown issue had occurred but (once it was reported) it had been resolved very quickly, another two stated that they had suffered leaks, one of whom had a very slow call-out period of c. 2 weeks (in December) to get the issue fixed.

3 of the 8 residents reported general maintenance issues in the initial pre-installation questionnaire related to their heating, insulation, moisture or mould and which caused them concern with keeping warm or increased their bills: one of these related to mould issues, and two to draughty windows and/or doors. 3 of 8 also reported such issues at the final questionnaire. These covered things like damp issues (2) and being unsure how to control the thermostat and timer of the heating (2). All issues were reported to Optivo for action. One householder showed that their hot water came out cloudy / bubbly, see Figure 2.18 (c), this cleared within minutes, but it caused them concern.

2.6 Customer service and installation issues

Comments about the installation process were requested and all residents gave glowing reports of how brilliant, nice, clean and patient the installers were. One such comment was that “despite a long day the installers still had time & patience to properly explain to me how to use the system”. However, another reported that “instructions were not simple to understand” (this may relate to the manual rather than verbal instructions). One householder who had issues with the controller of their system reported that “it works better if I go to Optivo rather than the installers” to get issues resolved. All were aware that they should contact Optivo for any issues on the new system.

Residents were asked about their satisfaction with various aspects of the project communications and installation process. As previously, the responses were averaged across each questionnaire period to see if there had been any change in opinions. The results are displayed in Figure 2.19. It is clear that householders' opinions of the communication and installation aspects of this project are very good, and their views about the installers were excellent.

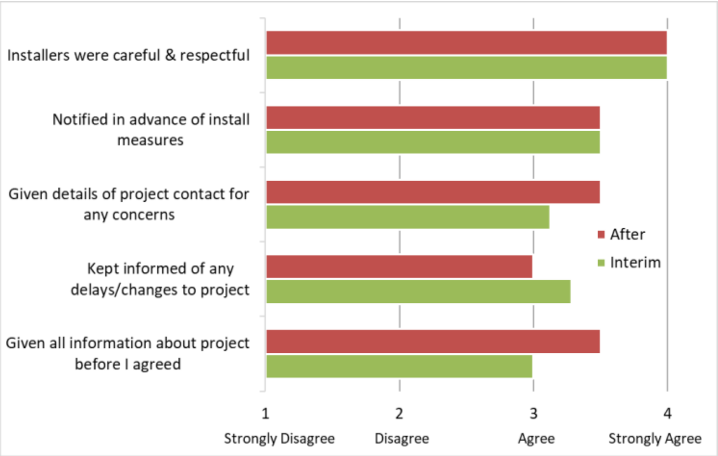


Figure 2.19 Resident satisfaction with project communications and installation of the measures

Another aspect of customer service to consider is that with this combination of technologies, it was recommended for households to switch to a flat-rate tariff if they were previously on an Economy 7 tariff. Many householders said that they were advised to switch their tariff type by either the installers or Optivo staff, and had no problems doing this themselves. However, by the end of the study, 2 of the 8 households were still on Economy 7 tariffs (and additionally, a third household had been switched back to Economy 7 by a new supplier, but they were not aware of this). One householder had requested the tariff-type change but this had not been enacted by the energy supplier, the other had not been aware that she needed to switch tariff type and did not understand her energy tariffs so would not have the confidence to request this change anyway, hence required additional support to do so (support to switch onto the correct tariff was provided by NEA staff following the final visit).

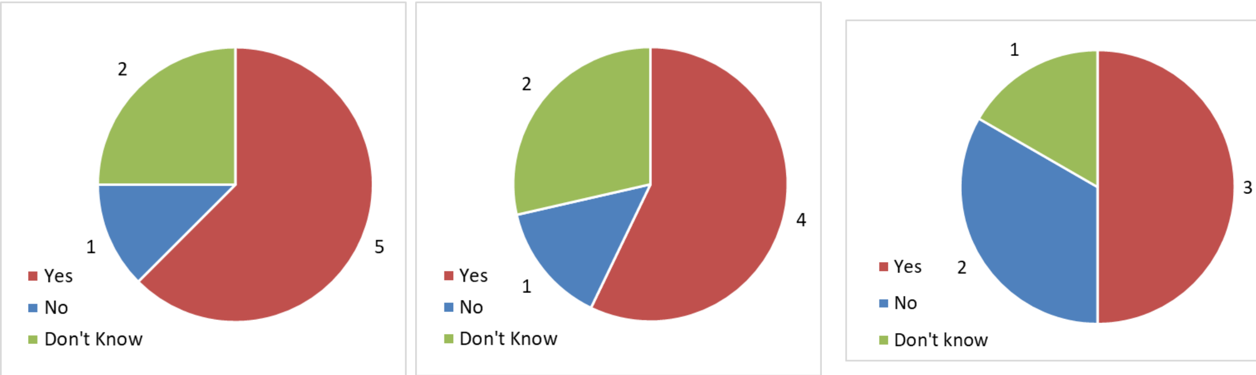


Figure 2.20 (a) Did the measures require a change of electricity tariff and if so, has the householder successfully switched (b) at the interim and (c) by the end of the study.

However, those who had not switched were slightly better off on the Economy 7 tariff according to their supplier, EDF (who supplied 4 of the 8 monitored properties). It may be that solar PV output had contributed to daytime electricity use, reducing the cost differential between peak and off-peak usage. Also, the timings of EDF off-peak rates, which are 21:30 – 23:30 and 01:30 – 06:30 in winter (22:30 - 00.30 then 02:30 – 07:30 BST, but we're mainly studying the winter heating period), may mean that the off-peak rate covers a higher proportion of some households' routine morning and evening electricity usage without any conscious effort / behaviour change. It does highlight that whether householders can make best use of the timings of Economy 7 off-peak rates, as well as the tariff rates themselves, must be considered when recommending a tariff-type switch.

3. Technical evaluation and results

3.1 Overview of technology

Solar Photovoltaic-Thermal (PV-T) are hybrid solar panels combining the functions of solar thermal collectors and PV in one, generating both electricity and hot water for use in the home[8]. Solar PV works most efficiently in cold sunny weather, with an optimum operating temperature below 25°C. For an average PV panel, for each degree warmer it gets above this, it will be around 0.5% less efficient. In the UK, where dark solar panels regularly hit 70-80°C, this could mean a 25% drop in efficiency at peak time. This is why installers mount solar panels on a frame, slightly raised from the roof, so air can circulate around the unit to help cool it. The theory behind running both solar PV and thermal through the same panel is that it cools the solar panels - improving the efficiency of the PV element by keeping it at its optimum operating temperature – and the heat is collected to use for domestic hot water (some types can also heat the home). It also eliminates the need to fit two sets of panels for hot water and electricity functions, which can look unsightly and take up more space. PV-T looks like a normal PV panel, but with pipework around the edges, see photos on cover.

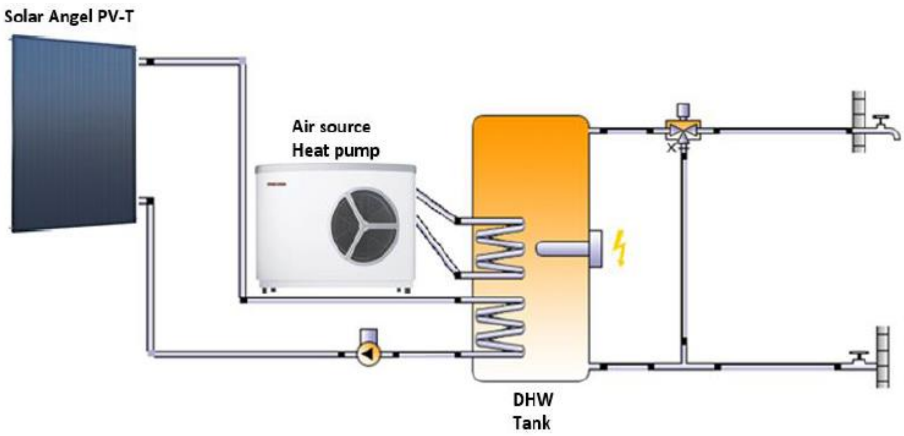


Figure 3.1 Schematic of the ASHP and PV-T system installed in homes in this study

Solar Angel literature claims their PV-T panels produce a total output of 4 times the useable energy of solar PV only. Their website is no longer operational, but further information / details about their PV-T panels can be found via Northburn Solar[7], such as the reported 250 Wp electrical output and 648 Wp_{th} thermal output per panel. Whilst electrical output per panel is no higher than for PV, PV-T panels should in theory give a higher total yield as they generate at peak capacity for longer during the day / year with less efficiency reduction due to overheating. Other sources suggest PV-T systems will produce about 40% more energy than equivalent separate PV and solar thermal[9].

The ASHP produces hot water to circulate through radiators for central heating and tops up the temperature of the domestic hot water if required (ideally timed to occur in the evening, after the PV-T panels have heated the tank during the day; for high hot water users this may need to occur multiple times per day). An electric immersion coil is also present to boost the tank if required.

According to the grant agreement with NEA, installation costs were on average £7,823 per property (£4,690 for ASHP and £3,133 for PV-T), however the monitored properties in Norton, Kent received 8 PV-T panels, while those in Iden, Rye received 6 panels (and smaller water tanks), so costs will have differed slightly between these two sites.

[8] The Green Age, Solar PVT – Hybrid Solar Thermal / PV panels https://www.thegreenage.co.uk/solar-pvt-hybrid-panels, [Accessed 27/9/2018]

[9] Homebuilding & Renovating, Solar PVT Panels Guide https://www.homebuilding.co.uk/solar-pvt-guide, [Accessed 27/9/2018]

3.2 Technological monitoring

To assess the performance of the ASHP and PV-T system, the following monitoring equipment was placed in the properties, as displayed in Figures 3.2 (a) and (b) below:

Thermal & humidity data loggers

Two Lascar EasyLog USB-2 loggers[10] were placed in each monitored property, one in the living room, and one in the main bedroom. They were placed in a background position in the room, away from direct heat / sun, cold or draughts. They recorded temperature and humidity once per hour initially, increased to every 20 minutes after the interim visits.

Current clamps

Tiny Tag View-2[11] or Lascar USB-ACT[12] non-invasive current clamps (and associated data loggers) were clipped around the main electricity meter tails. These regularly record current flowing through the cable to estimate electricity consumption (kWh). One current clamp was placed per household on the main electricity cable into the property, before any split for peak and off-peak/heating circuits if the household was on an Economy 7 tariff.

Thermal probe loggers

For each of the 4 properties which agreed to receive enhanced monitoring, one Lascar EasyLog TP-LCD logger's[13] metal probe was attached (using heat-resistant electrical tape) to the top back of the main - usually living room - radiator, to record its temperature every half hour initially, rising to every 10 mins after the interim visits.

Heat meters

In the 4 enhanced monitoring properties, three heat meters were fitted on hot water pipes near the household hot water tank, to monitor heat flows from each of: the solar thermal to the hot water tank; ASHP to the hot water tank; and from the ASHP to the central heating. They monitor both flow rate and temperature difference between sensors fitted on flow and return pipes to calculate heat energy flows in kWh. These record up to 12 months of data and were read at each household visit.

USB-5 Event Loggers

A Lascar EasyLog USB-5 pulse logger[14] was fitted to the pulse output of each heat meter, which generates an electrical pulse when each unit of heat is recorded by the heat meter. The pulse logger records the number of pulses in each 5-minute period to monitor heat generation / usage by time. These data loggers were replaced twice during the study, once in October 2016, and once in December 2017.

Watt-hour meters

All properties had a generation sub-meter fitted to record solar PV generation, and a sub-meter to monitor electricity use of the ASHP. Properties with enhanced monitoring also had additional sub-meters fitted to record the electricity usage of the immersion coil.

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[10] Lascar USB-2 product details: www.lascarelectronics.com/easylog-data-logger-el-usb-2, [Accessed 11/4/2018]

[11] Tiny Tag product information: www.geminidataloggers.com/data-loggers/tinytag-view-2/tv-4810, [Accessed 26/9/2018]

[12] Lascar USB-ACT product information: www.lascarelectronics.com/easylog-data-logger-el-usb-act, [Accessed 26/9/2018]

[13] Lascar thermal probe details: www.lascarelectronics.com/easylog-data-logger-el-usb-tp-lcd, accessed 13/6/2017

[14] Lascar USB-5 product details: www.lascarelectronics.com/easylog-data-logger-el-usb-5, [Accessed 11/4/2018]

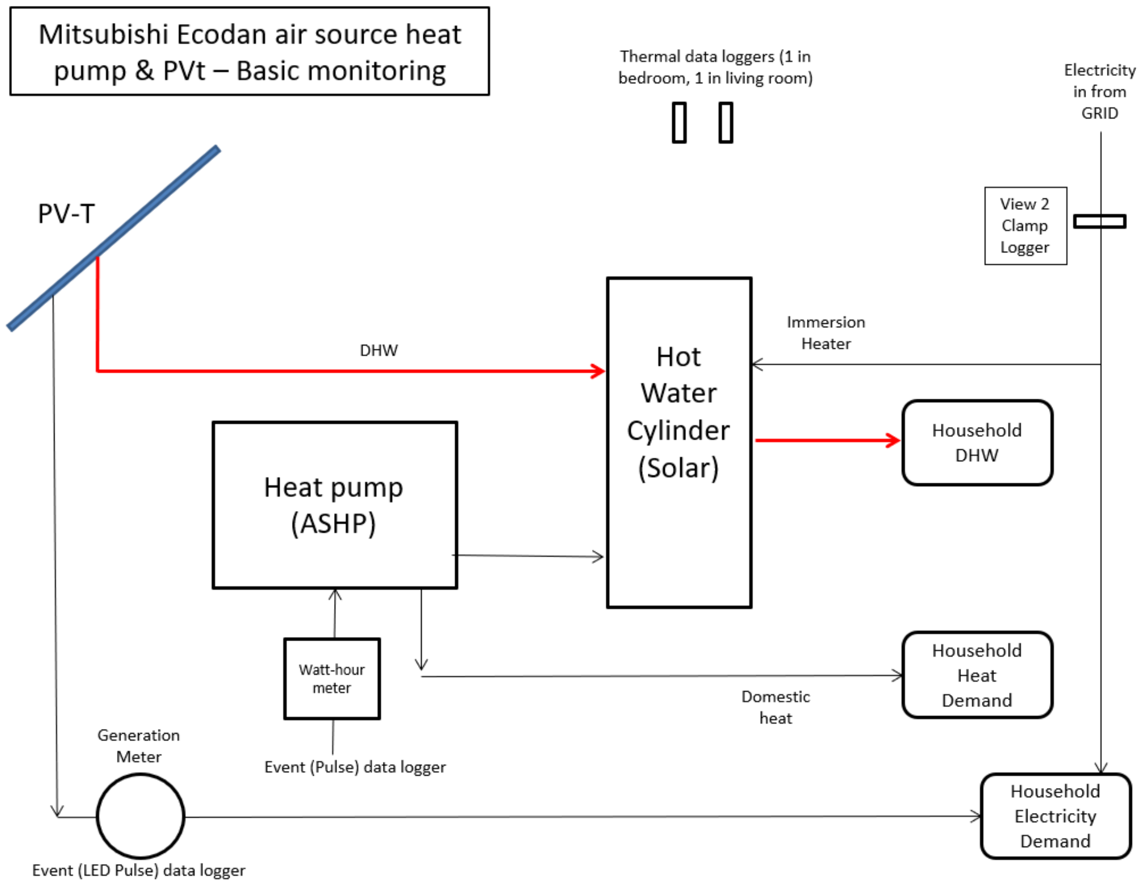
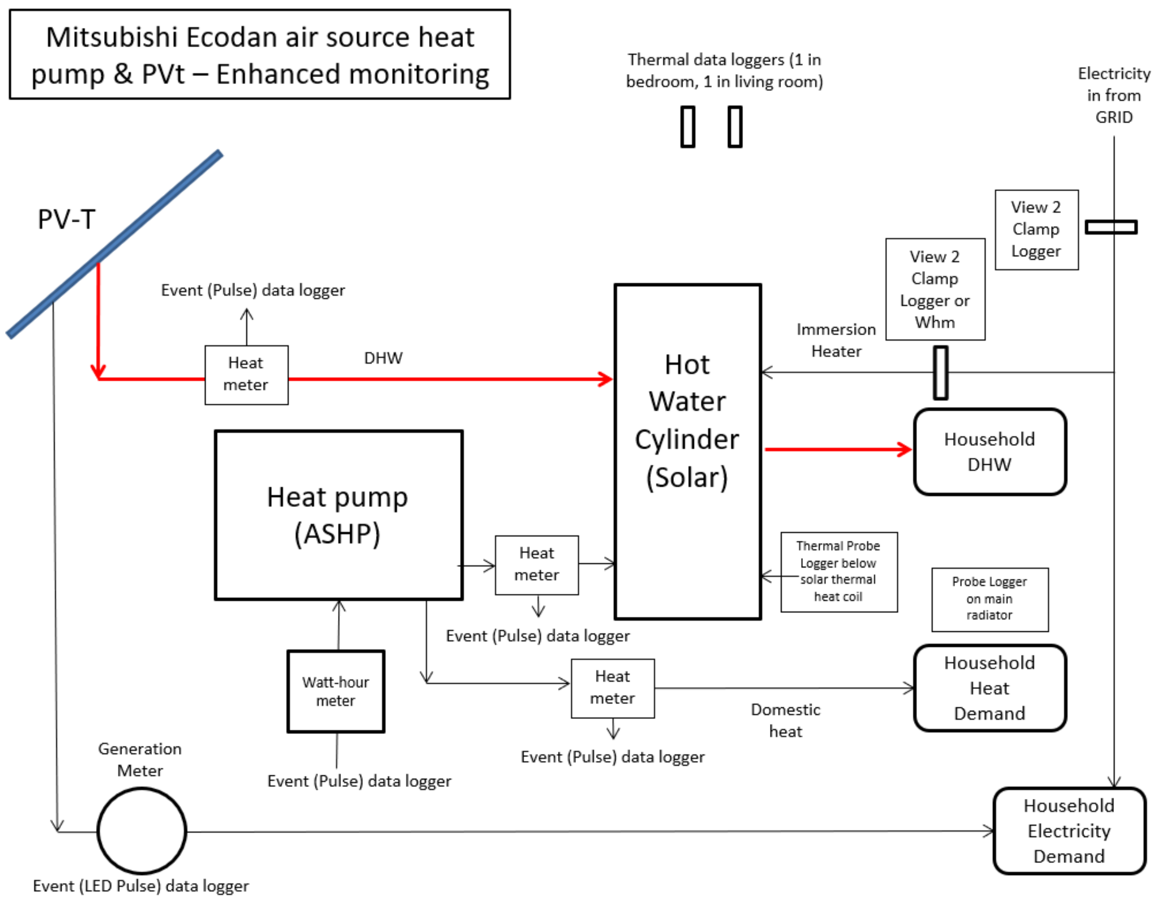


Figure 3.2 – Schematic diagram of monitoring equipment placed in properties receiving measures (a) above, with basic and (b) below, enhanced monitoring.



LED Pulse Event Loggers

Where household electricity meters and any sub-meters fitted had pulse outputs, light sensitive pulse loggers were fitted to record electricity use over time. Initially Enica Opti-pulse loggers were fitted, however these proved unreliable. They were replaced by Crucible LED sensors[15], attached to Omega pulse-101 data loggers[16] with a higher success rate, however some suffered issues of coming unstuck from the LED they were monitoring.

Energy meter readings

In addition to monitoring equipment, residents were requested to record their electricity meter readings regularly during the study period. Residents were also requested to retain energy bills or statements received during the winter prior to, and during the monitoring period. Many allowed NEA staff to phone their energy company during the initial visit to obtain previous meter readings, or signed consent forms to allow us to contact their energy company to request meter readings held on their account.

3.3 Cost

This analysis uses electricity consumption information obtained from householders manually recording regular meter readings, along with bills or energy supplier data (where provided). Meter readings from before the start of the study were used to calculate previous usage – these were obtained for all householders for electricity, and for many households for solid fuel usage & costs. This previous usage was compared against usage for the period after the measures were installed (studying only the winter heating period), to see if the measures had helped householders to make savings.

For all homes, standardised Economy 7 electricity costs of 18p/kWh for peak rate and 7p/kWh for off-peak usage were used for calculations, to allow comparisons to be made between properties and other projects. 16 p/kWh was used for flat rate (standard) tariffs. These are slightly higher than common tariff rates as they include a small element for standing charges etc. Solid fuel use information was requested, but this was mainly obtained for homes where it was the main heat source previously – other properties may also have used some solid fuel. Recollections of volumes and costs were “patchy”, so these should be viewed as indicative estimates only. Comparisons are displayed in Table 3.3 (a), including the solid fuel estimates from Table 3.3 (b), on the next page.

To properly analyse energy use for space heating, account must be taken of weather conditions over the monitoring period, as it is poor practice to compare the heating costs for two periods without compensating for different outdoor temperatures during the periods – particularly as winter 2017-18 was so cold. An external temperature of 15.5°C is the commonly-used base temperature that energy specialists assume below which heating is normally required inside a building, and above which no heating is normally needed. Degree days (dd) are a measure of heating demand of a building relative to the external weather i.e. the number of degrees below 15.5°C that the average temperature falls, for each day. For example, if the average outside temperature is 14.5°C, this is recorded as 1 degree-day. Degree days are summed together over the required period, to give a total number in the period. Different periods can then be compared in terms of energy consumption per degree day, so accounting for different external temperatures, to determine if savings have been made as a result of installation of energy efficiency measures[17].

[15] Crucible Technologies LED Pulse Sensor: http://www.crucible-technologies.co.uk/Product/1442, [Accessed 26/9/18]

[16] Omega Pulse Input Data Logger: https://www.omega.co.uk/pptst/OM-CP-PULSE101A.html, [Accessed 26/9/18]

[17] www.carbontrust.com/resources/guides/energy-efficiency/degree-days [Accessed 11/04/2018]

Table 3.3 Analysis of (a) electricity costs, left, before and after measures were fitted and (b) below, solid fuel costs prior to installation of the measures

20 year average degree-day comparison of savings — Region: South East — 20 year average: 2037.03

"Before" period - Assume Economy 7 tariff

Tech Ref	Period	Days	Peak rate use	Off-peak use	Total Period (kWh)	Total Period (kWh) inc. solid fuel	Cost per 30 days	Degree days	kWh per Degree Day	kWh/dd inc solid fuel	Estimated annual cost[#]	Estimated annual cost[#] inc. solid fuel
T-01[c]	12th Jan 2015 - 15th Jan 2016	368	5,270	1,716	6,986.0	14,927.1	£87.12	1,281.7	5.451	11.646	£1,698.53	£2,098.53
T-02	16th Feb 2015 - 25th Feb 2016	364	7,658	5,161	12,819.0	12,819.0	£143.38	1,284.7	9.978	9.978	£2,758.49	£2,758.49
T-03[c]	4th Feb 2015 - 8th Feb 2016	369	1,864	2,296	4,160.0	35,130.3	£40.34	1,278.3	3.254	27.482	£790.78	£2,584.78
T-04	25th Mar 2015 - 26th Feb 2016	336	4,332	1,901	6,233.0	6,233.0	£81.50	1,082.3	5.759	5.759	£1,718.06	£1,718.06
T-05	12 Mar 2015 - 12th Mar 2016	366	3,651	5,226	8,877.2	15,006.3	£83.85	1,386.4	6.403	10.824	£1,503.10	£1,503.10
T-09[c]	28th Jan 2015 - 6th Feb 2016	374	2,653	3,718	6,371.0	17,661.9	£59.18	1,342.4	4.746	13.157	£1,119.58	£1,717.58
T-10[e]	2nd Feb 2015 - 30th Feb 2016	387	10,179	2,683	12,862.0	12,862.0	£156.59	1,486.7	8.651	8.651	£2,767.78	£2,767.78
T-12	30th Mar 2015 - 17th Mar 2016	353	5,284	6,060	11,344.0	11,344.0	£116.88	1,307.6	8.675	8.675	£2,142.52	£2,142.52
Average							£96.11		6.615	12.022	£1,812.36	£2,161.36
Coal back-boiler properties							£62.22		4.484	17.428	£1,202.96	£2,133.63
Electric storage-heated properties							£106.41		7.704	8.809	£2,030.54	£2,030.54

"After" period - assume Single-rate tariff; Comparison

Tech Ref	Period	Days	Total Period (kWh)	Cost per 30 days	Degree days	kWh per Degree Day	Estimated annual cost[#]	Estimated Cost Saving[#]	Estimated Cost Saving[#] inc. solid fuel	Estimated Energy Saving[#]	Estimated Energy Saving[#] inc. solid fuel
T-01[c]	18th July 2016 - 4th July 2018	716	18,618.0	£124.81	2,950.5	6.310	£2,056.62	-21.08%	2.00%	-15.77%	45.82%
T-02	6th July 2016 - 5th July 2018	729	14,306.0	£94.20	2,953.2	4.844	£1,578.85	42.76%	42.76%	51.45%	51.45%
T-03[c]	2nd July 2016 - 4th July 2018	732	10,997.5	£72.12	2,955.1	3.722	£1,212.94	-53.39%	53.07%	-14.36%	86.46%
T-04	23rd June 2016 - 23rd June 2018	730	7,870.9	£51.75	2,950.4	2.668	£869.48	49.39%	49.39%	53.68%	53.68%
T-05	23rd June 2016 - 1st July 2018	738	13,377.1	£87.01	2,955.6	4.526	£1,475.14	1.86%	1.86%	29.31%	58.19%
T-09[c]	27th July 2016 - 4th July 2018	707	15,527.9	£105.42	2,950.2	5.263	£1,715.45	-53.22%	0.12%	-10.90%	60.00%
T-10[e]	12th Aug 2016 - 5th July 2018	692	22,468.8	£155.85	2,948.5	7.620	£2,483.67	10.26%	10.26%	11.92%	11.92%
T-12	13th June 2016 - 16th June 2018	733	15,520.0	£101.63	2,948.7	5.263	£1,715.45	19.93%	19.93%	39.33%	39.33%
All				£99.10		5.027	£1,638.45	-0.43%	22.43%	18.08%	50.85%
Previously coal back-boiler properties				£100.78		5.098	£1,661.67	-42.56%	18.40%	-13.68%	64.09%
Previously electric storage-heated properties				£83.65		4.325	£1,409.73	28.49%	28.49%	43.44%	50.66%

[c] previously heated by coal fire with back-boiler [e] previously heated with electric boiler [#] 12 month estimated costs based on 20-year average 15.5°C heating degree-day value (for 2018) for the region stated

Solid fuel use (kWh

Tech Ref	Logs: Softwood	Logs: Hardwood	Coal	Total	kWh/day	Cost
T-01	0	0	7,941	7,941	43.63	£400.00
T-03	0	0	30,970	30,970	170.17	£1,794.00
T-05	6,129	0	0	6,129	33.68	£0.00
T-09	6,129	0	5,162	11,291	62.04	£598.00
T-10	10,215	0	36,132	46,347	254.66	£1,430.00
Average				20,536	112.83	£844.40

Degree day data was obtained – from 1st June 2014 until the end of the monitoring period - from weather station IKENTFAV2, in Faversham, Kent, GB (0.88E,51.31N)[18] as this is close to the area in which the properties are located and had good quality data for many years. There was no suitable weather station location between the two areas of houses monitored. 20-year average degree day values are available on a regional basis only: the South East region experiences 2,037 degree days per year on average, which was used to normalise our data.

It was assumed that all properties used Economy 7 electricity prior to the measures being fitted, and all switched to a flat rate tariff on install of the ASHP & PV-T, whether or not this was the case. Those households which previously used solid fuels (often coal) to heat their home are denoted: [c], and the home which used an electric boiler is denoted: [e]. Considering electricity costs only, homes which used electric storage heating (ESH) made average savings (1st yellow column) of 28.45 % (£621 per year), varying between 1.9 % and 49.4 %. Property T-05 which made the lowest electricity cost savings, said that their storage heaters often ran out of heat in the evenings, so they burned logs which they obtained for free, to heat the home. This will be accounted for when solid fuels are discussed in the next section. The household which used an electric boiler previously, T-10, made a 10.3 % saving in electricity costs. All 3 properties which previously used coal / solid fuel saw an increase in their electricity costs (i.e. negative savings) of 21.1 - 53.2 % after install of the new system, averaging 42.6 % (£459 per year), as they were now using electricity in place of solid fuel.

Due to the assumed changes in electricity tariffs, cost savings differed from electricity usage savings in kWh (3rd yellow column), which were 29.3 – 53.7 %, average of 43.4 %, for previously storage heated homes, and an increase in electricity usage of 10.9 – 15.8 %, average 13.7 %, for the previously solid fuel heated homes. Household T-10, which previously used an electric boiler, saved 11.9 % on electricity usage.

Taking solid fuel usage into account is necessary but does introduce inaccuracies as mentioned previously due to poor recollection. It also causes aberrations in costs since properties were in rural areas and some residents worked in forestry, or otherwise knew where to source logs

[18] Bizee Degree Days: www.degreedays.net [Accessed 11/07/2018]

(assumed to be softwood) for free, so costs often do not reflect volumes of fuel used. It was assumed that solid fuel use after installation of the new measures was minimal (indeed most properties only had electric fires fitted in fireplaces) and was for aesthetic reasons rather than providing a significant heating need, so no usage is included for the period after measures were fitted. Energy savings in kWh, including estimates of solid fuel use before installation of the new measures, varied from 11.9 – 86.9 %, averaging 50.9 %. The property which made the lowest savings was T-10 which previously had the electric boiler – this household had also had a radiator leak after the new heating system was installed, resulting in it not working properly until late December 2017 with the household having to use electric heaters instead, plus this was one of the properties where the solar thermal system was found to be turned off at the final visit. Both issues would have reduced the potential savings seen. If this property is excluded from calculations, average savings were 56.4 %. The other property whose solar thermal system was turned off was T-12, which also shows slightly lower savings than the other households at 39.3 %. On average, previously storage heated homes reduced their energy use by 50.7% (reducing from 8.8 to 4.3 kWh/dd), and previously solid-fuel heated homes reduced their energy use by 64.1% (from 17.4 to 5.1 kWh/dd). As seen in Table 1.3 (p.14), the previously solid-fuel heated homes in Kent were larger than most of the ESH homes in East Sussex, which may in part explain their slightly higher energy usage, possibly also being used to more intense warmth.

Taking account of solid fuel use in terms of cost savings, it depended very much on how much solid fuel had been used, and whether or not householders had been able to obtain logs for free. Savings varied from 0.12 % to 53%, averaging 18.4 % for previously solid-fuel heated homes, and 28.5 % for storage heated homes.

To assess the significance of these, the standard deviation (SD or σ) of the savings was calculated – this measures the spread around the average, as displayed in Figure 3.4. A result is significant with 68.2 % certainty when savings are always greater than zero when σ is added to or subtracted from it (denoted ±σ), significant with 95.4 % certainty when savings are greater than zero ±2σ. In social studies, it is rare to meet the ±3σ requirement for a 99.6 % significance level. The standard deviation of the energy savings (including solid fuel estimates) across the whole sample is 21 %. The average saving of 50.9 % ± (2 x 21 %) would always be above zero, so we can say that these savings are therefore significant to 2σ, or 95.4 % confidence level. When T-10 is excluded, the standard deviation is 15 %, and 56.4 % ± (3 x 15 %) will always be above zero so savings are significant to 3σ, or 99.6 % confidence level.

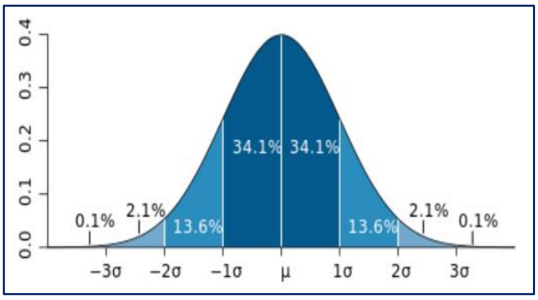


Figure 3.4 Illustration of mean (μ) and standard deviation (σ) in a normal distribution

Separating out for previous fuel type, energy savings for ESH properties have a standard deviation of 8.1%, so the average savings seen of 50.7 % ± (3 x 8.1 %) is always above zero, hence these savings are significant to 3σ, or 99.6 % confidence level. For solid fuelled homes, the standard deviation of savings was 20.6 %, so again the average savings seen of 64.1 % ± (3 x 20.6 %) is always above zero, hence these savings are significant to 3σ, or 99.6 % confidence level.

This data can sometimes be used to investigate whether energy costs in the properties are better controlled, in terms of being more closely related to heating need i.e. degree days, following the installation of the new measures. Meter readings taken by householders were used to plot energy usage against degree days for the periods before and after installation of the measures, see examples in Appendix 2.a). However, as the periods between meter readings were often irregular these should be taken as indicative rather than a quantitative analysis, however they still show that energy consumption points generally occur more tightly around the best fit line after install of the ASHP and PV-T than beforehand (when points are often scattered and little relationship between electricity use and degree days can be seen), giving a higher R^2 value for the best fit line. Apart from properties T-01 and T-04 where householders took meter readings from the ASHP sub-meter, plots for ASHP energy usage show little detail, but most show that the heat pump has a good relationship between its energy use and degree days (outside temperature and predicted heat need).

Summary of electricity use of the ASHP only									
Tech Ref	Period	Days	Total Period (kWh)	Cost per 30 days	kWh per day	Degree days	kWh per Degree Day	Estimated annual cost#	% of electricity bill
T-01	11th July 2016 - 4th July 2018	736	5,659	£36.91	7.69	2,955.5	1.915	£624.04	30.34%
T-02	18th March 2016 - 5th July 2018	839	7,628	£43.64	9.09	3,419.6	2.231	£727.06	46.05%
T-03	25th Feb 2016 - 4th July 2018	860	7,661	£42.76	8.91	3,674.9	2.085	£679.48	56.02%
T-04	10th June 2016 - 5th July 2018	755	4,991	£31.73	6.61	2,959.3	1.686	£549.63	63.21%
T-05	12th March 2016 - 5th July 2018	845	10,389	£59.01	12.29	3,485.0	2.981	£971.58	65.86%
T-09	24th Feb 2016 - 4th July 2018	861	9,312	£51.91	10.82	3,690.0	2.524	£822.48	47.95%
T-10	19th March 2016 - 4th July 2018	837	15,021	£86.14	17.95	3,407.9	4.408	£1,436.57	57.84%
T-12	No info available								
Average		819	8,666	£50.30	10.48	3,370.3	2.547	£830.12	52.47%
Median		839	7661.33	£43.64	9.09	3,419.6	2.231	£727.06	56.02%
Minimum		736	4,991	£31.73	6.61	2,955.5	1.686	£549.63	30.34%
Maximum		861	15,021	£86.14	17.95	3,690.0	4.408	£1,436.57	65.86%

Table 3.5 Analysis of ASHP electricity usage as a proportion of household electricity use

Electricity consumption of the ASHP, see Table 3.5, can also be analysed to determine the proportion of household usage it makes up, and estimate its approximate cost to the household. A period of as close to 1 year as possible was selected, however as visits at which this sub-meter was read were infrequent, this was not always possible, which will make the estimated annual cost less accurate. No information for household T-12 was available as the ASHP sub-meter had been fitted in an inaccessible location, but for all other properties, the ASHP used from 7.7 – 18.0 kWh per day, or 1.7 – 4.4 kWh/dd. The highest usage was seen in property T-10 which had high hot water demand, and where the solar thermal system was found to be turned off at the final visit. For all other properties, usage was 1.7 – 3.0 kWh/dd.

Cost estimates, again using the 20-year average number of degree days for the South East region of 2,037, varied from £550 - £972 for the “average user” properties, and £1,437 for property T-10, with a median cost of £727. This analysis found the ASHP’s energy use made up from 30 – 66% of the total electricity bill as estimated in Table 3.3 (a). Given heating and hot water usually makes up 82% of energy use in the average home[19], these percentages are significantly lower than normal.

[19] BEIS, Energy Consumption in the UK, 2016

3.4 Temperature and thermal comfort

Temperature and humidity loggers were placed - to see whether the property was able to achieve recommended temperatures (18-21°C) for comfort and good health - in the main living room and the main bedroom of the monitored properties. Data loggers were in position from February 2016 to July 2018, exchanged in December 2017. Some loggers were lost (in the initial batch), did not start, or stopped logging sometime during the monitoring period, for unknown reasons.

3 winter periods were selected over which to analyse temperatures. Period 1 covered 26/2 – 16/3/16, this was after the ASHPs had been installed in Kent homes but before they had been installed in Iden properties. It was a period of 20 days, during which 230.8 degree days of heating need were experienced, an average of 11.54 dd/day. N.B. properties did not have solar PV-T fitted until May-July, but these do not supply central heating so should not influence temperatures. Period 2 covered the winter period from 29/11/16 – 1/3/17, 93 days during which 765.2 degree days were experienced, averaging 8.23 dd/day. A final period 3 was selected covering winter 2017-18 from the day after the last replacement loggers were placed until the weather warmed up for spring, 20/12/17 – 6/4/18, a period of 109 days with 985.1 degree days, 9.04 dd/day. Note that winter 2017-18 was colder than 2016-17 with temperatures 0.8 °C colder, i.e. degree days this much higher, per day on average than the previous year, but Period 1 was particularly cold. Table 3.6(a) & Figure 3.6(b) display indoor temperatures recorded over these periods.

The letters after the property codes indicate the type of room in which the data logger was placed: L (or LR) for living room; B (or BR) for a bedroom and “avg.” is average. For logger positions where no data was available for that period, "-" is shown. The first two columns show average (mean) temperature: first for the 4-8pm heating period – from questionnaire responses, the times when most of the monitored households desired heating (see Figure 2.4) – then for the whole 24hr period average. SD is the standard deviation which measures the variability around the mean.

Temperature - Period 1: 26th Feb - 16th March 2016							
Property	4-8pm	24hr Avg.	Median	Mode	Min	Max	SD
T-01 L	21.21	20.12	20.00	21.00	15.50	25.00	1.85
T-02 L	16.30	16.17	16.00	16.00	13.50	18.50	0.90
T-03 L	17.96	17.80	18.50	19.00	12.00	24.00	2.86
T-04 L	-	-	-	-	-	-	-
T-05 L	20.89	20.03	20.00	20.00	16.00	26.50	1.81
T-09 L	22.26	21.40	21.50	21.50	13.00	24.50	1.48
T-10 L	-	-	-	-	-	-	-
T-12 L	-	-	-	-	-	-	-
LR avg	19.72	19.11	19.20	19.50	14.00	23.70	1.78
T-01 B	17.73	18.10	18.00	17.00	15.00	22.50	1.40
T-02 B	16.25	16.22	16.50	16.00	12.50	19.00	1.22
T-03 B	16.67	16.65	16.00	19.50	12.00	21.50	2.80
T-04 B	-	-	-	-	-	-	-
T-05 B	13.89	13.78	13.50	13.50	11.50	16.00	0.92
T-09 B	23.91	23.91	24.00	24.00	15.00	27.00	1.67
T-10 B	18.36	18.21	18.00	18.00	13.50	22.50	1.84
T-12 B	-	-	-	-	-	-	-
BR avg	17.80	17.81	17.67	18.00	13.25	21.42	1.64

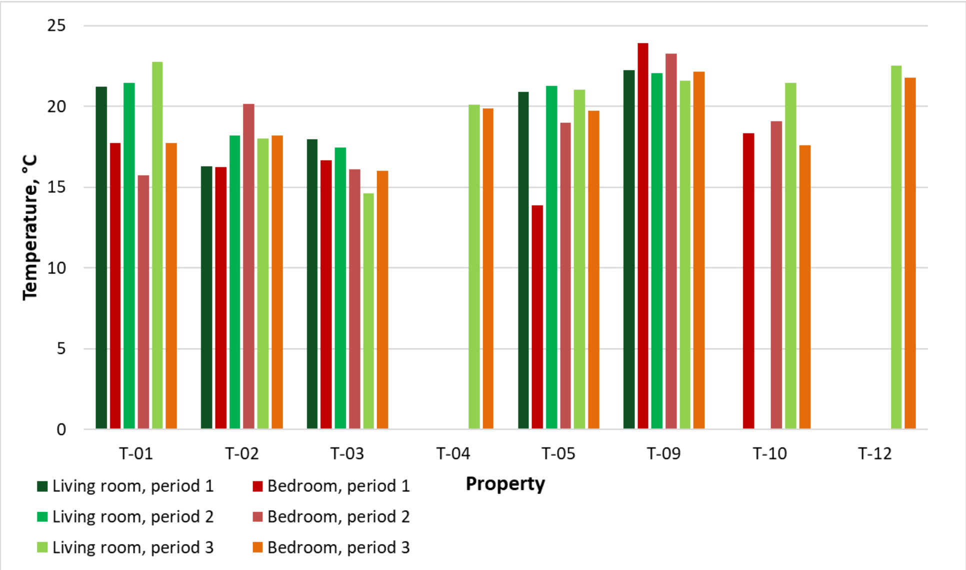
Period 2: 29th Nov 2016 - 1st Mar 2017							
Property	4-8pm	24hr Avg.	Median	Mode	Min	Max	SD
T-01 L	21.46	19.37	19.50	18.00	14.00	25.00	2.37
T-02 L	18.19	18.00	18.00	17.50	15.50	22.50	1.10
T-03 L	17.45	17.15	17.50	20.00	10.00	24.00	2.89
T-04 L	-	-	-	-	-	-	-
T-05 L	21.25	20.83	21.00	20.50	18.00	25.00	1.05
T-09 L	22.06	21.17	21.00	21.50	16.50	26.00	1.21
T-10 L	-	-	-	-	-	-	-
T-12 L	-	-	-	-	-	-	-
LR avg	20.08	19.31	19.40	19.50	14.80	24.50	1.72
T-01 B	15.75	16.03	16.00	16.00	13.00	19.50	1.16
T-02 B	20.18	20.15	20.00	20.50	14.50	37.00	1.47
T-03 B	16.10	16.29	16.50	18.50	10.00	20.00	1.95
T-04 B	-	-	-	-	-	-	-
T-05 B	19.01	19.06	19.00	19.00	16.50	21.00	0.66
T-09 B	23.28	22.80	22.50	22.50	20.00	27.00	0.98
T-10 B	19.10	18.95	19.00	19.50	16.00	22.00	1.13
T-12 B	-	-	-	-	-	-	-
BR avg	18.90	18.88	18.83	19.33	15.00	24.42	1.23

Period 3: 20th Dec 2017 - 6th Apr 2018							
Property	4-8pm	24hr Avg.	Median	Mode	Min	Max	SD
T-01 L	22.76	20.01	19.50	17.50	14.00	27.00	2.71
T-02 L	18.03	18.13	18.00	17.50	13.00	22.50	1.12
T-03 L	14.63	14.65	14.00	14.00	10.00	23.50	2.08
T-04 L	20.09	20.28	20.50	20.50	17.00	23.00	0.81
T-05 L	21.02	19.94	20.00	20.00	15.50	24.00	1.52
T-09 L	21.60	20.59	20.50	21.00	16.50	26.00	1.55
T-10 L	21.45	21.13	21.00	21.00	15.50	32.50	1.98
T-12 L	22.52	22.36	22.50	22.00	19.00	28.00	1.30
LR avg	20.26	19.64	19.50	19.19	15.06	25.81	1.63
T-01 B	17.75	17.39	17.50	17.50	14.00	23.50	1.22
T-02 B	18.21	18.36	18.50	18.50	15.50	21.50	0.92
T-03 B	16.01	16.30	16.50	15.50	13.00	20.50	1.18
T-04 B	19.88	20.08	20.00	20.00	17.50	22.50	0.81
T-05 B	19.76	19.35	19.50	18.50	15.50	22.50	1.27
T-09 B	22.18	21.69	21.50	21.50	18.50	26.00	0.96
T-10 B	17.58	17.52	17.50	17.00	14.00	22.50	1.40
T-12 B	21.78	21.70	21.50	21.50	18.50	29.00	1.40
BR avg	19.14	19.05	19.06	18.75	15.81	23.50	1.14

Table 3.6 (a) Temperature and thermal comfort in monitored properties
Figure 3.6 (b) Graph based on Table 3.6 (a) for the 7-10pm heating period average temperatures

Period 1 was before installation of the ASHPs in properties T-02 and T-05, whereas all other properties for which data is available already had their heat pumps fitted. In home T-02 both living room and bedroom achieved only 16 °C during period 1, colder than the recommended 18-21 °C range. Property T-05 (where a multi-fuel stove was used to heat the living room in the evenings) achieved 21 °C in the living room during the evening heating period, but the bedroom was very cold at only 14 °C. Temperatures in property T-02 increased to 18-20°C during periods 2 and 3 after install of the ASHP, and bedroom temperatures increase to 19-20°C in property T-05, within the recommended temperature ranges for comfort and good health.

Temperatures achieved in the other properties are generally within the recommended range – those households which contain elderly residents (T-01 and T-09) or young children (T-12) heat the rooms slightly warmer. Temperatures seen in property T-03 are of concern as they achieve 18°C in



period 1 but this decreases in subsequent winters. This was particularly cold weather, so residents may have required more heating to keep warm. However, this household did not have its loft insulation improved until March 2018 and stated that the external doors are still draughty so the hallway is still cold, hence temperatures seen could also be as a result of these physical issues, or affordability concerns meaning the residents had not been turning the heating up as high.

In general, across all the properties, minimum temperatures achieved are now higher and the standard deviation i.e. the temperature variability from the average, is lower. Temperatures in the evening heating period are generally slightly higher than the 24hr average temperatures, especially for living rooms, though this is not always the case. Bedroom temperatures are often lower than those in living rooms e.g. T-01, T-03, but again this is not always the case as property T-09 keeps the monitored bedroom warmer than the living room.

The median temperature is the middle of a list when sorted into size order, and the mode is the most frequently recorded temperature – comparing these different types of averages can identify whether a property's temperature is relatively even, or if it is skewed towards warm or cold. For most homes, the three types of average are similar. Variability (and a higher standard deviation) is seen in property T-03, the residents there work long shifts so heat the home on returning home, whereas other residents were more likely to be at home – and require heating - much of the day.

3.5 Humidity

Water vapour in the air is measured as relative humidity (RH) which is the percentage of water vapour held by the air compared to its saturation level (the highest quantity of water able to be supported by the air at that temperature). The saturation amount is dependent on temperature, as warmer air can hold more moisture, so relative humidity is a function of both moisture content and temperature. Humidity 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. However, 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. High values of RH are problematic as they can cause damage to building fabric and furnishings, mould growth and associated health problems. From the Building Regulations Part F[20]; the suggested average monthly maximum humidity for domestic dwellings during the heating season is 65%, weekly is 75% and daily is 85%.

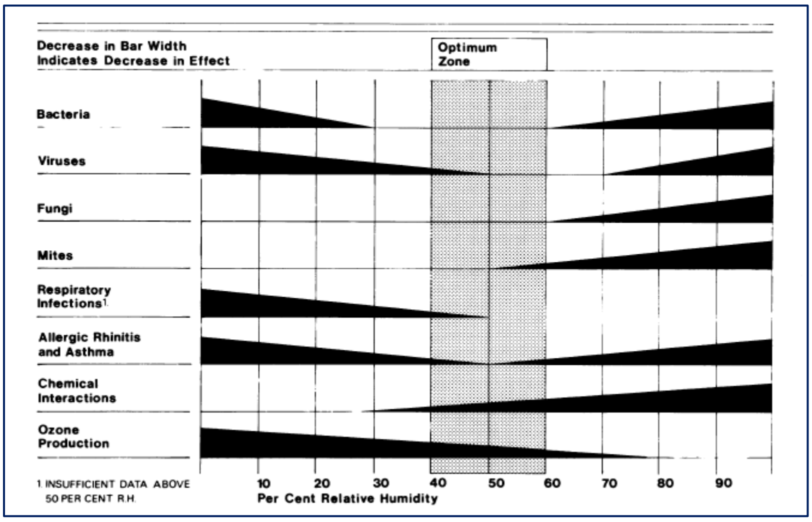


Figure 3.7 Optimum humidity levels to reduce indirect effects from pathogenic organisms or chemicals

Figure 3.7 illustrates the optimum humidity levels as cited by Arundel et al[21]. The study concluded that maintaining relative humidity levels between 40% and 60% would minimise adverse health effects relating to relative humidity.

Humidity - Period 1: 26th Feb - 30th Apr 2016

Property	4-8pm	24hr Avg.	Median	Mode	Min	Max	SD
T-01 L	45.14	43.62	43.50	40.00	34.00	66.00	4.13
T-02 L	55.16	55.67	56.00	53.50	38.00	66.00	4.41
T-03 L	45.71	45.49	45.50	47.50	37.50	58.50	3.96
T-04 L	-	-	-	-	-	-	-
T-05 L	46.10	45.22	45.00	44.50	37.00	60.50	3.83
T-09 L	40.14	39.06	38.50	38.50	32.50	48.00	3.08
T-10 L	-	-	-	-	-	-	-
T-12 L	-	-	-	-	-	-	-
LR avg	46.45	45.81	45.70	44.80	35.80	59.80	3.88
T-01 B	42.76	43.10	43.00	42.00	36.00	49.00	2.89
T-02 B	57.81	58.49	58.50	53.00	45.00	73.00	6.31
T-03 B	51.65	53.22	53.50	53.00	43.00	63.50	4.03
T-04 B	-	-	-	-	-	-	-
T-05 B	62.82	64.61	65.00	64.50	55.00	71.00	3.37
T-09 B	36.95	38.20	38.00	38.00	30.50	44.50	2.32
T-10 B	49.24	50.22	50.00	50.00	40.50	64.00	3.80
T-12 B	-	-	-	-	-	-	-
BR avg	50.20	51.31	51.33	50.08	41.67	60.83	3.79

Period 2: 29th Nov 2016 - 1st Mar 2017

Property	4-8pm	24hr Avg.	Median	Mode	Min	Max	SD
T-01 L	46.96	46.93	47.00	52.00	31.00	66.00	6.46
T-02 L	64.24	64.09	65.50	67.50	36.00	78.50	6.62
T-03 L	48.97	49.28	50.00	51.00	31.00	67.50	7.57
T-04 L	-	-	-	-	-	-	-
T-05 L	50.87	49.36	50.00	52.00	33.50	73.00	6.42
T-09 L	48.65	45.29	45.50	47.00	27.00	68.50	6.80
T-10 L	-	-	-	-	-	-	-
T-12 L	-	-	-	-	-	-	-
LR avg	51.94	50.99	51.60	53.90	31.70	70.70	6.78
T-01 B	52.48	52.48	52.50	53.00	39.50	65.00	5.13
T-02 B	58.81	59.27	59.50	59.50	23.00	80.00	6.47
T-03 B	53.55	54.49	55.50	57.00	41.00	65.50	4.87
T-04 B	-	-	-	-	-	-	-
T-05 B	52.85	54.08	54.00	54.00	43.00	65.00	4.39
T-09 B	42.10	41.68	42.00	44.00	27.50	55.50	5.39
T-10 B	54.15	54.39	54.00	53.50	40.50	71.50	5.28
T-12 B	-	-	-	-	-	-	-
BR avg	52.32	52.73	52.92	53.50	35.75	67.08	5.26

Period 3: 20th Dec 2017 - 6th Apr 2018

Property	4-8pm	24hr Avg.	Median	Mode	Min	Max	SD
T-01 L	42.42	42.97	43.50	38.50	25.00	68.50	6.17
T-02 L	58.98	59.16	59.50	60.50	41.00	71.00	4.49
T-03 L	53.08	53.10	53.50	56.00	34.00	72.50	7.05
T-04 L	60.11	60.11	60.50	61.00	54.00	64.50	2.16
T-05 L	49.11	47.93	48.50	48.50	28.00	73.50	5.92
T-09 L	47.67	45.46	45.50	45.50	23.00	74.50	7.74
T-10 L	49.67	49.39	50.25	50.50	21.50	73.00	7.71
T-12 L	43.45	43.03	43.50	44.50	24.50	60.50	4.41
LR avg	50.56	50.14	50.59	50.63	31.38	69.75	5.71
T-01 B	48.18	48.82	49.00	49.50	25.00	62.50	5.01
T-02 B	59.97	60.30	60.50	62.50	44.00	78.50	4.35
T-03 B	50.97	51.47	52.50	52.50	35.50	68.00	5.15
T-04 B	59.99	59.92	60.00	60.00	55.00	64.00	1.66
T-05 B	50.88	51.50	53.00	53.00	28.50	64.50	7.32
T-09 B	45.77	44.96	45.00	42.50	27.00	65.50	6.19
T-10 B	59.04	59.24	59.50	57.00	42.50	76.50	5.84
T-12 B	43.24	42.62	42.50	41.50	26.00	59.00	4.60
BR avg	52.25	52.35	52.75	52.31	35.44	67.31	5.01

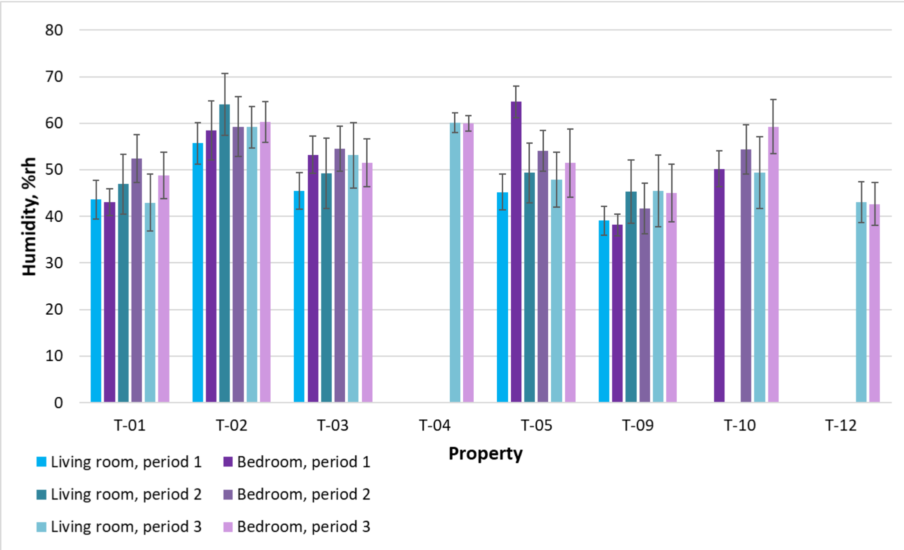
[20] Available from www.gov.uk/government/uploads/system/uploads/attachment_data/file/468871/ADF_LOCKED.pdf [Accessed 21/03/2017]
[21] Anthony V. Arundel, Elia M. Sterling, Judith H. Biggin, and Theodor D. Sterling: Indirect Health Effects of Relative Humidity in Indoor Environments: available at www.ncbi.nlm.nih.gov/pmc/articles/PMC1474709/ [Accessed 21/03/2017]

Table 3.8 (a) Table showing relative humidity (RH) in properties

Figure 3.8 (b) Graph based on Table 3.8 (a), for the 24-hour average relative humidity

Humidity data for the properties, over the same analysis periods as for the thermal loggers (as explained in section 3.4), is shown in Table 3.8(a) and presented in graph form in Figure 3.8(b). The error bars on this graph indicate the standard deviation, i.e. variability, from this mean value. There is a complex relationship between humidity and the evening heating period – as RH is inversely proportional to temperature, in some rooms the humidity decreases probably due to an increase in heating, whereas in others - presumably those which are occupied and where moisture releasing activities such as (breathing,) cooking or bathing is taking place - humidity increases. The whole 24-hour average is therefore the best period to use for humidity analysis.

This shows that for properties T-02 and T-05, in period 1 before installation of the ASHP, average humidity levels in property T-02 were within the recommended 40-60% range, however in property

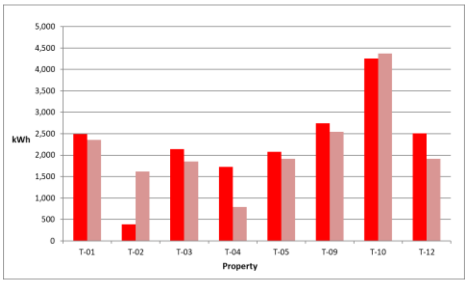


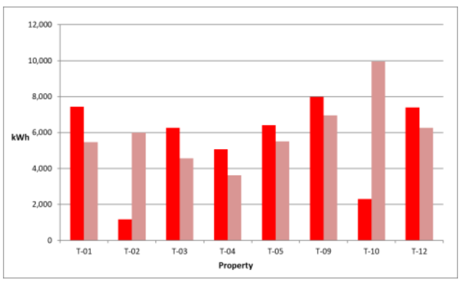
T-05, humidity levels in the bedroom were higher than the recommended range, probably as a result of the low temperatures seen. Humidity levels in property T-02 remain at the high end of the recommended range after ASHP install - it is known that this property suffered a leak from the roof which had been repaired, but the residents stated that the bathroom was often damp.

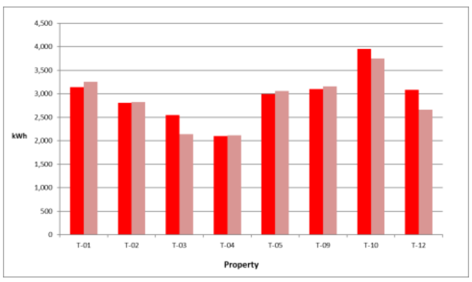
Across all monitored properties, most humidity levels fell within the recommended 40-60% range. Property T-09, which heated the home to the highest temperatures, had the lowest humidity levels. These were initially below the recommended minimum of 40%, but this increased in periods 2 and 3 to within the recommended range since the ASHP has been installed

3.6 Current clamp data

TinyTag View2 current clamps were fitted onto the main incoming electricity cable to each property, as a verification of electricity use in case householders did not take regular meter readings. We were able to obtain meter readings from the electricity supplier as many of the properties used







prepayment meters. We can compare the electricity use recorded against the closest period over which we have meter readings, displayed in Figure 3.9. Analysis periods were selected for when manual household meter readings were available: Period 1 ran from 17th March – 4th July 2016, Period 2 covered 13th August 2016 to 28th April 2017 (after this data logger memory was full), and 10th December 2017 to 2nd March 2018 (after which a current clamp became detached).

Figure 3.9 Comparison of current clamp (red) and meter reading-based (pink) energy consumption for (a) Period 1 (b) Period 2 and (c) Period 3.

The current clamp data matches well (within expected margin of error) with meter reading-derived electricity consumption, except in a few cases. At property T-02 the current clamp was not fitted correctly around the mains cable at NEA's interim visit, which could explain why it recorded very low readings for periods 1 and 2. Property T-04 shows much higher electricity use estimated by the current clamp than recorded by manual meter readings, but no explanation for this is known. On 12th August 2016 home T-10 had a smart meter fitted, and the current clamp was later found not to be correctly [re] fitted around the cable – probably disturbed by an engineer fitting the new meter – so this recorded low readings for period 2. At NEA's interim visit in December 2017 all current clamps were exchanged and checked for proper fitting, and all recorded electricity usage of a similar magnitude to that recorded by householder or energy supplier meter readings.

Having verified that this data correlates well with known meter reading consumption data (and excluding those periods when it does not, for the properties noted), TinyTag-measured electricity consumption can be plotted against degree days at regular intervals of 7 days to give a performance line, as shown in Appendix 2.b). This regular interval means there should be a similar amount of baseload consumption in each week's usage, hence conclusions are more able to be drawn from the best-fit line: the slope of the line represents the increase in electricity use expected per degree day, and the intercept is the baseline usage per week. (The few red points shown are final weeks of ESH-heating, for comparison – these are not part of the best-fit line.) These graphs show that household electricity use is related to degree days relatively well, with R^2 values (representing the significance of the best-fit line) varying from 0.58 – 0.75. Household electricity usage varied from 0.88 – 1.86 kWh/dd, averaging 1.44 kWh/dd, with the highest energy use in household T-10 with high hot water demand, and property T-05 containing retired couple who are at home most of the day. Baseline usage varied from 120 – 230 kWh per week, averaging 148 kWh/wk. This represents 17.1 – 33.3 kWh/day, average 22.3 kWh/day.

3.7 Temperature probe analysis

Thermal probes were attached with heat-resistant tape to the top-rear of the main living room radiator, to monitor the temperature it achieved. The probes appeared not to be attached (properly) initially, as two did not record a spike in radiator temperature until 10th March 2016. T-02 and T-04 were the two properties monitored which had not had their ASHP installed prior to loggers being fitted. Unfortunately, the thermal probe from property T-04 was lost, and that from property T-02 appears not to have been attached to the radiator (this household had ESH at the time that the thermal probes were installed), apparently recording room temperature until October 2016 (* on Fig. 3.10). Hence, we do not have any data on radiator temperatures with the previous heating system(s).

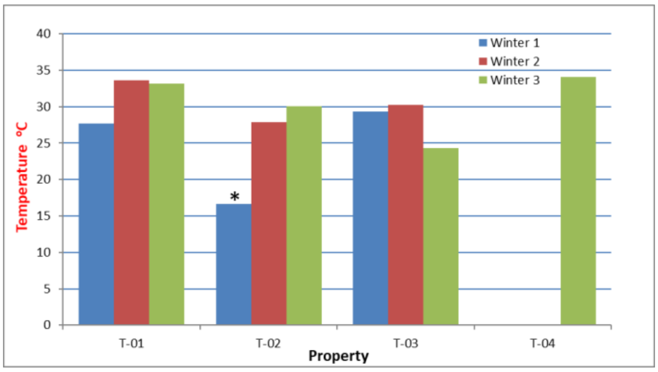


Figure 3.10 Radiator temperatures during the evening heating period (4-8pm) for the 4 properties monitored

Analysis periods selected were Winter 1, a period of 14 days from 10th – 23rd March; Winter 2, a period of 97 days from 5th Nov 2016 – 9th Feb 2017 (after which one logger became detached from the radiator); and Winter 3, a period of 29 days from 9th Dec 2017 (after NEA's visit to exchange loggers) to 6th January 2018 after which one of the loggers became detached from its radiator. The average temperature monitored between 4-8pm for each period are shown in Figure 3.10.

These indicate that radiator temperatures do not appear to have changed significantly throughout the monitoring period and achieve good temperatures (bearing in mind that this average may include times when heating is not on, or radiators have turned off due to thermostatic control).

Comparison with other times of day showed that this is the period when radiators are warmest for most households, apart from property T-03 in which higher temperatures (just above 30 °C) are recorded between 8pm and midnight for all periods. The drop in temperatures during the 4-8pm evening heating period seen here in winter 3, and in the temperature analysis section 3.4, may indicate that the household has changed their schedule and they heat the home later in the evening than previously. Property T-04 tends to heat the radiators relatively evenly throughout the day as the average radiator temperature seen does not change much.

3.8 Heat metering

Heat meters were fitted on the 4 properties fitted with enhanced monitoring – measuring both flow rate, and flow and return temperatures, to calculate kWh of heat provided from the solar thermal system to supply domestic hot water (DHW), from the ASHP to DHW, and from the ASHP to the central heating. Plotting this data for all monitored properties results in charts shown Figure 3.11. The pulse logger connected to the heat meter monitoring ASHP heat output to central heating in property T-03 did not log for the final monitoring period due to a broken connector wire, this may have occurred at the NEA interim visit.

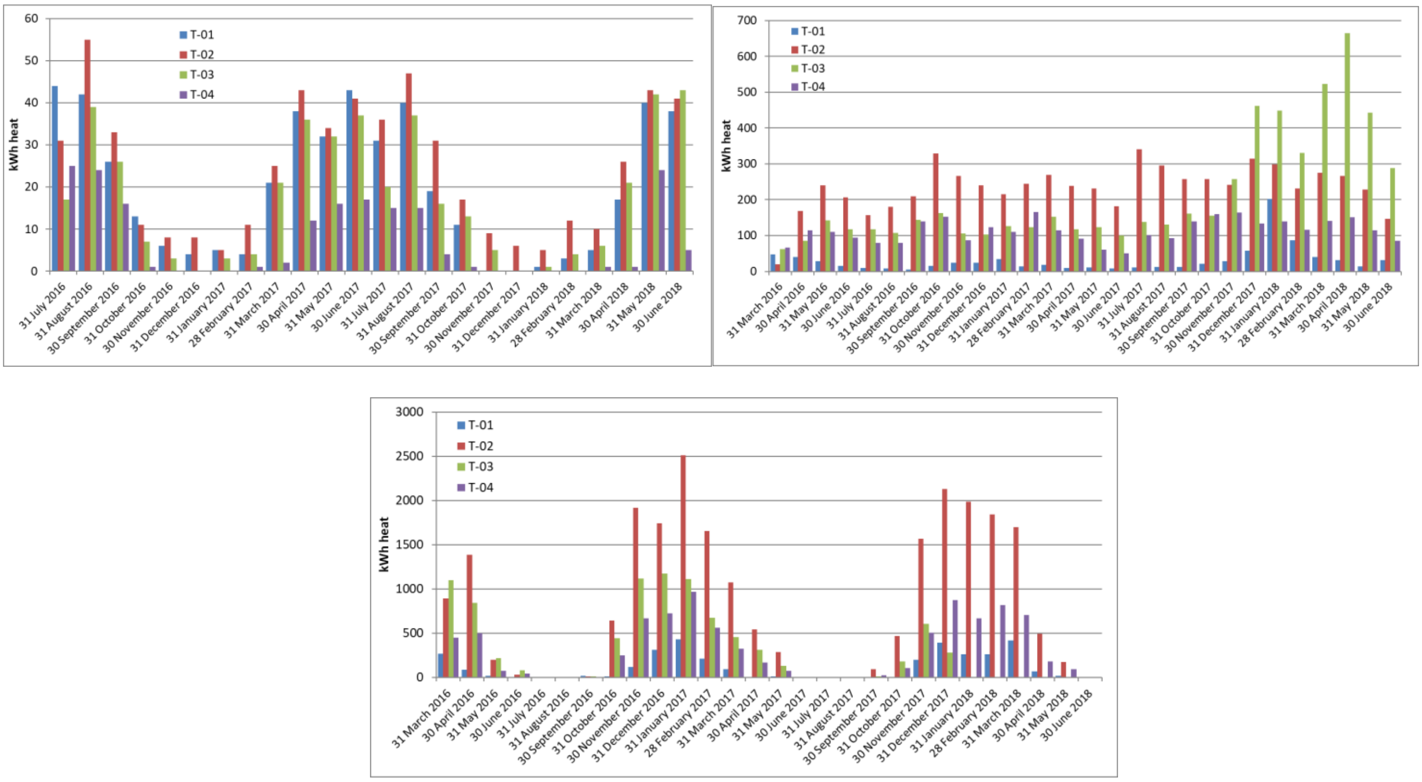


Figure 3.11 Heat meter data for (a) solar thermal to DHW, (b) ASHP to DHW and (c) ASHP to central heating.

This shows that the highest output of solar hot water occurs in April – August, ASHP contribution to DHW stays relatively even throughout the year with a slight reduction in the summer months. Note that the scale of Figure 3.11(b) is ten times that of 3.11(a). Unsurprisingly, central heating from the ASHP occurs mainly from November to February or March, and from the scale of this graph (Figure 3.11(c)) central heating clearly makes up the majority of heat energy use in the properties.

It is unclear whether the significant differences in magnitude of the central heating energy use between properties are real, or a result of the monitoring method: heat meter data is reliant on meters and sensors being fitted correctly by installers, with temperature sensors placed on the correct flow and return pipes. Incorrectly placed temperature sensors in some properties may explain the difference where no marked difference in usage was evident (see sub-metering section below). This could also explain the sudden jump in apparent heat to DHW from the ASHP seen in December 2017 for property T-03, if a temperature sensor was inadvertently disturbed or of course a change in the household/habits may mean they required more hot water than previously.

Plotting heat usage for central heating against degree days of heat need resulted in performance lines with R^2 values of 0.68 – 0.75 significance, indicating heat usage of 0.88 – 5.5 kWh/dd, with a median usage of around 2.45 kWh/dd. This wide variability also suggests problems with heat meter (sensor) installation which may influence the magnitude of the heat usage recorded.

There was no relationship seen between DHW generation by the ASHP and degree days, and a weak inverse relationship between degree days and solar hot water generated.

3.9 Sub-metering data

Watt-hour meters were fitted to measure solar generation, and electricity usage by the ASHP and immersion heater. As these were supplied new, and read zero on installation, and they were read on visits to the monitored properties. In as many cases as possible, light sensitive pulse loggers were placed over the LED on the meter which flashes every time a unit of electricity is recorded, so that more accurate electricity use over time could be monitored. Unfortunately, initial pulse loggers failed, and data unreliable.

Data was available for ASHP electricity usage for properties T-02 (Oct 2016 – July 2018) and T-04 (Dec 2017 – July 2018), as shown in Figure 3.12. Plotting this usage as performance lines against degree days shows a strong relationship (R^2 values of 0.79 and 0.83 respectively) with 1.5 kWh/dd used in property T-02, and a baseline usage of 27.5 kWh/week (or 3.93 kWh/day). T-04 used 1.11 kWh/dd, and baseline usage of 12.7 kWh/week or 1.8 kWh/day. ASHP sub-meter reads taken at visits (and by residents) were plotted in Appendix 2.a), graphs labelled (c) for each property. This show strong relationships (R^2 values of 0.91-0.97) between ASHP electricity consumption and degree days of heating need. Properties T-01 and T-04 (where residents took extra readings from the ASHP sub-meters) used 1.56 and 1.67 kWh/dd, whereas properties T-02 and T-03 (where only 3 points can be plotted for the periods between NEA's 4 visits, so they are less accurate) used 2.48 and 2.46 kWh/dd. Baseline usage could not be determined, and often appeared to be below zero.

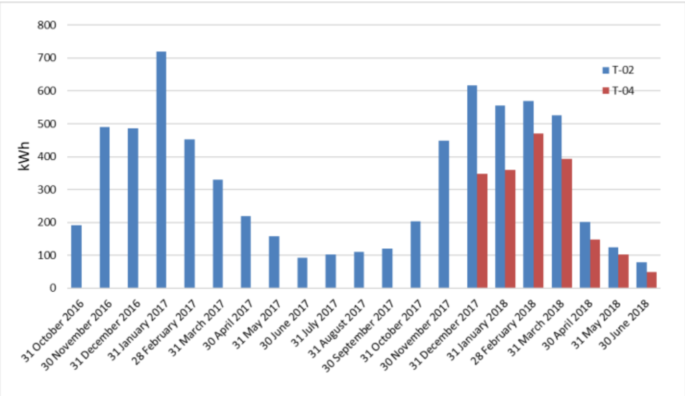


Figure 3.12 Monitored electricity usage by ASHP during study

Solar generation data is available for property T-01 from Oct 2016 – July 2018; T-03 from Oct-Nov 2016 and Dec 2017 – July 2018; and T-04 from April – May 2018 only. As for solar hot water in the previous section, plotting these as performance lines vs. degree days showed a weak (R^2 values of 0.1 – 0.4) negative relationship – it is logical that it is generally warmer when the sun is out.

No detailed data was available for immersion heater use, but most households had not used their immersion since soon after the ASHP system was fitted, which was verified by the sub-meter.

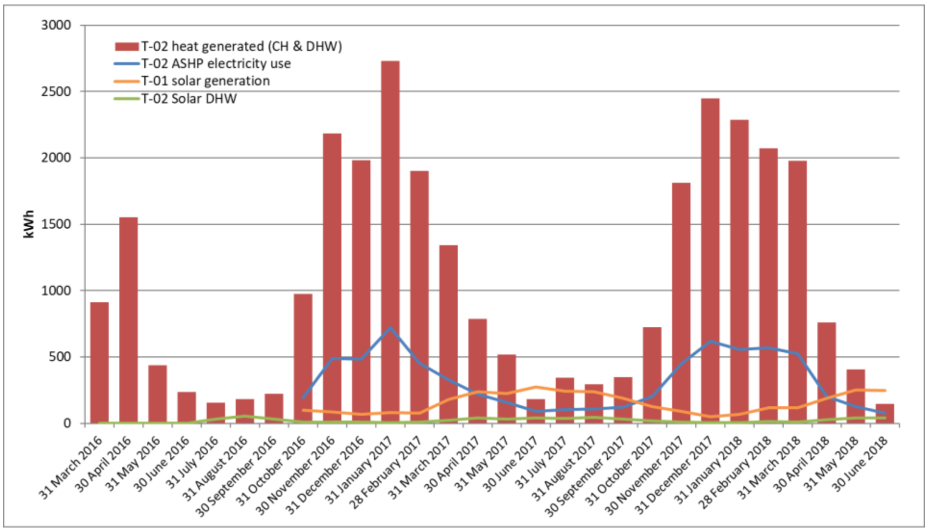


Figure 3.13 Energy flows for ASHP electricity consumption and heat output, solar PV generation and solar thermal heat output.

Figure 3.13 shows a combination of all the heat flows monitored – this is mainly for property T-02 where detailed data was available, however solar generation data from home T-01 was used as this was not available for T-02. This gives an indication of (magnitude of) energy uses and generation throughout the year. As previously noted, property T-02's heat meter readings for ASHP contribution to both DHW and central heating seem to be high compared to all others – which is not indicated by comparing their ASHP electrical usage – however this still shows visually that the heat pump achieved a coefficient of performance (CoP) of approximately 3, the solar PV generation is more than covering the electricity use of the ASHP in the summer but is contributing little towards its consumption in winter, while solar thermal makes a relatively small contribution.

Comparison of the sub-meter electricity consumption for the ASHPs with the total heat output measured via heat meters shows that for property T-01 a total seasonal performance of 0.6 is achieved, for property T-02 the seasonal performance is 3.92, for T-03 performance is 1.91 and for T-04 the total/seasonal performance measured is 2.14. The figures measured are very low for T-01 and on the high side for T-02, again suggesting issues with the installation of the heat meters (or their temperature sensors) affecting the magnitude of the readings measured. If these seasonal performance values for T-03 and T-04 are correct, they are reasonable and are representative of monitoring of their real-life use over this relatively long period.

3.10 SAP value improvements

EPCs were carried out for most properties prior to the works, and for all monitored properties after installation of the new measures – these are presented in Table 1.3, p 15.

This shows that the properties were initially rated E-G, with SAP values from 17 – 51, with an average of 40 (E). After the measures, SAP bands were D-E, with SAP ratings of 40 – 65 and an average of 55 (D).

This indicates the improvement due to the new heating and PV-T system, for properties where both before and after EPC assessments are available, varied from 9 - 33 SAP points, with an average improvement of 15.5 SAP points.

4. Conclusions and recommendations

4.1 Conclusions

The project's aims were to:

- Replace the existing heating system with a Mitsubishi ASHP system coupled with solar PV-T panels, to provide renewable heating, hot water and electricity for the households,
- Assess any change in residents' comfort – both reported in questionnaires, and measured using temperature and humidity monitors – after the new heating, and solar PV-T system,
- Quantify any change in electricity use for heating, and general household use, following the measures, compared to the period prior to installation,
- Quantify flows of renewable electricity and heat generated by the system,
- Report any change in ease of use of the heating system with the new measures fitted,
- Determine the effectiveness and cost-effectiveness of these measures to reduce fuel poverty in rural off-gas properties - information relevant to many social housing (and private) owners.

Summary of Findings

- Residents' feedback indicated a marked improvement in comfort, with numbers saying they could keep comfortably warm at home increasing from 3 up to 7 out of 8 (the final household could get warm but had problems of control so now often found it too hot). Numbers reporting that they had to wear additional warm clothes in the home to keep warm enough decreased from all 8 households to only 2 (2 others said it was needed only in extreme cold weather). 6 of the 8 said they could now use (more of) the home more comfortably.
- Supplementary heating use decreased from 6 households to 3 of the 8 questioned, and these used it only for short periods and/or when it was particularly cold.
- Benefits identified include: 7 had lower energy bills, more control over the heating, and felt it was reducing their impact on climate change, 6 felt the home was warmer & more comfortable, and they were saving energy in the home, and 5 felt the heating was easier to use or control.
- Other positives included no longer needing to carry solid fuels, or to have a cold house in the mornings until a fire was lit, that it was easier to achieve the desired temperature, and that the new radiators looked nicer than old storage heaters, and it was cleaner than coal.
- 6 of the 8 householders also said their hot water, and its ease of use, was better than before, and 3 households said there had been an improvement in damp issues.
- Householders were very satisfied with the installation of the measures, giving the installers glowing reviews, saying how good, friendly, patient and clean they were.
- Satisfaction with all aspects of the heating and insulation improved – particularly large improvements were seen in satisfaction with the cost of running the heating system, how warm it gets in the home when it's cold out, and the amount of control over the system. 4 households loved the system and thought that everyone in areas without gas should have one.
- Many felt it was easier to use than their old system, however 2-3 felt it was more difficult to use than their previous system. Some were unsure that they knew how best to use the measures which had been fitted, particularly mentioning that the controller was not intuitive, and the manual was too complicated/not written in user friendly terms for residents to understand. 7 of 8 said they knew how to use the thermostat of the system, but only 3 of 8 knew how to use the timer and a few households asked for support on how to do this, or get it set up for them.

- 4 of the 8 properties had suffered reliability issues with the measures, and whilst 2 of these had been fixed quickly, the other 2 had suffered leaks, and one had to wait 2 weeks in winter for a repair (without affordable alternative heating). Worryingly, 2 households' solar hot water systems were turned off – steps must be put in place both to explain to tenants what systems and their controls do and which should be left on, and to ensure that contractors always leave systems turned on after visits and provide support if they find such equipment turned off. One household also had cloudy hot water which was causing them concern.
- 2 of the 8 properties were still found to be on Economy 7 tariffs at the end of the study (one further had been switched back to E7 by a new supplier, which the residents were not aware of). One had requested to switch to a flat rate, but this had not been actioned by the supplier, the other was not confident enough to ask her energy company for any change. Additional support to ensure residents manage to switch is required. However, both residents had spent slightly less on E7 compared to their supplier's flat rate tariff. Advice to switch to a flat rate if an ASHP is fitted may not always be correct if combined with PV(-T) that reduces daytime electricity use, depending on how much residents can make use of off-peak times (e.g. EDF's, 2hrs evening then 5hrs in morning in SE-region).
- In terms of affordability perception, residents estimated that they paid £1,820 on average previously: an average of £2,025 for those on ESH; and £1,800 for electricity plus £400-£1,800 solid fuel costs for those who previously had solid fuel heating. This reduced to £1,144 on average with the new heating system, if property T-10 with high hot water usage and the solar hot water turned off is excluded. 7 of 8 residents felt that their bills were cheaper.
- Previously, significant concerns about affording (energy) bills and rationing strategies were seen: most respondents agreed that paying for energy meant they had to buy less of other essentials e.g. food, they had the heating on lower/less often than desired to keep the energy bill down, and they couldn't keep warm at home which impacted on residents' physical health. After the new heating, on average all these were no longer the case. Residents said they had seen savings and felt more in control of their energy bills. General money worries had also reduced. By the end of the study, 4 of 7 respondents said the measures had helped to reduce money worries a little, and another said they'd saved on bills but hadn't had money worries.
- Taking into account electricity use only (kWh):
    - Savings were 18.1 % on average but a distinct divide was seen between previous heating - households which used electric storage heaters saved 43.4 % on their electricity use (from 7.7 down to 4.3 kWh/dd), after installation of the new heating measures. The household, T-10, which previously had an electric boiler saved 11.9 % (8.65 down to 7.6 kWh/dd). Expectedly, homes which previously used solid fuels increased their electricity consumption by 13.7 % (up from 4.48 to 5.1 kWh/dd), as they used more electricity for heating.
    - In cost terms – due to assumed changes in electricity tariff - this equated to 28.45 % savings (£621 per year) on average for previously storage heated homes. Household T-10 which used an electric boiler saved 10.3%. Electricity costs for homes which previously used solid fuels went up by 42.6% (£459 per year) on average.

- Taking all fuel consumption into account, including estimates of solid fuel volumes and costs, added inaccuracies and gave unusual results as some households in these rural areas were able to obtain logs for free due to working in / connections with forestry activity:
    - The average saving in total fuel usage (kWh) was 50.9 % (down from 12.0 to 5.0 kWh/dd). With a standard deviation (σ) of 21 %, the savings are significant to a 2σ, or 95.4% confidence level. If property T-10 - which suffered many issues and made lowest savings, probably as a result - is excluded, total fuel savings averaged 56.4 % (from 12.5 down to 4.7 kWh/dd), with a σ of 15 %, so savings are significant to 3σ or 99.6%.
    - Breaking this down by previous heating type, this resulted in average savings in all energy use (kWh) of 64.1 % for previously solid fuel heated homes (17.4 down to 5.1 kWh/dd). With a standard deviation of 20.6 % this is significant to 3σ or 99.6%. Previously ESH-heated homes saw an average saving of 50.7 % (down from 8.8 to 4.3 kWh/dd), with a standard deviation of 8.1 %, this is also significant to 3σ or 99.6%.
    - In cost terms, savings depended significantly on whether households were previously able to obtain solid fuel (logs) for free. Savings varied from 0.12 % - 53 %, averaging 18.4 % (£472 per year down from £2,134 to £1,662) for previously solid fuel-heated homes, and 28.5 % (£621, £2,031 down to £1,410) for previously ESH-heated homes. However, with a standard deviation of 21.8 %, only this latter was statistically significant to 1σ or 68.2 %.
- Plotting performance lines of electricity use against degree days of heat need suggest that energy consumption was better controlled after installation of the new heating system, with points being closer to the best-fit line (and higher R^2 values).
- ASHP electricity usage was skewed by one high user (T-10) but median usage was 9.1 kWh per day or 2.23 kWh/dd, and a median cost of £727 per year. The ASHP made up 30 - 66 % of household theoretical energy bills, median 56 % based on degree day cost analysis, lower than the 82% of energy use for heating and hot water in the average home.
- Temperature monitoring showed that for those properties where monitoring began before the ASHP was fitted, temperatures evened out between a warm living room with multi-fuel stove and cold (14°C) bedroom in one property (T-05) to 19-20°C, and temperatures increased in both living and bedroom from 16°C to 18-20°C in the other property (T-02), after install.
- Properties were generally able to achieve the recommended range of 18-21°C. Those with elderly residents or young children tended to keep temperatures higher than this. Average temperatures in property T-03 decreased to below 18°C during the monitoring period which is of concern. This house had its loft insulated recently, but still reported draughty external doors. On average minimum temperatures increased, and temperature variability reduced.
- For the 2 properties monitored prior to ASHP installation, humidity levels in the cold bedroom of T-05 were above the recommended 40-60% range, and levels decreased after fitting of the new heating system. Humidity levels in property T-02 were within the recommended range.
- Humidity levels for most properties fell within the recommended range. One property which was heated to the highest temperatures (T-09) previously had humidity levels below the recommended minimum of 40%, but this has now increased to within the 40-60% range.
- Current clamp monitoring of electricity consumption indicated a relatively strong relationship between electricity use and degree days of heating need. Baseline usage in this sample averaged 22.3 kWh/day, and an increase in usage with heating need of 1.44 kWh/dd.

- For those properties which agreed to take part in the enhanced monitoring:
  - Thermal probe data could not provide a comparison with radiator temperature attained with the previous heating system, but did verify that the 4-8pm heating period analysed recorded the highest radiator temperatures, except for property T-03 where heating was now higher between 8pm-midnight. As expected, maximum radiator temperatures were lower than for non-ASHP systems, but room temperatures achieved were safe and comfortable.
  - Heat metering provided detailed indications of the different elements of home heating and DHW provision in this ASHP and PV-T system throughout the monitoring period. Whist some concerns are raised about absolute magnitudes of values recorded (whether heat meter temperature sensors were fitted correctly), patterns of consumption over the year(s) are clearly visible. Median heat pump increase in usage with heating need was 2.45 kWh/dd – similar to that calculated from ASHP usage sub-meter readings above.
  - Other sub-meters and pulse sensor data allowed detailed monitoring of patterns of use over time and plotting of performance lines. Pulse logger data showed baseline ASHP usage of 3.93 kWh/day in home T 02 plus 1.5 kWh/dd of heating. Home T-04 had baseline usage of 1.8 kWh/day plus 1.11 kWh/dd. From ASHP sub-meter readings, slopes were 1.56 and 1.67 kWh/dd for homes T-01 and T-04, 2.48 and 2.46 kWh/dd for T-02 and T-03 (less accurate).
  - Calculations of (seasonal) performance resulted in values of 0.6, 3.92, 1.91 and 2.14 for the 4 properties. The latter two are reasonable but the first is much too low and the second too high, suggesting incorrect fitting of temperature sensors on heat meters.
- SAP values of properties varied widely but averaged 40 (E) prior to improvements and this increased by an average of 15.5 SAP points to 55 (D) after the new ASHP heating and solar PV-T system was fitted.

4.2 Recommendations for potential future installations

Clearly, properties selected for install must be suitable for both PV and ASHP: they must have reasonable areas of unshaded roof at appropriate angle and orientation (however, not as sizeable an area is required as for PV), a suitable area within the home to fit the hot water tank, and a location within the curtilage of the building where an ASHP can be fitted.

As always for any renewable energy measure – to prevent the energy generated being lost via draughts and heat loss, maximise resident comfort, energy and carbon savings and minimise resident disruption - NEA recommends that heating upgrades should be carried out alongside a wider property thermal improvement programme. This should address all other heat loss issues evident in the property such as cavity wall and loft insulation, draughty windows/doors, single-glazing, insulation of rooms in the roof and external solid walls at the same time. Take-up of energy efficiency improvements is increased if works are done on a whole-house basis rather than individual technology-by-technology basis. Such works should ideally be carried out prior to installation of these measures so they run most efficiently, the householder can see the benefits, and can be supported in its configuration and use once, without having to change behaviour again later.

As the combination of measures includes solar hot water, it should be ensured that it is installed on homes where residents can make best use of the free hot water i.e. where baths and/or mains showers are fitted. Where electric showers are fitted, these should be replaced by mains showers, which can be installed over baths if no shower is currently present to reduce energy costs. As modern electrical goods such as washing machines and dishwashers are “cold-fill”, they will not use solar hot water so result in no savings. Washing hands or dishes in a sink is unlikely to result in significant savings from solar hot water for residents.

Advice and ongoing support should always be provided to all residents at installation of any measures: as well as specific information on how to best use the measures and their controls, this should also cover how (and when, to make best use of the solar power and economy 7 rates) to use energy most cheaply and efficiently in the home, to reduce expensive supplementary heating use in favour of whole-house heating, ensure residents are claiming all benefits for which they are eligible, that they are on the best energy tariff for their use, and to resolve any billing issues found. Greater support is also recommended to assist residents to switch electricity tariff type when this is advised – this opportunity should be taken to offer a full tariff check to ensure that they switch to the best tariff available for their usage patterns if they are on a poor-value or inappropriate tariff.

Particularly for more complicated technologies, greater support and a “Quick-start guide” would be recommended (laminated next to the controller so it cannot get lost) as a reminder / for reference to explain simply to residents how to set key parameters, such as temperature; timer to set different temperatures at different times of day if desired, hot water heating times / frequency; and how / when to set these to make best use of the PV-T panels.

However further research is also recommended to verify whether advice to switch to a flat-rate tariff is appropriate for this combination of technologies, and in areas where residents are more able to take advantage of lower cost off-peak rates during times they might normally use energy. This is a step beyond traditional switching advice normally offered to residents.

With a high proportion of monitored homes suffering issues with their system – either physical or misuse due to lack of understanding – follow-up checks are recommended soon after install, and early in the first winter following installation

Better training of contractors is recommended to ensure that they are able to look out for issues and provide enhanced support for residents. Engineers should check that equipment is always turned on after maintenance and switched clearly labelled. Remote monitoring of the system status should be considered to alert housing providers to issues.

4.3 Impact on fuel poverty

These measures appear to aid efforts against fuel poverty:

- Significant reductions in electricity bills for previously storage-heated homes of 28.45%, or £621 per year. Lower – and lesser savings of 18.4%, £472 per year, in homes where solid fuels were used, as some had obtained logs and wood free of charge.
- Clear and significant reductions in household energy need in kWh terms of 64.1% for previously solid-fuelled homes, and 50.7% for previously ESH homes, therefore if all fuels are paid-for, cost savings will result (though electricity costs rise in place of solid fuels).
- Marked improvement in comfort:
  - 7 of 8 households could now keep comfortably warm, compared to only 3 before,
  - Residents in only 2 homes now need to wear extra warm clothes in the home to keep warm, where all 8 said they had to previously.
  - 7 of 8 said they had more control over their heating, and 6 of 8 said their home was now warmer and/or more comfortable;
  - Improved satisfaction with the heating system, particularly the cost of running the heating, how warm the home gets when it's cold outside, and their amount of control over the system.
  - Benefits identified included no longer having to lug coal/logs, have a cold house in the mornings until a fire was lit (for solid fuel-heated homes) and that is was easier to achieve the desired temperature – not too hot or too cold (for storage heated homes).
- 7 of the 8 felt their energy bills had reduced. This had reduced money worries a little for 7 of 7 respondents, and another said they were saving money but hadn't had money worries before.
- Where there had been significant concerns about affording energy bills, and money in general previously - with residents cutting back on essentials to afford their energy bills, heating the home less than desired to save money, and suffering negative physical health impacts due to cold homes – these were no longer issues of concern, on average, after the new measures.
- Reduction in supplementary heating need from 6 households having to use it prior to the project to 3 after measures were fitted, and only for short periods or when weather was particularly cold.
- 6 of the 8 households also said their hot water quality and ease of use was better.
- 3 of the 8 felt that any damp, condensation or mould issues had improved after the measures.
- Temperatures achieved were higher and more even across the home after installation of the ASHP system, and mainly within the recommended 18-21°C range for comfort and health. Humidity levels were also mainly within the recommended 40-60% range.
- ASHP electricity usage made up 30-66% of energy use, lower than the 82% average for heating and hot water in the average home, as reported by DECC.
- The impact of these measures could be improved in any future wider roll-out by pairing them with other improvement measures including insulation, glazing and draught-proofing.

4.4 Performance comparison against manufacturer's claims

No claims had been made about how much energy this combination of technologies could save for properties in off-gas areas. Solar Angel literature states that their PV-T panels produce a total of 4 times the useable energy output of solar PV only. However, since we cannot realistically estimate outputs of PV-only systems on these properties - plus output will also be impacted by the PV-T's combination with an ASHP which also heats the hot water tank, it was not possible to test this.

The rule of thumb for ASHP CoP is that it should be between 2 and 3. The value we have recorded is probably closer to a seasonal performance factor, which is less well-defined, however should achieve approximately 2. It is suspected that there were issues with installation of heat meters in properties T-01 and T-02 resulting in low and high readings respectively, but for the remaining 2 properties the performance factors were 1.91 and 2.14, which are reasonable.

Savings calculated in this study are likely to be lower than seen in other more affluent households - the fact that the study targeted residents in a localised geographical urban area (southern UK), and who were in - or at risk of - fuel poverty. They were clearly using less heating than needed initially due to energy-rationing behaviour i.e. under-heating the home, so reducing their potential for cost savings. Most residents reported improved comfort, being more likely to attain the recommended 18-21°C temperature range (even with the colder outdoor temperatures of winter 2017-18), and/or able to heat or comfortably use more areas of the home than previously. This would also have reduced apparent financial savings as a result of the measures installed. These findings are therefore not necessarily transferable to other situations, or geographical areas of the UK.

4.5 Economic business case for installation of measures

Table 4.1 below shows the business case for installation of combined ASHP and PV-T systems:

Measure	Capital cost	Installation costs	Total	Annual energy saving (from this study)	Indicative annual payback	Assumptions
ASHP and PV-T	£7,832 per property	Included	£7,823 per property	£621 (ESH) £523 (average) £472 (solid fuel)	12.6 yrs 15 yrs 16.6 yrs	• Average savings used – may not save money if householders obtain solid fuels for free. • No solid fuel use – for provision of heating – after measures.

Table 4.1 Summary of business case

The cost per property reported is for this small study installing the systems to 21 homes – it could reasonably be expected that costs per property would be lower for larger volumes of installations. As for all new technology, it is expected to continue to develop, and costs to reduce further.

Total fuel cost savings are used above for this mixed sample containing households previously using both solid fuel and ESH. Savings were more clear-cut for storage heated properties (if little solid fuel was used as a top-up) – for installations in such areas the ESH figure should be used.

It must be ensured that residents are confident to use the measures installed, otherwise this can result in elements being turned off, not achieving comfortable temperatures, and extra usage costs.

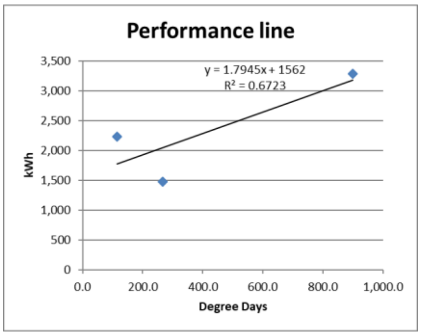
Savings will always be greatest if also combined with other measures to improve the insulation, and controllability of ventilation where this is needed – especially those measures which attract government ECO funding.

Appendix 1: Glossary of Terms

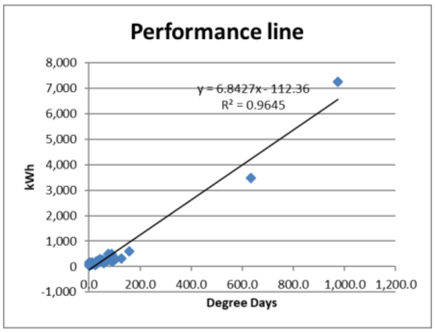
ASHP	*Air-source heat pump*
CoP	Coefficient of performance – measures efficiency of ASHP, should be between 2-3.
DD (or dd)	*Degree Days*
DHW	*Domestic hot water*
ECO	Energy Company Obligation (scheme requiring energy companies to fund energy efficiency improvements)
EPC	*Energy Performance Certificate*
ESH	*Electric storage heating*
HIP	*Health and innovation Programme*
IMD	*Indices of Multiple Deprivation – a measure of the level of deprivation in an area*
kWh	*kilowatt hour – unit of energy consumption*
LSOA	*Lower super-output area – the smallest area for which statistics are available*
NEA	*National Energy Action – the National Fuel Poverty Charity*
PV-T	*Photo-voltaic thermal (solar panels which produce both electricity & hot water)*
RH	*Relative Humidity*
SAP	*Standard Assessment Procedure (for assessing home energy efficiency)*
TIF	*Technological Innovation Fund*
TRV	*Thermostatic Radiator Valve*

Appendix 2.a): Performance lines of household electricity use (from meter)

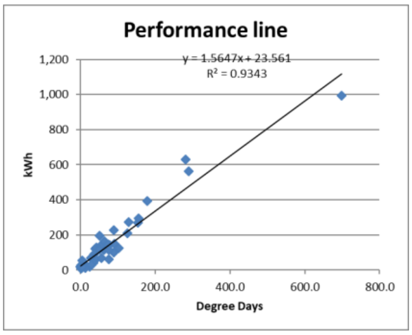
T-01 – a) before



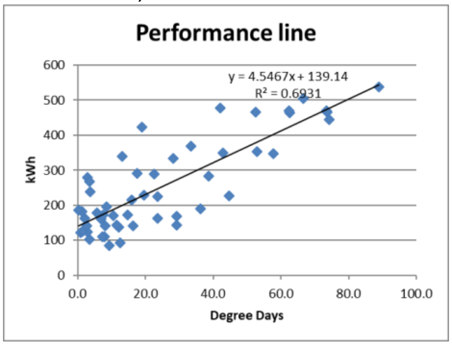
b) after



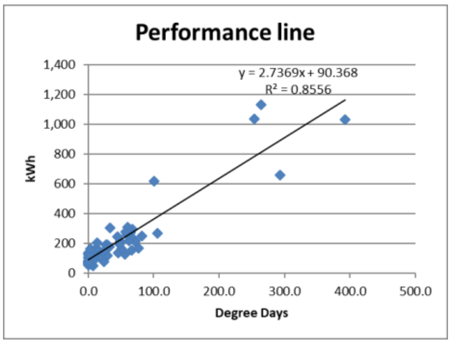
c) ASHP usage



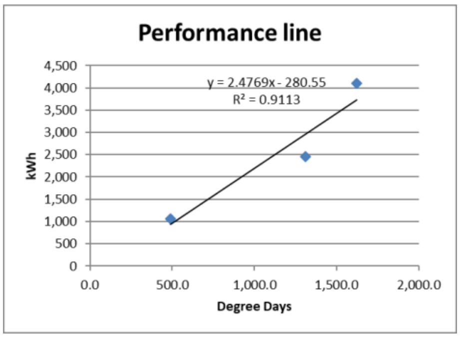
T-02 – a) before



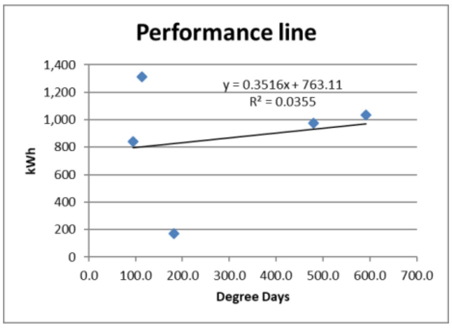
b) after



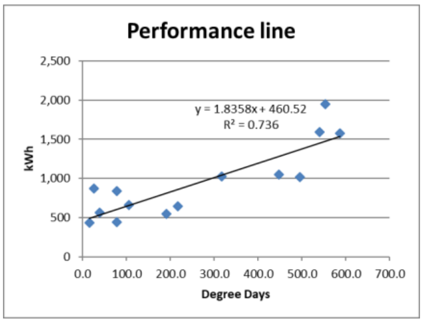
c) ASHP usage



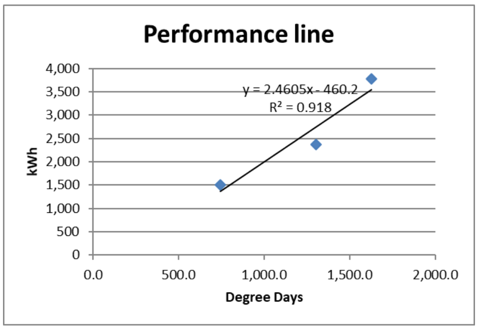
T-03 – a) before

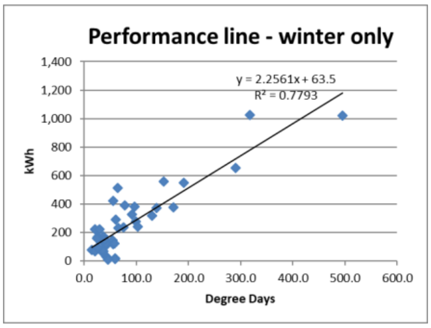


b) after



c) ASHP usage

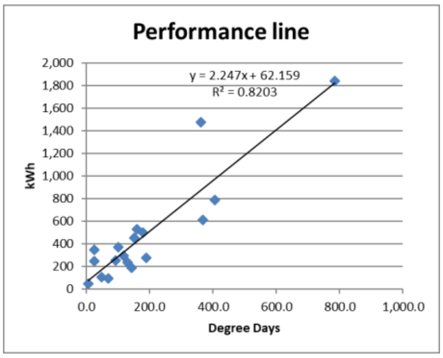




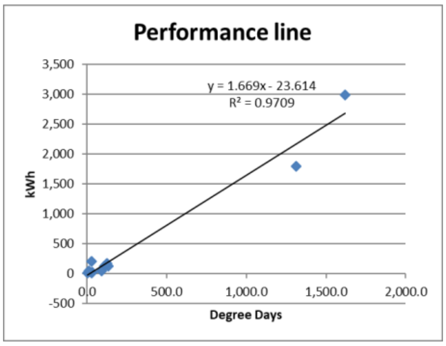
T-04 – a) before

Not available

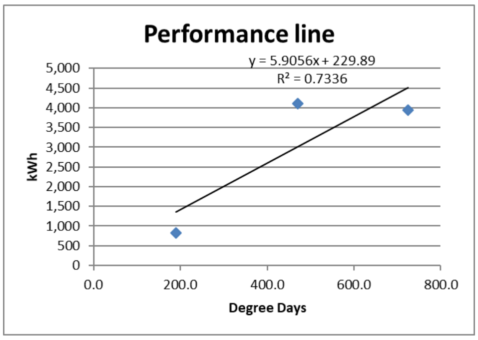
b) after



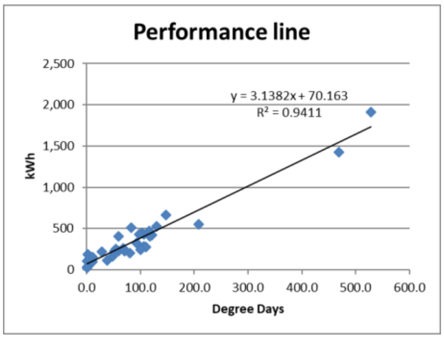
c) ASHP usage



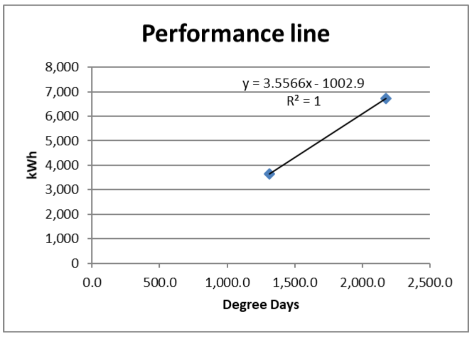
T-05 – a) before



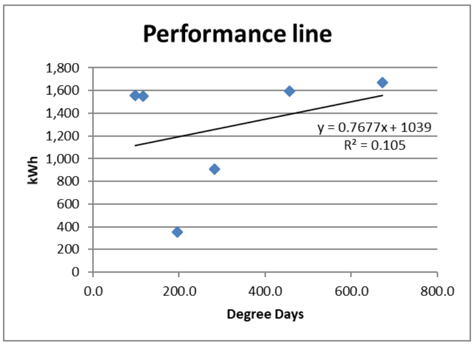
b) after



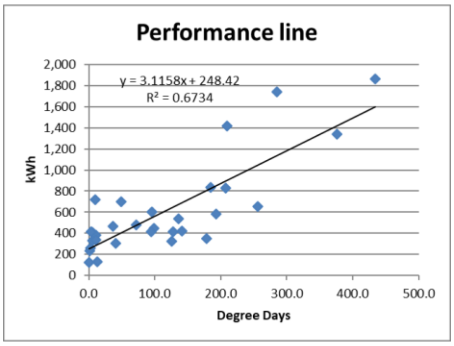
c) ASHP usage



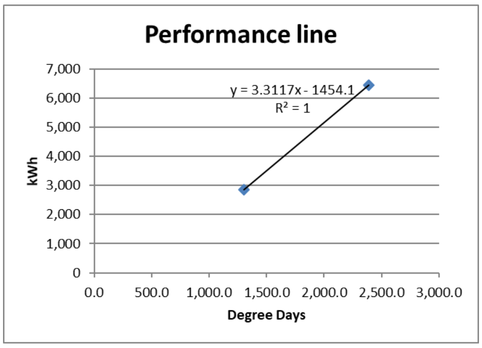
T-09 – a) before



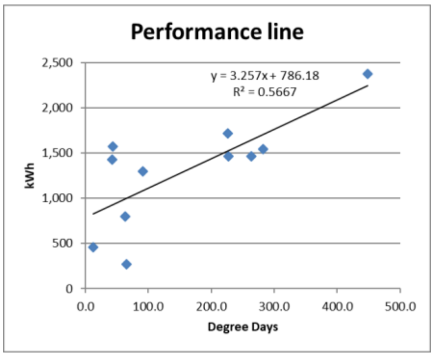
b) after



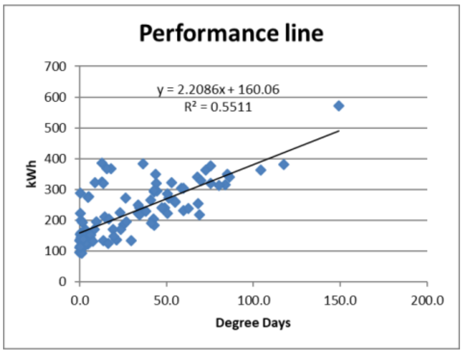
c) ASHP usage



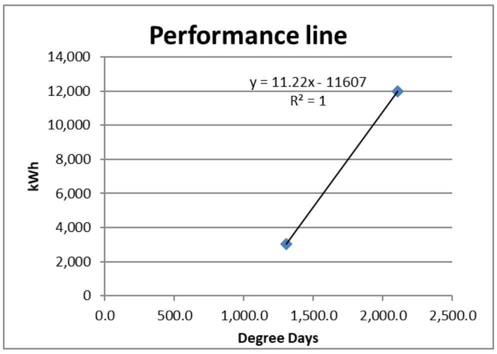
T-10 – a) before

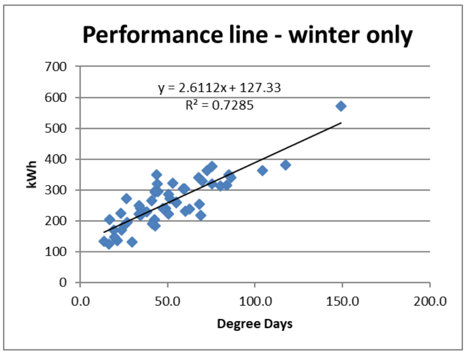


b) after



c) ASHP usage

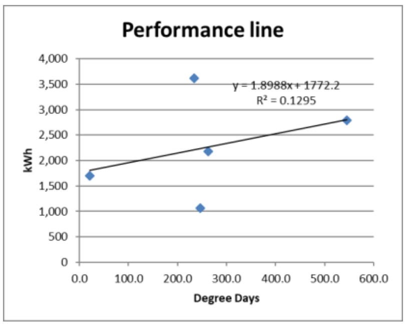




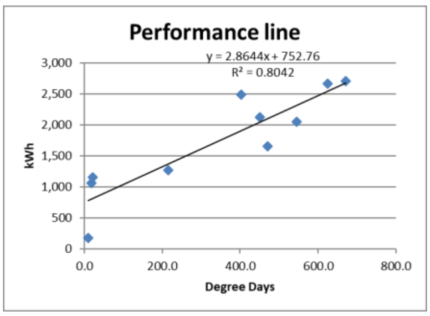
T-12 – a) before

Not available

b) after

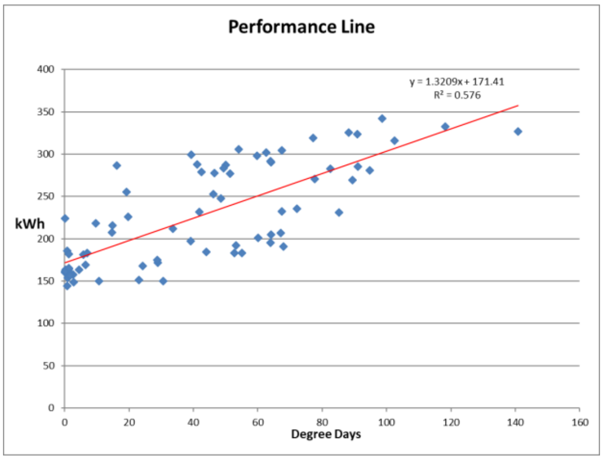


c) ASHP usage

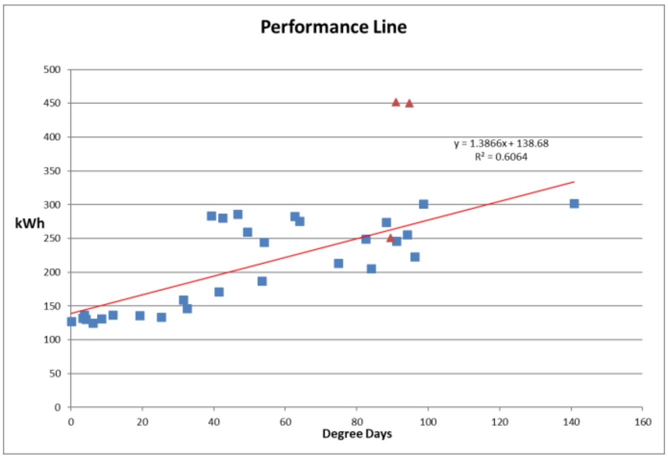


Appendix 2.b): Performance lines of home electricity use (via TinyTag)

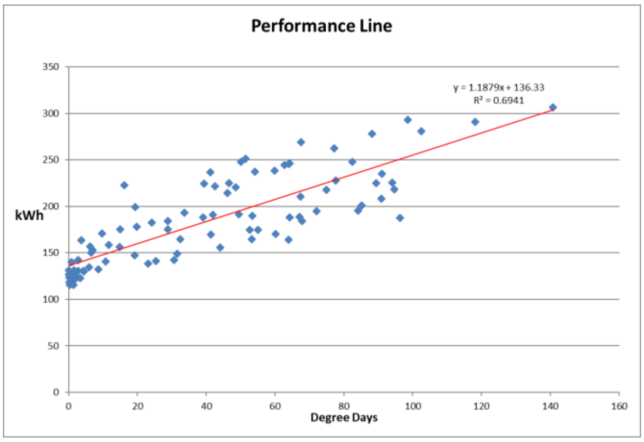
<- T-01



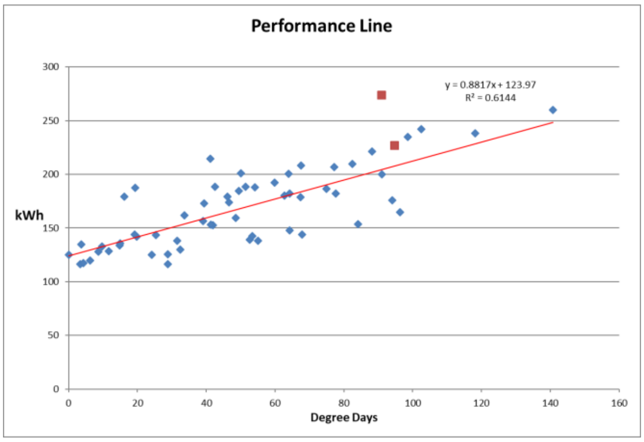
T-02 ->



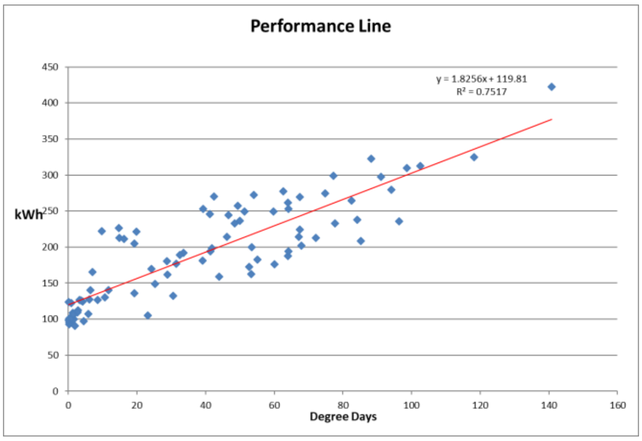
<- T-03



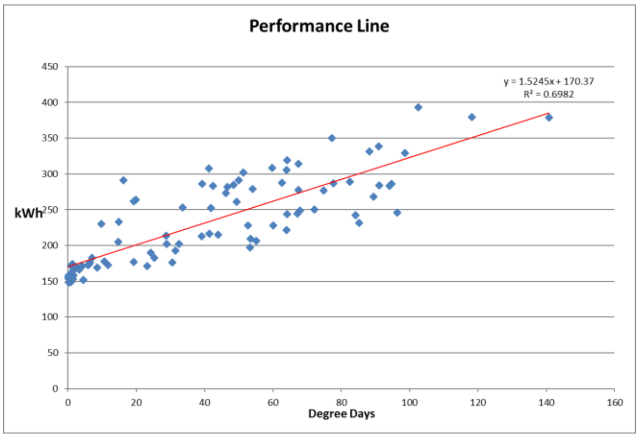
T-04 ->



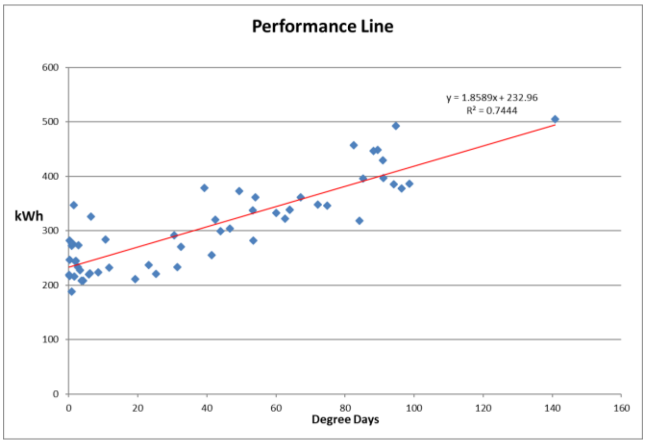
<- T-05



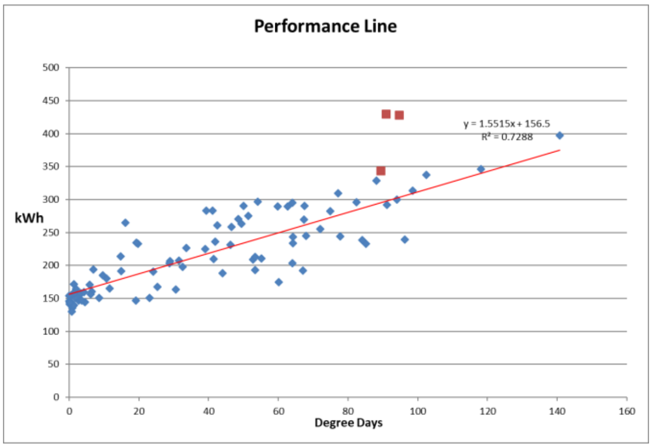
T-09 ->



<- T-10



T-12 ->



Appendix 3: Health and Innovation Programme 2015 – 2017

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

The programme comprised 3 funds

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

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

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

What it involved

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

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

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

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

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Action for Warm Homes