Heat Pumps for Park Homes, Basingstoke
YES Energy Solutions

Technical Evaluation Report

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September 2017

CP753
Heat Pumps for Park Homes, Basingstoke
YES Energy Solutions

Number of Households Assisted	30
Number of Households Monitored	12

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:

YES Energy Solutions – lead partner
Basingstoke and Deane Borough Council – park home site owner and contributed to the project financially to cover cost of EPCs and planning application costs
Payne's Heating & Plumbing – installer partner
Worcester Bosch – product manufacturer

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Executive summary

Project overview

This project was delivered by YES Energy Solutions in collaboration with Basingstoke and Dean Borough Council. It had the following aims:

- To establish running costs of air-to-air source heat pumps (ASHP) in a park home setting, ultimately reducing heating costs for residents of Attwood Close park home site;
- To examine customer satisfaction levels with ASHPs as a heating system;
- To provide a case study to be applied for future park home sites.

The scale of the issue

Around 200,000 residents in the UK live in park homes and a high proportion of these are elderly or have a health condition. Park homes typically have poor levels of energy efficiency and are frequently not connected to the mains gas grid[1] Attwood Close site is off the gas network and connections costing £4,000 per household including the Fuel Poverty Network Extension Scheme (FPNES) grant were cost prohibitive for the residents. The cost of park home insulation is also prohibitive and accessing funding for work under the Energy Company Obligation (ECO) has proved difficult. Residents are often reliant on more expensive heating fuels like oil, liquefied petroleum gas (LPG) or electricity. This combination leads to high costs for residents who are often vulnerable, on low incomes, and struggle to pay the bills. By cutting back on their heating, the residents risk low room temperatures which impact on health and well-being.

Air-to-air source heat pumps

Air-to-air source heat pumps operate on a similar basis to refrigerators and air conditioning units. They normally capture heat from outside the property and concentrate it for use inside by circulating a refrigerant fluid going through a cycle of evaporation and condensation in a closed loop system. A heat exchanger coil in the outdoor unit absorbs heat from the outside air (specific latent heat of evaporation) as the refrigerant evaporates at low pressure. The action of the heat pump compressor causes the pressure of the refrigerant fluid to increase and the specific latent heat of condensation is released as the refrigerant condenses. Warm air is emitted by the indoor unit as fans blow air past the heat exchanger coil heated by the condensing refrigerant.

In summer the air-to-air source heat pump can also act as an air conditioner if the cycle of evaporation and condensation is reversed. In this case the heat exchanger of the indoor unit is cooled due to evaporation of the refrigerant fluid. They generally operate at higher levels of efficiency to that of air-to-water source heat pumps and there are no requirements to install emitters like radiators or underfloor heating, reducing disruptive work and expense.

Air-to-air source heat pumps are not commonly used in the UK due to being currently ineligible for the Renewable Heat Incentive (RHI), resulting in limited data being available on their effectiveness.

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[1] Scoping ECO for Park Homes, NEA, March 2014 http://www.nea.org.uk/wp-content/uploads/2014/03/Scoping-Eco-for-Park-Homes.pdf

The project

This project involved installing 30 air-to-air source heat pumps at Attwood Close park home site in Basingstoke between April and August 2016. The system installed was a Worcester Bosch Greenstar 6kW air-to-air source heat pump with an outdoor unit and an indoor unit which emitted hot air. This replaced a variety of space heating methods, including electric convector heaters, and oil and LPG systems. Energy Performance Certificates (EPCs) were obtained for 32 of the 67 park homes across the site, with an average Standard Assessment Procedure (SAP) rating of 37, or EPC band F. 78% of the households were fuel poor according to the FPNES criteria[2].

8 out of 30 properties that received interventions were monitored for the full duration of the study, as well as several control properties. 82% of residents in the monitored group were over the age of 60 and three quarters had health conditions.

Summary of findings

An improvement in overall customer satisfaction and comfort;

- Following the installation of the ASHP, there was significant improvement in the satisfaction of residents with the cost of running their heating system.
- All thought their home got warmer faster with the ASHP.
- Three quarters felt their home was warmer and more comfortable, and that they had more control over the heating.

Lower electricity consumption in properties with ASHPs;

- The annual electricity consumption of 9 properties with ASHPs ranged from £375 to £1522, with an average of £616.
- In comparison the electricity consumption of properties with electric convector heaters ranged from £487 to £2400, with an average of £1096.
- A household that switched from space and water heating with LPG to space heating by the ASHP saw the electricity cost increase from £314 to £470. Although it was not possible to monitor LPG costs on this project, the temperature corrected cost of space and water heating by LPG was £634 for a control property on another project with a living room temperature of 16.6°C.
- The average saving from replacing electric convector heaters with an ASHP was 29%.
- When heated by electric convector heater, the consumption was between 1.6 and 8.1kWh per degree day, but this decreased to between 1.3 and 5.2kWh per degree day with the ASHP.

Other rooms, such as bedrooms, not always heated adequately

- After installation of the ASHPs, the average temperatures in the bedrooms ranged from 13.5°C to 19.5°C, with a number of the residents commenting "there is still no heating in the bedroom", and "the bedroom is chilly".
- The inclusion of vents on all internal doors in the property would help the warm air circulate.

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[2] Ofgem Fuel Poor Network Extension Scheme Factsheet November 2015 https://www.ofgem.gov.uk/sites/default/files/docs/2015/09/486_fuel_poor_networks_extension_scheme_factsheet_v3.pdf (Accessed 17 Mar 2017)

These vents were to be installed in all properties as part of this project but all residents declined this offer, stating that internal doors were generally left open. Residents who kept internal doors shut limited the potential circulation of heated air throughout the whole of their property.

- A comparison was made of room temperatures on cold days before and after installation of the ASHP and in homes where the ASHP replaced electric convector heaters, the living room and bedroom temperatures were typically warmer after the heat pump installation.
- For homes which previously had oil or LPG central heating, on a cold day, the living room was often warmer but the bedroom was frequently colder after the ASHP was installed.
- There was typically a smaller temperature difference between the living room and bedroom when properties had oil or LPG central heating compared to space heating by electric convectors or air to air source heat pumps.
- It was therefore more beneficial to install air to air source heat pumps in smaller park homes which use electric convectors for space heating rather than oil or LPG central heating.
- Maximum humidity levels in the bedroom reached over 86% for the majority of properties with ASHPs (vs. an optimum level of between 40 – 60%), which may be due to the minimum temperatures recorded in the bedrooms of these properties.

The air-to-air source heat pump could provide low cost heating and cooling

- Electricity consumption of 2 of the ASHPs was logged by an optical pulse logger on an electricity meter, revealing that on a cold day the output temperature from the unit can be about 30°C, consuming up to 1kW in an hour (costing about 16 pence), and on a milder day the output temperature is closer to 20°C and the unit may consume about 0.2kW per hour (costing about 3 pence).
- In summer, the unit can be used in reverse for air conditioning purposes, and on days where the external temperature exceeded 30°C, the ASHP lowered the average temperature of the living room by about 4°C at a cost of just over £1 during the day.

Conclusions and recommendations

Overall the project enabled many residents to successfully lower their heating costs and keep their living rooms warm; however, many of the residents found that other rooms like the bedroom were not adequately heated. Solutions to this might include:

- Additional indoor heat emitters in the bedroom
- Ducting and fans or vents on internal doors to improve warm air distribution
- Installing external wall insulation at the same time as the heat pump to reduce heat loss

Ensuring that residents are properly trained on the operation of the system gives them confidence in appropriately setting the thermostat and heating times for the ASHP and therefore improves thermal comfort. This is also vital as misuse of the product through lack of knowledge in the product's functionality could result in higher energy bills, and lower comfort levels as a result.

Potential impact on fuel poverty

This report shows that heating costs can be reduced by installing ASHPs in park homes. Resident satisfaction with the running costs was high, in marked contrast to their previous heating system.

To obtain maximum impact on lifting residents out of fuel poverty, it would be prudent to install heat emitters in the lounge and main bedroom and improve insulation as part of the retrofit. If ASHPs were to be included in the Domestic Renewable Heat Incentive (RHI), it may enable more residents to install a cheaper heating system in their park home.

1. Project overview

1.1 Introduction

This project was delivered by YES Energy Solutions, in collaboration with Basingstoke and Deane Borough Council. It involved installing 30 air-to-air source heat pumps at Attwood Close park home site near Basingstoke.

1.2 Aims

- To establish running costs of air source heat pumps (ASHP) in a park home setting, ultimately reducing heating costs for residents of Attwood Close
- To examine customer satisfaction levels with ASHPs as a heating system
- To provide a case study to be applied for future park home sites.

1.3 Context

Around 200,000 residents in the UK live in park homes and a high proportion of these are elderly or have a health condition. Park homes typically have poor levels of energy efficiency and are frequently not connected to the mains gas grid[3] Attwood Close is off the gas network and connections costing £4,000 per household including the Fuel Poor Network Extension Scheme (FPNES) grant were cost prohibitive. The cost of park home insulation is also often prohibitive and accessing funding for work under the Energy Company Obligation (ECO) has proved difficult. Residents are often reliant on more expensive heating fuels like oil, liquefied petroleum gas (LPG) or electricity. This combination leads to high costs for residents who are often vulnerable, on low incomes, and struggle to pay the bills. By cutting back on their heating, the residents risk low room temperatures which impact on health and well-being.

NEA wanted to examine the applicability and impact of air-to-air heat pumps installed in Park Homes. These are not currently eligible for domestic RHI support and so have been largely neglected in the UK, resulting in limited data being available on their effectiveness.

[3] Scoping ECO for Park Homes, NEA, March 2014 http://www.nea.org.uk/wp-content/uploads/2014/03/Scoping-Eco-for-Park-Homes.pdf

1.4 Project timeline

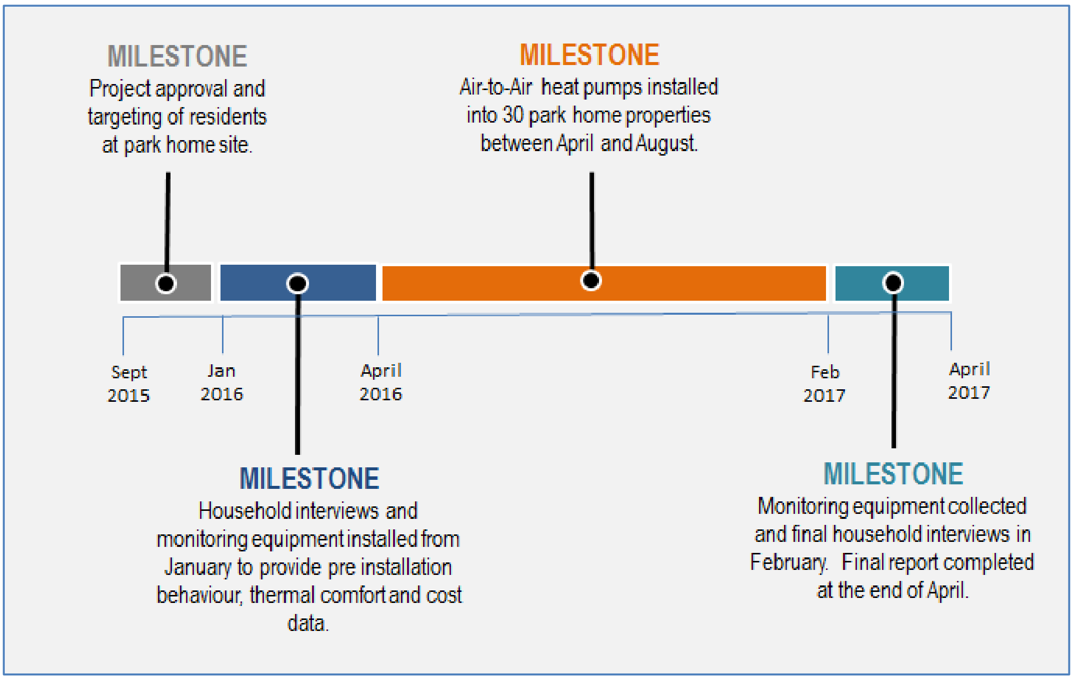

Figure 1.1 Project timeline

The project was approved in September 2015 and the main community engagement event recruiting residents took place on 14th December 2015. Installations took place between April and August 2016, with the majority of those in the study occurring in April and July. Most logging equipment was installed between January and July 2016 and initial questionnaires were completed by residents at this time. In the majority of cases, this logging equipment was collected in February 2017 and the final questionnaires were completed during these visits.

1.5 Attracting beneficiaries and establishing the monitored group

YES Energy Solutions have a strong working relationship with Basingstoke and Deane Borough Council, the owner of the park home site at Attwood Close.

A four-stage engagement process was used to find suitable properties for the installation of ASHPs at Attwood Close:

1. Initial mail-out – a letter written by YES Energy Solutions and signed off by the council was sent to Attwood Close residents, informed them of the ASHP opportunity and explained the funding and the monitoring requirement for the project. It also invited residents to a community engagement event.

2. Community engagement event – YES Energy Solutions gave a presentation about the project and the customer journey. Technical questions were answered by the installer partner, Payne's Heating & Plumbing, and the manufacturer, Worcester Bosch, who brought a display van showcasing the heat pump.

3. Identifying residents for monitoring - at the community engagement event, residents were

encouraged to take part in the monitoring for the project and shown what equipment would be installed. NEA later visited residents to install monitoring equipment, complete an initial questionnaire and collect historical meter readings and billing information.

4. Marketing stage 2 – this involved a second promotional mail-out, sending newsletter updates, and door-knocking by council and NEA staff. The aim of this activity was to increase the number of households signing up for the project and their understanding of what was being done. Once residents began to see installations taking place on their neighbours' homes, they were more willing to participate.

Payne's Heating & Plumbing arranged technical surveys and booked the installation dates for all residents who had signed up.

2. Technical evaluation methodology

2.1 Introduction

Figure 2.1 Park Homes at Attwood Close

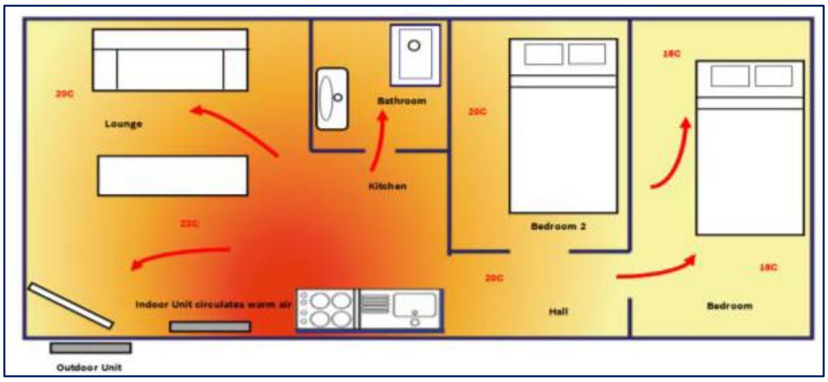

Figure 2.2 Floor plan for Park Home reference T-02 from Worcester Bosch heat pump specification

Tech Ref. No.	SAP Rating	Floor area	Previous Space Heating	Current Space Heating	Water Heating	Shape of Park Home
T-02	1	29	Electric convector	ASHP	LPG	Rectangle
T-03	33	31	Electric convector + LPG	ASHP	LPG	Long Rectangle
T-04	58	35	Oil	ASHP	Electric Instaneous	Rectangle
T-05	27	37	LPG boiler	ASHP	LPG	Short Rectangle
T-11	39	35	LPG boiler	ASHP	LPG	Long Rectangle
T-17	24	51	Electric convector	ASHP	Electric Immersion	L - shaped
T-19	28	32	Electric convector	ASHP	Electric immersion	T-shaped
T-23	27	46	Electric convector	ASHP	Oil	Rectangle with extension
T-49	35	38	Electric convector	ASHP	Oil	Short Rectangle
C-08	51	65	Oil	Oil	Oil	Rectangle with 2 extensions
C-20	40	45	LPG	LPG	LPG	
C-22	No EPC	No EPC	LPG	LPG	LPG	
C-25	24	42	Electric convector	Electric convector	Electric Immersion	

Table 2.3 Details of the Park Homes in the study and their reference numbers

There were initially 11 households that received ASHPs who agreed to be part of the monitored group. Out of these, 8 completed the full study while a further property, T-23 withdrew in December 2016. Table 2.3 shows details of the monitored (9) and control (4) properties. To protect the privacy of the residents, data in the study has been anonymised, each being allocated an identification number.

The energy efficiency ratings (SAP) of these park homes typically ranged from about 25 to 50. Figure 2.1 shows two of the park homes at Attwood Close, while Figure 2.2 shows the floor plan for Property T-02, which was a typical rectangular park home. Some of the park homes were longer, while others had extensions, making them L or T-shaped. The control group properties had a mixture of heating fuels including oil, LPG and electric convector heaters.

The heating systems installed in the park homes were Worcester Bosch Greenstar 6kW Air-to-Air Source Heat Pumps, with an outdoor and indoor unit (Figures 2.4 and 2.6). Installers fitted the indoor unit in an optimal position to provide good air flow across the park home.

The air-to-air source heat pump operates on a similar basis to refrigerators and air conditioning units. It normally captures heat from outside the property and concentrates it for use inside by circulating a refrigerant fluid going through a cycle of evaporation and condensation in a closed loop system. A heat exchanger coil in the outdoor unit absorbs heat from the outside air (specific latent heat of evaporation) as the refrigerant evaporates at low pressure. The action of the heat pump compressor causes the pressure of the refrigerant fluid to increase and the specific latent heat of condensation is released as the refrigerant condenses. Warm air is emitted by the indoor unit (Figure 2.6) as fans blow air past the heat exchanger coil heated by the condensing refrigerant.

In summer the air-to-air source heat pump can also act as an air conditioner if the cycle of evaporation and condensation is reversed. In this case the heat exchanger of the indoor unit is cooled due to evaporation of the refrigerant fluid.

The Worcester Bosch units were designed to heat spaces up to 80m^2. The average size of the park homes monitored at Attwood Close was 40m^2, while the maximum size was 65m^2. The ASHPs have a high efficiency, with a Seasonal Coefficient of Performance (SCoP) of 3.8. Each kW of energy the heat pump consumes could produce up to 5 times more heat in return[4].

Note that although the ASHP was used for space heating (and cooling), it was not used for water heating. The households either used an electric immersion heater or a gas or oil boiler for their water heating.

[4] Renewables Consumer Brochure, Worcester Bosch https://www.worcester-bosch.co.uk/products/heat-pumps/directory/greensource-air-to-air-heat-pump (Accessed 14th August 2017)

Figure 2.4 Outdoor unit of the ASHP

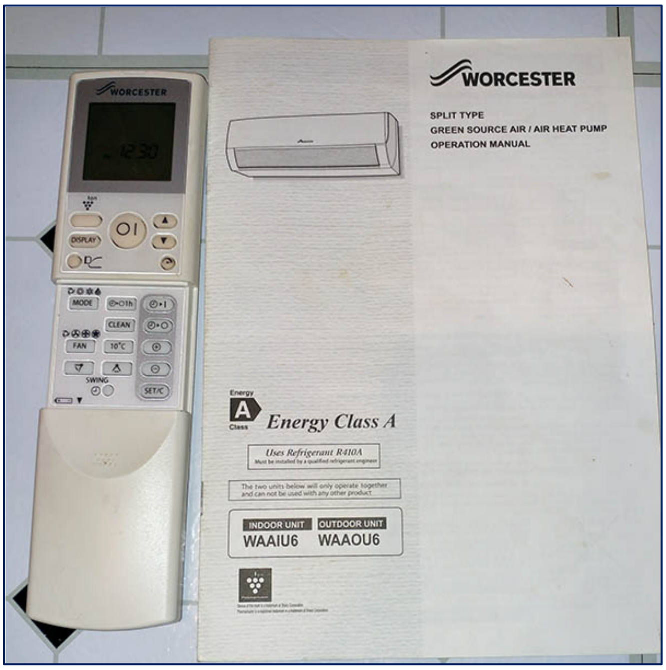

Figure 2.5 Controller & manual for ASHP

Figure 2.6 Indoor unit of ASHP with watt hour meter and Optipulse sensor

2.2 Social impact

Householder demographic details

Residents in the monitored group were interviewed before the ASHPs were installed and at the end of the monitoring period. This covered topics including the demographics of the household, the type, operation of and satisfaction with their heating system.

The age range of the householders in the monitored group is shown in the chart below. The largest proportion, 64%, were people in the age range 60-69, followed by an equal split between the working age of 16-59 and those aged 70 years or more. These results suggest that the majority of park home owners are likely to be close to, or of, retirement age. For the control properties, half of the households had a resident aged 70 years or more. Previous reports have also noted a high proportion of elderly residents in park homes[5].

These results align with occupation and employment status of the study group with 50% of the residents in retirement. There was only a small percentage (13%) within this study that worked full time. The remainder of the study group were either unemployed or not working due to a disability or ill health. This differed slightly within our control group with the largest proportion of residents, 75%, working part time and only 25% in retirement.

Figure 2.7 shows that 75% of households said there was someone living in the property with a health condition, disability, mobility issue or limiting long-term illness. 63% of those with a health condition who responded to a further question felt the condition was worsened by the cold.

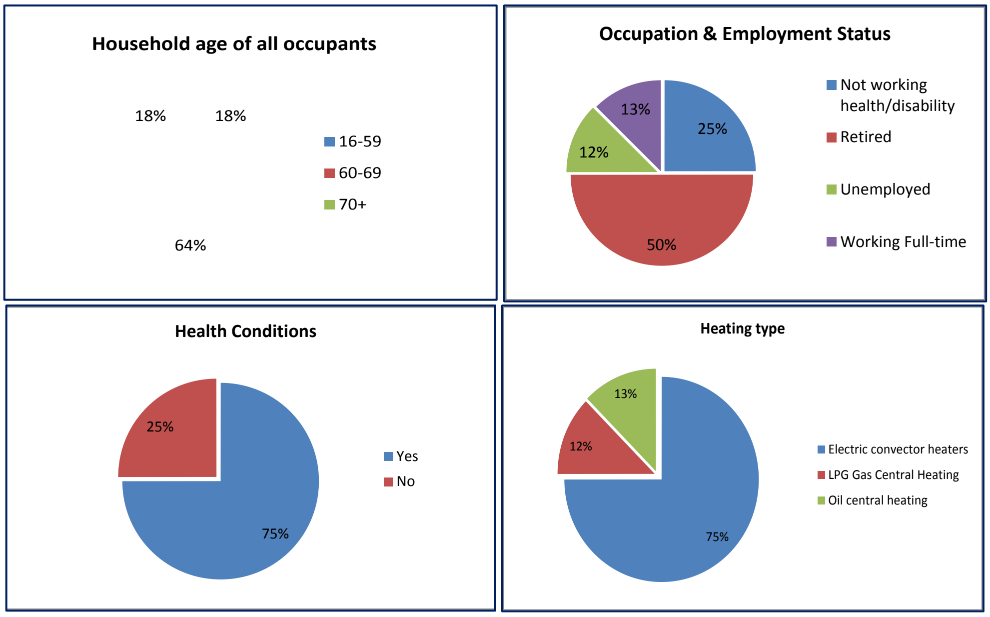

Figure 2.7 (a) Household age (b) Occupation (c) Health conditions (d) Heating type

Qualitative feedback given pre-installation of the ASHP

At the start of the project, the main home heating system for 75% of the properties interviewed was electric convector heaters, with the remainder being spilt between LPG central heating and oil central heating (Figure 2.7d).

Residents were asked if there was a specific time of the day when they felt it was most important to have a warm home. This might be when they are least active e.g. sitting watching TV in the evening or when washing/dressing first thing in the morning. Figure 2.8 shows the results summed up across all respondents. This shows a morning peak in heating demand between 6am-10am, dropping off in the afternoon and returning with a strong peak between 6pm-8pm. The majority of the residents in this study were retired or not working. It was therefore not unusual to see heating

[5] External wall insulation for Park Homes, NEA, 2011, http://www.nea.org.uk/wp-content/uploads/2015/08/Insulting-es-2-and-3-April-2011.pdf

patterns continuing through much of the day as some reported that it was important for their home to be warm all the time they were awake, as they were at home all day.

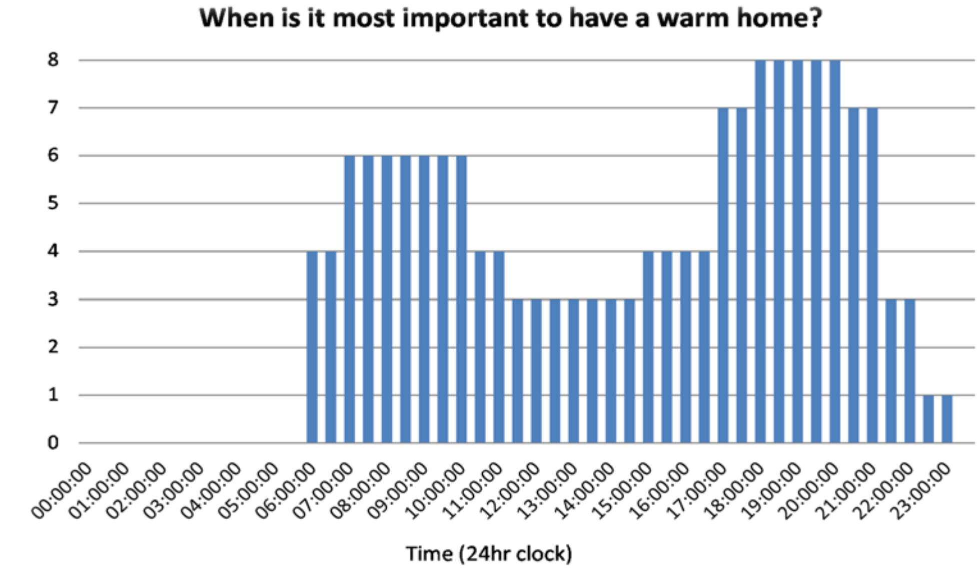

Figure 2.8 Times when it was important for the residents to have a warm home

Many residents (62.5%) reported that they wore warm clothing indoors, either to help save money or due to poor system performance, where it was unable to provide sufficient heat when needed (Figure 2.9).

Qualitative feedback given post-installation of the ASHPs

62.5% felt the ASHP heated the whole house or noted that they previously needed heaters in all rooms. However, 25% of the study said they used electric plug-in heaters alongside their heat pump to heat additional rooms where they felt the temperature was too cold (Figure 2.9a). The bedroom was considered to be “chilly” by 37.5% of the residents with the ASHP.

Electricity costs before and after the installation of the ASHP are shown in Figure 3.5 (in the monitoring section). There was a significant reduction in electricity costs when households switched from space heating only by electric convectors to use of the ASHPs. Following the installation of the ASHP none of the residents stated they needed to wear extra clothing to keep warm in winter (Figure 2.9b).

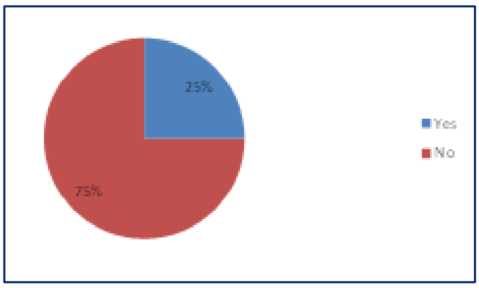

Figure 2.9a Supplementary heating with heat pump

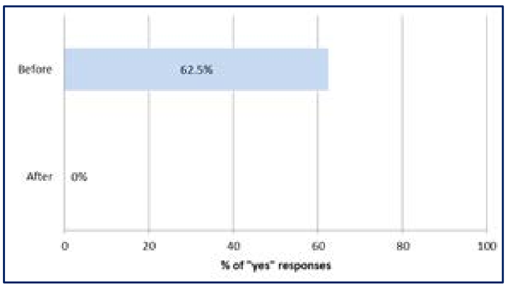

Figure 2.9b Wear extra clothing to keep warm

Resident acceptance & satisfaction

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

There was a marked improvement in residents' satisfaction in the cost, the ease-of-use and how warm their homes get following the installation of the ASHP. Over 90% of resident responses rated their satisfaction as either 'satisfied' or 'very satisfied' for each question. Satisfaction levels for the residents with ASHPs were higher on each question than for those in the control group (Figure 2.10). The biggest difference noted was in 'cost of running your heating system' with all residents with the ASHP currently 'satisfied' or 'very satisfied' with their heating costs while all control group properties were currently 'dissatisfied' with their heating costs.

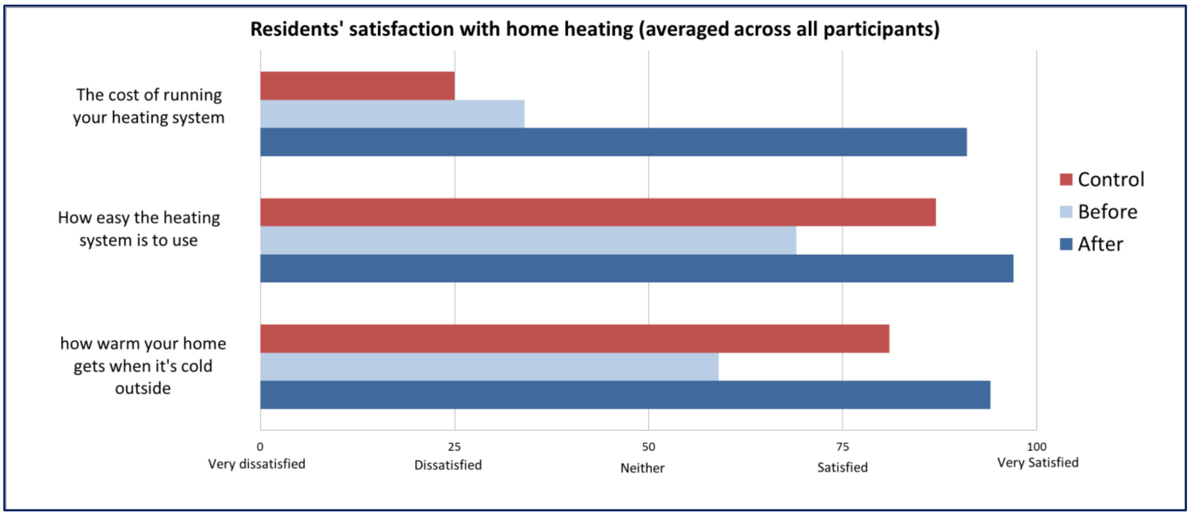

Figure 2.10 Residents' satisfaction with their heating system

Perceived cost

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

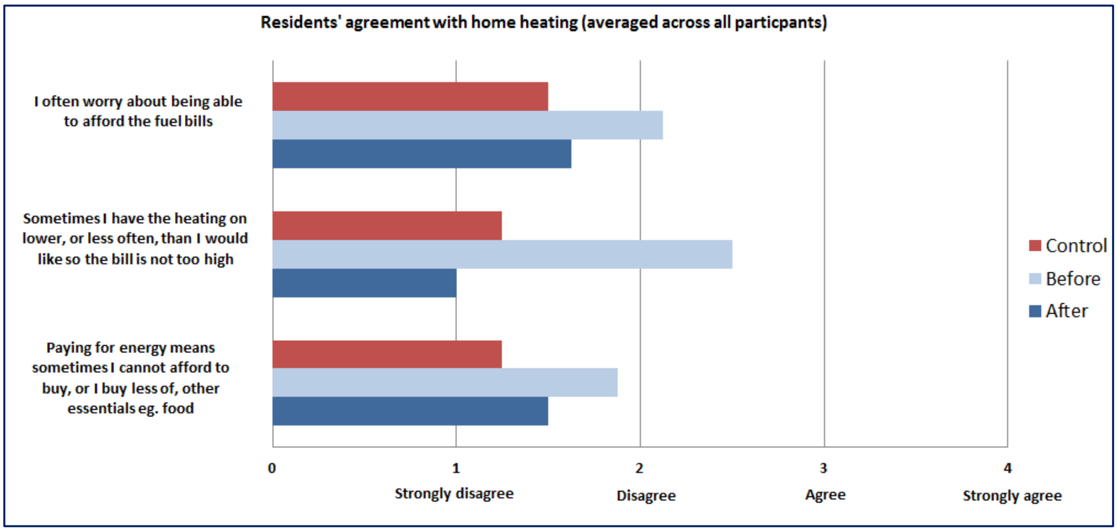

Figure 2.11 Agreement with statements about affordability of fuel bills

Residents were less concerned about being able to pay the fuel bills, keep warm and pay for essentials following the installation of their air-to-air heat pump (Figure 2.11). Some residents had their heating on less or lower prior to the installation of the ASHP. Following installation, there was a significant change where all the residents strongly disagreed that they had to have the heating on less. This correlates with the results in Figure 2.10 which showed a marked improvement in satisfaction with cost of running the heating system. The resident in property T-17 which was L-shaped and had the largest floor area commented that he was very happy to have a heating system which had lower running costs.

Whilst Figure 2.11 indicates that pre-installation of the ASHP, residents were not particularly worried about being able to afford their bills; this may be due to an acceptance of the level of bills over a period of time.

It should be noted that residents in the control group were less concerned about their fuel bills than the monitored group pre-ASHP installation and in some cases afterwards. This lower concern over ability to pay their energy bills may have made residents in the control group less inclined to accept the offer of a free ASHP installation with the potential to reduce energy bills.

Perceived comfort and benefits

Residents were also asked about a range of potential benefits following installation of the ASHP. The responses in the form of percentages of the residents are shown in Figure 2.12. All the residents felt the house warmed faster, while 87.5% felt the new heating system was easier to use/control. Three-quarters of the monitored group noticed the ‘home is warmer & more comfortable’ and felt there was an ‘improvement in the quality of the home’. Half of the study group also noted experiencing a reduction in their energy bills, alongside saving energy in their home as a direct result.

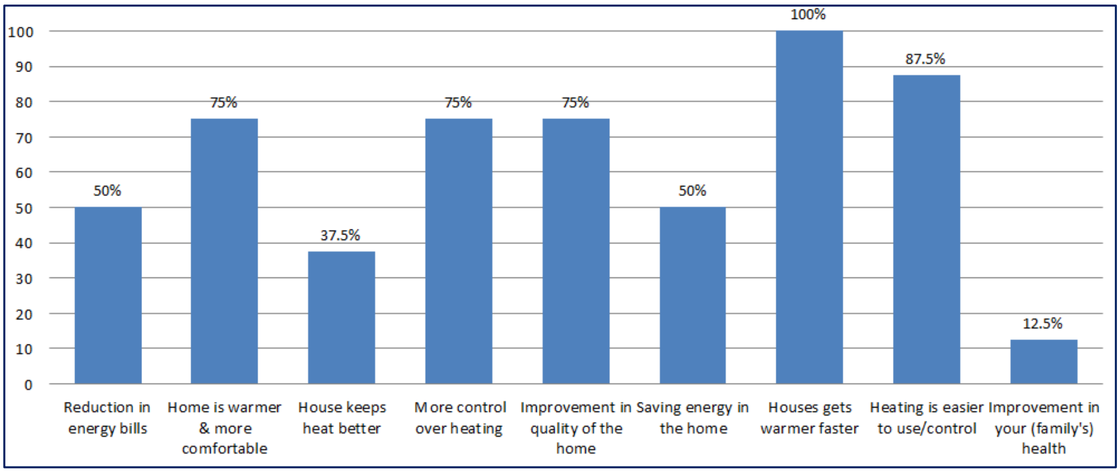

Figure 2.12 Benefits experienced by residents after installation of their air-to-air heat pump

3. Technical evaluation

3.1 Technical monitoring methodology

In order to assess the performance of the ASHPs, monitoring equipment was placed in the park homes with ASHPs and similarly within the control group properties. The following monitoring equipment was used on the project:

Temperature and humidity data loggers

Temperature and humidity in the monitored properties was recorded every hour using Lascar EL-USB-2 temperature and humidity loggers[6]. Two loggers were installed in each of the park homes, with one placed in the living room and one in the bedroom.

Electricity consumption meters

Standard electricity consumption or watt hour meters were fitted on one of the wires to the heat pump to record the total electricity consumption in kWh. These were fitted on five of the heat pumps (see the white electricity meter to the bottom right of the indoor unit in Figure 2.6).

Optipulse sensors

The watt hour meter has an LED which flashes due to electricity consumption. An Optipulse sensor was fitted over the LED of each of the watt hour meters to capture the kWh consumption by time (see dark box to the right of Figure 2.6).

Current clamp and Tiny Tag logger

These loggers were used to regularly record the electricity consumption (kWh) by placing the current clamp around the electricity meter tails (Figure 3.1).

Thermocouple temperature loggers

These were placed in the air discharge of the outdoor unit of the air-to-air source heat pump for two of the monitored properties. These logged data between the middle of January and the beginning of February (Figure 3.2).

External waterproof temperature sensor

A temperature sensor was installed in accordance with good practice for external ambient temperature monitoring on one of the fences on the park home site to record the external temperature.

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

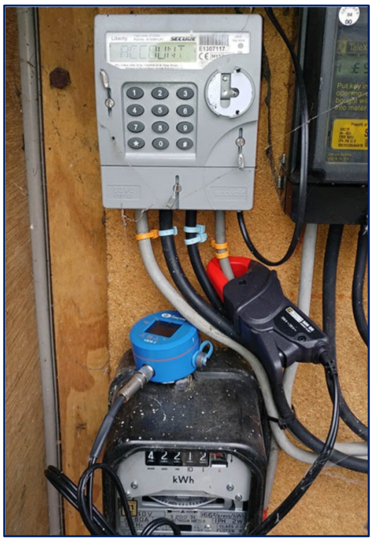

Figure 3.1 Current clamp & Tiny Tag

Figure 3.2 Outdoor unit with temperature logger

Property Type	Monitoring Equipment	Number of properties
Monitored	USB Thermal data loggers – 2 for each monitored ASHP property	9
Monitored	Current clamps to measure total electricity consumption	7
Monitored	Electricity Meters with Pulse sensors to measure ASHP consumption	5
Monitored	Thermocouple temperature loggers on heat pumps	2
Control	USB Thermal data loggers – two for each control property	4
Control	Current clamps to measure total electricity consumption	3
Control	External temperature logger on garden fence (in shade)	1

Table 3.3 Summary of monitoring equipment used for the study

Table 3.3 summarises the monitoring equipment used in the study, and the schematic diagram in Figure 3.4 illustrates the monitoring used in the study.

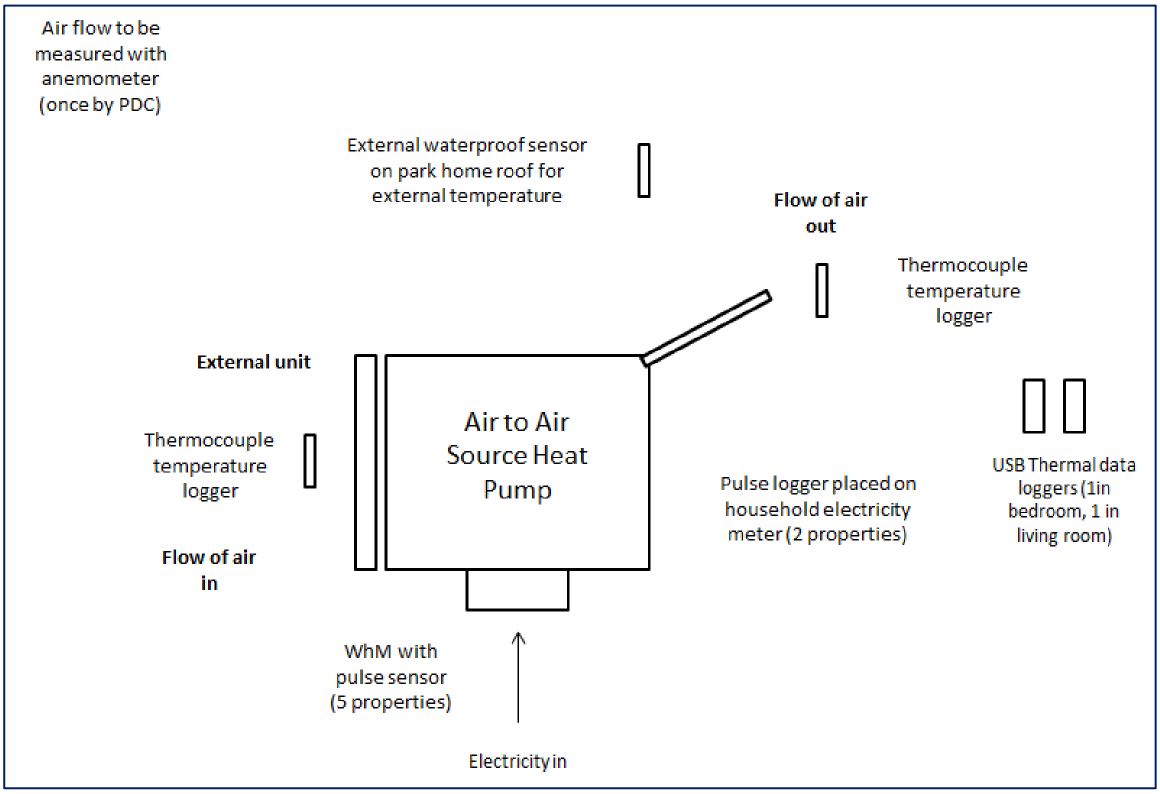

Figure 3.4 Schematic diagram showing monitoring regime for installations

3.2 Factors affecting the evaluation methodology

Issue	Description and mitigation
Size of monitoring group	The monitoring group was reduced from 11 to 8 residents due to 3 dropping out of the study for personal reasons. These were due to no longer wanting the heating system, ill health and selling their property. 8 properties completed the full study, with a further property completing the study up to December 2016.
Identification of the monitored group and control group	It was not possible to identify the monitored group until early 2016 (following the engagement event on 14th December 2015), due to the need for engagement and technical surveys of properties to determine suitability for the technology. As a result, the installation of data loggers was later than originally planned, thus limiting the amount of "pre-install" data available. This was mitigated by the adoption of a control group of properties with similar characteristics but which did not receive ASHPs.
Start of monitoring	Installations were phased between April and September due to delays caused by planning applications and recruitment of residents for installations. This resulted in some of the monitoring starting later than planned and there being a range of monitoring periods for the properties.

Control group	Recruitment of residents for the control group proved a challenge. Residents joining the control group had turned down the opportunity of a free new heating system. They wanted minimal disruption from the monitoring and so it was not possible to install LPG gas and oil consumption meters. This meant any assessment of their fuel costs was reliant on resident receipts and their own knowledge about the cost of their heating. This left one control with electric convector heaters.
Requirement for planning permission	Caused delays and extra cost.
System performance	The resident with the largest property in the study requested the removal of the air-to-air heat pump due to unhappiness with its heat output and positioning within the property.
Meter readings	Many of the residents in the study were retired or had health conditions and it was not always convenient for them to take meter readings. It was possible to get current and historic meter reading data from the energy companies, but in some cases there were only two actual meter readings per year.
Failure of equipment	Two Optipulse loggers proved to be faulty and therefore failed during the study for unknown reasons outside of NEA's control. This reduced the data on the consumption of the heat pumps down to two properties.

3.3 Monitoring results

Cost

Analysis using electricity meter readings and energy bills

	"Before" period							"After" period with ASHPs							
Tech Ref	Period	Days	Total Period (kWh)	Electricity £ / 30 days	Degree days	kWh per Degree Day	Estimated Annual Electricity Cost[1]	Period	Days	Total Period (kWh)	Electricity £ / 30 days	Degree days	kWh per Degree Day	Estimated Annual Electricity Cost[1]	Saving
T-02	02/10/15 - 02/02/16	123	1805	£70.44	749.4	2.41	£715.18	14/09/16 - 03/02/17	142	1596	£53.95	1129.3	1.41	£419.64	41.3%
T-03	30/09/15 - 02/02/16	125	1241	£47.65	756.4	1.64	£487.16	14/09/16 - 03/02/17	142	1427	£48.24	1129.3	1.26	£375.20	23.0%
T-11		-	-	-	-	-	-	20/09/16 - 14/02/17	147	2228	£72.75	1254.8	1.78	£527.22	-
T-17	27/08/15 - 20/01/16	146	6083	£199.99	752.7	8.08	£2,399.65	22/09/16 - 03/02/17	134	5796	£207.62	1122	5.17	£1,533.86	36.1%
T-19	30/11/15 - 24/05/16	176	4086	£111.44	1356.9	3.01	£894.13	18/09/16 - 23/02/17	158	2446	£74.31	1318.8	1.85	£550.72	38.4%
T-23	07/10/15 - 22/02/16	138	2874	£99.97	930.5	3.09	£917.11	19/09/16 - 20/12/16	92	1650	£86.09	620.8	2.66	£789.19	13.9%
T-49	30/09/15 - 28/02/16	151	1729	£54.96	1025.1	1.69	£500.82	14/09/16 - 03/02/17	142	1454	£49.15	1129.3	1.29	£382.30	23.7%
T-04	23/10/15 - 02/02/16	102	1003	£47.20	651.9	1.54	£456.85	06/10/16 - 13/02/17	130	2030	£74.95	1204.7	1.69	£500.34	-9.5%
T-05[2]	20/08/15 - 02/02/16	166	907	£26.23	858.9	1.06	£313.56	16/09/16 - 13/02/17	150	1977	£63.26	1249.8	1.58	£469.70	-49.8%
C-08[2]	15/09/16 - 14/02/17	152	1299	£41.02	1260.5	1.03	£306.00								
C-20[2]	29/07/16 - 13/02/17	199	1183	£28.53	1278.2	0.93	£274.81								
C-22[2]	08/07/16 - 24/02/17	231	1007	£20.92	1367.7	0.74	£218.62								
C-25	31/08/16 - 13/02/17	166	4876	£140.99	1258.7	3.87	£1,150.25								
Average	Elec convector					3.69	£1,096.19								
Average	LPG & Oil						£278.25								
Average	ASHP												2.08	£616.46	29.4%
														Standard Deviation	11%

[1] - Using the Twenty-year average annual degree-day value for the South of England = 1856 degree days per year; Electricity cost = 16p/kWh

This does not include potential electricity consumption from the ASHP when used as an air conditioner

[2] - Note the electricity costs here are for powering appliances.

Analysis of oil bills from C-08 suggests a temperature corrected annual heating oil bill of about £696 using a cost of 40p / litre

Table 3.5 Analysis of electricity costs before and after the ASHPs were fitted using bill and meter readings

Electricity meter readings were recorded by households during the study. Consumption data was also obtained from bills prior to the monitoring period. These meter readings allowed the electricity consumption of households to be compared before and after the installation of the ASHPs (Table 3.5). The 'before' period was during the winter heating period of 2015/16 while the 'after' period was during 2016/17. Wherever possible a similar period was chosen before and after for each property. There was also an assessment of the electricity consumption of 4 control households: 1 with oil heating (C-08), 2 with LPG boilers (C-20 and C-22) and 1 using electric convector heaters (C-25). This consumption data was from the winter of 2016/17. Properties with space heating provided by oil or gas had lower electricity bills, but additional oil or LPG bills.

In order to properly analyse energy use for space heating, account must be taken of the weather. For example, it is poor practice to compare the heating costs for two periods without compensating for different outdoor temperatures. An external temperature of 15.5°C is accepted by energy professionals as the outside temperature below which heating will be required, and above which no heating is necessary. The heating requirement for a building is proportional to the number of heating degree days (DD) i.e. the number of degrees below 15.5°C that the average temperature is on each day during the period. When the average outside temperature drops to 14.5°C, this is classed as 1 degree-day, for example. Degree days are added together for the required period to give the total number of degree days for the period. Different periods can then be compared for their energy consumption and the results used to predict energy consumption on a normalised basis taking into account the outside temperature for those different periods[7]. Degree day data was obtained from weather station EGVO - Odiham, as this was close to the area in which the properties were located, and had good quality data for many years. 20-year average degree day values were available only on a regional basis, so the south of England region was used, into which Basingstoke falls[8].

In Table 3.5, meter readings and bill data were used to obtain the electricity consumption in kWh for the 'before' and 'after' periods. These were converted to a cost per 30 days using a standardised cost of 16p/kWh for electricity. The figure of kWh per degree day was calculated by dividing the electricity consumption by the number of degree days for the same period. The estimated annual electricity cost for the sites was obtained by multiplying the unit electricity cost by the number of kWh per degree day for the property and the twenty year average annual number of degree days in the South of England.

The electricity consumption was strongly affected by whether there was electric space or water heating. The types of space and water heating used in the park home properties are shown in Figure 2.3. For properties C-08, C-20, C-22 and T-05 in the 'before' period, the electricity costs were particularly low (£219 to £314). This was because neither the space nor the water heating was electric and the electricity costs shown were due to powering only appliances and lighting. Heating oil bills from C-08 indicated a temperature corrected annual heating oil bill of about £696 using a standard cost of 40p/litre.

It was not possible to assess the LPG consumption of households on this project. However, the LPG space and water heating cost was calculated for a control property on another project with

[7] https://www.carbontrust.com/resources/guides/energy-efficiency/degree-days/ [Accessed 20/03/2017]
[8] http://www.vesma.com/ [Accessed 05/05/2017]

park homes[9]. The temperature corrected annual LPG heating cost was £732 assuming a cost of 7.5p/kWh for LPG. Correcting the cost for the 20 year average of degree days in the South of England gives an annual cost of £634. It should be noted that this was for a 45m^2 park home with an average living room temperature of 16.6°C between 1st October 2016 and 31st March 2017.

The park homes using electric convector heaters to provide space heating had the highest electricity bills and were in the range £487 to £2400. Of these, properties such as T-02, T-03 and T-49, which had oil or LPG water heating, typically had the lower electricity bills. Property T-04, which originally had an oil-fired boiler, had a higher electricity bill (£457) than other park homes with oil or LPG space heating due to having an electric water heater.

T-17 had the highest electricity bill among those in the study. During the 'before' period, this was about £2400 and about double the cost of the second most expensive electricity bill. Factors contributing to this were space heating by electric convectors, water heating by an electric immersion using the standard rate tariff, the park home having a larger floor area and lower SAP rating than others and the resident requiring a higher level of thermal comfort.

Following the installation of the ASHPs, the annual electricity cost for these park homes ranged from £382 to £1534. The park homes with ASHPs and electric water heating such as T-04, T-17 and T-19 typically had the higher electricity bills.

Although T-17 continued to have the highest electricity bill following the installation of the ASHP, the bill reduced by £866 or over 35%. The continued use of supplementary heating by properties T-17 and T-23 are likely to be significant contributors to them having the highest electricity bills of the properties with the ASHPs. The park homes which were not simple rectangles appeared to require greater use of the ASHP or supplementary heating.

The park homes which previously used electric convector heaters for space heating saw reductions in their electricity costs from 13.9% to 41.3%. Properties T-04 and T-05 saw an increase in their electricity bills of 9.5 and 49.8% respectively following the installation of the ASHP. This increase was due to switching from space heating fuelled by oil or LPG. The previous space heating costs for T-04 and T-05 were not available. However the control property C-08 with space and water heating provided by oil had an annual oil bill of about £696. When combined with the electricity bill for that property, this gave a total annual energy bill of £1002. The annual electricity bill for T-04, with the ASHP and electric water heating was £500, although the floor area to be heated was lower than for C-08.

The mean annual electricity cost of the properties with electric convector heaters was £1096. This was skewed however by the high value for T-17. A more typical value for the annual electricity cost is the median which in this case was £906. The mean annual electricity cost following the installation of the ASHP in the park homes was £616.46, with the median annual cost £500. This was calculated using the annual costs for each of the properties with ASHPs. The average saving of 29.4% on switching to an ASHP was calculated using only the costs of the properties which previously had electric convector heaters. The mean annual electricity cost of the properties with

[9] Elizabeth Lamming, Jamie Barnes, Paul Rogers & Michael Hamer, 'External wall insulation on Park Homes in North Lincolnshire', NEA, 2017, (in press)

space and water heating provided by oil or LPG was £278. This provides an indication of typical electricity costs for appliances and lighting in the park homes.

Analysis of the electricity consumption by the ASHP

Tech Ref	Period	Household Electricity Consumption (kWh)	kWh per DD	Estimated annual electricity cost[1]	ASHP Electricity Consumption (kWh)	kWh per DD	Percentage of electricity used by ASHP	Estimated annual electricity cost of ASHP from heating[1]
T-02	14/09/16 - 03/02/17	1596	1.41	£419.64	824	0.73	51.6%	£216.71
T-05	16/09/16 - 03/02/17	1755	1.56	£461.85	1025	0.91	58.4%	£269.74

[1] - Unit rate = 16p/kWh. Note this does not include potential costs from using the ASHP as an air conditioner

Table 3.6 Household and ASHP electricity consumption between mid-September 2016 and early February 2017

Properties T-02 and T-05 had electricity meters installed which recorded the electricity consumption of the ASHP. An Optipulse data logger was also fitted with a sensor attached to the electricity meter which detected LED pulses from the meter (Table 2.6). The Optipulse logger was able to record the electricity consumption by the ASHP every 5 minutes. It was not possible to fit all the ASHP installations with Optipulse loggers for budgetary and aesthetic reasons.

For the period between mid-September 2016 and 3rd Feb 2017, readings from the household electricity meter were used to obtain the household electricity consumption. The number of kWh per degree day and the temperature corrected annual electricity cost were obtained as for Table 3.5. Data from the Optipulse logger was analysed to provide the electricity consumption of the ASHP over the same mid-September to early February period as the household electricity meter readings.

Between 14th September 2016 and 3rd February 2017, the heat pump for property T-02 consumed 824kWh. When compared to the electricity consumption of the whole property, the ASHP consumed 51.6% of the total. The temperature corrected annual electricity cost for space heating from the ASHP for the property was £217.

Over a similar period the ASHP for household T-05 used 1025kWh which was 58.4% of the total household consumption. The annual space heating cost of the ASHP was £270 using a standard unit rate of 16p/kWh. This does not include any cooling costs from the ASHP being used as an air conditioner.

Both properties T-02 and T-05 used LPG for water heating. A park home which had electric water heating would have a lower percentage of the total electricity consumption coming from the air-to-air source heat pump.

Graphs of kWh against number of degree days

Where there were sufficient meter readings during the winter heating period, it was possible to plot a graph of electricity consumption against number of degree days. Adding the performance line to the graph using a line of best fit allows a judgement to be made on how well the heating has been controlled in respect to outside temperatures. Data points appearing on the performance line indicate that there has been good control of the heating system which has enabled a consistent temperature to be achieved. Scattered data points indicate less control and more variation in the internal temperature. Data points above the line indicate overheating and below, under heating.

Figures 3.7a and 3.7b shows that the consumption per degree day decreased for property T-19 after replacing the electric convector heaters with the ASHP. With both graphs there was a strong correlation between electricity consumption and number of degree days, indicating that the resident in property T-19 was able to maintain good temperature control with both the electric heater and heat pump.

Figures 3.7c and 3.7d show similar plots for property T-49. Here the electricity consumption per degree day also fell when the electric convector heaters are replaced by the heat pump. In the case of these graphs there is a poorer correlation between the electricity consumption and number of degree days which shows that the resident struggled to maintain a uniform temperature in the property as the outside temperature fell. This was particularly true with the electric convector heaters, but was also an issue with the heat pump.

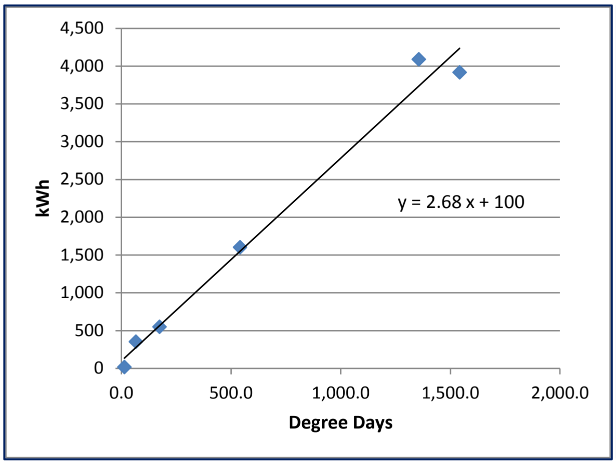

Figure 3.7a Property T-19 with electric heaters

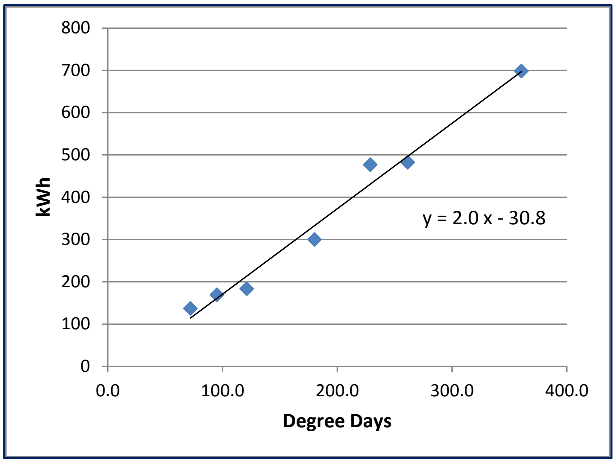

Figure 3.7b Property T-19 heated by ASHP

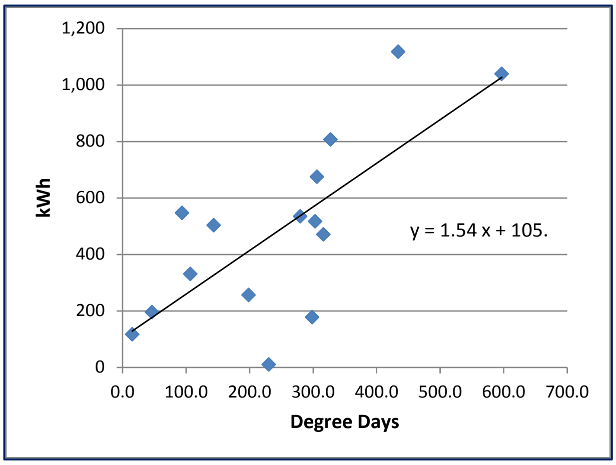

Figure 3.7c Property T-49 with electric heaters

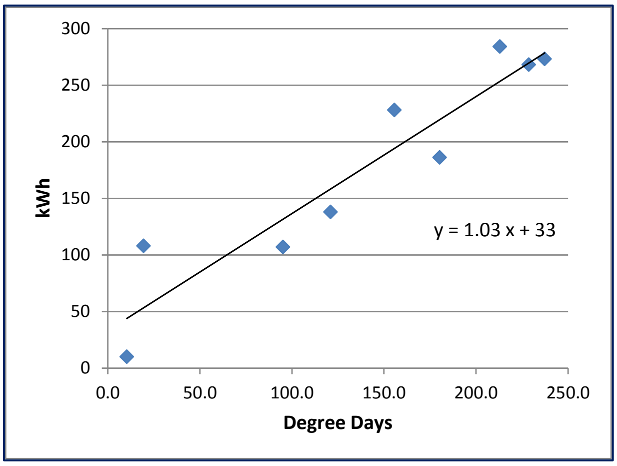

Figure 3.7d Property T-49 heated by ASHP

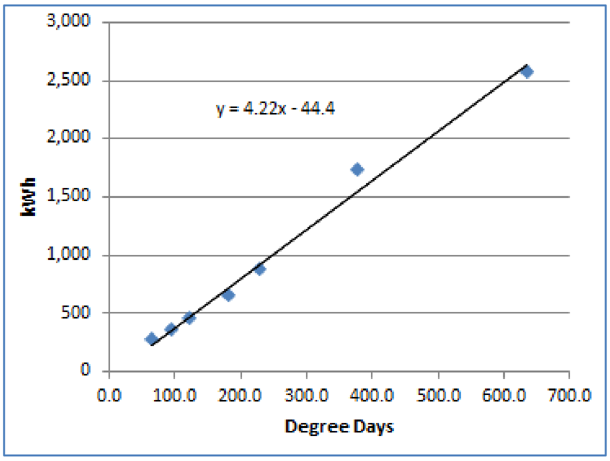

Figure 3.7e Property C-25 with electric heaters

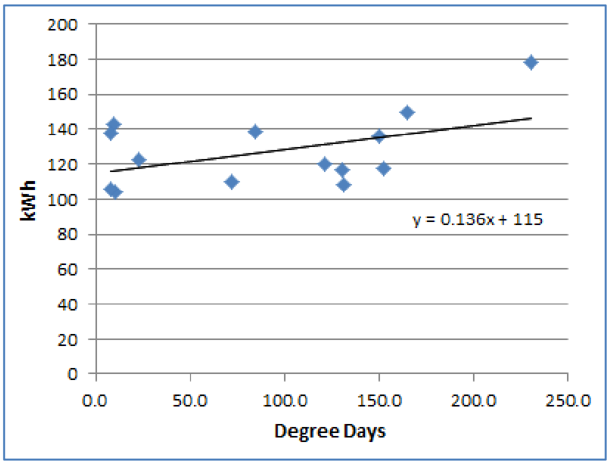

Figure 3.7f Property C-08 with oil heating

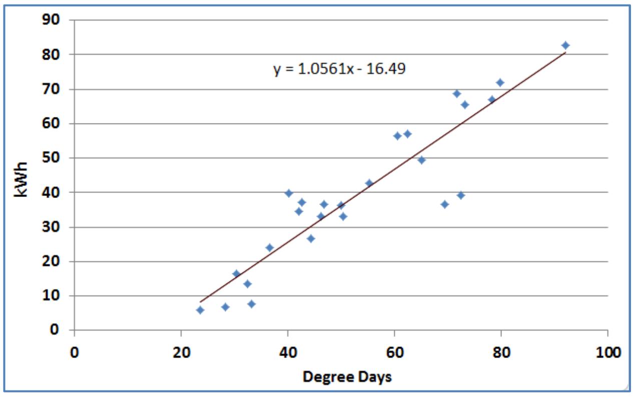

Figure 3.8a ASHP consumption for property T-02

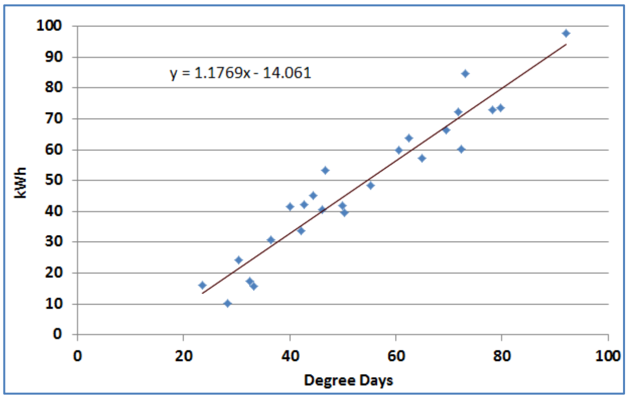

Figure 3.8b ASHP consumption for property T-05

Figure 3.7e shows a graph of electricity consumption against number of degree days for control property C-25, with space heating by electric convectors. There was good temperature control, but the greater gradient than for the properties with the ASHPs indicates the greater electricity consumption. A similar graph is shown in Figure 3.7f for control property C-08. Since the space and water heating was provided by an oil central heating system for this property, the electricity consumption showed little temperature dependence as show by the low gradient of the performance line.

The graphs in Figure 3.7 used household electricity meter readings and therefore included electricity consumption from all appliances in the home. Figure 3.8 shows 2 graphs using Optipulse data from the electricity meter fitted to the ASHPs in properties T-02 and T-05. These graphs show only consumption by the ASHP between 1st October 2016 and 3rd February 2017 with data points every 5 days. There is greater scatter of the data points on the graph for T-02, indicating there was more variation in room temperature. 2 data points were significantly below the performance line, indicating periods of under heating. The consumption of the ASHP increased more for household T-05 as the weather became colder, as shown by the higher gradient of the performance line. The negative intercept of the performance line on the graphs for T-02 and T-05 suggests that both properties may have been under heated.

3.4 Temperature and thermal comfort

Temperature and humidity loggers were placed in each of the monitored and control homes during the study. There was a logger installed in the living room while a second was placed in the main bedroom. To represent the temperatures logged in properties over the monitoring period, the mean temperature was calculated for 24-hour periods and the evening heating period between 5pm and 9pm when the residents wanted to keep warm.

Other important values recorded were the maximum and minimum temperatures and the standard deviation, which shows the spread either side of the mean temperature. As an example, if the mean temperature of a household is 21.3°C and the standard deviation is 1.9, then for 68.2% of the time (34.1% either side of the mean), the temperature is within one standard deviation (in this case between 19.4°C and 23.2°C).

Such analysis can confirm following installation of a new heating system if the household achieved the recommended temperatures for health of 21°C in living rooms (where most of the thermal data loggers were placed) or 18°C in bedrooms, and/or whether there was an improvement in thermal comfort over their previous heating system.

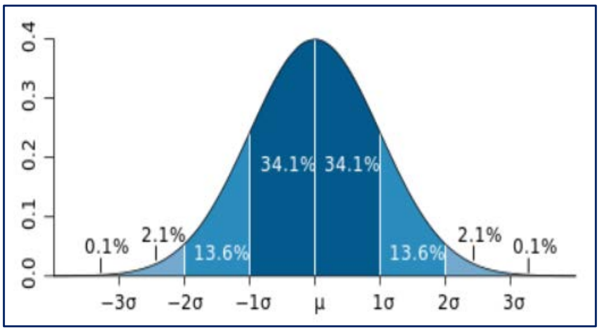

Figure 3.9 Illustration of mean (μ) and standard deviation (σ) in a normal distribution

		Living Room					Bedroom				
		5pm - 9pm	24 hours	24 hours	24 hours	24 hours	5pm - 9pm	24 hours	24 hours	24 hours	24 hours
House Ref. No.	Current heating	Average Temp (°C)	Average Temp (°C)	Maximum Temp (°C)	Minimum Temp (°C)	Standard Deviation (°C)	Average Temp (°C)	Average Temp (°C)	Maximum Temp (°C)	Minimum Temp (°C)	Standard Deviation (°C)
T-02	ASHP	17.3	17.1	24.0	0.5	3.0	16.3	16.0	21.5	1.0	2.6
T-03	ASHP	19.0	17.1	27.5	0.5	5.1	12.8	13.5	22.5	-0.5	3.6
T-04	ASHP	25.0	22.4	35.5	10.5	4.2	21.1	19.1	24.0	10.5	2.3
T-05	ASHP	24.0	20.0	31.5	5.0	4.9	19.0	16.5	26.5	3.5	3.6
T-11	ASHP	20.8	18.5	26.0	8.5	3.4	18.8	17.2	25.5	9.5	2.9
T-17	ASHP	19.4	19.0	35.0	14.5	1.8	20.8	19.5	25.0	12.0	2.0
T-19	ASHP	22.2	21.4	28.5	11.5	2.5	18.9	19.0	25.0	10.5	2.2
T-49	ASHP	20.3	18.8	29.0	8.0	3.4	16.0	15.2	21.5	7.0	2.2
C-08	Oil	22.8	21.1	25.0	15.5	2.0	21.0	19.6	23.5	14.5	1.7
C-20	LPG	20.3	19.6	24.5	15.5	1.3	18.9	18.5	22.5	15.5	1.1
C-22	LPG	23.2	21.0	28.0	12.0	2.7	22.4	21.2	27.0	14.0	2.0
C-25	Electric convector	20.9	18.7	27.5	9.5	2.6	20.9	19.5	26.5	11.5	2.2
Average	ASHP	21.0	19.3	29.6	7.4	3.5	18.0	17.0	23.9	6.7	2.7
Average	Oil / LPG	22.1	20.6	25.8	14.3	2.0	20.8	19.7	24.3	14.7	1.6

Table 3.10 Temperatures in the monitored and control properties between 1 Oct 2016 and 1 Feb 2017

Data from the loggers was analysed for the period between 1 Oct 2016 and 1 Feb 2017. Table 3.10 shows that the residents in properties T-02 and T-03 kept their living room and bedroom at lower temperatures than others in the monitored group with ASHPs. The minimum temperature fell to 1°C or below for these properties. This occurred over the Christmas holiday when electricity consumption data indicated that the residents were away. Outside this period, the resident at property T-02 normally kept the room temperatures at or above the average temperature. In property T-03 the average temperature in the bedroom was only 13.5°C. There was a wider variation in temperature and on a number of days the temperature fell as low as 5°C. Such low temperatures are a concern and have health impacts[10]. However, the resident noted in survey responses that he was able to have the heating on for longer following installation of the ASHP as the bills were lower. He was also very satisfied with how warm his home got when it was cold outside and said the system had changed his life.

Other residents with ASHPs maintained an average temperature in the evening of between 19 and 25°C in the living room and 16 and 21°C in the bedroom. There was however a wide range between the maximum and minimum temperature. For example, the temperature of the living room at property T-04 fell to 12°C at 5am on 6th January 2017. The heat pump was turned on and by 6am the temperature increased to 19°C. It continued to be used during the day and the living room temperature rose to 35.5°C at 1pm and decreased to 21°C by 7pm. In the bedroom the temperature reached 19.5°C by 1pm and 21.5°C by 6pm. On the final survey the resident stated that the heat pump only took the chill off the bedroom.

The difficulty raising the temperature in the bedroom might explain the overheating in the living room. The resident in property T-49 had an average temperature of only 15.2°C in the bedroom and during the final survey noted that there was still no heating in the bedroom. Property T-19 also stated their bedroom was chilly and the heat did not flow. This all indicates that while there was high satisfaction with the cost of running the ASHP, there was mixed success at adequately heating the whole building to the residents' expected comfort levels with just a single indoor unit. If residents had taken up the offer of internal door vents installed at the same time as the ASHP this may have helped the circulation of warm air. Similarly the size, shape and layout of a property is a

[10] The Health Impacts of Cold Homes and Fuel Poverty, Marmot Review (2011) https://www.foe.co.uk/sites/default/files/downloads/cold_homes_health.pdf (Accessed 21 Mar 2017)

factor; if a property had all rooms coming off the main room where the ASHP was installed the warm air circulated more easily, where there were rooms between the unit and the bedroom then the heated air did not circulate as much and the bedrooms recorded a lower temperature.

For the control group, the properties heated by LPG or oil maintained an average temperature over the 24-hour period of about 19 to 21°C. The minimum temperatures typically did not fall as low as for the ASHP properties. This may be due to radiators in the living room and bedroom and having a room thermostat and timer. The minimum temperatures for property C-25 with electric convector heaters were comparable to many which had ASHPs. This suggests the electric convector heaters did not offer better thermal comfort and were significantly more expensive to run.

It was possible to compare room temperatures in the properties during similar cold periods before and after installation of the ASHPs. Most of the temperature and humidity loggers were set up in the monitored properties in late January or early February 2016. On 15th and 16th February 2016, the number of degree days were 13.5 and 14.4. There was a cold spell on 5th and 6th December 2016 with comparable temperatures, where the number of degree days were 13.9 and 14.2.

Table 3.11 shows room temperatures for 15th and 16th February 2016 for six properties before their ASHP installations and four control properties which kept the same heating systems. The average living room temperatures ranged from 16.44 to 23.05°C over the period. In the bedrooms, the average temperatures were between 11.9°C and 23.05°C. Typically the properties with electric convector heaters had lower room temperatures and the bedrooms were colder than the living rooms.

15/16 February 2016		Living Room				Bedroom			
		5pm-9pm	24 hours	24 hours	24 hours	5pm - 9pm	24 hours	24 hours	24 hours
House Ref. No.	Current heating	Average Temp (°C)	Average Temp (°C)	Maximum Temp (°C)	Minimum Temp (°C)	Average Temp (°C)	Average Temp (°C)	Maximum Temp (°C)	Minimum Temp (°C)
T-02	Electric convector heaters	17.80	16.48	21.0	13.0	15.40	14.00	18.5	10.5
T-04	Oil central heating	23.10	20.53	23.5	14.0	21.05	18.70	21.5	13.5
T-05	LPG gas central heating	20.05	17.60	25.0	9.5	18.35	16.38	23.0	8.5
T-11	LPG gas central heating	17.05	17.42	18.5	16.0	17.05	17.40	18.5	16.0
T-17	Electric convector heaters	17.70	16.44	20.0	12.0	13.80	11.90	18.0	10.5
T-23	Electric convector heaters	20.05	23.05	27.0	19.0	24.95	23.05	27.0	20.5
C-08	Oil central heating	20.95	19.88	22.5	16.0	20.45	19.11	21.5	16.0
C-20	LPG gas central heating	17.15	17.39	18.5	16.0	16.95	17.34	18.5	16.0
C-22	LPG gas central heating	17.00	17.25	18.5	16.0	17.00	17.31	18.4	16.0
C-25	Electric convector heaters	17.00	17.31	18.5	16.0	17.15	17.34	19.0	16.0
Average	Electric convector heaters	18.14	18.32	21.63	15.00	17.83	16.57	20.63	14.38
Average	Oil / LPG	19.22	18.35	21.08	14.58	18.48	17.71	20.23	14.33

Table 3.11 Temperatures in monitored and control properties on 15th and 16th February 2016 (13.6 and 14.4 degree days)

4/5 December 2016		Living Room				Bedroom			
		5pm-9pm	24 hours	24 hours	24 hours	5pm - 9pm	24 hours	24 hours	24 hours
House Ref. No.	Current heating	Average Temp (°C)	Average Temp (°C)	Maximum Temp (°C)	Minimum Temp (°C)	Average Temp (°C)	Average Temp (°C)	Maximum Temp (°C)	Minimum Temp (°C)
T-02	ASHP	17.55	17.35	18.5	16.5	16.30	15.95	17.5	15.0
T-04	ASHP	25.60	22.25	31.5	13.0	21.65	18.41	23.0	12.5
T-05	ASHP	25.40	19.34	27.0	8.5	19.45	14.89	20.5	6.5
T-11	ASHP	19.65	16.41	22.0	8.5	18.40	15.38	22.0	10.0
T-17	ASHP	18.05	18.29	35.0	14.5	20.10	19.05	22.5	15.0
T-23	ASHP	22.25	21.25	25.5	18.5	19.20	18.07	21.5	15.0
C-08	Oil central heating	21.22	20.05	22.5	16.0	20.05	18.60	20.5	15.5
C-20	LPG gas central heating	20.00	19.05	21.5	17.0	18.25	17.60	19.5	15.5
C-22	LPG gas central heating	22.40	20.33	24.5	13.0	21.60	20.27	23.5	14.0
C-25	Electric convector heaters	19.85	16.78	21.0	12.0	19.50	17.14	21.0	13.5
Average	ASHP	21.42	19.15	26.58	13.25	19.18	16.96	21.17	12.33
Average	Oil / LPG	21.21	19.81	22.83	15.33	19.97	18.82	21.17	15.00

Table 3.12 Temperatures in monitored and control properties on 4th and 5th December 2016 (13.9 and 14.2 degree days)

Property T-03 was not included in this analysis as the resident was away for 3rd and most of 4th December 2016, which led to particularly low room temperatures. For the period of 4th and 5th December, Table 3.12 shows room temperatures for 6 of the properties with ASHPs and the 4 controls. Properties T-02, T-04, T-05 and T-17 had average temperatures which were higher in the living room after the ASHPs were installed. However, the bedrooms in T-04 and T-05 were colder than on 15th/16th February 2016, with the old heating systems. For properties T-11 and T-23, the living rooms and bedrooms were warmer on 15th/16th February than on 4th/5th December 2016 with the new ASHP. The room temperatures of the control properties were on average warmer on 4th/5th December, but the minimum temperatures were typically lower.

Figure 3.13 shows the variation in room temperature with time during the two monitoring periods for property T-02. On 15th/16th February, T-02 was heated by electric convectors, while on 4th/5th December heating was provided by the ASHP. The temperature showed less variation with the ASHP and average temperature difference between the living room and bedroom was up to 1.4°C. In contrast when the property was heated by electric convectors, the average temperature difference between the rooms was 2.5°C.

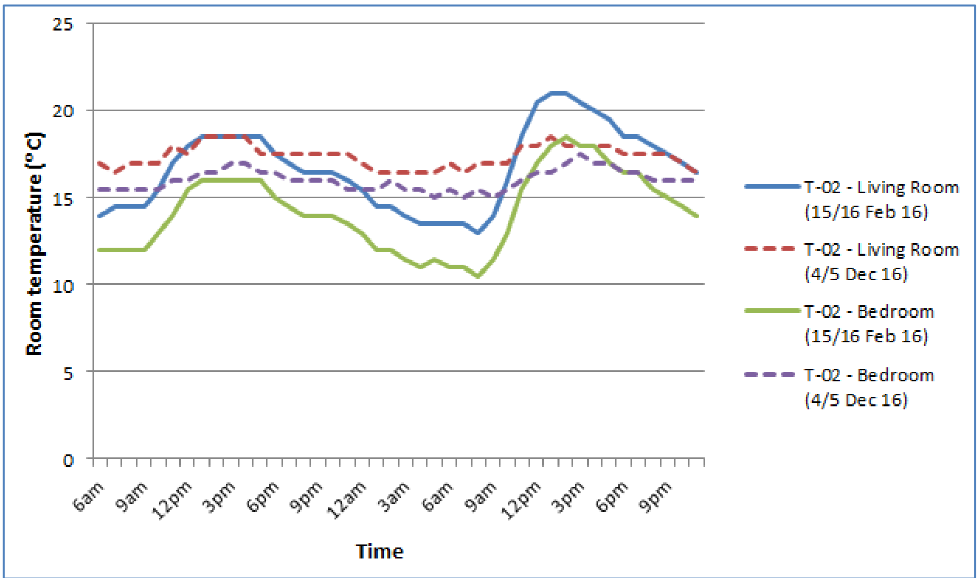

Figure 3.13 Variation of room temperature with time for property T-02 using electric convector heaters on 15th/16th February 2016 and using the ASHP on 4th/5th December 2016

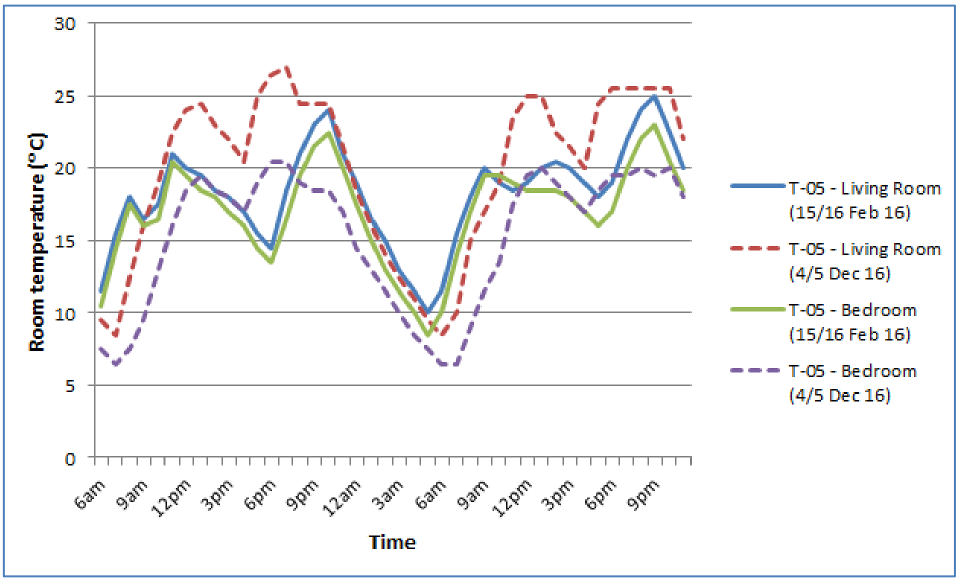

Figure 3.14 Variation of room temperature with time for property T-05 using LPG gas central heating on 15th/16th February 2016 and using the ASHP on 4th/5th December 2016

Figure 3.14 shows that for property T-05, there was considerable variation in room temperature on both 15th/16th February and 4th/5th December 2016. The temperature difference between the living room and the bedroom was small (average of 1.2°C) when the property was heated by LPG gas central heating. However the average temperature difference between the rooms was 4.5°C when heated by the ASHP. This meant that on 4th/5th December, with the ASHP the living room was typically warmer than for the other monitored period with LPG heating, but bedroom was colder.

In general there was a smaller temperature difference between the living room and bedroom when the space heating was provided by oil or LPG gas central heating, with radiators in each room. When heating was supplied by electric convectors or the ASHP there was a greater variation of temperature across the property.

Humidity

Water vapour, usually measured as relative humidity or the percentage of water vapour held by the air compared to the saturation level, is not usually considered to be an indoor contaminant or a cause of health problems. In fact, some level of humidity is necessary for comfort. On the other hand, the relative humidity of indoor environments (over the range of normal indoor temperatures of 19 to 27°C), has both direct and indirect effects on health and comfort. The direct effects are the result of the effect of relative humidity on physiological processes, whereas the indirect effects result from the impact of humidity on pathogenic organisms or chemicals.

Figure 3.15 below illustrates the optimum humidity levels as cited by Arundel et al[11]. The study concludes that maintaining relative humidity levels between 40% and 60% would minimise adverse health effects relating to relative humidity. The indirect health effects of relative humidity may be growing in importance as a result of the continuing construction of energy efficient sealed buildings with low fresh air ventilation rates, but this subject is outside of the scope of this study.

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

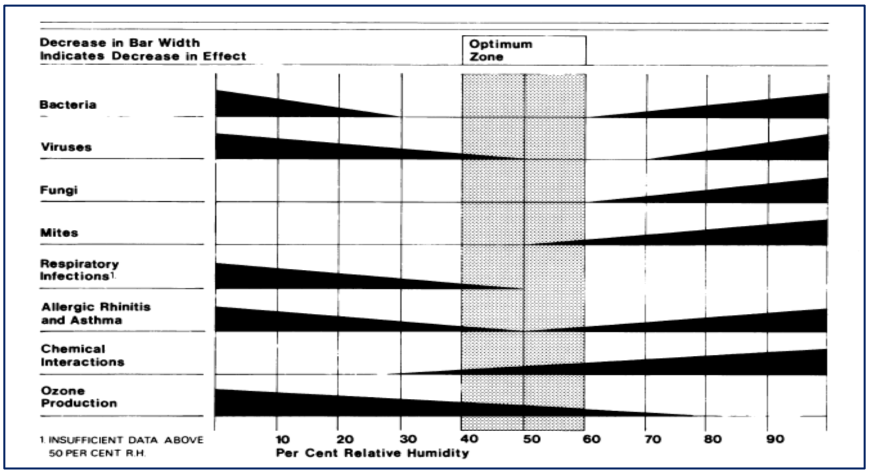

Figure 3.15 Optimum humidity levels to reduce indirect effects from pathogenic organisms or chemicals

The automated data-loggers record both temperature and relative humidity (RH) at regular intervals across the study properties. RH is a ratio (expressed as a percentage) of the amount of moisture present in the air at each logging point, relative to the amount that would be present if the air were saturated. Since the latter amount is dependent on temperature, relative humidity is a function of both moisture content and temperature. Relative humidity is derived from the associated temperature and dew point for the indicated sample. The higher the value of RH, the more water vapour is contained in the air. High values are problematic, and can cause damage to building fabric and furnishings, and can cause mould growth and the health problems associated with this high humidity. From the building regulations part F[12]; the suggested average monthly maximum humidity levels for domestic dwellings during the heating season is 65%.

		Living Room					Bedroom				
		5pm - 9pm	24 hours	24 hours	24 hours	24 hours	5pm - 9pm	24 hours	24 hours	24 hours	24 hours
House Ref. No.	Current heating	Average Humidity	Average Humidity	Maximum Humidity	Minimum Humidity	Standard Deviation	Average Humidity	Average Humidity	Maximum Humidity	Minimum Humidity	Standard Deviation
T-02	ASHP	60.4%	59.5%	88.0%	40.0%	9.8%	64.7%	64.3%	88.0%	44.5%	9.2%
T-03	ASHP	53.3%	53.5%	77.5%	33.5%	7.2%	75.1%	76.1%	92.0%	54.0%	5.5%
T-04	ASHP	49.6%	52.5%	76.0%	29.0%	9.2%	64.2%	65.9%	83.0%	48.0%	6.0%
T-05	ASHP	44.0%	59.5%	82.5%	27.0%	9.6%	58.6%	61.6%	89.0%	40.0%	8.5%
T-11	ASHP	57.7%	59.2%	76.0%	38.5%	6.3%	64.5%	67.1%	90.5%	48.5%	6.7%
T-17	ASHP	54.4%	53.6%	67.5%	25.0%	7.0%	53.1%	53.4%	73.5%	32.5%	7.3%
T-19	ASHP	51.6%	51.4%	78.0%	33.5%	7.7%	58.7%	57.1%	74.5%	39.5%	7.6%
T-49	ASHP	52.2%	54.3%	74.0%	33.5%	6.9%	70.5%	69.6%	86.0%	55.0%	5.2%
C-08	Oil	50.6%	51.3%	64.5%	34.5%	5.8%	56.6%	57.3%	73.0%	41.0%	61.6%
C-20	LPG	50.9%	50.8%	62.5%	40.0%	4.2%	55.4%	54.8%	74.5%	41.5%	4.5%
C-22	LPG	49.3%	51.9%	70.5%	34.0%	6.6%	51.1%	52.7%	75.0%	35.0%	6.9%
C-25	Electric convector	62.6%	64.7%	82.0%	44.0%	6.5%	63.6%	64.2%	83.5%	42.5%	8.8%
Average	ASHP	52.9%	55.4%	77.4%	32.5%	8.0%	63.7%	64.4%	84.6%	45.3%	7.0%
Average	Oil / LPG	50.3%	51.3%	65.8%	36.2%	5.5%	54.4%	54.9%	74.2%	39.2%	24.3%

Table 3.16 Average humidity in the monitored and control properties with readings taken between 1 Oct 16 & 1 Feb 17

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

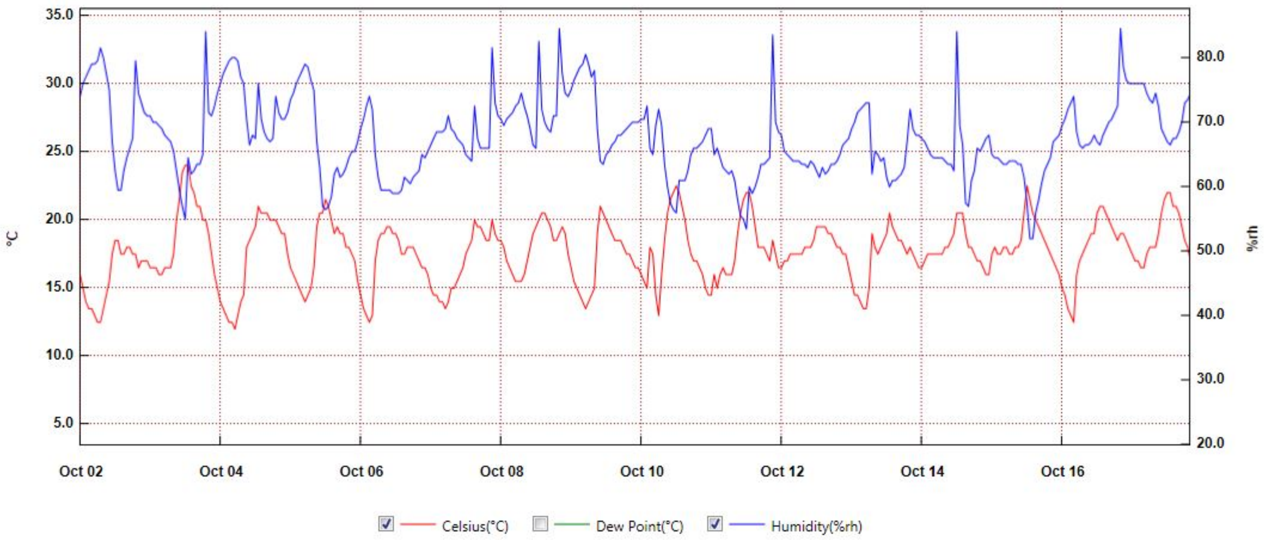

Figure 3.17 Graph of temperature (in red) and humidity (blue) in October 2016 for the living room of property T-02

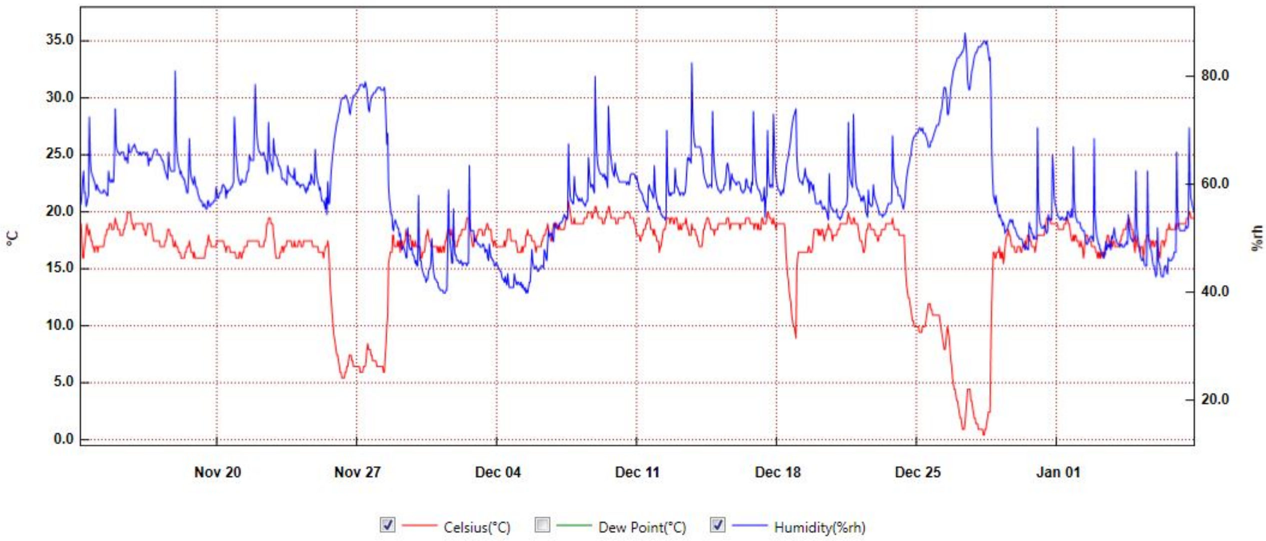

Figure 3.18 Graph of temperature (red) and humidity (blue) in December 2016 for the living room of property T-02

Table 3.16 shows that the average humidity levels in the living rooms for the properties with ASHPs were between 50 and 60% over a 24-hour period. The average values in the bedroom were between 53 and 76% for the properties with ASHPs over a 24-hour period. The maximum level of humidity in the bedroom was above 86% for 5 of the 8 monitored properties.

Figure 3.17 shows a plot of temperature and humidity for household T-02 during the first half of October 2016. The average temperature over this period was 17.6°C and the average relative humidity was 68%. There were sharp peaks in relative humidity likely to be due to greater moisture in the room as a result of behaviour of the resident such as cooking or bathing. Examples are on 3rd October at 7pm when the temperature was 17.2°C and there was a peak in relative humidity of 84% and on 11th October at 9pm with a living room temperature of 18.5°C and relative humidity of 83.5%.

There were also broader peaks in relative humidity which occurred at times with minima in temperature. An example of this was on 4th October at 5am when the temperature decreased to 12°C, while the relative humidity increased to 80%. Figure 3.18 shows that the temperature in the living room of T-02 dropped to about 6°C in late November 2016 for over two days, most likely due to the resident being away and having turned off the heating. During this period, there was a broad peak in relative humidity with a maximum value of 79%. A similar period where the heating was turned off occurred after Christmas, with the temperature decreasing to 0.5°C and the relative humidity increasing to 88%.

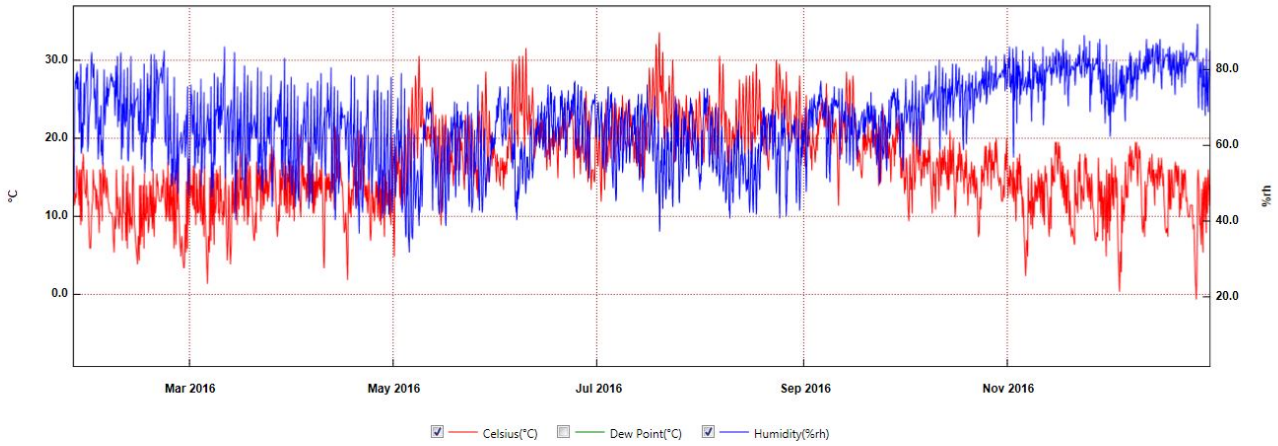

Figure 3.19 Graph of temperature (red) against humidity (blue) for the bedroom of property T-03 in 2016

The bedroom temperature and relative humidity for property T-03 between February 2016 and January 2017 is shown in Figure 3.19. Up until mid April, the space heating at the property was provided by electric convector heaters, and was subsequently replaced by the ASHP. In November and December, there was less variation in the relative humidity and the average value was higher than during February and March when the old heating system was being used.

Figure 3.20 shows a plot of temperature and relative humidity for the bedroom of property T-03 in December 2016. The average relative humidity over this period was just under 80% and the maximum value 92%. The average temperature was 12.8°C, although dropped to -0.5°C during a period away after Christmas. There was a less obvious relationship between temperature and relative humidity than for living room of T-02, however the consistently low temperatures were a factor in the consistently high relative humidity.

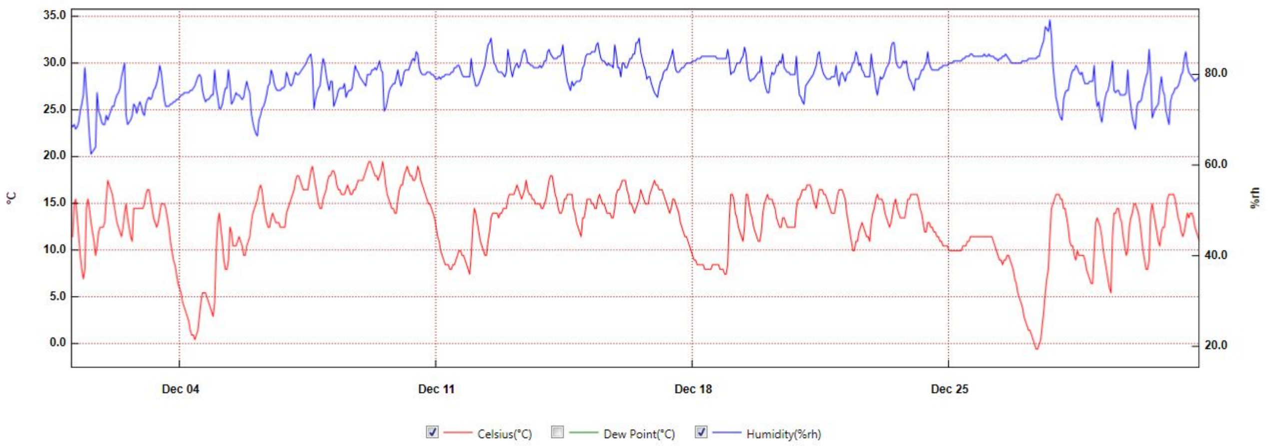

Figure 3.20 Graph of temperature (red) against humidity (blue) for the bedroom of property T-03 in December 2016

Property T-03 had the lowest electricity bill of the properties receiving the ASHPs and this can explain the lower room temperatures. The resident noted in the final survey that the level of condensation in the bedroom was worse following the installation. Property T-19 was also worried about condensation in the bedroom, although the maximum humidity was one of the lowest among the properties with ASHPs. Properties T-02, T-04, T-17 and T-49 all felt there was less of a problem with damp, condensation or mould following the installation of the heat pump. Residents in the monitored group were provided with energy saving advice by NEA staff, however residents would have benefited from further support on reducing condensation and advice on ventilation.

The average humidity in the living room of property C-25 was 64.7%. This mean value was higher than for all the properties which received heat pumps and the maximum value was higher for all but two. The average value of humidity in the bedroom for property C-25 was close to the average of the values for the properties with heat pumps. This suggests that replacing electric convector heaters by an air-to-air heat pump may lower the humidity in the living room, but make no improvement in the bedroom and if there is poor air circulation, it might lead to worse condensation.

Humidity levels were lower for properties C-08, C-20 and C-22 with oil and LPG heating.The average values for humidity in the living room ranged from 50.8 to 51.9% over 24 hours, while the maximum values ranged from 62.5 to 70.5. These values were lower than for all but one of the properties with heat pumps. The maximum humidity in the bedroom ranged from 73 to 75%. 2 of the properties with heat pumps also had maximum humidity levels in this range, while the other 6 were all higher.

Analysis of output temperatures from the air-to-air heat pump

Between mid-January and early February 2017, thermocouples and data loggers were fitted on the outdoor and the indoor units of the air-to-air heat pumps at properties T-02 and T-03. The thermocouples measured the temperature of the air going into the outdoor unit and the air blown out from the indoor unit. Examples of how the system performed on a cold day and a mild day are shown in Figures 3.21 and 3.22.

On 21st January, between 6am and 9am, the external temperature was about -5°C. The ASHP output temperature was between 30 and 34°C, while the electricity consumption of the heat pump was between about 0.9 and 1.0 kW per hour. As the external temperature rose between 9am and 12pm, the output temperature from the heat pump indoor unit decreased and the power consumption of the unit decreased to just under 0.4 kW per hour. During this morning period, the room temperature was maintained at between 16.5 and 17.0°C.

On 1st February, the external temperature ranged from 9 to 11°C. During the morning heating period between 6am and 9am, the ASHP consumed between 0.22 and 0.17 kW per hour. After 10am the unit turned off. The output temperature of the unit was between 18.5 and 20.1°C between 6am and 9am, while the room temperature was steady at 17.5°C.

Although it was possible to make limited measurements of the temperature inputs and outputs from the ASHP, this study was not intended to nor was it sufficiently detailed to test the manufacturer’s claims on the coefficient of performance. To effectively evaluate the coefficient of performance of these air to air units, a controlled environment within a laboratory setting would be required, and was outside of the scope of this evaluation.

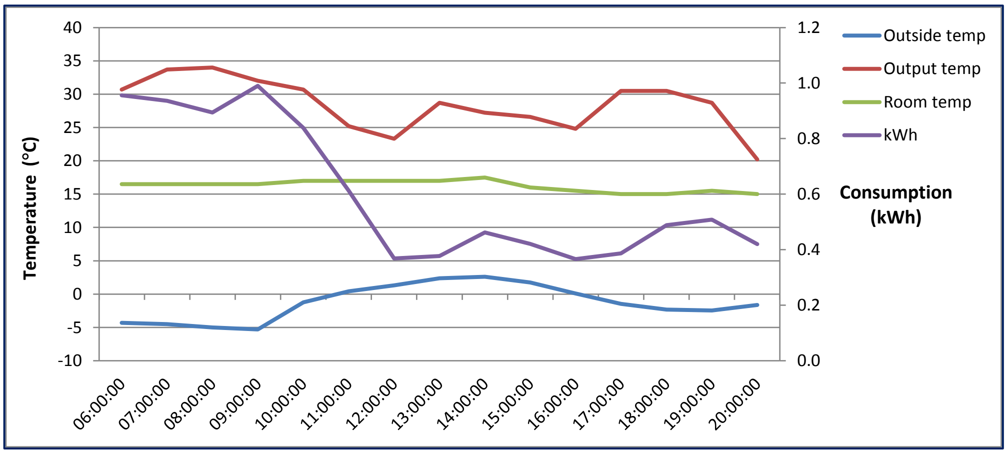

Figure 3.21 Temperatures and electricity consumption for the ASHP at property T-02 on 21st Jan 2017

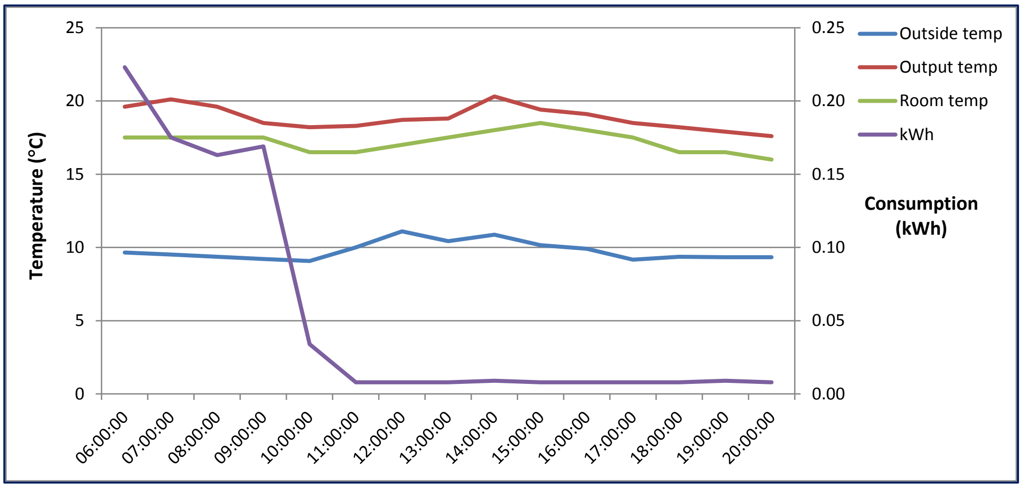

Figure 3.22 Temperatures and electricity consumption for the ASHP at property T-02 on 1st Feb 2017

Use of the air-to-air source heat pump as an air conditioning unit

The air-to-air source heat pump could also operate as an air conditioning unit for cooling the internal environment. There was a period of hot weather in the middle of July 2016 where property T-05 used their heat pump as an air conditioner, but property T-02 did not. Figures 3.23 and 3.25 show that the electricity consumption of the ASHP in property T-05 was greater on the days where the external temperature was higher.

The hottest day was 19th July 2016, where the mean external temperature between 10am and 8pm measured was 31.5°C. On the 18th & 19th July, the daytime electricity consumption of the ASHP in property T-05 was 6.2 and 6.65kWh respectively. The average daytime temperature of the living room in property T-05 was 3.93 and 4.55°C cooler than the external temperature on those days. In contrast, the temperature of property T-02 was comparable or hotter than the external temperature on those days.

It cost property T-05 £1.06 to run the ASHP as an air conditioning unit on July 19th. Figure 3.24 shows a graph of electricity consumption against cooling degree days to a base of 20.0°C. The average number of cooling degree days over the last 2 years at the Odiham weather station was

40.5. Based on this and the kWh/CDD, property T-05 would typically spend about £8.55 per year on using the ASHP as an air conditioner.

Overheating can have a serious impact on health, particularly for the elderly and disabled[13]. Park homes tend to get hotter in summer than conventional homes. Use of ASHPs as air conditioners could improve the thermal comfort of park home residents in summer and reduce the risk of residents overheating.

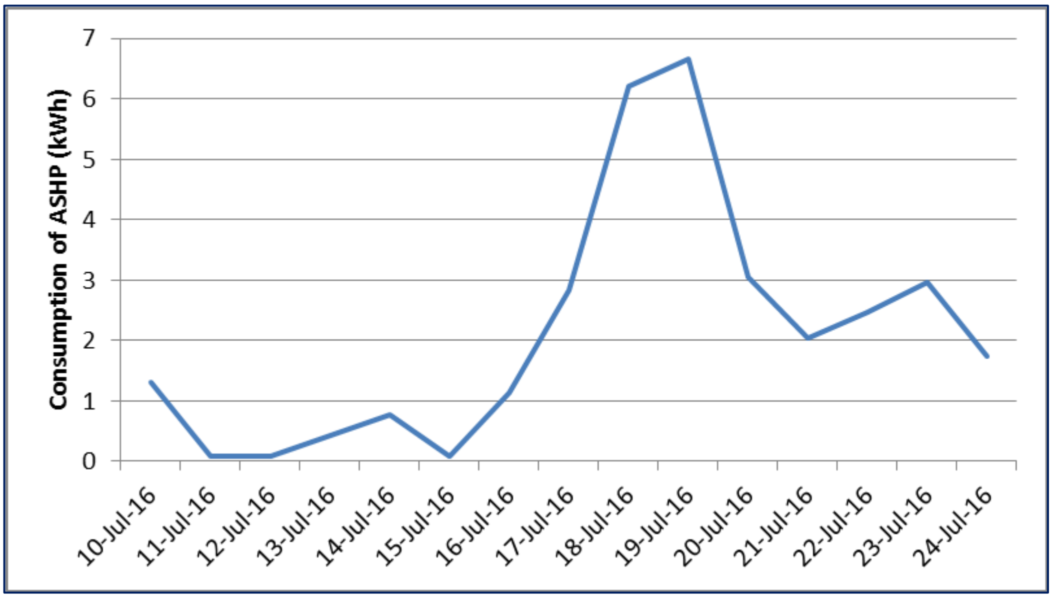

Figure 3.23 Electricity consumption of ASHP in T-05

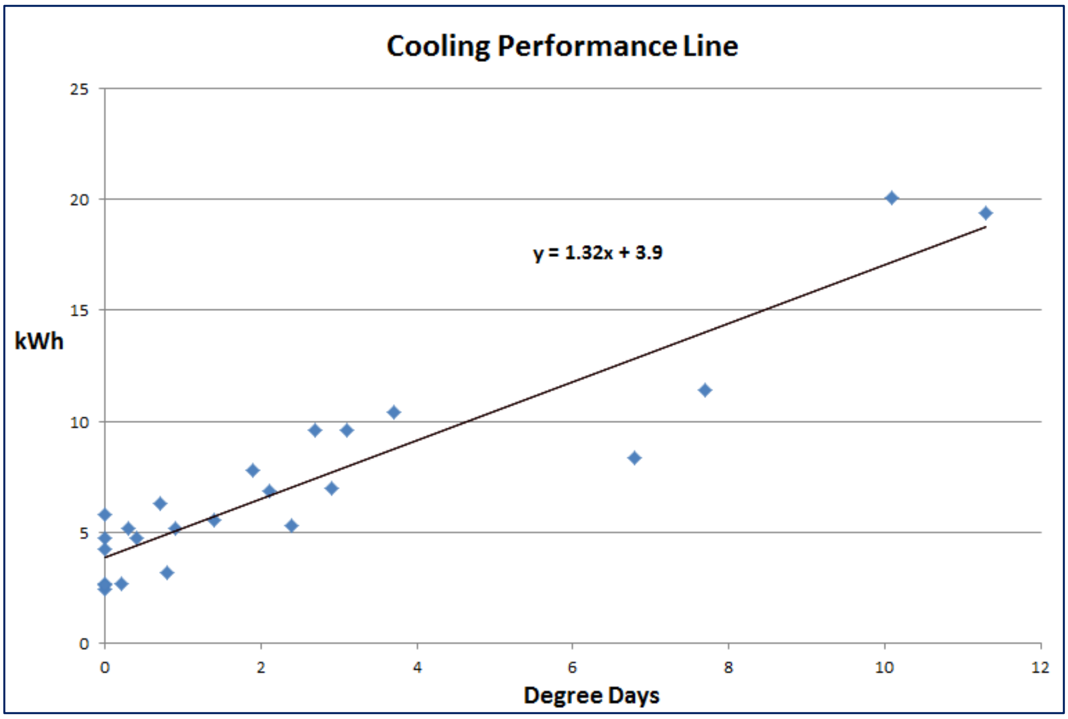

Figure 3.24 Graph of kWh against cooling degree days (CDD)

[13] Heatwave Plan for England 2013, Public Health England https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/201150/Heatwave_plan_2013_-_Making_the_case_Accessible_updated.pdf

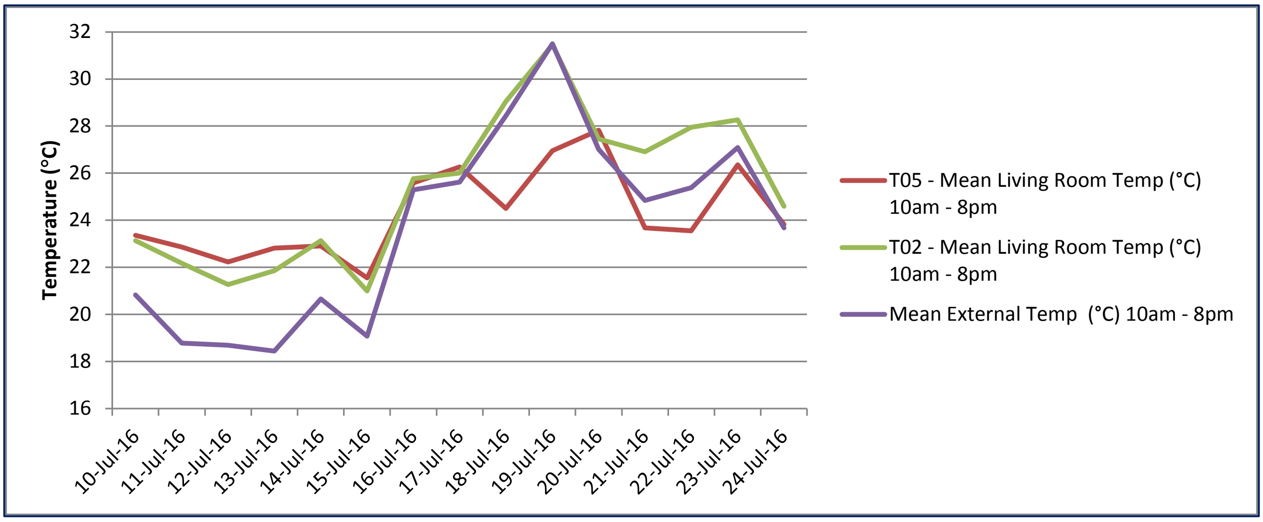

Figure 3.25 Average temperatures in the living rooms of properties T-02 and T-05 between 10am and 8pm

3.5 Economic business case for installation of measures

Measure	Capital cost and installation	Energy Saving from Study	Indicative payback time (years)	Assumptions
Air to Air source heat pump replacing electric convectors	£2,300	£480	4.8	Installation of 30 ASHPs with a single indoor unit and no project management costs. No renewable heat incentive payments

Table 3.26 Payback time for an air to air source heat pump replacing electric convector heaters

The air-to-air source heat pump assessed in this project provides residents in park homes which are off the gas grid a lower cost option for heating their home. A business case can be made for installation of the ASHP based on the estimated costs determined in this project.

The average electricity cost for the park homes with space heating provided by electric convectors was £1,096. When there was space heating provided by the ASHP, the average electricity cost was £616. If households changed from space heating using electric convectors to using an ASHP, the average electricity saving would be £480 (Table 3.26). For multiple installations of Worcester Bosch 6kW air to air source heat pumps in park homes, the capital and installation cost would be about £2300 excluding project management costs. This would mean an average payback time of 4.8 years. Property T-17 had the highest electricity costs in the study and made the largest cost savings (£866) after the ASHP was installed. Here the payback time was 2.7 years.

These calculations assume no payments from the Domestic Renewable Heat Incentive (RHI). However it would be beneficial for this technology to be included in the RHI or another funding stream as it would enable more fuel poor households in park homes to switch to a type of heating with lower running costs than electric convectors.

3.6 Alternative air-to-air source heat pumps heating multiple rooms

In this project a Worcester Bosch Greenstar 6kW air to air source heat pump was installed with an outdoor unit and a single indoor unit which emitted the heat. This was placed in a location to ensure a good flow of heat through the property.

After the ASHP was installed there was an improvement in resident satisfaction with the cost of running their heating system and how warm the home got when it was cold outside. However a number of residents noted that the bedroom was not properly warmed by the single heat pump indoor unit. This could lead to over-heating in the living room to properly warm the bedroom or needing to continue to use an electric convector heating to ensure the bedroom was properly warmed. For property T-05, the average temperature difference between the living room and the bedroom was 4.5°C on a cold day.

A solution to the issue of colder bedrooms would be to install a system with more than 1 indoor unit. The Worcester Bosch system uses a single indoor unit where the heat output is up to 6kW. The only way to include a second indoor unit with this system would be to install a full second ASHP system including a second outdoor unit. This would double the cost per property and the heating system in the bedroom would be more powerful than was required.

Other manufacturers offer air-to-air source heat pumps which include 2 or more indoor units. The Mitsubishi M Series includes a 5.4kW outdoor unit which can operate with 2 or 3 indoor units, while the 7.2kW can run with between 2 and 4 indoor units[14]. The sizes of the indoor units include: 2.0kW, 2.5kW, 3.5kW and 5.0kW. A system that could also provide heating for the main bedroom would be a 7.2kW outdoor unit (MXZ-4D72VA) paired with a 5.0kW indoor unit in the living room and a 2.0kW indoor unit in the bedroom (both wall mounted MSZ-SF models). Assuming no technical complications, the cost of an installation of such a system would be approximately £3,800 +VAT. Assuming similar running costs, the payback time would increase to 7.9 years.

Other options are available from Panasonic including their Multi E and Multi Z systems[15]. Here a 7.5kW outdoor unit could again be paired with a 5.0kW indoor unit in the living room and a 2.0kW unit in the bedroom.

[14] Mitsubishi Air Conditioning Brochure http://library.mitsubishielectric.co.uk/pdf/book/Air_Conditioning_Brochure_2015#page-1 (Accessed 15th August 2017)

[15] Panasonic Domestic air to air heat pump http://www.aircon.panasonic.eu/GB_en/ranges/domestic/free-multi-split/ (Accessed 15th August 2017)

4. Conclusions and recommendations

4.1 Conclusions

Air to air source heat pumps were installed in 30 park homes which were off the mains gas grid and the resulting benefits were assessed

- The project installed Worcester Bosch Greenstar 6kW air to air source heat pumps in 30 properties at a park home site without access to mains gas in Basingstoke.
- 8 of the households which received ASHPs were monitored for the full duration of the study along with 4 control properties at the site which kept their original heating systems.
- The monitored group were interviewed before and after the installations to assess the social impact of the installations and energy saving advice was provided.

There was an improvement in overall customer satisfaction and comfort

- There was a marked improvement in the satisfaction of residents with the cost of running their heating system following ASHP installation (91% post-installation, vs. 34% before).
- All monitored residents felt the house got warmer faster and three quarters of the residents felt their home was warmer and more comfortable and that they had better control over their heating.

There was a reduction in household electricity cost/consumption

- Electricity meter readings before and after installation of the ASHP were used to make a temperature corrected assessment of the annual electricity consumption. The electricity costs were also calculated using a standardized unit rate of 16p/kWh.
- The annual household electricity cost for properties with ASHPs ranged from £375 to £1533, with a mean annual cost of £616.
- The annual electricity cost where the households with ASHPs had electric water heating ranged from £500 to £1533, while those with LPG or oil water heating had an electricity bill between £375 and £789.
- The electricity consumption of 2 of the ASHPs was monitored and the annual space heating cost for the ASHPs was determined to be £217 and £270. This represented 52% and 58% of the total electricity cost for these households which did not use electricity for water heating.
- By contrast, the total annual electricity costs of properties using electric convectors for space heating ranged from £487 to £2400, with an average of £1096.
- The average reduction in annual electricity cost for park home households replacing electric convector heaters with ASHPs was 29%.
- The consumption of properties with electric convector heaters ranged from 1.6 to 8.1 kWh per degree day, vs. between 1.3 and 5.2 kWh per degree day for those with ASHPs.

The ASHP did not always heat all of the property adequately, or improve humidity levels in bedrooms

- Average temperatures achieved in the living rooms of the properties with ASHPs were between 17 and 21°C, representing a wider temperature range compared to the control properties - this may be due to residents with the ASHPs running them for a shorter time than the control heating systems.

- Average bedroom temperatures over 24 hours were between 13.5 and 19.5°C for the properties with ASHPs vs. 18.5 to 21.2°C for the control properties. The inclusion of vents on all internal doors in the property would help the warm air circulate. These vents were to be installed in all properties as part of this project but all residents declined this offer, stating that internal doors are generally left open. Residents who kept internal doors shut limited the potential circulation of heated air throughout the whole of their property.
- The size, layout and shape of a property could also be a factor in the effectiveness of the ASHP to heat the whole property. A large property with rooms farther away from the ASHP would see lower temperatures in those rooms or would require the ASHP to be running for longer in order to see an increase in temperature.
- 37.5% of the homes with ASHPs who completed the study noted that the heat pump did not adequately heat the bedroom.
- Replacing electric convector heaters with ASHPs lowers the humidity in the living room, but humidity levels did not improve in the bedroom: the maximum humidity in the bedroom was above 86% for 62.5% of the properties with ASHPs (which may be due to low minimum temperatures in the bedrooms of these properties).
- On cold mornings, the heat pump may consume about 1kW per hour and output hot air with a temperature above 30°C. On a milder day, the heat pump may consume 0.15 to 0.20 kW per hour and output air at about 20°C.

The ASHP was more suitable for smaller park homes with electric convector heaters

- The average cost reduction on replacing electric convector heaters with the ASHP was £480 compared to £385 for a property which previously had oil fired central heating.
- There was a smaller temperature difference between rooms in properties with oil and LPG central heating compared to those with electric convectors or the ASHP.
- The Worcester Bosch Air-to Air source heat pump (ASHP) had difficulty adequately heating some of the larger and more complex-shaped park home properties.
- Alternative air to air source heat pump systems are available from Mitsubishi and Panasonic and these can include an additional indoor heating unit in the bedroom.

In summer, the ASHP also cooled the property

- For days where the outside temperature exceeds 30°C, the heat pump can reduce the average daytime temperature in the living room by about 4°C at a cost of just over £1 over the day.

Overall the project enabled many residents to successfully lower their heating costs and keep their living rooms warm, with comments ranging from "Love it, it has changed my life" to "Very pleased, much better than the old system, would recommend".

4.2 Recommendations for potential future installations

- Include more than one heat emitter in the property to deal with the problem of bedrooms remaining cold.
- Other ways of improving the distribution of warm air in the property include installation of vents in internal doors as was originally planned with this project or use of ducting and fans for properties with a single indoor heat emitter.
- Combine the installation of ASHPs with external wall insulation (and loft and floor insulation where possible) to reduce the heat losses from the property - this would further reduce energy consumption as the ASHP could operate more efficiently.
- High relative humidity levels were recorded in this study in the bedrooms and low room temperatures were a significant cause. An additional heat emitter in the bedroom (allowing residents to better heat the room) and external wall insulation (reducing heat loss) would both help raise the average room temperature. This should also lead to lower values of average relative humidity.
- Ensure residents are properly trained on the operation of the system, to give them confidence in appropriately setting the thermostat and heating times for the ASHP and therefore improve thermal comfort.

4.3 Impact on fuel poverty

Park homes often have poor insulation and are frequently off the gas grid, which makes them expensive to heat. This report shows that heating costs can be reduced by installing ASHPs in park homes. Resident satisfaction with the running costs was high, in marked contrast to their previous heating system.

To obtain maximum impact on lifting residents out of fuel poverty, it would be prudent to install heat emitters in the lounge and main bedroom and improve insulation as part of the retrofit. If ASHPs were to be included in the Domestic Renewable Heat Incentive (RHI), it may enable more residents to install a cheaper heating system in their park home.

Appendix 1: Glossary of Terms

ASHP	Air Source Heat Pump
CoP	Coefficient of Performance
DD	Degree Days
EPC	Energy Performance Certificate
FPNES	Fuel Poor Network Extension Scheme
GCH	Gas Central Heating
HIP	Health and Innovation Programme
LPG	Liquefied Petroleum Gas
NEA	National Energy Action – the National Fuel Poverty Charity
RH	Relative Humidity
RHI	Renewable Heat Incentive
SAP	Standard Assessment Procedure (for assessing home energy efficiency)
SCoP	Seasonal Coefficient of Performance
SD	Standard Deviation
TIF	Technical Innovation Fund

Appendix 2: Comments from residents following installations

Household reference	Comments
T-02	Extremely happy with the programme. I received a new heating system that allows me to be warm in winter. Previously I used just one heater in the living room. The new heating system now heats all rooms. It has been a godsend.
T-03	Would like a fact sheet to understand the heat pump more. Condensation is worse in the bedroom, but I am unsure why. The heating system is a lot cheaper to run. I am very happy. I love it (the heating system) – it has changed my life
T-04	Generally pleased and impressed, but unhappy that the heating system stopped working in a very cold snap. The heat pump only takes the chill out of the bedroom. There is a lot less condensation. Electric bill is the same, but no oil bill though.
T-05	Very satisfied and very glad to have taken part. It took a while to understand the controls and the system. Happy and like it better than the old system.
T-17	Had to request a manual to be sent. No more condensation on windows. Really happy with this much better system. A real benefit to me to have an efficient heating system that lowers bills. No more condensation on the windows.
T-19	Very good, however likely to need a heater in the bedroom as it was removed during the installation. The bedroom is chilly and the heat does not flow. Worried about condensation in the bedroom.
T-23	Very good, I like it a lot. The heat pump was limited in where it could be installed in the property. Some neighbours had it located in a better place in the home to heat every room. No issues with noise, very cheap to run. Happy to have it running 24 hours a day. Extra bonus of using it as an air conditioner in summer. Happy with lower cost of energy bills
T-49	Very happy. It is not often you get something for free which has benefited me so much. Very pleased, it is much better than my old system and would recommend. There less damp and less moisture in the air.

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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