Project code CP746
Ground Source Heat Pump
Moat Homes Ltd & Mears

Technical Evaluation Report

Paul Cartwright, Michael Hamer – September 2018

Background

About National Energy Action

National Energy Action (NEA) 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, 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 installed products 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:

Moat Homes Ltd – Project Partner - all further references to this partner will refer to 'Moat'
Mears – Moat's Project Managers
Ground Heat Installations Ltd – Installer
David Thompson, Director, Ground Heat Installations Ltd.
Rachael Obabisi, Estate Manager, Fletchers Close
Sue Rich, Head of Partnering, Moat

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Legal limitations and disclaimer

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Executive summary

Project overview

The Project comprises the replacement of the heating and hot water systems of two residential sheltered blocks whose residents are over 55 years of age. The main block comprises 41 flats numbered 16 – 56. The second and smaller block to the rear of the main block comprises 15 flats numbered 1-15.

The project had the following aims:

- Learning more about the performance of Ground Source Heat pump technology in low rise tower blocks and at householder level, the role it can play in tackling fuel poverty.
- Reduce heating and hot water bills to just £180 per annum.
- Provide residents with greater control and information about energy consumption using the remote monitoring and installed control system.
- Provide residents with an improved level of reliability, response, and service should any technical issues arise indicated by remote monitoring of the smart system being applied.
- Provide insight into the suitability of the technology in other property types.

Context

Moat, the project partner and owner of the two blocks are part of a portfolio of 16,800 properties of various types. The two blocks of flats, built in 1980, involved in this project accommodates those aged over 55. This project monitored group of residents were all retired and over 60 and the majority over 70 years of age. Half of the residents suffered health conditions which are exacerbated during cold conditions.

The technology

The communal space heating to all flats was previously provided by 3 Ideal Concord CXA gas boilers. These boilers were 25 years old and reaching the end of their serviceable life. In both blocks of flats, each flat was fitted with a Vaillant geoTHERM mini 3kW ground source heat pump, a 100-litre unvented hot water cylinder, and Vaillant VCR 470 room thermostat/controller. Existing radiators were replaced with larger sizes to allow for the lower temperature of the circulating water. The heating systems in each flat were installed during the period 16th to 23rd June 2016.

The project

Following project approval in late 2015, the project partner, Moat together with Mears, Moat's Project Managers, selected suitable residents to participate in the monitoring for the project. Initial vists to residents were made by NEA staff in December 2015. During that visit monitoring equipment was installed and a questionnaire completed based on structured questions to the residents and evidence collected concerning observed conditions regarding the flat and occupant. Monitoring equipment was fitted by NEA staff during the initial visit.
The majority of the monitoring was conducted in 12 flats selected from different floors and 'end-terrace' or 'mid-terrace' of the larger main block. The flats selected had either a single bedroom or were a 'bed-sit' layout. All were occupied by one person, all of whom were over 60 years of age

and retired. Ground Heat Installations Ltd conducted a phased installation of connecting a total of 56 flats in the 2 blocks during June 2016. Throughout the project electricity meter readings for each flat were collected by Mear's Estate Manager.
A final visit was made during February 2018 to conduct a final questionnaire, retrieve the various data loggers and any information residents had recorded or produced as part of the project.

Summary of findings

Energy costs

Prior to the installation of the GSHPs in this project all residents paid the same standing charge of £156 per year for heating provided by the three communal gas boilers. This charge was the same for all flats and did not depend on the size, position, or aspect of the flat. More importantly, it did not take account of the resident's desired room temperatures or period of heating. The new GSHP in each flat consumed electricity and was connected to the utility electric meter for each flat.

It therefore follows that a resident heating their flat to lower temperatures and/or shorter periods than others will have lower electricity costs. It is therefore extremely difficult to compare 'before' and 'after' install costs. A breakdown during the first year after installation, adjustments to controls by unauthorised persons, and lack of understanding on the part of the residents all accumulate to this difficult comparison.

In addition, problems with both technical monitoring equipment and access to web portal data caused gaps in data preventing fully detailed analysis. However extensive data was available on manual utility meter readings which could be used in conjunction with degree day data to provide a method of analysis.

Residents sometimes consider heating cost by the amount they spend on electricity and not take account of the outside weather temperatures. This chart shows that cost and also does NOT include the £156 charge in 2015/16 prior to the installation of the GSHP. However, complications of the amount of electricity can clearly be seen between the three flats.

Tech. Ref.	2015/16		2016/17		2017/18	
	Weekly use (kWh)	Weekly cost	Weekly use (kWh)	Weekly cost	Weekly use (kWh)	Weekly cost
T-03	53.74	£7.52	60.33	£8.45	78.98	£11.06
T-06	28.90	£4.05	76.07	£10.65	202.74	£28.38
T-18	40.65	£5.69	73.89	£10.34	58.30	£8.16
Average		£5.75		£9.81		£15.87

The first year of using the GSHP was warmer than the previous year. The second year of using the GSHP was colder than both the first year using the GSHP and the last year of the previous system. Taking these conditions into account, meter reading data for 11 properties, and adding the £156 charge for the last period of the previous system, the projected average annual electricity cost based on a 20 Year average year is:

Note: these values including ALL electricity use by each flat and therefore include lighting and appliances.

Year 1 (previous system)	£469.46 per year
Year 2 (first year using GSHP)	£606.30 per year
Year 3 (final monitored year)	£842.34 per year

The figures are based on:

- Calculations of electricity use from actual utility meter readings obtained by partners.
- Degree day data, for the periods covered by those readings, to show kWh per degree day.
- 20 year average degree day data to provide cost comparisons on a like-for-like basis
- In year 1 the standard charge of £156 has been added to the total cost calculation

Temperature and humidity

Residents had complained that the previous system was difficult to control and were often too hot or too cold. Data from temperature monitors showed that temperatures were very similar before and after the installation of the GSHP. It should however be understood that actual temperature and the difficulty in controlling it is two very different things. Residents reported using addition heating where necessary and, whilst not reported, windows could have been opened. (They were aware the original heating charge would not change if they used more heat).

Conclusions and recommendations

The new controls were confusing to residents and complaints were received relating to inadequate training. Furthermore, there was anecdotal evidence that system controls had been changed by unauthorised people causing faults to occur resulting in breakdowns and additional costs to residents due to the inefficiency of the system and, during system breakdowns, the use of portable electric heaters.

In this project the residents previously paid a standing charge for their heating, as much, or as little, as they wished to suit their particular circumstances, health issues, or occupancy patterns. There was therefore a large range of heating demands but all residents paid the same standing charge.

Reliability of the system was due to unauthorised tampering with the control systems. The remote monitoring of the system did not appear to have been utilised to the benefit of residents. NEA was able to access data at times although there were significant gaps which are covered in this report.

This project did not highlight any issues which would preclude its use in other property types.

Potential future installations of GSHP, and to some extent, other replacement heating system should consider, and where necessary consult with residents and landlords (where applicable) on the following.

- What system and controls are currently used?
- How do residents currently pay for their heating and hot water?
- Will the same system apply to the new system?
- How will the new system be controlled differently to the old system?
- Are residents able to understand how to control their new system
- What training (or other arrangements) are needed for residents
- Do residents need guidance on energy tariffs/fuels to take full advantage of the new system

Manufacturer's claims on performance and cost are impossible to comment on as these are based on previous costs which did not accurately reflect the cost to individual residents whereas the new system did. Meaningful comparison could only be achieved if either:

- All flats in the block were monitored
- All flats paid actual energy costs before and after improvements

1. Project overview

1.1 Introduction

The Project comprises the replacement of the heating and hot water systems of two residential sheltered blocks whose residents are over 55 years of age. The main (larger) block comprises 41 flats numbered 16 – 56. The second (smaller) block to the rear of the main block comprises 15 flats numbered 1-15.

The communal space heating to all flats was provided by 3 Ideal Concord CXA gas boilers (see figure 1-1). These boilers were 25 years old and reaching the end of their serviceable life. Boiler efficiency was estimated to be approximately 84% with less controllability than more modern systems. This resulted in residents complaining of being too hot or too cold. In addition, every £1 spent on gas used by the old boilers resulted in 16p lost through inefficiency compared to a modern gas boiler (with an indicative efficiency of 88% - 91%). These efficiencies result in a maximum loss of 9p - 12p for every £1 spent on gas.

Figure 1-1, 3 gas boilers previously used for the communal heating system

The new GSHP heating system in the main block is independent of the system in the smaller block to the rear. The two systems are similar but have one distinct difference:

- The main block incorporates a pre heat system, whereby two Vaillant geoTHERM 30kW and 38kW heat pumps take heat from the ground heat exchange loop[1] (using a brine solution) and pre heats a buffer tank to a constant 20°C (see figure 1-2). The buffer tank

[1] Ground Source Heat Pump Association http://www.gshp.org.uk/ground_source_heat_pumps_Domestic.html

supplies the individual heat pump units in each of the 41 flats. The units in each flat, Vaillant geoTHERM mini 3kW, have a rated evaporator of 1.7kW (41 flats x 1.7kW = 69.7kW) which raises the temperature from 20°C to 45°C at peak time to provide space heating and hot water to each flat (see figure 1-3).

- The system in the smaller block to the rear does not have the pre-heating system and buffer tank; the units in each flat draw heat directly from the boreholes (see figure 1-4) and therefore need to raise the temperature from ground temperature to 45°C.

Figure 1-2, Two Vaillant geoTHERM pre-heating GSHPs and buffer tank

Figure 1-3, Vaillant geoTHERM mini 3kW

Figure 1-4 Underground pipes & (inset) prior to excavation

1.2 Aims

The project had the following aims:

- Learning more about the performance of Ground Source Heat pump technology in low rise tower blocks and at householder level, the role it can play in tackling fuel poverty.
- Reduce heating and hot water bills to just £180 per annum.
- Provide residents with greater control and information about energy consumption using the remote monitoring and installed control system.
- Provide residents with an improved level of reliability, response, and service should any technical issues arise indicated by remote monitoring of the smart system being applied.
- Provide insight into the suitability of the technology in other property types.

1.3 Context

Moat, the project partner, and owner of the two blocks, own a portfolio of 16,800 properties of various types as shown[2] in figure 1-5.
The two blocks of flats, built in 1980, house residents aged 55 and over.
The project monitored a group of residents who were all retired and over 60 years of age, with the majority over 70. Half of the residents suffered health conditions which are exacerbated during cold conditions.

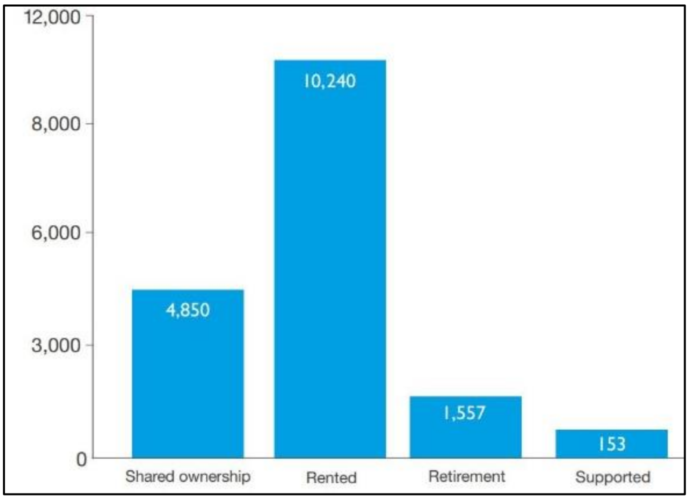


Figure 1-5, Moat property types

Fletchers Close is part of the Bromley 020D Lower Layer Super Output Area (LSOA) and is ranked 23,067 out of 32,844 LSOAs in England in the index of Multiple Deprivation (IMD); 14,765 for Income Deprivation Affecting Older People Index; and 26,710 for Health Deprivation and Disability Domain. In contrast, the nearby area, Bromley 026A LSOA is ranked 2,184 out of 32,844 LSOAs in England.

1.4 Project timeline

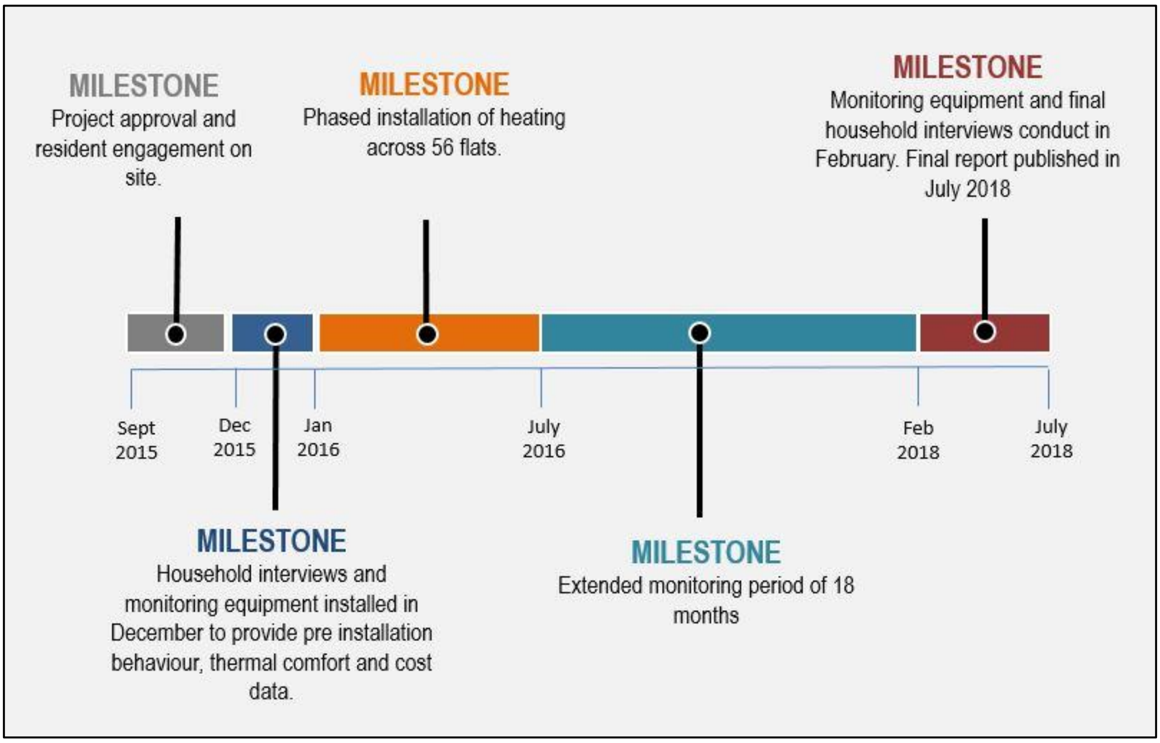


Figure 1-6, Project timeline

[2] Moat 2016/17 Annual Report https://www.moat.co.uk/uploadedFiles/About_Moat/Efficiencies_and_transparency/A

Ground Heat Installations Ltd installed two Ground Source Heat Pump systems, one in the main block and a second in the rear block. They conducted a phased installation of connecting a total of 56 flats in the 2 blocks. The main block, consisting of 41 homes, were connected to the 2 'pre-heating' units. The rear block, consisting of 15 flats, was connected directly to the boreholes; no pre-heating was involved.

Due partly to reliability issues and to allow for a period of resident familiarisation, an extension of the project was arranged until the spring of 2018. This would allow further comparisons to be made between comfort levels and energy costs between the previous and new system. NEA staff therefore visited the homes for a second time in July 2016 to confirm that homes still had monitoring equipment installed, changed loggers and/or batteries where required and changed logging equipment. It was also important to confirm that residents were still 'engaged' with the project. Electricity meter readings continued to be collected by the Estate Manager for each flat. These meters were all located in a locked room on the ground floor of the main block. Only homes in the main block were originally selected for monitoring as, at that time, the 'pre-heating' system was specified for both blocks.

The contractor, Ground Heat Installations later made the decision to change from the originally agreed system to one where the smaller rear block extracted heat directly from the ground and fed to the units in each flat. To help provide some analysis between the two system types NEA obtained some information on the energy consumption of the homes in the rear block. However, that data was less comprehensive, and it was not possible to install NEA monitoring equipment.

A final visit was made during February 2018 to conduct a final questionnaire and retrieve the data logging equipment from residents.

1.5 Attracting beneficiaries and establishing a monitored group

The project partner, Moat together with Mears, selected and engaged suitable residents to participate in the monitoring for the project. Monitoring equipment was fitted by NEA staff during the initial visit in December 2015 and a questionnaire was carried out with the residents at that time.

1.6 Factors affecting the planned evaluation methodology

Figure 1.6 shows details of those factors that affected the planned evaluation methodology together with mitigation where needed.

Issue	Description and mitigation
Size of monitoring group	The monitored group of 12 flats are all in the main block containing a total of 41 homes.
Identification of the monitored group and control group	Ground source heat pumps were installed in all flats in both the main and rear blocks. A control group could not therefore be selected but monitoring was able to start prior to the new systems being installed allowing comparisons to be made.
Start of monitoring	Monitoring equipment was first installed during late December 2015 and programmed to start recording immediately after the Christmas period. Several flats were expected to be empty of the holiday period with occupants staying with relatives.
System performance	System performance was monitored using data from a web based portal. Data was not available for all NEA monitored properties. NEA installed heat meters in several properties but this needed to be reconciled with Web portal data, which as mentioned above was not always available
Meter readings	Electricity used by the GSHP in flat was to be obtained from the web portal but not always available. NEA obtained meter readings during their periodic visits and also arranged with partner staff in order to augment readings obtained from the portal and data loggers. However, there were still gaps in the available data which restricted the ability to perform complete analysis for all sections of this report. The lack of portal data readings may have been due to residents interfering with switches controlling power to the metering equipment.
Monitoring equipment	NEA installed temperature and humidity monitors in all monitored properties. In the main these were retrieved at the end of the project. However, some had been lost or misplaced by the residents resulting in lost data. Data loggers attached to heat meters were programmed to record each kWh of heat (water) produced by the GSHP. These worked well until the middle of 2017 when they were exchanged due to battery depletion or full memory. The replacements however did not perform as expected and no data was available for the 2017/18 winter.
Other factors	During the project it became clear that only the main block had been installed with two GSHPs to provide pre-heating prior to circulation to the individual GSHPs in each flat. The smaller rear block did not have a GSHP installed for pre-heating. As the entire monitoring group had been selected from the main block, NEA tried to enlist (with limited success) the involvement of residents in the rear block to provide data enabling NEA to compare the effects of the two different systems

Figure 1-7, Factors affecting monitoring methodology

2. Social evaluation and impacts

2.1 Qualitative feedback from initial questionnaire

The project consists of two blocks of flats, the main block (see figure 2-1) and a smaller block at the rear (see figure 2-2). The main block consisted of 41 flats covering five floors containing a mix of 'mid-terrace' and end-terrace' flats. The majority of the monitoring was conducted in 12 of these flats selected from different floors and 'end-terrace' or 'mid-terrace' to represent the cross section of flats in the building. The flats selected had either a single bedroom or were a 'bed-sit' layout. All were occupied by one person, all of whom were over 60 years of age and retired.

Figure 2-1, Main (larger) block of flats

Figure 2-2, Rear (smaller) block of flats

Figure 2-3 provides details of the properties selected for monitoring, floor areas are taken from EPCs lodged on the Landmark Website[3]. All of the EPC's for the monitored properties shown are based on surveys made prior to the installation of the GSHP – see later section 'EPC Data'.

Technical Ref. No.	Flat Type	Position in block	Floor area (m^2)	EPC Rating	EPC Band
T-08	1 Bedroom Flat	Ground floor, end ter.	48	70	C
T-04	1 Bedroom Flat	Ground floor, end ter.		N/A	N/A
T-18	Bedsit	Ground floor, end ter.	41	77	C
T-16	Bedsit	Mid. floor, mid. Ter.	30	84	B
T-02	1 Bedroom Flat	Mid floor, mid. Ter.		N/A	N/A
T-11	1 Bedroom Flat	Mid. Floor, end ter.		N/A	N/A
T-12	Bedsit	Mid floor, end ter.	30	66	D
T-20	1 Bedroom Flat	Mid. Floor, mid. Ter.		N/A	N/A
T-23	Bedsit	Mid. Floor, mid. Ter.		N/A	N/A
T-03	Bedsit	Mid. Floor, end ter.		N/A	N/A
T-01	1 Bedroom Flat	Top floor, end ter.	42	61	D
T-06	1 Bedroom Flat	Top floor, End ter.		N/A	N/A

Figure 2-3, Project monitored properties

[3] Landmark Register of Domestic Energy Performance Certificates - https://www.epcregister.com

The age range of residents in the monitored flats is shown in Figure 2.4; 6 of the 12 residents reported that they suffered from health conditions and that these conditions were worsened by exposure to cold conditions within their homes.

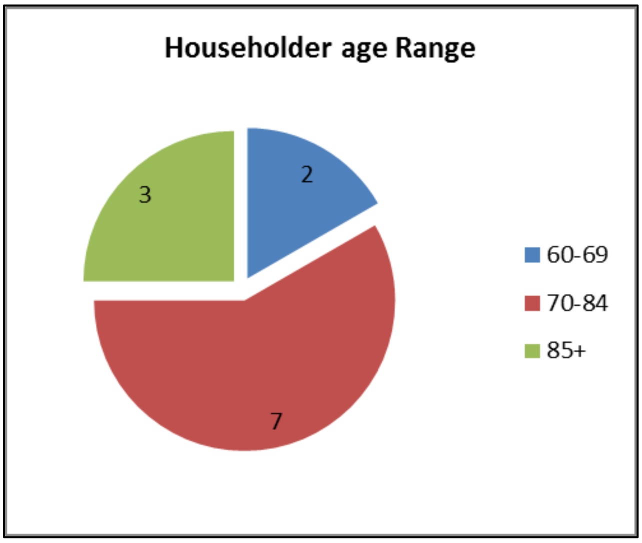


Figure 2-4, Householder age range

Health issues stated were:

- Alzheimer's
- Arthritis
- Diabetes
- Heart Condition
- High blood pressure
- Limited mobility
- Muscular degeneration
- Osteoperosis
- Varicous vein

Residents were asked when they used their new heating system to warm their flats. The numbers for each period is shown in Figure 2-5.

However, each resident also specified actual times that their heating was on during these periods. From this information the bar chart in Figure 2-6 was produced to allow a common period to be identified and therefore allow analysis across all flats. From the bar chart it can be seen that approximately half the residents heated their flats between 06:00hrs and 09:00hrs and approximately two thirds between 17:30hrs and 21:00 hrs.

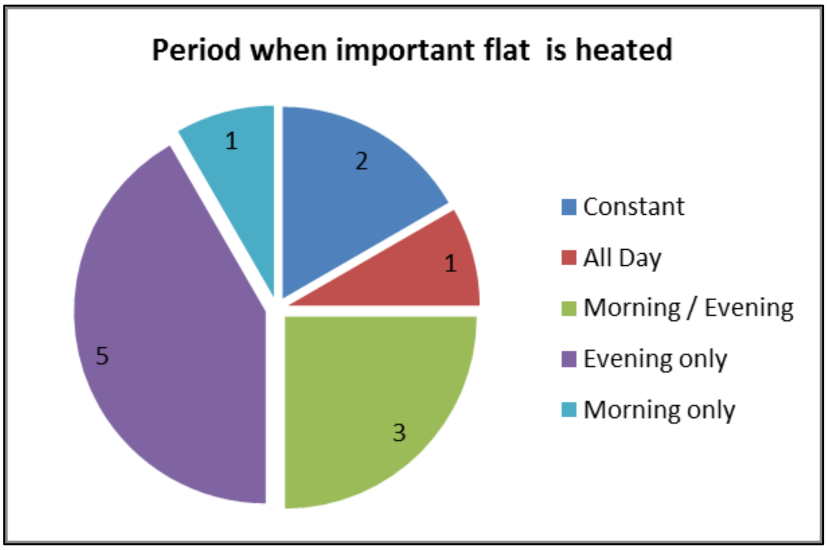


Figure 2-5, When residents used the new heating system

This evening period has predominantly been used in this report when analysing energy use data and comfort level data in the Technical Evaluation and results section of this report.

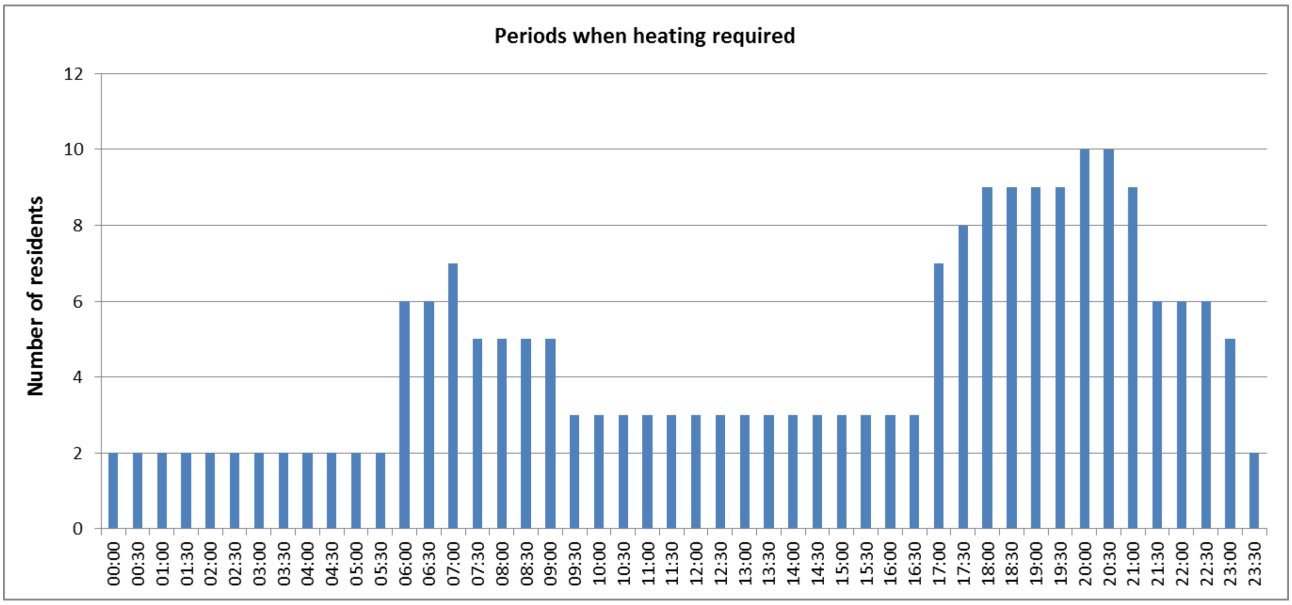


Figure 2-6, Bar chart analysis of periods when heating required

2.2 Use of supplementary heating

Following the installation of the GSHP 12 residents were asked for their comments regarding any use of addition heating using portable electric heaters. 5 used supplementary heating but only rarely when the outside temperature was very low.

2.3 Resident acceptance and satisfaction

During the first visit by NEA, residents were asked 5 questions concerning their satisfaction of the existing heating system prior to the installation of the GSHP. During the final visit residents were again asked the same 5 questions concerning the new GSHP system. During the first visits 9 residents provided answers; during the last visits 11 residents provided answers. To enable a comparison to be made the number of those giving a reply has been expressed as a percentage of residents for each period. The results and shown in the bar chart at Figure 2-7.

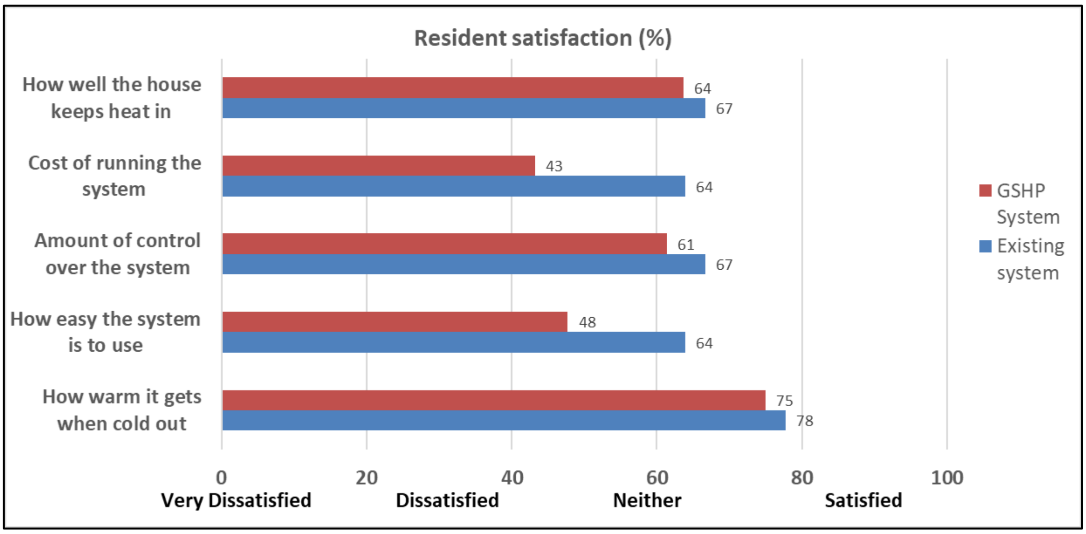


Figure 2-7, Resident's satisfaction of the GSHP compared to their previous heating system

It can be seen that, based on the answers to the same questions, the GSHP system provided less satisfaction to all questions. The cost of the running the system was the area of least satisfaction, dropping from 64% for the previous heating system to 43% following installation of the GSHP. However, a number of issues could have contributed to this reduction in cost satisfaction.

- Their electricity used by each flat includes energy used by the GSHP whereas previous, communal heating costs, were charged at a standard fixed flat rate of £156 per year.
- Residents previously used heating at different times and for varying periods, this would have had no effect on cost with the previous system but would have potentially a considerable effect when the GSHP was installed and residents used the same heating regime as previously.
- Whilst residents did receive some compensation for periods when the heating failed, the increase in their electricity usage and, in consequence, their regular monthly payment would probably be a consideration when answering the question.
- Residents used electricity to heat domestic hot water prior to the GSHP. Currently, this is included within the energy costs of running the GSHP in flats. This would probably reduce the amount of electricity used to heat the water, but the amount is dependent on the hot water used in each flat.

2.4 Training and use of the GSHP System

Moat responsive repairs contractor, Mears, managed the project on a day to day basis, and carried out some engagement and training with residents, but there were issues in relation to resident understanding. During the final visits residents were asked about their experience of the training and instructions provided, and their thoughts and experiences of using the various controls. Their replies are shown in four bar charts in Figure 2-8. The 'y' axis of the bar charts has been maintained the same for all four charts to enable visible comparisons. Positive comments are shown in blue, less positive/negative comments are shown in red. Age and memory may be a factor with these answers as some of younger residents managed better than the older.

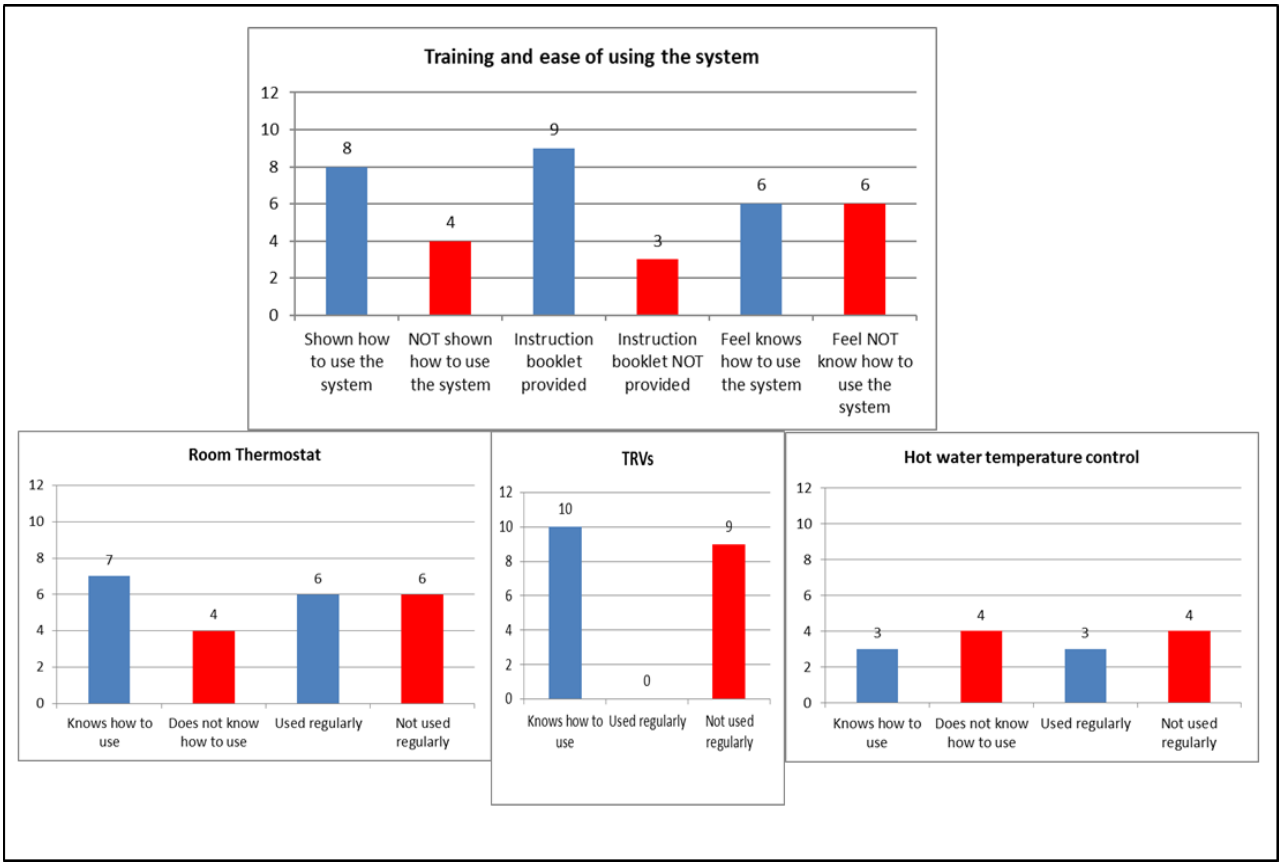


Figure 2-8, Responses to training and use of the GSHP

All residents questioned, reported that the thermostatic radiator valves (TRVs) were the main method of controlling their system.

- 4 residents reported adjusting them daily
- 1 resident reported adjusting them weekly
- 2 residents reported adjusting them monthly (in cold weather)
- 1 resident was unsure
- 1 resident did not use the heating

Satisfaction with 'ease of use' and 'control over' the system in the previous section is down by 16 and 6 percentage points respectively, however this may be due to initial lack of knowledge in using the controls as shown in Figure 2-8.
Satisfaction with 'how warm their flat is' and 'stays warm' in the previous section were both 3 percentage points down but again could be due to lack of knowledge in Figure 2-8.

When residents were asked on what action they would take if they were too cold, they replied as indicated in the bar chart in Figure 2-9.

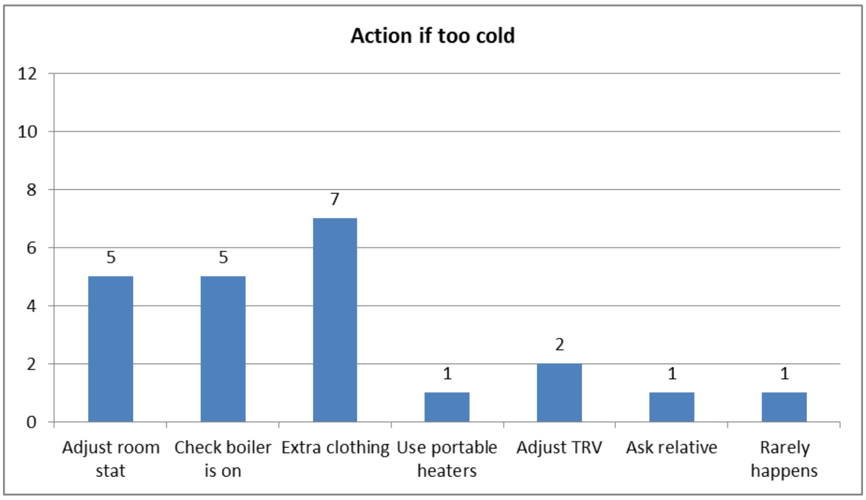


Figure 2-9, Resident action if they were too cold

Half of the residents reported wearing additional clothing rather than reconfiguring their heating controls; with similar numbers making appropriate adjustments to the heating controls. Some residents felt that the thermostat installed in the hall was in the wrong place.

Between February and April 2017 residents were less accepting of the new heating system.
In February 2017 there was a complaint concerning the system not working. An engineer (not from original contractor - Ground Heat) wrongly increased the temperature of the pre-heat system and caused a fault to develop. The fault was finally resolved by an engineer from Ground Heat Installations by which time this problem had caused the system to be out of order for approximately one week.
Residents were provided with electric fan heaters by Mears. The fan heaters caused the electricity bills of the residents to increase, and this led their energy suppliers increasing their monthly direct debit payments. Compensation was paid to residents to offset this increase. Property ref T-03 raised a complaint with their MP, however the issue was dealt with by the time he responded. Property ref T-01 suffered water damage, and Ground Heat agreed to pay for a new carpet.
In the summer, hot weather with temperature above 30°C caused the system to shut down. A cooling plate heat exchanger was fitted to prevent a reoccurrence.
The acceptance of the system improved as residents gained additional understanding of the system. The bar chart in Figure 2-10 shows information and actual comments in quotation marks, by residents regarding the break-downs. These were recorded in the questionnaire during the final visit by NEA.

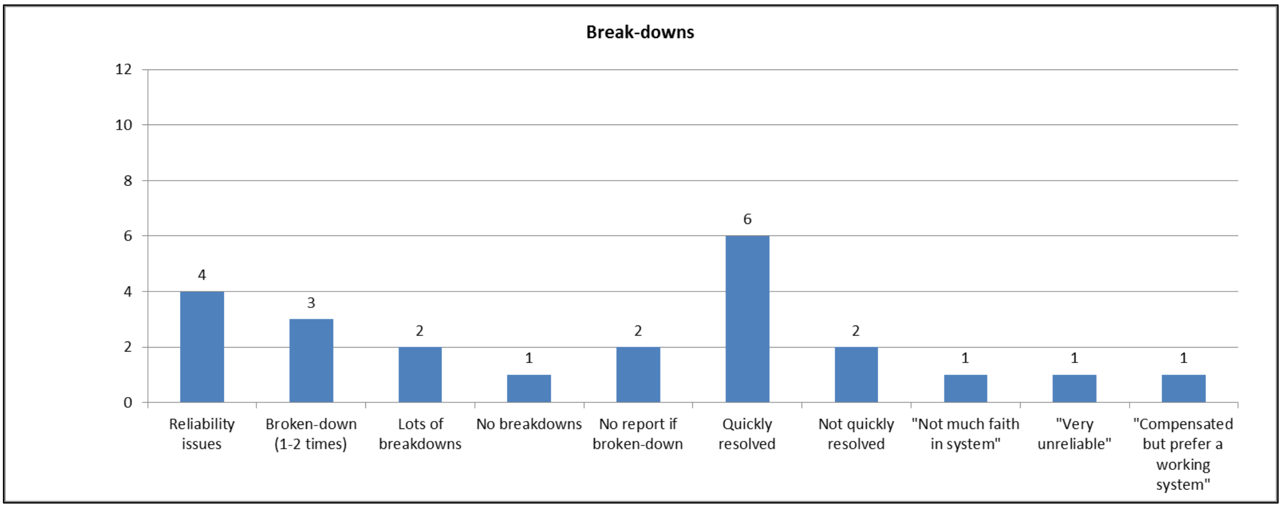


Figure 2-10, Resident comments regarding breakdowns

2.5 Perceived comfort and benefits

During the final visits residents were asked questions to gauge their perceived comfort levels and other benefits following the installation of the GSHP. The questions and their responses, expressed as a percentage of those providing the answers, are shown in the bar chart of Figure 2-11. The most obvious response was that no-one thought that the new system had reduced their energy bills. However, 50% thought that their home became warmer faster and were more comfortable.

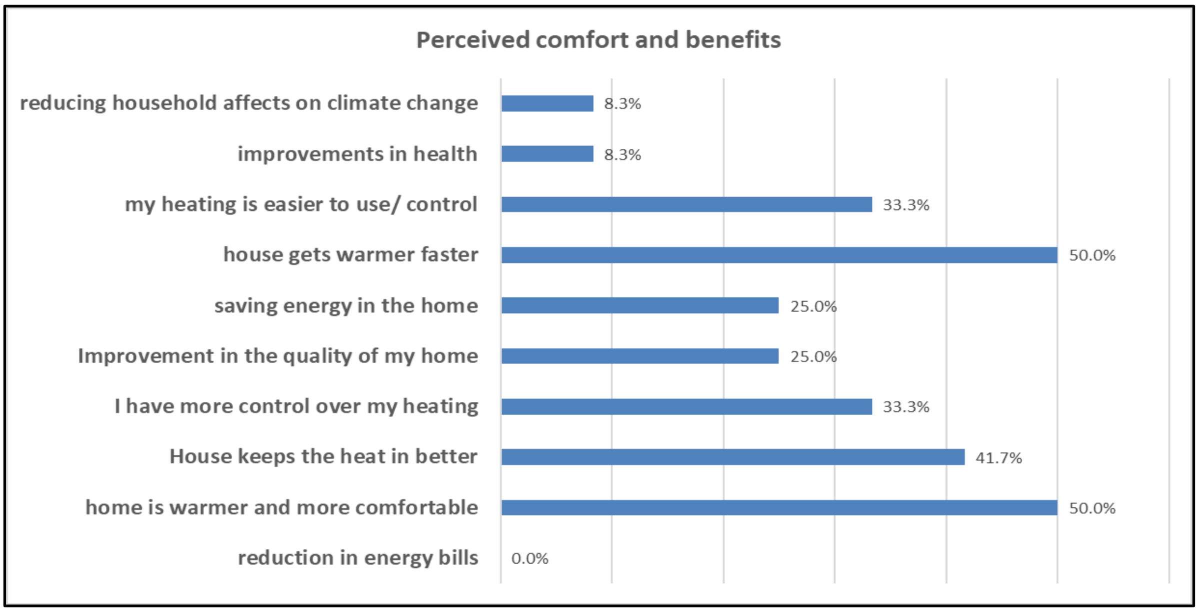


Figure 2-11, Perceived comfort and benefits

3. Technical evaluation and results

3.1 Overview of technology

In both blocks of flats, each home was fitted with a Vaillant geoTHERM mini 3kW ground source heat pump (see figure 3-1), a 100-litre unvented hot water cylinder, and Vaillant VCR 470 room thermostat/controller (see figure 3-2). Existing radiators were replaced with larger sized units to allow for lower temperature emitters characteristic of heat pump systems. The heating systems in each home were installed during the period 16th to 23rd June 2016.

Figure 3-1, Vaillant geoTHERM mini 3kW

Figure 3-2, Vaillant geoTHERM mini 3kW

In the main, larger, block 2 Vaillant geoTHERM ground source heat pumps were installed (1 - 30kW and 1 - 38kW) to pre-heat the brine solution from the bore holes. Pre-heated glycol was then distributed to the Vaillant geoTHERM mini 3kW units in each flat.

3.2 Technological monitoring

Temperature and Humidity levels in each flat were monitored by NEA using two self-contained Lascar USB-2 data loggers, placed in the lounge and bedroom. These were initially installed in each flat during late December 2015. These loggers were changed in early July 2017 to replenish the batteries, and finally removed during the middle of February 2018. Heat meters provided by NEA were installed by Ground Heat Installations as part of the new system installation works, in a limited number of the monitored flats. Event loggers attached to each heat meter, recorded heat energy (kWhs) produced by the Vaillant geoTHERM mini 3kW units. Ground Heat Installations installed electricity meters on cables supplying the GSHP units in each flat. Remote monitoring of these electricity meters allowed NEA to analyse household electricity consumption at 30 minute intervals, to reveal space heating and DHW energy demand for all 56 flats (including the monitored flats). This was achieved via a web portal[4] which enabled the data to be accessed for a period of up to 6 months. Due to portal access issues, historic data for the entire two-year period was not possible and resulted in gaps in available data.

The 'pre- heating' system in the main block (using two large 'pre-heating' GSHPs), was also planned for the smaller rear block but never installed. The units installed in the main, block were specified to increase the efficiency of the individual GSHP units in each flat. Once NEA was made aware that the pre- heat system was not installed in the rear block, attempts were made to recruit a monitored group from this population for comparison – but due to the profile of the residents, this had limited success.

Figure 3-3 shows a schematic of monitoring equipment used for the monitored flats in the main block. No monitoring was planned for the rear block but due to the difference in system design some residents in this block were approached to provide feedback. Data from the web portal was also downloaded to provide comparison of electricity used by the GSHP unit in each flat, and to compare between the two blocks.

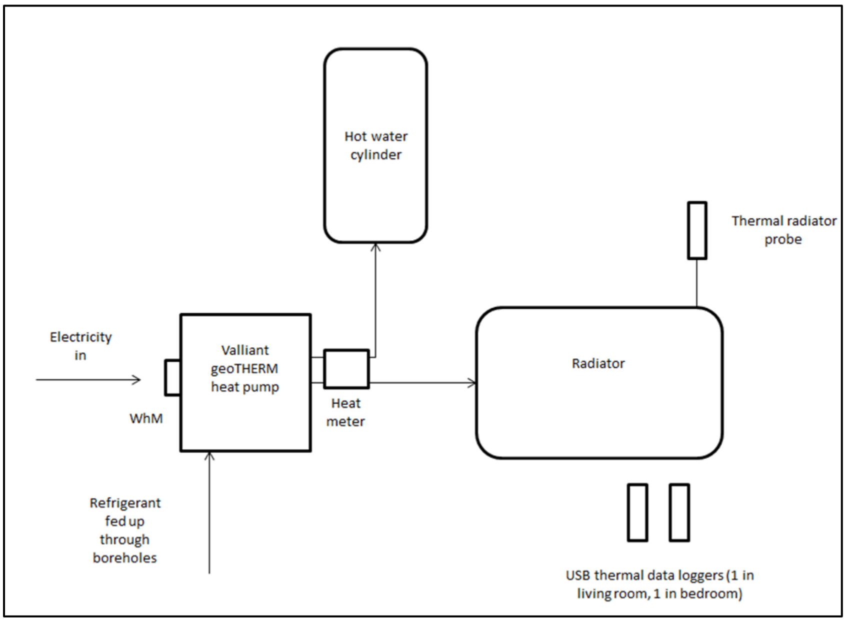


Figure 3-3, Schematic diagram of monitoring equipment

Figure 3-4 shows a schematic of the system used in the main block where the two larger GSHPs heat a buffer tank (Marked) which then supplies a constant 20°C temperature to the units in each flat.

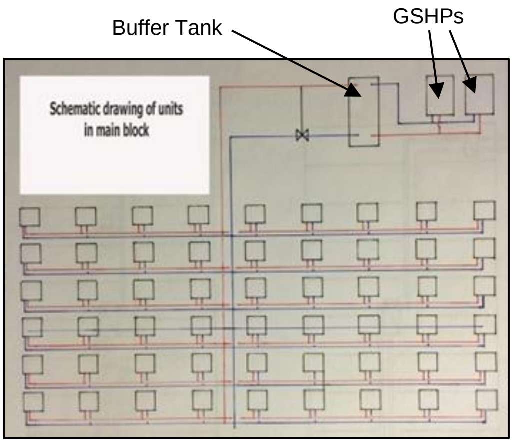


Figure 3-4, Schematic drawing of heating system in the main block

4 https://myreadings.readmymeter.biz/ [Accessed 22/05/2018]

3.3 Cost

Prior to the installation of the GSHP system, residents were charged a flat rate £156[5] per flat for heating provided from the old gas fired communal boiler system. Residents could have their heating on as long, or as little as they desired, paying a flat rate of £156 for unmetered heat. Residents reported that when in use they had very little control over the temperature in their individual flats. The heating system did not supply hot water, which was heated through electric immersion heaters and charged through resident's electricity accounts along with electricity used for other purposes such as lighting, domestic appliances, and portable electric heaters (if used).

The new system involved a change in the mechanism for paying for their heating. Residents now pay for the electricity to operate their heating system through their nominated electricity supplier, along with electricity used for other purposes such as lighting and other appliances. Electricity used by the GSHP alone in each flat is also separately metered as described earlier as part of this report to provide detailed analysis on space heating and DHW energy requirements (and therefore cost).

During the questionnaire phase of the project, some residents mentioned that they heated their homes 24/7 whilst others only heated their homes at selected times. As all residents previously paid a flat rate it follows that some residents were receiving more heat for the £156 than others.

The new system, as mentioned above, resulted in charges for electricity used by each flat to provide space and hot water heating. This will result in differing charges across the households, for different amounts of heat. The GSHP provides hot water heating, eliminating the older hot water tanks and immersion heater combination, and now having a modern 100 litre "renewable compatible" water tank heated by the GSHP. It should be noted that a scheduled sterilisation process takes place once a week (to control the risk from Legionella) whereby water temperature is raised to 60°C. The process is controlled by a time clock. It has been reported that in several instances, the time clock has been altered, resulting in lower electricity usage than expected, accompanied by a heightened risk of legionella. In instances where the clock times have been increased, there will be an associated increase in electricity usage, as the immersion heater will use more electricity than the GSHP to heat the water.

Some residents used electric showers which would reduce the demand for stored hot water (produced by the GSHP) and increase the electricity used through the household utility meter. Since the residents have an electric shower and no bath, the main use for water supplied by the water tank is for washing up. The 100 litre hot water tank was therefore likely to have been over specified and an instant water heater may have been more appropriate.

[5] Provided as part of original project bid by Moat Homes.

Analysis is based on available data from a number of sources; unfortunately, there are often gaps in that data that prevent complete analysis. Ideally the data should be available for the parameters detailed in Figure 3-3 and additionally:

1. Electricity consumption of the GSHP in each flat to provide space heating and DHW
2. Electricity consumption for lighting & household appliances including additional heating if used. (Calculated by deducting item 1 from the main electric meter).
3. Temperature and Humidity levels monitored in each flat
4. Data recorded by the heat meter and event logger
5. Degree-day data for the monitored period
6. Flat size, type, and position
7. EPCs lodged with the Land Mark website
8. Residents preferred comfort levels and heating periods

Where all the above is available full analysis can be achieved; however, some analysis can be achieved with partial data, but some assumptions need to be made.

Electricity consumption by GSHP in each flat

Of the sample of 12 monitored properties, data from the portal on electricity meters supplying the GSHPs was only available for 3 flats, due to metering communication issues with available WIFI and other technical factors. The following tables and charts are based on the three properties with available data.

Figure 3-5 shows the total electricity used by the GSHP in each property over the winter period stated.

Energy Use Analysis Period #1	
Start Date	**01 October 2017**
End Date	**04 March 2018**
Number of Days	**154**
Start Time	**00:00:00**
End Time	**23:59:00**
Hours per day	**23:59:00**
Tech Ref	**Total Consumption (kWh)**
T-03	308.10
T-06	2979.00
T-18	457.40
Count	3
Maximum	2,979.00
Minimum	308.10
Average	1,248.17
Median	457.40
Std Dev	1,500.80

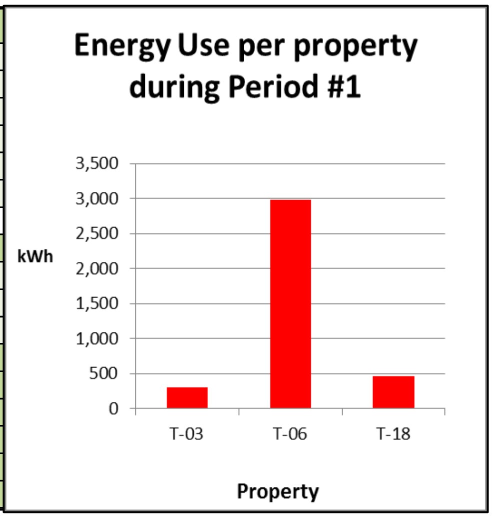


Figure 3-5, winter period GSHP electricity consumption, 24/7

Figure 3-6 shows the electricity used by the GSHP in each property over the same period but only during the times residents expressed as the period when heating was important (between 05:30pm and 9:00pm). The data suggests that property T-06, over the 24hr period is using vastly more electricity than the other two, 551.3% greater than T-18 and 866.9% greater than T-03). However, during the evening period, whilst T-06 is using more, the difference is greatly reduced, particularly compared to T-18. Further analysis of the heat meter data for the preferred heating period during the dates specified is not possible due to missing or malfunctioning equipment.

Energy Use Analysis Period #2	
Start Date	**01 October 2017**
End Date	**04 March 2018**
Number of Days	**154**
Start Time	**17:30:00**
End Time	**21:00:00**
Hours per day	**03:30:00**
Tech Ref	**Total Consumption (kWh)**
T-03	75.40
T-06	416.80
T-18	237.30
Count	3
Maximum	416.80
Minimum	75.40
Average	3.07
Median	237.30
Std Dev	170.78

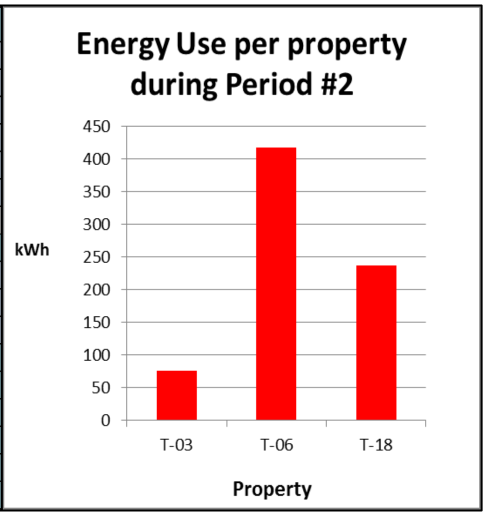


Figure 3-6, winter period GSHP electricity consumption, 17:30 to 21:00 only

Degree Day data analysis

Degree day data analysis is used to compensate for differences in outside temperature between the periods being compared. Zero Degree Days indicates an average outside temperature of 15.5°C and the generally accepted point below which internal heating is required. One degree below 15.5°C (14.5°C) is equivalent to 1 degree-day; two degrees below 15.5°C (13.5°C) is equivalent to 2-degree days etc. etc. The greater the number of degree days, the colder the outside temperatures, and the greater the need to heat the property to maintain adequate comfort levels. Degree Day data is available from various sources and is based on data collected from weather stations across the UK. Degree day data for this project was obtained from the Bizee website[6] using the London Weather Station (Ref: EGLL), which is close to the project site.

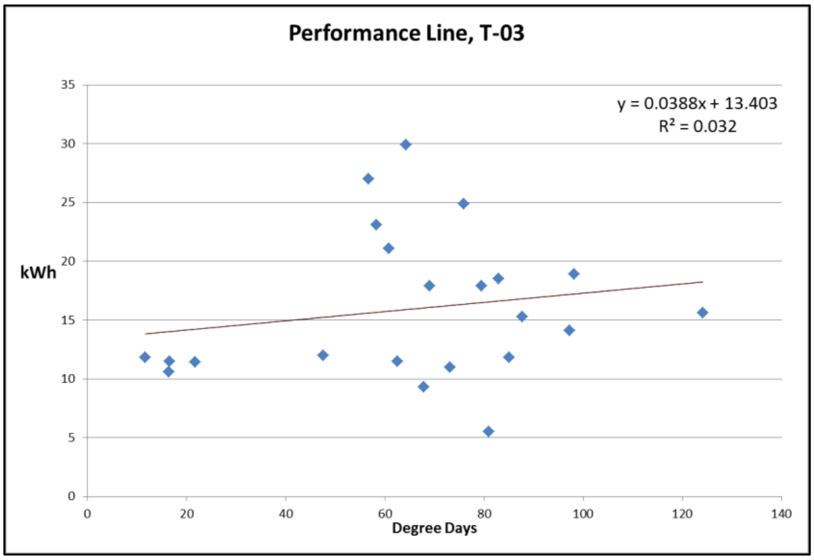
Analysis using energy consumption recorded on the meter installed with the GSHP and degree-day data for the same period was used to prepare performance line graphs shown in Figure 3-7. Note that the y axis scale differs between the graphs, which follow an accepted format by energy professionals.

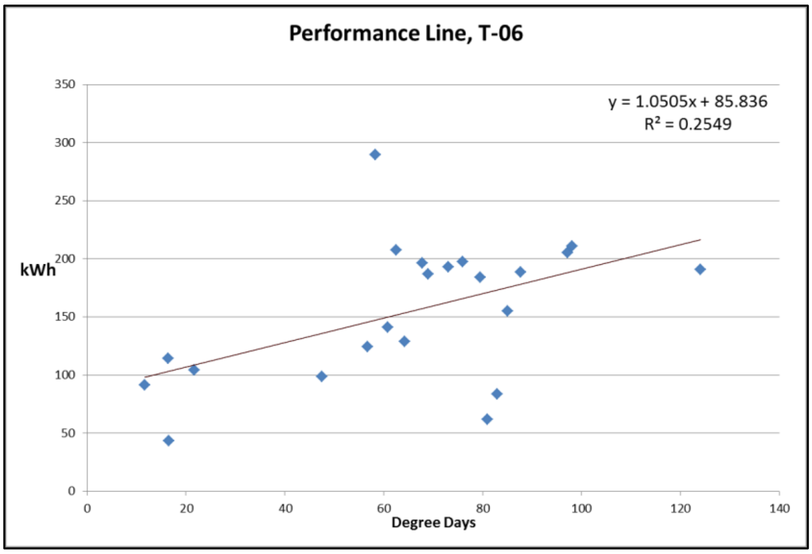
The point at which the performance line crosses the Y axis is also very different for the 3 properties. This point is shown in the equation after the '+' sign and indicates the base load - considered as non-weather dependant energy use. As the only energy use monitored by this meter is the GSHP and the immersion heater for sterilisation purposes, the base load will either be excessive space heating or DHW.

Data points on, or close to, the Performance Line indicate good control over the heating based on outside weather conditions (obtained from Degree Day data). It should also be noted that data point scatter could also be due to a number of other factors including the number of outside walls or the possibility of heat gained form adjoining flats (the floor below or adjacent on the same floor), or increased heat loss through the roof for flats on the top floor. The graphs in Figure 3-7 suggest that:

- Property T-03 (Bed-sit, mid floor, end ter.) has poor control (scatter) over the heating in relation to the outside weather conditions and a base load of 13.403 kWh, presumably for hot water.
- Property T-06 (1 bedroom, top floor, end ter.) has slightly improved control over the heating (compared to property T-03) but has a very high base load of 85.836kWh. The later section on monitored temperature suggests that excessive heating is NOT the case in properties T-03 and T-18. But may be the case here.
- Property T-18 (Bed-sit, ground floor, end terrace) has the most efficient control over the system in relation to outside weather conditions and the lowest base load of 9.0965kWh.

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





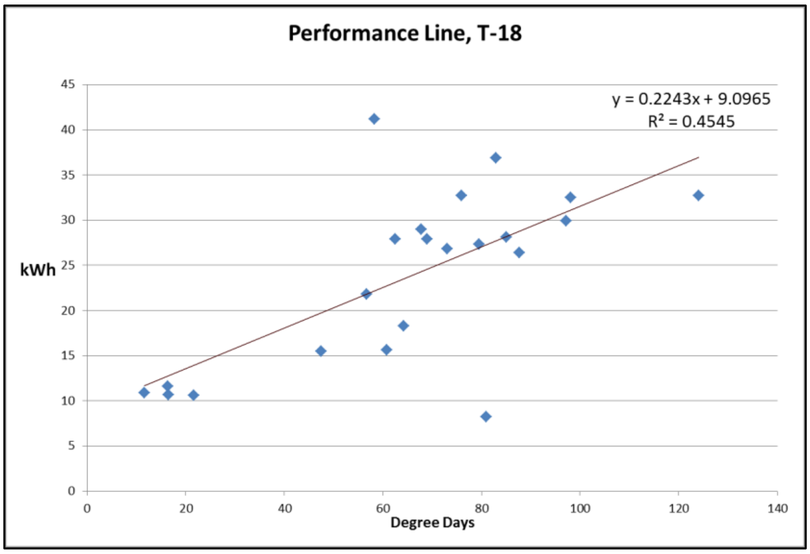


Figure 3-7, Performance Line graphs

From various discussions during the project with partners and residents, concerns were raised that heating controls may have been adjusted without the necessary understanding of the implications of those adjustments.

NEA's understanding is that the electricity meter installed with the GSHP (accessed via the web portal), recorded the energy consumption of the GSHP. Manufacturer's datasheets state that the heat pump has an energy demand of 0.75kW[7]. In addition, energy consumption by an immersion heater to provide sterilisation of the DHW periodically and regularly would also be included. It was therefore expected that the power demand via this meter would generally record a figure of 0.75kW plus occasional peaks of 3.0kW for the immersion heater when required.

However, data analysis from the portal does not support this assumption, the three graphs below show power demand for the three properties during the period of March 2018. Property reference numbers T-03 andT-08 indicate some peaks above 0.75kW but not up to the 3.0kW expected for immersion heating / sterilisation process.

Property reference T-06 has multiple peaks above 0.75kW but again not up to the expected 3.0kW level - see figures 3-8, 3-9, and 3-10).

These findings suggest that due to unidentified adjustments made to the controls, the immersion heater timing and/or temperature may have been reset to provide DHW to a temperature of 60°C for longer periods than intended.

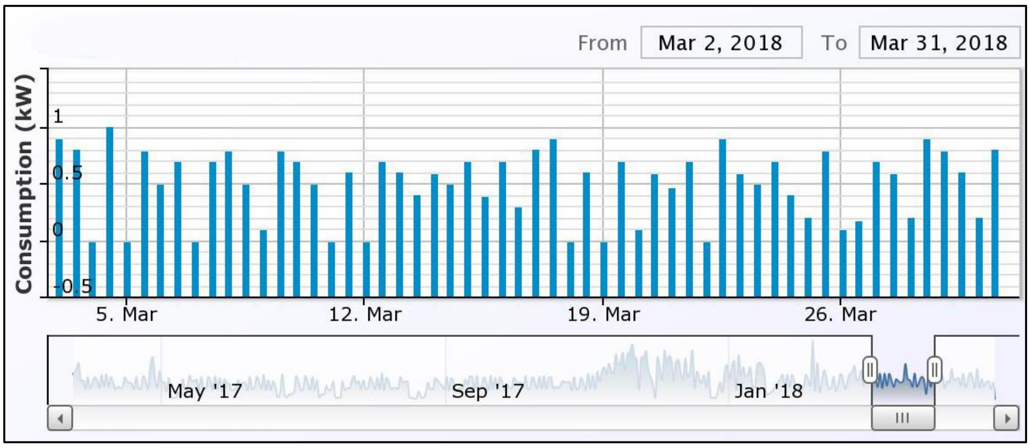


Figure 3-8, Power demand T-03

[7] https://www.vaillant.co.uk/downloads/geotherm-mini-1/geotherm-3kw-mini-tech-spec-1-4-web-1204120.pdf [Accessed 22/05/2018]

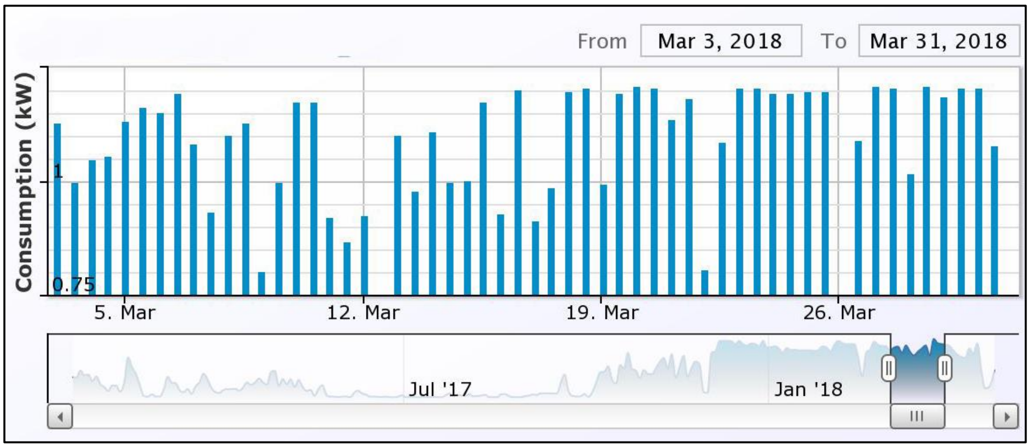


Figure 3-9, Power demand T-06

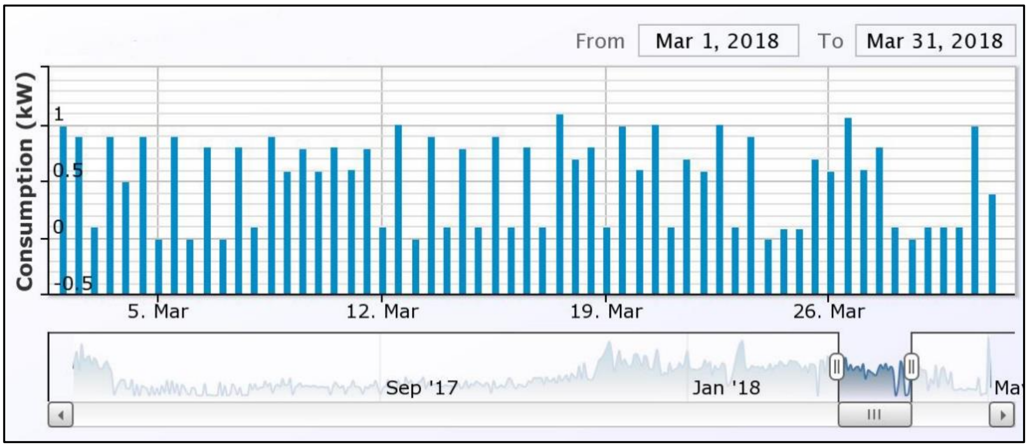


Figure 3-10, Power demand T-18

Analysis of portal data for other flats supports this theory. In the example below meter FC41966 is analysed for a 12 month period from 5th March 2017 to 4th March 2018. Peaks above 2.5kW can be seen during March 2017 but none for the remaining 12 month period, (see figure 3-11)

Figure 3-11, Power demand T-20 (12 months)

Closer analysis of the period in March 2017 in the graph in figure 3-12 shows that power demand over very short periods (up to 5 minutes) was as follows:

- Wednesday March 8th at 08.32hrs the power demand was 3.00kW
- Sunday March 12th at 08:02hrs the power demand was 3.50kW
- Wednesday March 15th at 19:32hrs the power demand was 3.94kW
- Wednesday March 29th at 18:03hrs the power demand was 3.79kW

The varying number of days between each peak demand and the time it occurred does not support the theory that a time-clock had been set to provide regular sterilisation, but this may have occurred where the water thermostat had been set to the appropriate temperature, or a "boost" was required due to high domestic hot water demand. However, the remaining 11 months does not show any sterilisation process operating. If both the time clock and water temperature thermostat had been manually adjusted, then sterilisation may have occurred, but further investigation would be needed to establish whether: -

1. Sterilisation is being achieved at appropriate intervals / temperatures?
2. Whether the DHW system provides the most economic method or supplying DHW requirements?

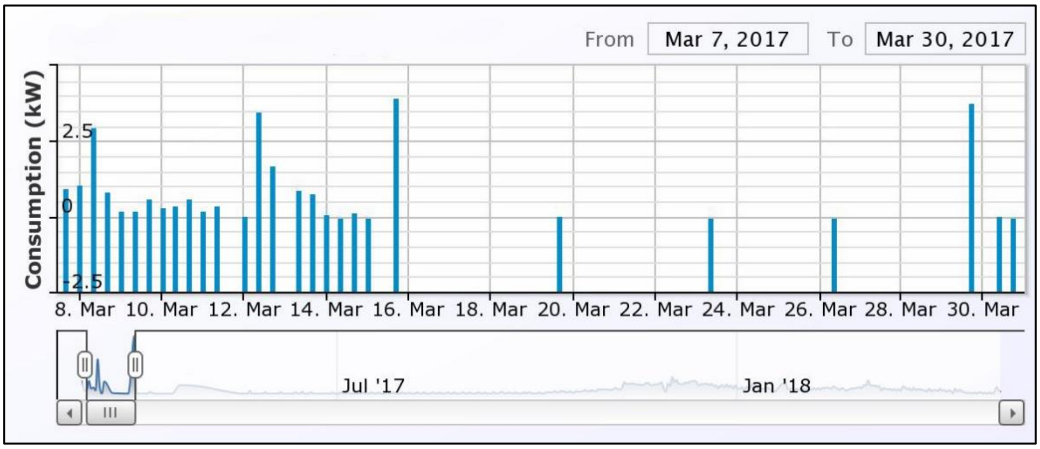


Figure 3-12, Power demand T-20 (March 2017 only)

Main utility electric meter analysis

The planned monitoring regime for this project specified that energy consumption was logged from a number of sources, and cross referenced to provide increased confidence levels in the data. Due to a number of reasons covered earlier, full data was only available for a very limited number of the monitored properties. NEA intended to have data relating to:

- Electricity consumption of the GSHP in each flat (via the web portal)
- Heat energy produced by the GSHP in each flat (via event loggers connected to installed heat meters in each flat)
- Total electricity used by each flat from meter readings taken by NEA and partner staff in the flats)
- Data should have been available for 3 consecutive years.

Prior to the installation of the GSHP, the utility meter in each flat would have recorded all energy used (except for that supplied by the communal heating and covered by the £156 standing charge per year) for heating provided by the communal gas heating system. Following the installation of the GSHP the communal charge ceased and all energy use in each flat was recorded on their individual utility meter. This included the electricity recorded by the sub-meters installed as part of the GSHP system project.

As mentioned earlier, each flat has a main electricity meter (in a locked room on the ground floor) which is used by the resident's energy supplier to charge for all electricity used by each flat. The meter installed with the GSHP is a sub-meter of this main utility meter and therefore by deducting the GSHP usage from the main meter allows calculation of "other" energy use (excluding space and hot water heating now provided by the GSHP). The remaining usage will include:

- Lighting
- Domestic appliances
- Electric shower (where used
- Immersion heater for sterilisation
- Immersion heater for DHW (where applicable)
- Portable electric heaters (if/where used)

Figure 3-13 analyses electricity consumption in each flat. Although these periods may be slightly different from the earlier section, the table uses the same period for the utility meter and sub-meter in each of the three properties concerned, to calculate the percentage of energy used by the GSHP compared to non-GSHP use.

Tech. Ref.	Period			Flat Main Electricity meter		Flat GSHP meter (noon to noon)		Use without GSHP (kWh)		Percentage of use	
	From	To	days	Total	Per week	Total	Per week	Total	Per week	GSHP	Non-GSHP
T-03	05/10/2017	13/02/2018	131	1,478	78.98	266	14.21	1,212	64.76	18.0%	82.0%
T-06	17/01/2018	13/02/2018	27	782	202.74	676	175.26	106	27.48	86.4%	13.6%
T-18	05/10/2017	13/02/2018	131	1,091	58.30	380.5	20.33	711	37.97	34.9%	65.1%
Average				**1,117**	**113.34**	**441**	**69.94**	**676**	**43.40**	**61.7%**	**38.3%**

Figure 3-13, Electricity consumption in each flat comparing GSHP to non-GSHP

Data from the web portal is not available for the 2016/17 winter as the portal only allows for the most recent 6 months of data to be downloaded. Whilst data has been downloaded several times access to the portal data was not available during some periods to download data for the 2016/17 winter. In addition, no data was available for some flats.

However, NEA and partner staff collected meter readings from the main utility meter over an extended period of up to three years. Table 3-14 analyses total energy used by each flat as recorded on the main utility meter during the following 3 periods:

- 2015/16 winter prior to the installation of the GSHP
- 2016/17 winter, the first winter period of using the GSHP
- 2017/18 winter, the second winter period of using the GSHP (as analysed in the last section)

Tech. Ref.	2015/16			Flat Main Electricity meter		2016/17			Flat Main Electricity meter		2017/18			Flat Main Electricity meter	
	From	To	days	Total	Per week	From	To	days	Total	Per week	From	To	days	Total	Per week
T-03	22/02/2016	24/03/2016	31	238	53.74	15/09/2016	23/03/2017	189	1,629	60.33	05/10/2017	13/02/2018	131	1,478	78.98
T-06	22/02/2016	24/03/2016	31	128	28.90	15/09/2016	23/03/2017	189	1,755	65.00	17/01/2018	13/02/2018	27	782	202.74
T-18	22/02/2016	24/03/2016	31	180	40.65	15/09/2016	23/03/2017	189	1,995	73.89	05/10/2017	13/02/2018	131	1,091	58.30
Average				**182**	**41.10**				**1,793**	**66.41**				**1,117**	**113.34**

Figure 3-14, Energy consumption (kWh's) calculated from main meter readings

The weekly use (KWhs) from figure 3-14 have been used in figure 3-15 with a cost of 14p/kWh to provide a comparison weekly cost over the three winter periods. Note that the 2015/16 winter cost in figure 3-16 excludes the communal charge for heating - £156 per year (£3.00 per week). Both the 2016/17 and 2017/18 figure included the cost of heating from the GSHP as this is included in the main utility meter readings.

Tech. Ref.	2015/16		2016/17		2017/18	
	Weekly use (kWh)	Weekly cost	Weekly use (kWh)	Weekly cost	Weekly use (kWh)	Weekly cost
T-03	53.74	£7.52	60.33	£8.45	78.98	£11.06
T-06	28.90	£4.05	76.07	£10.65	202.74	£28.38
T-18	40.65	£5.69	73.89	£10.34	58.30	£8.16
Average		£5.75		£9.81		£15.87

Figure 3-15, Weekly electricity cost using utility meter readings

Using the £156 per year (£3 per week) communal heating charge for 2016/17, the average weekly figures can be summarised as:

2015/16	**£8.75**
2016/17	**£9.81**
2017/18	**£15.87**

It should be noted that 2017 had 875.0 degree days, 111.8 (11.3%) fewer than 2016 (986.8) based only on the period of analysis (see Figure 3.16). During the same period in 2018, the number of degree days increased to 1,023.1, 36.3 more (colder) than 2016 and 148.1 (even colder) than 2017.

Degree Days, 4th January to 30th April			
Year	2016	2017	2018
Total	986.8	875.0	1,023.1
Maximum	15.1	16.1	19.6
Minimum	2.7	1.3	0.7
Average	8.4	7.5	8.7

Figure 3-16, Three year degree day comparison

The data from figure 3-16 is shown in graphical form in Figure 3-17

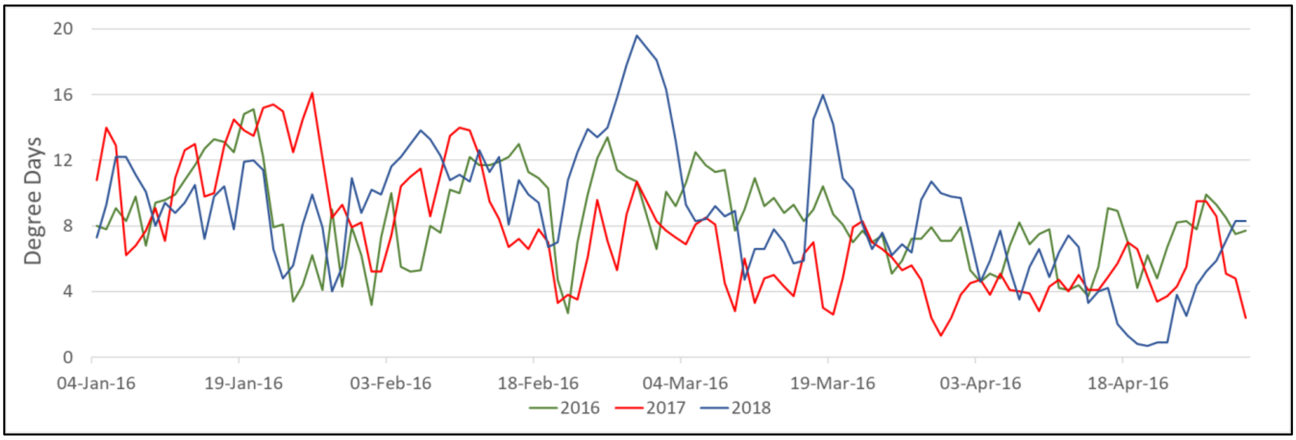


Figure 3-17, Graph showing 3 year degree day data

During February, March and April 2017, part of the first winter following installation of the GSHP, the graph clearly shows (red line) that the number of degree days were generally lower than the other two, indicating warmer outside weather conditions. During the same months of 2018 the graph clearly shows (blue line) that the number of degree days were generally higher than the other two, indicating colder outside weather conditions.

By using a 20 year average of degree days analysis can be provided to indicate the energy used in a standardised format across all three years. This enables comparisons to be made between the periods, compensating for differences in outdoor temperatures.

Table 3-13 shows the details for 11 flats where adequate energy data is available, based on electricity utility meter readings. One flat has been omitted from this table as it was unoccupied by the resident for a considerable time and would have adversely influenced the reliability of the results.

The figures are based on:

- Calculations of electricity use from actual utility meter readings obtained by partners.
- Degree day data, for the periods covered by those readings, to show kWh per degree day.
- 20 year average degree day data to provide cost comparisons on a like-for-like basis
- In year 1 the standard charge of £156 has been added to the total cost calculation

	3 year total electricity cost comparison based on 20 year average degree day data								
	Year 1, communal gas heating			Year 2, GSHP			Year 3, GSHP		
Tech. Ref	kWh/DD	20Yr average kWh	Total annual cost	kWh/DD	20Yr average kWh	Total annual cost	kWh/DD	20Yr average kWh	Total annual cost
T-01	0.463	1222.5	£327.16	1.775	4683.1	£655.63	1.838	4850.6	£679.08
T-02	1.037	2737.4	£539.24	1.277	3369.4	£471.72	1.536	4052.5	£567.35
T-03	1.151	3038.8	£581.43	1.386	3656.5	£511.91	1.707	4505.0	£630.70
T-04	0.570	1504.3	£366.60	1.559	4113.9	£575.95	0.951	2510.0	£351.41
T-06	1.110	2928.6	£566.00	1.716	4528.5	£633.99	3.259	8600.4	£1,204.05
T-08	0.621	1639.2	£385.49	2.671	7047.7	£986.68	5.442	14360.7	£2,010.49
T-11	1.346	3552.5	£653.34	2.777	7327.7	£1,025.87	4.613	12173.4	£1,704.28
T-16	0.896	2365.8	£487.22	1.457	3844.3	£538.21	1.924	5077.1	£710.79
T-18	0.698	1841.8	£413.86	1.456	3842.0	£537.88	1.577	4161.8	£582.66
T-20	0.832	2196.2	£463.46	1.120	2955.3	£413.74	1.523	4018.3	£562.56
T-23	0.607	1601.6	£380.22	0.860	2269.1	£317.67	0.710	1874.0	£262.37
Minimum	0.463	1,222.544	£327.16	0.860	2,269.081	£317.67	0.710	1,874.048	£262.37
Maximum	1.346	3,552.456	£653.34	2.777	7,327.662	£1,025.87	5.442	14,360.660	£2,010.49
Average	0.848	2,238.974	£469.46	1.641	4,330.686	£606.30	2.280	6,016.704	£842.34
includes £156 communal heating charge ↑				20 year average degree days (London)				2,639	

Figure 3-18, 3 year total flat electricity cost comparison

Note:
Appendix 4 shows tables for the three years covered and provide more background data for the figures in the figure 3-18.

Figure 3-18 shows that, based on a 20 year average number of degree days, the total annual electricity cost in:

- **Year 1** (prior to the installation of the GSHP) plus the £156 communal heating charge per flat ranged from £327.16 to £653.34, an average of £469.46 per year.

- **Year 2** the first year following the installation of the GSHP, the total cost for electricity reduced for 4 flats (T-02, T-03, T-20, & T-23), but increased for the other 7 flats. On average the minimum cost reduced by £9.49 (2.9%) on the previous year but the maximum cost increased by £372.53 (57.0%) over the previous year.

- **Year 3** 2 flats (T-04, & T-23) showed a reduction on year 1, with the same 2 flats also showing a reduction over year 2. The minimum average cost reduced to £262.37 (17.4%) compared to year 2 and 19.8% lower than year 1. The maximum average cost increased by 96% over year 2 and 207% over year 1. Average annual costs in year 3 increased to £842.34, 39% higher than year 2 and 79% higher than year 1.

There are potentially a number of reasons for the wide difference mentioned above including (but not exhaustively):

- During year 1 ALL flats paid the same charge of £156 for heating. Different residents will have heated their flat at different times, for different lengths of time, and to different temperature levels than others.
- Different flats will have different heat-loss requirements depending on flat size, and flat position within the block.

Energy Performance Certificate (EPC) Data

Heating Costs based on EPC data was analysed to augment the data obtained and analysed in this report. EPC data was obtained from EPC Certificates lodged on the Landmark website[8]. To help provide sufficient comparison data between ‘before’ and ‘after’ the GSHP was installed, it was necessary to use data from non-monitored properties as there are a limited number of EPCs lodged on the Landmark website, (see Figure 3-19).

Available EPC Data	Previous system	GSHP system
Monitored properties	5	0
Non-monitored properties, Main block	17	4
Non-monitored properties, Rear block	9	0

Figure 3-19, Availability of EPC data

In Figure 3.20 the non-monitored properties are indicated in the ‘Tech Ref’ (Technical reference) column as ‘N/M’ to maintain the anonymity of all residents. Selection was made based on matching floor area and if Ground, Mid, or top floor where possible. This however limited the choice to just 4 flats, 2 before and 2 after the installation of the GSHP.
Figure 3.20 also shows anomalies due to a number of factors, in particular, the method of heating the hot water listed on the EPC (see key below the table). Lighting costs, although a relatively low improvement had 83% of low energy lighting had a lower cost for lighting than a similar sized proportion of the overall energy cost, also show unexpected results. The ground floor flat before and after improvements and 100% low energy lighting.

Tech Ref.	Floor	Floor area	Heating System	Heating cost	Hot-Water cost	Lighting cost	Low-energy Lighting	Total cost	EPC Rate	EPC Band
N/M	Ground floor	31m²	Community	£113.00	[1] £288.00	£18.00	83%	£419.00	64	D
T-18	Mid-floor	41m²	Community	£156.00	[2] £142.00	£44.00	40%	£342.00	77	C
Average				£134.50	£215.00	£31.00	61.5%	£380.50	70.5	
N/M	Ground floor	30m²	GSHP	£180.00	[3] £134.00	£24.00	100%	£338.00	75	C
N/M	Mid-floor	41m²	GSHP	£119.00	[3] £109.00	£38.00	80%	£266.00	81	C
Average				£149.50	£121.50	£31.00	90%	£302.00	78.0	

[1] Hot water from electric immersion at standard tariff
[2] Hot water from Community system
[3] Hot water ‘from main’ (GSHP)

Figure 3-20, EPC comparison data before and after installation of the GSHP

[8] https://www.epcregister.com/ [Accessed 22/05/2018]

Based on the EPC for the four properties (2 before and 2 after the improvements) the average reduction in energy costs was £78.50 (20.63%). Average EPC ratings increased from 70.5 to 78.0 (7.5 points).

Analysis of data for the 5 monitored flats, for which EPCs are available, shows the lowest rating was 52 (Band E) and 84 the highest (Band B); all of which are based on the original communal heating system. Following the installation of the GSHP the four non-monitored properties lowest rating was 75 (Band C); the highest was 85 (Band B).

Figure 3.21 shows the Energy Efficiency Ratings and band used in EPCs.

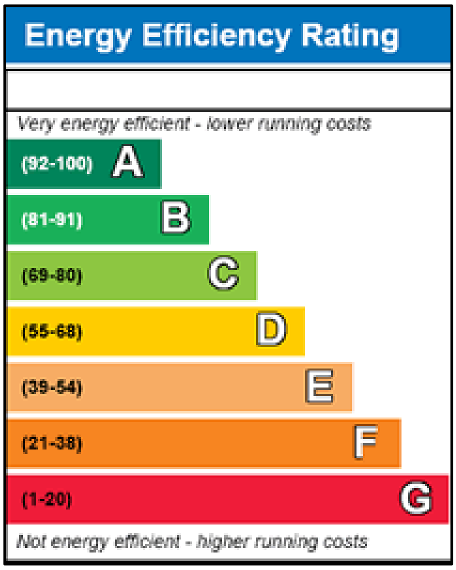


Figure 3-21, Energy Efficiency ratings & bands

3.4 Temperature and thermal comfort

Analysis of the data downloaded from the temperature and humidity loggers placed in the lounge of each property is shown in Figure 3.22. This data allows comparisons to be made on the comfort levels before and after GSHP was installed and between various flats within the block. It was also possible to compare the periods when the residents reported that it was important for their home to be warm. This was taken as between 5.30pm and 9:00pm as discussed in the previous section. The 7 properties listed are those where there is sufficient data. Data was lacking for other properties due to a number of reasons but in particular to loggers being lost, misplaced, or incorrectly installed (usually too near a heat source).

	Living room pre-measures 4th Jan - 30th April 2016				Living room post measures 4th Jan - 30th April 2017			
	5.30 - 9pm	24 hours	24 hours	24 hours	5.30 - 9pm	24 hours	24 hours	24 hours
Tech Ref. No	Average Temp (°C)	Average Temp (°C)	Maximum Temp (°C)	Minimum Temp (°C)	Average Temp (°C)	Average Temp (°C)	Maximum Temp (°C)	Minimum Temp (°C)
T-01	21.00	20.64	26.00	16.00	21.80	21.52	26.50	16.50
T-02	21.74	21.29	25.50	17.50	21.72	21.24	24.00	18.50
T-03	24.14	23.43	28.00	18.50	22.62	21.93	30.50	18.00
T-08	24.18	24.08	30.50	18.50	25.33	25.29	28.50	20.50
T-18	19.97	18.88	29.00	13.00	20.00	18.82	28.50	12.50
T-20	22.84	22.78	25.00	20.50	21.13	20.46	25.50	15.50
T-23	25.10	24.93	28.50	22.00	25.04	24.71	30.00	20.00
Average	**22.71**	**22.29**	**27.50**	**18.00**	**22.52**	**22.00**	**27.64**	**17.36**
Degree days	**997.6**				**875.0**			

Figure 3-22, Analysis of room temperature data

Temperatures in properties indicated by the table in Figure 3.11 show the pre- installation period from 4th January 2016 to 30th April 2016 and the equivalent post-installation monitored period in 2017. The average figure for the 7 properties across the 4 columns in the pre-section and 4 in the post section show a difference of between -0.64 °C and +0.14 °C.

During the preferred heating period (5:30 – 9:00pm) property T-08 increased the average temperature by 1.5°C; Properties T-03 and T-20 reduced their average temperature by 1.5°C and 0.7°C respectively. All others maintained the same average temperature (within ±0.1°C) following the improvements to their properties.

This suggests that most residents achieved a similar temperature range as that recorded prior to the new system being installed. This is contrary to the earlier comment that the old system had limited controls and residents complained about being too hot or too cold. One exception is property T-20 where the minimum temperature over the 24-hour period rose from 15.5°C for the 'pre' period to 20.5°C after the GSHP was installed. However, T-18 maintained a similar low temperature 'pre' and 'post' installation of the GSHP.
Residents were generally able to maintain very similar comfort levels before and after the improvements. The amount of energy used to achieve this is covered in the preceding sections.

Figure 3.23 shows a graphical representation of the comfort levels before and after the installation of the GSHP.

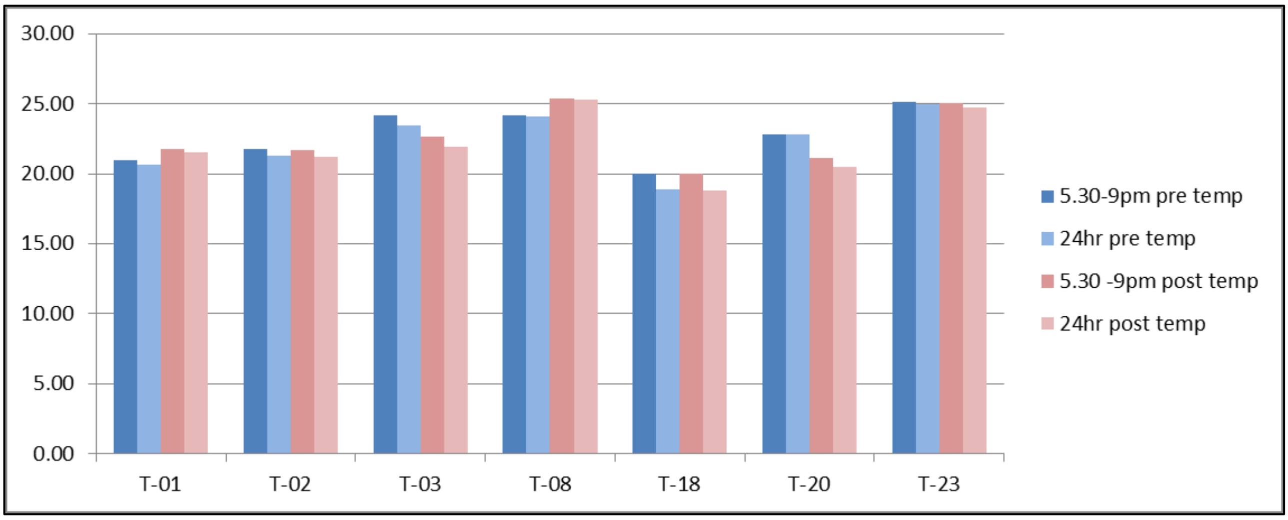


Figure 3-23, Graphical representation of comfort levels

3.5 Humidity

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

Figure 3.24 illustrates the optimum humidity levels as cited by Arundel et al[9]. The study concluded that maintaining relative humidity levels between 40% and 60% would minimise adverse health effects relating to relative humidity.

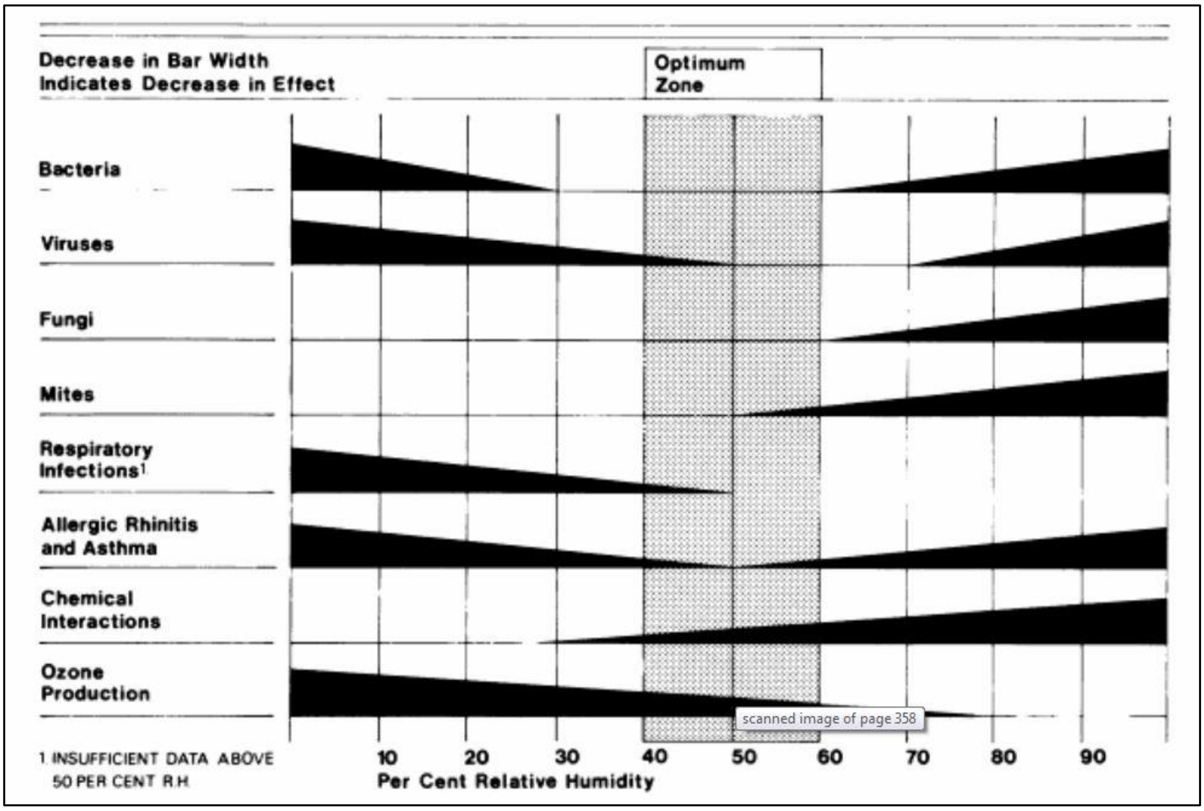


Figure 3-24, Optimum levels of Relative humidity

The automated data-loggers used in this project record both temperature and relative humidity (RH) at pre-determined regular intervals across the monitored 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

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

related health problems. From the Building regulations part F[10]; the suggested average monthly maximum humidity levels for domestic dwellings during the heating season is 65%.
The table (Figure 3.26) and graph (3.27) shows data obtained from the temperature and humidity loggers mentioned in the previous section. The same dates and time periods have also been used as for temperature in the temperature section. The data for the period prior to the installation of the improvements indicate that the relative humidity is close to or slightly below the 40% figure mentioned above as the minimum to avoid adverse health conditions. After the new heating system was fitted the overall average improved to just over 41% although T-08 and T-20 reduced by approximately 3%. Property T-20 also reduced their average temperature by 1.5°C which, in theory, would have possibly increased the relative humidity. However as, in general, the room temperatures were above the recommended temperature levels of 18-21°C across a wider age group, the lower humidity levels are not unexpected.

	Living room pre-measures 4th Jan - 30th April 2016				Living room post measures 4th Jan - 30th April 2017			
	5.30 - 9pm	24 hours	24 hours	24 hours	5.30 - 9pm	24 hours	24 hours	24 hours
Tech Ref. No	Average Humidity (%)	Average Humidity (%)	Maximum Humidity (%)	Minimum Humidity (%)	Average Humidity (%)	Average Humidity (%)	Maximum Humidity (%)	Minimum Humidity (%)
T-01	37.72	38.03	55.50	23.00	41.18	40.98	59.50	25.50
T-02	38.72	37.65	60.50	24.50	44.23	43.07	64.00	27.00
T-03	38.65	38.38	56.50	24.50	43.92	42.54	62.00	25.50
T-08	38.52	35.94	49.00	18.00	35.58	35.28	51.50	22.50
T-18	43.50	43.31	64.00	27.00	45.10	44.67	64.50	28.00
T-20	40.66	37.41	59.50	20.00	37.07	36.98	49.00	23.50
T-23	39.25	38.92	57.00	24.00	40.08	39.55	62.00	27.00
Average	**39.57**	**38.52**	**57.43**	**23.00**	**41.02**	**40.44**	**58.93**	**25.57**

Figure 3-25, Table of humidity levels

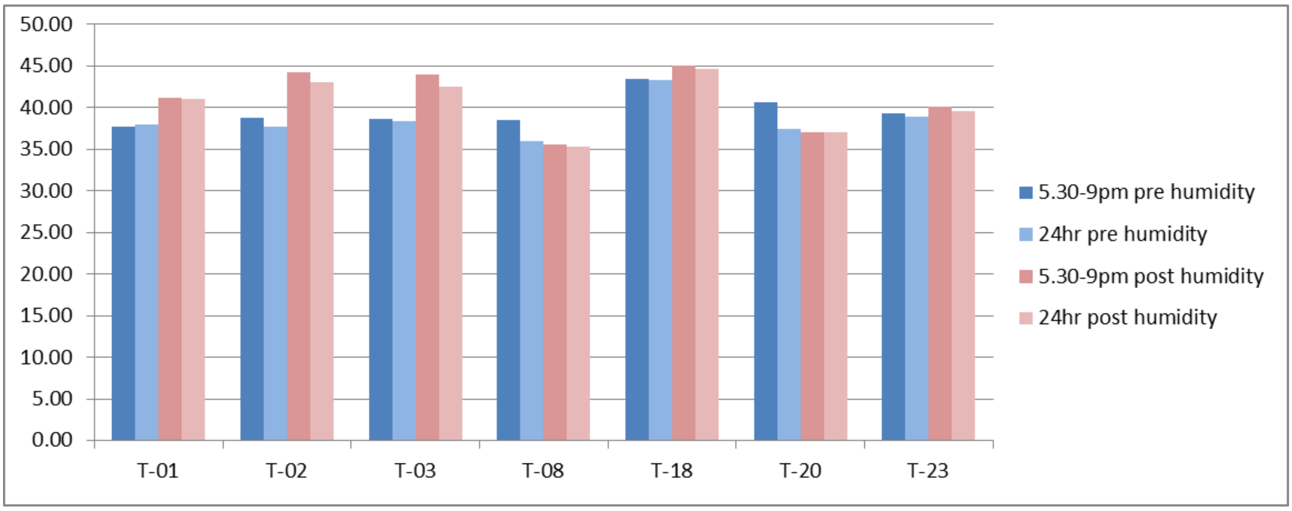


Figure 3-26, Graph based on data from Figure 3.16

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

The basic level of warmth required for a healthy and well-dressed person is 18°C. This standard is recognized by the World Health Organization and is the minimum standard in the latest UK cold weather plan[11]. Basic benchmarks for indoor temperatures are:

- Higher than 24°C cardiovascular risk
- 18-21°C comfortable temperature
- 18°C minimum for comfort
- 12-16°C respiratory risk
- Less than12°C cardiovascular risk

[11] The Cold Weather Plan for England, https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/652564/Cold_Weather_Plan_2017.pdf [Accessed 22/05/2018]

4. Conclusions and recommendations

4.1 Conclusions

The project had the following aims:

- Learning more about the performance of Ground Source Heat pump technology in low rise tower blocks and at householder level, the role it can play in tackling fuel poverty.
- Reduced heating and hot water bills to just £180 per annum.
- Provide residents with greater control and information about energy consumption using the remote monitoring and installed control system.
- Provide residents with an improved level of reliability, response, and service should any technical issues arise indicated by remote monitoring of the smart system being applied.
- Provide insight into the suitability of the technology in other property types.

Learn more about the performance of GSHP technology
Communal heating was originally provided to all flats through a gas boiler system. Each flat having limited control of the amount of heat provided. Residents had complained that there was insufficient control was available to them, causing temperatures to be too high or too low at times.

The new GSHP controls were confusing to residents, with complaints made about insufficient training. Furthermore, there was anecdotal evidence that system controls had been changed by unauthorised people causing faults to occur resulting in breakdowns and additional costs to residents due to issues with the system and, during system breakdowns, the use of portable electric heaters. (Compensation was paid to residents for any additional expense incurred for operating electric portable heating).

Reduced heating and hot water bills
In this project the residents previously paid a standing charge for their heating. There was a large range of heating requirements, and all residents paid the same standing charge, irrespective of the energy they used on heating their flat. Project findings show that most residents pay more for their heat using the new system, through increased electricity bills.

Provide residents with greater control
Comments on part of this aim are also covered above. Energy consumption was an area of concern from residents, partly due to the breakdown ad provision of more expensive heating. However, the greatest area of complaint concerned increases heating costs due to the fact that residents now paid for the amount of electricity they actually used to heat their flat. Those that used low levels of heat with the previous communal system and continued at the same comfort levels using the GSHP experienced little if any change in cost. Those that heated their flats for long periods and/or higher than average temperatures would pay considerably more as their heat demand is related to electricity costs metered through their utility meter, whereas previously there was an equal charge to all flats.

Provide residents with an improved level of reliability
Reliability of the system was only seen to be a problem due to the unauthorised tampering with the control systems. The remote monitoring of the system did not appear to have been utilised to the benefit of residents. NEA could access data at times although there were gaps which are covered in this report.

Provide insight into the suitability of the technology
This project did not highlight any issues which would preclude it' use in other property types.

4.2 Recommendations for potential future installations

The GSHP in this project replaced a communal gas-fired boiler system for which residents contributed an equal share of its operating costs. The migration to the new [metered] system created notable areas of complaint and confusion. Potential future installations of GSHP (and to some extent, other replacement heating systems) should consider:

- What system and controls are currently used
- How residents currently pay for their heating and hot water?
- Will the same billing system apply to the new system?
- How will the new system be controlled - differently to the old system?
- Are residents able to understand how to control their new system
- What training (or other arrangements) are needed for residents – tailored to the audience
- Do residents need guidance on energy tariffs/fuels to take full advantage of the new system

4.3 Impact on fuel poverty

In the majority, residents paid more for the heat provided by the GSHP. However, this was probably not due to the change to a GSHP but due to the previous charging methodology for their heating which had little or no correlation with the amount of heat actually used by a resident. The new system involved charges for the amount of heat they actually used. Fuel poverty is measured according to the new methodology[12] in England as defined by Prof John Hills in his review "Getting the measure of fuel poverty", and considers whether required fuel costs that are above the average national median level, and if the household were they to spend the modelled heating cost value, they would be left with a residual income below the official poverty line. The project did not capture either modelled energy demand on a per flat basis, nor precise financial income data, as we were unable to determine whether there was a change in fuel poverty levels.

[12] https://www.gov.uk/government/publications/final-report-of-the-fuel-poverty-review [Accessed 22/05/2018]

Appendix 1: Glossary of Terms

DD	Degree Days
DHW	Domestic Hot Water
EAS	Energy Action Scotland
EPC	Energy Performance Certificate
EWI	External Wall Insulation
GSHP	Ground Source Heat Pump
HDD	Heating Degree Days
HIP	Health and innovation Programme
IMD	Index of Multiple Deprivations
kWh	Kilowatt Hour – Unit of Electricity
LSOA	Lower Layer Super Output Area
NEA	National Energy Action – the National Fuel Poverty Charity
RH	Relative Humidity
SAP	Standard Assessment Procedure (for assessing home energy efficiency)
SRA	Social Research Association
TIF	Technical Innovation Fund
TRV	Thermostatic Radiator Valve
WZF	Warm Zone Fund

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

Appendix 4: Full details for table in Figure 3-18

Summary of electricity use PRIOR to the installation of improvement measures												
Tech Ref	Days	Single tariff or peak rate use	Off-Peak use	Total Period (kWh)	Off-peak tariff total	Standard Tariff Total	On-Peak tariff Total	Total cost	kWh per day	kWh per 30 days (mth)	Degree days	kWh per Degree Day
T-01	169	534	0	534	£0.00	£74.76	£0.00	£74.76	3.16	94.79	1,152.70	0.463
T-02	108	673	0	673	£0.00	£94.22	£0.00	£94.22	6.23	186.94	648.80	1.037
T-03	115	751	0	751	£0.00	£105.14	£0.00	£105.14	6.53	195.91	652.20	1.151
T-04	176	659	0	659	£0.00	£92.26	£0.00	£92.26	3.74	112.33	1,156.10	0.570
T-06	108	720	0	720	£0.00	£100.80	£0.00	£100.80	6.67	200.00	648.80	1.110
T-08	169	716	0	716	£0.00	£100.24	£0.00	£100.24	4.24	127.10	1,152.70	0.621
T-11	190	1,570	0	1,570	£0.00	£219.80	£0.00	£219.80	8.26	247.89	1,166.30	1.346
T-12	182	707	0	707	£0.00	£98.98	£0.00	£98.98	3.88	116.54	1,156.10	0.612
T-16	189	1,041	0	1,041	£0.00	£145.74	£0.00	£145.74	5.51	165.24	1,161.20	0.896
T-18	190	814	0	814	£0.00	£113.96	£0.00	£113.96	4.28	128.53	1,166.30	0.698
T-20	122	547	0	547	£0.00	£76.58	£0.00	£76.58	4.48	134.51	657.30	0.832
T-23	129	402	0	402	£0.00	£56.28	£0.00	£56.28	3.12	93.49	662.40	0.607
Minimum	108	402	0	402	£0	£56	£0	£56	3.12	93.49	648.80	0.463
Maximum	190	1,570	0	1,570	£0	£220	£0	£220	8.26	247.89	1,166.30	1.346
Average	154	761	0	761	£0	£107	£0	£107	5.01	150.27	948.41	0.829

Summary of electricity use AFTER the installation of improvement measures												
Tech Ref	Days	Single tariff or peak rate use	Off-Peak use	Total Period (kWh)	Off-peak tariff total	Standard Tariff Total	On-Peak tariff Total	Total cost	kWh per day	kWh per 30 days (mth)	Degree days	kWh per Degree Day
T-01	231	1,875	0	1,875	£0.00	£262.50	£0.00	£262.50	8.12	243.51	1,056.60	1.775
T-02	210	1,818	0	1,818	£0.00	£254.52	£0.00	£254.52	8.66	259.71	1,423.90	1.277
T-03	280	2,007	0	2,007	£0.00	£280.98	£0.00	£280.98	7.17	215.04	1,448.50	1.386
T-04	287	2,266	0	2,266	£0.00	£317.24	£0.00	£317.24	7.90	236.86	1,453.60	1.559
T-06	287	2,495	0	2,495	£0.00	£349.30	£0.00	£349.30	8.69	260.80	1,453.60	1.716
T-08	287	3,882	0	3,882	£0.00	£543.48	£0.00	£543.48	13.53	405.78	1,453.60	2.671
T-11	196	3,939	0	3,939	£0.00	£551.46	£0.00	£551.46	20.10	602.91	1,418.60	2.777
T-12	273	1,236	0	1,236	£0.00	£173.04	£0.00	£173.04	4.53	135.82	1,443.40	0.856
T-16	259	2,091	0	2,091	£0.00	£292.74	£0.00	£292.74	8.07	242.20	1,435.40	1.457
T-18	210	2,073	0	2,073	£0.00	£290.22	£0.00	£290.22	9.87	296.14	1,423.90	1.456
T-20	84	797	0	797	£0.00	£111.58	£0.00	£111.58	9.49	284.64	711.70	1.120
T-23	266	1,236	0	1,236	£0.00	£173.04	£0.00	£173.04	4.65	139.40	1,437.50	0.860
Minimum	84	797	0	797	£0	£112	£0	£112	4.53	135.82	711.70	0.856
Maximum	287	3,939	0	3,939	£0	£551	£0	£551	20.10	602.91	1,453.60	2.777
Average	239	2,143	0	2,143	£0	£300	£0	£300	9.23	276.90	1,346.69	1.576

Summary of electricity use for the 2nd period AFTER the installation of improvement measures												
Tech Ref	Days	Single tariff or peak rate use	Off-Peak use	Total Period (kWh)	Off-peak tariff total	Standard Tariff Total	On-Peak tariff Total	Total cost	kWh per day	kWh per 30 days (mth)	Degree days	kWh per Degree Day
T-01	369	3,048	0	3,048	£0.00	£426.72	£0.00	£426.72	8.26	247.80	1,658.30	1.838
T-02	273	2,113	0	2,113	£0.00	£295.82	£0.00	£295.82	7.74	232.20	1,376.00	1.536
T-03	224	1,851	0	1,851	£0.00	£259.14	£0.00	£259.14	8.26	247.90	1,084.30	1.707
T-04	180	1,016	0	1,016	£0.00	£142.24	£0.00	£142.24	5.64	169.33	1,068.20	0.951
T-06	320	4,323	0	4,323	£0.00	£605.22	£0.00	£605.22	13.51	405.28	1,326.50	3.259
T-08	216	2,119	0	2,119	£0.00	£296.66	£0.00	£296.66	9.81	294.31	389.40	5.442
T-11	320	6,119	0	6,119	£0.00	£856.66	£0.00	£856.66	19.12	573.66	1,326.50	4.613
T-12	174	63	0	63	£0.00	£8.78	£0.00	£8.78	0.36	10.81	812.20	0.077
T-16	320	2,552	0	2,552	£0.00	£357.28	£0.00	£357.28	7.98	239.25	1,326.50	1.924
T-18	224	1,710	0	1,710	£0.00	£239.40	£0.00	£239.40	7.63	229.02	1,084.30	1.577
T-20	224	1,651	0	1,651	£0.00	£231.14	£0.00	£231.14	7.37	221.12	1,084.30	1.523
T-23	224	770	0	770	£0.00	£107.80	£0.00	£107.80	3.44	103.13	1,084.30	0.710
Minimum	174	63	0	63	0	9	0	£9	0.36	10.81	389.40	0.077
Maximum	369	6,119	0	6,119	0	857	0	£857	19.12	573.66	1,658.30	5.442
Average	256	2,278	0	2,278	0	319	0	£319	8.26	247.82	1,135.07	2.096

TECHNICAL INNOVATION FUND

NEA Technical
September 2018

NEA
Action for Warm Homes