Heating your house the smart way, Spalding & South Holland
South Holland District Council

Technical Evaluation Report

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September 2017

CP788
Heating your house the smart way, Spalding and South Holland
South Holland District Council

Number of Households Assisted	43
Number of Households Monitored	22

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:

South Holland District Council – lead partner
Elecsure – installer partner
Heat Genius – product manufacturer

NEA team:

Elizabeth Lamming – Project Development Coordinator, NEA
Paul Rogers – Project Development Coordinator (Technical), NEA
Michael Hamer – Technical Development Manager, NEA

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Legal limitations and disclaimer

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Executive summary

Project description

This project was delivered by South Holland District Council (SHDC). It mirrored a similar project with the same partner which compared 3 other smart heating control products in other properties[1]. Each project was recommended by the funders to involve installation of 45 to 60 heating controls and compare 3 technologies. The projects were on too large a scale to be combined, but the methodologies were comparable and so there are benefits in comparing results from both. The current project had the following aims:

- To establish the heating costs for households with the Honeywell evohome, Heat Genius and Heatmiser neo smart thermostats compared to the previous period when the properties had a wall-mounted dial thermostat;
- To determine potential benefits of a smart thermostat with smart Thermostatic Radiator Valves (TRVs) on radiators to allow different temperatures in different rooms;
- To determine the ease-of-use and resident satisfaction levels for each of the smart heating control systems;
- To contribute towards an evidence base for landlords to assess the suitability of different models of smart thermostats for their properties.

Context

Around 1.65m households in England live in local authority-owned housing and a further 2.28m live in properties owned by housing associations. Many of these properties will currently only have a basic thermostat and programmer. In 2010, 38% of homes with a boiler did not have a room thermostat and 45% had no thermostatic radiator valves[2]. The average energy efficiency rating for social housing is EPC Band D. According to the 2015 fuel poverty statistics, 53.4% of fuel poor households lived in a property with EPC Band D[3]. It is worth noting that all of the properties selected for this trial had at least EPC Band D, with an energy efficiency rating of between 55 and 68 determined using Reduced Data Standard Assessment Procedure (RdSAP).

It has been claimed that smart thermostats can reduce bills by 20-30%; however heating controls have received limited funding from Government schemes in the past. Boiler replacement schemes or funding for new central heating systems have usually only involved the installation of basic thermostats and programmers, and while smart heating controls were included in the Green Deal and Green Deal Cashback schemes these closed in 2015.

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[1] Elizabeth Lamming, Paul Rogers & Michael Hamer, 'Heating your house intuitively', NEA, May 2017 (in press)
[2] Smarter heating controls research program (DECC, 2012) https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/254877/smarter_heating_controls_research_programme_overview.pdf (Accessed 23 May 2017)
[3] Table 4, Fuel Poverty Detailed tables 2015 data https://www.gov.uk/government/statistics/fuel-poverty-detailed-tables-2017 (Accessed 6 September 2017)

The technologies

Honeywell evohome

The Honeywell evohome smart thermostat system has an intuitive full-colour touch screen controller and smart thermostatic radiator valves (TRVs). The thermostat on the smart TRV measures the room temperature around the TRV and shows it on a liquid crystal display (LCD) panel. Based on the room heating schedule, the smart TRV uses a motor to open or close the radiator valve to ensure the room approaches the required temperature.

Different rooms can be set to have different heating schedules. This makes it possible to avoid heating rooms when they are not being used to help reduce heating bills. Schedules can be set and temperature altered remotely via an app.

Honeywell estimates that use of smart zoning in the Honeywell evohome system can reduce space heating demand by up to 40% compared to a system with just a basic timer and thermostat[4].

Heat Genius

The Heat Genius system is another smart thermostat system which includes smart TRVs on the radiators. Like the Honeywell evohome system this allows different rooms to have different heating schedules. In addition to offering the opportunity to control the system remotely by a phone app, Heat Genius can also allow the system to automatically set a heating schedule based on learning the typical room occupancy. The system uses weather forecast information to determine the amount of pre-heating required to achieve the set point temperature.

Case studies of earlier models published on the Heat Genius website indicate that the product has led to reductions in energy costs of 16-22% at 2 student properties[5]; and 40% for residents of a large period house.

Heatmiser neo

The Heatmiser neo smart thermostat system includes the neoStat programmer and the neoHub communication unit. The neoStat is a wired thermostat which is programmed with the required heating schedule. It can be set with different schedules for weekdays and the weekend or for each individual day. Residents can remotely alter their heating schedule via an app, and the system can use the mobile phone masts, WIFI and GPS to determine the location of the phone compared to the home. When the system detects the last household member has left home, the system turns down the thermostat temperature. Likewise, when the first household member is detected to be returning home, the thermostat temperature is turned up again.

Unlike some other systems there is no option to have smart TRVs installed on radiators which would allow for different heating schedules in different rooms. It is however possible to control multiple zones of a heating system independently with multiple Heatmiser neoStats.

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[4] https://getconnected.honeywell.com/en/evohome (Accessed 1 August 2017)
[5] https://www.geniushub.co.uk/case-study-bernard-sampson/ (Accessed 1 August 2017)

The project

Between January and April 2016 South Holland District Council installed smart thermostats, some including TRVs, in 43 of its social housing properties. This consisted of 15 Honeywell evohome, 11 Heat Genius and 17 Heatmiser neo thermostats.

Of these, 22 properties were monitored and completed the duration of the study - 12 with Honeywell evohome, 4 with Heat Genius and 6 with Heatmiser neo systems. The average pre-installation energy efficiency - SAP ratings - for the monitored homes which received the smart thermostats were between 66 and 68 which corresponds to EPC band D.82% of homes were semi-detached, the remainder were terraced houses. The average EPC space and water heating demand was 11,258kWh which corresponds to an annual gas bill of £563, using a standardized gas tariff of 5p/kWh. 55% of households monitored had a member with a health condition, disability or limiting long-term illness.

Temperature and humidity in the monitored properties was recorded every hour, and households were asked to regularly record gas and electricity meter readings in a log book. Recent and historic meter readings were used to assess the gas consumption before and after the installation of the smart thermostat. Householders were also asked to complete a questionnaire both before and after the installation to assess some of the impacts of the technology.

Summary of findings and insights

Ease of use

Over 90% of residents with the Honeywell evohome thought that the heating was easier to use, provided more control and their home was warmer and more comfortable. This compared to 68% for Heatmiser neo, and 50% for Heat Genius. These are positive results across all three products but performance varied significantly in different circumstances

Energy savings

- Households with the **Heat Genius** had the greatest energy savings and reduced gas consumption on average by 12%. While 1 resident made savings of 35.8%, another saw a 9.1% increase in gas consumption which was most likely due to improved thermal comfort.
- Households which received the **Honeywell evohome** system on average made savings of 0.5%, but for individual properties this ranged from a 19% saving to a 14.4% increase in gas consumption. The 3 Honeywell evohome systems with the largest increases in gas consumption included 2 where the homes were likely to previously have been under-heated and 1 where the resident spent more time at home following the installation. Therefore projected energy savings were unlikely to have been met
- For the **Heatmiser neo** installations, the average decrease in gas consumption was 6.1%. Half of these installations saw a reduction in gas consumption of between 8.6% and 22%, but the property where the greatest savings was recorded also had the boiler and hot water cylinder replaced at a similar time to the thermostat installation. The other households with Heatmiser neo installations saw an increase in consumption of up to 3.3%, mostly due to improved thermal comfort and in 1 case where they did not use the phone app to control

the temperature. The average saving for the Heatmiser neo installations excluding the property which had a replacement boiler and hot water tank was 2.9%.

A number of factors affected the effectiveness of the controls which are explored in the report

Humidity levels

- Living room humidity levels for homes in the study were normally in the desirable range of 40 to 60% as long as the average temperature was not allowed to fall below 19°C

Conclusions and recommendations

The smart thermostats enabled many of the residents in this study to make savings on their heating bills. Where there were increases in consumption, this was usually due to improved thermal comfort in previously less well-heated homes. The Honeywell evohome system was considered the easiest to use by the residents, while households where Heat Genius was installed had the greatest energy savings. Heating controls with mobile phone apps can allow residents to reduce heating of their homes when they are out, while those with smart thermostatic radiator valves can allow residents to focus the heating on rooms when they are being used.

Residents vary from the young who have grown up with digital technology to older residents who rarely use it. A smart thermostat must therefore be intuitive and easy to operate. The technology must be sufficiently mature to avoid technical and operational issues which could lead residents being left without their heating. If a system is too complex, vulnerable residents may at best not use the system properly or at worst request it is taken out.

Where smart thermostats are to be fitted in social housing, it is important that adequate training and written instructions is provided for residents at the point of installation, and for any new residents who subsequently move into a home with a smart thermostat. Landlords could add video guides to their websites showing residents how to operate the thermostats as these may be easier to understand for some than written instructions.

Contact should be made by the landlord several weeks after installation or at the start of the winter heating season, to confirm the system is working correctly and the resident understands how to configure a heating schedule to optimise the balance between savings and thermal comfort.

Housing officers and maintenance staff should be provided with a list of all properties with the smart thermostats and suitable training on its operation and maintenance. Guidance for residents on use of their heating controls could also potentially be provided by organisations offering energy advice in the local area.

1. Project overview

1.1 Introduction

This project was delivered by South Holland District Council (SHDC) which owns and manages just under 4000 council homes. Between January 2016 and April 2016 3 different smart thermostats, the Honeywell evohome, Heat Genius and Heatmiser neo, were installed in a total of 43 South Holland Council properties. The council recruited Elecsure, an installer experienced in working with smart thermostats to ensure smooth installation and effective instruction for the households. NEA monitored a sub-set of 22 households that participated in the evaluation study. A further 3 products were installed and monitored under a separate project and the results of those trials can be read alongside this report. Since installation of the smart thermostats 1 property in this project has been sold to the residents under the Right to Buy scheme as well as a second property which took part in the other smart thermostat project with SHDC.

Honeywell evohome is a technology with an intuitive touch screen controller and smart thermostatic radiator valves (TRVs) which allow different temperature schedules to be set in different rooms. The Heat Genius system also has smart TRVs but includes room sensors as well which can measure occupancy and room temperature. Heatmiser neo is a cheaper thermostat technology which does not use smart TRVs, but can allow the system to automatically turn down the temperature after the resident's mobile phone leaves the home.

1.2 Aims

- To establish the heating costs for households with the Honeywell evohome, Heat Genius and Heatmiser neo smart thermostats compared to the previous period when the properties had a wall-mounted dial thermostat.
- To determine potential benefits of a smart thermostat with smart TRVs on radiators to allow different temperatures in different rooms.
- To determine the ease-of-use and resident satisfaction levels for each of the smart heating control systems.
- To contribute towards an evidence base for landlords to assess the suitability of different models of smart thermostats for their properties.

1.3 Context

Around 1.65m households in England live in local authority-owned housing and a further 2.28m live in properties owned by housing associations. Many of these properties will currently only have a basic thermostat and programmer. In 2010, 38% of homes with a boiler did not have a room thermostat and 45% had no thermostatic radiator valves[6]. The average energy efficiency rating for social housing is EPC Band D and in 2015 fuel poverty statistics 53.4% of fuel poor households lived in a property with SAP Band D[7].

It has been claimed that smart thermostats can reduce bills by 20-30%; however heating controls have received limited funding from Government schemes in the past. Boiler replacement schemes or funding for new central heating systems have usually only involved the installation of basic thermostats and programmers, and while smart heating controls were included in the Green Deal and Green Deal Cashback schemes these closed in 2015.

NEA wanted to understand whether these devices lead to a reduction in energy use and bills by removing the need for manual heating adjustment, and offer a comparison between three different smart thermostats.

1.4 Project timeline

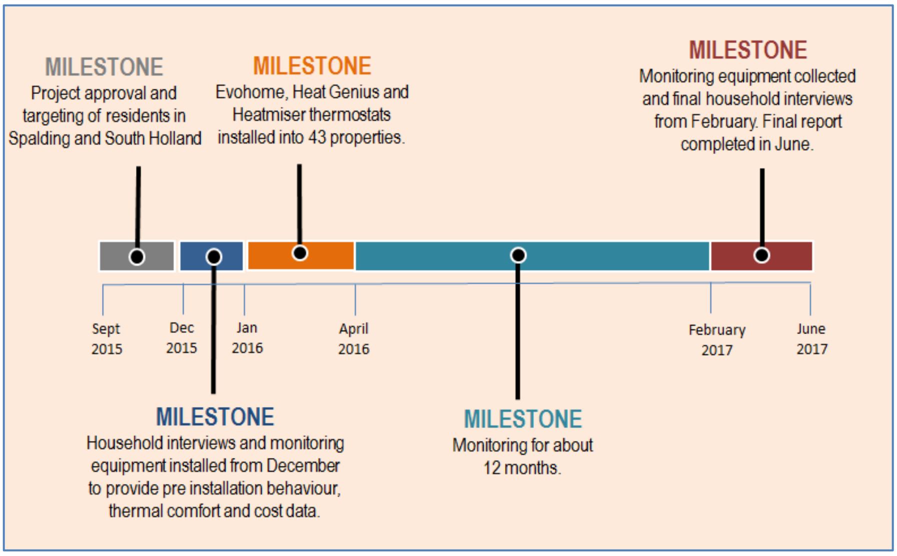

Figure 1.1 Project timeline

1.5 Attracting beneficiaries and establishing the monitored group

A member of South Holland District Council's housing department acted as the key contact person for the residents over the duration of the project. Engagement consisted of:

- Initial mail-out - a letter written by South Holland District Council was sent to residents inviting them to take part in the smart thermostat project. This informed them of the smart thermostat opportunity and explained the funding and monitoring obligation. The letter also

[6] Smarter heating controls research program (DECC, 2012) https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/254877/smarter_heating_controls_research_programme_overview.pdf (Accessed 23 May 2017)
[7] Fuel Poverty Statistics Detailed Tables, https://www.gov.uk/government/statistics/fuel-poverty-detailed-tables-2017 (Accessed 1 August 2017)

explained that it was necessary for residents to have a broadband connection and smart phone in order to participate. A questionnaire also set out requirements for participation in the project;

- Identifying residents to be monitored – visits to those responding to the initial letter confirmed that broadband and smart phones were available in the homes. Residents were encouraged to take part in the monitoring for the project and shown the data-loggers used;
- Installation of monitoring equipment - SHDC placed monitoring devices in December 2015 in homes where residents agreed to join the monitored group. NEA later visited residents to complete a questionnaire and collect historical meter readings and billing. Some further residents were recruited for monitoring purposes in July 2016.

2 Technical evaluation methodology

2.1 Introduction

The smart thermostats were installed in social housing owned by South Holland District Council. Figure 2.2 shows where the systems were installed. 7 of the installations were in Sutton Bridge, with others nearby in Long Sutton, Lutton and Gedney. Other installations were in and around Spalding, in Gosberton and Tongue End.

Figure 2.1 Example of a property receiving a smart thermostat installation

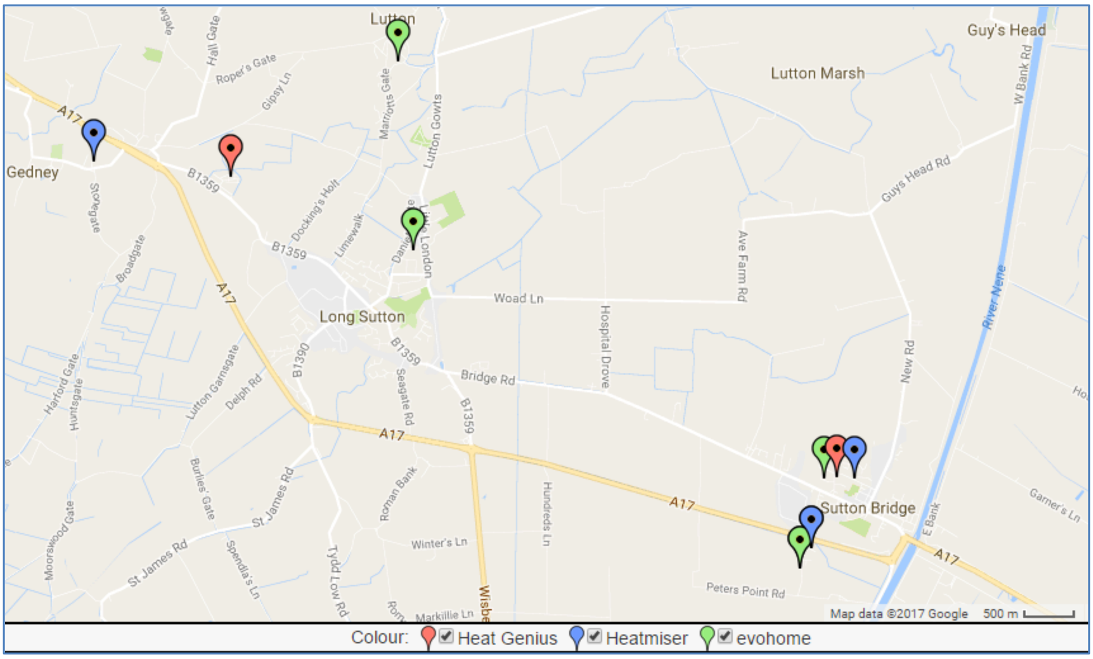

Figure 2.2a Locations of smart thermostat installations in Sutton Bridge, Long Sutton, Lutton & Gedney

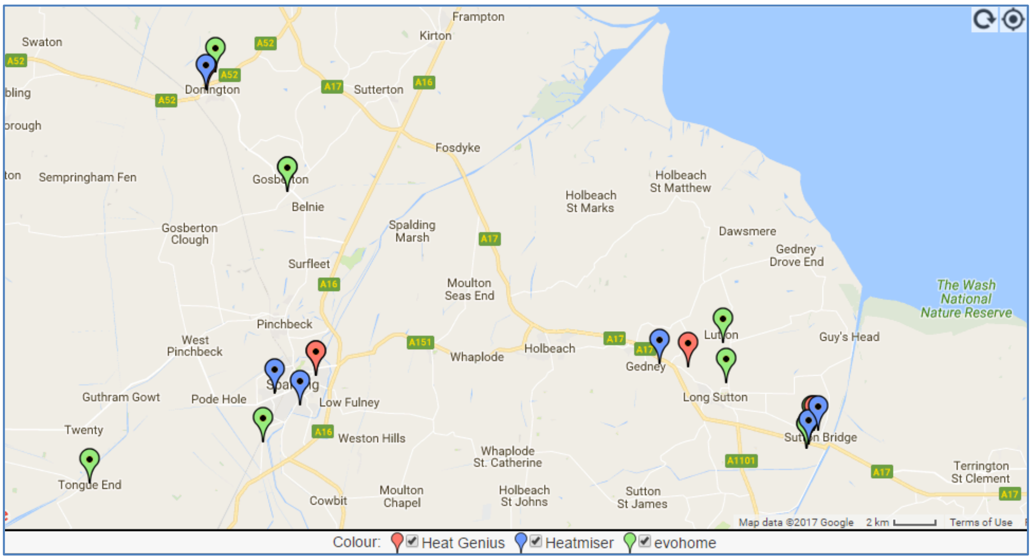

Figure 2.2b Locations of smart thermostat installations in South Holland District Council properties

The monitored properties were each allocated a property reference to protect the privacy of the residents. These reference numbers will be used when referring to individual properties throughout this report.

Details of the houses in the study which received the Honeywell evohome thermostats are shown in Table 2.3a and the homes which received the Heat Genius and Heatmiser neo thermostats are shown in Table
2.3b. These details were derived from the Energy Performance Certificates (EPC).

Out of these properties 82% were semi-detached and 14% were end-terraced houses, with the remainder mid-terraced. The pre-installation Energy Efficiency or SAP ratings ranged from to 58 to 74. The houses with the lower SAP rating and larger floor area tended to have the greatest predicted space and water heating demand. For the EPC, the assessor assumed there was no loft insulation for properties T-05, T-10 and T-49 and no cavity wall insulation for T-49. If insulation was in fact present, then the SAP rating should have been higher and the space and water heating demand lower than the high values of 18,494kWh, 12,690kWh and 20,920kWh shown on the EPC. Most of the properties had higher than the average household energy efficiency but were living on below average low incomes.

Property Ref.	House type	SAP Rating	Floor area	EPC Space & water heating demand (kWh)	New Thermostat
T-04	Semi-detached House	71	75	-	evohome
T-05	Semi-detached House	64	118	18,494	evohome
T-10	End-terrace House	61	78	12,690	evohome
T-12	Semi-detached House	73	86	9,942	evohome
T-13	Semi-detached House	70	67	8,398	evohome
T-15	Mid-terrace House	74	78	7,552	evohome
T-19	Semi-detached House	71	86	10,589	evohome
T-21	Semi-detached House	62	68	11,641	evohome
T-22	Semi-detached House	61	67	11,746	evohome
T-27	Semi-detached House	71	97	10,678	evohome
T-33	Semi-detached House	67	93	11,992	evohome
T-34	Semi-detached House	68	87	11,187	evohome
Average		68	83.3	11,355	

Table 2.3a Details of properties taking part in the study receiving the Honeywell evohome smart thermostat

Property Ref.	House type	SAP Rating	Floor area	EPC Space & water heating demand (kWh)	New Thermostat
T-01	Semi-detached House	68	67	8,372	Heat Genius
T-07	Semi-detached House	67	74	10,033	Heat Genius
T-49	Semi-detached House	58	103	20,920	Heat Genius
T-54	Semi-detached House	63	86	-	Heat Genius
Average		64.0	82.5	13,108	
T-02	Semi-detached House	69	74	9,972	Heatmiser neo
T-08	Semi-detached House	64	70	9,130	Heatmiser neo
T-30	Semi-detached House	68	88	10,872	Heatmiser neo
T-36	End terrace House	59	73	12,481	Heatmiser neo
T-50	Semi-detached House	69	63	8152	Heatmiser neo
T-52	End terrace House	65	77	10,325	Heatmiser neo
Average		66	74.2	10,155	

Table 2.3b Details of properties taking part in the study receiving the Heat Genius and Heatmiser neo thermostats

2.2 Technical Monitoring

Figure 2.4 Lascar EL-USB-2 temperature and humidity logger

Temperature and humidity in the monitored properties were recorded every hour using a Lascar

EL-USB-2 temperature and humidity logger[8]. These were placed in 19 of the living rooms of the monitored properties and in 8 of the bedrooms.

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

It was possible to access temperature data through Heat Genius so temperatures were recorded directly from these room sensors. The system only recorded the temperatures when the WIFI router was turned on or operating correctly.

2.3 Factors affecting the evaluation methodology

Issue	Description and mitigation
Size of monitored group	The group selected for the monitoring processes was reduced from 25 (originally proposed) to 22 households due to requests for the Council to remove 2 of the systems. A further Heat Genius system was removed from the monitoring group as it was not set up correctly during the monitoring period. The sample size was unevenly split with a much greater number engaged in the Honeywell evohome trials
Systems removed	A log burner for supplementary heating was installed at the expense of the tenant in a home where a Honeywell evohome system had been fitted. The resident felt the log burner 'confused' the thermostat and 1 person in the household struggled with the system as it kept losing the Internet connection and had to be reinstalled on their phone. Another household with a Heat Genius system had a problem arise with their boiler which they blamed on the Heat Genius thermostat and insisted the thermostat should be removed.
System not correctly setup	There were problems setting up 1 of the Heat Genius systems due to the resident with the compatible smart phone not being present during the installation. The resident was later unable to install the Heat Genius app on the phone and so the system did not work correctly. During the visit for the final interview, NEA staff, (with assistance from Heat Genius), were able to set up the system. The data recorded during the study however did not illustrate the performance of Heat Genius.
Identification of the monitored group	The monitored group was selected and initial visits to distribute the temperature loggers were carried out by the partner in December 2015. The initial households selected were not evenly distributed between the 3 thermostat technologies and it

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

	was necessary to recruit further households during the summer of 2016.
Start of monitoring	Monitoring equipment was placed in the properties taking part in the study during December 2015 and July 2016. With the smart thermostats installed between January and April 2016 there was only a limited pre-installation period. The exact date the loggers were placed in households in December was not recorded leading to uncertainty in the data. Pre-installation temperatures were therefore taken from January 2016 when it was known that the loggers were in location.
Assistance from manufacturers	NEA received support from Heat Genius to set up heating schedules, and understand performance and temperature data. Involvement by the other manufacturers in the project was more limited.
Meter readings	It was not possible to obtain a long period of gas meter readings prior to the smart thermostat installation for property T-27. This was due to a faulty gas meter at the property at that time
Other factors	A number of factors were identified by NEA through the course of the trials which impacted the original methodology. NEA was able to adapt the evaluation methodology in order to maximise the information and data that would be available. However, where limitations in data has affected our confidence in the findings on the technical performance of the products, we have instead focussed on gathering insights into the customer attitudes and experiences of using them, which are also an important part of what we set out to do

2.4 Smart thermostats

Honeywell evohome

Figure 2.5 Honeywell evohome controller

Figure 2.6 Honeywell HR92 smart TRV

The Honeywell evohome smart thermostat system has an intuitive full-colour touch screen controller and smart TRVs. Typically about 6 Honeywell HR92 smart TRVs were installed on radiators in properties in this study.

The thermostat on the smart TRV measures the room temperature around the TRV and shows it on a LCD display. Based on the room heating schedule, the smart TRV uses a motor to open or close the radiator valve to ensure the room approaches the required temperature. The motor is powered by 2 AA batteries which may last up to about a year.

Different rooms can be set to have different heating schedules. For example bedrooms and the kitchen could be heated in the morning while the dining room and the lounge could be heated in the evening. This makes it possible to avoid heating rooms when they are not being used and reduce heating bills. Honeywell estimates that use of smart zoning in the evohome system can reduce space heating demand by up to 40% compared to a system with just a basic timer and thermostat[9].

The system can be programmed with temperature schedules for each room for each day of the week. These can be set using the evohome controller or with the Honeywell Total Connect Comfort app. The schedules can be quickly dropped for a more appropriate alternative by selecting a 'Quick Action' which can change settings to 1 of the following alternatives:

- Economy mode – reduces the temperatures in all rooms by 3°C;
- Away mode – all rooms set to 15°C;
- Day off mode – switching to the heating schedule for a non-work day;
- Heating off – all room TRVs are closed;
- Special day – a pre-set heating schedule for a day with a different pattern to normal.

[9] https://getconnected.honeywell.com/en/evohome (Accessed 5 June 2017)

Figure 2.7 Honeywell HR92 smart TRV

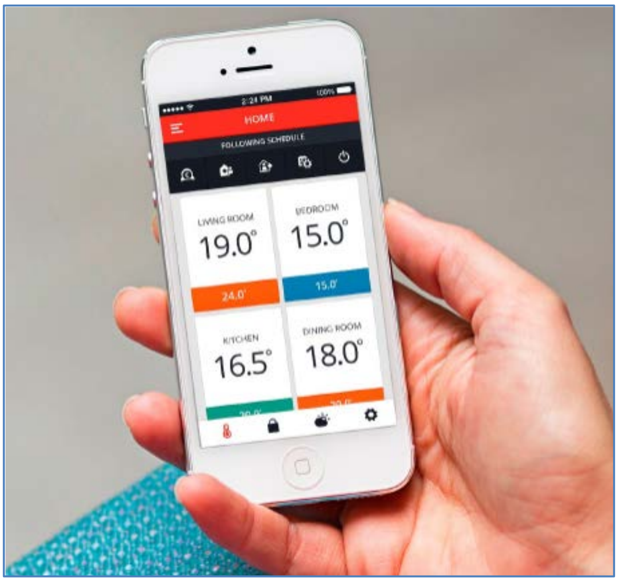

Figure 2.8 Honeywell Total Connect Comfort app

The Honeywell Total Connect Comfort app is available for Apple and Android phones. It is free and requires no subscription. It can be used to set schedules and alter temperatures remotely.

The system does not work on Windows mobile phones although an unofficial app has been released by a third party developer which can control the Honeywell evohome system.

For the app to work, the Honeywell evohome controller needs to be paired with the home WIFI system. If the WIFI router is turned off or the Internet provision is interrupted, the phone app will stop working. However it is straightforward to reconnect the system after any disruption or to a new WIFI router.

Honeywell does not have a web portal where it is possible to set schedules or access historic temperature data. Other systems like Heat Genius and Netatmo offer this option.

The Honeywell evohome does not learn patterns of behaviour as the Nest thermostat does and it is not able to detect if residents are in the room as the Heat Genius does, or if they have left the building as the Heatmiser neo does.

As well as the Honeywell evohome controller and the smart TRVs, the system includes a BDR91 wireless relay box which is connected to the boiler. This provides the wireless interface between the boiler and the rest of the Honeywell evohome system. Properties with a gas boiler and hot water cylinder would require an additional Honeywell evohome hot water kit.

Technical support is provided by phone and email, with contact details available on the Honeywell UK website[10]. Brochures and user guides are also available on the company website. Further information about the evohome system and the Total Connect Comfort app can also be found on other Honeywell websites[11] [12].

The Honeywell evohome connected thermostat pack with the WIFI connected controller and the

[10] http://www.honeywelluk.com/contact/ (Accessed 6th June 2017)
[11] https://getconnected.honeywell.com/en/evohome (Accessed 6th June 2017)
[12] https://info.mytotalconnectcomfort.com/en-GB (Accessed 6th June 2017)

BDR91 Wireless Relay unit is available from about £200; a pack of 4 Honeywell HR92 wireless radiator controllers costs from about £190.

Heat Genius

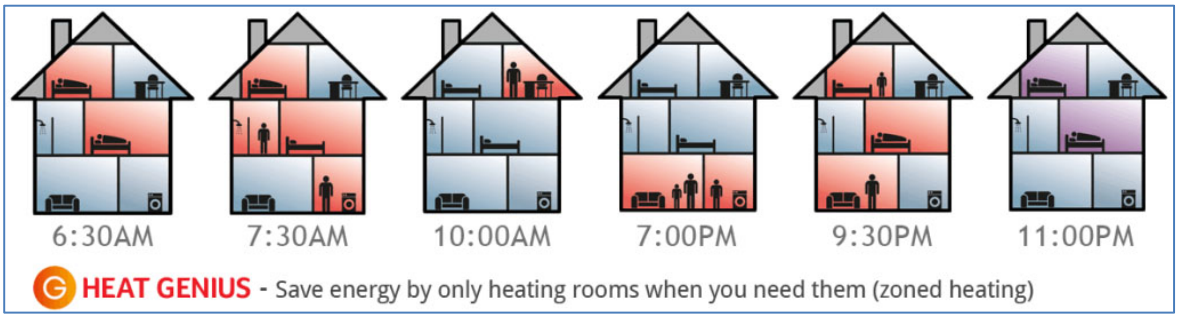

Figure 2.9 Illustration of the potential for energy savings by using zoned heating with the Heat Genius system

Figure 2.10 Heat Genius wireless room thermostat and boiler controller Heat Genius smart TRV

Heat Genius is another smart thermostat system which includes smart TRVs on the radiators. Like the Honeywell evohome system, this allows different rooms to have different heating schedules (Figure 2.9). In addition to offering the opportunity to control the system remotely by a phone app, Heat Genius can also allow the system to automatically set a heating schedule based on learning the typical room occupancy. The system uses weather forecast information to determine the amount of pre-heating required to achieve the set point temperature.

The Heat Genius systems installed in the homes in this project typically included:

- The Genius Hub which communicates with the other components and plugged into the home WIFI router, providing the system with Internet access;
- Wireless thermostat which provided temperature readings used for rooms without sensors and determined whether the heating needed to be turned on;
- Single Channel Receiver which replaced the old boiler programmer or wired thermostat;
- Smart thermostatic radiator valves (TRVs), with 6 typically installed per home;
- Wireless room sensors – these were fitted away from the radiators and provided a more accurate room temperature and also measured room occupancy;

- Smart plugs – boost the wireless signal in the home between the radiator valves, room sensors and the receiver units. Equipment plugged into to the socket could also be turned on and off using the phone app.

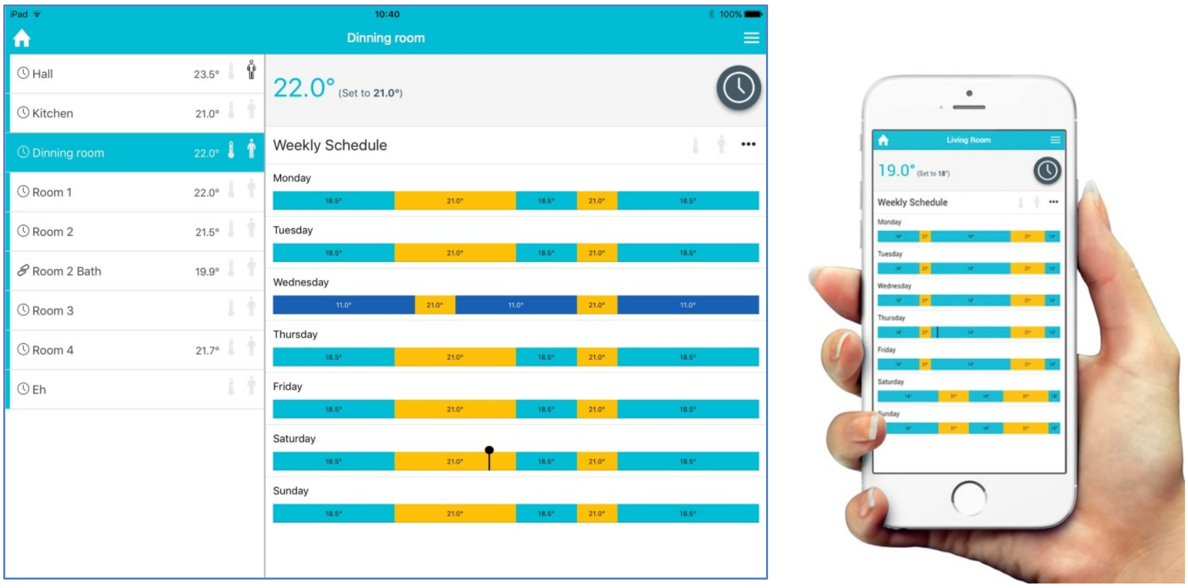

Figure 2.11 Heat Genius app on the iPad and iPhone

Temperature schedules for the Heat Genius system can be changed using a mobile phone app or with a web portal. The mobile phone app is only available for Apple and Android phones.

There are 4 different heating modes which can be selected:

- Off mode – in this mode the heating in the room is turned off. If the temperature drops below 4°C the radiator valve will be opened again to provide frost protection;
- Timer mode – in this mode residents can set up the heating times and temperatures required on different days of the week;
- Footprint mode – this automatically sets the heating schedule based on the system learning typical occupancy times using the motion sensor built into the room sensor;
- Override – a way to temporarily override normal settings when there are changes such as returning home early.

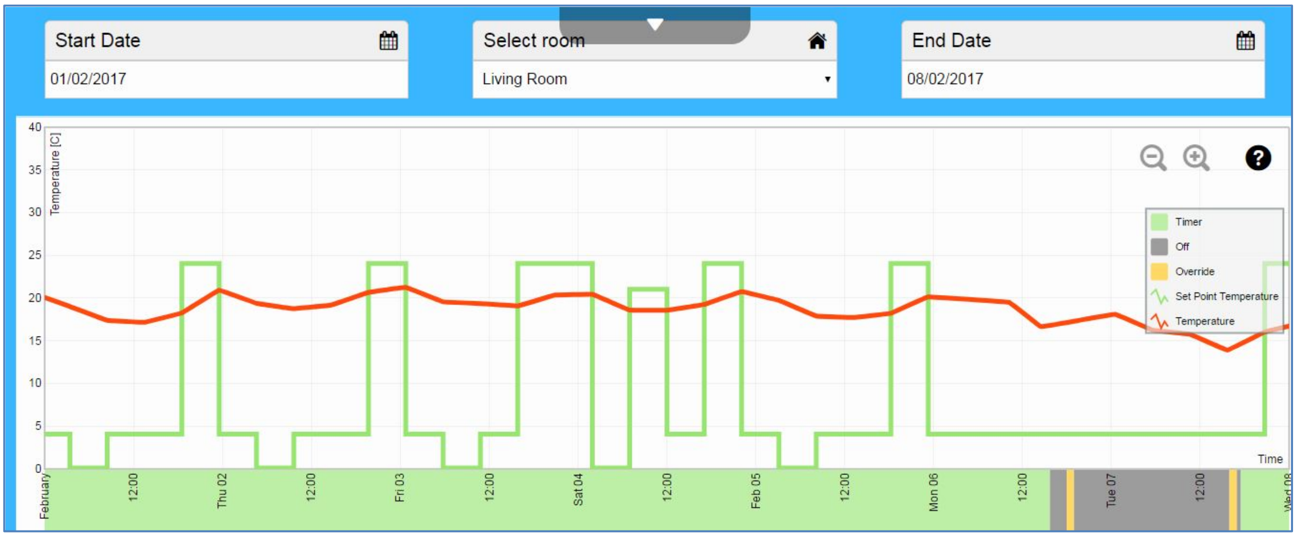

Figure 2.12 Historical temperatures and settings from the Heat Genius web portal

The web portal also allows residents to access historical data from the system. This includes the room temperature, set point temperature, occupancy and heating mode (Figure 2.12). The web portal and phone app are both free to use and require no subscription.

If the home WIFI router is switched off, remote access to the system via phone or web is lost. The pre-set temperature schedule still runs and it is possible to alter temperatures manually on the wireless TRVs, but it is not possible to adjust temperatures with the app. If the Internet service provider is switched, this causes no problems as the Gateway is plugged into the WIFI router and does not rely on passwords.

A published case study on the Heat Genius website states that a housing management organisation installed the Heat Genius system in 2 properties with student tenants. After the installation, the energy consumption was 16% lower compared to the previous year. In the second year the system was set up to use the automatic 'footprint' mode and the savings were 22% compared to before[13]. The case study does not state the methodology or whether there was temperature compensation in the calculations. A large period house also received the Heat Genius system on all 28 radiators in the property and the cost of heating the house dropped by 40% in the first winter[14].

Heat Genius has updated its hardware since these units were installed. The latest wireless radiator valves can determine a suitable room temperature without the need of a room sensor. While this can reduce the installation cost, using a room sensor provides a more representative room temperature because it is positioned at chest height on an internal wall and is not located on the end of the radiator as is the case with any radiator valve. The room sensor also doubles as an occupancy sensor, which allows the system to operate in 'footprint mode' which, the manufacturer claims, provides greater energy savings. This is achieved because the room sensor enables the system to learn when the rooms are used, enabling the radiators to automatically turn down when those rooms are not occupied.

The starter kit with the Genius Hub, Single Channel Receiver and wireless room thermostat

[13] https://www.geniushub.co.uk/case-study-bernard-sampson/ (Accessed 9 Jun 17)
[14] https://www.thegreenage.co.uk/heat-genius-case-study/ (Accessed 12 Jun 17)

currently costs £249.99. This basic system can operate in a similar way to the Nest thermostat and smart radiator valves can be added to the system at a later date. The Genius radiator valves are £59.99, room sensors £34.99 and smart plugs are £29.99 each.

There is a ‘Frequently Asked Questions’ section on the Heat Genius website with lots of advice on how the system works. It is also possible to access a user manual via the web app. Heat Genius offers technical support by phone or by submitting a request via their website home page. The company is able to remotely assess problems and was able to set up a suitable heating schedule for a resident in the study where this had not been set up by the installer.

Heatmiser neo

Figure 2.13 Images showing the Heatmiser neoStat and neoHub

The third smart thermostat system in this study was Heatmiser neo. The system installed consisted of the neoStat programmer and the neoHub communication unit. The neoStat is a wired thermostat which is programmed with the required heating schedule. The system can be set with different schedules for weekdays and the weekend or for each individual day. A holiday mode is also available which sets the temperature to provide frost protection.

The neoHub communication unit is connected to the home WIFI unit with an Ethernet cable. When it is initially set up, the neoHub is wirelessly paired with the neoStat. Each resident also sets up the Heatmiser neoApp on their mobile phone (Apple, Android or Windows). The neoApp enables the residents to remotely alter their heating schedule. It also enables Heatmiser neo to potentially reduce energy consumption with a feature called Geo Location. The neoApp uses a combination of the mobile phone masts, WIFI and GPS to determine the location of the phone compared to the home. When the system detects the last household member has left home, the system turns down the thermostat temperature. Likewise when the first household member is detected to be returning home, the thermostat temperature is turned up again. The tado smart thermostat also includes a similar feature[15] [16].

If there is loss of the broadband connection for the home, it is still possible to alter the temperature settings manually using the neoStat controller. Remotely altering the thermostat temperature with the phone app or use of the Geo Location feature are not possible if there is a problem with the broadband or the WIFI router has been turned off. It is not necessary to reinstall the system if the resident switches Internet provider. Since the neoHub plugs directly into the WIFI router, there is no

[15] Elizabeth Lamming, Paul Rogers & Michael Hamer, ‘Heating your house intuitively’, NEA, September 2017 (in press)
[16] Smart Thermostats: market analysis for social landlords (2015) http://innovationlaunchpad.org/wp-content/uploads/2016/04/Smart-Thermostats-Market-Analysis-For-Social-Landlords-June-2015-2.pdf (Accessed 2 August 2017)

need to change settings on the Heatmiser system if a new WIFI router with a different password is installed.

Unlike the Honeywell evohome and Heat Genius systems, there is currently no option to have smart TRVs installed on radiators which allow different heating schedules in different rooms. It is possible to control multiple zones of a heating system independently with multiple Heatmiser neoStats. This is however a more expensive option and multi-zone heating systems are not common in smaller houses.

The Heatmiser kit with a neoStat and neoHub currently costs from £160. There is no subscription cost for use of the neoApp and the neoHub automatically downloads feature enhancements and bug fixes which also update the neoStat. Technical support is available via a UK national phone number and email address which can be found on the Heatmiser website. There are however fewer support documents available on the website than for some other smart thermostats such as Nest and Heat Genius.

3. Social impacts

3.1 Householder demographic details

The age range of the householders in the monitored group is shown in Figure 3.1a. Most of the households were families with children and this can be seen by the age ranges of the residents. The largest proportion, 43% were between 30 and 59 years, followed by 38% who were under 16. A further 11% were young adults (16-29) still living with their families. Only 8% of the residents in the study were over 60 years old.

36% of households had a resident who was not working due to a health condition or being a carer for a household member with a health condition.
In a further 36% of households the residents were working full time and in 5% of the households the interviewee was working part-time. At the start of the study, 14% of the residents interviewed were unemployed and 9% were retired. Therefore around 60% of households had members who potentially could be at home during the day.

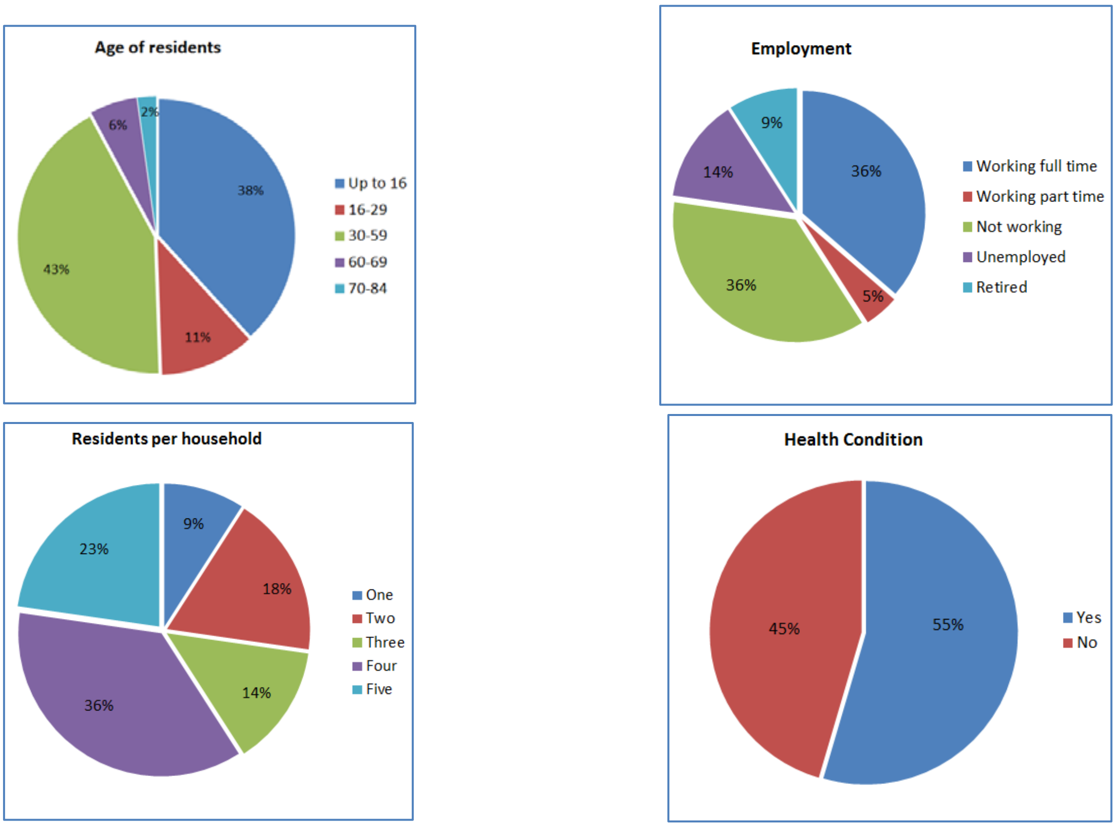

Figure 3.1 (a) Age (b) Employment (c) Number of residents (d) Health

Figure 3.1c shows that the most common household size was 4 residents (36%), with a further 23% of households having 5 residents. Smaller households of 1 or 2 residents made up 27% of the occupancy of properties. 55% of the households had a member with a health condition, disability or limiting long-term illness. All these residents noted that the condition was worsened by the cold.

In comparison to another study looking at smart thermostats in the same district[17], the household sizes were larger and had a greater proportion of residents who were unable to work due to a long-term illness. More of the residents in this study were likely to be at home during the day and required heating for longer periods.

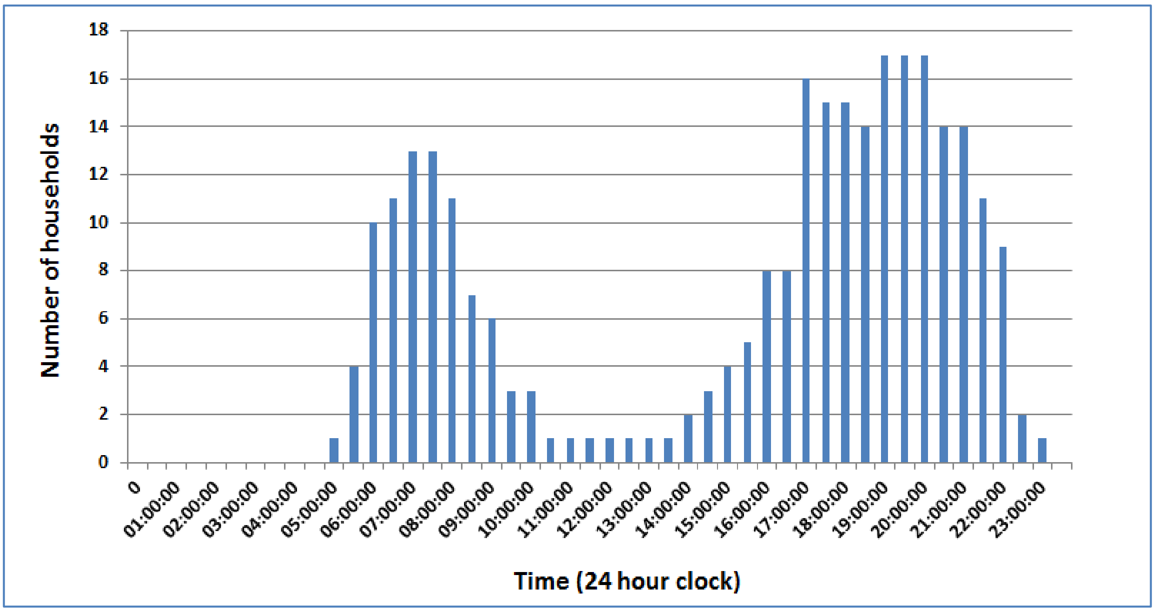

Figure 3.2 Times when it was important for the residents to have a warm home

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 were least active e.g. sitting watching TV in the evening or when washing/dressing first thing in the morning. Figure 3.2 shows the results summed up across all respondents.

This shows a morning peak in heating demand between 6am-10am. Most residents required their homes to be warm in the early evening with the greatest number wanting the house warm between 5pm and 9pm.

[17] Elizabeth Lamming, Paul Rogers & Michael Hamer, 'Heating your home intuitively', NEA, September 2017 (in press)

3.2 Affordability of Energy Bills

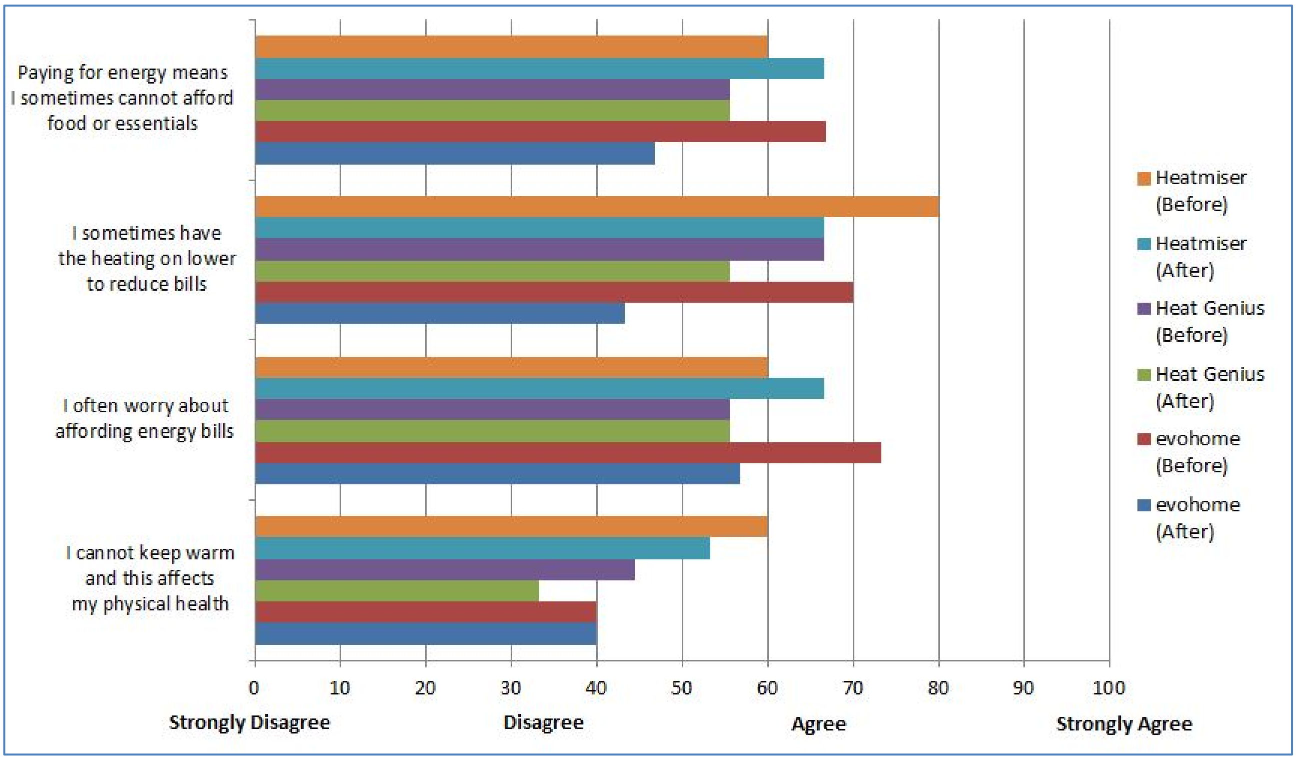

Figure 3.3 Agreement with statements about affordability of fuel bills

During the initial and final interviews, householders were asked how much they agreed with statements about the affordability of their energy bills. The responses were either 'strongly disagree', 'disagree', 'agree' or 'strongly agree'. Each of the responses was assigned a score where 'strongly disagree' scored zero, and 'strongly agree' scored 100. An average (mean) score of between zero and 100 was calculated for the periods before and after the installation for each smart heating control system. Figure 3.3 shows a chart with responses to statements related to the affordability of energy bills.

There were 10 households who received Honeywell evohome systems who provided responses both pre and post-installation along with 3 households with Heat Genius and 5 households with Heatmiser neo installations. The variation in responses on affordability of energy bills prior to the heating control installation reflected the differing circumstances of the households in each group. Changes in response following the installation may have been influenced by changes in household circumstances, a natural variation in responses, but potentially also the smart heating control.

When asked whether paying for energy meant that they sometimes could not afford to buy, or buy less of, other essentials such as food, the households with Heatmiser neo scored 60% before and 66.7% after installation. On average this represents most households agreeing with the statement and during the final interview 1 household who previously disagreed with the statement changed their response to agreeing. The households with Heat Genius scored 55.6% both before and after installation. . There was a significant change in the response from the residents with Honeywell evohome where the score decreased from 66.7% to 46.7% after installation. 8 of the 10 residents changed their response in the final interview, with 6 of these being less concerned about their ability to buy essentials.

After installation of each smart heating control technology, there was less of an agreement with the statement that residents sometimes had the heating on lower to reduce bills. For Heatmiser neo the score for the responses decreased from 80% to 66.7%.. The score for Heat Genius decreased from 66.7% to 55.6%, with one of the 3 residents changing their response from agree to disagree after the installation. The greatest change in response was seen among the households which received the Honeywell evohome. Here the response score decreased from 70% to 43.3%, with 3 households who initially strongly agreed and 2 that agreed changing their responses to disagreeing that they sometimes had the heating on lower or less often. The change in response to the statement suggests that the households and those receiving Honeywell evohome in particular improved their thermal comfort after installation of the smart heating controls.

The response scores for Heatmiser neo and Heat Genius on the statement that ‘I often worry about being able to afford the fuel bills’ were the same as for the statement about being unable to afford or buying fewer essentials due to paying for energy. For Heatmiser neo, the response score increased from 60% before the installation to 66.7% afterwards, while for Heat Genius the score was 55.6% and did not change after installation. For Honeywell evohome the response score prior to installation was 73.3%, with all but 1 resident agreeing or strongly agreeing with the statement. After the installation it decreased to 56.7%, with 3 households changing their response from strongly agree or agree to disagree. It should be noted that these households either switched tariff or had energy debt issues resolved over the course of the project.

Finally residents were asked how much they agreed or disagreed with the statement that ‘I cannot keep warm at home and this affects my/our physical health’. A higher percentage of the residents with Heatmiser neo agreed with this statement than for the other technologies, Here 3 households either strongly agreed or agreed with the statement. Out of these, 2 had household members with long term medical conditions. During the final interview, 1 resident changed his response from strongly agree to agree and this led the response score to decrease from 60% before the installation to 53.3% afterwards.

For Heat Genius, only 1 resident agreed with the statement about being unable to keep warm and it affecting physical health prior to the installation. This response changed to disagree after the installation with the response score decreasing from 44.4% to 33.3% (with all disagreeing). For the residents with Honeywell evohome, the response score did not change from the pre-installation value of 40% after the smart heating control was fitted. Although the average score did not alter, there was variation in the individual responses.

Although the scores were lower on this statement than the others, it is still a concern that significant number of residents said that a family member could not keep warm at home and this affected their physical health. At the end of the project, 31.8% of households had a family member who agreed with the statement. This includes households that only took part in the final interview.

3.3 Resident acceptance & satisfaction

Residents were asked how satisfied they were with their heating system using the following responses: ‘very dissatisfied’, ‘dissatisfied’, ‘neither’, ‘satisfied’ or ‘very satisfied’. Each of these responses was assigned a score where ‘very dissatisfied’ scored zero and ‘very satisfied’ scored 100. An average (mean) score of between zero and 100 was calculated for each of the smart thermostats. 4 residents with Heat Genius systems were interviewed along with 6 who had the Heatmiser neo thermostat and 12 who had the Honeywell evohome system. The responses to a series of questions are shown in Figure 3.4, with the residents using the Honeywell evohome system the most satisfied.

When asked about satisfaction with the cost of running their heating system, residents scored the Honeywell evohome at 77.1% where a score of 75 corresponded to ‘satisfied’. On the same question, Heat Genius scored 75% and Heatmiser 54.2%.

Satisfaction was high with the amount of control provided over the heating system. Honeywell evohome and Heatmiser neo scored 87.5% and 79.2% respectively, compared to 75% for Heat Genius. The same ranking was found on ‘how easy the heating system is to use’, with Honeywell evohome scoring 91.7%, Heatmiser neo 75% and Heat Genius 68.8%. The intuitive touch screen controller of the Honeywell evohome was very popular with residents and this is likely to be a major factor in the high satisfaction with the evohome system.

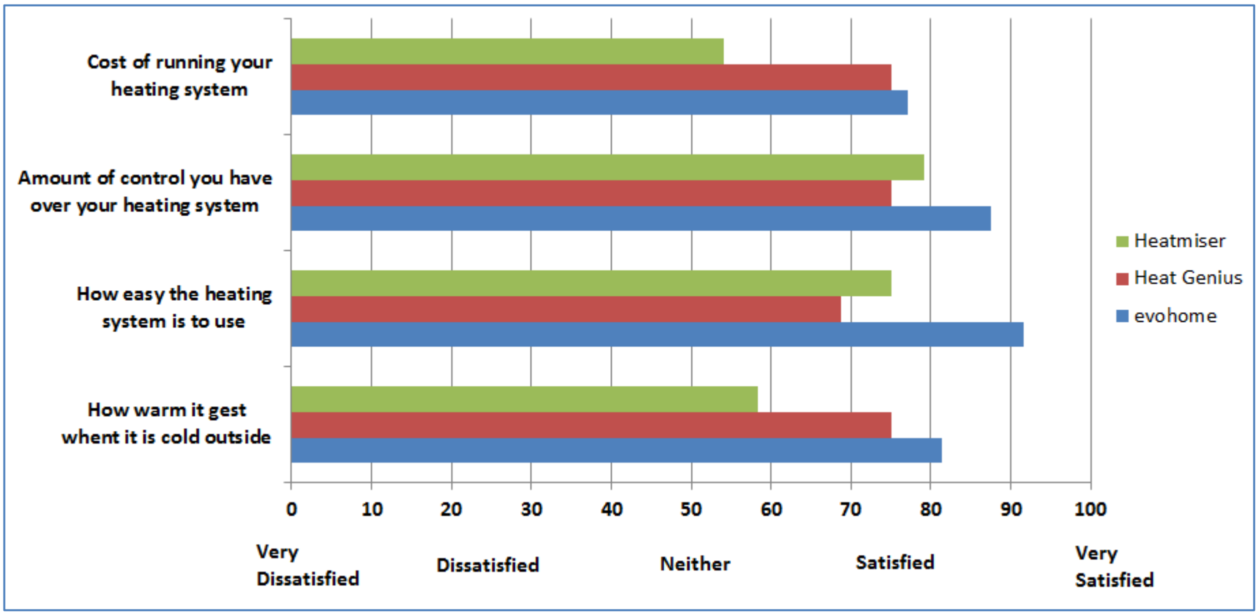

Figure 3.4 Satisfaction of residents with the their heating system

Household T-07, who had a Heat Genius system, was ‘dissatisfied’ with the amount of control and ease-of-use of the heating system and this lowered the average scores on these statements. The WIFI connection at the property was often lost and since the temperature schedule could only be altered by the app or web portal, this led to inconsistent control of the system.

In contrast household T-54 found the Heat Genius system straightforward to use from the start. They gave a response of ‘very satisfied’ on each question and said they wouldn’t go back to their previous heating control system. Household T-49 also responded as 'satisfied' or 'very satisfied' to each question.

Residents with the Honeywell evohome system were most satisfied with how warm their home became when it was cold outside, scoring 81.3%. For this question, household T-54 with Heat Genius was 'very satisfied' and the overall score was 75%. The satisfaction rating for Heatmiser neo was the lowest at 58.3%. 2 households were dissatisfied and the remaining 4 were satisfied with this control.

3.4 Ease of use and reliability

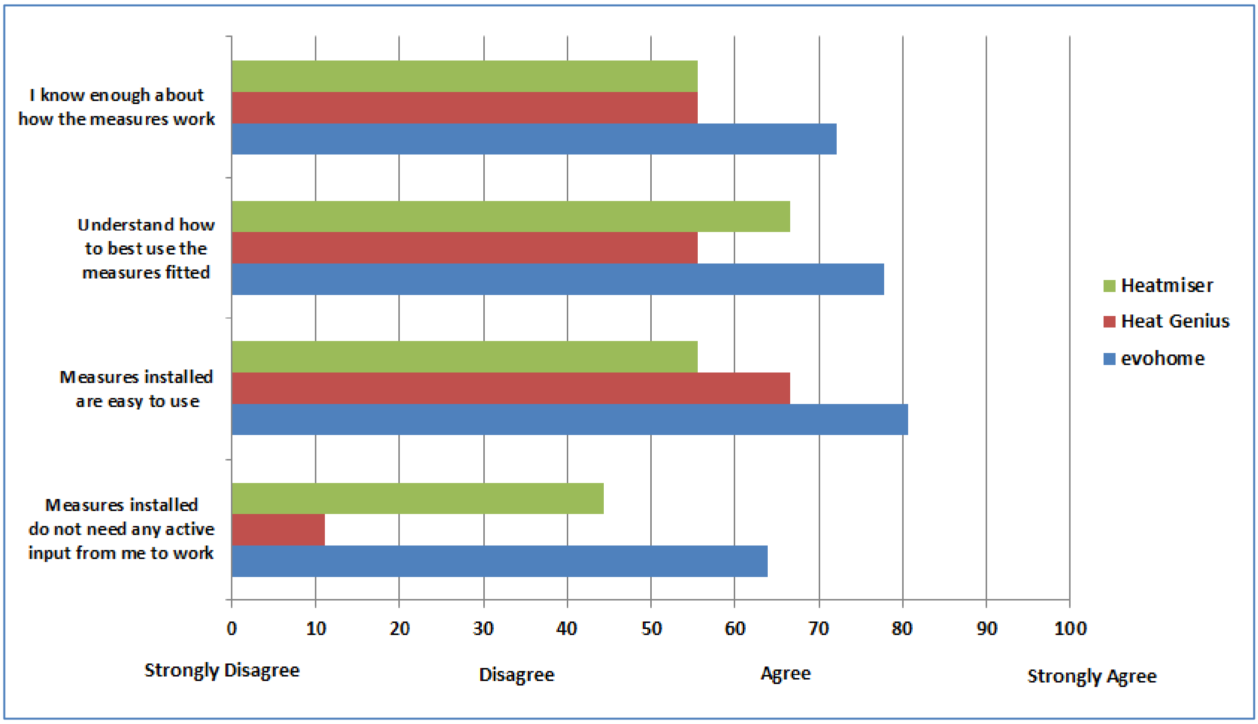

Figure 3.5 Agreement with statements about ease of use of the smart thermostat

Residents were asked a series of statements at the end of the study about the ease of use and reliability of the product. Their responses: 'strongly disagree', 'disagree', 'agree' and 'strongly agree' were each assigned a score, where 'strongly disagree' scored zero and 'strongly agree' scored 100. Figure 3.5 shows the scores to statements about ease-of-use of the smart thermostats.

As in section 3.3 the Honeywell evohome system scored highest in each question. This indicated the Honeywell evohome thermostat was the easiest to use and the households understood how to best use the system.

When residents were asked if they knew enough about how the measure worked, the Honeywell evohome system scored 72.2% while both Heat Genius and Heatmiser neo scored 55.6%. A score of 66.6% corresponds to the resident agreeing with the statement.

The Honeywell evohome scored particularly well on the measure being easy to use with a value of 80.6%. In comparison, Heat Genius scored 66.6% and Heatmiser neo 55.6%. Heat Genius received the lowest score on whether residents understood how best to use the measures fitted with a value of 55.6% compared to 66.6 for Heatmiser neo and 77.8 for the Honeywell evohome. Household T-49 thought the Heat Genius system was easy to use, but felt they could benefit from further instruction to get the most out of the system.

On the statement that the measure installed did not need active input from the resident, Honeywell evohome scored 63.9%, with 44.4% for Heatmiser neo. Heat Genius scored poorly with a value of 11.1%. Here all the residents 'disagreed' or 'strongly disagreed' with the statement. Among those who 'strongly disagreed' was household T-07 who had had technical problems with the control.

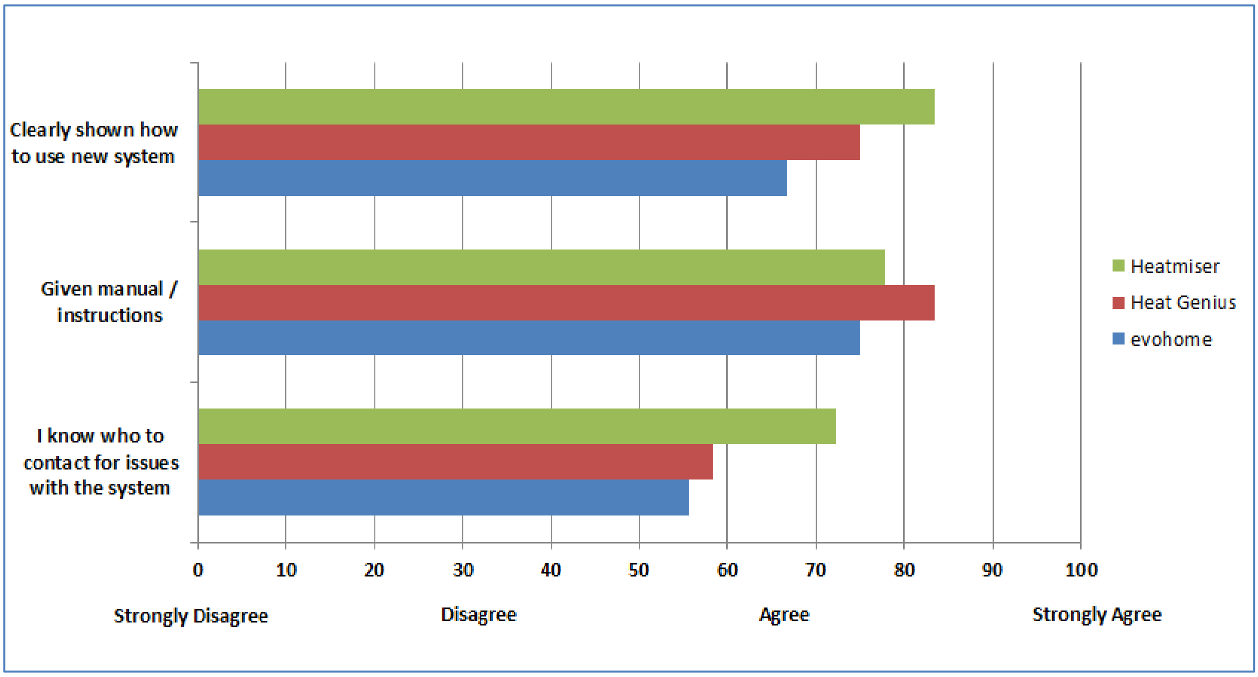

Figure 3.6 Information and training on use of smart thermostat

During the period of the evaluation, 50% (2 out of 4) of the households with the Heat Genius system which completed the study had technical issues. These were due to home WIFI /broadband, and a faulty room sensor, (which was replaced). In comparison 8.3% of the Honeywell evohome systems had reliability issues and none of the Heatmiser neo households noted any technical problems.

An indication of the quality of the training and information provided with the smart thermostat systems is provided in the responses to the statements shown in Figure 3.6. Here advice provided at the time of the Heatmiser neo installation came out most favourably on 2 of the 3 statements.

While residents scored 83.3% on being shown how to use the Heatmiser neo system, the training at installation was less successful for Heat Genius and the Honeywell evohome with scores of 75% and 66.7%.

All the residents in the monitored group that completed the study indicated that 'they were given a manual or instructions.

Residents were less confident that they knew who to contact if any issues arose with the Honeywell evohome and Heat Genius than they were with the Heatmiser neo. This may reflect the literature or advice provided by the installer at the time the system was fitted.

3.5 Perceived Comfort and Benefits

Residents were also asked about the potential benefits resulting from installation of their new controls. The responses in the form of percentages of the residents in the monitored group are shown in Figure 3.7.

On each question, Honeywell evohome had either the highest or the joint highest percentage of residents stating they saw these benefits. Heat Genius performed less well on ease of control and how well the home warmed and kept in the heat. The small sample size and problems household T-07 had as a result of broadband connection issues affected the results.

Over 90% of the households with the Honeywell evohome system felt the heating was easier to use, they had more control over their heating and their home was warmer and more comfortable. 66% of these households also thought their home got warmer faster, the house retained the heat better and there was an improvement in the quality of the home. Honeywell evohome was the only system where a significant number of the residents felt the installation had improved the quality of home.

The greatest benefits perceived by Heatmiser neo residents were that the heating was easier to use and they had more control over the system, their home was warmer and more comfortable and it got warmer faster. In each case, 66% of the households with Heatmiser neo noted these benefits.

75% of Honeywell evohome residents thought they saw a reduction in their energy bills or were saving energy in the home as did 50% of residents with Heat genius. Only 17% of residents with the Heatmiser neo system thought they were saving energy and reducing their energy bills. It should be noted that NEA staff helped some residents switch energy company or tariff to save money during the study. This will have affected perceived costs, but not actual consumption.

It is noteworthy that 41.7% of Honeywell evohome households felt there was an improvement in their family health following the installation. This compared to 25% for Heat Genius and 17% for Heatmiser neo. Benefits included fewer colds and an improvement in asthma symptoms.

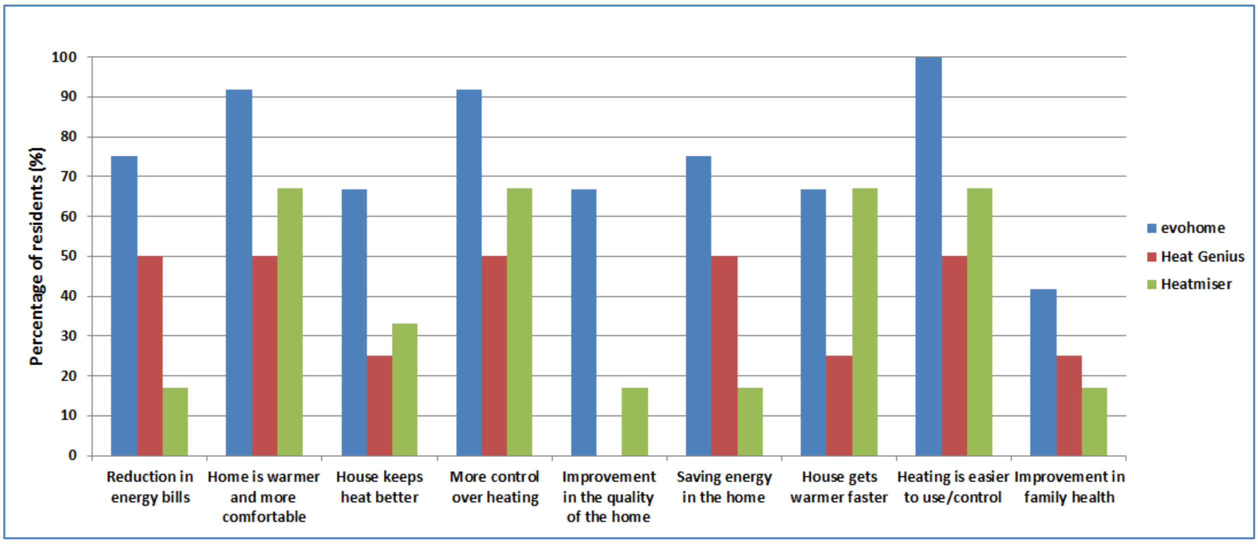

Figure 3.7 Benefits perceived by residents after installation of the smart thermostat

4. Technical evaluation and results

4.1 Cost

Analysis using gas meter readings and energy bills

	"Before" period							"After" period with smart thermostat							
Tech Ref	Period	Days	Total Period (kWh)	Gas[1] £/30 days	Degree days	kWh per Degree Day	Estimated Annual Gas Cost[2]	Period	Days	Total Period (kWh)	Gas[1] £/30 days	Degree days	kWh per Degree Day	Estimated Annual Gas Cost[1]	Saving
T-04	26/09/14 - 25/02/16	517	11,972	£34.74	3,227	3.71	£397.85	22/03/16 - 07/02/17	322	6,194	£28.85	1,746	3.55	£380.31	4.4%
T-05	07/08/14 - 02/03/16	573	25,224	£66.03	3,375	7.47	£801.43	29/04/16 - 01/03/17	306	12,230	£59.95	1,638	7.47	£800.76	0.1%
T-10	28/09/14 - 17/02/16	507	11,703	£34.62	3,142	3.72	£399.39	03/03/16 - 07/06/17	461	8,528	£27.75	2,675	3.19	£341.82	14.4%
T-12	18/07/14 - 16/03/16	607	22,323	£55.16	3,540	6.31	£676.26	14/04/16 - 09/02/17	301	9,145	£45.57	1,595	5.73	£614.93	9.1%
T-13	10/09/14 - 24/02/16	532	16,180	£45.62	3,237	5.00	£535.96	28/03/16 - 31/03/17	368	11,075	£45.14	2,117	5.23	£561.12	-4.7%
T-15	07/07/14 - 05/02/16	578	8,864	£23.00	3,112	2.85	£305.49	14/04/16 - 13/01/17	274	3,557	£19.47	1,269	2.80	£300.52	1.6%
T-19	29/05/14 - 13/02/16	625	13,252	£31.80	3,248	4.08	£437.48	14/03/16 - 28/02/17	351	8,775	£37.50	2,012	4.36	£467.60	-6.9%
T-21	23/09/14 - 17/03/16	541	17,201	£47.69	3,470	4.96	£531.50	15/04/16 - 10/02/17	301	6,429	£32.04	1,602	4.01	£430.30	19.0%
T-22	31/12/14 - 23/02/16	419	11,782	£42.18	2,570	4.58	£491.62	23/09/16 - 06/02/17	382	9,695	£38.07	2,199	4.41	£472.85	3.8%
T-27	02/02/16 - 23/03/16	50	2,166	£64.98	530	4.09	£438.35	30/03/16 - 11/03/17	346	8,909	£38.62	1,971	4.52	£484.62	-10.6%
T-33	15/07/14 - 27/02/16	592	11,658	£29.54	3,341	3.49	£374.24	17/03/16 - 14/03/17	362	8,079	£33.48	2,098	3.85	£412.92	-10.3%
T-34	11/08/14 - 10/01/16	517	8,056	£23.37	2,834	2.84	£304.87	20/02/16- 19/03/17	393	7,810	£29.81	2,408	3.24	£347.75	-14.1%
Average	**evohome**					4.43	£474.54						4.36	£467.96	0.5%
T-01	10/01/15 - 10/03/16	425	11,580	£40.87	2,660	4.35	£466.81	17/03/16 - 09/03/17	357	8,864	£37.24	2,067	4.29	£459.90	1.5%
T-07	06/03/15 - 07/03/16	367	7,484	£30.59	1,982	3.78	£405.02	07/04/16 - 03/04/17	361	6,228	£25.88	2,054	3.03	£325.18	19.7%
T-49	02/07/14 - 03/02/16	581	17,392	£44.90	3,096	5.62	£602.34	06/07/16 - 11/06/17	340	12,085	£53.31	1,972	6.13	£657.01	-9.1%
T-54	07/10/14 - 14/04/16	555	20,096	£54.31	3,658	5.49	£589.15	04/05/16 - 09/06/17	401	7,523	£28.14	2,133	3.53	£378.23	35.8%
Average	**Heat Genius**					4.81	£515.83						3.40	£455.08	12.0%
T-02	09/07/14 - 28/04/16	659	22,228	£50.59	3,901	5.70	£610.98	08/05/16 - 19/05/16	376	12,170	£48.55	2,083	5.84	£626.59	-2.6%
T-08	30/03/15 - 04/03/16	340	8,236	£36.33	1,729	4.76	£510.89	18/03/16 - 27/02/17	346	9,661	£41.88	1,963	4.92	£527.70	-3.3%
T-30	09/01/15 - 27/02/16	414	12,803	£46.39	2,527	5.07	£543.19	29/03/16 - 30/04/17	397	10,278	£38.83	2,306	4.46	£478.01	12.0%
T-36	26/09/14 - 06/03/16	527	18,020	£51.29	3,341	5.39	£578.34	15/04/16 - 10/05/17	390	9,403	£36.17	2,235	4.21	£451.13	22.0%
T-50	13/06/14 - 01/04/16	658	12,646	£28.83	3,718	3.40	£364.77	05/05/16 - 17/05/17	377	7,125	£28.35	2,088	3.41	£366.00	-0.3%
T-52	24/07/14 - 29/10/15	462	14,160	£45.98	2,379	5.95	£638.25	02/02/16 - 08/02/17	372	12,399	£50.00	2,278	5.44	£583.65	8.6%
Average	**Heatmiser neo**					5.05	£541.07						4.71	£505.51	6.1%

[1] - Gas cost = 5p/kWh

[2] - Using the 20 year average annual degree-day value for East Pennines = 2145 degree days per year

Table 4.1 Analysis of gas costs before and after the smart thermostats were fitted using bill and meter readings

Gas meter readings were recorded by the households during the study. Consumption data was also obtained from bills prior to the monitoring period. These meter readings allowed the gas consumption of households to be compared before and after the installation of the smart thermostats. The smart thermostats were installed between late January 2016 and April 2016. Meter readings from the before-period were in the range May 2014 to April 2016. Those from the after-period ranged from shortly after the smart thermostat installation up until the June 2016. Table 4.1 shows the gas consumption (in kWh) for the before and after periods and the cost of the gas in £/30 days, using a standard gas price of 5p/kWh.

In order to properly analyse energy use for space heating, account must be taken of the weather, known as normalising heating costs. For example, it is poor practice to compare the heating costs for two periods without compensating for different outdoor temperatures. An external temperature of 15.5°C is accepted by energy professionals as the outside temperature below which heating will be required, and above which no heating is necessary. The heating requirement for a building is proportional to the number of heating degree days (HDD) i.e. the number of degrees below 15.5°C that the average temperature is on each day during the period. 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[18]. Good quality temperature data was available from weather stations nearby. Since Conningsby (EGXC) was to the north of Spalding, Wittering (EGXT) to the south west and Holbeach (EGYH) to the east, it was decided to use an average of the degree-day values from these sites. An average of the number of degree days per year over a 20-year period was only available on a regional basis, which was used to normalise the savings which can be expected in the following analysis. In this case, 2,145 degree days, the value for the East Pennines region was used as the households around Spalding were located in this area[19].

In Table 4.1, the figure of kWh per degree day was calculated by dividing the gas consumption by the number of degree days for the same period. The estimated annual gas cost for the sites was obtained by multiplying the unit gas cost by the number of kWh per degree day for the property and the 20-year average number of degree days in the East Pennines region.

For the properties with **Honeywell evohome** systems, the estimated annual gas cost before the thermostat was installed ranged from £305 to £801. After the evohome system was installed the costs were in the range £301 to £801. Half of the properties saw a decrease and half an increase in gas consumption. These ranged from 19% savings to a 14% increase in consumption. Averaged across all the evohome installations, there was a 0.5% reduction in gas consumption. Despite this the product proved the most popular for ease of use.

With the **Heat Genius** system, 3 of the residents experienced savings in the temperature-corrected annual gas cost, while the other system saw an increase. Initial bills were in the range £405 to £602 and those following installation of Heat Genius were between £325 and £657. The average saving over all the Heat Genius systems was 12%.

Half of the homes which received the **Heatmiser neo** thermostat saw a reduction in gas consumption. The average annual gas bills prior to installation were in the range £365 to £638 and after the smart thermostat was installed, they were between £366 and £627. On average there was a 6.1% reduction in gas consumption.

Appendix 4 provides details of the age of the boiler and other recent changes to the heating system based on anecdotal evidence from residents during the final interview in February or March 2017. In some households the boiler may have been changed during the pre-monitoring period or near the time of the smart heating control installation.

For household T-10, the boiler was more than 1 year old at the time of the final interview, suggesting it may have been replaced a few months before the smart heating control was installed. The reduction in consumption after the evohome system was installed was 14.4%, but the new boiler is likely to have contributed to these savings. Household T-36 had a new boiler and hot water tank fitted in March 2016 in the same month as the Heatmiser neo control. The savings from the combined installation was 22%. If this property was excluded from the average savings for Heatmiser neo, the value would decrease to 2.9%.

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

Other properties where a new boiler was fitted about a year before the final interview saw less benefit. Household T-22 with evohome made savings of 3.8%, while household T-49 with Heat Genius saw an increase in consumption of 9.1%.

Among the households where the boiler was about 2 years old at the time of the final interview, during the evaluation there was an increase in consumption of 4.7% for household T-13, and 10.6% for T-27, both with evohome systems. Household T-08 with a Heatmiser neo system also saw increased consumption of 3.3%.

Recent boiler changes were likely to have contributed to savings achieved by households T-10 and T-36. Other households which also had similar upgrades like T-08, T-13, T-22, T-27 and T-49 made small savings or saw increased consumption over the monitoring period. This suggested that improved thermal comfort may have outweighed the benefit of savings from a more efficient boiler and the heating control.

Influence of annual gas consumption and EPC space heating demand on savings

The space and water heating demand assumed in an Energy Performance Certificate (EPC) provides an indication of gas consumption requirements to achieve a standardised level of comfort that could be achieved within a property. Comparing the pre-installation annual gas consumption in this study (normalised for temperature) with the EPC heating demand provides an indication of the comfort level experienced by households before the installation (Table 4.2). The annual gas consumption, normalised for temperature was calculated by multiplying the value of kWh per degree day by the 20-year average number of degree days in the region, which in this case was 2145.

The EPCs for properties T-04 and T-54 were produced before 2012 and these do not include details of the space and water heating demand. As a result these values are not included in Table 4.2.

			"Before" period			"After" period			
Tech Ref	Smart Thermostat	EPC space and water heating demand (kWh)	kWh per Degree Day (Before)	Pre install annual gas consumption (kWh)1	Ratio of annual consumption to EPC heating demand (pre install)	kWh per Degree Day (After)	Post install annual gas consumption (kWh)[1]	Ratio of annual consumption to EPC heating demand (post install)	Cost Saving
T-04	evohome	-	3.71	7,957	-	3.55	7,607	-	4.4%
T-05	evohome	18,494	7.47	16,029	0.87	7.47	16,016	0.87	0.1%
T-10	evohome	12,690	3.72	7,988	0.63	3.19	6,837	0.54	14.4%
T-12	evohome	9,942	6.31	13,526	1.36	5.73	12,299	1.24	9.1%
T-13	evohome	8,398	5.00	10,720	1.28	5.23	11,223	1.34	-4.7%
T-15	evohome	7,552	2.85	6,110	0.81	2.80	6,011	0.80	1.6%
T-19	evohome	10,589	4.08	8,750	0.83	4.36	9,352	0.88	-6.9%
T-21	evohome	11,641	4.96	10,631	0.91	4.01	8,606	0.74	19.0%
T-22	evohome	11,746	4.58	9,833	0.84	4.41	9,458	0.81	3.8%
T-27	evohome	10,678	4.09	8,768	0.82	4.52	9,693	0.91	-10.6%
T-33	evohome	11,992	3.49	7,485	0.62	3.85	8,259	0.69	-10.3%
T-34	evohome	11,187	2.84	6,098	0.55	3.24	6,955	0.62	-14.1%
Average		11,355		9,491	0.86			0.86	0.5%
T-01	Heat Genius	8,372	4.35	9,337	1.12	4.29	9,198	1.10	1.5%
T-07	Heat Genius	10,033	3.78	8,101	0.81	3.03	6,504	0.65	19.7%
T-49	Heat Genius	20,920	5.62	12,047	0.58	6.13	13,141	0.63	-9.1%
T-54	Heat Genius	-	5.49	11,783	-	3.53	7,565	-	35.8%
Average		13,108		10317	0.83			0.79	12.0%
T-02	Heatmiser	9,972	5.70	12,220	1.23	5.84	12,532	1.26	-2.6%
T-08	Heatmiser	9,130	4.76	10,218	1.12	4.92	10,555	1.16	-3.3%
T-30	Heatmiser	10,872	5.07	10,864	1.00	4.46	9,561	0.88	12.0%
T-36	Heatmiser	12,481	5.39	11,567	0.93	4.21	9,023	0.72	22.0%
T-50	Heatmiser	8,152	3.40	7,296	0.89	3.41	7,320	0.90	-0.3%
T-52	Heatmiser	10,325	5.95	12,766	1.24	5.44	11,673	1.13	8.6%
Average		10,155		10822	1.07			1.01	6.1%

[1] Annual gas consumption calculated using the 20 year average degree-day value for East Pennines = 2145 degree days per year

Table 4.2 Influence of space and water heating demand on savings from smart thermostats

The RdSAP methodology used to calculate energy efficiency (SAP) ratings and the space and water heating demand treats all programmers and room thermostats the same. A household where a basic dial thermostat and programmer was replaced by a smart heating control such as the Honeywell evohome will therefore see no change in the SAP rating or space and water heating demand recorded on an EPC after the installation. In practice there is likely to be a change in the space and water heating demand after installation of a smart heating control

If the ratio of the pre-installation annual gas consumption to the EPC heating demand is greater than 1.0, the residents typically had a higher level of thermal comfort or heating demand than predicted by the RdSAP software for the EPC. There is likely to be more potential to make savings for those properties where the ratio is greater than 1.0.

For those where the ratio is significantly less than 1.0, the residents were likely to be under-heating their home and it is possible that using the smart thermostat could lead to an increase in gas consumption due to greater thermal comfort.

The 3 households with Honeywell evohome systems which showed the largest increases in gas consumption (T-27, T-33 and T34) all had a lower ratio of annual consumption to EPC heating demand. This suggests the homes had been under-heated and the residents improved their thermal comfort after the evohome system was installed. One of the residents at T-27 developed a health condition during the study and was subsequently at home more which would have led to increased gas consumption.

Property T-12 had the highest ratio of pre-installation annual gas consumption to EPC heating demand (1.36) and showed savings of 9.1%. This suggests the home had a high level of thermal comfort before the Honeywell evohome system was installed and by using the smart thermostat it was possible to make savings without adversely affecting the thermal comfort. Property T-21 had a ratio of annual gas consumption to EPC heating demand of 0.91 and showed the greatest reduction in gas consumption, with savings of 19%. The space and water heating demand on the EPC may not be accurate as the EPC assumed no loft insulation and the resident stated during the first interview that there was 250 – 270mm of insulation. If this was the case, the space and water heating demand should therefore have been lower and the ratio of annual gas consumption to EPC heating demand greater than 0.91.

Property T-10 showed a 14.4% saving after the Honeywell evohome system was installed. In this case the ratio of pre-installation annual gas consumption to EPC space and water heating demand was only 0.63. The EPC assessor had assumed there was no loft insulation and the resident stated at the first interview there was 250-270mm of insulation fitted. Loft insulation would have increased the ratio beyond 0.63. Since the EPC survey was in January 2016, it was likely to have included the new boiler.

With the Heat Genius installations, property T-49 had the lowest ratio of pre-installation annual gas consumption to EPC heating demand. This household showed a temperature-corrected increase in gas consumption of 9.1%. It is likely that this increase was due to improved thermal comfort.

The ratio of pre-installation annual gas consumption to EPC heating demand for the Heatmiser neo installations ranged from 0.89 to 1.24. This suggests that these homes in the study are likely to have had an adequate level of thermal comfort before the smart thermostat was installed.

Property T-52 had a ratio of pre-installation annual gas consumption to EPC heating demand of 1.24. This was the highest for the Heatmiser neo installations and was due to 1 of the residents in the household having a medical condition which required the house to be warm when they were home. The household made savings of 8.6% on their gas consumption after installation of Heatmiser neo. This may have been due to being able to lower temperatures at times when heating was not required.

Properties T-02 and T-08 with the next highest ratios showed increases in gas consumption. This suggests that these households maintained a high room temperature following the installation of Heatmiser neo. The householder in T-08 stopped using the phone app as when that particular phone left the house it turned off the heating leaving other family members cold. Although installation of an electric shower in T-02 in April 2016 should have reduced gas consumption, high levels of thermal comfort recorded may have led to the rise in consumption.

The Heatmiser neo installations which made the greatest savings were properties T-36 and T-30. These households had a ratio of pre-installation gas consumption to EPC space heating demand of 0.93 and 1.0 respectively and saw decreases in gas consumption of 22% and 12%. It should be noted that the EPC survey for property T-36 was in February 2016, prior to replacement of the boiler and hot water tank. Following this upgrade, the space and water heating demand would have reduced and the property was likely to be overheated based on previous gas consumption.

Graphs of kWh usage against number of Degree Days

Where there are sufficient meter readings it is possible to plot a graph of gas 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.

Figure 4.3 shows Performance Line graphs for properties T-04, T-21 and T-33 before and after the Honeywell evohome thermostat installation. The graphs include equations of the line of best fit for the data points as well as the value for R^2. A value of R^2 closer to 1.0 indicates the data points are closer to the line of best fit.

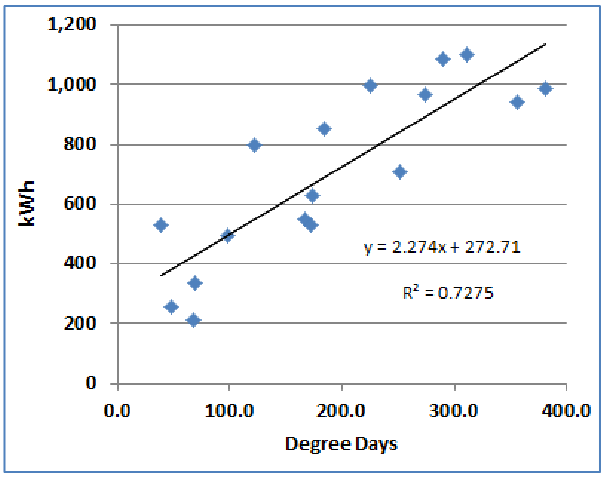

Figure 4.3a Property T-04 before evohome installation

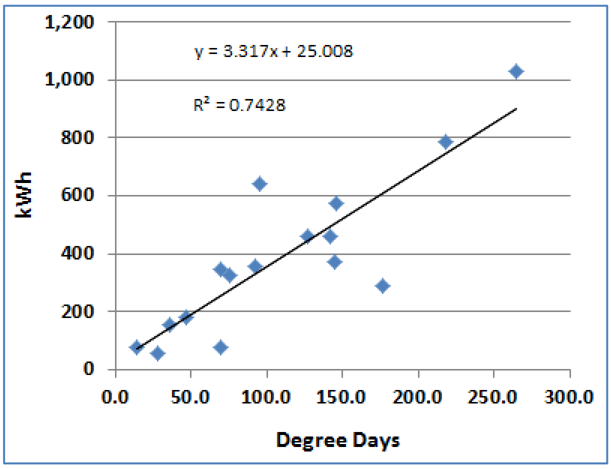

Figure 4.3b Property T-04 after evohome installation

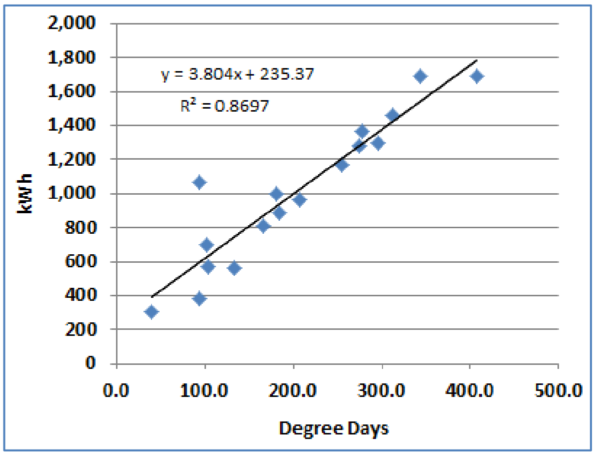

Figure 4.3c Property T-21 before evohome installation

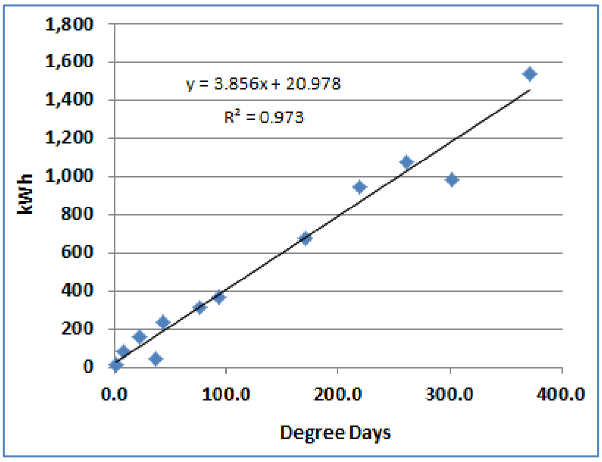

Figure 4.3d Property T-21 after evohome installation

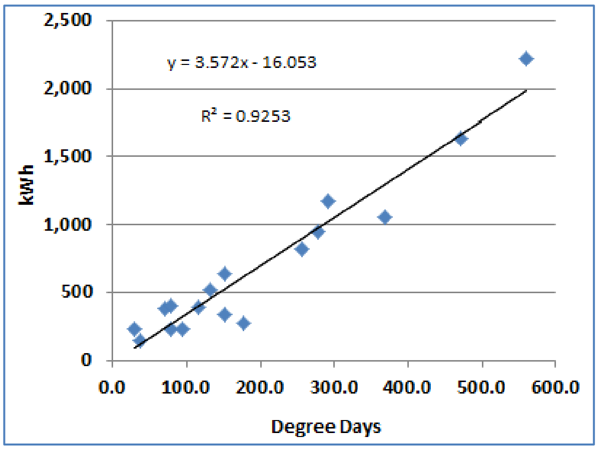

Figure 4.3e Property T-33 before evohome installation

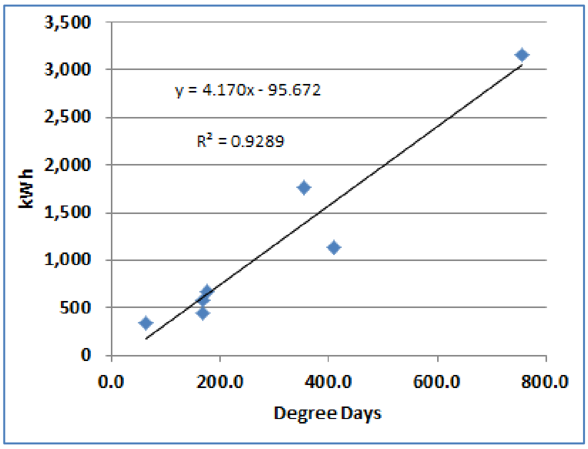

Figure 4.3f Property T-33 after evohome installation

Residents in property T-04 saw a 4.4% decrease in gas consumption after the Honeywell evohome system was installed. Figure 4.3a shows for T-04 there was considerable scatter in the data points which suggests there was likely to have been poor heating control and a wider variation in temperature at the property. Following installation of the evohome system, Figure 4.3b shows that the scatter in the data points was reduced to some extent, suggesting the temperature was more consistent. The intercept of the line of best fit with the y-axis (kWh) decreased from 273kWh to 25kWh after the evohome thermostat was installed. This indicates that during the pre-installation period, there was considerable heating of the property even on days when it was less cold outside. After the evohome system was installed, the amount of overheating was reduced and there was reduced 'base load' gas consumption. As the weather got colder, the gas consumption for T-04 increased at a greater rate after the evohome installation as indicated by the gradient of the performance line.

The performance lines for T-21 before and after the Honeywell evohome installations are shown in Figures 4.3c and d. The gas consumption reduced by 19% following the evohome installation, which was the greatest saving of all the evohome systems. There was far less scatter of data points around the performance line, which indicates the household maintained a consistent temperature control both before and after the evohome installation. The value of the y-intercept of the performance line again reduced following the smart thermostat installation. This suggests there was a reduction in heating the home on days when it was less cold outside.

Figures 4.3e and 4.3f show the performance line graphs for property T-33 before and after the installation of the Honeywell evohome system. While there were reductions in consumption for T-04 and T-21 after the thermostat was installed, property T-33 showed a 10.3% increase following installation of the evohome system.

There was relatively limited scatter of the data points around the performance line graph for T-33 for the periods both before and after the evohome installation. This suggested there was fairly consistent temperature control. The performance line had a negative intercept with the y-axis; this, and the ratio of gas consumption to EPC heating demand being low (Table 4.2), suggests that there was under-heating of the home. The gas consumption rate increased more at lower temperatures after the evohome system was installed. This might be due to the householder being more likely to turn up the thermostat in cold weather after evohome was installed.

Figure 4.4a and 4.4b show the performance line graphs for property T-07 before and after the installation of the Heat Genius smart thermostat system. The resident saw a 19.7% reduction in consumption following the installation. There were some technical difficulties with the system which seemed to be largely associated with the reliability of the home broadband and WIFI connection and the resident gave negative feedback on understanding how best to use the system.

The wide scatter in data points in Figure 4.4a suggests there was poor control of the temperature in the period prior to installing Heat Genius. Although there are few data points after installation, they are closer to the performance line, which suggests a more consistent temperature was achieved. The y-intercept of the performance line decreased from 122.6kWh to 74.6kWh after Heat Genius was installed. This suggests there was less overheating of the property on days with milder temperatures following the installation of the smart thermostat.

Property T-54 showed the greatest reduction in gas consumption out of the Heat Genius installations and for all the smart thermostats in this study. The savings achieved were 35.8% compared to pre-installation consumption. Figures 4.4c and 4.4d show performance line graphs before and after installation. There was little scatter of the data points both before and after installation indicating a steady temperature was maintained in the property. There was a significant decrease in the gradient of the performance line after Heat Genius was installed. This shows the gas consumption increased less as the weather became colder outside. This may have been achieved by the resident focusing the heating on rooms that were occupied and reducing the temperature in rooms which were unoccupied using the smart TRVs.

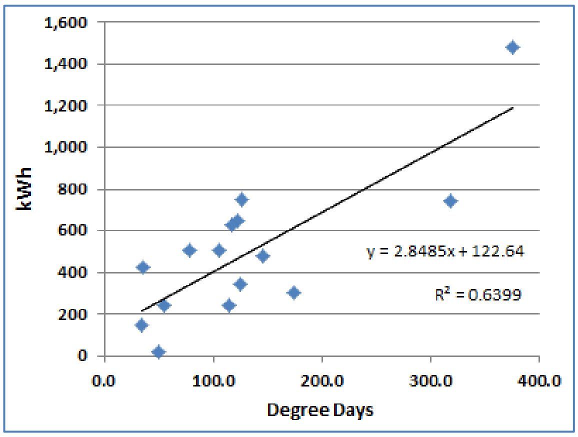

Figure 4.4a Property T-07 before Heat Genius installation

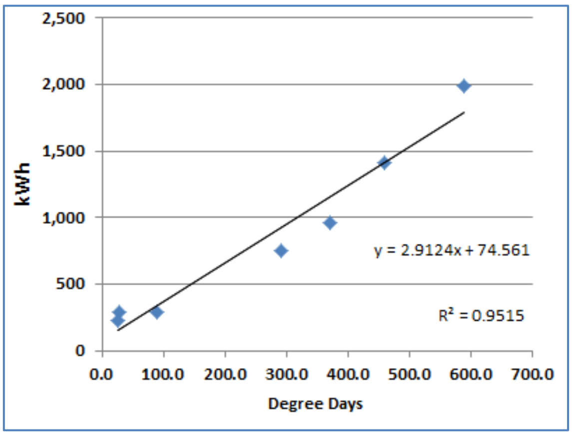

Figure 4.4b Property T-07 after Heat Genius installation

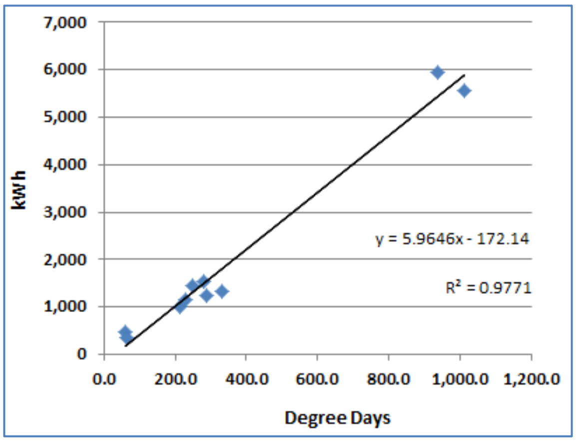

Figure 4.4c Property T-54 before Heat Genius installation

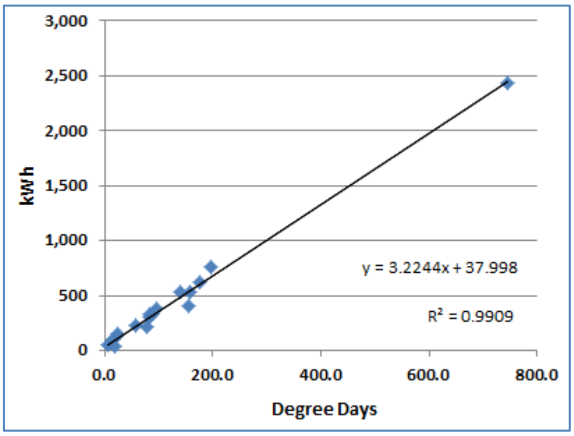

Figure 4.4d Property T-54 after Heat Genius installation

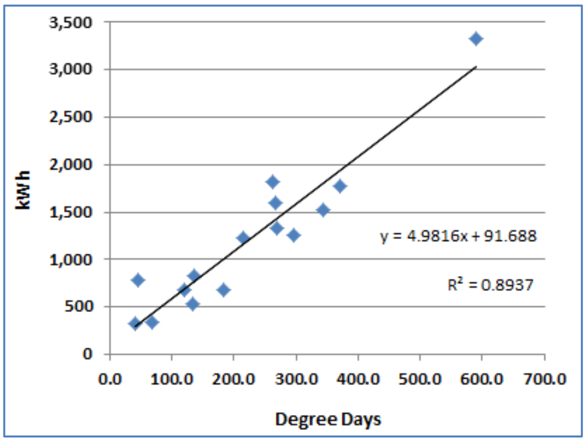

Figure 4.5a Property T-36 before Heatmiser neo installation

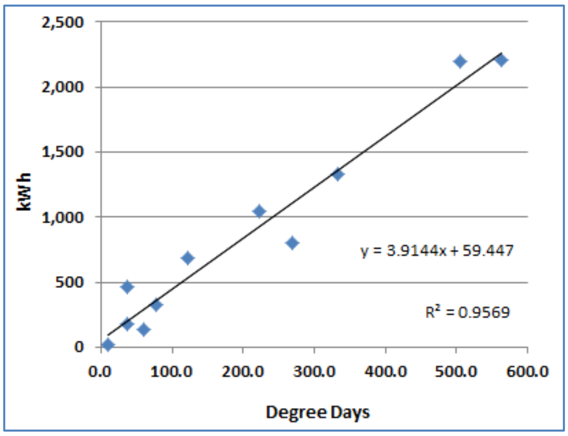

Figure 4.5b Property T-36 after Heatmiser neo installation

Property T-36 showed a 22% reduction in gas consumption following the installations of the Heatmiser neo thermostat. Figures 4.5a and 4.5b show the performance lines before and after installation. The amount of scatter of the data points on Figure 4.5a is not high, indicating the temperature control was quite good before installation. The scatter reduced after installation which suggests the temperature control improved. There was a significant reduction in the gradient of the performance line following installation, indicating the gas consumption increased less as the weather became colder. The boiler and hot water tank for the system was replaced in March 2016 which contributed to savings and the reduction in the y-intercept from 92kWh to 59kWh.

4.2 Temperature and thermal comfort

Temperature and humidity loggers were placed in each of the monitored homes during the study. One was located in the living room while a second was placed in the main bedroom of many of the properties. Data from the loggers was typically analysed over the period between 1 Oct 2016 and 31 Jan 2017.

All of the Honeywell evohome loggers were placed in households in December 2015 and this provided a short period before the measures were installed when these loggers were recording pre-installation temperatures. About half of the loggers for Heat Genius and Heatmiser neo were set up in December 2015. The rest were installed during July 2016, after additional households were identified for the monitoring group. 5 loggers failed and did not record data over the full duration of the study.

It was possible to assess the temperature and humidity before and after the smart thermostats were fitted by analysing data from the loggers installed in December 2015. The pre-installation period chosen was 1 Jan 2016 to 15 Jan 2016 during the time when households wanted to keep warm, between 17:00 and 21:00. The same dates a year later were chosen for the post-installation period. For the dates in January 2016, there were 155 degree days, while it was colder over the same period in 2017 with 168 degree days. Table 4.6 and Figure 4.7a/b summarise the average living room temperature and humidity for the properties in January 2016 and January 2017 respectively.

Properties T-04, T-12 and T-21 had a warmer average living room temperature in the 'after' installation period in January 2017 than during the 'before' installation period in January 2016. This is despite the properties showing a decrease in gas consumption (Figure 4.1).

The difference in the average living room temperature between the before and after installation period was negligible for properties T-33 and T-19. This is despite increases in gas consumption of 10.34% and 6.89% respectively which indicates that other parts of the home were being heated and creating a warmer environment.

Only property T-10 showed significant savings (14.4%) and clear reduction in average temperature (0.98°C). Figure 4.8 shows that typically there was a poor correlation between the average temperature change between January 2016 and January 2017 and the savings or increases in consumption following the installation of the Honeywell evohome systems.

It is likely that the average temperature during the 2-week period in January 2016 and January 2017 did not provide a good representation of the typical thermal comfort before and after the Honeywell evohome installation. The pre-installation period used for the consumption calculations ranged from 50 to 625 days while the post-installation period was in the range 274 to 461 days.

This comparison only considered the temperature in the living room. The zoning with the Honeywell evohome smart TRVs allows different heating schedules and temperatures in different rooms. Some residents are likely to have made better use of the opportunity to reduce heating times and temperatures in some rooms than others.

	'Before' period					'After' period					
Tech Ref	Smart thermostat	Date range	Time range	Average Temp (°C)	Average Humidity (%)	Date range	Time range	Average Temp (°C)	Change in Average Temp (°C)	Average Humidity (%)	Change in Average Humidity (%)
T-04	evohome	01/01/16 - 15/01/16	17:00 - 21:00	18.66	56.16	01/01/17 - 15/01/17	17:00 - 21:00	20.3	1.64	47.73	-8.43
T-05	evohome	01/01/16 - 15/01/16	17:00 - 21:00	22.9	48.33	01/01/17 - 15/01/17	17:00 - 21:00	21.07	-1.83	48.57	0.24
T-10	evohome	01/01/16 - 15/01/16	17:00 - 21:00	20.38	57.92	01/01/17 - 15/01/17	17:00 - 21:00	19.4	-0.98	60.07	2.15
T-12	evohome	01/01/16 - 15/01/16	17:00 - 21:00	20.72	57.31	01/01/17 - 15/01/17	17:00 - 21:00	21.19	0.47	58.81	1.5
T-13	evohome	01/01/16 - 15/01/16	17:00 - 21:00	21.94	47.55	01/01/17 - 15/01/17	17:00 - 21:00	20.76	-1.18	49.93	2.38
T-15	evohome	01/01/16 - 15/01/16	17:00 - 21:00	21.96	56.15	01/01/17 - 15/01/17	17:00 - 21:00	21.97	0.01	54.11	-2.04
T-19	evohome	01/01/16 - 15/01/16	17:00 - 21:00	22.91	53.04	01/01/17 - 15/01/17	17:00 - 21:00	22.87	-0.04	45.76	-7.28
T-21	evohome	01/01/16 - 15/01/16	17:00 - 21:00	20.84	63.02	01/01/17 - 15/01/17	17:00 - 21:00	21.05	0.21	58.73	-4.29
T-22	evohome	01/01/16 - 15/01/16	17:00 - 21:00	21.82	59.97	01/01/17 - 15/01/17	17:00 - 21:00	21.87	0.05	51.99	-7.98
T-33	evohome	01/01/16 - 15/01/16	17:00 - 21:00	18.41	60.59	01/01/17 - 15/01/17	17:00 - 21:00	18.41	0	50.38	-10.21
Minimum				18.41	47.55			18.41		45.76	
Maximum				22.91	63.02			22.87		60.07	
Average				21.05	56.00			20.89		52.61	

Table 4.6 Average temperature and humidity in the living room before and after Honeywell evohome installations

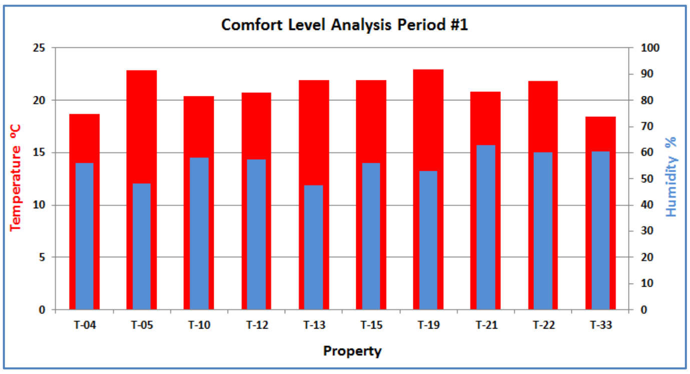

Figure 4.7a
Average living room temperature and humidity prior to Honeywell evohome installation – 17:00 to 21:00 in January 2016.

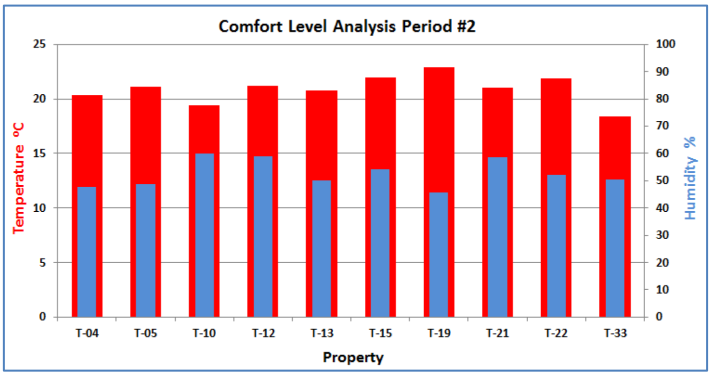

Figure 4.7b
Average living room temperature and humidity after Honeywell evohome installation – 17:00 to 21:00 in January 2017.

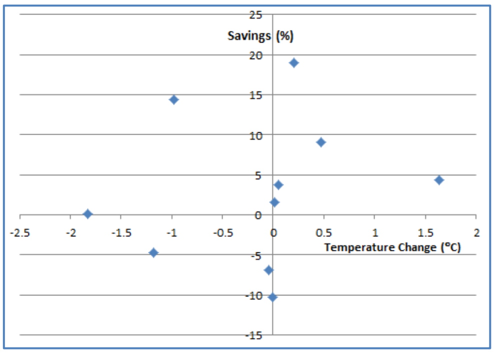

Figure 4.8 Plot of savings in gas consumption following smart thermostat installation against temperature change between January 2016 and January 2017 in the living room

Only 4 households with Honeywell evohome installations recorded temperature and humidity data in the bedroom for both pre and post installation periods. Table 4.9 shows that the average bedroom temperature of household T-04 increased from 16.64ºC to 19.11ºC between January 2016 and 2017. There was a smaller temperature increase of 0.28ºC for property T-19. There was little difference in the bedroom temperatures for T-22 for the two analysis periods. The bedroom temperature for property T-13 fell from 19.79ºC in January 2016 to 19.07ºC in January 2017.

Comparing Tables 4.6 and 4.9 shows that the bedrooms for properties T-04, T-13, T-19 and T-22 were all colder than the living rooms in both analysis periods. The bedroom temperatures for the properties were between 2 - 4ºC colder during the pre-installation analysis period and between 1.2 and 3.8ºC colder in January 2017.

		'Before' period				'After' period					
Tech Ref	Smart thermostat	Date range	Time range	Average Temp (°C)	Average Humidity (%)	Date range	Time range	Average Temp (°C)	Change in Average Temp (°C)	Average Humidity (%)	Change in Average Humidity (%)
T-04	evohome	01/01/16 - 15/01/16	17:00 - 21:00	16.64	61.68	01/01/17 - 15/01/17	17:00 - 21:00	19.11	2.47	56.63	-5.05
T-13	evohome	01/01/16 - 15/01/16	17:00 - 21:00	19.79	53.76	01/01/17 - 15/01/17	17:00 - 21:00	19.07	-0.72	53.56	-0.2
T-19	evohome	01/01/16 - 15/01/16	17:00 - 21:00	18.95	62.92	01/01/17 - 15/01/17	17:00 - 21:00	19.23	0.28	56.31	-6.61
T-22	evohome	01/01/16 - 15/01/16	17:00 - 21:00	17.98	65.86	01/01/17 - 15/01/17	17:00 - 21:00	18.07	0.09	63.85	-2.01
Minimum				16.64	53.76			18.07		53.56	
Maximum				19.79	65.86			19.23		63.85	
Average				18.34	61.06			18.87		57.59	

Table 4.9 Average temperature and humidity in the bedroom before and after Honeywell evohome installations

'Before' period						'After' period					
Tech Ref	Smart thermostat	Date range	Time range	Average Temp (°C)	Average Humidity (%)	Date range	Time range	Average Temp (°C)	Change in Average Temp (°C)	Average Humidity (%)	Change in Average Humidity (%)
T-01	Heat Genius	01/01/16 - 15/01/16	17:00 - 21:00	20.00	47.71	01/01/17 - 15/01/17	17:00 - 21:00	21.91	1.91	39.46	-8.25
T-07	Heat Genius	01/01/16 - 15/01/16	17:00 - 21:00	19.35	64.67	01/01/17 - 15/01/17	17:00 - 21:00	16.64	-2.71	68.74	4.07
T-02	Heatmiser	01/01/16 - 15/01/16	17:00 - 21:00	20.18	47.29	01/01/17 - 15/01/17	17:00 - 21:00	22.28	2.1	38.19	-9.1
T-36	Heatmiser	01/01/16 - 15/01/16	17:00 - 21:00	16.72	67.90	01/01/17 - 15/01/17	17:00 - 21:00	18.13	1.41	64.18	-3.72
Minimum				16.72	47.29			16.64		38.19	
Maximum				20.18	67.90			22.28		68.74	
Average				19.06	56.89			19.74		52.64	

Table 4.10 Average temperature and humidity in the living room before and after the smart thermostat installations

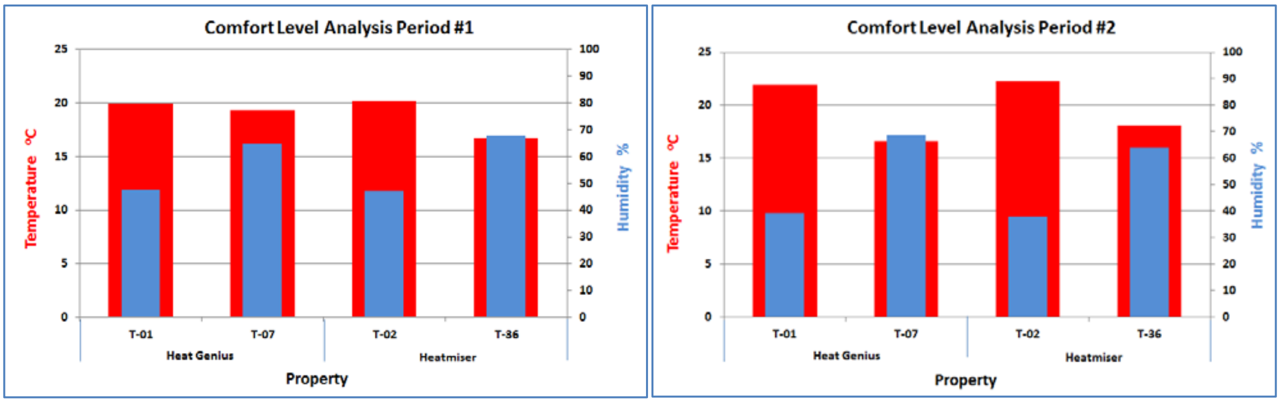

Figure 4.11 Average living room temperature and humidity before and after smart thermostat installations 17:00 to 21:00 in January 2016 (Period #1) and in January 2017 (Period #2).

It was also possible to assess the average early evening living room temperature and humidity before and after the smart thermostat installation for 4 properties with Heat Genius and Heatmiser neo. These are shown in Table 4.10 and Figure 4.11 for the 2-week period in January 2016 and January 2017.

The average early evening living room temperature for property T-01 in the 'before' installation period in January 2016 was 20.0°C. This increased to 21.91°C in the 2-week period in January 2017. Corresponding to this increase in thermal comfort, the gas consumption rose by 1.5%. This suggests the resident made use of zoning or did not heat the home as much in milder weather.

For T-07, the average living room temperature dropped from 19.35°C in January 2016 to 16.64°C in January 2017. There was a saving of 19.7% after installation of the Heat Genius thermostat, however issues over broadband connection limiting control of the system may have led to lower than desired temperatures at certain times.

Both the homes with Heatmiser neo thermostats where temperature was monitored before and after installation showed an increase in average living room temperature. For property T-02 this increased from 20.18°C in January 2016 to 22.28°C during the same 2-week period the following year. The resident had a health condition and preferred the living room to be warmer than the normally recommended 21°C. This however led to a 2.6% increase in gas consumption. The average living room temperature for T-36 increased from 16.72°C to 18.13°C. Overall, following installation of the Heatmiser neo thermostat, there was a 22% reduction in gas consumption for property T-36. With a new thermostat, boiler and hot water tank installed in March 2016, household T-36 made significant savings and apparently also improved thermal comfort.

Comfort Level Analysis Period #1			
Start Date	01 October 2016	Start Time	00:00:00
End Date	31 January 2017	End Time	23:59:00
Number of Days	122	Hours per day	23:59:00
Property	Average Temperature		Average Humidity
T-04	20.39		50.68
T-05	21.47		51.15
T-10	19.00		62.50
T-12	21.30		59.86
T-13	19.92		52.36
T-15	21.99		57.57
T-19	21.13		53.05
T-21	20.86		57.85
T-22	21.59		53.69
T-33	18.25		54.48
T-34	19.58		59.84
Count	11		11
Maximum	21.99		62.50
Minimum	18.25		50.68
Average	20.50		55.73
Median	20.86		54.48
Std Dev	1.18		3.98

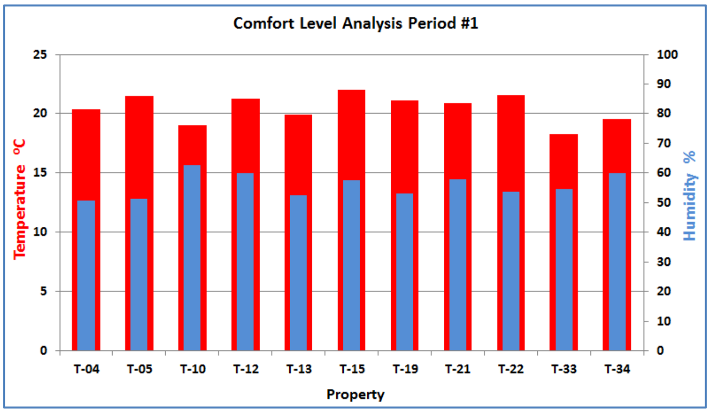

Figure 4.12 Average living room temperature and humidity for properties with the Honeywell evohome throughout the day for the period between 1 Oct 2016 and 31 Jan 2017.

Comfort Level Analysis Period #1			
Start Date	01 October 2016	Start Time	00:00:00
End Date	31 January 2017	End Time	23:59:00
Number of Days	122	Hours per day	23:59:00
Property	Average Temperature		Average Humidity
T-01	20.63		48.08
T-07	16.53		70.28
T-49	20.18		53.06
T-54	22.19		46.91
Count	4		4
Maximum	22.19		70.28
Minimum	16.53		46.91
Average	19.88		54.58
Median	20.40		50.57
Std Dev	2.40		10.80

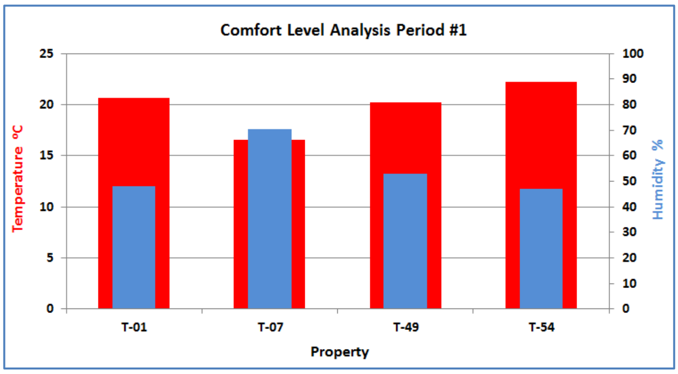

Figure 4.13 Average living room temperature and humidity for properties with the Heat Genius smart thermostat throughout the day for the period between 1 Oct 2016 and 31 Jan 2017.

Comfort Level Analysis Period #1			
Start Date	01 October 2016	Start Time	00:00:00
End Date	31 January 2017	End Time	23:59:00
Number of Days	122	Hours per day	23:59:00
Property	Average Temperature		Average Humidity
T-02	21.18		45.28
T-36	18.01		65.60
T-50	17.57		57.18
T-52	19.16		55.09
Count	4		4
Maximum	21.18		65.60
Minimum	17.57		45.28
Average	18.98		55.79
Median	18.59		56.13
Std Dev	1.61		8.35

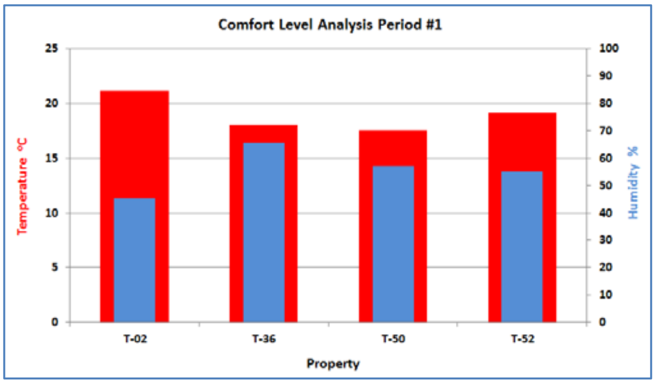

Figure 4.14 Average living room temperature and humidity for properties with the Heatmiser neo smart thermostat throughout the day for the period between 1 Oct 2016 and 31 Jan 2017.

Figure 4.12 shows a graph and table with the average living room temperature and humidity for properties with the Honeywell evohome thermostats between 1 Oct 2016 and 31 Jan 2017. This was for the full 24 hours per day rather than just the early evening period when residents mostly wanted to be warm.

All the Honeywell evohome properties maintained the living room at a comfortable average temperature of between 18.25°C and 22.0°C. Comparing Figure 4.12 with Table 4.6 shows that properties T-13 and T-19 were on average 0.84°C and 1.74°C warmer during the evening heating period in January 2017 than the average over the full 24 hours between 1 October 2016 and 31 January 2017. For the other properties, the temperatures for the 2 analysis periods were within 0.4°C

3 of the properties with Heat Genius thermostats maintained comfortable average living room temperatures during the period 1 October 2016 to 31 Jan 2017. These were in the range 20.18°C to 22.19°C as shown in Figure 4.13. The fourth property, T-07 had an average temperature of 16.53°C. The residents preferred living room temperature was 21°C or higher. This suggests technical problems with the broadband and control led to lower temperatures than desired.

The average living room temperature for property T-54 was 22.19°C in the October to January period. This property showed a 35.8% saving in gas consumption following the installation. Retaining a high living room temperature suggests the property had previously been overheated and that use of zoning in a home with higher than typical temperatures may lead to greater savings.

Figure 4.14 shows that for property T-02, the average living room temperature between October and January was 21.18°C. This was 1.1°C lower than the average early evening value in January 2017 shown in Figure 4.10. During the final interview it was noted that the Heatmiser neo thermostat was set to 26°C. This shows the resident preferred a warmer living room than the normally recommended 21°C during winter evenings.

The other households with Heatmiser neo thermostats had average living room temperatures between October 2016 and January 2017 which were lower than T-02. The average for household T-50 was 17.57°C. At the time of the final interview with the resident in February 2017, the thermostat was normally set to 16°C during the day and 18°C in the evening.

For property T-52, the average living room temperature was 19.16°C. For this household it was necessary to keep the home warm as 1 of the residents had a health condition. Here they set the thermostat to 18°C between 9pm and 6am and to 20°C during the day. The improved control over their previous dial thermostat is likely to have led to the savings of 8.56% on gas consumption.

Table 4.15 and Figure 4.16 show the average temperature and humidity between 1st October 2016 and 31st January 2017 for properties where loggers were placed in the bedrooms of households.

These can be compared with the average living room temperatures recorded for the 3 smart thermostat technologies over the same period in Figures 4.12 to 4.14.

Throughout the day						Early evening					
Tech Ref	Smart thermostat	Date range	Time range	Average Temp (°C)	Average Humidity (%)	Date range	Time range	Average Temp (°C)	Difference in Average Temp (°C)	Average Humidity (%)	Difference in Average Humidity (%)
T-08	Heatmiser	01/10/16 - 31/01/17	00:00 - 23:59	19.06	62.72	01/10/16 - 31/01/17	17:00 - 21:00	19.51	0.45	62.61	-0.11
T-52	Heatmiser	01/10/16 - 31/01/17	00:00 - 23:59	20.70	54.37	01/10/16 - 31/01/17	17:00 - 21:00	21.13	0.43	54.1	-0.27
T-49	Heat Genius	01/10/16 - 31/01/17	00:00 - 23:59	19.80	60.65	01/10/16 - 31/01/17	17:00 - 21:00	19.48	-0.32	59.03	-1.62
T-54	Heat Genius	01/10/16 - 31/01/17	00:00 - 23:59	17.98	67.22	01/10/16 - 31/01/17	17:00 - 21:00	18.01	0.03	63.45	-3.77
T-04	evohome	01/10/16 - 31/01/17	00:00 - 23:59	19.20	58.71	01/10/16 - 31/01/17	17:00 - 21:00	18.54	-0.66	58.42	-0.29
T-13	evohome	01/10/16 - 31/01/17	00:00 - 23:59	19.87	55.94	01/10/16 - 31/01/17	17:00 - 21:00	20.05	0.18	56.31	0.37
T-19	evohome	01/10/16 - 31/01/17	00:00 - 23:59	19.86	61.10	01/10/16 - 31/01/17	17:00 - 21:00	20.01	0.15	59.84	-1.26
T-22	evohome	01/10/16 - 31/01/17	00:00 - 23:59	18.93	66.33	01/10/16 - 31/01/17	17:00 - 21:00	18.72	-0.21	65.27	-1.06
Minimum				17.98	54.37			18.01		54.10	
Maximum				20.70	67.22			21.13		65.27	
Average				19.43	60.88			19.43		59.88	

Table 4.15 Average temperature and humidity in the bedroom between 1 Oct 16 and 31 Jan 17

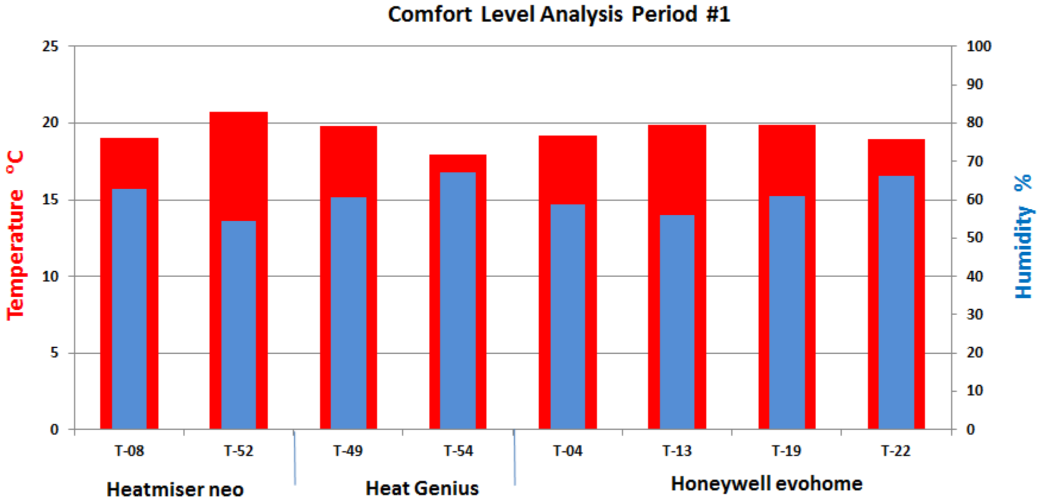

Figure 4.16 Average bedroom temperature and humidity throughout the day for properties with the Heatmiser neo, Heat Genius and Honeywell evohome thermostats for the period between 1 Oct 2016 & 31 Jan 2017.

The average bedroom temperatures throughout the day ranged from 17.98 to 20.70°C for the analysis period. This compared to average living room temperatures in the range 19.16°C to 22.19°C for all the properties which had loggers in both rooms. The average bedroom temperature was lower than the average living room temperature for all the properties apart from 1.

Household T-52, with a Heatmiser neo installation had an average temperature of 19.16°C in the living room, but 20.7°C in the bedroom. One of the residents had a medical condition and needed to be constantly warm. The Heatmiser neo system does not include smart TRVs and so this was a function of the heating system or how the manual TRVs were set.

The bedroom was about 0.45°C warmer in the early evening for both Heatmiser neo households. The average bedroom temperature in the early evening was lower than during the full 24-hour period for properties T-49 (Heat Genius), T-04 and T-22 (evohome).

4.3 Analysis of temperature data from the smart thermostats

Honeywell evohome

Tech Ref	Date	Time	Living Room	Kitchen / Dining room	Bedroom 1	Bedroom 2	Bedroom 3	Bathroom / Hall
T-12	09/02/2017	15:26	19.5°C	17.5°C	15°C	14°C		
T-21	06/02/2017	18:21	22°C	26°C	25.5°C	23.5°C	22°C	21°C
T-22	07/02/2017	15:35	26°C	21°C	19.5°C	22°C	20°C	18.5°C
T-33	09/02/2017	16:15	18°C	16 / 18.5°C				17.5°C

Table 4.17 Zone temperatures for Honeywell evohome systems at time of final interview

It was not possible to access temperature data from the Honeywell evohome system or app, but the temperatures of the different zones were recorded at the time of the final interview for some residents with evohome systems.

All of the households seem to be making use of the zoning and have the living room or dining room set at a higher temperature than other rooms.

Properties T-21 and T-22 had the highest temperature for the living room or dining room, with a setting of 26°C. For comparison, the early evening average living room temperatures were 21.05°C and 21.87°C for the period 1 Jan 2017 to 15 Jan 2017. The temperature settings for property T-21 may be higher than for the other households as the visit took place in the early evening rather than mid-afternoon as for the others.

The Honeywell evohome system which showed the greatest saving was installed in property T-21 where the residents achieved a reduction in gas consumption of 19%. Significant savings can be achieved by reducing the room temperatures from 26°C to 21°C or below. The zoning for T-21, with some rooms at lower temperatures should have led to significant savings compared to the house being uniformly at the highest temperature.

Residents in property T-22 made better use of the zoning at the time of the monitoring visit. Overall they made a 3.8% saving in gas consumption after installation of the Honeywell evohome system. Although some rooms were kept at lower temperatures during the visit in February 2017, the savings achieved were dependent on how the heating system was used during the extended pre and post-installation period shown in Figure 4.1.

Greater savings in gas consumption of 9.1% were achieved in property T-12. At the time of the visit, the living room and kitchen were maintained at a comfortable temperature of 19.5°C and 17.5°C. The bedrooms which were unoccupied at the time were at a lower temperature of 14°C and 15°C. Such zoning will have enabled savings compared to maintaining all rooms at a steady 19°C. The average living room temperature between 1 Oct 2016 and 31 Jan 2017 was 21.3°C. This suggests that the temperature was set to above 21.3°C during the evening.

The room temperatures in property T-33 were between 16°C and 18.5°C during the visit in February 2017. The average living room temperature was 18.25°C over the analysed period between 1 Oct 2016 and 31 Jan 2017. The gas consumption increased by 10.3% following installation of the Honeywell evohome. Figure 4.2 suggests that property T-33 was under-heated prior to installation of the smart thermostat.

Heat Genius

Temperature data for the monitored properties was obtained through Heat Genius. This included the temperature schedule for each room and the temperatures measured by the room sensor. The temperature was recorded approximately every 5 minutes and had a resolution of 0.5°C. If the WIFI connection was lost due to the resident turning off the WIFI router or through technical problems with the connection, no data was recorded. This led to gaps in the temperature data, particularly for property T-07. On a few occasions, there were data gaps between midnight and about 10am for the systems due to an issue with the conversion from the database.

Table 4.18 shows the average room temperatures for 3 of the Heat Genius installations for the period between the beginning of October 2016 and the end of January 2017. For properties T-01 and T-54 the analysis period started on the 1st October, but for T-49 it started on 11th October due to a gap in the data.

The average living room temperature for T-01 at 20.57°C compares well with data recorded by the temperature and humidity logger of 20.63°C. For property T-49, the average living room temperature measured by the room sensor was 20.53°C compared to 20.08°C over the same period by the logger. With property T-54, the difference in the average temperatures measured for the living room was even greater, with an average of 21.36°C determined from the sensor and 22.19°C from the temperature and humidity logger.

The temperature and humidity logger only recorded data every hour compared to every 5 minutes by the Heat Genius sensors. The locations of the logger and sensor will also have an effect and there can be variations of over 1°C across a room. The temperature recorded by the Heat Genius system for the living room in T-54 may also have come from the main Wireless Thermostat which was located in the hall.

Between October 2016 and January 2017, the average temperature in each room for households T-01, T-49 and T-54 was in the range 19.28°C to 22.73°C. In property T-01, during much of November the room temperature was in the range 16 to 20°C. From late November, the heating was left on 24 hours a day with the room temperature normally greater than 21°C. With many temperature readings at the high and low end of the temperature range, this led the standard deviation for the temperatures to be greater for property T-01.

	Living Room		Kitchen		Bedroom 1		Bedroom 2		Bedroom 3		Other	
Tech Ref	Mean Temp	S. Dev	Mean Temp	S. Dev	Mean Temp	S. Dev	Mean Temp	S. Dev	Mean Temp	S. Dev	Mean Temp	S. Dev
T-01	20.57	1.80	19.75	1.66	20.56	1.39	20.45	1.44	20.02	1.56	19.28	1.45
T-49 *	20.53	1.35	20.72	1.08	20.80	1.12	20.64	0.92	20.95	0.98	20.96	1.52
T-54	21.36	1.36	21.16	1.32	22.73	1.25	21.77	1.04	19.69	1.23		

* Data starting from 11th October 2016

Table 4.18 Average room temperatures between October 2016 and January 2017 for Heat Genius systems

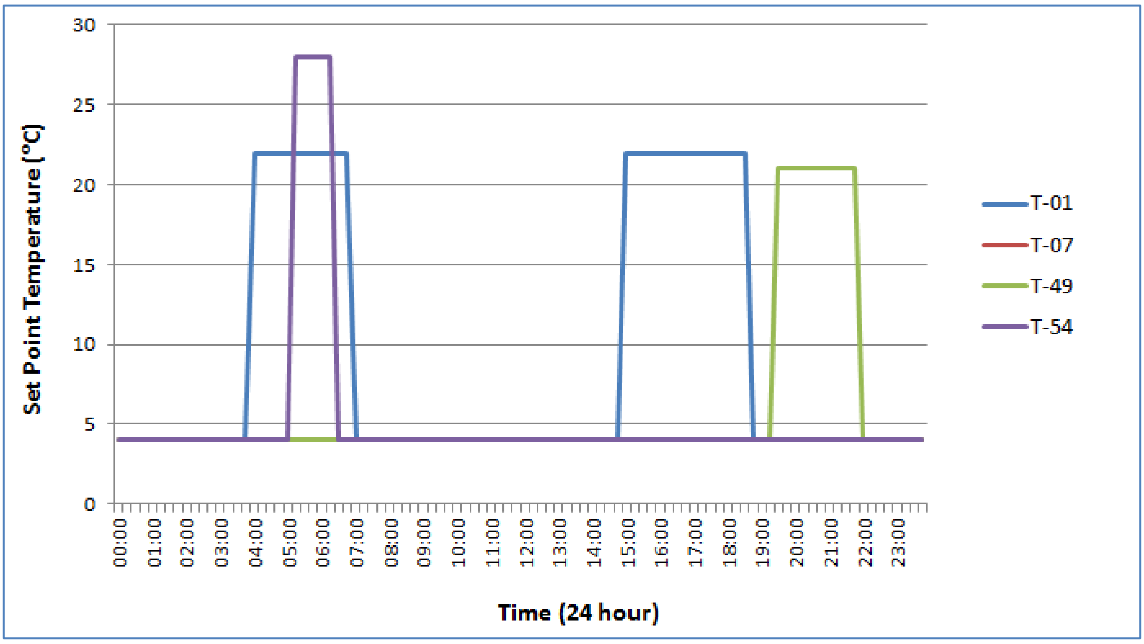

Figure 4.19 Graph of living room set point temperature against time for Heat Genius installations on 15 Oct 2016

Figure 4.19 shows a plot of the living room temperature schedule for the different Heat Genius installations on 15 Oct 2016. If the room temperature was above the set point temperature no heat was drawn by the radiator. If the room temperature was lower than the set point, the system triggered the boiler to be turned on and the TRV was controlled to ensure the room reached and maintained the set point temperature.

The temperature was mild on 15th October 2016 and the number of degree days was 3.97 relative to a base temperature of 15.5°C. As a result households were not using their mid-winter heating schedules.

Property T-01 had an early morning and afternoon /evening heating period where the set point temperature for the living room was 22°C. Outside these periods, the temperature settings were on frost protection, which ensured the temperature was maintained above 4°C. In property T-07 the temperature was set to frost protection throughout the day.

There was a single heating period between 7.30pm and 10pm for T-49 where the temperature setting was 21°C. In property T-54 there was a single heating period in the morning between 5.15am and 6.15am with a set point temperature of 28°C. Outside these heating periods, the temperature was set to frost protection for both T-49 and T-54.

By 15th January 2017, the heating periods for the Heat Genius households were generally longer as shown in Figure 4.20. For household T-01, the living room was set to a warmer temperature 24 hours a day. Between midnight and 6am, the thermostat was set to 21.5°C and this increased to 22°C for most of the time until 5pm. In the early evening the temperature setting increased to 22.5°C but was reduced to 22°C again between 8pm and midnight.

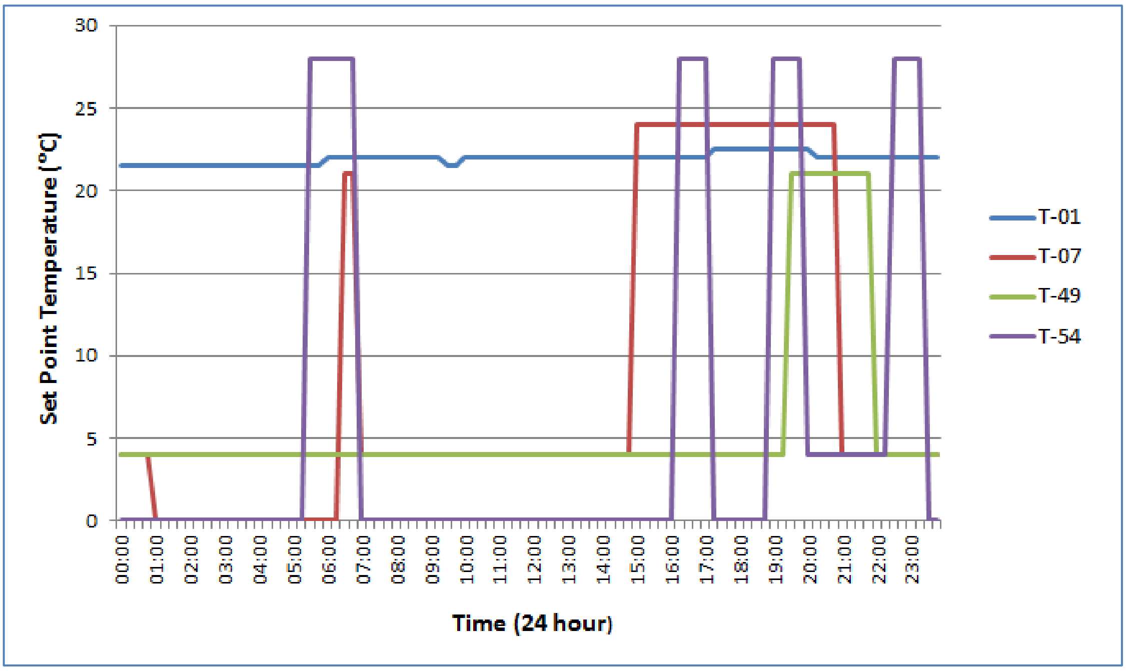

Figure 4.20 Graph of living room set point temperature against time for Heat Genius installations on 15 Jan 2017

The temperature schedule for Property T-01 was altered by the resident in late November so that temperatures were set higher (typically more than 21°C) 24 hours a day. The schedule was not static as there were small adjustments to the temperatures from day to day. From February, the resident occasionally altered the set point to frost protection (4°C) for much of the day. This most likely corresponded to days when the household members were out.

Property T-01 only made savings of 1.5% following installation of Heat Genius. Greater savings could have been achieved with a winter heating schedule where the set point temperature was lower at night and at times when rooms were unoccupied.

For property T-07, there was a morning heating period between 6.30am and 7am where the temperature set point was increased to 21°C. Apart from this heating period the system was set at either 4°C or 0°C until 3pm. There was an afternoon/evening heating period from 3pm to 9pm with a target temperature of 24°C. The temperature set point was subsequently reduced to frost protection.

The heating schedule on 15th January 2017 for property T-07 seemed quite sensible for the household needs. Overall there was a 19.7% saving following installation of Heat Genius. However technical problems with the WIFI connection meant there was limited control at times leading to under-heating of the property. This will have contributed to some of the savings achieved.

The living room heating schedule on 15th January 2017 for property T-49 was the same as it was in October, with an evening heating period with a set point of 21°C between 7.30pm and 10pm, with the system set to frost protection at other times. Although the heating schedules shown on the days in October and January were the same, the household regularly adjusted the schedule. This included a longer evening heating period, higher temperatures and adding a morning heating period.

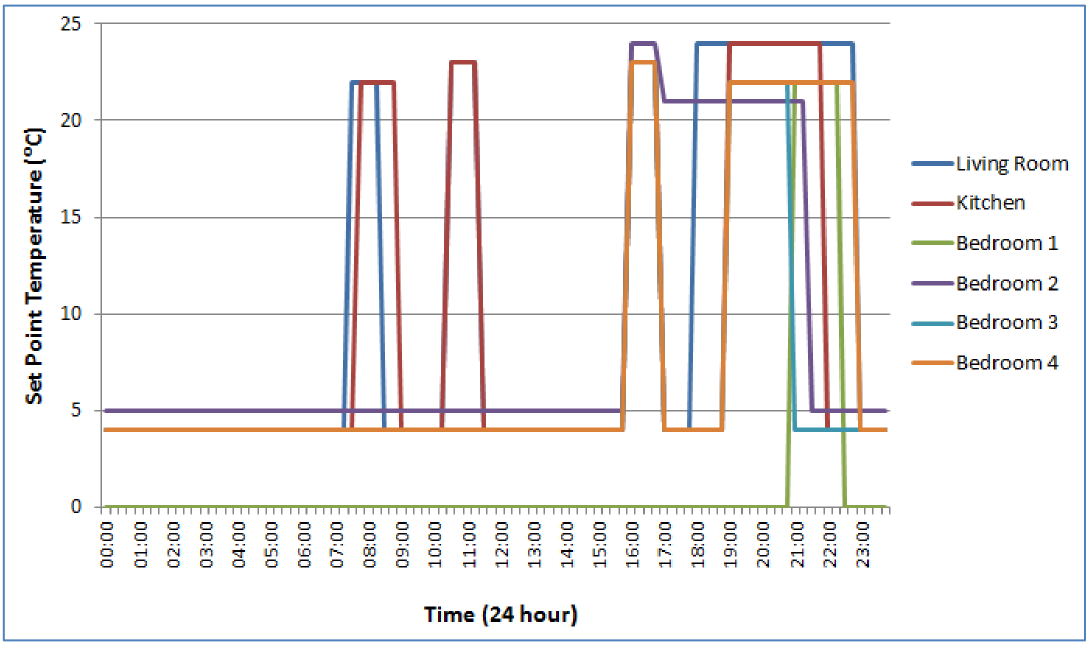

Figure 4.21 Graph of set point temperature against time for each zone in property T-49 on 31 Jan 2017

Household T-54 had 4 heating periods on 15th January 2017. For the periods 5.30am - 7am, 4pm - 5pm, 7pm - 8pm and 10.30pm-11.30pm, the temperature set point was 28°C. At other times the temperature was set to either 0°C or 4°C. The household made savings of 35.8% following installation of Heat Genius. The basic dial thermostat and programmer which was used before Heat Genius was installed did not allow the residents in property T-54 to programme multiple heating schedules and zones which could be adjusted on a daily basis. The Heat Genius system is likely to have allowed them to reduce over heating of the home.

Figure 4.21 shows the heating schedule for the different zones for property T-49 on 31st January 2017. It is clear from the graph that they were making good use of the ability to set different temperature schedules for each zone.

There were 4 heating periods for the living room that day. These were 7.30am – 8.30am (22°C), 10.30am – 11.30am (23°C), 4pm – 5pm (23°C) and a longer evening period, 6pm – 11pm (24°C). Some of these occurred at the same times as heating periods for other rooms and so are not clear on Figure 4.21.

There were also 4 heating periods for the kitchen, with 2 the same as for the living room. These were 7.45am – 9am (22°C), 10.30am – 11.30am (23°C), 4pm – 5pm (23°C) and 7pm – 10pm (24°C).

The bedrooms had only 1 or 2 heating periods per day. Bedroom 1 was heated to 22°C between 9pm and 10.30pm. Bedroom 2 had an afternoon/evening heating period between 4pm and 9.30pm, where for the first hour the temperature set point was 24°C and was subsequently reduced to 21°C.

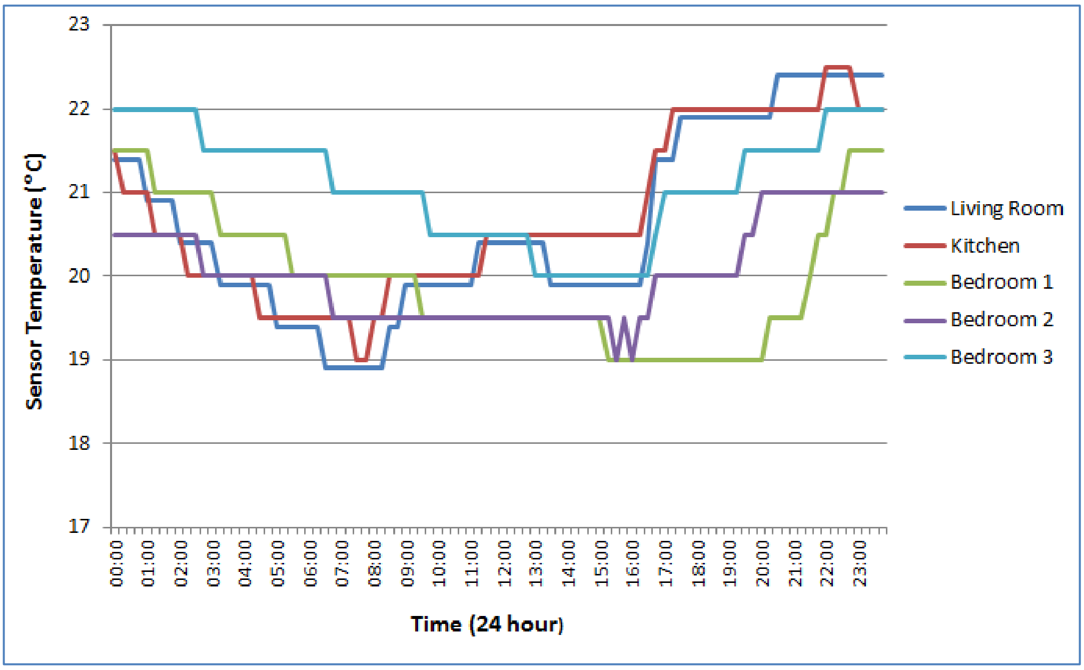

Figure 4.22 Graph of room sensor temperature against time for each zone in property T-49 on 31 Jan 2017

Bedrooms 3 and 4 had a heating period in the late afternoon and in the evening. Both were heated to 23°C between 4pm and 5pm. Subsequently bedroom 3 was heated to 22°C between 7pm and 9pm while for bedroom 4 it was between 7pm and 11pm.

While the temperature set point for the different rooms varied between 0°C and 24°C in Figure 4.21, the actual temperatures measured by the room sensors only varied between about 19°C and 22.5°C as shown by Figure 4.22. It should be noted that there was not a separate room sensor for Bedroom 4 and this relied on the sensor used for the living room.

For bedroom 1, the temperature gradually decreased from 21.5°C at midnight to 19°C by 3.15pm. The temperature started to increase after 8pm, with the heating coming on in the room at 9pm. By 10.45pm the temperature had returned to 21.5°C. The increase in the room temperature before the heating came on in the room was most likely due to warming of the house in general.

The living room temperature started at 21.4°C at midnight and gradually fell to 18.9°C at 6.30am. The first morning heating period started at 7.30am and the temperature had risen to 19.4°C by 8.25am and continued to rise to 20.4°C at 11.15am, during the second morning heating period between 10.30am and 11.30am. The room temperature fell 0.5°C by 1.15pm, but rose again from 4.30pm, during the afternoon heating period between 4pm and 5pm. The temperature continued to rise from 20.4°C and reached 22.4°C at 8.30pm during the evening heating period. The temperature started to fall again just before midnight.

The temperature schedule for T-49 ensured the home was kept at a comfortable temperature of between 19°C and 22.5°C throughout the day. Appropriate use of zoning in the rooms ensured the temperatures were warmest when the rooms were occupied and the temperature was allowed to decrease at other times. Despite the sensible use of temperature zones, there was a 9.1%

increase in gas consumption following installation of Heat Genius. This was most likely due to the household benefiting from increased thermal comfort. Savings could be made by reducing the temperature set points closer to the minimum recommended temperatures of 21°C for the living room and 18°C for bedrooms.

4.4 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 4.23 below illustrates the optimum humidity levels as cited by Arundel et al[20]. The study concludes that maintaining relative humidity levels between 40% and 60% would minimise adverse health effects relating to relative humidity.

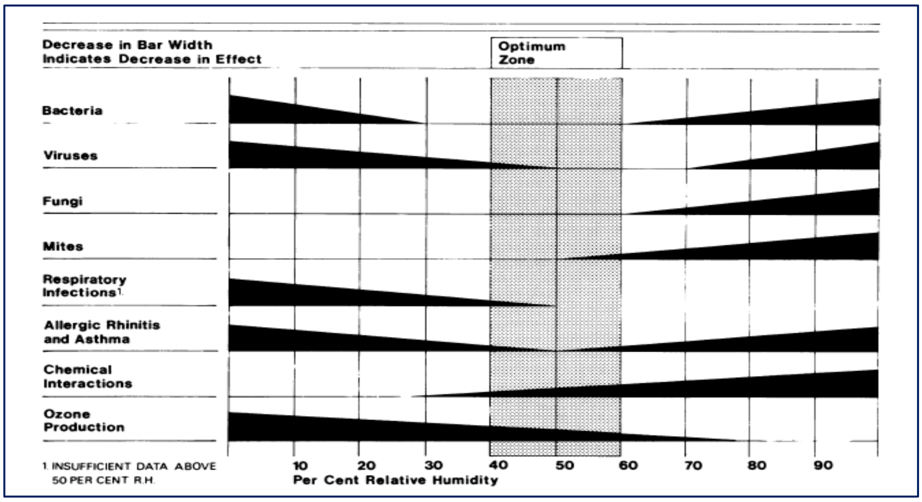

Figure 4.23 Optimum humidity levels to reduce indirect effects from pathogenic organisms or chemicals

The automated data-loggers recorded 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

[20] 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]

with this high humidity. From the Building regulations part F[21]; the suggested average monthly maximum humidity levels for domestic dwellings during the heating season is 65%.

For the period 1 Oct 2016 to 31 Jan 2017, Figures 4.12 to 4.14 show the average humidity for the properties after the smart thermostats were installed. For the 12 Honeywell evohome thermostats, the average humidity ranged from 50.68% to 62.5% in the living room.

Among the households with Honeywell evohome, only property T-10 had a living room average humidity slightly above the recommended 60%. Here the average room temperature was 19.0°C, the second lowest for the analysis period.

There were temperature and humidity loggers placed in the bedrooms of 4 evohome households. The average bedroom temperatures were in the range 18.93°C to 19.87°C, which was lower than the typical average living room temperatures. The average bedroom humidity ranged from 55.94% to 66.3%.

Property T-22 had the highest average humidity level at 66.3% and the lowest average temperature at 18.93°C. The average living room temperature for T-22 was 21.59°C and the humidity was 53.69%.

The average temperature in the monitored bedroom for household T-13 was 19.9°C between 1st October 2016 and 31st January 2017. The average relative humidity was 55.9%, with a maximum value of 72%. Figure 4.24 shows the relative humidity in blue with some sharp peaks such as on 13th December 2016 when it rose to 72% and on 12th January 2017 at 5pm where it rose to 71.5%. Such peaks were likely to have been due to household behaviour which raised the humidity level such as bathing, cooking or drying clothes.

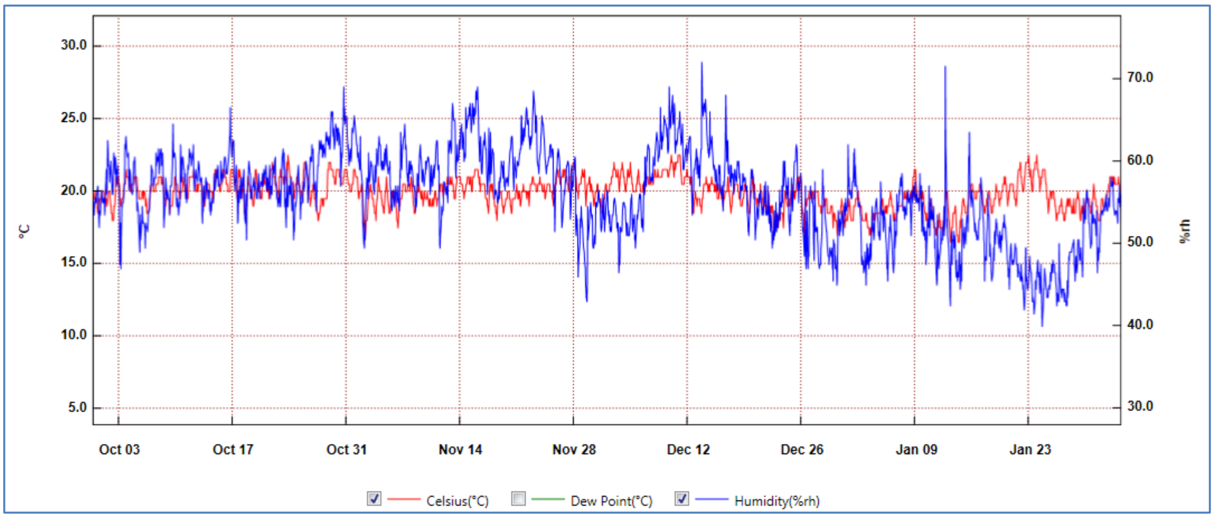

Figure 4.24 Bedroom temperature and relative humidity for household T-13 (Oct 2016 to Jan 2017)

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

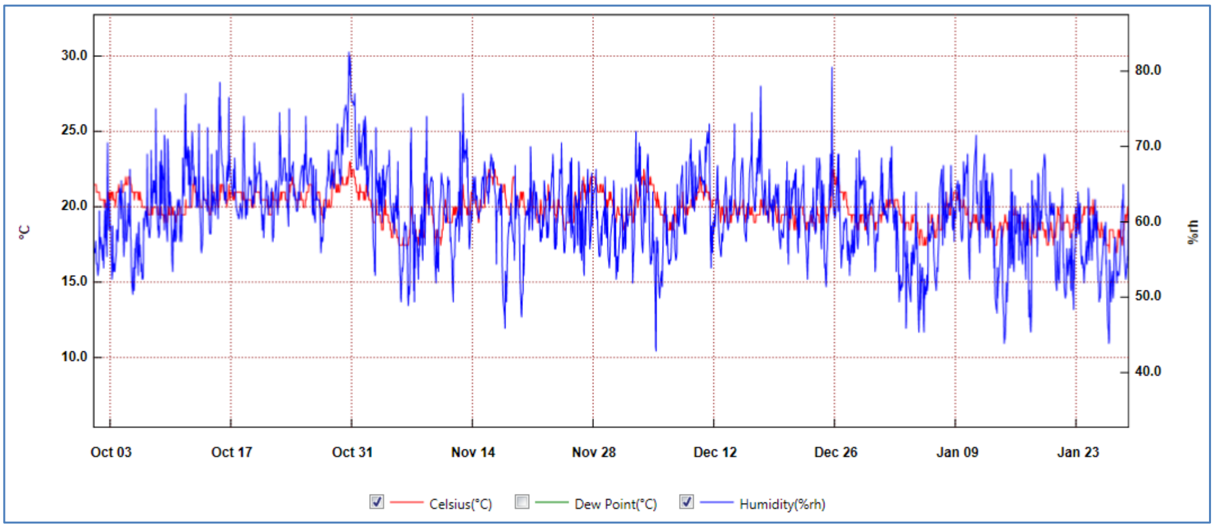

Figure 4.25 Bedroom temperature and relative humidity for household T-19 (Oct 2016 to Jan 2017)

For household T-19, the average bedroom temperature over the October to January period was the same as for T-13. However the average relative humidity at 61.1% was higher and the maximum humidity was 82.5%. There was a damp problem in the house as a result of broken guttering which led to mould in the bedroom which was regularly cleaned off. Ventilation was provided to address the problem by opening of windows for at least 1 hour per day. Figure 4.25 shows there were sharp peaks in humidity in the bedroom. The damp problem may have raised the average humidity while sharp peaks such as on Christmas Day at 5pm were again likely to be a result of household behaviour such as cooking.

The average living room humidity for 3 of the Heat Genius households was among the lowest in the study and they were 48.08%, 53.06% and 46.91% respectively for properties T-01, T-49 and T-54. Here the average living room temperature was in the range 20.18°C to 22.19°C.

Property T-07, which had technical problems with the WIFI connection, had the highest living room relative humidity for the analysis period, with a value of 70.28%. The average living room temperature was 16.53°C and the high value for the average humidity is likely to have been caused by the low temperatures in the property.

The Heat Genius properties which had loggers in the bedroom were T-49 and T-54. Here the average humidity was 60.65% and 67.22% respectively. The increase in humidity compared to the living room for property T-54 was likely to be associated with lower average room temperature of 17.98°C.

The Heat Genius bedroom temperature schedule set by household T-54 often to had the set point at 28°C for about 1.5 hours and at frost protection (4°C) at other times. Figure 4.26 shows there were sharp peaks in temperature (in red) where the temperature could increase by over 2°C in a short time period. Associated with the temperature peaks were sharp dips in the relative humidity. For example, at 6pm on 19th October 2016, the bedroom temperature was 17.0°C and the relative humidity was 67%. By 8pm the temperature had risen to 20.5°C and the relative humidity had dropped to 61.5%. However at 10pm the temperature had decreased to 17.5°C and the relative humidity had risen to 67.5%.

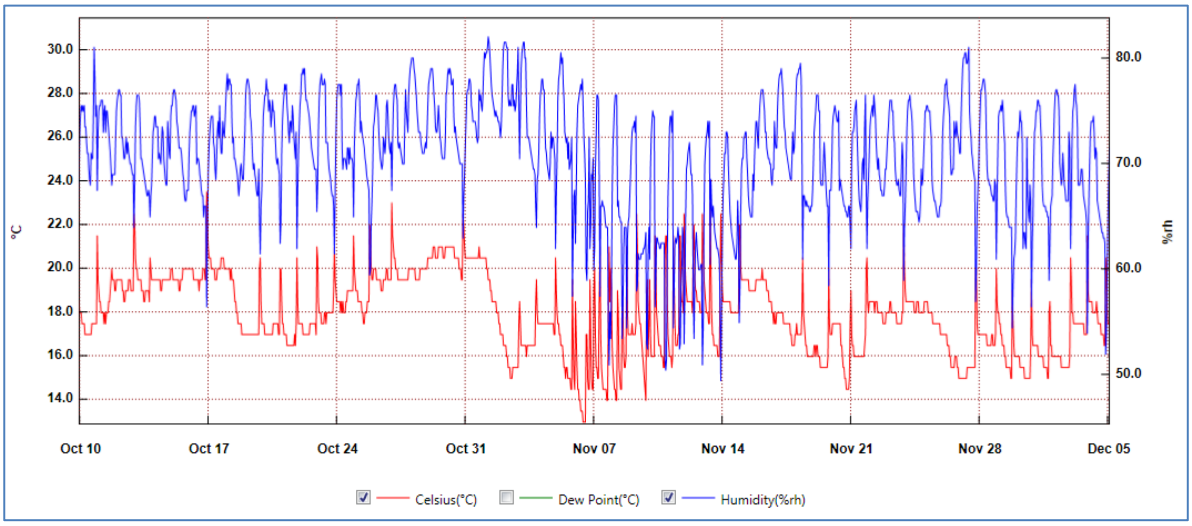

Figure 4.26 Bedroom temperature and relative humidity for household T-54 (Oct 2016 to Dec 2016)

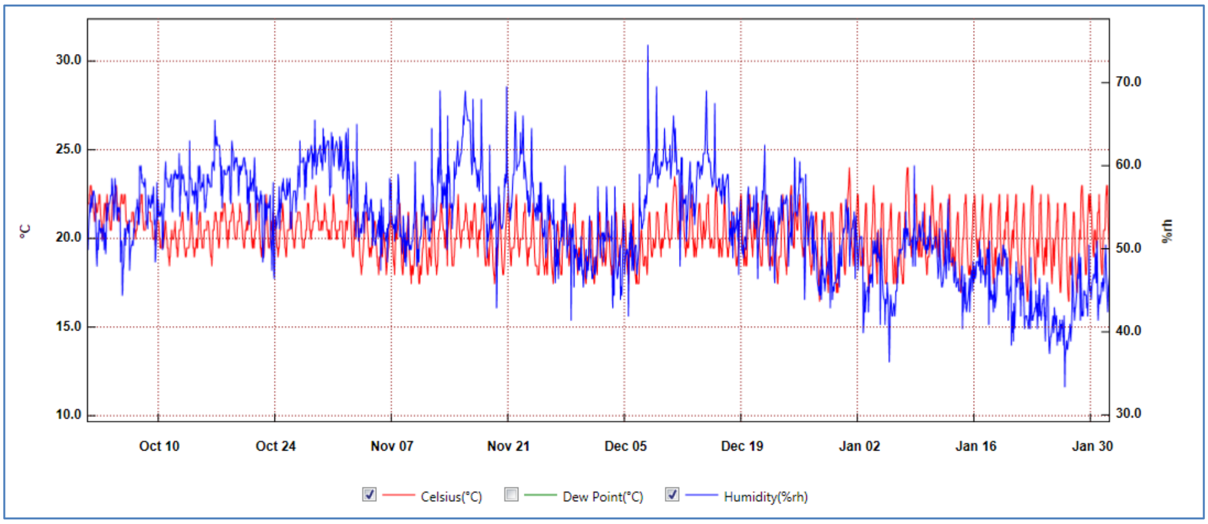

Figure 4.27 Living room temperature and relative humidity for household T-49 (Oct 2016 to Jan 2017)

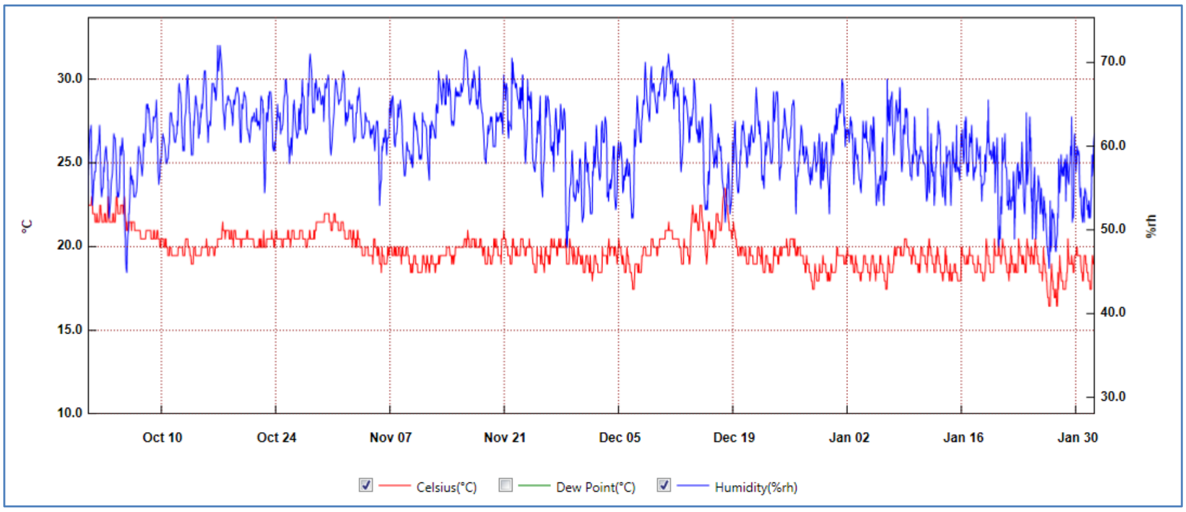

Figure 4.28 Bedroom temperature and relative humidity for household T-49 (Oct 2016 to Jan 2017)

Over the 1st October 2016 to 31st January analysis period, the average living room and bedroom temperatures for T-49 were not significantly different with values of 20.18°C and 19.80°C respectively. The difference in humidity was more noticeable, with 53.06% for the living room and 60.65% for the bedroom. Figure 4.27 shows a plot of temperature and relative humidity for the living room. Although the average relative humidity was quite low at 53.06%, there were short periods with much higher humidity. One such peak occurred on 7th December 2016. At 6pm the temperature was 18.5°C and the relative humidity was 58.5%. The temperature had risen to 19.5°C at 7pm, but the relative humidity had significantly increased to 74.5%. This peak in relative humidity was due to household behaviour such as cooking.

The temperature and relative humidity for the bedroom in household T-49 can be seen in figure 4.28. Although sharp increases in relative humidity due to household behaviour were not clearly apparent, it is possible that activities such as bathing might have influenced humidity in the bedroom. This could be reduced by ventilating bathrooms or showers after bathing through use of an extractor fan or opening a window as well as closing the bathroom door to avoid water vapour entering other rooms[22]. There may also be more of an inherent damp problem in the bedroom and regularly opening the bedroom window might be beneficial.

The humidity was monitored in the living room of 4 properties with Heatmiser neo thermostats. The average humidity between 1st October 2016 and 31st January 2017 ranged from 45.28% to 65.60%. The humidity level only exceeded the recommended maximum of 65% for property T-36 where the average temperature was 18.01°C. The average temperature for T-50 was lower, at 17.57°C, but the average humidity was within the normal range at 57.18%.

2 of the properties with Heatmiser neo thermostats had loggers in the bedroom. For household T-52, the average temperature was 20.70°C and the average humidity at 54.37% was within the desired range. Property T-08, where the average bedroom temperature was lower (19.06°C), saw an average humidity of 62.72% which was just above the desired range (figure 4.29).

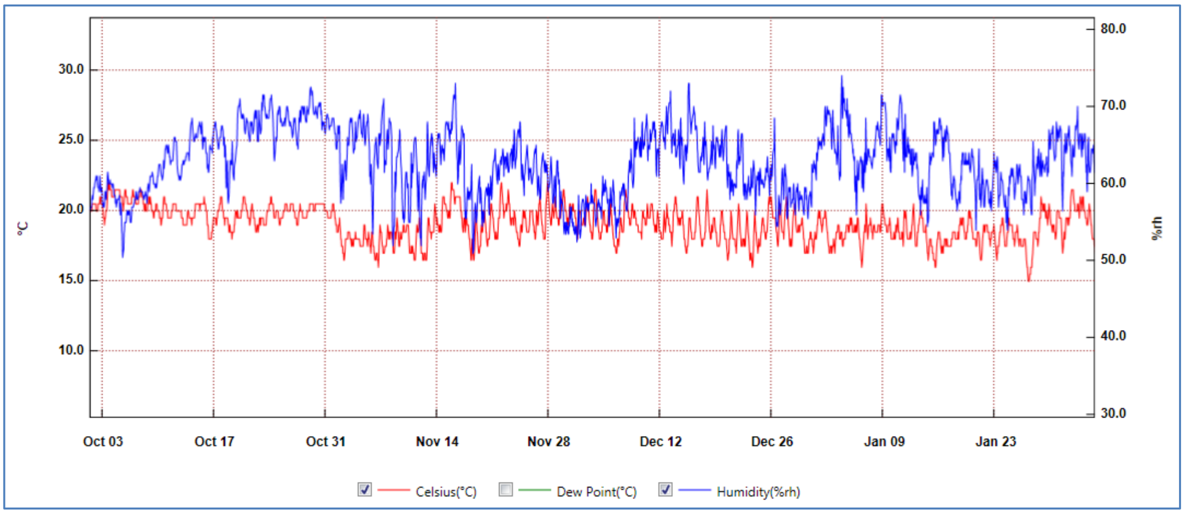

Figure 4.29 Bedroom temperature and relative humidity for household T-08 (Oct 2016 to Jan 2017)

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22 Dealing with Damp and Condensation, NEA, http://www.nea.org.uk/wp-content/uploads/2015/07/Resource-Dealing-with-damp-and-condensation-lo-res.pdf (Accessed 22 May 17)

Average room temperature is a factor which affects the average relative humidity. Figure 4.30 is a plot of the average relative humidity against the average living room temperatures for each of the 3 smart thermostats. If the average living room temperature was within the range 19°C to 22°C, the average humidity was likely to be within the desired humidity range of 40 to 60%.

There was more scatter in the data points for the Honeywell evohome than for Heat Genius or other smart thermostats in another report[23]. This might be due to the larger sample size for evohome and differences in household behaviour influencing the humidity level becoming clearer[24].

Although residents save money by reducing the average temperature to 18°C and below, there are health impacts from the lower temperatures and higher humidity levels.

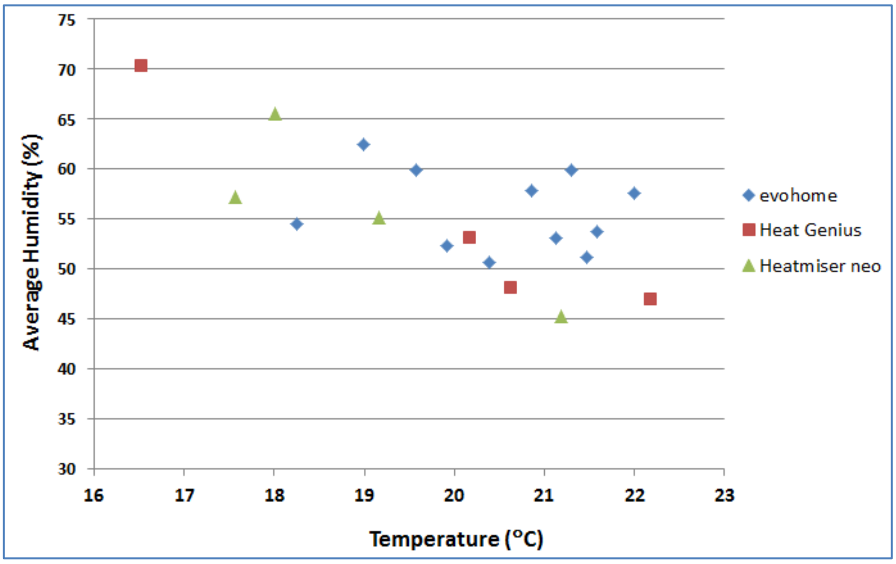

Figure 4.24 Graph of average humidity against average living room temperature between 1 Oct 16 and 31 Jan 17

[23] Elizabeth Lamming, Paul Rogers & Michael Hamer, 'Heating your house intuitively', NEA, May 2017 (in press)
[24] Dealing with Damp and Condensation, NEA, http://www.nea.org.uk/wp-content/uploads/2015/07/Resource-Dealing-with-damp-and-condensation-lo-res.pdf (Accessed 22 May 17)

5. Conclusions and recommendations

5.1 Conclusions and insights

The project installed 43 smart heating control systems and assessed the benefits

- Smart heating controls were installed in 43 homes owned by South Holland District Council using 3 different technologies: Honeywell evohome, Heat Genius and Heatmiser neo

- An in depth study of 22 of these households was completed which involved technical monitoring and assessment, interviews and advice on energy tariff switching

- The households in the monitored group included 12 homes with Honeywell evohome, 4 with Heat Genius and 6 with Heatmiser neo

The original aims of the project evaluation were:

- To establish the heating costs for households with the Honeywell evohome, Heat Genius and Heatmiser neo smart thermostats compared to the previous period when the properties had a wall-mounted dial thermostat;

- To determine potential benefits of a smart thermostat with smart TRVs on radiators to allow different temperatures in different rooms;

- To determine the ease-of-use and resident satisfaction levels for each of the smart heating control systems;

- To contribute towards an evidence base for landlords to assess the suitability of different models of smart thermostats for their properties.

Energy savings and thermal comfort

- Gas meter readings before and after the installation were used to make a temperature corrected assessment of the annual gas consumption and the associated change in gas costs using a standardized unit rate of 5p/kWh

- The residents who received a **Honeywell evohome** installation had pre-installation annual gas costs in the range £301 to £801. Half of these saw a decrease in gas consumption and half an increase. These ranged from 19% savings to a 14.4% increase in gas consumption. Among those residents who saw an increase, 1 had become ill and spent more time at home while 2 of the properties were previously under-heated. Averaged across all the Honeywell evohome installations there was a 0.5% reduction in gas consumption.

- The households with **Heat Genius** thermostats had pre-installation annual gas costs between £325 and £657. 1 household reported savings of 35.8% while another reported gas consumption increased by 9.1%. The Heat Genius household which reported an increase in gas consumption was likely to have previously under-heated the home.

- The Heat Genius systems which completed the study saw savings of 12%.This compares to savings of 16 to 22% noted in a case study by the manufacturer. Greater savings are likely with better advice on setting up and using the system, including use of the 'footprint mode'.

- Some of the households with **Honeywell evohome and Heat Genius** systems made good use of the ability to set different temperature schedules in different rooms and this led to savings or improved thermal comfort.

- The 6 households with **Heatmiser neo** thermostats had annual gas costs in the range £366 to £627. Half the residents reported a decrease in gas consumption and half reported a small increase. The maximum reduction in gas consumption was 22%, but the household replaced their boiler and hot water tank at a similar time to the thermostat being installed and this will have contributed to savings. On average the Heatmiser neo installations showed a 6.1% decrease in gas consumption. If the property which had a replacement boiler and hot water tank was excluded from the average, this would decrease to 2.9%.

- The best to average pay back times for the controls ranged from 1.7 years to 87 years in this study due to a whole range of factors.

Ease of use and resident satisfaction

- The Honeywell evohome thermostat was rated the easiest to use and residents were most satisfied with the amount of control it provided over their heating system. Over 90% of residents with the Honeywell evohome thought the heating was easier to use, provided more control and their home was warmer and more comfortable. The touch screen control was very popular with residents and this is likely to have been a factor in the high satisfaction with the evohome system. One resident described the system as the "best thing in the council house" and said they wouldn't be without it. There was also a high degree of satisfaction with the other controls

- Among the households in the monitored group, 55% had a member with a health condition, disability or long-term illness and all these residents stated that this condition was made worse by the cold. 41.7% of households who received a Honeywell evohome thermostat noted there was an improvement in their family's health. This compared to 25% for Heat Genius and 16.7% for Heatmiser neo. Health benefits included improvements to asthma symptoms and fewer colds.

Humidity levels

- The relative humidity was influenced by factors including household behaviour and the room temperature. Average relative humidity levels were generally within an acceptable range of between 40% and 65%. However, the maximum relative humidity in some properties exceeded 80%. Household behaviour such as cooking, bathing or drying clothes was likely to have caused sharp increases in relative humidity.

- When the average living room temperature for properties with the smart thermostat installations fell below 19°C, the average humidity tended to be greater than 60%. Residents are therefore more likely to avoid mould developing by maintaining average room temperatures above 19°C.

Overall there was generally high satisfaction with the smart thermostat technologies and each system made savings when averaged across the monitored group, with some households benefiting from greater warmth at required times and bill savings.

5.2 Recommendations for potential future installations

The trials provided evidence that smart controls can bring benefits to residents but social landlords who do upgrade their heating system controls should take into account that:

- It is important that residents are shown how to use smart thermostats when they are fitted, and instructions are provided. Where new residents move into a property with a smart thermostat, adequate procedures must be in place to ensure they receive written instructions and training on use of the thermostat. Landlords could potentially provide video guides for operation of the thermostat on their website which may be easier to understand for some than written instructions. Housing officers and/or community champions could also be used to advise residents on appropriate settings and schedules to optimise savings;

- Housing officers should also receive a list of where smart thermostats are located and trained on how to operate any types installed. Heating engineers used by the social landlord should be informed about the locations of any smart thermostats and should have training on installation and operation of these technologies, so they are able to help residents review their heating schedules when circumstances change and maximise the impact of the controls.

- Residents vary from the young who have grown up with digital technology to older residents who rarely use it; a smart thermostat must therefore be intuitive and easy to operate.

5.3 Impact on fuel poverty

Smart thermostats have the potential to help resident's lower fuel bills by enabling them to reduce unnecessary heating. This can be achieved by easier control of the heating schedule via mobile phone or detecting when residents are not at home.

The optimum temperature for occupied rooms in winter is between 18°C and 21°C. A number of households in this study had average temperatures in the main living space which were greater than this. While some vulnerable residents may require temperatures higher than 21°C, there can often be overheating of rooms. Technologies like Honeywell evohome and Heat Genius can allow residents to focus the heating on rooms when they are occupied.

Better control of room temperatures by smart thermostats could lead to reductions in heating bills; however residents need adequate advice on operation of the thermostats, setting of schedules and appropriate room temperatures. This is particularly true of systems with different temperature zones.

Smart thermostats can also benefit residents who are under-heating their homes, ensuring their living areas are sufficiently warm. While heating bills are likely to rise, the residents are living in a healthier environment. There are physiological impacts on the body from living in a home which is too cold and the higher humidity levels encourage growth of mould. Use of a smart thermostat allowed the residents with the coldest homes to achieve a more suitable average room temperature. Although better control can improve thermal comfort for some residents the thermostat technology must be sufficiently mature to avoid technical or operational issues, which could lead to residents being left without access to heating.

For residents to benefit from a smart thermostat, it must be easy to use. If the system is too complex, some vulnerable residents may at best not use the system properly or a worst request that it is taken out.

5.4 Performance comparison against manufacturer's claims

This study has tested the performance of 3 different smart thermostat technologies in social housing owned by South Holland District Council. While the investigation has taken into account variation in the outside temperature, the energy consumption of heating systems in homes can be affected by a number of other factors:

- Components of the heating system
    - Boiler, radiators, thermostat and hot water cylinder
- Building fabric
    - Cavity wall insulation, loft insulation and quality of glazing
- Residents behavioural patterns
    - Amount of time at home, temperature setting and times for thermostat

Some changes such as these were noted in a few households during the study. Although real world changes can influence savings in energy consumption, it is still important to compare the savings in this study with those quoted by the manufacturers.

In a quote on their website, Honeywell suggested that homes installing evohome can save up to 40% on their consumption. Heat Genius has included a case study where a HMO (House in Multiple Occupation) landlord saw savings of up to 22% after installing the system in properties rented by students.

Table 5.1 compares the average and maximum savings for the thermostats in this study with the savings that would be expected for these properties based on the quoted savings from the manufacturers.

It can be seen that the maximum saving measured in these social housing settings for the Honeywell evohome systems was £111 less than the amount calculated based on the claims from the manufacturer. The average saving across the 12 properties in the study was very small at just £7. The average saving for the evohome system in this study was likely to be low as it was influenced by 2 of the properties previously being under-heated and 1 household where a resident became ill and spent more time at home.

The average saving from the 4 Heat Genius installations was £53 less than the manufacturer's case study. However the property which achieved the maximum savings in the study made greater savings than those predicted based on the savings from the Heat Genius case study. The maximum savings for Heat Genius in the study was £211 which was £81 more than the amount predicted by the figures from the Heat Genius case study.

No claims for the potential savings from Heatmiser neo have been found and so only the average and maximum saving from the current study have been quoted.

Measure	Household	Annual energy cost saving from NEA study	Annual energy cost saving claimed by manufacturer	Differential	Assumptions
Honeywell evohome	Average	£7	£190	£183	Average saving across all evohome households Savings of up to 40% quoted on Honeywell website
Honeywell evohome	Maximum	£101	£212	£111	Single household with largest savings Savings of up to 40% quoted on Honeywell website
Heat Genius	Average	£61	£113	£53	Average savings across all Heat Genius households Savings of up to 22% from Heat Genius case study
Heat Genius	Maximum	£211	£130	-£81	Single household in study with largest savings Savings of up to 22% from Heat Genius case study
Heatmiser neo	Average	£36	-		No potential savings quoted by Heatmiser
Heatmiser neo	Maximum	£127	-		No potential savings quoted by Heatmiser

Table 5.1 Comparison of savings in the study with those claimed by the manufacturer

5.5 Economic business case for installation of measures

The smart thermostats in this study offer residents the opportunity to set their heating times remotely and more conveniently by mobile phone. With Honeywell evohome and Heat Genius they can also set different heating times and temperatures in different rooms. While the thermostats provide greater control and convenience for residents, a business case can also be made as a result of the reduction in energy bills for the residents.

Table 5.2 shows the typical component costs for a smart thermostat installation in a 3-bedroom house with a combi-boiler. The costs for a heating system with a hot water tank would be higher as an additional component would be required to provide control of the heating time and temperature for the hot water tank. For Heat Genius this would cost £55 while for Honeywell evohome it is from £77.50.

For Honeywell evohome and Heat Genius, the system specification assumes smart TRVs in the bedrooms, living room, kitchen and 1 other room. For Heat Genius, 4 room sensors have been specified. Although the smart TRVs can provide a room temperature reading, the room sensor is installed away from the radiator at chest height and provides a more representative temperature of the room. It also operates as an occupancy sensor and allows the system to operate in 'footprint mode', which automatically sets the heating schedule based on typical occupancy times.

The prices quoted are based on the best prices available online at the time of writing. Some suppliers might offer discounts and a typical bulk discount might be about 5%. The Heat Genius system had to be bought directly via their website and discounts were not available.

Installation of the Heatmiser neo system is more straightforward as the technology replaces the previous thermostat, while Honeywell evohome and Heat Genius also replace the thermostatic radiator valves (TRVs) on 6 radiators. An indicative cost for a series of installations would be £60 for Heatmiser neo and £100 for Honeywell evohome and Heat Genius.

Measure	Components	Unit cost	Number	Sub total	Total
Honeywell evohome	Evohome WiFi connected thermostat pack	£ 195.00	1	£ 195.00	
	Evohome radiator controller HR92UK	£ 46.50	6	£ 279.00	
					£ 474.00
Heat Genius	Genius Hub, wireless thermostat and single channel receiver	£ 249.99	1	£ 249.99	
	Genius Radiator Valve	£ 59.99	6	£ 359.94	
	Genius Room sensor	£ 34.99	4	£ 139.96	
	Genius Smart Plug & signal booster	£ 29.99	1	£ 29.99	
					£ 779.88
Heatmiser neo	Heatmiser neo kit 1 with Neo Stat and Hub	£ 160.00	1	£ 160.00	
					£ 160.00

Table 5.2 Typical system costs for smart thermostat systems in a 3-bedroom house

Measure	Capital Cost	Indicative Installation Costs	Total	Energy saving from the study	Indicative payback time (years)	Assumptions
Honeywell evohome	£474	£100	£574	£7	87.2	Average saving for evohome in the study. Best component prices on internet
Honeywell evohome	£474	£100	£574	£101	5.7	Maximum saving for evohome in the study. Best component prices on internet
Heat Genius	£780	£100	£880	£61	14.5	Average saving for Heat Genius in the study. Prices on Heat Genius website
Heat Genius	£780	£100	£880	£211	4.2	Maximum saving for Heat Genius in the study. Prices on the Heat Genius website
Heatmiser neo	£160	£60	£220	£36	6.2	Average saving for Heatmiser neo in the study. Best kit price on the internet
Heatmiser neo	£160	£60	£220	£127	1.7	Maximum saving for Heatmiser neo in the study. Best kit price on the internet

Table 5.3 Indicative payback times based on the average and maximum savings from this study

Table 5.3 shows an indicative payback time for each of the 3 smart thermostat technologies. This is based on the typical system costs in Table 5.2, an indicative installation cost and the energy savings from the study in Table 5.1. Payback times are estimated for both the average savings for each thermostat in this study and also the maximum savings for the thermostat.

Based on the average savings in the study, the Honeywell evohome system had a payback time of 87 years. As discussed earlier, the average saving was affected by increases in consumption for 2 properties being under-heated and a further property where the resident spent more time at home. The evohome system was also the most popular with the residents, the ease of use and ability to heat their home effectively may be just as important to them as any savings. With the maximum saving achieved for an evohome system in this study, the payback time would be 5.7 years.

Heat Genius is the most expensive system, but achieved the greatest savings in the study. For the average savings achieved in the study, the payback time is 14.5 years. If a Heat Genius system were to achieve savings as high as the maximum in this study, the payback would be 4.2 years.

Heatmiser neo has cheaper capital and installation costs. Although it does not offer easy zoning via wireless TRVs, worthwhile savings were still achieved. Thanks to the low cost of the system compared to the other technologies, the indicative payback time was 6.2 years based on the average savings in this study. Using the maximum savings measured during the study the payback time decreases to just 1.7 years. The property with the Heatmiser neo thermostat which saw the greatest decrease in gas consumption also replaced their boiler and hot water tank at a similar time to the installation of the smart thermostat. As a result the payback time of 1.7 years is in practice likely to be too short. The short payback time of Heatmiser neo could make it worth considering despite the more limited features compared to Honeywell evohome and Heat Genius.

Appendix 1: Glossary of terms

DD	Degree Days
ECO	Energy Company Obligation
EPC	Energy Performance Certificate
GCH	Gas Central Heating
HDD	Heating Degree Days
HMO	House in Multiple Occupation
NEA	National Energy Action – the National Fuel Poverty Charity
RdSAP	Reduced Data Standard Assessment Procedure
RH	Relative Humidity
SAP	Standard Assessment Procedure (for assessing home energy efficiency)
SD	Standard Deviation
SHDC	South Holland District Council
TRV	Thermostatic Radiator Valve

Appendix 2: Case studies

Case study 1 – Honeywell evohome

Mrs T lives in a semi-detached house with her husband and two children aged seven and thirteen. They live in rented social housing and responded to the invitation from their housing association to take part in the trials. They received the Honeywell evohome heating controls in their home and as a result have seen a reduction in their energy bills; since the installation the energy direct debit has reduced by £35 per month.

Mrs T feels that their home is more comfortable as the radiators are working better. In the past she felt that there was often a need to call the council to ask them to send someone to look at the radiators and she has not had to do so in the last year since the evohome was installed.
She also feels that she has greater control over the temperature in individual rooms. As a result of their warmer home her son has been unwell less frequently with his asthma. In the past, during the winter months, she has visited the GP with her son at least three or four times. Since the installation of the evohome device however she has not had to take her son to the GP at all because his health has much improved. This has also meant that he missed less days at school last winter – only two days compared with multiple instances of up to a week off school each year previously. As her son is now 13 years old Mrs T is extremely pleased with this outcome because she feels that less interruption to his education is very beneficial and she hopes this situation will now continue through his GCSE years in school.

Case study 2 – Heat Genius

Mrs D lives in a 2-storey house as a tenant of the housing association. She responded to the letter from the housing provider asking for volunteers to trial the technology. When the Heat Genius control was first installed the resident felt that insufficient instruction was provided and as a result, she was unable to use the system. The resident even feared that her heating system had broken down completely before getting assistance from NEA with guidance on how to use the system correctly. NEA ensured that the resident was able to set up the control on her phone to manage the system.

Two weeks after receiving the instruction we revisited the household. At that point the house was much warmer and the resident was feeling much better about her home. Mrs D has four children between the ages of six and fourteen and they are now able to use their rooms comfortably.

Mrs D has severe fibromyalgia and suffers in cold conditions. The new heating controls make it much easier for her to manage her illness because she knows when cold days are about to occur and she can be confident that she can control her heating accordingly, ensuring sufficient warmth to maintain her health. It has also enabled her to take her medication more accurately as she now knows when it is her illness that is causing her to feel unwell rather than the impact of a cold home.

NEA also helped Mrs D to change from an Economy 7 to a single rate electric tariff which has resulted in the electricity bill being halved; from approximately £40 per week to £20 per week which is really helpful for their family budget. They are now using much less electricity as they do not need to use their electric fire in the lounge which used to contribute to their high consumption. The gas usage has not increased as a result which Mrs D attributes to using her gas more efficiently following the installation of the Heat Genius.

Case Study 3 – Heat Genius

Mr and Mrs I are in their 40s and live in a rented 4-bedroom semi-detached house together with their four children aged 4, 13, 16 and 20. They received the Heat Genius heating control after getting involved in the NEA Technical Innovation Fund project via a letter from the council inviting them to participate.

As a large family with quite a variance in age between the children, they need to keep their home warm affordably. Mr I also suffers from emphysema and their heating bills in the past have pushed them into fuel debt. At the time of intervention the family was still paying off last year's energy debt which had built up over the winter months. The savings that they have made on the current year's bills have however enabled them to clear the debt from the previous year quicker.

NEA advised the family to switch providers and they were able to do so for their gas supply which helped save money. However, debt on their electricity account prevented them from switching electricity providers initially so they are aiming to do this as soon as their debt is paid off at which time they will take up the cheapest dual fuel tariff from their new gas supplier.

Appendix 3: Comments from residents following installations

Household reference	Comments
T-01 **Heat Genius**	There was a problem with a room sensor but Heat Genius sent a replacement. I am glad I took part in the project. It has helped to control bills and improve comfort at home.
T-02 **Heatmiser neo**	Found it difficult to alter the controls as it moves on too fast.
T-04 **Honeywell evohome**	I have not really used the evohome as I did not understand how it could save energy and money. I was given instructions on the day of the installation, but it was confusing and I could do with more help.
T-05 **Honeywell evohome**	The house is definitely warmer
T-07 **Heat Genius**	The installers were excellent and they even hoovered up. It would be useful to know how to use the system without the internet. Frustrated with the control. It is a brilliant idea but I feel it needs a few tweeks so my dad doesn't get cold when he baby sits.
T-08 **Heatmiser neo**	So far so good. I was very impressed with the installation and have everything I need should I want to reinstall on the phone. The technician was fantastic. I stopped using the app on the phone as when that particular phone left the house the heating went off leaving family members at home with no heating. It was too complicated to overcome so I deleted it from the phone.
T-10 **Honeywell evohome**	The installation process was brilliant and there were no problems. We have stopped using the electric fire and the house is much warmer – never been so warm.
T-12 **Honeywell evohome**	The demonstration after the install was rushed and I felt I had to let the engineer go even though I wasn't clear on how to use the system. I would like the engineer to come out and show us how to use it again a little slower than last time. I am absolutely pleased I took part – it has benefited us a lot as well as saving money. My son's asthma has improved.
T-13 **Honeywell evohome**	I know how to use the system now, but I had to work it out for myself. The installers were not very helpful and didn't show us how the use the settings. There were no smart TRVs fitted in the bathroom as it was a towel rail radiator and in the main bedroom as the radiator was too old. This means I have no control over these radiators, they are connected to the lounge radiator which is too hot at 20°C for a bedroom. The project has been very enlightening and has given me a lot of information.
T-15 **Honeywell evohome**	The bathroom used to be damp, but we have not got any now. I can now keep my home comfortably warm when I couldn't before the new heating control. I no longer need to wear extra clothes. It's the best thing we ever did as we are now comfortable in our own home. This is the first year we have not had to cut back on heating or worry about having enough gas to keep warm. My daughters have commented that our home is warmer. The NEA advisor switched energy supplier and resolved a debt dispute on the final bill with the previous supplier.

T-18 **Heat Genius**	Since the Heat Genius system was properly set up, the children have been able to use their own rooms much more. If it hadn't been for the help from NEA we would have been stuck. Thank you for helping to get the heating system working.
T-19 **Honeywell evohome**	I have been extremely happy with the project. Everyone has been fantastic
T-21 **Honeywell evohome**	It was so simple to use once explained. Definitely improved comfort and easier to use from the phone. Easy to change temperature in individual rooms and saves (money) too.
T-22 **Honeywell evohome**	Definitely pleased we took part. Love the new system and very pleased with the control we have over our heating.
T-27 **Honeywell evohome**	I think it is fantastic and I cannot believe the difference it has made. It's really useful and I am really pleased I took part.
T-33 **Honeywell evohome**	My youngest daughter's asthmatic cough is not as bad this year. I am glad I took part in the project and it has helped me save money.
T-34 **Honeywell evohome**	Nice to be able to individually set the heating temperature in different rooms to suit our needs. The TRVs can be altered by children and could do with child locks.
T-36 **Heatmiser neo**	Enjoyed being part of the project and think it's a good idea to have these projects to find out if these things work.
T-49 **Heat Genius**	Although I don't have a problem operating the system, I would like someone to come and give more instruction on how the system works and how to get the best from it. I am very pleased we took part. It was simple enough to do and increased my awareness and helped save money.
T-50 **Heatmiser neo**	The installers were very good when they put it in. It is far better than the last system. I can get on with it. I am pleased I took part and made minor savings
T-52 **Heatmiser neo**	It has been helpful taking part in the project. I had wanted to change electricity from pre-payment to direct debit. The NEA advisor helped me do this and gave me the information I needed to find a new supplier with a cheaper tariff. After taking meter readings regularly, it has encouraged me to continue to take meter readings in the future. I feel more in control of my bills. I stopped using Heatmiser on the phone last October.
T-54 **Heat Genius**	Home gets warmer faster so I am able to have the heating on for less time. The children have fewer colds this year and they are noticeably healthier. I am finding it so much easier to use our heating and enjoying using it. I am pleased I took part, love the new heating control, saving energy and money.

Appendix 4: Age of the boiler and other relevant upgrades from the final interview

Household reference	Gas boiler age and other comments
T-01 **Heat Genius**	About 3 years old
T-02 **Heatmiser neo**	Boiler about 3.5 years old. Installation of an electric shower in April 2016
T-04 **Honeywell evohome**	About 8 years old
T-05 **Honeywell evohome**	About 4 years old
T-07 **Heat Genius**	About 3 years old
T-08 **Heatmiser neo**	About 2 years old
T-10 **Honeywell evohome**	Over 1 year old
T-12 **Honeywell evohome**	About 6 years old
T-13 **Honeywell evohome**	About 2 years old.
T-15 **Honeywell evohome**	About 4 years old
T-18 **Heat Genius**	Over 5 years old
T-19 **Honeywell evohome**	Unknown
T-21 **Honeywell evohome**	About 2.5 years old
T-22 **Honeywell evohome**	About 1 year old
T-27 **Honeywell evohome**	About 2 years old
T-30 **Heatmiser neo**	About 8.5 years old
T-33 **Honeywell evohome**	About 3 years old
T-34 **Honeywell evohome**	About 9 years old
T-36 **Heatmiser neo**	Boiler and hot water tank replaced in March 2016
T-49 **Heat Genius**	About 1 year old
T-50 **Heatmiser neo**	About 4 years old
T-52 **Heatmiser neo**	Over 4 years old
T-54 **Heat Genius**	About 4 years old

Appendix 5 - 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