CP1138

Comparison of Two Electric Heating Solutions for a Tower Block

WHG

Technical Evaluation Report

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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.

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Legal limitations and disclaimer

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Executive summary

Project overview

This project installed two different combinations of electric heating systems to 20 x 2-bedroom flats in a tower block in Walsall, West Midlands, also comparing them against a control group who did not receive new heating:

1. Enviroheat EconoRads and EconoCylinder, controlled by Honeywell room stats and Switchee on a flat-rate tariff – 10 flats (4 flats switched to control by Honeywell Evohome),
2. Elnur storage heaters, and Switchee, controlled by VCharge on an Economy 10 tariff (no change of immersion tank) – 10 flats,
3. Controls: original electric storage heaters and immersion cylinder, with Switchee fitted for monitoring purposes only – 5 flats.

The properties were owned by WHG (previously Walsall Housing Group but now expanding beyond Walsall), one of the West Midlands' leading providers of high-quality homes, owning and managing around 21,000 properties across the Midlands, and providing affordable, good quality homes and community-based services to the local community. The monitored properties were all 2-bedroom flats in a 15-storey tower block, though occupant types varied. This is part of a pair, so some of the control properties were found from the neighbouring identical tower block.

The flats were of concrete and brick construction, and had relatively recently been externally clad with insulation (completed in 2016). At the same time, external doors (to balconies) and windows had been replaced with new UPVC double glazing, upgrading the thermal retention of the building.

The project had the following aims, to:

- Replace the existing storage heaters with either Elnur storage heaters coupled with Ovo's VCharge technology on an Economy 10 (time-of-use) tariff, or Enviroheat's lower-energy on-peak EconoRads and EconoCylinder, on a flat-rate energy tariff.
- Assess any change in residents' comfort – as reported in questionnaires, and measured using temperature and humidity monitors – after the new heating, any solar PV and coupled system,
- Quantify any change in electricity use and costs for heating, and general household use, following the measures, compared to the period prior to installation, and the control properties
- Report any change in ease of use of the heating system with the new measures fitted,
- Compare these two energy solutions in terms of cost, comfort / temperatures achieved, ease of control by the tenants, in comparison to control properties,
- Determine the effectiveness and cost-effectiveness of these measures to reduce fuel poverty in off-gas developments of flats, and whether either solution is more suitable or effective - information relevant to many social housing (and private) owners in many areas of the country.

Context

In the Little Bloxwich / Stoney Lane area, 24.4% of the properties do not have access to mains gas, although all these are within 50m of a gas main. The vast majority of these use electric heating. The area suffers 11.2% fuel poverty[1]. This lower super-output area (LSOA) - the smallest area for which robust statistics are available - is in the top 30% most deprived in the country in overall Indices of Multiple Deprivation (IMD), and in terms of deprivation of income, education and skills, health and disability, income deprivation affecting both children and older people It is in the

[1] Non-gas map, www.nongasmap.org.uk [Accessed 15/1/2019]

top 20% most deprived in terms of employment[2]. It is on the boundary with an area in the top 20% most deprived in the country. In addition, those who qualify to live in socially-rented affordable housing are necessarily at greater risk of fuel poverty, with low and variable incomes, unemployment, and single parent families.

From 2011 census data[3], in the area covering the two WHG-owned tower blocks of Thomas and Smith Houses (output area E00051985) the average age was 31.2 (median 29), compared to a national average of 39. This relatively high proportion of young residents had little knowledge of energy, particularly the concept of electric storage heating, or how to control it. Only 31.1% were living as a couple (either married or cohabiting), compared to a national average of 57.8%, putting them at greater risk of fuel poverty as the remaining 68.9% manage their energy bills on their own.

71% of the 122 households in the area have no adults in employment (compared to a national average of 33.3%, and an average in Walsall of 38.6%). Of the 164 usual residents aged 16 to 74, 34.1% are unemployed and 39.6% are economically inactive:16.5% because they are long-term sick / disabled, and 6.7% look after the home/family, but 12.2% are inactive for other reasons. 47.9% of the residents have no qualifications, 22.2% have Level 1 qualifications, and 18.6% have Level 2 qualifications (compared to 22.5%, 13.3% and 15.2% averages respectively for England) putting these residents at higher risk of low-paid and unstable employment.

In Great Britain, it is estimated that around 10% of households (4 million) do not have a mains gas connection, with just over half of these using electricity as their primary heating source[4]. Dwellings with electric heating tend to have lower energy efficiency ratings, partly reflecting higher running costs and lower levels of heating controllability. Storage heating is not well-understood, with many residents assuming heaters did not work because they didn't heat up as soon as turned on – and so used on-peak electric supplementary heating instead. Even where used, storage heaters have controls which many do not understand or use, often leading to overheating in the early part of the day, and low temperatures in the evening when heat is required for comfort and wellbeing (and peak-rate supplementary heating is often used to attain comfortable temperatures, at high cost). Due to their higher heating costs, such households are more likely to be fuel poor, and in discomfort. This is compounded by the above demographics, with residents more likely to be unemployed, have young children and/or health issues so they may need to keep their flat warmer, and/or are in the home more so require more hours of heating.

WHG wanted to test two different solutions to determine how new technologies might help them to deliver controllable and affordable warmth for residents in their electrically-heated stock. One solution involved modern Elnur storage heaters combined with a time-of-use Economy 10 tariff, and dynamic charge control to allow thermostatic programming of heating as required. This was compared against Enviroheat HET on-peak water-filled radiators, controlled by room thermostats. These are described as lower-energy than standard electric radiators. NEA's grant funded the addition of the Switchee smart thermostat to the improvements already planned for each flat. These detect temperature, humidity, light, movement and pressure to create an occupancy profile of the flat, so as to predictively optimise the heating settings, even if the resident did not engage with it. It also calculates risk factors such as mould, fuel poverty etc. for the landlord. These solutions would be relevant to many other housing providers in the UK.

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[2] English indices of deprivation 2015, http://imd-by-postcode.opendatacommunities.org/ [Accessed 21/01/2019]

[3] Nomis official labour market statistics, www.nomisweb.co.uk [Accessed 21/01/2019]

[4] Insights paper on households with electric and other non-gas heating, 11/12/2015, ofgem.gov.uk/ofgem-publications/98027/insightspaperonhouseholdswithelectricandothernon-gasheating-pdf [Accessed 21/01/2019]

The technology: Elnur storage heaters & VCharge

Old storage heaters (and panel heaters in the bedrooms) in all flats in this group were replaced by modern Elnur / Gabarrón storage heaters[5]: these were not high heat-retention models so had basic controls, but were combined with VCharge dynamic charge control[6] which also provides weather compensation. VCharge allows background, and comfort i.e. higher-temperature time-periods and set-points to be set. As VCharge was owned by Ovo / Boost (the latter being their prepayment "brand", which all householders used), recipients were required to switch to Boost's Economy 10 tariff, and have a smart meter fitted. Householders could see their usage and top up via the Boost smart-phone app. The hot water immersion tank was not changed.

It must be noted that since 1st January 2018, all local space heaters manufactured for sale in the EU must comply with Lot 20[7] - for storage heaters it means they must have electronic heat charge control with room and/or outdoor temperature feedback or controlled by the energy supplier; electronic room temperature control plus week timer; and fan assisted output. The heaters installed in this project were not compliant alone, but were deemed to be, fitted in conjunction with VCharge. As that solution is no longer available, the model of heaters installed is no longer available for sale.

Enviroheat HET electric radiators and immersion heaters

Old storage heaters and bedroom panel heaters were replaced by Enviroheat's HET lower-energy on-peak water-filled EconoRad electric radiators[8]. These claim to be the most energy efficient and cost-effective heater on the market. The household's immersion tank was also replaced by their EconoCylinder[9], which also claims up to a 66% saving on electrical hot water heating costs compared to competitors. The radiators were controlled by room thermostats, with overall control provided by Switchee. This also controlled turning the hot water tank on and off. This technology was sold and installed by Tempergreen, so the group is referred to by that name in this study.

To meet the Lot 20 regulation described above, direct-acting heaters must have an electronic room temperature control plus week timer, and one of: a distance control option; adaptive start control; open window sensing. Combined with Switchee, which learns a household's routine so can act as a timer and an adaptive control, this system was deemed to meet the regulation.

Switchee

A smart thermostat designed to be intuitive to use to change the temperature set-point, and turn hot water on or off. It measures temperature, humidity, light, movement and pressure to create an occupancy profile of the flat, to predictively optimise settings of the heating methods installed, even if the resident does not engage with it. It also calculates risks such as mould, fuel poverty, poor insulation etc. for the landlord, so they can target properties for repairs or tenant engagement. It was fitted as a controller in all properties receiving measures, and as a monitor in 5 control flats.

The project

WHG had identified a tower block of suitable properties to improve. 26 of these households were willing to be part of the study (all of whom received monitoring): 10 in the Elnur and VCharge group; 10 in the Enviroheat group; and 6 controls (one of these moved out shortly after the start of

[5] Elnur storage heaters (model fitted no longer available) https://www.elnur.co.uk/product-category/storage-heaters [Accessed 22/01/2019]

[6] VCharge information from Ovo https://www.ovoenergy.com/vcharge [Accessed 22/01/2019]

[7] What is Lot 20? http://www.lot20.co.uk/about [Accessed 29/01/2019]

[8] EconoRad information, http://www.enviroheathet.com/econorad [Accessed 22/01/2019] I

[9] EconoCylinder information, http://www.enviroheathet.com/econocylinder [Accessed 22/01/2019]

the study, reducing this group to 5). All the properties were 2-bedroom flats with electric storage heating (if used), except for one which had electric panel heaters fitted. All had electric immersion heaters for domestic hot water (DHW) but this was not necessarily used.

All properties were monitored for temperature and humidity, and current clamps were also fitted to monitor household and heating electricity use in all properties. 5 of those receiving each type of heating system were fitted with sub-meters and pulse loggers to monitor the heating and hot water system's energy use. All households were asked to record their electricity meter readings every 2 weeks for the duration of the study, and to provide bills detailing previous consumption, or to permit us to contact their electricity supplier to gather this information. Pre-installation questionnaires were carried out with residents in November 2017 to gather information on household occupancy, energy using behaviours and costs, and satisfaction with the existing heating and insulation.

Installation of the Enviroheat radiators and Elnur storage heaters took place in Oct-Nov 2017, then the smart meters were installed in those which required them in December 2017. Unfortunately, some of these were suitable for Economy 7 but not an Economy 10 tariff, so 2 had to be changed again in February 2018. There were also connection issues with some of the Switchees, and many of these units were swapped for those with upgraded firmware in January 2018. Due to delays at Ovo, most VCharges were not installed – and heating wired through the meter for the first time in some properties – until Feb-early March, although 2 properties had them fitted in late March and April 2018. Properties were visited in late February 2018 to check that all monitoring equipment was still present and in the correct location after all the works carried out, and corrected if required. Monitoring continued until June 2018 when all removable monitoring equipment was collected, and a final questionnaire was carried out to gauge resident satisfaction with their heating, hot water and electricity usage now they had experienced most of a winter with the measures fitted.

Summary of findings:

Energy use and costs

Taking into account electricity use (kWh) and costs:

- Small savings of 2.2% in energy use and 2.8% costs were calculated for the Tempergreen group if flats T-03 (very low energy use in previous year) and T-19 (faulty PPM, not paying for energy so high use) are excluded, but these were not statistically significant as 2 householders made savings, and 2 increased both their costs and energy use. Usage averaged 2.4 kWh/dd, and degree-day normalised average costs for the winter were £810 for this group.
- The VCharge group flats saw increases in energy use – linked to many having heating wired through their household meter for the first time. The two households which did not previously have this wiring issue, V-18 and V-44, saved 17% and 33.6% on heating costs respectively (average 25.4%) when normalised for the colder winter in 2017-18, although V-44 used 28% more energy, as their living room storage heater did not previously work. This is indicative only as a sample size of 2 is not statistically significant. Average energy use was 4.1 kWh/dd for this group, and their degree day-normalised average costs were calculated as £837.
- For the control group, savings were not expected as no measures were received. Their energy usage was 4.6 kWh/dd, and average normalised costs were £1,053.
- Cost intensity for heating (normalised for this period) is therefore calculated at £339/kWh/dd for the Tempergreen group, and £206/kWh/dd for the VCharge group. This compares to £230/kWh/dd for the control properties.

- Plotting performance lines of electricity use against degree days suggests that only a few Tempergreen properties saw better control of energy consumption after installation of the new heating, with points closer to the best-fit line (higher R^2 values) and/or lower slope or intercept. As this is an on-demand heating system with manual, residents are likely to use it as required to achieve comfort when they are at home – which may not correlate with external temperature / heating need. More information was available from VCharge properties as smart meters were fitted as part of the project, but not all had previous usage information to compare against. The properties with previously correct wiring showed improved efficiency for V-18 and increased energy use (use of an extra storage heater) but better correlation with heating need in V-44. Households which were previously only paying for household circuit electricity use showed an almost flat line before install (no correlation with degree days), and a slope relatively well correlated with degree days after the wiring was corrected.
- Current clamp and sub-meter monitoring of heating energy usage show that Tempergreen group properties used less energy for heating - and a lower proportion of total energy use - than those in the VCharge group on average. Households using Enviroheat heaters (Tempergreen group) may have either restricted heating to ensure affordability, or be used to using only spot-heating, attaining cooler temperatures on average. VCharge group properties used more energy but at lower cost, due to the majority being on the lower cost off-peak rate.
- This also allowed analysis of patterns of usage, which show that the Tempergreen system is easily adaptable to the resident's lifestyle, with distinct patterns of use in some households and irregular usage in others. Energy usage in off-peak periods shows the effect of VCharge, tailoring charging times & amounts to heating times and temperatures set by the householder. The properties which had yet to receive VCharge (in the analysed period), and control flats, all had an Economy 7 profile, apart from a control property that used supplementary heating only.

Thermal comfort

- Temperature monitoring showed that living room temperatures for the Tempergreen group were cooler on average than for the VCharge group after their new heating was fitted, however both groups were cooler than the control properties.
- However, all but one property, V-06, achieved the 18-21°C recommended temperature range for comfort and good health before installation, and all did after the new heating was installed.
- Bedroom temperatures were more variable, with properties T-16 and C-09 clearly hardly heating the bedroom, T-01 increased heating in the bedroom during the study, but V-34 evening bedroom temperature decreased during the study period.
- 3 households heated their flat significantly warmer than recommended temperatures (a control, C-15, and 2 VCharge properties, V-18 and V-33) which would increase their costs. No change in temperature could be noted after properties received EvoHome or VCharge.

Damp and humidity

- Humidity levels were not well controlled, with some households (generally but not always those with high temperatures) having lower than the recommended range of 40 - 60% rh, but others having higher levels than this, approaching 80-90% in bedrooms. These were generally properties with identified leaks or water ingress / cold bridging, or under-heating issues (C-09). High humidity in property T-01 which was previously under-heated was brought under control once temperatures increased with the new heating. However, no general trends were detected in humidity levels during the study.

Switchee data

- Temperature and humidity data from Switchee – located in the hall - again shows that Tempergreen properties were on average cooler, and their humidity levels higher, than VCharge and Control group homes. Again, households with known leaks or other issues were more likely to show up with higher humidity. No notable effect can be seen of installing either EvoHome or VCharge in those which received them, compared to those which did not.

Resident satisfaction and comfort

- Residents' feedback indicated a marked improvement in comfort, with numbers saying they could keep comfortably warm at home increasing from 2 of the 9 initially interviewed in the Tempergreen group, up to all 10 at the end of the study. In the VCharge group, this increased from 7 out of 9, up to all 10 by the end of the study. In the control group, all felt they could keep warm enough. Numbers reporting they needed to wear additional warm clothes in the home to keep warm enough decreased from 7, and 6 out of 9 households in the Tempergreen and VCharge groups respectively, to only 3, or 4 of 10 in the same two groups by the end of the study. Only 2 of the 6 control group reported needing to wear warm clothing at home.
- 5 of the 10 Tempergreen group said they could now heat and/or comfortably use more of the flat, as did 6 of the 10 VCharge group. Before the new heating, 3 of the 10 Tempergreen group had only heated one room, and 2 rarely heated the flat at all. Only 3 heated most rooms, but none heated the whole flat. By the end of the study, whilst 3 still reported heating only the living room, none used no heating, and 4 of the 10 stated they could now heat the whole flat. For the VCharge group, 2 of the 10 had previously heated only the living room, and only one heated the whole flat, whereas after the new heating, 7 of 10 said they heated the whole flat and only one heated just the living room.
- The households did not have thermostats previously so residents' prior ideas of their heating temperatures would not be accurate. At the end of the study, all 10 Tempergreen group said they heated their flat to 18-21°C or higher (7 to over 21°C). In the VCharge group, 9 of the 10 heated to 18-21°C or higher (4 to over 21°C) and only one heated to 17°C by preference.
- Daily supplementary heating use decreased from 12 of the 20 households (7 of these instead of storage heaters) to 2 of the 10 Tempergreen group, who used it only briefly to heat rooms quickly on getting up / bathing children. In the VCharge group, only 3 of 10 now needed to use supplementary heating daily, 2 in evenings and one resident's young son liked to turn the living room fire on – this was reported to WHG to fit a child-proof lock.
- Notable benefits identified included: the heating being easier to use / control, the flat being warmer and more comfortable, and the new radiators looking better than the old ones. 8 of the Tempergreen group also felt that their home kept the heat in better – as no insulation work was done, we believe this question was interpreted as being able to have heat later in the evening than was previously possible. Many said the new heating improved the quality of the home, and the house got warmer faster. However, few felt they were saving energy or money on bills. Parents of young children in both groups commented that the new heaters were cooler to the touch than the old storage heaters – less likely to burn children – so safer to use.
- Residents' behaviour also changed – few previously adjusted the controls of their storage heaters, but after the new heating, 9 of the 10 Tempergreen group adjusted the heater controls if they were too hot/cold rather than putting on/taking off clothes or opening windows. However, only 3 of the 10 VCharge group would log onto the VCharge website to adjust the settings if too cold/hot, so a few still resorted to supplementary heating and extra clothes.

- In both groups, 4 residents felt their hot water use was easier / better than previously, and 4 felt it was the same as before (2 did not answer in each group). 5 of 8 households in the Tempergreen group who had previously suffered damp / mould issues said it was improved, and all 3 in the VCharge group who'd had damp issues felt it was better (though not gone).
- Satisfaction with all aspects of the heating improved, especially for the Tempergreen group, particularly relating to how much control they had over the heating and how easy it was to use, both very low previously. The VCharge group stayed on average a little dissatisfied with costs of heating: this is likely to link to historic wiring issues being rectified, so having to pay for their heating costs for the first time. In many aspects, satisfaction increased above the control group levels – for both new heating systems in amount of control over their heating, and for the Tempergreen group with the cost of running the system. Both groups were now on average satisfied with how warm their flat gets when it's cold outside, how easy the system is to use, and how well the home keeps the heat in.
- In terms of ease of use, most householders in the Tempergreen group felt the new heaters were easier to use than their old ones, knew as much as they needed to about how the system worked, and how best to use it. They only slightly agreed that it didn't require too much input, as most were actively turning the heating on and off as needed. For the VCharge group, there was more agreement that the new heating didn't require their active input, and on average agreed that the measures were easy to use. But their responses fell exactly between agree and disagree for both knowing enough about how the new heating worked and understanding how best to use it, indicating that many were unsure. 5 VCharge group residents stated that they were unsure how to control the system, needed assistance to set up VCharge via phone or internet, or to log in, and others also wanted a reminder of how to use it in the autumn.
- Householders' comments about the installations were mixed, with some reporting that the Enviroheat installations didn't take long, but some negative aspects were reported: leaving a resident's hot water on boost - which used up all the credit on their meter, so they had to turn everything off and stay elsewhere until it was resolved – and a disorganised installer who used offensive language, making a resident feel uncomfortable. In the VCharge group, half felt the installation was fine, with installers being helpful, explaining everything, one said the first installers were careful but another who came later to fit Switchee and VCharge was very rude. 3 of the 10 said they got confused with lots of visits to install / fix different parts of the system, and the whole installation period was too long. Residents' views about the organisation of the project were generally good, agreeing that installers were careful and respectful, they were told in advance when installers were coming and had been given all the info needed before they agreed to take part. Those in the Tempergreen group also agreed that they were kept informed of any delays or changes, and they'd been given details of a contact for any issues, but the VCharge group agreed less with both these aspects – unsurprising as it is known that this was a long and complicated installation process, with various installers involved.
- For support needs, most in the Tempergreen group agreed that they were clearly shown how to use the system, and received a manual / guide, knew who to contact about any issues, and received prompt & effective support if needed. Despite one householder being unsure if they'd received paper instructions, all 10 felt they knew how to control their system. In the VCharge group, respondents only slightly agreed with these statements on average. 7 of the 10 said they were shown how to use the controls for the system clearly enough but only 5 said they received paper instructions to refer to, and 4 felt they can't control the system adequately for their needs, showing that lack of knowledge, and dissatisfaction / confusion remain with this more complex system - particularly to access and control the system via the VCharge website.

- 5 of the 10 Tempergreen group had suffered breakdown/reliability issues with the new heating: 3 related to room thermostats losing connection with radiators, all of which had been resolved quickly (but it reportedly recurred) and 2 related to Switchee “freezing” – one rectified itself, but the other was never resolved – the household received an EvoHome but it reportedly also lost connection from the system, so residents controlled the heaters using room thermostats only. 4 of the 10 VCharge group reported issues where heating had stopped working: all were fixed within a few days, but one issue rectified itself before the resident had reported it.
- All residents in the VCharge group had received support - either from installers or WHG Energy Champions - to ensure they switched to Ovo’s Economy 10 tariff, as VCharge only works with this, but there was some confusion, with a type of smart meter only compatible with Economy 7 initially installed in some flats. One resident switched away from Ovo later and their heating & hot water stopped working until the VCharge was “wired-around” – so tying residents to a tariff may result in practical as well as ethical issues (limiting choice). 2 flats never received VCharge so are free to switch to any supplier. Most in the Tempergreen group were aware that they should switch to a flat rate tariff, and had done so (some discovered they were already on one), with some requesting support to do this, but 2 residents were found to still be on an Economy 7 tariff at the final interview. One was assisted to switch to a flat rate at that time, the other was referred to WHG for this support.
- 16 of 19 initial respondents reported general maintenance issues which caused them concern with keeping warm or increased their bills. At the final questionnaire, 4 out of 10 Tempergreen respondents and 7 of 10 VCharge group householders highlighted issues. These included draughty windows and front doors, mould above the living room window, a major roof leak, insufficient hot water, assistance required with using the VCharge website, and billing issues related to meter exchanges during the project. These should be fixed / resolved to maximise benefits from the new heating. All issues reported were passed to WHG for action.
- 5 of 9 Tempergreen group residents recalled receiving energy advice as part of the project, though only 2 had made changes as a result. For the VCharge group, 6 of 8 who responded to the question recalled receiving energy advice, and 4 had made changes as a result: fitting low energy light bulbs, doing washing late at night, and understanding the heating controls better.
- A key difference noted was that 7 of the 10 in the Tempergreen group stated they did not know who to go to for energy advice, and 6 wouldn’t consider changing how they used / paid for energy to help save money. In contrast, 8 of 9 in the VCharge group said they knew where to go for energy assistance, and 5 of 8 would consider making changes to save them money. This difference in engagement was visible in behaviour around energy bills/statements with 7 of the 10 Tempergreen group never receiving or checking any information from their supplier, whereas only 2 of the 10 in the VCharge group said they hadn’t had any statements, with more checking to see if they were in credit/debit, if they’d made savings, or against meter readings.
- In terms of affordability perception, residents’ statements about their energy payments resulted in estimates that the Tempergreen group paid £1,084 per year on average at the start of the study (varying between £390-£2,340), and £1,160 per year (varying from £480-£3,120) after the measures. The VCharge group’s estimates were £863 (varying from £348-£2,080) at the start of the study and £1,234 (varying between £480 and £2,860) at the end of the study. Energy prices increased during the study, and winter 2017-18 was very cold, which will affect the responses, as would the wiring issues experienced mainly but not only by the VCharge group. In comparison, control properties paid £1,108 (between £480 and £1,825) at the start and £1,029 (from £360 to £1,820) at the end of the monitoring period, changing very little.

- By the end of the study, 3 of the 10 Tempergreen households felt that their bills were cheaper, 2 said this had reduced their money worries a little, and one reported it had reduced financial concerns a lot. 5 felt that they were paying about the same as before, but 2 felt that their energy bills were a little bit more expensive. Some commented that they were heating the flat for longer for the same cost. In the VCharge group, of the 8 residents who responded, only 1 felt their energy bills were cheaper, 1 said they were about the same, but the remaining 6 said their bills were more expensive. This is likely to be due to having their heating circuit wired through their household meter for the first time. Whilst 2 households felt the new heating had reduced money worries a little, and 1 felt they were the same as before, the remaining 5 felt the measures / project had made their money worries worse (3) or a lot worse (2).
- Previously, whilst the control group showed low levels of concern about energy affordability, both groups due to receive new heating showed more concern. On average there was slight agreement that they worried about paying fuel bills, and they have the heating on lower or less often than they'd like so their bills weren't too high. All these concerns had reduced markedly by the end of the study for the Tempergreen group. But whilst concerns over their ability to keep warm (and its impacts on health) had reduced in the VCharge group, their worries over affordability of energy and rationing strategies had not reduced much: half of respondents still agreed that paying for energy meant buying less of other essentials e.g. food, and they had the heating on lower or less often than desired to keep the bill down.
- Most residents in the Tempergreen group said they felt more in control of their energy bills, though they neither agreed nor disagreed that they'd seen savings on their energy payments, or reduced unnecessary heating, and few said they'd specifically tried to save energy / money on energy. Their general money worries had changed little since the start of the study. In comparison, the VCharge group disagreed that they'd seen savings on their energy payments, and slightly disagreed that they'd reduced unnecessary heating in their home (most felt there hadn't been any unnecessary heating previously), and that they felt more in control of their energy bills. Again, this latter can be linked to the financial effects of correcting previous wiring issues. There was slight agreement that they had tried to save energy more, and understood more about how to save energy. However, this group's general money worries had decreased slightly since the start of the study.

Conclusions and recommendations

- Installation of both new heating systems helped improve comfort, but significant cost savings could not be calculated for either group in this study. The 2 VCharge properties with correct wiring previously saw a 25.4% cost saving on average when normalised for degree days, but this is only indicative with such a small sample group. (Clearly the residents found not to have been previously paying for their heating saw costs increase after their wiring was corrected.)
- Even where households did not make a saving, satisfaction with heating generally improved: homes were warmer and more comfortable, and the temperature was felt to be easier to control in Tempergreen group flats. The install process was liked better by Tempergreen group residents, some in the VCharge group found the installation excessively long and confusing. Many other benefits were also identified, and general money worries decreased (except in the above-mentioned homes were costs increased, generally in the VCharge group).
- Safe and comfortable temperatures were achieved in most monitored properties, but a few properties' bedroom temperatures were worryingly low, potentially due to under-heating. Some flat's temperatures were also significantly higher then the recommended range of 18-21°C, which would increase their costs, and in both cases advice or assistance may be required.

- High humidity was detected in some properties, generally those with reported leaks or water ingress issues. Data from the Switchee smart thermostat appeared to correctly identify those flats at risk of moisture/mould.
- Enviroheat heaters (Tempergreen group) were felt to be simple to use and control, apart from an issue with room thermostats un-linking from radiators in some properties – most knew how to re-link these, or one flat used the Switchee controller instead. However, this group used less heating and paid more in bills than the VCharge group, attaining lower temperatures (within the recommended 18-21°C range). 2 of the 4 homes which received an Evohome controller liked it, one using it for zoning the flat (heating rooms to different temperatures at different times), another to set heating periods and temperatures across the whole flat and it reportedly helped to control costs. However, one householder did not mention having / using it at all, and the other said it lost contact with the heating so they using room thermostats only. No clear evidence was seen of any change in temperature, humidity or costs in the flats after its fitting.
- The combination of the Elnur, Switchee and VCharge technologies was more complicated than the old storage heaters so some had issues with access and knowledge about VCharge's use, and it was unknown whether Switchee had any control of the system or not. VCharge control is via a website: a few householders were not online, and others had trouble finding or logging into this, which limited desired control (it is controllable by phone, but no sticker showing the telephone number was evident in flats, so most residents were unaware of this). Some were unaware that VCharge was set up by installers, and 2 were set at high temperatures (24°C) not advised for fuel poor households. However, their costs were cheaper per degree day of heat required than even control properties, achieving higher average temperatures than the Tempergreen group. For those who do not understand the controls, energy champion follow-up support is required to ensure the heating meets their needs comfortably and affordably, otherwise it risks being turned off, more expensive supplementary heating used, and/or the resident switching energy supplier so VCharge has to be "wired around", removing its use.
- Therefore, neither solution can be wholly recommended. A simpler-to-control off-peak system would be better, giving both the ease of use of the Enviroheat heaters, but with lower cost off-peak electricity costs. This must be combined with clear instructions for use, given regularly, and to new tenants. Enviroheat heaters may have a place in well-insulated properties which do require little heat, but cannot be recommended as the main heating in social housing with low-income residents, where their extra cost may lead to under-heating of homes.
- Greater follow-up support to troubleshoot faults and ensure residents know how to use each system is suggested – provision of a "Quick-start guide" laminated in the property so it can't get lost – as well as identification and assistance for residents to switch to the best tariff type.
- Installation of the whole system should occur over a short period to minimise tenant disruption. For greatest resident comfort and energy saving, it should be part of wider property thermal improvement, solving as many heat-loss issues as possible at once, before fitting new heating.
- Provision of advice to residents - at the time of installation - on the most effective and efficient use of energy in the home is always recommended; as well as how to time their use to make best use of their new technology installed (and a permanent record of this laminated in the property so it cannot be lost); to ensure residents are on the best energy tariff for their use; and that they are claiming all benefits for which they are eligible.
- If metering issues are discovered – particularly in tower blocks – meaning residents may not be paying for the whole of their electricity usage, advice must be provided as part of a project to raise awareness of normal heating costs and support to help residents budget for this.

1. Project overview

1.1 Introduction

This project installed two different combinations of electric heating systems to 20 x 2-bedroom flats in a tower block in Walsall, West Midlands, also comparing them against a control group who did not receive new heating:

1. Enviroheat EconoRads and EconoCylinder, controlled by Honeywell room stats and Switchee on a flat-rate tariff – 10 flats (4 flats switched to control by Honeywell Evohome).
2. Elnur storage heaters, and Switchee, controlled by VCharge on an Economy 10 tariff (no change of immersion tank) – 10 flats,
3. Controls: original electric storage heaters and immersion cylinder, with Switchee fitted for monitoring purposes only – 5 flats.

The properties were owned by WHG (previously Walsall Housing Group but now expanding beyond Walsall), one of the West Midlands' leading providers of high-quality homes, owning and managing around 21,000 properties across the Midlands, and providing affordable, good quality homes and community-based services to the local community. The monitored properties were all 2-bedroom flats in a 15-storey tower block, though occupant types varied. This is part of a pair, so some of the control properties were found from the neighbouring identical tower block.

The flats were of concrete and brick construction, and had relatively recently been externally clad with insulation (completed in 2016). At the same time, external doors (to balconies) and windows had been replaced with new UPVC double glazing, upgrading the thermal retention of the building.

1.2 Aims

The project had the following aims, to:

- Replace the existing storage heaters with either Elnur storage heaters coupled with Ovo's VCharge technology on an Economy 10 (time-of-use) tariff, or Enviroheat's lower-energy on-peak EconoRads and EconoCylinder, on a flat-rate energy tariff,
- Assess any change in residents' comfort – as reported in questionnaires, and measured using temperature and humidity monitors – after the new heating, any solar PV and coupled system,
- Quantify any change in electricity use and costs for heating, and general household use, following the measures, compared to the period prior to installation, and the control properties,
- Report any change in ease of use of the heating system with the new measures fitted,
- Compare these two energy solutions in terms of cost, comfort / temperatures achieved, ease of control by the tenants, in comparison to control properties,
- Determine the effectiveness and cost-effectiveness of these measures to reduce fuel poverty in off-gas developments of flats, and whether either solution is more suitable or effective - information relevant to many social housing (and private) owners in many areas of the country.

1.3 Context

In the Little Bloxwich / Stoney Lane area, 24.4% of the properties do not have access to mains gas, although all these are within 50m of a gas main. The majority of these use electric heating. The area suffers 11.2% fuel poverty[1]. This lower super-output area (LSOA) - the smallest area for which robust statistics are available - is in the top 30% most deprived in the country in overall Indices of Multiple Deprivation (IMD), and in terms of deprivation of income, education and skills, health and disability, and income deprivation affecting older people. It is in the top 20% most

deprived in terms of employment[2]. It is also on the boundary with an area in the top 20% most deprived (overall, and for income – including affecting children - employment, education, crime). In addition, those who qualify to live in socially-rented affordable housing are necessarily at greater risk of fuel poverty, with low and variable incomes, unemployment, and single parent families.

From 2011 census data[3], in the area covering the two WHG-owned tower blocks of Thomas and Smith Houses (output area E00051985) the average age was 31.2 (median 29), compared to a national average of 39. This relatively high proportion of young residents had little knowledge of energy, particularly the concept of electric storage heating, or how to control it. Only 31.1% were living as a couple (either married or cohabiting), compared to a national average of 57.8%, putting them at greater risk of fuel poverty as the remaining 68.9% manage their energy bills on their own.

71% of the 122 households in the area have no adults in employment (compared to a national average of 33.3%, and an average in Walsall of 38.6%). Of the 164 usual residents aged 16 to 74, 34.1% are unemployed and 39.6% are economically inactive:16.5% because they are long-term sick / disabled, and 6.7% look after the home/family, but 12.2% are inactive for other reasons. 47.9% of the residents have no qualifications, 22.2% have Level 1 qualifications, and 18.6% have Level 2 qualifications (compared to 22.5%, 13.3% and 15.2% averages respectively for England) putting these residents at higher risk of low-paid and unstable employment.

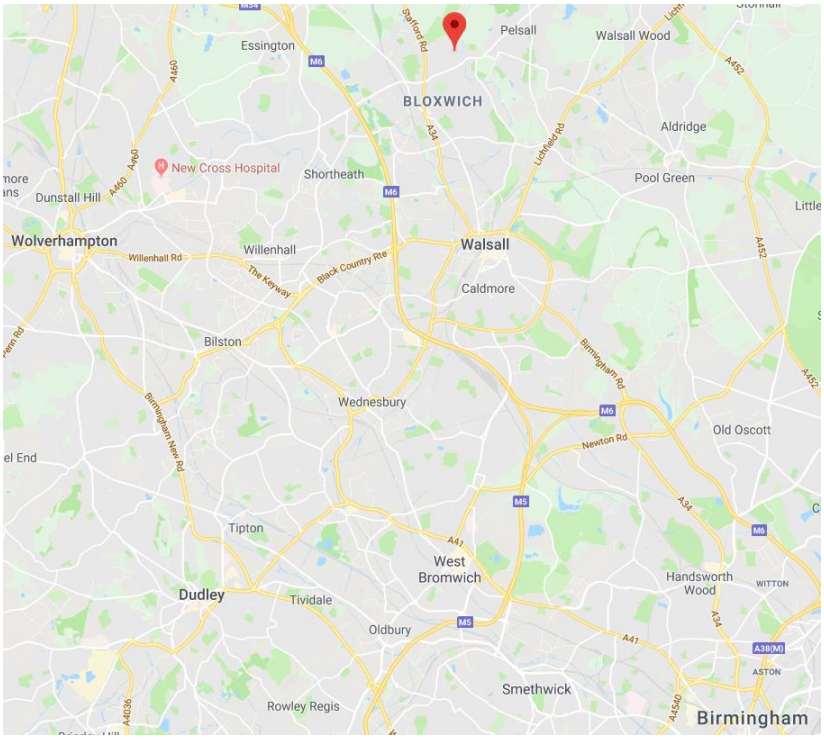


Figure 1.1 - Map showing location of the monitored properties, in Little Bloxwich, Walsall, West Midlands

In Great Britain, it is estimated that around 10% of households (4 million) do not have a mains gas connection, with just over half of these using electricity as their primary heating source[4]. Dwellings with electric heating tend to have lower energy efficiency ratings, partly reflecting higher running costs and lower levels of heating controllability. Storage heating is not well-understood, with many residents assuming heaters did not work because they didn't heat up as soon as turned on – and so used on-peak electric supplementary heating instead. Even where used, storage heaters have controls which many do not understand or use, often leading to overheating in the early part of the day, and low temperatures in the evening when heat is required for comfort and wellbeing (and peak-rate supplementary heating is often used to attain comfortable temperatures, at high cost).

Due to their higher heating costs, such households are more likely to be fuel poor, and in discomfort. This is compounded by the above demographics, with residents more likely to be unemployed, have young children and/or health issues so they may need to keep their flat warmer, and/or are in the home more so require more hours of heating.

WHG wanted to trial two different solutions to determine how new technologies might help them to deliver controllable and affordable warmth for residents in their electrically-heated stock. One solution involved modern Elnur storage heaters combined with a time-of-use Economy 10 tariff, and dynamic charge control to allow thermostatic programming of heating as required. This was compared against Enviroheat HET on-peak water-filled radiators, controlled by room thermostats. These are described as lower-energy than standard electric radiators. NEA's grant funded the addition of the Switchee smart thermostat to the improvements already planned for each flat. These detect temperature, humidity, light, movement and pressure to create an occupancy profile of the flat, so as to predictively optimise the heating settings, even if the resident did not engage with it. It also calculates risk factors such as mould, fuel poverty etc. for the landlord. These solutions would be relevant to many other housing providers in the UK.

1.4 Project timeline

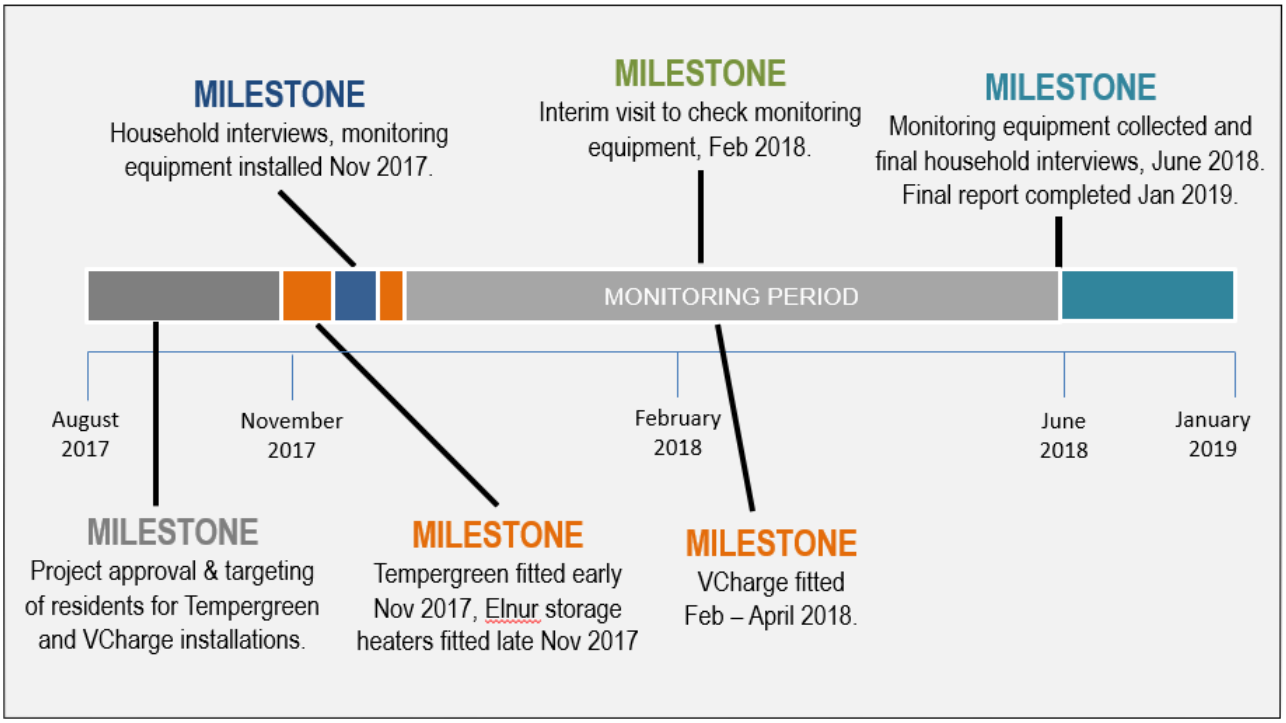


Figure 1.2 - Project timeline

This project was agreed in summer 2017, when WHG had already identified a tower block they owned for the heating improvement trial. Householders were recruited, carried out initial interviews, and installation started in November 2017. However, as both technologies were relatively complex, many changes / further installations were made throughout the monitoring period until early March – a few until late April 2018. An interim visit was made by NEA to check on monitoring equipment in February 2018. Monitoring equipment was collected at final interview visits in June 2018.

1.5 Attracting beneficiaries and establishing a monitored group

Initial engagement with householders was done by WHG, supported by NEA and installers:

- WHG identified the tower block in which to carry out the electric heating improvement trial.
- NEA and installers attended a coffee-morning to inform & recruit households (Sept 2017)
- WHG continued further recruitment, and informed tenants of works to be carried out. As the trial had limited install numbers, only those willing to be monitored received new heating.
- WHG supported NEA, accompanying staff on some visits to carry out initial questionnaires and install data loggers in November 2017, introducing to householders (and contractors), and arranging translator services as required.
- NEA staff provided energy advice at initial home visits, and installers provided support in using the new technology on its install to each household. WHG liaised with NEA and installers following various issues which would impact on the monitoring of the project.

26 households were willing to be part of the study (all of whom received monitoring): 10 in the Elnur and VCharge group; 10 in the Enviroheat group; and 6 controls (one of these moved out shortly after the start of the study, reducing this group to 5). All properties were 2-bedroom flats of approx. 61 m^2. with electric storage heating (if used), except for one which had electric panel heaters fitted. All had electric immersion heaters for domestic hot water (DHW) but this was not necessarily used. Details of the properties monitored are shown in Table 1.3, and a photograph of the exterior of the block treated is shown on the front cover of this report.

All properties were monitored for temperature and humidity, and current clamps were also fitted to monitor household and heating electricity use in all properties. 5 of those receiving each type of heating system were fitted with sub-meters and pulse loggers to monitor the heating and hot water system's energy use. All households were asked to record their electricity meter readings every 2 weeks for the duration of the study, and to provide bills detailing previous consumption, or to permit us to contact their electricity supplier to gather this information. Pre-installation questionnaires were carried out with residents in November 2017 to gather information on household occupancy, energy using behaviours and costs, and satisfaction with the existing heating and insulation.

EPCs were carried out for all properties in September 2016, after cladding of the tower blocks and installation of new double glazing, prior to installation of the measures being tested in this study. The SAP values of the monitored properties varied from 37 (F) to 71 (C), with an average value of 64 (D), before the measures were installed. However, these were significantly skewed with most SAP values being 69-71 (C) and a median of 70, but a few monitored on ground or top floors had values of 37-39 (F-E), and those on the first floor above unheated space had EPC values of 49-51 (E). The results are shown in Figure 1.3. No new EPCs were carried out after these heating improvement works, so we cannot comment on the change in SAP values they result in.

Installation of the Enviroheat radiators and Elnur storage heaters took place in Oct-Nov 2017, then the smart meters were installed in those which required them in December 2017. Unfortunately, some of these were suitable for Economy 7 but not an Economy 10 tariff, so 2 had to be changed again in February 2018. There were also connection issues with some of the Switchees, and many of these units were swapped for those with upgraded firmware in January 2018. Due to delays as Ovo reassessed their continued deployment of VCharge, most VCharges were not installed – and wiring issues corrected i.e. heating wired through the meter for the first time in some properties – until Feb-early March, although 2 properties had them fitted in late March and April 2018.

Properties were visited in late February 2018 to check that monitoring equipment was still present and in the correct location after most works had been carried out, and corrected if required. Monitoring continued until June 2018 when all removable monitoring equipment was collected, and a final questionnaire was carried out to gauge resident satisfaction with their heating, hot water and electricity costs now they had experienced much of a winter with the measures fitted. A final download of Switchee data was made from the online portal at this point.

To maintain anonymity for study participants, all properties are reported using randomly allocated reference numbers, as shown in Figure 1.3, along with the EPC rating and any issues of note at that property. Properties fitted with Enviroheat HET heaters (by, and known as Tempergreen in this study) have a property ref. prefixed T-. Flats which received Elnur and VCharge have reference numbers prefixed V-, and control properties - which were monitored but did not receive measures other than a Switchee for monitoring purposes – are prefixed C-.

Property	Measures	EPC	SAP	Installation & other social issues
T-01	Enviroheat	F	37	
T-02	Enviroheat & Evohome	E	49	Evohome only installed 23/4
T-03	Enviroheat	C	69	Rare heating use
T-04	Enviroheat	C	71	
T-05	Enviroheat & Evohome	F	37	Leak in roof: high humidity
T-16	Enviroheat	C	70	
T-19	Enviroheat	C	70	PPM in flat not working (not paying for usage), supplier alerted
T-26	Enviroheat & Evohome	C	69	Switchee froze & Evohome lost connection: manual control
T-42	Enviroheat & Evohome	C	70	Leak in cold water tank: high humidity
T-52	Enviroheat	C	71	Rare heating use
V-06	Elnur only	C	70	Tenant not engaged - install unfinished, no smart meter: exclude
V-07	Elnur only	C	70	Change of tenant - install unfinished: exclude
V-18	Elnur & Vcharge	C	69	VCharge only installed 23/4
V-29	Elnur & Vcharge	C	71	
V-33	Elnur & Vcharge	C	70	
V-34	Elnur & Vcharge	E	39	High household electricity use, potential illegal activity: exclude
V-37	Elnur & Vcharge	C	71	
V-39	Elnur & Vcharge	E	50	Resident did not understand or engage with new heating
V-44	Elnur & Vcharge	C	70	VCharge only installed 27/3
V-59	Elnur & Vcharge	C	69	
C-09	Control	C	70	
C-10	Control	C	70	
C-11	Control	C	71	
C-12	Control	C	70	Moved out at Christmas
C-14	Control	E	51	
C-15	Control	C	70	

Table 1.3 - Type of installation, SAP and other details of monitored properties

All-but-one monitored households completed an initial questionnaire at the outset of the project in November 2017 – before or shortly after installation of the new heating (for those receiving it) – about their household occupancy, energy-using behaviours, and experiences of heating their home using the old heating system: their costs and satisfaction with their heating, insulation, and comfort. Checks were made of the monitoring equipment, and meter readings were taken, at one interim visit in February 2018, and an initial questionnaire was carried out with the new tenant in the instance where there had been a change of tenant in a flat. Final questionnaires were carried out for all monitored properties in June 2018 at a final visit to collect all removeable data loggers.

1.6 Factors affecting the planned evaluation methodology

Issue	Description and mitigation
Monitoring period	Monitoring equipment started to be placed in properties on 6th November 2017, however some households could not be reached, so the last data loggers were only fitted in January 2018. This means that data is not available for all properties, for all parts of the monitoring period. Interim visits, when data loggers were checked, and meter readings taken, were in February 2018, and all loggers were collected in June 2018. Due to the many installations, and alterations, of different parts of the measures during the monitoring period, many different short periods have had to be selected for comparison and analysis, to try to isolate the impacts of the different parts of the measures in place during different periods.
Switchee connection issues	The Switchee was wired into the heating circuit and fitted on the hall wall, near the entrance to the flat, close to the centre of the block where there is very little mobile phone signal. This may have led to many Switchees often losing connection and "freezing", so tenants could no longer use the heating. Switchees were replaced for those with upgraded firmware, however for this reason, in many systems the Switchee's control over the heating system was removed so it performed a monitoring role only. NEA is unaware which flats received this modification, and the residents themselves did not know. It also became clear that a few residents turned their heating circuit off at the mains switch on leaving the flat – more probable amongst those receiving the Enviroheat on-peak heaters. This meant the Switchee would not function or monitor the property whilst they were not at home, so couldn't carry out a role of intuitively turning on heating before the resident(s) were normally expected home. This behaviour may be more expected in fuel poor households, to guarantee that the heating will not cost them while they are out of the flat.
Meter readings	Meter readings were obtained for all properties from energy log books, bills or energy company records for the period prior to and after install, aided by many residents using prepayment meters which record an automated meter reading at every top-up. However, especially for properties which did not have a (working) meter in the flat, residents were unable to take meter readings and had infrequent (or no) supplier readings due to access issues to the landlord's meter cupboard, so little data was available.
Monitoring equipment	Thermal and humidity data loggers from the bedroom of property C-12, the living room of T-01 and V-39, and both loggers from property V-29 were lost. The second data logger at property V-39 stopped working in Nov 2017 (before install) for unknown reasons, so no data is available for this property. Some current clamps were removed / moved / incorrectly re-fitted by installers during works on the flats, hence the need for an interim visit, when any issues found, or lost loggers, were re-placed correctly.
Change of tenant and incomplete installations	The initial resident of property V-07 moved out, and a new tenant moved in. As different people use energy differently, we therefore cannot compare against previous usage for this property. Due to the change in tenancy, installation at this property was not completed, with VCharge never being installed. This therefore cannot be compared like-for like with other properties which received the full installation. Data loggers were removed after the first tenant moved out, and re-installed at February visits, hence a gap in data.

	Similarly, due to household V-06's resident not engaging with installers, this flat did not have a smart meter installed, nor did they receive VCharge, so data from this household cannot be compared against others.
Withdrawals from study	There were initially 6 control properties, but residents of flat C-12 moved out at Christmas 2017 and their data loggers were collected. A Switchee was never installed here. They did give NEA consent to obtain electricity meter readings from their supplier, to use their historic usage / cost and monitoring data for the early part of the study.
Wiring issues	Many flats in this tower block had old radio tele-switch or other Economy 7 meters, locked in landlord-accessible only stairwell cupboards, where peak and off-peak circuit switches were also located. Many tenants had requested pre-payment meters be fitted in their flat, so the landlord had provided both peak and off-peak meter tails from the landlord cupboard to flats for metering. Only one set of wiring can be monitored per meter, so in many cases the off-peak circuit had been wired directly into the heating fuse board, and only the household circuit had been monitored (and paid for) via the PPM. Tenants were not aware of this. It meant that when meters in the landlord's cupboard were removed and replaced with smart meters in the flat, it corrected such historic wiring issues, so some residents had to pay for their heating energy use for the first time. Clearly, this unexpected change caused some hardship, and dissatisfaction with the cost of the heating. It was more prevalent in flats in the VCharge (and control) groups, as these were all using both peak and off-peak heating circuits. It was less of an issue for households which had previously not used their storage heaters (mainly in the Tempergreen group), especially if their off-peak circuit was not switched on.

Table 1.4 - Issues experienced which may affect the monitoring and evaluation of this project

2. Social evaluation and impacts

2.1 Qualitative feedback from initial – pre-installation – questionnaire

25 monitored householders were interviewed at the start of the monitoring period (Nov 2017): 6 controls, 10 receiving Elnur and VCharge, and 9 of the 10 households receiving Enviroheat. One completed a short questionnaire in the middle of the study (Feb 2018) after a change of tenancy; and 25 were interviewed at the end of the project (June 2018) as a control household had moved out, but the outstanding Enviroheat household was questioned. These interviews identified aspects of the property's type, occupancy and resident behaviour that affect energy use, and captured experiences of and satisfaction with using heating. The final questionnaire aimed to identify any changes, benefits and other effects at the end of the project. It must be emphasised that questionnaire responses are resident opinions, so may not be factually correct - this also highlights levels of resident knowledge about their home. This section displays questionnaire results regarding the residents' views, acceptance of the technology etc. and any immediate findings.

a)

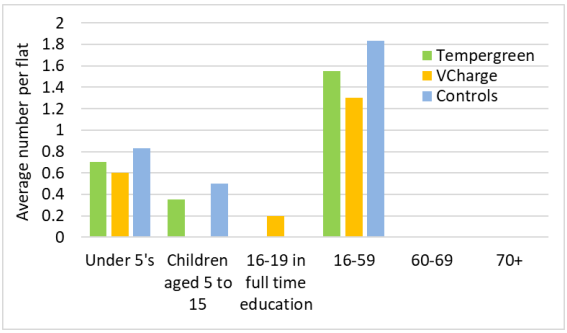
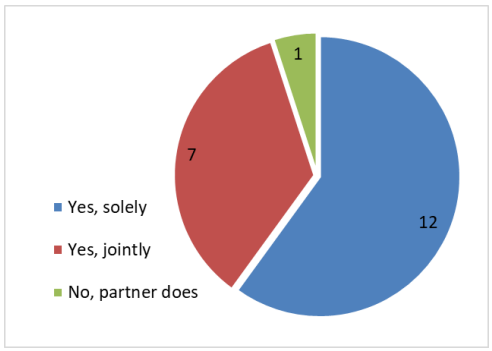


Figure 2.1 - (a) Numbers and age distribution per flat, (b) Energy bills responsibility, (c) Occupation of main bill-payer(s) i. for households receiving measures, and ii. control properties

b) i.



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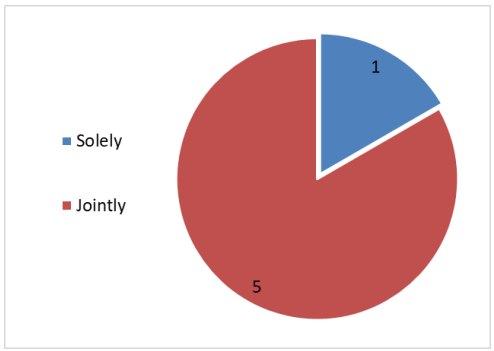
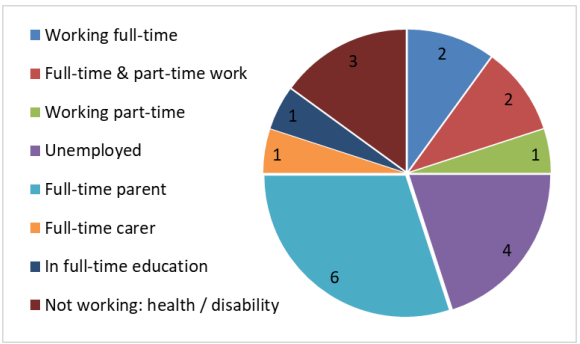


c) i.



ii.

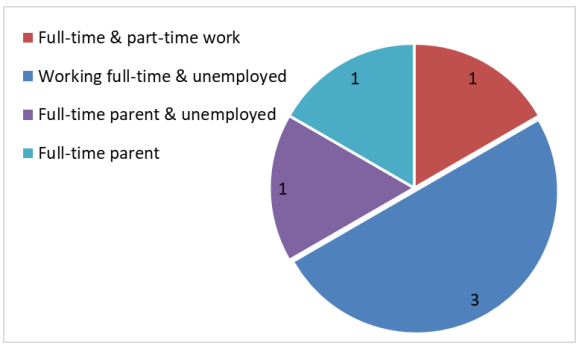
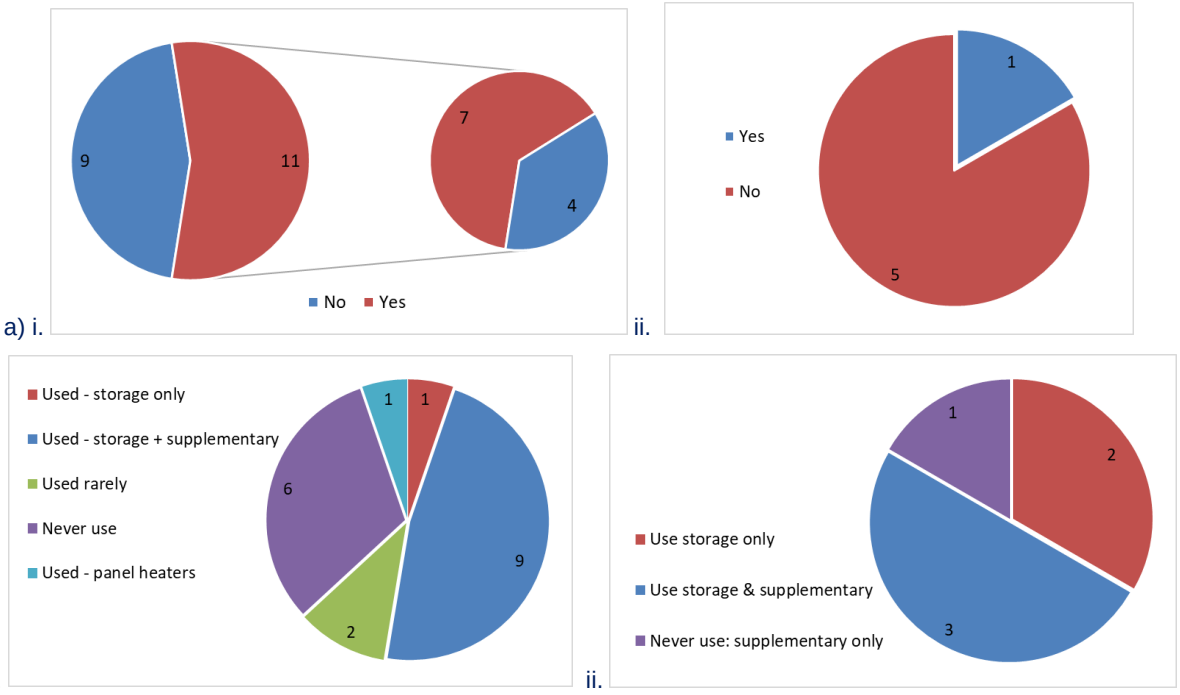


Figure 2.1(a) shows that all residents were working-age people (individuals and couples) with or without children. The control group had the highest proportion of couples, and of children, whereas the VCharge had the lowest number of adults and children per flat on average. However, the proportions in the groups are broadly comparable. Householders' ability to share responsibility for

energy bills may be a useful guide to vulnerability to high energy costs. As shown in Figures 2.1(b) i. and ii., a much higher proportion of the control group manage their energy bills jointly with another adult resident, compared to those in the groups receiving new heating, where 12 of 20 reported managing bills on their own. Figure 2.1 (c) i. and ii. show that households in the control group saw a much higher proportion (4 of 6) where at least one resident was in employment, whereas in the groups receiving measures, only 5 of 20 had residents in work, the remainder are therefore more likely to be living on limited incomes, and hence at higher risk of fuel poverty.

Figure 2.2 – Residents a) with health conditions, and whether this is worsened by cold, and b) use of the installed heating system for i. both groups which were to receive new heating and ii. control group.



As shown in Figures 2.2 (a) i. and ii., 11 of the 20 households receiving measures reported having a resident with a disability or limiting long-term health issue, and 7 of these reported that this was worsened by living in a cold home (so for best health they need to keep the home warm, possibly warmer than the usual 18-21°C). In comparison, only one of the control households reported health issues (this one was also reported worse health if the flat was too cold). Health issues present included: mental health issues (depression, anxiety, schizophrenia), fibromyalgia, epilepsy, asthma, arthritis, diabetes, Reynaud's syndrome, heart condition, auto-immune condition affecting the lungs (sarcoidosis), migraines and alcoholism.

Before the new heating was fitted, all properties had electric storage heating (ESH), except one which only had electric panel heaters fitted. However, as displayed in Figure 2.2(b) i. only one property used storage heating alone, 9 households reported also needing to use supplementary heating (5 of these on a daily basis, 4 only in particularly cold weather). 2 households reported rarely using storage heaters, as they felt their flat got warm enough without heating). 6 households never used the storage heaters, using supplementary heating instead. Reasons for this varied from the storage heaters not working (properly), or being insufficient, the resident not knowing how to use them, feeling they got too hot for safe use with small children in the home, and for comfort reasons (too hot at night and too cold in the evening). Hence in total 11 of the 19 households reported regularly using supplementary heating, plus one with only panel heaters fitted, and 5 more used it only occasionally if very cold, ill, or before the ESH was turned on in the autumn.

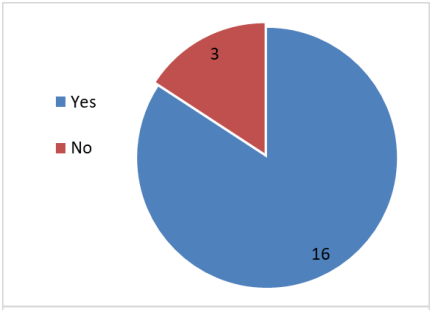
In comparison (Figure 2.2(b) ii.), all control properties had ESH fitted, and 2 used this alone, while 4 more also used supplementary heating: 3 of these used it only briefly when particularly cold or to warm rooms up quickly, but 1 used it instead of the main heating system for cost reasons.

None had a room thermostat so did not know their normal living room temperature. All had electric immersion tanks to heat domestic hot water (DHW), though not all used this.

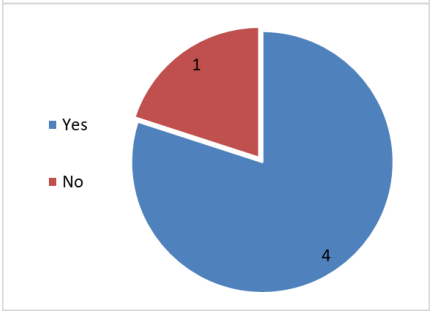
All properties had double glazing. However, many issues were reported regarding the windows and external (balcony) doors, with 9 of 20 households due to receive measures stating that they were draughty or had gaps. 8 also reported that front doors were draughty, with gaps under (into the landing: an unheated space and well-ventilated via grilles in the stairwell). Flats did not have a loft to insulate, but uninsulated floors and ceilings of ground and top floor flats respectively led to much lower SAP ratings (Table 1.3) and higher heat loss from and heating need in these properties.

Figure 2.3 - (a) Repair issues causing concern with increasing bills / keeping warm in i. groups to receive measures and ii. control group, and (b) energy using appliances present in the different households

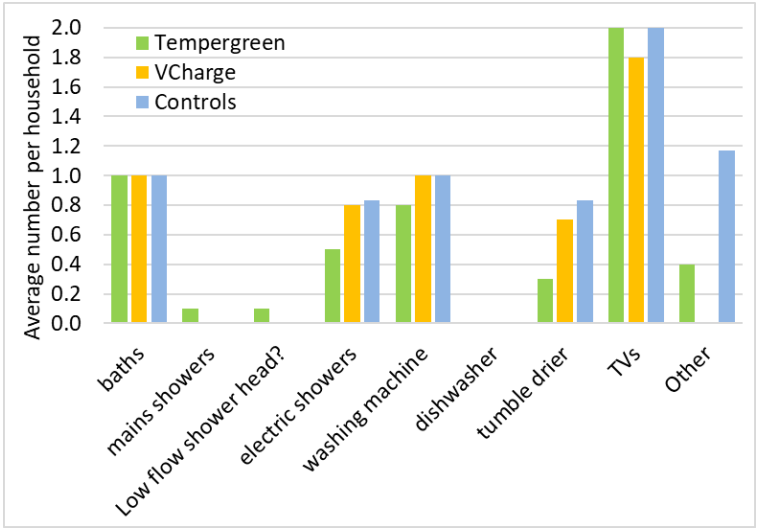
a) i.



ii.



b)



The incidence of repair issues which increased bills or made it hard for the household to keep warm was high at 16 of the 19 respondents. 13 mentioned draughty windows and doors, but other issues mentioned were 2 said certain heaters were not working, 8 suffer damp issues (1 in airing cupboard, 4 in living room from cold bridging / water ingress from balcony above, 3 in bedrooms), no labelling of off-peak / boost switches in airing cupboard, comments re. lack of extractor fan in bathroom, and 2 issues with water tanks. The proportion was however similar to those reporting issues of concern in the control properties.

The energy-using appliances present in the 26 households are shown in Figure 2.3(b) – all had a bath fitted and most had a washing machine. Fewer households in the Tempergreen group had a shower (either electric or mains) fitted than in the other groups. The control group had the highest incidence of having a tumble drier, and the Tempergreen group had the lowest incidence. None had a dishwasher. Other items identified were (other than electric fires, cookers and fridge-freezers which it was assumed all households would have) computers and games consoles. The most frequent appliances were large TVs, with an average of 2 per property, as many had at least one other TV in addition to the main one in the living room.

Residents were asked what time(s) of day it was important for them to have a warm home, at both the start and end of the project. The resulting “heating desire profile”, as shown in Figure 2.4, was

created by dividing residents' stated heating need into half-hour slots over a 24hr period, starting at the time shown. This was used in the technical monitoring to assess whether homes achieved warm and safe temperatures during the required time period(s), in this case deemed to be 5 - 9.30 pm, when the greatest proportion of the households said they required it warm.

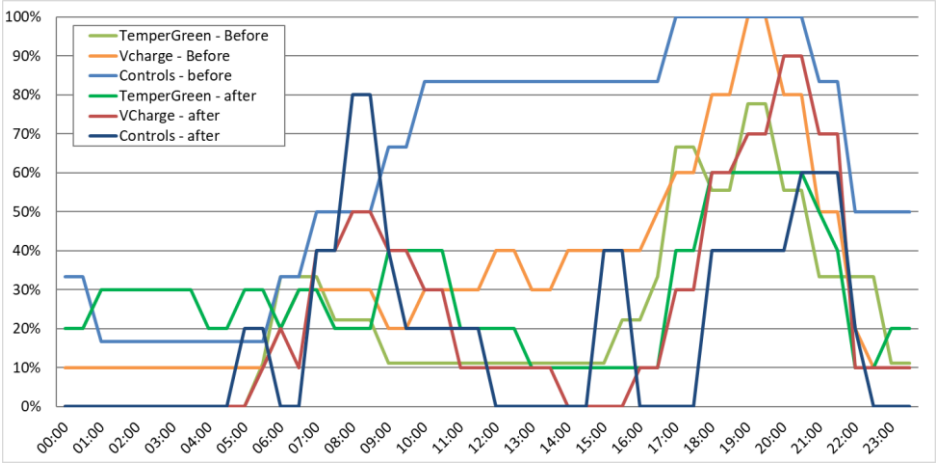


Figure 2.4 -Times when residents stated it was important for them to have a warm home

2.2 Affordability of energy bills

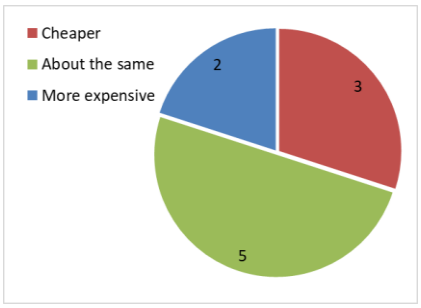
At each interview, residents were asked to estimate how much they paid for energy, and how often. This was used to estimate an annual total. Whilst this method is not accurate (due to incorrect recollection, rounding, accounts in debt / credit, delays in energy suppliers amending direct debits) it is useful as a measure of residents' perception of their heating costs.

Before the new heating was fitted, the 9 in the Tempergreen group (who would receive Enviroheat heaters) reported payments averaging £1,084 per year, or median of £910, a minimum of £390 (a household who did not use heating) and a maximum of £2,340. These payments are relatively high for the size of the flats, possibly as most were not using storage heaters, but costly supplementary heating instead, or in addition. The 10 households in the Elnur & VCharge group stated payments averaging £863, or median £520, with minimum £348 and maximum £2,080. Some payments in this group are very low (with no indication as to why), suggesting that residents were not paying for the heating part of their electricity use. In comparison, the 6 control properties reported payments averaging £1,108, or median £1,066, with a minimum of £480, and maximum of £1,825 – higher on average than all the groups which would receive new heating.

By the end of the study, only 8 residents interviewed in the Tempergreen group reported payment amounts which averaged £1,160 or median £1,040, with a minimum of £480 and a maximum of £3,120. This is a reported increase from before, and the latter household's very high bills are concerning! Similarly, due to smart meter issues, only 8 residents in the Elnur & VCharge group knew their payment amounts, which averaged £1,234 or median £1,056, with a minimum of £480 and a maximum of £2,860. In comparison, the 5 control group properties reported paying £1,029 on average, or median £910, a minimum of £360 and a maximum of £1,820.

Energy prices increased during the study period which will confound estimates, and winter 2017-18 was particularly cold, so more heating would have been required, which may explain an increase for some, but it is clear that average payments have increased for both groups receiving measures, particularly those receiving VCharge, while payments reported by the control group remained similar or decreased slightly.

a) i.



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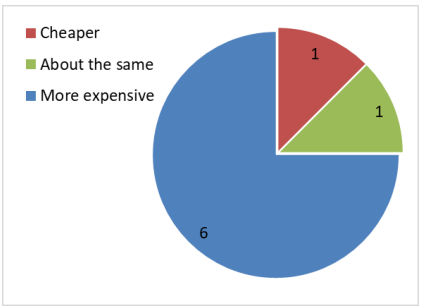
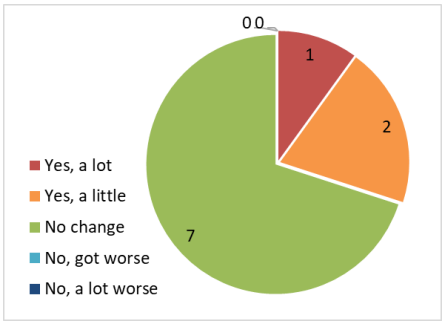
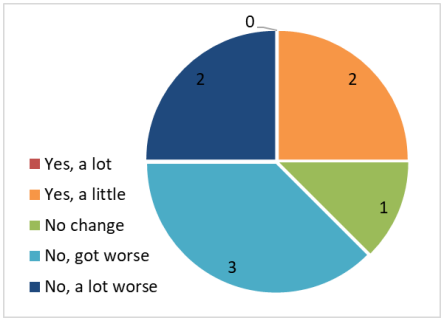


Figure 2.5 - Stated effect of measures on (a) heating bills, (b) money worries for i. Tempergreen and ii. VCharge group

b) i.



ii.



NEA also asked residents whether their energy bills had reduced or not, as shown in Figure 2.5(a) i. and ii. At the end of the study, of the 10 Tempergreen respondents, 3 felt that their heating bills were cheaper, 5 said that they were paying about the same as before, and 2 said that they were paying “a little bit” more. One householder said they were heating the flat for longer, for the same cost. 2 residents in the VCharge group did not know their bill amounts so could not respond, but of the remaining 8, 1 felt their energy bills were cheaper, 1 said they were paying about the same, but the remaining 6 felt the heating system was now more expensive. For many, this is likely to have been due to having their off-peak wiring connected to their meter for the first time. One household had high household (i.e. not heating) electricity use, which would have increased the energy bills.

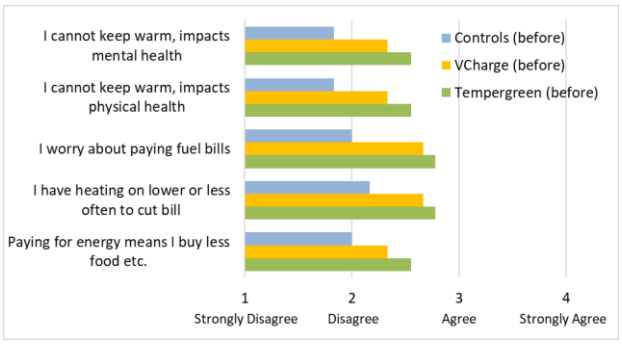
Figure 2.5(b) i. and ii. shows residents' views on whether the measures had reduced any money worries. Of the 10 Tempergreen respondents, 7 felt the measures had not changed their money worries, 2 said the measures had reduced their worries a little, and 1 said that it had reduced their bills – and worries - a lot. One stated that it gave them more control for the same money, another said it had reduced worries, as it was a lot warmer in the evening when they wanted the heat.

Respondents were asked how much they agreed or disagreed with a series of statements relating to energy affordability issues, feelings of control over energy bills, and money concerns in general. Responses were allocated a score of 1 for strongly disagree, 2 for disagree, 3 for agree and 4 for strongly agree. Scores were then averaged across all respondents for each questionnaire period so any change in opinions over time could be seen – results are shown in Figures 2.6 – 2.7. Statements in Figures 2.6 and 2.7(b) were negatively phrased, so a lower score is better in fuel poverty terms, whereas in Figure 2.7(a) the statements were positively phrased, so a higher score shows feelings of greater control.

Figure 2.6 (a) shows that at the outset, the control group showed far lower concerns over energy affordability and resultant coping strategies – mostly disagreeing with the statements – than the Tempergreen and VCharge groups. The Tempergreen group showed the most concerns. On average, slight agreement was seen with statements “I worry about paying energy bills” and “I sometimes have the heating on lower, or less often than I would like, so that the bill is not too high”. In all aspects, concerns reduced after installation of the new heating in the Tempergreen group, whereas in the VCharge group there was less, or no, change.

Figure 2.6 - Impact of the study on energy affordability concerns (a) before and (b) after the new heating measures

a)



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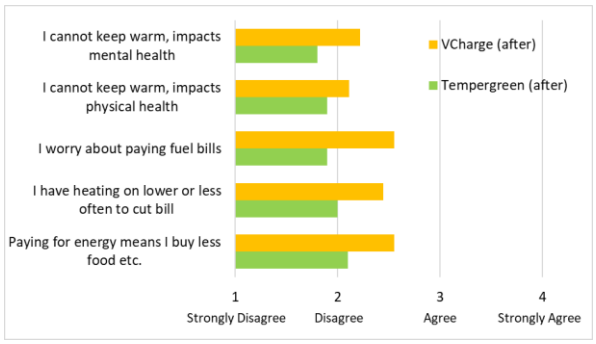


Respondents' views on the impact of the measures on their behaviour around their energy bills at the final questionnaire, Fig 2.7 (a), showed that on average most respondents in the Tempergreen group felt more in control of their energy bills, but those in the VCharge group were unsure. Slight agreement was seen with statements about having tried to save money on their energy bills, and understanding more about how they could save energy. On average those in the VCharge group disagreed that they had seen savings on their energy payments or that they'd reduced unneeded heating, whereas the Tempergreen average was that they neither agreed nor disagreed.

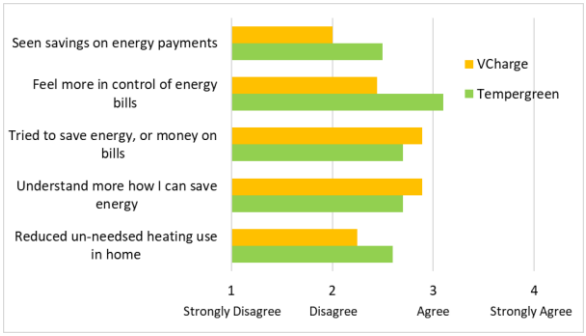
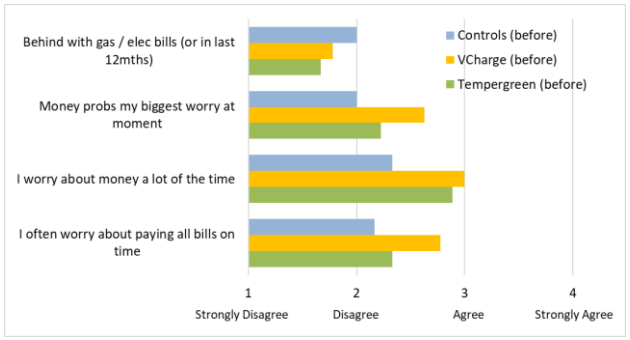


Figure 2.7 - (a) energy saving issues after install, and (b) general money worries i. before and ii. after installation.

b) i.



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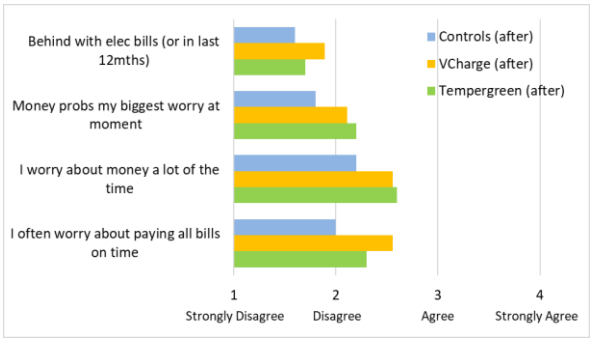
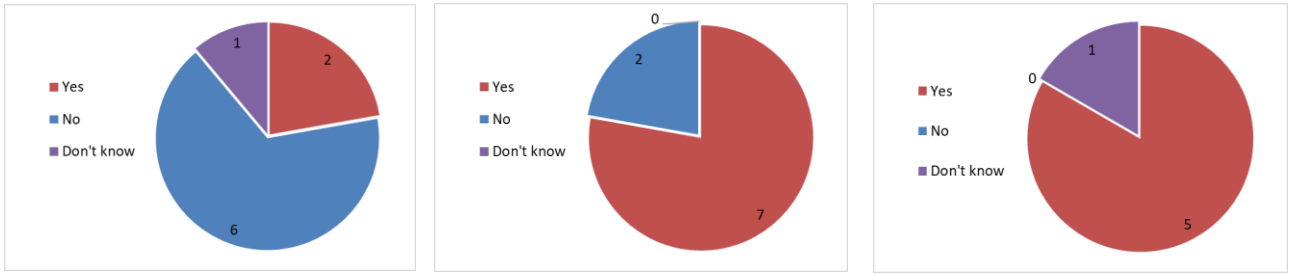


General affordability issues, Fig 2.7 (b) showed that residents on average disagreed that they were behind with their energy bills both before and after the new measures – many residents used prepayment meters, so it was not possible. The control group had relatively low levels of concern about money at both questionnaire points. Before the new heating, the greatest money worries were in the VCharge group, where on average respondents agreed that they worried about money a lot of the time. In this category, the Tempergreen group's money worries were not far behind. For the VCharge group, more agreed than disagreed that they often worried about paying their bills on time, and equal numbers agreed and disagreed that money was their biggest worry, whereas for the Tempergreen group, more people disagreed with these statements. For the Tempergreen group, these concerns changed very little after the new heating was fitted, though there was a slight reduction in those saying they worried about money all the time. Money worries reduced slightly for the VCharge group after the new heating was installed.

2.3 Perceived comfort and benefits

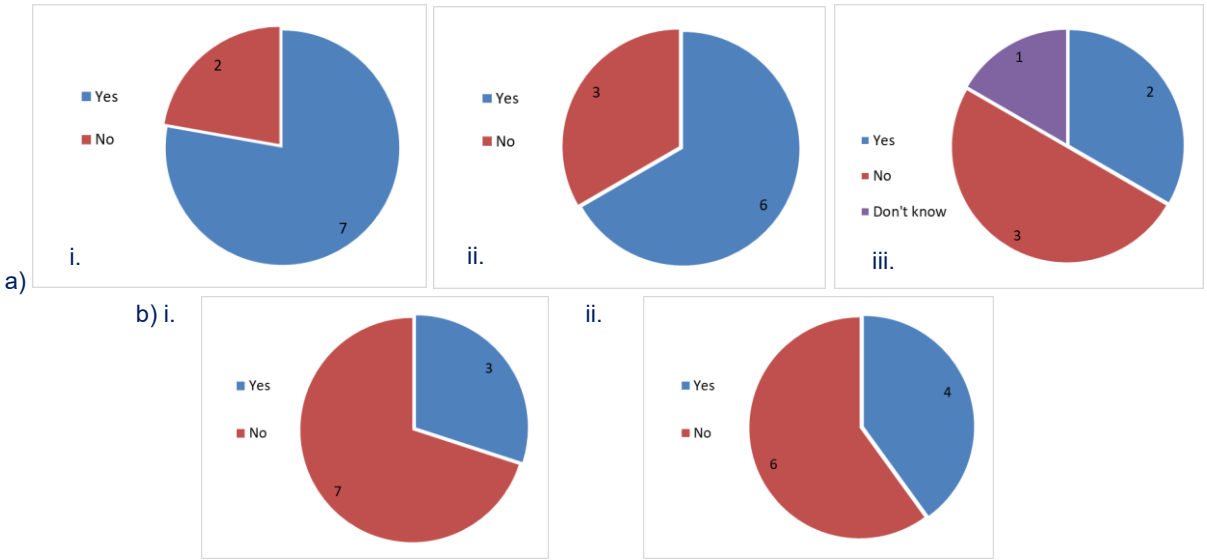
Participants were asked about their comfort with their existing heating, before the measures were installed, and again in the final questionnaire, to see if there was any improvement. Figure 2.8 shows whether respondents felt they could mostly keep comfortably warm at home, before the new heating was fitted. Only 2 of 9 in the Tempergreen group (a) who answered this question felt they could mostly keep warm enough before the measures, whereas 7 could not (one did not know as they had only recently moved in). By contrast, in the VCharge group (b), who tended to use their storage heaters more, 7 of the 9 respondents said they could mostly keep warm enough at home. Of those who said they couldn't keep warm, most did not state why, but the majority of those who did said it was both too expensive to heat the home enough and was not possible, stating that was too hot in the mornings and too cold at night. After install, all 10 respondents from both groups said they could now keep warm enough at home – a notable improvement in comfort, especially for the Tempergreen group. In comparison, the controls (c) felt they could mostly keep warm enough at the start (one had moved in recently so didn't know), and all kept warm enough at the study end.

Figure 2.8 - Whether householders could mostly keep comfortably warm at home in winter / when it's cold outside, before the measures, for (a) the Tempergreen, (b) the VCharge group and (c) the control group.



Respondents were asked if they ever needed to wear additional clothes in the flat to keep warm e.g. coat, dressing gown, blanket or multiple jumpers over clothes. Figure 2.9 (a) shows that 7 of 9 Tempergreen respondents, and 6 of 9 in the VCharge group said they needed to wear extra warm clothes to keep warm enough prior to installation of the new measures. In comparison, only 2 of 6 in the control group said they needed to wear extra clothing in the home (one moved in recently so didn't know). By the end of the study (Figure 2.9 (b)), only 3 (of 10) Tempergreen group, and 4 (of 10) VCharge group, reported needing to wear extra warm clothes indoors. For some this may be cultural rather than a necessity e.g. to put a cosy blanket over the knees when sitting on the sofa.

Figure 2.9 - Need to wear extra warm clothes in the home (a) before and (b) after the new measures for i. Tempergreen, ii. VCharge and iii. Control groups.

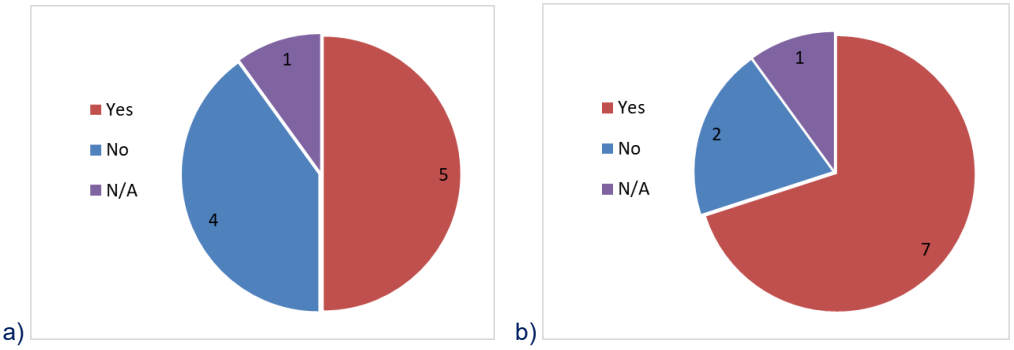


11 households had reported needing to use supplementary heating on a daily basis at the start of the study: 6 instead of using storage heaters, and 5 in addition to them. In addition, one household only had flat-rate panel heaters fitted, effectively the same cost as supplementary heating. 5 more used it only occasionally if very cold, ill, or before the ESH was turned on in the autumn. In comparison, 3 of the 6 control properties used supplementary heating on a daily basis: 1 as their only heating in place of the storage heating, 1 in place of a storage heater in a particular room that was blocked off by / too close to a large piece of furniture, and 1 only for a short period. 1 other household used supplementary heating only in very cold weather.

After the new heating was fitted, only 2 of the 10 Tempergreen group flats used supplementary heating to heat a room up quickly on getting up / after bathing kids. 3 of the 10 VCharge group households used supplementary heating daily, 2 in the evenings and one as the resident's young son liked to turn it on (this issue was reported to WHG to fit a child-proof lock), two more reported using supplementary heating only rarely when it was particularly cold weather. Both groups have seen a significant decrease in need for supplementary heating.

Residents were also asked whether they felt they could heat or comfortably use more rooms since the measures were fitted, shown in Figure 2.10. 5 of the 10 Tempergreen group said that they could now use the home more comfortably, either being able to heat more rooms than previously, or use the same number of rooms as before but being more comfortable in them. 2 reported that they had only been able to heat the living room previously, another that they could now have it warmer in the evening when they wanted it. In the VCharge group, 7 of the 10 households felt more comfortable, with 2 reporting that they'd previously only heated the living room, 1 that their living room heater hadn't previously worked, and 1 that none of their heaters had worked before. 1 person in each group couldn't say if it was warmer: they had moved in shortly before install, so had no prior experience of a winter in the flat to compare to.

Figure 2.10 - Householders reporting that they could heat or comfortably use more rooms at the final questionnaire for (a) Tempergreen and (b) VCharge group.



This is evident from asking householders which rooms they normally heated in winter, as shown in Figure 2.11. Initially, Figure 2.11 (a), the Tempergreen group were significantly under-heating their homes: 2 households did not normally heat their flat, and 4 of the 10 heated only one room. The remaining 4 heated a significant proportion of the home, but none in this group heated their whole flat – this may be due to a bedroom being unused, or by preference not to heat bedrooms. In the VCharge group, 2 households heated the living room only, but a much larger proportion heated a greater number of the rooms in the flat, and one household reported heating the whole flat. In comparison, only one household in the control group (who used supplementary heating only) heated only the living room, the remainder heated either the whole flat, or the living room and hall due to a preference for cooler bedrooms.

After installation of the new heating, Figure 2.11 (b), whilst 3 of the 10 households reported heating

the living room only (including one which rarely used the heating) a much larger number of households now heat multiple rooms, and 4 of 10 report heating the whole flat. In the VCharge group, a very large proportion, 7 of the 10 households, now report heating the whole flat, with 2 preferring not to heat the bedroom(s), and only 1 heating just the living room. The proportions in the control property group had changed slightly due to one withdrawing from the monitoring, and another preferring not to heat the bedroom(s).

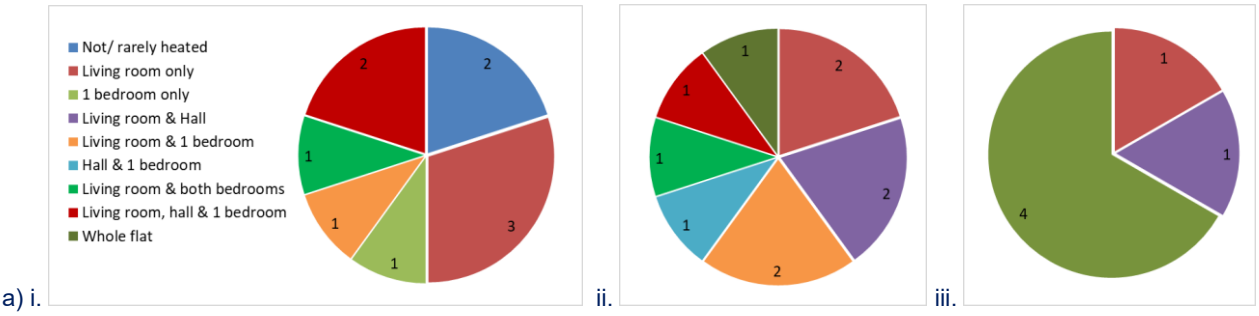
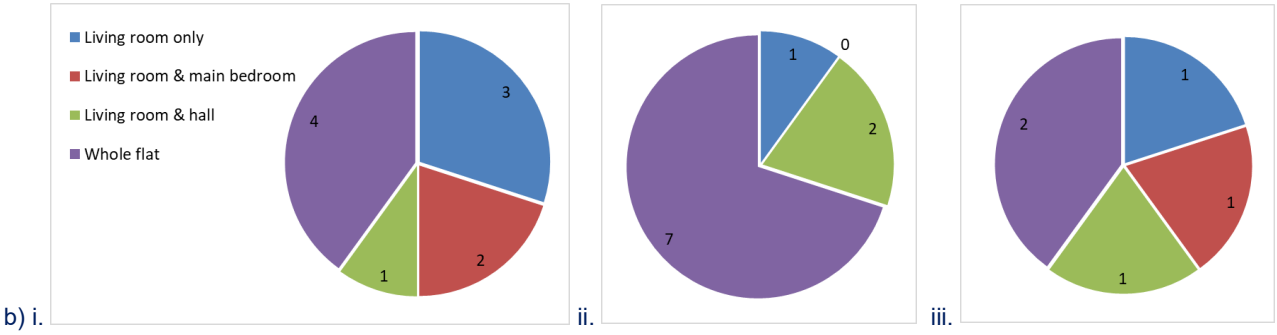


Figure 2.11 – Reported areas of the home which were heated (a) before (above) and (b) after (below) measures for i. the Tempergreen, ii. VCharge and iii. Control groups



Comparing rooms that were not heated in winter, Figure 2.12, shows that the Tempergreen group were least likely to heat many rooms in the flat in cold weather. N.B. the control group was only 5 people compared to 10 in both other groups. The second bedroom was often left unheated in all groups, and no groups had storage heaters / radiators fitted in the kitchen or bathroom (but only Tempergreen group residents mentioned this), but the Tempergreen group had a higher incidence of not heating the hall and main bedroom.

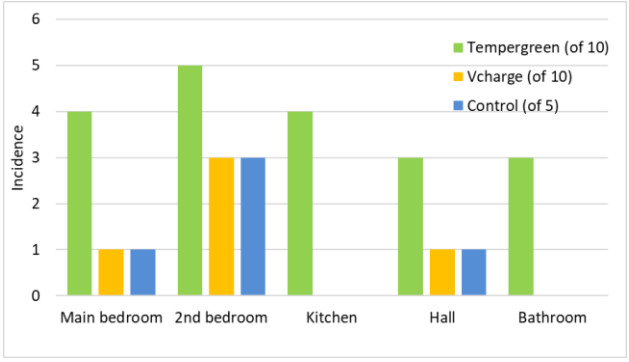


Figure 2.12 – Rooms not heated during the winter

Figure 2.13 shows numbers of households identifying benefits after installation of the measures. In the final questionnaire, few felt that their energy bills had reduced or that they were saving energy. The most notable benefits were that the heating was easier to use / control, and their flat was warmer and more comfortable, with slightly higher numbers in the Tempergreen group reporting these benefits than in the VCharge group. A high proportion in the Tempergreen group also felt that the home kept the heat in better – we think this question was understood as them being able to have heat later in the evening when they had previously not been able to. Many felt that the new heating improved the quality of the home, and the home gets warmer faster. Few noted that there had been any improvement in their or their family's health as a result.

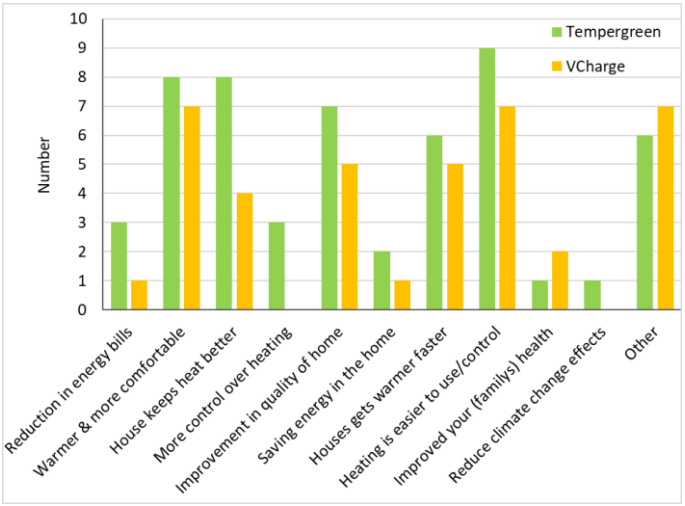
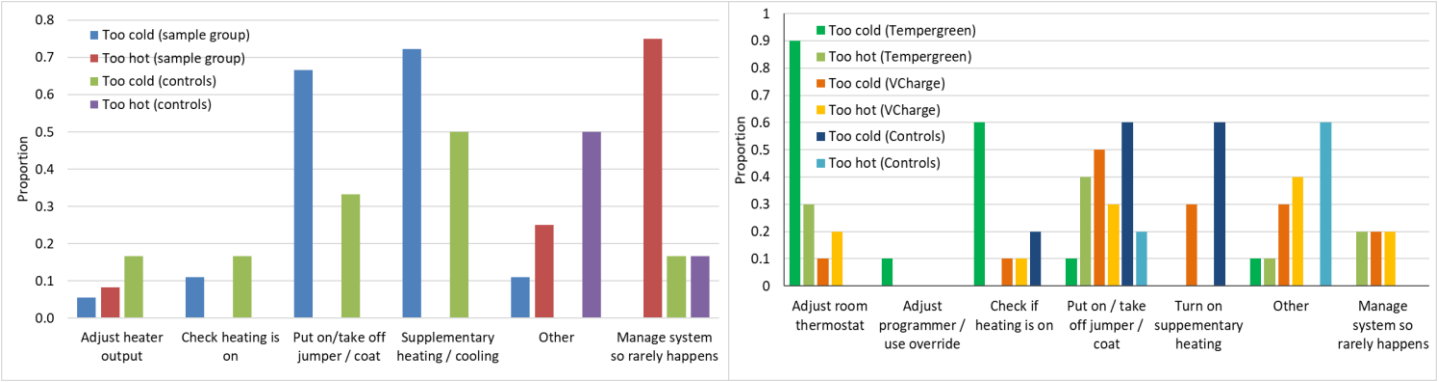


Figure 2.13 - Benefits perceived by residents after installation of the new heating

Other benefits noted were that 5 of both groups stated that the new heaters were much nicer to look at than the old storage heaters, and 1 of each group said the new heaters were cooler to the touch and hence more child-friendly. One in the VCharge group felt that old storage heaters gave out a dry heat which affected a resident's breathing, but that the new storage heaters were better.

Figure 2.14 - Actions if too hot/cold (a) before and (b) after install of new measures

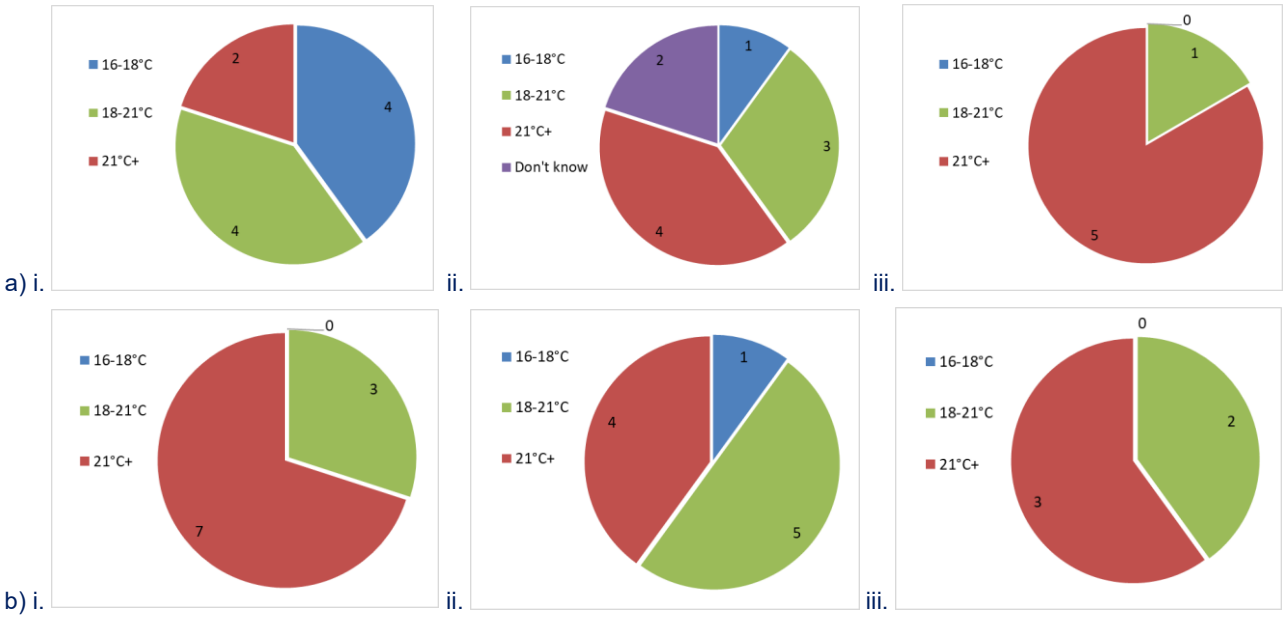


In terms of heating controllability, residents were asked what actions they took if they were too cold or too hot, both before and after the new measures. As shown in Figure 2.14, previously very few residents adjusted the controls of their storage heaters if they were too cold or too hot – mainly resorting to putting on or taking off extra clothes or supplementary heating. After the new heaters were installed, 9 of the 10 from the Tempergreen group adjusted the controls of the new heaters if they were too cold and 3 if they were too hot. Instead of adjusting the radiator dials, those in the VCharge group – 3 respondents - were more likely to log into the VCharge website to change the settings if they were too hot/cold. Fewer people felt they needed to put on a jumper or coat if they were too cold, or turn on supplementary heating, though the reduction was lower for the VCharge group than in the Tempergreen group where these actions were (almost) eliminated. The proportion doing this in the VCharge group was still lower than in the control group. One resident had previously gone to bed if the flat was too cold, they reported no longer needing to do this after the new heating was fitted. If residents were too hot, a smaller proportion in both groups which received new heating reported opening windows, showing that not as much heat is being wasted.

Residents were asked what temperature range the living room was normally heated to, shown in Figures 2.15 (a) and (b). As they did not have thermostats previously, (a) will be a guess, but is still useful to gauge residents' opinion of their comfort level. In contrast, (b) was likely to be based on

the setting of the storage heaters, in control properties it may be based on the Switchee-reported temperature. This shows that 4 of the Tempergreen group households initially felt their flat was colder than the recommended 18-21°C range. By the end of the study, no resident reported the home being cooler than the recommended range. 3 now kept the living area within the 18-21°C range with the remaining 7 households all heating it to over 21°C. This may be because it is now possible to increase comfort, or an increased awareness of the home's temperature, but this will increase their electricity costs and risk of fuel poverty, so further advice may be required.

Figure 2.15 - Reported normal living room temperature (a) before and (b) after installation of the new heaters for the i. Tempergreen, ii. VCharge and iii. Control groups



For the VCharge group, 1 household felt their temperatures were lower than recommended initially, 4 reported heating to higher than 21°C, with 2 having no idea of their room temperature. After install of the new heaters, a different householder reported preferring to heat their flat to 17-18°C, 5 were heating to the 18-21°C recommended temperature range, and 4 were heating the flat warmer than this. This suggests that residents can set their desired temperature, but it is unknown whether those heating to over 21°C are overheating, or require warmer temperatures for comfort or health. In contrast, a high proportion of the control group reported heating the flat warmer than 21°C, slightly lower by the end of the study. This may be due to greater knowledge of the controls, or better awareness of the temperature in the flat due to installation of the Switchee.

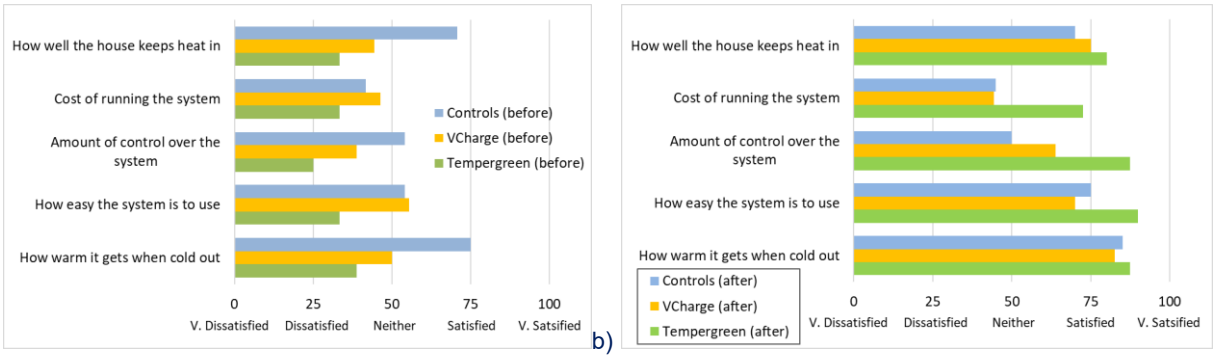
The impact of the new system on the resident's ease of hot water use was asked about, in both groups, 4 householders reported that it was better than before, and another 4 reported that it was the same as previously. In the VCharge properties, even though the same immersion tank was in place, the Economy 10 tariff changed the hot water heating frequency, and one issue with a faulty main coil had been solved by wiring the off-peak circuit to the boost coil instead.

Issues of damp, condensation and mould in the flat were asked about. 8 of the Tempergreen households had previously had damp / condensation issues, and 5 of them said this was now improved, while 3 said it was the same as before. All 3 households in the VCharge group which suffered damp issues said it was better after install of the new heating. One household had a problem with a leak from their cold water tank, and another on the top floor had suffered recurring major leaks through from the roof of the block – putting the second bedroom and electrics in the hall out of use. Neither were associated with the new heating, and were referred to WHG for repair.

2.4 Resident acceptance and satisfaction

Residents were asked about their satisfaction with different aspects of their home heating and insulation in the start and end questionnaires. Similar to questions where residents were asked how much they agreed or disagreed with statements, a response of very satisfied was allocated a value of 100, satisfied with 75, neither satisfied nor dissatisfied with 50, dissatisfied with 25, and very dissatisfied valued at zero. These scores were averaged across all responses for each period, to see whether overall opinions changed during the study. Results are displayed in Figure 2.16.

Figure 2.16 - Resident satisfaction with aspects of their heating system & insulation (a) before and (b) after new heating



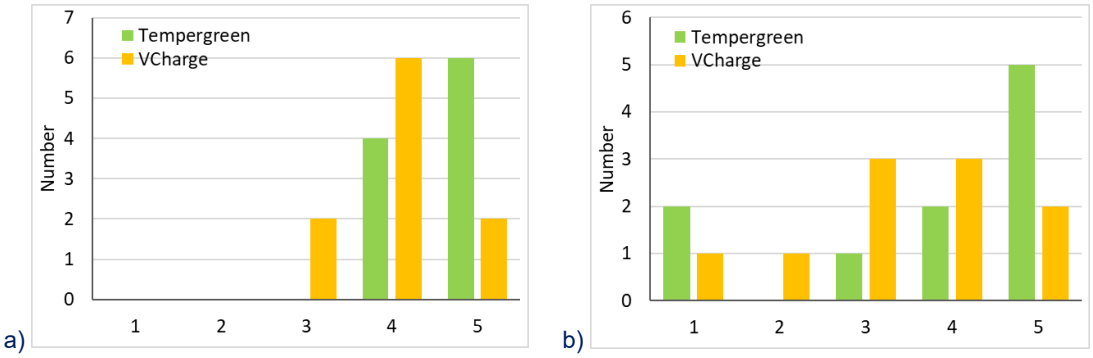
This shows that satisfaction with the heating was generally highest amongst the control group at the outset (though overall they were still slightly dissatisfied with the cost), with significant dissatisfaction seen in all aspects, worst in the Tempergreen group. Satisfaction improved markedly in all questions in the two groups receiving measures after install, but particularly in the Tempergreen group. Their ratings for the amount of control they had over the system and how easy it was to use were particularly low previously, and overall they were now Satisfied to Very satisfied with these aspects. Satisfaction with costs did not improve for the VCharge group - they were overall still not satisfied with the cost of running the system – this is likely to be due to historic wiring issues resulting in some households paying for their heating for the first time. A small improvement was seen in how easy the system was to use and the amount of control over it, as 2-3 residents did not understand it, did not have it set up correctly for their needs or have login details for the VCharge website to change the settings. A surprise improvement in both groups (as no insulation works were carried out) was in how well the residents felt the home kept the heat in – this question may have been perceived as how well the heat was retained in the storage heaters, or being able to use Enviroheat radiators, to maintain the temperature of the home later in the day.

Resident comments about their satisfaction included 3 households in the Tempergreen group who were very satisfied with the new heating, one saying it was “100% easier and more comfortable – we’d only been able to heat the living room before, the bedrooms were very cold”, and another said that “in the evenings the storage heaters used to go cold so it’s a lot better, especially at night”. However, one stated that “the temperature is not as even as storage heaters, the heat goes very quickly, the flat never felt cold before”, and “it works ok, but it’d be expensive if we had them all on”.

In the VCharge group, 4 householders really liked the new heating stating: “it’s much warmer and more comfortable” and “a more even temperature than just the living room fire before, I can now heat the whole flat” also “it’s good that you can control it remotely – if away, you can turn it up a day before coming home!”. But 3 said that it was more expensive than expected / previously, and “the sudden jump in costs was a bit much”. One resident was concerned that VCharge was wired in with loose wires, saying “it could be easy for children to pull out”. 5 residents were uncertain how to control the system, needing assistance to set up VCharge (via phone or internet), or log in, and wanted a reminder how to use it in the autumn. All issues were referred to WHG for assistance.

From comments made, the interviewer was asked to rank each respondent's feelings out of 5 (with 1 being very negative, 3 being indifferent, and 5 being very positive) and their involvement / engagement with their new heating system, presented in Figure 2.17.

Figure 2.17 - Ranking of householders' (a) feelings about using and (b) engagement with their new measures



6 of the Tempergreen group's comments suggested that they felt very positive about using their new heating, while 4 were mildly positive. A few properties had some issues, for example with thermostats "unbinding" themselves from radiators after power interruptions, so felt slightly less positive about the new heating. T-26 felt that it was not as warm as the previous storage heaters. In terms of engagement with the heating, 2 Tempergreen group residents seemed to engage with it very little, but most were relatively actively controlling the heating, and re-binding controls if their connection to the radiators was lost.

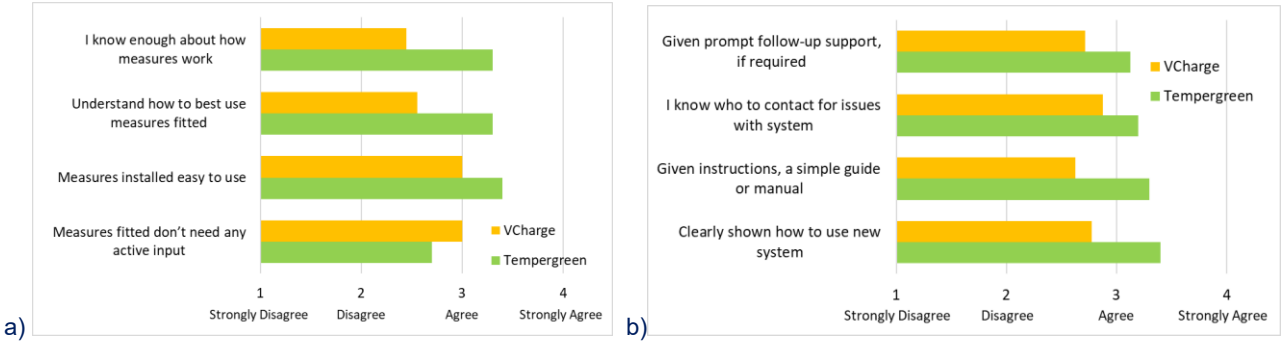
Fewer in the VCharge group were "very positive" about the heating, with most finding it ok / good, but had had some issues, and 2 were relatively indifferent. Most residents felt less need to be too engaged with the heating, however 2 were actively disengaged, having issues but not contacted the housing association for assistance to resolve them. Some were confused about how best to control the system, so could not engage as much as they wanted.

2.5 Ease of use and reliability

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

At the final questionnaire, participants were asked about how they used the system and whether they felt they had received enough support to use it. As previously described, responses were allocated a numerical value so that they could be averaged across the sample, to compare the two groups, with results displayed in Figures 2.18 (a) and (b).

Figure 2.18 - Resident (a) understanding and use of their new system, and (b) the support they received to use it



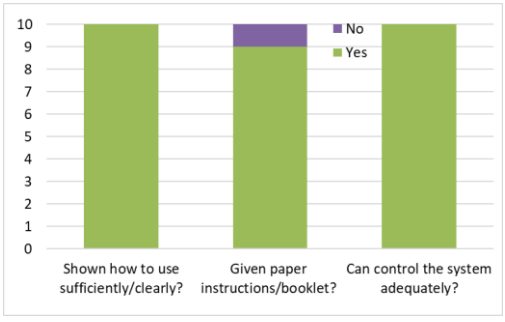
In the Tempergreen group the average response was neutral to the statement that “the system doesn’t need too much active input” as this system required more active involvement, however this group agreed on average with all other statements in Fig. 2.18(a). They felt the heating was easy to use, and knew enough about how to work it. The VCharge group agreed on average that the heating didn’t require their active involvement (as it was controlled by VCharge), and was easy to use, but they were less certain that they knew how best to use the heating system, or enough about how it all worked, with responses falling between agree and disagree on average.

In Fig. 2.18(b), those in the Tempergreen group agreed that they had received sufficient support to use the new system, whereas responses in the VCharge group fell between agree and disagree on average. This is likely to be due to the more complex nature of this system and its controls, with a few residents feeling the new heating was more difficult to use than the old system, some asking for assistance / support to use it at visits. Some said they had been told how to use it but had since forgotten. One resident – who moved in after the heaters were fitted - said they had never been told how to use the system, and didn’t know how best to use them; and two residents who could not make the heaters work for their needs felt they didn’t understand / know enough about them.

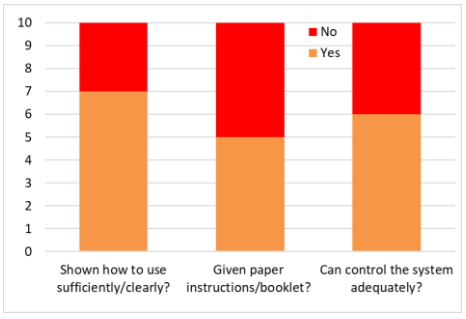
In terms of follow-up support, a wide variety of issues had arisen. In the Tempergreen group, most common was room thermostats “un-binding” from radiators, especially after a power cut – 2 had phoned to request support and been talked through how to reconnect them (so could do it again if required), but one had used the Switchee to control the system instead since then. Another had got support to switch to a flat-rate tariff after a month of high bills. One householder was dissatisfied, stating they hadn’t received info of the community meeting about how to use the heating controls, so missed being shown how to use everything. For VCharge, some felt they had received sufficient support with the VCharge set-up, but others did not, stating they didn’t have a direct phone number, so “had to phone Ovo and hope to be put through to the right department”. Another felt it would have been most helpful to set up the VCharge app / website on her phone - it was set up via the website but now she couldn’t remember the password / site to get in and make any changes. One householder had received instructions but didn’t understand them, so “left the heating to its own devices” and required more support. Most mentioned that they could do with a reminder how to control the heating system / use VCharge at the start of the heating season.

Figure 2.19 - Support received to use the controls and knowledge / confidence to use the system for (a) Tempergreen and (b) VCharge group

a)



b)



All residents received new controls as part of the new heating system. Knowledge of the heater controls, see Figure 2.19, was very good for the Tempergreen group, with all saying they had been clearly shown how to use the controls on install, and understood how to use the system, even though one did not think they had received a manual / instructions. However, for those in the VCharge group, 3 of 10 felt that they were not clearly shown how to use the system when it was installed, only half the group recalled receiving any paper manual / instructions / Quick Start guide to refer to, and only 6 of 10 felt that they could adequately control the system.

The 4 households who felt unable to control the system sufficiently were V-29 who knew their Switchee wasn't connected to the heating controls, they'd been told someone would call to set up VCharge never had, so didn't know how to control the system that way. V-37 said the heating came on at the wrong times, being too hot at 5am even though the comfort period was set at 8-10am, and was too cold after 8pm when they got home in the evening, but the VCharge website had changed so their password didn't work any more. They had instead turned off the heating in the bedroom, and used supplementary heating in the mornings, but clearly this caused dissatisfaction. V-39 found the instruction manual too complicated. They had only recently got a smartphone with internet access at the final interview, so did not know how to set up VCharge on it. They turned the heating up and down using the Switchee, but did not know that it made any difference, and didn't know how to turn the heating off "properly" for the summer. V-06 had never received a VCharge due to the resident's lack of engagement in the project, but requested support at the final visit.

Figure 2.20 - Breakdowns / reliability issues with the system, and whether prompt follow-up support was received for (a) Tempergreen and (b) VCharge groups

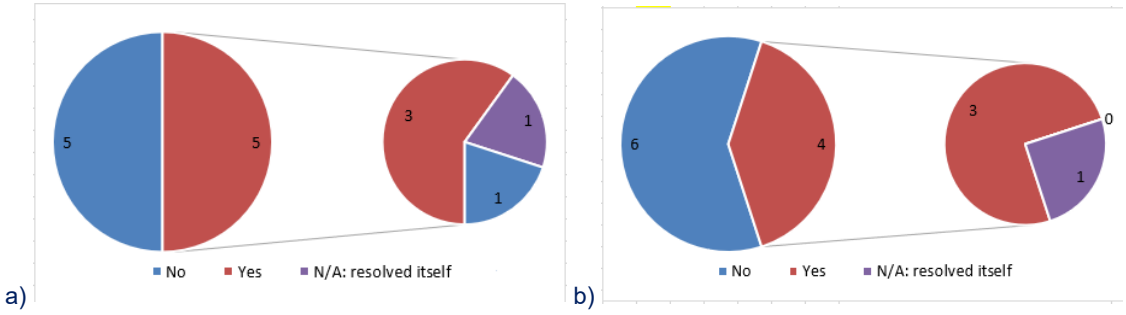


Figure 2.20 shows whether residents suffered reliability issues / breakdowns of the measures. It is concerning that half the Tempergreen households reported reliability issues: 3 were thermostats unbinding from radiators, 2 related to Switchee "freezing" – one rectified itself (no support needed), but the other was never resolved - the household received an Evohome but it reportedly also kept losing connection from the system, so heating was being controlled manually via room thermostats only. One of these households also saw a conflict of the hall thermostat with Switchee, also located here. The resident was advised to set both at the same temperature, which resolved the issue.

For the VCharge group, 4 of the 10 reported reliability issues or breakdowns: some did not state clearly what the issue had been, simply that the heating stopped working / wouldn't come on. All were rectified within a few days apart from one where the heating came back on again without any intervention, before the resident had reported the issue. One household had a storage heater wired in incorrectly which had to be rectified, and their Switchee also stopped working and was replaced.

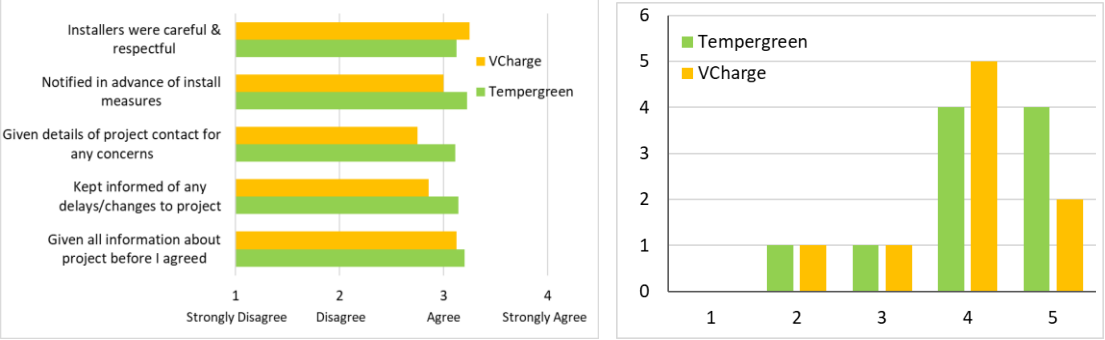
16 of the 19 respondents reported general maintenance issues in the pre-installation questionnaire related to their heating, insulation, moisture or mould and which caused them concern with keeping warm, or increased their bills as presented in Figure 2.3(a). At the final questionnaire, 4 of the 10 Tempergreen group also reported such issues at the final visit: broken & draughty front doors, a non-working prepayment meter (reported to the energy supplier but they'd taken no action), mould above the living room window, and a major leak from the roof of the block. In the VCharge group, 3 householders needed support to use the new heating system, 1 had not enough hot water, 3 reported draughty windows / external door in the living room, and 1 reported a draughty front door, 2 reported mould issues, 1 reported the lack of a smart meter, 1 was concerned at the lack of emergency credit with Boost as they had a young son so couldn't always go out to top up. In addition to physical problems, 2 householders requested support for billing issues which were linked to the new heating installation project. All issues were reported to WHG for action.

2.6 Customer service, installation issues and energy advice

Comments about the installation process were requested and 3 of the Tempergreen group reported that the installation didn't take long (one of these reported that it was a bit stressful, but all done in a day), 2 reported rather short notice for the installation. One householder reported that installers did, and one said they didn't hoover up after themselves. More seriously, one vulnerable resident was unhappy that installers left the hot water on boost, using up all their electricity credit; another said an installer was disorganised and used offensive language, which they found disrespectful.

5 of the VCharge group reported that the installation was fine, with installers being helpful, able to work around people, explaining everything and hoovering up after themselves. One reported that the installers of the storage heaters were very careful but that the person who fitted the Switchee and VCharge was very rude. 3 people said it was very confusing during the installation period as there were lots of visits, the installation period was too long, installers had to keep coming back to fix things that stopped working, or replace the smart meter, and didn't always show up on time. One resident was concerned that they were not phoned to set up VCharge after it was fitted.

Figure 2.21 – Resident (a) satisfaction with project communications and installation of the measures and (b) feelings about the install process



Residents were asked about their satisfaction with various aspects of the project communications and installation process. The results are displayed in Figure 2.21 (a), averaged across each group. Householders views about the installers were very good, with most agreeing with all statements on average. Those in the VCharge group were a little less sure that they were given all the information they needed before agreeing to take part, or whether they were given details of a contact for any issues relating to the project.

Figure 2.21(b) shows the interviewer's ranking of each respondent's feelings out of 5 (with 1 being very negative, 3 being indifferent, and 5 being very positive) from comments they made in the final questionnaire. This shows that most residents were positive or very positive about the install process, though those who had experienced the negative issues above felt less positive.

Another aspect of customer service essential to this project is that the storage heaters work best on Ovo's Economy 10 tariff, charging up at different periods during the night and day on a cheaper off-peak rate and releasing heat during the day as programmed. Indeed, as VCharge is an Ovo technology, these ONLY work on Ovo's tariffs. As this was a key part of the installation, residents of all flats in the VCharge group received support to do this, with a home visit by the installer or an energy champion to assist any who had not already phoned Ovo to arrange the switch themselves. However, one household was sent a letter saying that they were unable to switch to Economy 10, so presume they may still be on a standard Economy 7 tariff (their meter states day and night rates - Econ 7 descriptions - rather than peak and off-peak - Econ 10 descriptors), which may not allow them to maximise their benefit from the VCharge. Due to tenancy changes / lack of engagement by tenants combined with the discontinuation of VCharge part-way through its installation, 2 flats did

not receive VCharge, so are on single rate with smart meter, or Economy 7 with an old standard meter. They should be made aware that they are free to switch to any supplier of their choice.

Another householder did not realise the requirement to be on Ovo tariff, switched away to another supplier, and found that the heating and hot water did not work until the VCharge technology was "wired around" so it no longer controlled the heating. One tenant specified at the final visit that they "wished they had realised the requirement to switch to and stay on the specific tariff, as they would not have chosen to take part in the study if they had known", and that "the technology is good but it should be opened up to all suppliers so that tenants can get proper choice and competition". This raises ethical questions of tying social tenants to a specific tariff: it gives them a lack of choice, preventing them from choosing a supplier which they may prefer, or which is better value for their usage; it also means households are locked in even if prices of the tariff rise, as happened during the period of the study. In a separate but linked issue, residents were initially Ovo customers, but Ovo then separated its business, rebranding the prepayment side as Boost. Some residents had been happy on the Ovo tariff, but after the rebrand, found that they no longer got any emergency credit with Boost, which they stated to be inconvenient, putting them at higher risk of self-disconnection if they didn't have enough money in their account to top up electronically via the app, and couldn't leave the house to top up manually at a PayPoint. This is more likely to be the case for vulnerable, low-income, social tenants. From the social landlord's point of view, having to wire around the VCharge if the current or future tenants wish to switch away to a different electricity supplier is inconvenient and time-consuming, and requires ongoing knowledge of this technology to be maintained in the electrician staff pool to be able to do so.

The Enviroheat radiators work best on a flat-rate tariff as they cannot store heat from an off-peak rate to release later, using most of their energy during peak times, so remaining on an Economy 7 tariff would unnecessarily increase the household's costs. All households in the Tempergreen group reported being advised to switch to a flat rate tariff, and some reported that the WHG Energy Champion assisted them to do this. 2 reported that they had phoned to switch tariff type and discovered that they had already been on a flat rate tariff. However, 2 residents in this group were found to still be on an Economy 7 tariff at the end of the study. One was assisted to switch to a flat rate tariff during the final visit, the other was referred for further support from WHG.

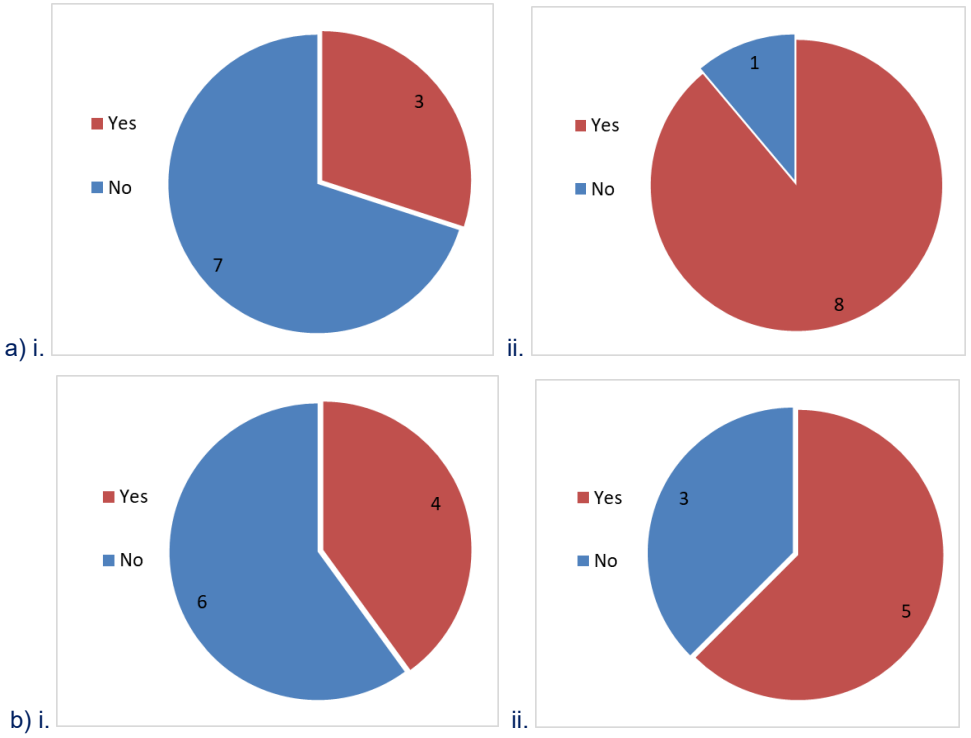
5 of 9 respondents in the Tempergreen group recalled receiving advice about saving energy, or saving money on energy, as part of the project, and 6 of 8 VCharge group. Only 6 of each group responded to whether or not they had made changes as a result, and only 2 of the Tempergreen group reported that they did make changes (one reported switching to a flat rate) whereas 4 of the VCharge group said they made changes: 1 installed energy-saving light bulbs, 1 did the washing late at night, 1 felt they knew better how to use the controls of the new heating.

Obviously as switching supplier was part of the installation for the VCharge group, all had changed supplier. For the Tempergreen group only 2 of the 10 had switched supplier since the start of the project, compared to 11 of 18 reporting switching in the previous 2 years who responded in the first questionnaire. Of the electricity suppliers used, 6 of 19 who initially responded were with British Gas, 7 with Utilita, and the remainder were with smaller suppliers: Ovo, Economy Energy and Utility Warehouse. By the end of the study, all 10 in the VCharge group were with Ovo except for one which had switched to Utilita. In the 10 Tempergreen group, 4 were with British Gas, 4 with Utilita, and one each with Economy Energy and Ovo – quite a low incidence of "Big-Six" suppliers.

In terms of engagement with energy advice, and openness to new technologies, there was a clear difference noted between the two monitored groups. As shown in Figure 2.22 (a), those in the Tempergreen group were more likely to report (7 of 10) that they would not know who to go to for

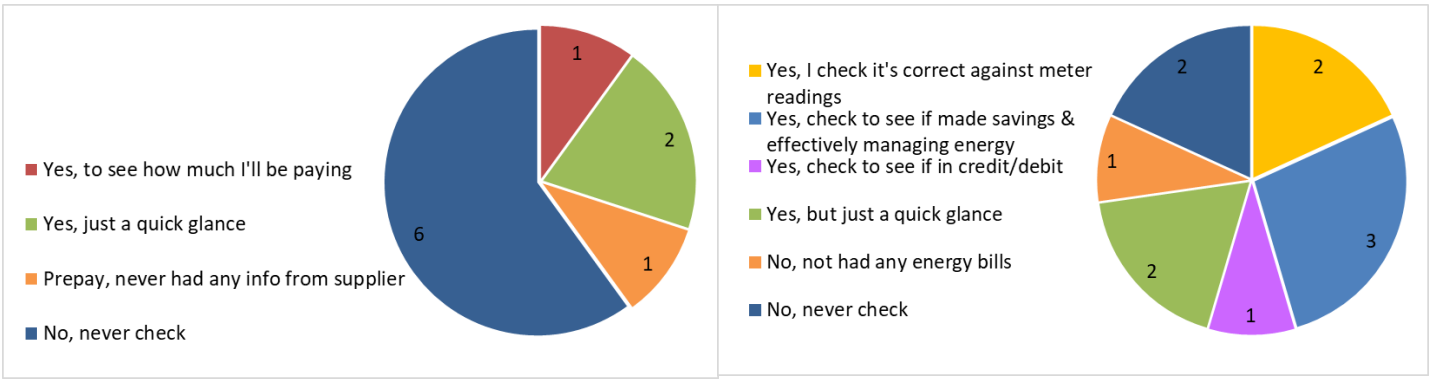
energy advice in future, whereas 8 of 9 who responded in the VCharge group reported knowing who to speak to. Similarly, 6 of the 10 Tempergreen group would not consider changing how they paid for energy if it would help to save them money, whereas 5 of 8 who responded in the VCharge group would consider making changes that would save them money.

Figure 2.22 - Residents who (a) know who to go to for energy advice and (b) would consider changing how they use or pay for energy if it would help to save them money for i. TemperGreen and ii. VCharge groups



This lack of engagement was evident in households' bill management, with 7 of the 10 households in the TemperGreen group stating they never checked their statements, or had never had any information from their energy supplier. By contrast, in the VCharge group, more residents reported checking their bills against meter readings to make sure they were correct, and whether they had made savings compared to the previous year. It is not known whether this is as a result of self-selection of the groups, with more of those who are relatively disengaged about energy use choosing the heating measure which does not require as much pre-planning / engagement, or whether the interventions involved in this project helped those in the VCharge group to become more engaged and empowered around their energy-using behaviour.

Figure 2.23 – Whether, and what, residents check for in bills / statements for (a) Tempergreen and (b) VCharge groups



3. Technical evaluation and results

3.1 Overview of technology

Elnur / Gabarrón storage heaters and VCharge

Old storage heaters (and panel heaters in the bedrooms) in all flats in this group were replaced by modern Elnur / Gabarrón storage heaters[5]: these were not high heat-retention models so had basic controls, but they were combined with VCharge dynamic charge control[6]. (Which is cheaper than the market leading brand of high heat retention storage heaters.) VCharge is set either by phoning Ovo to change settings, or is controlled directly via a website/app, to set background temperature and higher temperature time-periods and set-points. As VCharge was an Ovo-specific technology, this required householders to switch to Ovo's Economy 10 tariff, and have a smart meter fitted. The prepayment part of Ovo's business - which all householders used - was re-branded as Boost, and householders were able to see their usage and top up via the Boost smart-phone app. The households' hot water system was not changed – they retained their old electric immersion tank.

Since 1st January 2018, all local space heaters manufactured for sale in the EU must comply with Lot 20[7] - for storage heaters it means they must have electronic heat charge control with room and /or outdoor temperature feedback or controlled by the energy supplier; electronic room temperature control plus week timer; and fan assisted output. Heaters installed in this project weren't compliant alone, but were deemed to be, fitted in conjunction with VCharge. As that solution is no longer available, the model of heaters installed is no longer available for sale.

Enviroheat HET electric radiators and immersion heaters

Old storage heaters and bedroom panel heaters were replaced by Enviroheat's HET lower-energy on-peak water-filled EconoRad electric radiators[8]. These claim to be the most energy efficient and cost-effective heater on the market, using up to 70% less energy than standard electric heaters, by using electricity gradually at a maximum of 600W per hour. The household's immersion tank was also replaced by their EconoCylinder[9], which claims unrivalled energy consumption of 1.2kW/h, plus 3kW/h using the boost function, up to a 66% saving on electrical hot water heating costs compared to their competitors. The radiators were controlled by individual room thermostats, with overall control provided by Switchee. This also controlled turning the hot water tank on and off.

To meet the Lot 20 regulation, direct-acting heaters must have an electronic room temperature control plus week timer, and one of: distance control option; adaptive start control; open window sensing. Combined with Switchee, which learns a household's routine so can act as a timer and an adaptive control, this system was deemed to meet the regulation.

Switchee

This is a smart thermostat designed to be intuitive to use to change the temperature set-point, and turn a hot water tank on or off. It creates an occupancy profile of the flat – by measuring temperature, humidity, light, movement and pressure - to predictively optimise the heating settings, even if the resident does not engage with it. It also calculates risk factors such as mould, fuel poverty, poor insulation etc. for the social landlord, so that they can target properties at risk for repairs or tenant engagement. This was installed as a controller in all properties receiving new measures, and also fitted for monitoring purposes only in the 5 control properties. It is fitted with both GSM (mobile phone) and Wi-Fi connectivity (Wi-Fi was originally planned to be installed as part of this project but could not be for logistical reasons) to help prevent connectivity problems in

those who do not have broadband, or who turn it off overnight / when out. The occupancy profile, plus temperatures set by the resident should pass a resident's desired heating profile onto VCharge, and if this changes over time, Switchee should learn this new routine.

Each VCharge flat had 4 new storage heaters installed – 1 in the living room, one in the main bedroom, one in the second bedroom, and one in the hall. Tempergreen group properties had 5 heaters installed in total, with 2 heaters fitted in the living room, and all others in the same location as for the VCharge group properties. Pictures of the technologies installed – both types of heater and their controllers - are shown in Figure 3.1 below.

Figure 3.1 – Examples of (a) Elnur storage heater & VCharge (b) Enviroheat heater (c) VCharge temperature sensor, (d) Honeywell room thermostats for Enviroheat, (e) Switchee smart thermostat and (f) Honeywell EvoHome controller.

The grant agreement with NEA funded only the addition of Switchee to the already-planned heating

improvements in this block. For both groups receiving measures, this included removal of old storage heaters. Total costs were:

- 4 x Elnur storage heaters, 5 x VCharge, installation etc.: £1,719 measures + £504 Switchee = £2,223 (ex. VAT).
- 5 x Enviroheat EconoRad, 1 x EconoCylinder, new consumer board, and associated works: £4,920.36 + £504 Switchee = £5,424.36 (ex. VAT)
- Controls (Switchee only): £504 per property

WHD / OVO funding contributed to some measures and installation costs, and to communications infrastructure costs (provided by Social Telecoms), a total of around £16,500. NEA also funded £3,024 towards the Wi-Fi connection to the block so VCharge (& Switchee) could function.

NEA later funded the addition of a Honeywell EvoHome controller to 4 properties which had received the Enviroheat radiators (control was moved from Switchee to the EvoHome, Switchee remained in place for monitoring purposes only), which allowed zoning i.e. different temperature settings at different times, and in different rooms, to see if this made improvements to control and costs over-and above Switchee, which does not have a zoning function.

- Cost: £200 x 4 + installation £367 = £1,167 (or £1,400 including VAT) = £291.75 per flat

3.2 Technological monitoring

To assess performance of the new systems, the following monitoring equipment was placed in flats, as shown in Figure 3.2. Logging equipment was placed from November 2017, check visits were made in February 2018 that it was in the correct place, and it was collected in June 2018:

Thermal & humidity data loggers

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

Current clamps

Tiny Tag View-2[11] or Lascar Easylog USB-ACT[12] non-invasive current clamps were clipped around the main electricity cables. These regularly recorded current flow through the cable to quantify electricity consumption (kWh). Two current clamps were placed per household: either on the live peak and off-peak/heating circuit tails of the household meter; or on the wires into the heating and household fuse boxes if no meter / split wiring at the meter was evident in the flat.

Watt-hour sub-meters and wired-in pulse loggers

For 5 flats receiving each type of heating system, a sub-meter was provided to contractors to be wired into the heating and hot water circuit on installation of the system. This had an Omega CP-101 pulse logger wired directly into it, which was attached firmly with tape. The pulse logger only was cut off on collection of the monitoring equipment, the sub-meter remains installed.

Switchee data portal

The Switchee – which was placed in the hall of each flat - recorded each household's temperature, humidity, light, motion, and the status of the heating system in those in which it was the controller.

[10] Lascar EL-USB-2 product details: www.lascarelectronics.com/easylog-data-logger-el-usb-2, [Accessed 22/1/2019]

[11] Tiny Tag product information: www.geminidataloggers.com/data-loggers/tinytag-view-2/tv-4810, [Accessed 22/1/2019]

[12] Lascar EL-USB-ACT product information: https://www.lascarelectronics.com/easylog-data-logger-el-usb-act, [Accessed 22/1/2019]

This data is available to download (with householder's and landlord's permission) via the Switchee web portal, up to the end of the previous day. The temperature and humidity data can be compared against that monitored by the Lascar data loggers in the living- and bedrooms.

Energy meter readings

In addition to monitoring equipment, residents were requested to record their electricity meter readings regularly during the study period, normally every 2 weeks. They were also asked for any historical energy bills / statements from the previous winter, and to retain any received during the monitoring period. Many signed consent forms to allow NEA to contact their energy supplier to request records of meter readings held on their account prior to and during the study. As there were also cupboards of historic meters – accessible only to the landlord so mainly no longer used for billing purposes by the householders - these were also read on NEA's 3 visits, as back-up should residents not provide their own meter readings.

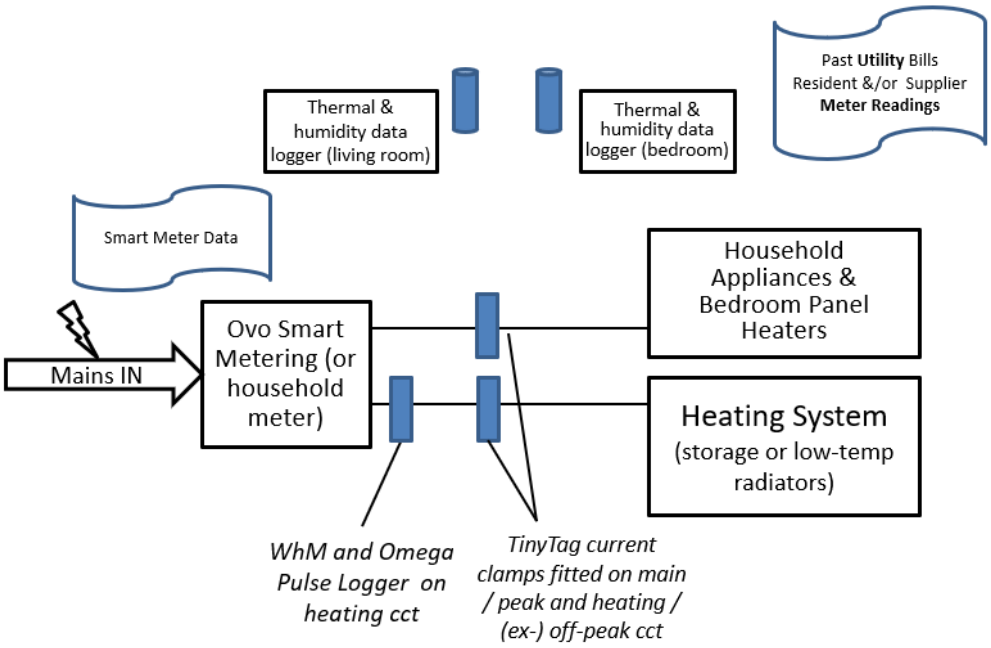


Figure 3.2 – Schematic of monitoring placed in properties receiving new electric heating.

3.3 Cost

This analysis uses electricity consumption data obtained from householders via manual recording of meter readings on a regular basis, along with bills or energy supplier data (where available). Meter readings from before the start of the study were used to calculate previous usage – these were obtained for many households. Previous usage was compared against usage for the period after the measures were installed - a comparable period to the monitoring period of Nov – June was selected, where possible - to see if the measures had helped householders make savings.

For all homes in The VCharge group, standardised Economy 7 electricity costs of 18p/kWh for peak rate and 7p/kWh for off-peak usage were used for calculations, to allow comparisons to be made between properties. For flat-rate tariffs, a standard price of 16p/kWh was used. Households in the TemperGreen group which had Enviroheat on-peak heaters fitted, were assumed to switch to a flat-rate tariff for cost comparison purposes, even if they did not. The unit costs used are slightly higher than common tariff rates as they include a small element for standing charges etc. Costs from the period prior to installation of the new measures, were calculated using whichever tariff type householders were on. Comparisons are displayed in Table 3.3.

To properly analyse energy use for space heating, account must be taken of weather conditions over the monitoring period, as it is poor practice to compare the heating costs for two periods without compensating for different outdoor temperatures between the periods – particularly as winter 2017-18 was particularly cold. An external temperature of 15.5°C is the commonly-used base temperature below which heating is normally required inside a building, and above which no heating is normally needed. Degree days (dd) are a measure of heating demand of a building relative to the external weather i.e. number of degrees below 15.5°C that the average temperature falls, for each day. For example, if the average outside temperature is 14.5°C, this is recorded as 1 degree-day. Degree days are summed together over the required period, to give a total number in the period. Different periods can then be compared in terms of energy consumption per degree day, to account for different external temperatures, and determine if savings have been made as a result of installation of energy efficiency measures[13].

Degree day data was obtained – from 1st June 2012 until the end of the monitoring period - from weather station EGBB, at Birmingham Airport (1.76W, 52.46N)[14] as this is in the same region as Walsall, and had good quality data for many years. 20-year average degree day values are available on a regional basis only: the Midland region experiences 2,119.6 degree days per year on average, which was used to normalise our data.

Savings were calculated for normalised energy use in kWh (1st yellow column). As the combination of storage heaters, VCharge and Economy 10 tariff were designed to maximise off-peak heating use, allow more controllability, and also provide off-peak periods during the day which households could use to reduce the cost of running high energy-using appliances, this could be expected to reduce peak-rate electricity consumption. Conversely, households switching from storage heating to on-peak heaters lose the opportunity to benefit from cheap-rate charging of heaters, heating of hot water, and running any high-energy appliances during the night. Due to this, cost savings may differ from energy consumption changes, and were therefore calculated separately (2nd yellow column). Note that as only a period of November to June was monitored (and a similar “before” period was used for comparison), neither Normalised costs nor energy use will be an accurate reflection of actual total annual energy costs – these are for comparison relative to each other only.

The 6 households in the Tempergreen group - which received Enviroheat on-peak heaters – for which NEA was able to obtain energy usage information for a similar period the year before installation of the new heating, used an average of 2.2 kWh/dd, at a normalised cost of £746 per year. However, household T-03 appeared to use very little electricity, only 0.14 kWh/dd during this period, equating to a normalised cost of only £48 per year – it is unknown whether they did not use heating (or any other electrical items) during that period, or if there was a billing or metering issue. The highest usage in this group before the new measures was 3.4 kWh/dd, at a normalised cost of £1,140 per year, by property T-02.

After installation of the new heaters, the group saw electricity use increase slightly on average, to 2.39 kWh/dd, at a normalised annual cost of £810. Comparing only households where previous information was available, property T-03 was excluded due to excessively low previous usage, as was property T-19 whose prepayment meter malfunctioned so they were not paying for electricity, which may have affected their significantly increased usage. On average, the remaining properties saved 2.23% in energy usage (in kWh), and 2.83% in cost terms, £43 per year. But this varied from savings of up to 43% in 2 flats, to extra costs of up to 35% in another 2 flats (generally those which required more constant heat), so neither of these figures can be deemed conclusive.

[13] Carbon Trust degree day information, www.carbontrust.com/resources/guides/energy-efficiency/degree-days [Accessed 07/12/2018]

[14] Bizee Degree Days: www.degreedays.net [Accessed 6/12/2018]

Table 3.3 – Analysis of electricity costs before and after installation of measures for the 3 groups

20 year average degree-day comparison of savings		Region:	Midland		20 year average:	2119.6								
	"Before" period							"After" period							Comparison	
Tech Ref	Period	Days	Total Period (kWh)	Cost per 30 days	Degree days	kWh per Degree Day	Normalised annual cost#	Period	Days	Total Period (kWh)	Cost per 30 days	Degree days	kWh per Degree Day	Normalised annual cost#	Normalised cost# using Ovo rates	Estimated Energy Saving#	Estimated Cost Saving #
T-01								17th Nov 2017 - 18th Jun 2018	208	2,785.4	£64.28	1,678.8	1.659	£562.67			
T-02	3rd Nov 2016 - 22nd Jun 2017	231	5,774.2	£118.26	1,693.1	3.410	£1,139.98	2nd Nov 2017 - 21st Jun 2018	231	8,437.5	£175.32	1,860.8	4.534	£1,537.74		-32.96%	-34.89%
T-03	6th Oct 2016 - 7th Jun 2017	244	258.0	£5.08	1,825.3	0.141	£47.94	12th Nov 2017 - 27th Jun 2018	227	2,263.0	£47.85	1,791.7	1.263	£428.34		-793.58%	-793.58%
T-04	30th Nov 2016 - 24th Jun 2017	206	5,531.0	£79.42	1,438.9	3.844	£1,390.29	7th Nov 2017 - 21st Jun 2018	226	4,231.0	£89.86	1,823.4	2.320	£786.92		39.63%	43.40%
T-05								7th Nov 2017 - 19th Jun 2018	224	4,934.2	£105.73	1,823.1	2.706	£917.86			
T-16								6th Nov 2017 - 19th Jun 2018	225	2,695.6	£57.51	1,832.6	1.471	£498.84			
T-19	20th Oct 2016 - 16th Jun 2017	240	3,496.0	£61.20	1,768.6	1.977	£585.82	8th Nov 2017 - 20th Jun 2018	224	6,596.3	£141.35	1,816.1	3.632	£1,231.78		-83.75%	-110.27%
T-26	22nd Oct 2016 - 30th Jun 2017	251	4,331.0	£76.87	1,765.1	2.454	£772.35	7th Nov 2017 - 23rd Jun 2018	228	5,010.0	£105.47	1,827.2	2.742	£929.87		-11.75%	-20.39%
T-42								8th Nov 2018 - 20th Jun 2018	224	4,254.2	£91.16	1,816.1	2.342	£794.42			
T-52	30th Dec 2016 - 1st Jun 2017	153	1,603.0	£56.32	1,133.4	1.414	£537.13	8th Nov 2017 - 19th Jun 2018	223	2,208.9	£47.55	1,816.1	1.216	£412.48		14.00%	23.21%
T Avg.					1,604.1	2.207	£745.58					1,808.6	2.389	£810.09		2.23%	2.83%
V-18	9th Jan 2017 - 26th May 2017	138	4,923.0	£132.19	1,022.2	4.816	£1,259.70	13th Dec 2017 - 21st Jun 2018*	189	5,952.3	£95.60	1,472.6	4.042	£868.45	£835.86	16.07%	33.65%
V-29	9th Feb 2017 - 1st Jun 2017	112	1,018.0	£43.63	680.9	1.495	£507.04	7th Mar 2018 - 30th May 2018	84	2,242.0	£75.24	503.3	4.455	£888.19	£851.90	-197.94%	-68.01%
V-33	25th Feb 2017 - 15th Jun 2017	110	1,293.0	£56.42	558.3	2.316	£785.42	7th Feb 2018 - 20th June 2018	132	3,231.8	£79.12	886.0	3.648	£835.83	£808.74	-57.50%	-2.97%
V-34	6th Mar 2017 - 6th Jun 2017	91	1,333.0	£70.31	459.9	2.898	£1,105.84	14th Feb 2018 - 27th May 2018	102	5,001.4	£143.14	776.9	6.438	£1,327.40	£1,224.19	-122.10%	-10.70%
V-37	31st Jan 2017 - 30th Jun 2017	150	1,185.6	£37.94	802.2	1.478	£501.22	8th Feb 2018 - 21st June 2018	133	2,615.1	£57.46	874.6	2.990	£615.59	£621.34	-102.31%	-23.97%
V-39	19th Jan 2017 - 19th July 2017	181	1,804.0	£46.29	963.5	1.872	£614.41	7th Feb 2018 - 18th Jun 2018	131	3,886.6	£84.20	885.5	4.389	£877.35	£842.75	-134.42%	-37.17%
V-44	25/4-17/6/16 & 20/12/16-19/3/17	142	2,078.0	£76.14	1,045.5	1.988	£730.65	13th Dec 2017 - 21st Jun 2018*	189	3,755.0	£65.59	1,472.6	2.550	£595.80	£605.32	-28.29%	17.15%
V-59								28th Feb 2018 - 20th Jun 2018	112	2,099.4	£51.72	621.3	3.379	£657.67	£656.59		
V-06[1]								8th Nov 2017 - 20th Jun 2018	224	8,491.0	£99.33	1,816.1	4.675	£865.60	£832.06		
V Avg.					790.4	2.409	£786.33					1,034.3	4.063	£836.88	£808.75	-89.50%	-13.15%
C-09	13th Nov 2016 - 12th Jun 2017	211	3,979.0	£93.51	1,589.2	2.504	£877.20	8th Nov 2017 - 20th Jun 2018	224	4,659.4	£99.84	1,816.1	2.566	£870.07		-2.47%	0.81%
C-10								22nd Feb 2018 - 20th Jun 2018	119	4,542.8	£183.92	733.2	6.196	£1,445.41			
C-11								22nd Nov 2017 - 20th Jun 2018	210	6,159.0	£89.04	1,709.2	3.603	£772.96			
C-14								8th Nov 2017 - 20th Jun 2018	224	7,896.4	£169.21	1,816.1	4.348	£816.92			
C-15								22nd Feb 2018 - 20th Jun 2018	119	4,523.5	£119.18	733.2	6.170	£1,361.46			
C Avg.					1,589.2	2.504	£877.20					1,361.6	4.576	£1,053.37		-2.47%	0.81%
Average						2.223	£740.45						3.351	£841.91			

12 month estimated costs based on 20 year average degree-day value for the region * Vcharge fitted late, cannot separate out effects [1] incomplete install (no Vcharge), exclude from group analysis

Residents of flat T-26 seemed used to using storage heaters, saying the flat had never previously felt cold, and they also needed some heating left on overnight to dry work clothes for the following day (hence still used 31% of their electricity overnight). Property T-02 set the heating temperature relatively high, it was on all day, and they also left the hot water on permanently, all of which would increase costs. Both properties later received an EvoHome controller for the system to help them control costs, which reportedly helped for T-02, but T-26 said that this kept disconnecting from the radiators, so they did not use it. In contrast, homes T-04 and T-52 had previously both used their storage heaters but found that they lost the heat too early in the day, so had to use supplementary heating in the evenings. Hence these residents found that the new heaters could be used only when they needed heat, mainly in the evening, helping them save both energy and money.

For households which received Elnur storage heaters and VCharge, issues with historic wiring confounded the results. Before the new heating, it appeared that household energy usage was relatively low at 2.41 kWh/dd, a normalised cost of £786 per year. However, it came to light during the study that most of these households' heating & hot water circuits had not previously passed through their prepayment meter. The wiring was corrected during the fitting of the heating system and smart meter, so this resulted in an unexpected increase in electricity costs as they were paying for their heating for the first time. After install of the whole system including VCharge - when this group were known to be metered correctly - the average consumption was 4.06 kWh/dd, equating to a normalised annual cost of £837. Only properties V-18, V-34 and V-44 did not suffer this wiring correction issue. However, in flat V-34, a significant, unexplained, increase in electricity usage on the household circuit was seen (i.e. unrelated to the heating) after installation, hence this property is excluded from comparisons. Therefore, comparing before and after periods for V-18 and V-44 only, V-18 saw a reduction in normalised energy use of 16%, and a normalised cost saving of 33.6% (£423.80). Flat V-44 used 28.3% more electricity (unsurprising as the previous living room storage heater did not work), yet still saved 17.2% in cost (£125.30). Averaging these two households clearly saw no overall energy saving, however did show a 25.4% cost saving. N.B. both these properties had VCharge fitted late March-April (after weather had started to warm up), so we cannot asses only the period after VCharge as it is not winter weather conditions, hence analysed for the whole post-install period. No sudden change was seen after install of VCharge.

It was unknown whether wiring issues mentioned above affect other households in the block. One property in the Tempergreen group also saw a sudden increase in costs during the study period after a smart meter was fitted (which presumably corrected historic wiring), but it appeared to be less of an issue in households where the off-peak circuit was turned off in the landlord's cupboard. The issue was also found in some control properties. If different consumption was measured by the two meters, the higher - landlord's cupboard - readings were used in all calculations.

In comparison, control properties used on average 4.58 kWh/dd, at a normalised cost of £1,053 per year. Information about previous energy consumption was only available for one of these households, which showed that their usage did not change very much from one year to the next. It is of note that due to the wiring issues above, those households which did not appear to be paying for their heating energy use, used significantly more electricity (4-6 kWh/dd) compared to those who were paying for it (2.5-3.6 kWh/dd) as affordability would clearly affect any energy rationing behaviour which might otherwise be present.

To assess the significance of these, the standard deviation (SD or σ) of the savings was calculated – this measures the spread around the average, as displayed in Figure 3.4. A result is significant with 68.2 % certainty when savings are always greater than zero when σ is added to or subtracted from it (denoted ±σ), significant with 95.4 % certainty when savings are greater than zero ±2σ. In

social studies, it is rare to meet the ±3σ requirement for a 99.6 % significance level.

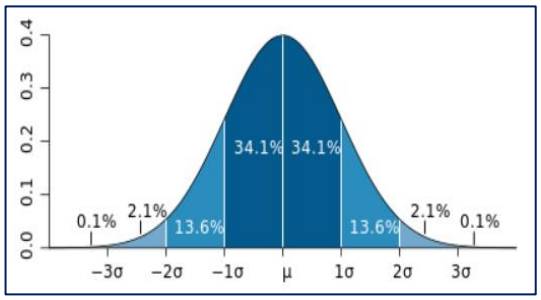


Figure 3.4 – Illustration of mean (μ) and standard deviation (σ) in a normal distribution

Calculating these showed that no average savings, in terms of either energy or cost, for the Tempergreen group were significant, even at the lowest significance level. For the VCharge group, considering only V-18 and V-44 where there were no other issues, the SD was 11.66%, so their reported average cost savings of 25.4% were significant ±2σ. However, as this is only a very small sample size, this must be viewed as an indication rather than empirical evidence.

To compare whether the levels of energy use seen are as expected for the size of these properties, this was compared against energy need estimated in Sutherland tables for the Midlands region[15]. These are not available for 2-bedroom flats, only for an average-sized room (3100 kWh heat per year), or a 2-bedroom terraced house (9850 kWh space heating & 2000 kWh for DHW per year). For flat-rate electric heating, used by the Tempergreen group, Sutherland tables estimate annual costs to be £649 for one room, or £2,274 for a 2-bedroom house. As most of the flats heated 2 (or more) of the rooms, the room cost could be doubled to £1,298, or 6200 kWh per year as a more accurate estimate for these flats (does not include an element for DHW). All-but-one of the normalised energy costs calculated are lower than this 2-room cost. However, as most degree days occur in winter, and we monitored properties for only 6 months over winter, this will underestimate households' baseline electricity consumption (and costs) in summer. It is therefore more accurate to compare against kWh used during the monitoring period: only 2 properties, T-02 and T-19, used more than the consumption estimate for 2 rooms for a whole year. 4 households (T-01, -03, -16 and -52) used less than the 3100 kWh predicted for heating only 1 room for a whole year. But 4 other households used 4-5,000 kWh, in the range between heating 1 and 2 rooms. As the energy consumption reported in this study is total electricity usage, not just for heating, most households in this group are using lower levels of heating than Sutherland tables estimate are needed.

Economy 7 heating - the closest tariff type to Economy 10, used by the VCharge group, for which Sutherland table estimates are available – costs for 3100 kWh electricity to heat a single room are estimated as £429 (assuming 90% off-peak heating, and 10% supplementary heating at peak rate). For a 2-bedroom terraced house, estimated costs are £1,590. Comparing against electricity use in kWh rather than cost for greater accuracy, only one household – V-06 which did not receive VCharge or a smart meter – used almost 8,500 kWh, more than the energy need to heat 2 rooms. Flats V-18 and V-34 used 5,000 – 6,000 kWh, around the level expected for heating 2 single rooms. Households V-33, -39 and -44 use a little more energy than estimated to be required to heat one room. But the remaining flats in this group: V-29, -37 and -59, used very low levels of heating, less than what Sutherland tables estimate is required to heat one room. Affordability of electricity is very likely to be an issue, potentially resulting in under-heating.

In comparison, the Control group used 4,500 – 7,900 kWh during the monitoring period, again lower than the projected energy need for a 2-bedroom terraced house (as this tower block is well insulated on its external surface) and as a minimum, between the energy need to heat 1-2 rooms.

This data can sometimes be used to investigate whether energy costs in the properties are better

[15] Sutherland tables, Comparative domestic heating costs, October 2018, www.sutherlandtables.co.uk [Accessed 21/12/2018]

controlled, in terms of being more closely related to heating need i.e. degree days, following the installation of the new measures. Meter readings taken by householders were used to plot energy usage against degree days for the periods before and after installation of the measures, as seen in Figure 3.5 below. As the meter readings were sometimes taken at infrequent and irregular intervals (especially before the start of the study) these are indicative rather than a quantitative analysis.

Evidence of improved energy efficiency would be: data points more tightly clustered around the best fit line after install (giving a higher R^2 value of the line), a lower slope of the best fit line shows less need to increase heating by as much as it gets colder, and/or a lower intercept shows a reduced energy need per day

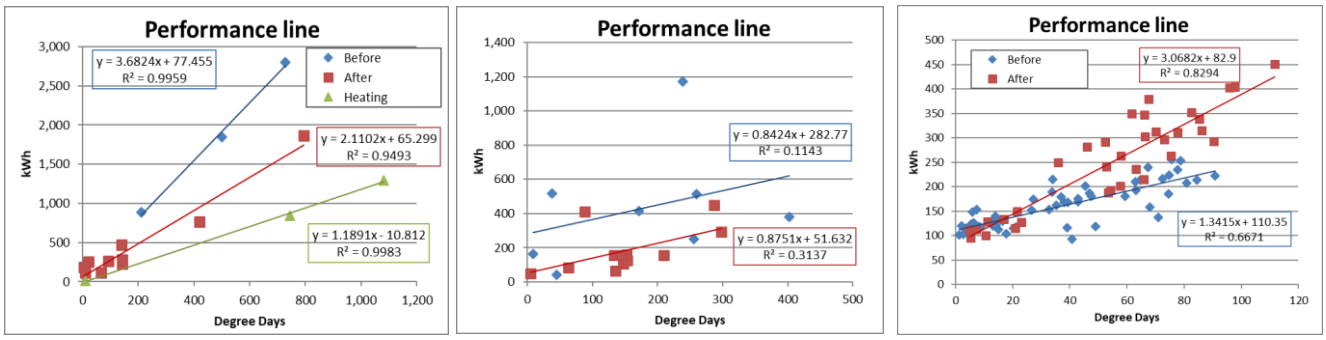
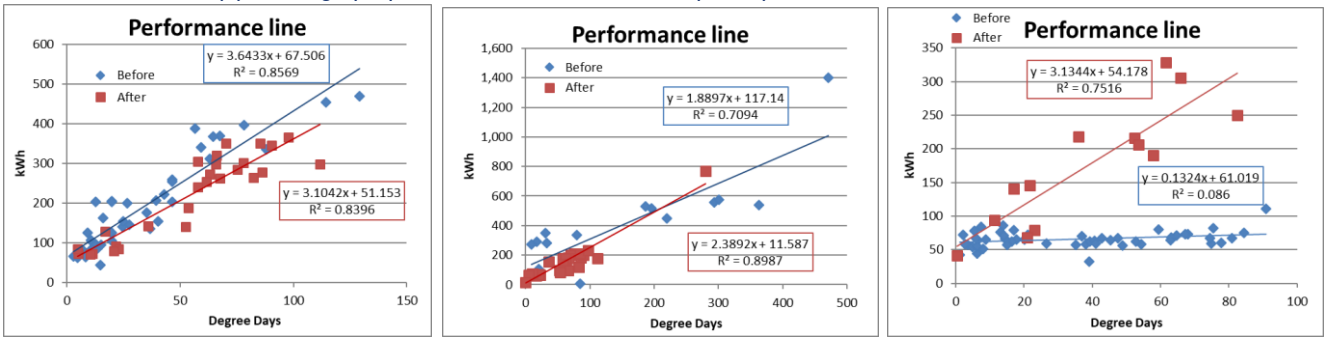


Figure 3.5 – Performance lines for (a) Tempergreen properties T-04, T-52 and T-02 (above) and (b) VCharge properties V-18, V-44 and V-29 (below), before and after the measures



For the Tempergreen-group properties shown in Fig 3.5(a), flat T-04 showed both a reduced slope and intercept of the best-fit line after the new Enviroheat heaters were installed. The heating line is also included for interest in this chart as it was a flat which received a sub-meter. Property T-52 saw no change in slope of the best-fit line, but has a lower intercept, so the household has reduced its baseline electricity use per day. However, for property T-02, with its high usage and costs, the slope of the line has increased since the new heating was installed i.e. more energy is being used, though the baseline usage is slightly lower, and their energy use is better correlated with heating need (degree days). This may be because heating is now possible in more rooms of the flat.

Figure 3.5(b) shows examples of the 2 VCharge properties which did not have wiring issues: V-18 shows a small improvement in slope of the line and lower baseline use / intercept with the new heating; whereas V-44 shows an increase in slope (the living room storage heater previously did not work, they were now able to heat that room, using more energy). V-29 is an example of a household which did not previously have the heating circuit wired through the PPM. Clearly metered energy use increased after installation of the new heating, when this issue was rectified.

The proportion of electricity which the household use for heating and hot water could be calculated for the properties which had sub-meters fitted on their heating circuit. These were only fitted for the VCharge properties at the time the VCharge was installed, hence the shorter monitoring period, and only 4 properties in this group had one fitted. Results are shown in Figure 3.6 below.

Summary of sub-meter readings														
Tech Ref	Days	Single tariff or peak rate use	Off-Peak use	Total Period (kWh)	Off-peak tariff total	Standard Tariff Total	On-Peak tariff Total	Total cost	kWh per day	Cost per 30 days (mth)	Degree days	kWh per Degree Day	Cost per Degree day	% heating usage
T-01	225	2,066		2,066		£330.58		£330.58	9.18	£44.08	1,823.10	1.133	£0.18	69.9%
T-02	233	5,513		5,513		£882.01		£882.01	23.66	£113.56	1,882.00	2.929	£0.47	65.3%
T-03	225	594		594		£95.00		£95.00	2.64	£12.67	1,816.40	0.327	£0.05	26.1%
T-04	227	2,147		2,147		£343.54		£343.54	9.46	£45.40	1,832.90	1.171	£0.19	50.7%
T-05	225	2,911		2,911		£465.69		£465.69	12.94	£62.09	1,832.60	1.588	£0.25	59.0%
Average T	227	2,646		2,646		£423.36		£423.36	11.58	£55.56	1,837.40	1.430	£0.23	54.2%
V-29	98		1,950		1,950		£115.04	£115.04	19.90	£35.22	624.00	3.125	£0.18	74.2%
V-33	132		1,747		1,747		£103.09	£103.09	13.23	£23.41	886.00	1.972	£0.12	66.5%
V-37	131		1,617		1,617		£95.42	£95.42	12.35	£21.85	885.70	1.826	£0.11	61.8%
V-39	131		2,839		2,839		£167.52	£167.52	21.67	£38.36	900.20	3.154	£0.19	73.1%
Average V	123		2,038		2,038		£120.27	£120.27	16.79	£29.71	823.98	2.519	£0.15	68.9%

Table 3.6 – Heating circuit energy usage and costs for the properties which received sub-meters

This shows that on average, households in the Tempergreen group used only 11.6 kWh per day or 1.4 kWh/dd. For this level of usage, they paid on average £55.69 per month, or 23p per degree day of heating need. Households used 54% of their electricity for heating and hot water, though this varied widely from only 26% to 70%. As household T-02's usage is much higher than all others, it may skew this data. Excluding this property gives an average energy usage of 8.5 kWh per day, or 1.06 kWh/dd, and costs of £41.10 per month or 17p per degree day.

VCharge households used 16.8 kWh per day and 2.5 kWh/dd, for which they paid £29.70 per month, or 15p per degree day. Heating and hot water made up 69% of their total electricity use, varying from 62-74%. In cost-effectiveness terms, VCharge households could use more electricity on heating than Tempergreen households, at lower cost. The next section will assess whether this allowed them to attain greater comfort, or if either set of households were over- or under-heating.

3.4 Temperature and thermal comfort

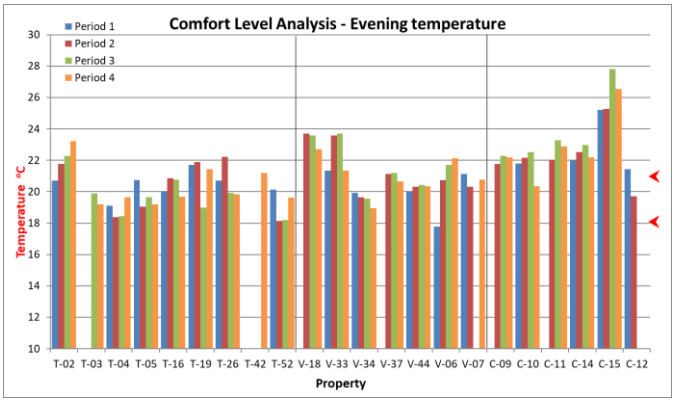
Temperature and humidity loggers were installed in the main living room and bedroom of all the monitored properties - to see whether each flat was able to achieve recommended temperatures (18-21°C) for comfort and good health. Data loggers were in position from November 2017 (last placed in Jan 2018) to June 2018, and most were checked – and replaced if necessary – in February 2018. A few loggers were lost by residents, or not recovered when a household moved out, and one stopped recording at the start of the monitoring period for unknown reasons.

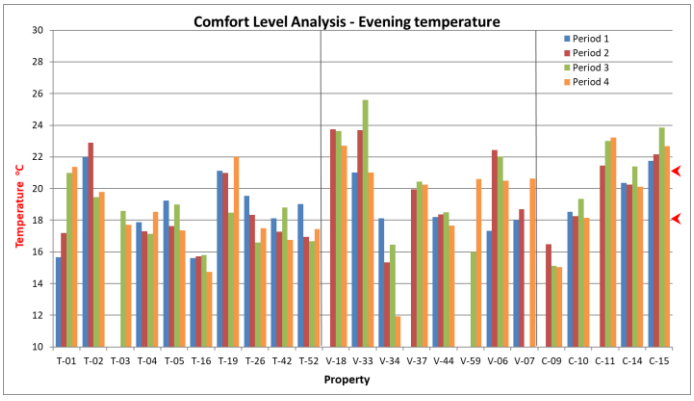
4 periods were selected during winter 2017-18 over which to compare temperatures: Period 1 was 9th – 12th Nov 2017, a period of 4 days before new storage heaters were fitted in VCharge properties, during which 7.7 degree days of heating need were experienced per day. Period 2 was a 20-day period from 23rd Nov – 12th Dec 2017, shortly after install of the new storage heaters, but before VCharge properties had new smart meters, wiring changes and VCharge fitted. The weather during this period was more severe, with an average of 11.18 degree days experienced per day during the period (2-4 degrees colder per day than other periods). Period 3 covered 23rd – 29th January 2018, 7 days during which an average 7.74 degree days per day were recorded. This was after the VCharge properties had smart meters fitted, and also after most Switchees which lost connection were exchanged (except property T-26 where Switchee was never exchanged, so they control the heating manually). Period 4 was selected from 7th – 25th March 2018, after most properties had VCharge fitted, but before residents started to turn heating off for the spring. During this period of 19 days, 9.88 degree days were recorded on average per day. Temperatures measured in living rooms during these periods are presented in Table 3.9(a) and bedrooms in (b), and these are displayed graphically for the evening heating period in Figures 3.8 (a) and (b).

Properties are grouped by the type of measure they received, with the average, abbreviated "avg." calculated for each group. For loggers where no data was available for that period (because it was

not yet in place, malfunctioned or was lost), "-" is shown. If no data was available for a property or location, it was not included in table at all. The first 2 columns in each analysis period show mean / average temperature: first for the 5 - 9.30pm evening heating period – from questionnaires, these were the times when the most monitored households desired heating (see Figure 2.4) – then for the whole 24hr period. The median (middle of the list when sorted into size order) and mode (most frequent incidence) averages are also calculated to see whether the temperature distribution in the home was skewed towards either cold or hot. SD is the standard deviation, which measures the variability around the mean, as described in Figure 3.4 and explanatory text.

Figure 3.7 – Graph from Table 3.8 for the 5-9.30pm heating period average temperatures for (a) living room (b) bedroom





Tempergreen group properties were in the process of having their heaters installed during period 1, so the period is not analysed for this group. For the VCharge group, Period 1 was before the new storage heaters were fitted: the average evening temperature of living rooms across the group was 20°C, and all but one property – V-06 – achieved the 18-21°C recommended temperature range during the evening, but V-06 still averaged 18°C over the whole 24hr period. Both V-06 and V-34 saw low minimum temperatures, often similar to the mode, indicating that they used supplementary spot-heating at limited times, during which high maximum temperatures were seen. In comparison, control properties experienced higher temperatures: 22.6°C on average during the evening period.

Looking at bedroom temperatures during the same period, these were lower: 18.5°C on average for the VCharge group during the evening period, and for the 24hr average. Again, control group properties kept bedrooms warmer, at 19.6°C in the evenings, but warmer at 19.8°C over 24hrs.

Period 2 had outdoor temperatures 3.48°C colder per day on average than period 1; was after new storage heaters were installed in the VCharge group flats (apart from V-34, where it was delayed); and all Tempergreen properties had their new heaters in. Average temperatures for the VCharge group increased on average, to 21.3°C in the evening heating period and 21°C across all 24hrs. Comparing only those properties monitored in period 1, these values were 20.9°C and 20.4°C respectively, so it's not only due to monitoring more flats which heated to higher temperatures. New heaters were not fitted in V-34 until later in December, so it is unsurprising to see very low minimum temperatures in this less well insulated ground-floor flat, however, it is surprising to also see such low temperatures in V-06. It is possible that the resident had not started to use the new storage heaters yet when this low temperature was recorded. However, the average temperature in the flat is now higher, so they appear to have started to use the heaters during the period.

Temperatures in the Tempergreen group properties were all reasonable, with all achieving at least 18-21°C during the evening heating period, with an average of 20.3°C across the group. The average over the 24hr period was 20°C. Flats T-04 and T-52 show low minimum temperatures during this period, but their average temperatures do not cause concern. In comparison, the control group heated homes to 22.2°C on average during the evening heating period and also over the

24hr period, higher than both the groups which received measures.

Bedroom temperatures were lower than living rooms on average for all groups during this period, at 18.3°C for both the evening heating and 24 hr periods in Tempergreen properties. The only household which saw a warmer bedroom than the living room was T-02 at a high 22.8°C – it is unsurprising that this household was experiencing high costs, at these temperatures. Property T-16 clearly does not heat the bedroom, as low and consistent temperatures averaging around 16°C were recorded here. In VCharge properties, the evening average was 20.3°C, slightly cooler than the 20.5°C 24 hr average. V-34 did not have their new storage heaters fitted yet, and saw very cold bedroom temperatures, with a minimum of 8.5°C, an average of 15.3°C and a maximum of 18.5°C. Control property C-09, which uses only peak-rate supplementary heating, sees low minimum and high maximum temperatures in the bedroom, but all other control properties experience safe and comfortable temperature ranges.

Period 3 was after any properties in both measures groups had their Switchees exchanged if they had experienced connectivity issues (except T-26 where residents were unavailable on the visit date and never got their Switchee changed, so control their heating manually); properties in the VCharge group had also had smart meters installed if they did not already have one. In this period, living room temperatures reduced on average in the Tempergreen group, although the average minimum temperature rose and the maximum decreased, implying better control. In the VCharge group, average temperatures increased slightly. Notably, property V-34's 24hr average living room temperature also increased to 18.8°C, its median and mode were both 18.5°C, so whilst a low of 15.5°C was still seen, its temperature had increased significantly. Control group properties' living room temperatures also increased in this period, attaining very high temperatures in property C-15. Bedroom temperatures followed a similar pattern decreasing slightly in the Tempergreen group and increasing slightly in the VCharge and control groups. Property T-02 appears to have addressed / reduced their high bedroom temperatures, whereas property T-26 now experiences low bedroom temperatures (minimum 11°C), indicating that they now only manually spot-heat the room as their Switchee programmer no longer works. During this period, properties V-18 and particularly V-33 heated their bedrooms to very high temperatures, which would significantly increase their costs.

Period 4 was after replacement of smart meters in those VCharge properties which required it, and VCharge was installed in properties (V-29,) V-33, V-34, V-37, and V-59 – which correctly wired all these properties' heating through their meter for the first time, so increasing their costs. EvoHome controller was also installed in properties T-05, T-26 and T-42. Average living room temperatures reduced slightly in both T-05 and T-26 between periods 3 and 4, and bedroom temperatures dropped more markedly for T-05 and T-42 (the latter now sees a worryingly low minimum temperature), but bedroom temperature increased in property T-26 to less worryingly lows. Unfortunately, the initial living room logger in T-42 was lost, so the effect of Evohome cannot be determined there. In properties which received VCharge, living room temperatures reduced a little, however this was also the case for V-18 and V-44 who had not yet received their VCharge. The most marked drop was seen in V-33 and V-37 whose wiring had not been correct previously, hence they may have reduced their heating temperatures to compensate for suddenly (and unexpectedly – the issue was not realised in advance) having to afford the heating costs. Bedroom temperatures also reduced slightly across all properties, except V-33 and V-34 where they reduced markedly, and V-59 where they increased. This reduction was also seen in properties which had not yet received VCharge, V-18, V-44 and V-06. V-34's bedroom temperatures reduced to incredibly low levels, an average of only around 12°C (whether using mean, median or mode), and a maximum of only 17°C. Reasons for this are unknown since the household had only electric panel heaters on

peak-rate wiring previously so were not used to getting any off-peak heat for free that they now had to pay for. The householders should be advised that such low temperatures may be damaging to health and increase risks of mould, and the landlord may wish to seek to improve insulation further in this less well insulated ground floor property so that the heating system is able to cope with the higher heat demand that this will require. Control property temperatures also reduced slightly between periods 3 and 4, suggesting that they may also have turned heating down a little as the weather became less harsh.

Across all time periods after measures were installed, both groups which received measures are able to control their temperatures to achieve the recommended 18-21°C temperature range, and most do so, though a few heat their properties to higher than this which will increase costs. Some heat bedrooms to lower temperatures, presumably by preference. On average, the flats which received Enviroheat heaters (Tempergreen group) have lower temperatures, the VCharge group have higher temperatures, and the control group properties have the highest temperatures. This may be because residents choosing the peak heating tended to be unfamiliar with storage heaters, who did not use or like them, more used to using supplementary spot-heating for short periods, and those who preferred the modern storage heating option appreciated the more even warmth. It is likely that, where affordability of energy bills was a key limiting factor, control properties were able to afford to heat their flats warmer because many did not have their heating circuit wired through the prepayment meter, so were not paying their off-peak heating costs. However, their heating temperatures are generally still not excessive, and concerns would be likely to arise around their ability to adequately heat their flat if the wiring issues were to be rectified in future.

3.5 Humidity

Water vapour in the air is measured as relative humidity (RH), which is the percentage of water vapour held by the air compared to its saturation level (the highest quantity of water able to be supported by the air at that temperature). The saturation amount is dependent on temperature, as warmer air can hold more moisture, so relative humidity is a function of both moisture content and temperature. Humidity is not usually considered to be an indoor contaminant or a cause of health problems. In fact, some level of humidity is necessary for comfort. However, the relative humidity of indoor environments (over the range of normal indoor temperatures of 19 to 27°C), has both direct and indirect effects on health and comfort. The direct effects are the result of the effect of relative humidity on physiological processes, whereas the indirect effects result from the impact of humidity on pathogenic organisms or chemicals which may affect health. High values of RH are problematic as they can cause damage to building fabric and furnishings, mould growth and associated health problems. From the Building Regulations Part F[16]; the suggested average monthly maximum humidity for domestic dwellings during the heating season is 65%, weekly is 75% and daily is 85%.

Figure 3.10 illustrates the optimum humidity levels as cited by Arundel et al[17]. The study concluded that maintaining relative humidity levels between 40% and 60% would minimise adverse health effects relating to relative humidity.

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

Table 3.8 – Temperature and thermal comfort in (a) living rooms and (b) bedrooms of monitored properties

a)

	Period 1:	9-12th Nov 2017		DD/day:	7.70	Days:	4	Period 2:	23 Nov-12 Dec 2017		DD/day:	11.18	Days:	20	Period 3:	23rd-29th Jan 2018		DD/day:	7.74	Days:	7	Period 4:	7-25th Mar 2018		DD/day:	9.88	Days:	19
Property	5 - 9.30pm	24hr Avg.	Median	Mode	Min	Max	SD	5 - 9.30pm	24hr Avg.	Median	Mode	Min	Max	SD	5 - 9.30pm	24hr Avg.	Median	Mode	Min	Max	SD	5 - 9.30pm	24hr Avg.	Median	Mode	Min	Max	SD
T-02	20.70	21.18	21.0	22.0	18.5	22.5	0.91	21.78	21.73	21.5	20.5	19.5	24.5	1.13	22.29	21.87	22.0	22.5	20.0	23.5	0.94	23.21	22.66	22.5	23.5	19.5	26.0	1.30
T-03	-	-	-	-	-	-	-	-	-	-	-	-	-	-	19.88	19.66	19.5	19.5	18.5	23.5	0.66	19.19	19.09	19.0	20.0	17.0	21.5	1.19
T-04	19.10	18.41	18.5	18.0	17.0	20.5	0.83	18.38	17.49	17.5	17.0	15.0	21.0	1.06	18.44	17.50	17.0	17.0	16.0	21.5	0.95	19.66	18.74	18.5	18.5	17.0	22.5	0.87
T-05	20.74	20.50	20.5	20.0	19.0	23.5	0.99	19.04	18.74	18.5	18.5	17.0	23.0	1.01	19.64	19.37	19.5	20.0	17.0	22.5	1.47	19.19	18.75	18.5	18.5	16.0	25.0	1.59
T-16	20.03	19.69	19.5	19.0	17.0	21.5	1.02	20.85	20.56	20.5	20.5	18.0	24.5	0.98	20.76	20.01	20.0	19.0	18.0	23.0	1.22	19.67	18.96	18.5	18.5	16.0	24.0	1.77
T-19	21.70	21.32	22.0	22.0	16.0	24.0	2.01	21.89	21.65	21.5	21.5	18.5	24.0	0.92	18.97	19.00	18.5	17.5	17.0	23.0	1.79	21.44	21.47	21.0	21.0	18.5	24.5	0.78
T-26	20.71	20.74	20.5	20.0	19.5	24.5	0.97	22.21	22.09	22.0	22.5	18.5	27.5	1.59	19.91	20.18	20.0	19.5	18.5	26.0	1.28	19.84	19.96	20.0	19.0	18.0	25.0	1.10
T-42	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	21.19	20.31	20.5	19.5	15.0	30.0	2.03
T-52	20.13	19.94	20.0	20.0	19.0	20.5	0.40	18.14	18.08	18.0	18.5	15.5	21.5	1.41	18.20	18.00	18.0	18.0	17.0	19.0	0.39	19.61	19.29	19.0	18.5	17.5	21.5	1.07
Avg T	20.44	20.25	20.29	20.14	18.00	22.43	1.02	20.33	20.05	19.93	19.86	17.43	23.71	1.16	19.76	19.45	19.31	19.13	17.75	22.75	1.09	20.33	19.91	19.72	19.67	17.17	24.44	1.30
V-18	-	-	-	-	-	-	-	23.70	23.68	24.0	24.0	21.5	26.0	0.68	23.58	23.65	23.5	23.5	22.0	25.0	0.59	22.70	22.75	23.0	23.0	21.0	24.5	0.56
V-33	21.33	21.04	21.0	21.5	19.5	22.5	0.73	23.58	23.59	23.5	23.5	21.0	25.5	0.93	23.69	23.56	24.0	24.5	21.0	25.0	1.19	21.34	21.08	21.0	21.0	19.0	23.5	1.19
V-34	19.94	18.40	18.0	16.5	15.5	23.5	2.02	19.64	16.50	15.5	15.0	11.0	24.0	3.11	19.55	18.81	18.5	18.5	15.5	23.0	1.38	18.97	18.40	19.0	19.0	11.0	27.5	3.88
V-37	-	-	-	-	-	-	-	21.14	21.18	21.0	21.0	19.5	26.0	0.74	21.19	21.28	21.0	21.0	20.0	32.0	1.26	20.64	20.56	21.0	21.5	16.5	23.5	1.29
V-44	20.00	19.99	20.0	20.5	18.5	24.0	0.99	20.31	20.25	20.0	20.0	18.5	23.5	0.90	20.44	20.38	20.5	20.5	20.0	24.5	0.48	20.36	20.35	20.5	22.0	17.5	25.0	1.67
V-06	17.77	18.07	17.5	17.0	17.0	24.5	1.45	20.73	21.27	22.0	23.0	11.5	27.0	2.86	21.70	21.68	21.5	21.5	20.0	26.5	1.11	22.13	22.12	22.0	22.5	19.0	25.5	1.36
V-07	21.14	21.08	21.0	21.0	20.0	22.0	0.36	20.32	20.33	20.0	20.0	17.5	22.5	0.72	-	-	-	-	-	-	-	20.78	20.75	20.5	20.0	19.0	31.5	1.24
Avg V	20.04	19.72	19.50	19.30	18.10	23.30	1.11	21.35	20.97	20.86	20.93	17.21	24.93	1.42	21.69	21.56	21.50	21.58	19.75	26.00	1.00	20.99	20.86	21.00	21.29	17.57	25.86	1.60
C-09	-	-	-	-	-	-	-	21.77	21.68	21.5	21.5	19.5	25.0	1.00	22.27	21.07	21.0	20.0	18.5	24.0	1.44	22.19	21.34	21.5	22.0	17.0	26.0	1.64
C-10	21.80	21.73	22.0	22.5	19.0	23.0	0.94	22.16	22.41	22.5	23.0	20.5	24.5	0.86	22.53	22.26	22.5	22.5	19.5	23.5	0.77	20.35	20.16	20.0	20.0	17.5	23.0	1.05
C-11	-	-	-	-	-	-	-	22.03	21.96	22.0	21.5	21.0	23.5	0.67	23.28	23.14	23.0	23.0	22.5	24.0	0.37	22.87	22.78	23.0	22.5	22.0	23.5	0.48
C-14	21.99	22.15	22.0	22.5	20.5	23.0	0.54	22.54	22.84	23.0	23.0	19.5	25.5	1.07	22.99	23.16	23.0	23.5	21.0	24.5	0.71	22.19	22.24	22.5	23.5	19.5	24.5	1.07
C-15	25.22	24.92	25.0	25.5	22.5	27.0	1.00	25.26	24.51	24.5	24.0	20.5	29.0	1.76	27.80	26.44	26.0	28.0	23.5	29.0	1.61	26.55	25.39	25.0	24.0	22.0	29.5	1.64
C-12	21.43	20.89	21.5	22.0	16.0	24.0	1.75	19.71	19.76	19.5	19.0	16.5	23.5	1.13	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Avg C	22.61	22.42	22.63	23.13	19.50	24.25	1.06	22.25	22.19	22.17	22.00	19.58	25.17	1.08	23.77	23.22	23.10	23.40	21.00	25.00	0.98	22.83	22.38	22.40	22.40	19.60	25.30	1.18

b)

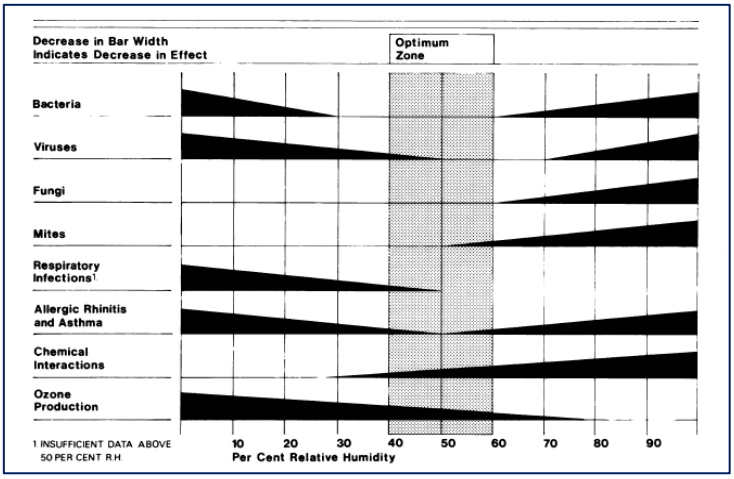
	Period 1:	9-12th Nov 2017		DD/day:	7.70	Days:	4	Period 2:	23 Nov-12 Dec 2017		DD/day:	11.18	Days:	20	Period 3:	23rd-29th Jan 2018		DD/day:	7.74	Days:	7	Period 4:	7-25th Mar 2018		DD/day:	9.88	Days:	19
Property	5 - 9.30pm	24hr Avg.	Median	Mode	Min	Max	SD	5 - 9.30pm	24hr Avg.	Median	Mode	Min	Max	SD	5 - 9.30pm	24hr Avg.	Median	Mode	Min	Max	SD	5 - 9.30pm	24hr Avg.	Median	Mode	Min	Max	SD
T-01	15.68	15.28	15.0	15.0	14.0	17.0	0.55	17.19	17.14	16.0	16.0	13.0	23.5	3.47	20.98	21.43	21.0	20.5	19.0	24.5	1.61	21.38	21.73	21.5	21.0	19.0	26.0	1.18
T-02	21.99	21.52	21.5	22.5	19.5	23.0	0.90	22.88	22.82	23.0	23.0	20.0	25.0	0.92	19.47	19.47	19.5	19.5	14.0	20.5	0.76	19.78	19.96	20.0	20.0	14.5	22.0	1.10
T-03	-	-	-	-	-	-	-	-	-	-	-	-	-	-	18.60	18.53	18.5	18.5	18.0	19.5	0.40	17.70	17.71	17.5	19.0	16.0	20.0	1.14
T-04	17.87	18.08	18.0	18.0	17.0	19.0	0.47	17.29	17.22	17.0	17.0	15.5	19.5	0.81	17.13	16.87	17.0	17.0	15.5	19.0	0.65	18.54	18.31	18.5	18.0	17.0	20.0	0.65
T-05	19.25	19.42	19.5	19.5	18.5	20.5	0.46	17.64	17.92	17.5	17.5	16.0	21.5	1.02	18.98	18.80	19.0	19.0	16.5	21.5	1.31	17.35	17.30	17.5	17.5	15.0	21.0	1.21
T-16	15.62	15.91	16.0	16.0	15.0	16.5	0.32	15.72	15.94	16.0	16.5	13.5	19.0	1.01	15.80	15.85	16.0	16.0	14.0	17.0	0.65	14.73	14.74	15.0	15.5	12.0	17.0	1.20
T-19	21.13	20.85	21.0	21.0	16.0	23.5	1.83	21.00	21.02	21.0	21.0	19.0	22.5	0.69	18.47	18.51	18.0	17.5	17.5	21.0	1.19	21.99	21.95	22.0	22.5	19.0	23.5	0.66
T-26	19.55	19.88	20.0	19.5	18.5	21.5	0.76	18.35	18.53	18.5	18.5	16.5	21.5	1.23	16.58	16.34	16.5	16.5	11.5	17.5	0.96	17.48	17.49	17.5	17.5	13.5	20.0	1.19
T-42	18.12	18.20	18.0	18.0	17.5	21.5	0.47	17.28	17.37	17.0	17.0	14.0	21.0	1.41	18.81	18.44	18.5	18.5	17.0	22.5	0.74	16.75	16.24	16.0	16.5	12.0	26.0	2.03
T-52	19.02	19.12	19.0	19.0	18.5	19.5	0.29	16.94	17.09	17.0	17.0	14.5	20.0	1.29	16.66	16.70	16.5	17.0	15.0	17.5	0.43	17.45	17.52	17.5	17.0	15.0	19.0	1.07
Avg T	18.69	18.70	18.67	18.72	17.17	20.22	0.67	18.26	18.34	18.11	18.17	15.78	21.50	1.32	18.15	18.09	18.05	18.00	15.80	20.05	0.87	18.32	18.30	18.30	18.45	15.30	21.45	1.14
V-18	-	-	-	-	-	-	-	23.76	23.88	24.0	24.0	22.5	25.0	0.60	23.64	23.78	23.5	23.5	23.0	25.0	0.50	22.71	22.80	23.0	23.0	21.0	24.0	0.53
V-33	21.02	21.21	21.0	21.0	20.0	22.0	0.46	23.69	24.23	24.5	25.0	21.5	26.5	1.04	25.61	26.94	27.0	28.5	23.5	30.0	1.72	21.02	21.23	20.5	18.0	17.5	27.5	2.99
V-34	18.13	17.70	17.5	17.5	16.5	19.0	0.51	15.33	14.95	15.5	16.5	8.5	18.5	2.47	16.47	16.65	16.5	16.0	13.5	18.5	0.90	11.94	11.85	12.0	12.0	10.0	17.5	1.02
V-37	-	-	-	-	-	-	-	19.96	20.14	20.0	20.0	18.0	22.5	1.00	20.45	20.65	21.0	21.0	19.5	22.0	0.56	20.26	20.36	20.5	21.5	18.0	23.0	1.27
V-44	18.20	18.36	18.5	18.0	17.5	19.0	0.37	18.36	18.39	18.0	17.5	16.5	28.5	1.22	18.50	18.60	18.5	18.5	17.5	20.0	0.55	17.67	17.71	17.5	16.0	15.5	20.5	1.44
V-59	-	-	-	-	-	-	-	-	-	-	-	-	-	-	16.00	16.04	16.0	16.0	15.0	16.5	0.36	20.60	20.32	20.5	20.5	19.0	22.0	0.68
V-06	17.34	17.30	17.0	17.0	17.0	18.5	0.36	22.43	22.95	23.0	23.5	19.5	25.0	1.05	22.03	22.39	22.5	23.0	20.5	24.0	0.80	20.48	20.58	21.0	21.0	17.5	23.0	1.07
V-07	18.00	18.09	18.0	18.0	17.0	19.5	0.62	18.70	18.92	19.0	18.5	16.5	21.5	1.13	-	-	-	-	-	-	-	20.64	20.80	20.5	20.5	19.0	23.0	0.94
Avg V	18.54	18.53	18.40	18.30	17.60	19.60	0.46	20.32	20.50	20.57	20.71	17.57	23.93	1.22	20.38	20.72	20.71	20.93	18.93	22.29	0.77	19.42	19.46	19.44	19.06	17.19	22.56	1.24
C-09	-	-	-	-	-	-	-	16.49	16.87	17.0	20.5	7.0	22.5	3.39	15.11	15.16	15.0	16.5	13.0	17.5	1.17	15.03	15.26	15.0	15.0	10.5	29.0	2.41
C-10	18.53	18.48	18.5	19.0	17.5	19.5	0.57	18.26	18.50	18.5	18.0	16.5	21.0	0.94	19.34	19.45	19.5	19.0	17.5	25.0	0.88	18.14	18.27	18.5	19.0	16.0	20.5	0.86
C-11	-	-	-	-	-	-	-	21.46	21.77	21.5	21.5	20.0	23.5	0.82	23.00	23.31	23.5	23.5	21.5	24.5	0.60	23.22	23.59	23.5	23.5	22.0	25.0	0.70
C-14	20.37	20.42	20.5	20.5	19.5	21.0	0.36	20.25	20.17	20.5	20.5	17.0	22.5	1.08	21.38	21.25	21.5	21.5	19.5	22.5	0.62	20.13	19.95	20.5	21.0	16.5	22.0	1.33
C-15	21.75	21.96	22.0	22.0	20.5	23.5	0.78	22.17	22.23	22.0	22.0	19.5	24.5	1.01	23.86	24.66	25.0	25.5	22.0	26.5	0.98	22.67	22.49	22.5	23.0	20.0	25.0	0.79
Avg C	20.21	20.29	20.33	20.50	19.17	21.33	0.57	19.72	19.91	19.90	20.50	16.00	22.80	1.45	20.54	20.76	20.90	21.20	18.70	23.20	0.85	19.84	19.91	20.00	20.30	17.00	24.30	1.22

Table 3.9 – Table showing relative humidity (RH) in (a) living rooms and (b) bedrooms of monitored properties

	Period 1:	9-12th Nov 2017		DD/day:	7.70	Days:	4	Period 2:	23 Nov-12 Dec 2017		DD/day:	11.18	Days:	20	Period 3:	23rd-29th Jan 2018		DD/day:	7.74	Days:	7	Period 4:	7-25th Mar 2018		DD/day:	9.88	Days:	19
Property	5 - 9.30pm	24hr Avg.	Median	Mode	Min	Max	SD	5 - 9.30pm	24hr Avg.	Median	Mode	Min	Max	SD	5 - 9.30pm	24hr Avg.	Median	Mode	Min	Max	SD	5 - 9.30pm	24hr Avg.	Median	Mode	Min	Max	SD
T-02	46.73	48.15	49.5	52.5	37.5	54.5	4.50	43.43	44.31	45.0	45.5	33.5	57.0	4.81	47.37	47.04	47.0	48.5	43.0	50.5	1.77	41.11	41.86	42.0	44.5	29.5	50.5	3.94
T-03	-	-	-	-	-	-	-	-	-	-	-	-	-	-	55.93	57.09	56.5	55.5	50.0	68.0	3.19	52.65	55.00	54.5	51.0	38.5	69.5	6.72
T-04	62.39	60.92	60.0	57.0	51.5	70.0	4.08	62.42	58.12	59.0	61.5	41.0	74.0	6.61	69.22	66.51	66.5	68.0	58.5	76.0	3.01	56.06	53.69	53.5	60.5	40.0	72.5	6.91
T-05	63.93	64.58	65.5	68.0	53.5	69.5	3.65	66.08	65.94	66.0	64.0	53.0	75.0	3.75	67.42	65.70	66.0	66.5	57.0	74.5	2.97	61.77	61.29	61.5	61.5	44.0	74.0	5.55
T-16	49.50	49.21	49.5	52.0	38.0	57.0	3.29	50.05	49.48	49.5	49.5	36.0	59.0	4.15	54.01	53.75	53.0	52.0	46.5	60.5	2.91	45.34	44.93	45.5	46.0	30.0	58.5	6.15
T-19	51.94	53.26	53.5	51.5	40.5	68.5	5.32	50.78	51.62	52.0	53.0	39.5	63.0	5.12	54.64	54.96	55.0	56.5	49.5	60.5	2.43	37.80	37.08	38.0	37.5	19.5	49.0	6.04
T-26	46.43	44.45	44.0	41.5	35.5	57.0	4.22	42.53	41.63	41.5	42.5	29.5	58.5	5.38	49.58	48.37	48.5	51.0	38.0	66.5	5.68	51.81	50.27	52.0	55.0	31.5	64.0	7.22
T-42	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	59.65	59.35	60.5	58.0	32.0	77.0	9.24
T-52	46.58	47.02	47.5	49.0	38.0	53.5	2.81	46.90	45.97	46.0	50.0	33.0	63.0	5.91	52.66	52.40	52.0	51.0	46.0	60.0	2.26	45.36	45.13	45.0	45.0	32.0	56.0	4.18
Avg T	52.50	52.51	52.79	53.07	42.07	61.43	3.98	51.74	51.01	51.29	52.29	37.93	64.21	5.10	56.35	55.73	55.56	56.13	48.56	64.56	3.03	50.17	49.84	50.28	51.00	33.00	63.44	6.22
V-18	-	-	-	-	-	-	-	37.42	36.71	36.5	30.5	28.0	55.5	4.89	42.33	40.86	40.5	40.0	34.5	56.0	3.20	39.74	39.03	38.5	37.5	30.5	51.0	3.81
V-33	65.55	64.81	64.0	58.5	55.0	74.0	5.07	50.20	49.18	49.0	48.0	37.0	61.5	4.93	48.74	46.65	46.0	45.0	37.5	56.5	4.25	55.55	55.97	56.0	61.0	38.5	71.0	5.89
V-34	58.97	58.85	58.8	66.5	40.5	75.5	6.35	51.10	55.41	53.5	50.5	35.0	82.0	9.63	53.69	54.25	53.3	52.5	41.5	69.0	5.32	59.36	62.00	58.0	54.0	36.0	94.5	12.98
V-37	-	-	-	-	-	-	-	39.14	39.67	39.5	37.0	32.0	56.0	3.91	41.89	42.11	42.5	44.0	25.0	49.5	2.94	40.53	40.80	41.0	36.0	30.5	60.0	4.18
V-44	67.21	69.71	70.5	71.5	52.5	77.0	4.55	62.08	61.84	62.0	61.0	49.5	79.5	4.69	70.04	69.81	70.0	70.0	54.5	79.5	2.59	60.97	60.62	62.5	66.5	38.5	75.5	8.24
V-06	54.29	54.74	55.5	57.0	42.0	58.5	2.81	42.48	41.77	40.0	37.5	28.0	67.0	6.96	50.08	48.66	49.0	50.5	34.5	59.0	4.33	35.85	35.97	37.0	37.5	22.5	52.5	5.64
V-07	44.84	46.43	47.5	48.0	33.0	54.5	3.57	35.13	35.92	35.0	32.0	28.0	49.5	4.60	-	-	-	-	-	-	-	37.85	38.05	38.0	38.5	15.0	54.0	6.66
Avg V	58.17	58.91	59.25	60.30	44.60	67.90	4.47	45.37	45.79	45.07	42.36	33.93	64.43	5.66	51.13	50.39	50.21	50.33	37.92	61.58	3.77	47.12	47.49	47.29	47.29	30.21	65.50	6.77
C-09	-	-	-	-	-	-	-	50.87	51.02	51.0	51.0	34.5	70.5	5.40	59.91	61.08	61.0	61.5	55.0	68.0	2.53	50.83	51.20	52.0	54.0	35.0	64.0	5.45
C-10	52.29	53.55	54.5	56.0	41.5	62.0	4.48	43.91	45.48	45.5	50.5	33.0	64.0	5.69	47.81	48.87	49.5	50.0	36.0	59.0	4.14	51.48	53.65	53.0	51.0	36.0	67.5	5.62
C-11	-	-	-	-	-	-	-	44.68	44.25	44.0	45.0	35.5	58.5	5.02	45.85	45.05	45.0	45.5	38.5	53.0	3.08	45.43	44.77	45.0	43.5	37.5	54.5	3.31
C-14	48.10	48.22	48.3	50.5	43.5	52.5	2.27	42.32	41.50	41.5	44.0	28.0	53.0	4.61	45.67	45.38	45.0	44.5	39.0	50.5	2.51	39.40	38.70	40.0	40.5	24.5	49.5	5.85
C-15	35.97	35.34	35.0	35.0	27.5	46.5	3.20	33.24	32.30	32.0	29.5	21.5	48.0	4.69	32.95	33.19	33.5	35.5	24.0	40.5	3.16	29.67	30.01	30.0	29.0	17.5	48.5	4.99
C-12	48.59	48.62	49.5	49.5	38.0	59.0	3.97	51.77	51.34	51.0	50.0	31.5	65.5	5.61	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Avg C	46.24	46.43	46.81	47.75	37.63	55.00	3.48	44.46	44.31	44.17	45.00	30.67	59.92	5.17	46.44	46.72	46.80	47.40	38.50	54.20	3.08	43.36	43.67	44.00	43.60	30.10	56.80	5.04

	Period 1:	9-12th Nov 2017		DD/day:	7.70	Days:	4	Period 2:	23 Nov-12 Dec 2017		DD/day:	11.18	Days:	20	Period 3:	23rd-29th Jan 2018		DD/day:	7.74	Days:	7	Period 4:	7-25th Mar 2018		DD/day:	9.88	Days:	19
Property	5 - 9.30pm	24hr Avg.	Median	Mode	Min	Max	SD	5 - 9.30pm	24hr Avg.	Median	Mode	Min	Max	SD	5 - 9.30pm	24hr Avg.	Median	Mode	Min	Max	SD	5 - 9.30pm	24hr Avg.	Median	Mode	Min	Max	SD
T-01	80.13	80.23	79.5	79.5	76.5	83.5	1.37	74.18	75.65	80.5	82.5	48.5	91.0	11.17	57.33	57.36	60.0	61.0	45.0	65.0	5.43	53.00	53.56	55.3	58.5	37.0	65.5	6.58
T-02	43.66	46.21	47.5	48.5	34.5	53.0	4.49	39.95	40.55	40.5	40.0	24.0	55.5	6.03	54.77	54.37	54.5	54.0	45.5	70.0	3.88	47.50	48.51	49.0	54.5	28.5	66.5	7.28
T-03	-	-	-	-	-	-	-	-	-	-	-	-	-	-	61.58	62.60	62.0	62.0	56.5	74.0	3.29	59.12	60.95	61.5	59.0	41.5	74.0	7.22
T-04	65.54	66.24	67.5	69.0	57.0	73.0	3.80	66.40	67.65	68.5	71.0	49.0	81.5	5.91	69.47	71.24	71.5	70.0	59.5	81.0	4.02	57.70	58.55	58.0	65.0	44.5	73.0	6.56
T-05	69.90	71.32	71.5	72.5	64.5	77.0	2.94	71.87	72.96	72.5	70.0	61.5	82.5	4.07	72.43	74.22	73.5	71.5	65.5	84.0	4.04	70.95	71.00	73.0	75.0	55.5	80.0	5.53
T-16	53.51	58.44	58.5	53.0	45.0	69.5	5.62	62.89	65.02	65.5	62.5	43.0	78.5	7.51	68.67	70.53	71.0	71.0	49.0	77.0	4.01	62.99	64.70	67.5	70.0	43.5	76.0	8.16
T-19	55.84	56.46	56.5	56.5	45.5	71.5	4.75	55.68	56.72	56.5	57.5	42.0	72.5	5.86	57.55	57.73	57.0	54.0	50.0	69.0	4.35	39.86	40.38	39.0	39.0	29.0	55.0	4.78
T-26	55.71	58.55	59.0	59.0	45.0	67.0	4.55	57.01	57.01	57.5	59.0	38.5	73.5	5.21	62.60	62.87	63.0	59.0	52.0	74.0	4.86	61.00	61.35	63.0	68.0	40.5	78.0	7.38
T-42	67.81	67.83	68.0	68.5	53.0	76.5	4.68	70.86	70.84	70.0	70.0	56.0	93.0	8.17	78.23	80.01	80.5	79.5	60.0	85.5	3.01	78.70	79.35	81.5	85.0	54.0	92.5	8.38
T-52	49.38	50.77	51.5	51.5	45.0	57.5	2.49	48.15	48.66	49.0	53.0	40.0	61.0	4.34	56.02	56.50	56.0	55.0	52.5	63.0	1.86	50.55	50.89	50.5	48.0	44.0	60.0	2.83
Avg T	60.17	61.78	62.17	62.00	51.78	69.83	3.85	60.77	61.67	62.28	62.83	44.72	76.56	6.47	63.87	64.74	64.90	63.70	53.55	74.25	3.87	58.14	58.92	59.83	62.20	41.80	72.05	6.47
V-18	-	-	-	-	-	-	-	35.90	36.17	36.0	39.5	25.5	50.5	4.29	40.97	40.68	40.5	39.5	34.0	49.0	2.64	38.42	38.67	39.0	40.0	29.5	48.5	3.33
V-33	64.77	64.26	65.0	66.0	57.5	70.0	3.18	50.24	50.04	50.0	50.5	39.0	63.0	4.29	44.00	41.66	41.5	38.5	32.5	50.0	3.64	55.78	56.90	58.0	66.5	38.0	76.5	8.26
V-34	75.53	76.24	76.5	77.5	66.0	84.0	4.12	76.40	76.84	76.0	74.0	51.5	97.0	7.10	70.42	75.19	76.0	80.0	49.5	95.0	8.99	89.35	91.19	93.0	98.0	52.5	99.0	7.16
V-37	-	-	-	-	-	-	-	48.74	49.39	49.0	50.5	41.0	75.5	5.06	50.03	50.04	50.3	51.5	44.0	59.5	3.22	46.32	46.48	46.5	51.0	35.0	59.5	4.74
V-44	70.27	71.95	72.0	73.5	62.5	80.5	3.02	66.76	67.46	69.0	70.5	50.5	94.5	5.70	78.06	78.50	79.0	79.0	69.5	86.5	3.34	71.25	71.85	75.0	61.0	53.5	85.5	9.77
V-59	-	-	-	-	-	-	-	-	-	-	-	-	-	-	53.57	54.28	53.5	53.0	45.5	64.5	3.11	46.21	48.13	47.0	43.0	33.5	64.5	6.64
V-06	59.60	60.48	60.5	59.0	55.0	64.5	2.34	43.58	45.51	45.5	47.5	35.5	57.5	4.03	47.64	48.67	48.5	48.0	43.5	54.5	2.47	41.13	43.35	44.0	46.5	30.0	60.0	6.08
V-07	56.14	57.84	58.5	59.5	48.0	67.5	3.75	48.60	49.50	49.5	50.0	40.5	59.0	4.33	-	-	-	-	-	-	-	43.23	45.40	45.5	42.5	27.0	62.0	7.38
Avg V	65.26	66.15	66.50	67.10	57.80	73.30	3.28	52.89	53.56	53.57	54.64	40.50	71.00	4.97	54.96	55.58	55.61	55.64	45.50	65.57	3.91	53.96	55.25	56.00	56.06	37.38	69.44	6.67
C-09	-	-	-	-	-	-	-	64.82	63.93	64.5	52.0	46.0	91.5	9.93	90.44	90.38	91.0	91.5	81.5	96.5	3.46	79.04	79.03	81.0	89.5	49.0	97.0	10.38
C-10	68.88	67.58	68.0	68.5	60.0	73.0	3.14	62.56	64.84	65.0	69.0	53.0	76.5	5.60	60.86	63.40	63.5	68.0	52.5	72.0	4.94	61.62	63.96	63.5	60.0	50.5	79.0	6.01
C-11	-	-	-	-	-	-	-	47.22	49.08	49.0	48.0	38.5	65.0	5.08	46.44	48.15	48.0	47.0	43.0	54.0	2.95	42.88	45.14	45.5	44.0	36.5	54.5	3.91
C-14	57.00	57.68	58.0	59.0	53.0	63.5	2.12	53.59	54.05	54.0	54.0	48.0	61.5	2.35	54.60	55.14	55.0	55.0	47.5	59.0	1.46	48.89	49.33	50.0	49.5	40.5	54.5	3.38
C-15	45.81	47.02	47.0	44.0	41.5	55.0	2.91	41.78	43.33	43.0	39.0	27.5	62.0	5.30	40.84	42.68	42.5	42.5	33.0	51.0	4.11	36.85	37.29	36.5	35.5	25.5	52.5	5.27
Avg C	57.23	57.43	57.67	57.17	51.50	63.83	2.72	53.99	55.05	55.10	52.40	42.60	71.30	5.65	58.64	59.95	60.00	60.80	51.50	66.50	3.39	53.85	54.95	55.30	55.70	40.40	67.50	5.79

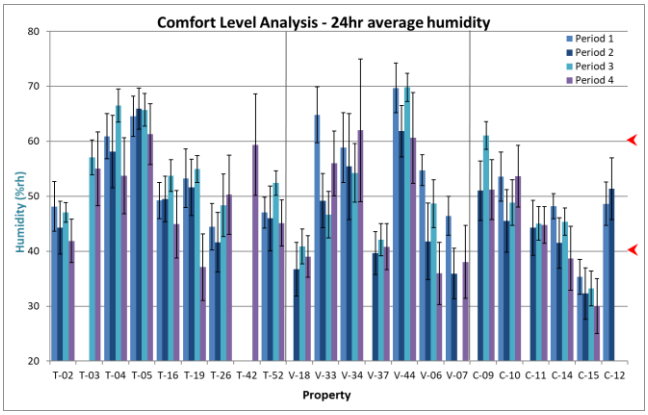
Figure 3.10 – Optimum humidity levels to reduce indirect effects from pathogenic organisms or chemicals

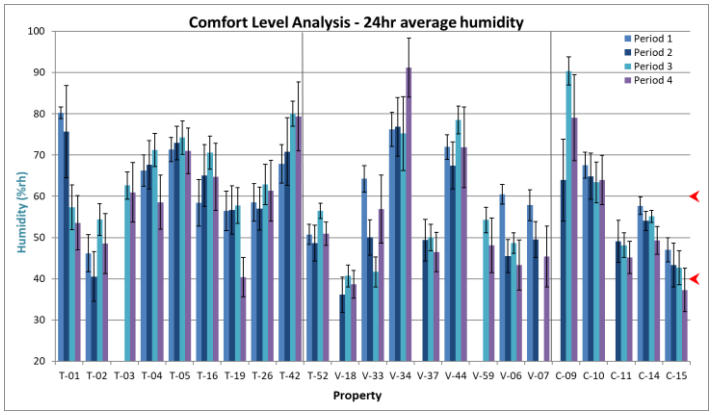


Humidity data for the properties, over the same analysis periods as for the thermal loggers (as explained in section 3.4), is shown in Table 3.9 and presented in graph form in Figure 3.11. The error bars on this graph indicate the standard deviation, i.e. variability, from this mean value. There is a complex relationship between humidity and the evening heating period – as RH is inversely proportional to temperature, in some properties the humidity may decrease, probably due to an increase in heating, whereas in others - presumably rooms which are occupied and where moisture-releasing activities such as (breathing,) cooking or bathing is taking place - humidity increases. The whole 24-hour average is therefore the best period to use for humidity analysis.

As can be seen in Table 3.9, before installation of the new storage heaters, most flats' humidity levels fell within the recommended range of 40-60% rh, apart from C-15, where temperatures are relatively high, and hence humidity was lower than recommended, and properties T-04, T-05, V-33, and V-44 where there were known to be issues of damp and mould - particularly in the latter 2 flats, this was above the living room window and was unclear whether it was penetrating damp from an issue on the building exterior, or condensation due to cold-bridging via the concrete balcony above.

Figure 3.11 – Graph based on Table 3.9 for the 24-hour average relative humidity for (a) living rooms and (b) bedrooms





During Period 2, the humidity levels in properties T-04 and V-33 to within the recommended range, and V-44 to almost within range. However, humidity levels in V-07 were now below the 40% rh, and V-18 which is newly monitored in this period, also has humidity lower than recommended, probably due to its relatively high temperature. On average, humidity levels decrease across all groups between periods 1 and 2, including for the control group, so it cannot be concluded that this is solely as a result of the new heating, but may be due to households turning heating on/up more. It is of note that, comparing only properties monitored in both period 1 and 2, the average humidity

reduced the most for those households receiving the new Elnur storage heaters (VCharge group), from 58.9% to 48.8% rh. By period 3, flats T-04 and T-05 average humidity levels have returned to above 60% rh, as have levels in V-44, and humidity in C-09 has also increased. It is known that T-05 suffered a leak from the roof, and V-44 was still suffering from damp issues in the living room (repairs had taken place but this had not completely rectified the problem), but the cause of high humidity in the other two properties is not known, neither appearing to be under-heated.

In period 3, humidity levels increased again on average across the group – this is likely to be weather-related as it also occurs in the control group. Period 4 shows humidity levels reduce again across all groups. Average humidity levels in property V-34 increase, slightly above 60%, likely to be due to reduced heating temperatures, particularly low minimum temperatures. Other than this household, only those mentioned above, T-05 and V-44 with known issues of water ingress, see humidity levels above the recommended 40-50% range. Properties C-14 and C-15 retain lower humidities than recommended, in C-15 this is due to high heating temperatures, whereas in C-14 the cause is unknown. T-19, V-06 and V-07 in the groups receiving measures also have slightly lower than recommended humidity with no visible explanation as they do not appear to have particularly warm temperatures, whereas V-18 also has slightly low humidity but this is likely to be due to relatively high heating temperatures.

In bedrooms a significant number of properties had humidity levels higher than the recommended 40-60% range, often due to lower heating temperatures here. Flat C-09, which heated the flat using supplementary heating only, saw very high humidity levels, particularly during period 3. Only in property V-18 were humidity levels lower than recommended during most of the analysis periods, due to relatively high heating temperatures. Property T-01, which used little supplementary heating initially and had very high humidity levels, saw levels reduce to below 60% following installation of the new heating. Properties T-04 and V-33 also saw bedroom humidity levels reduce to within the recommended 40-60% range during the course of the study. Properties with known damp / mould issues – T-05, T-42 (which had a small crack and leak in the cold water tank, not repaired during the study period, causing mould in the airing cupboard) and V-44 all showed high humidity levels, as did V-34 where this is likely to be caused by insufficient heating in the bedroom (which attained an average of less than 12°C in period 4). This is known to be causing mould, and was referred to WHG to see if insulation could be improved further in this property.

On average, there was a slight reduction in the relatively high humidity levels in bedrooms throughout the study, but there were still individual properties with high levels which may cause concern and increase risk of damp and mould causing health issues and damage to the fabric of the property. This may require repairs if caused by a specific issue, and/or tenant engagement to recommend some low level of heating in the bedroom if it results from under-heating.

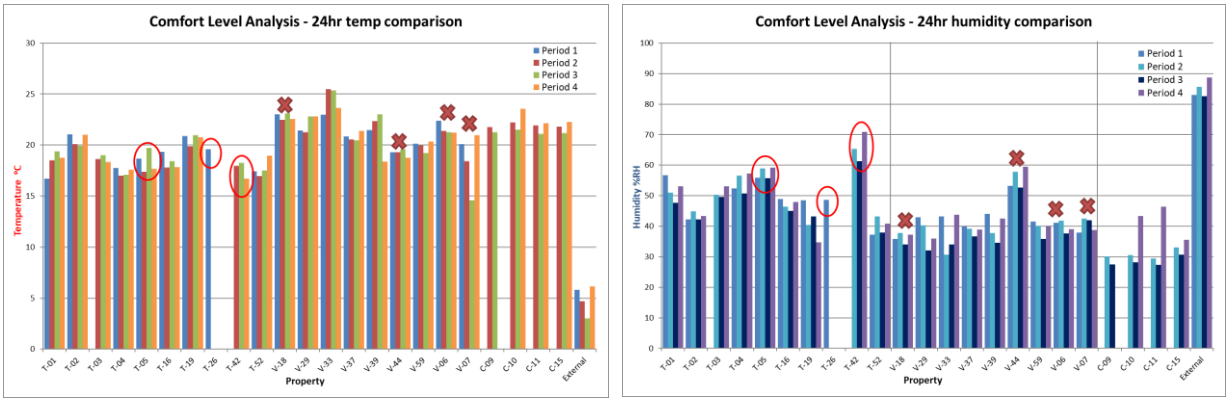
3.6 Switchee data, and other controllers

Switchee smart thermostat monitors temperature, humidity, light and motion (and the status of the heating system where it is the controller) where it is located in the hallway of the flat, every 10 minutes when it is turned on and connected to the network via Wi-Fi or GSM (mobile phone network). Unfortunately it is known that this data is incomplete since some properties' Switchees lost connection during certain periods, and other households were in the habit of turning the heating off at the mains switch before leaving the flat – as Switchee is wired into the heating circuit this also disables it, so it cannot either monitor, nor intuitively control the heating to pre-warm the flat for when the resident normally arrives home. Switchees were only fitted in control properties during the period 18th-21st Dec 2017, and no Switchee was fitted in flat V-34 for unknown reasons.

A Switchee was fitted at flat C-14 however the installer broke a wire during the fitting, so reported to the tenants that they would have to return to swap it, but this was never done, hence no data was recorded in that property. Flat T-26 received a Switchee but it “froze” soon after install and did not function since then. As residents of this flat were not available on the date that a Switchee rep. visited the building to swap out malfunctioning Switchees, theirs was never exchanged, (they later received an Evohome but this reportedly also lost connection) so the residents must control their heating system manually without a programmer.

Due to the different installation and functioning dates, different analysis periods were selected from the temperature and humidity analysis in the previous 2 sections. Period 1 was 7 days, 30th Nov – 6th Dec 2017, immediately after the installation period while most Switchees were functioning. Another 7-day period from 11th – 17th January 2018 was analysed as period 2, after Switchees were swapped on 10th January; Period 3 was from 31st Jan – 6th February 2018, after EvoHome was installed in 3 of the 4 properties which received it, and Period 4 was 7th – 13th March 2018, after most VCharge group households had their VCharge installed. External temperatures were also noted from property T-01, but it is not known how these are monitored as they differ in different flats, hence this should be viewed as an indication of external conditions only.

Figure 3.12 – Analysis of (a) temperature and (b) humidity in properties from Switchee data



Those properties in the Tempergreen group where bars are circled are those which received Evohome between period 2 and 3. All households in the VCharge group received a VCharge between periods 3 and 4, except for those marked with a cross who received it later, or not at all.

This shows that temperatures in the Tempergreen group properties are on average lower than those in the VCharge and control groups, and humidity is higher. Few significant changes were notable during the monitoring: T-01 increased the temperature from 16°C to a more comfortable and safe 18-19°C; Property V-33 increased the temperature to very high levels, over 25°C, though this was controlled better by installation of VCharge. Temperatures in flat V-39 also crept up until VCharge was fitted. In flat V-07, temperatures dropped significantly in period 3 – this flat saw a change of tenancy, and this was the period when the flat was vacant, with no heating on.

Of the properties which received Evohome, no data was available for the later periods for T-26 as Switchee had stopped working. Average temperature increased by 2°C between periods 2 and 3 in T-05, and increased very slightly in T-42. However, temperatures in both properties decreased in period 4. Evohome settings for T-05 were viewed at the visit on 21st Feb 2018, shown in Figure 3.13 (a), set at 16°C except for a 21.5°C comfort period in the living room and hall from 7-11am, and in all rooms from 6.30 - 10.30pm. Household T-42 did not mention Evohome at the final interview so were not asked whether or what settings they used on it. Flat T-02 did not receive Evohome until April, due to issues contacting the resident. At the final visit in June, this property was set to heat to 18°C at all times, except for a comfort period at 21°C from 6.30 - 8am, and from

6 - 10.30pm, see Fig 3.13(b). This householder felt that the new controller gave better control of the heating system and its costs, although they were not using it for zoning control as T-05 were.

Figure 3.13 – Evohome settings for (a) T-05 (setting different rooms at different temperatures i.e. zoning) and (b) T-02

In terms of the effect of VCharge, average temperatures dropped in homes V-33 and V-39 – this could be as a result of better control of the desired temperature following install of the VCharge, or because of the increased cost following correction of the wiring at the time of VCharge install. In properties V-29, V-37 and V-59 a slightly larger increase was seen between periods 3 and 4.

VCharge settings were requested from Ovo for the participating households in March 2018, shortly after VCharge was fitted. This allowed zoning i.e. setting of (higher temperature) comfort periods at different temperatures and times of day in different rooms. The settings in use at 13/3/2018 are shown in Figure 3.14 below.

Figure 3.14 – VCharge settings for properties which had them installed in February and early March 2018

	Living room					Bed 1					Bed 2					Hallway					Notes
	AM		PM			AM		PM			AM		PM			AM		PM			
	From	To	From	To	Temp	From	To	From	To	Temp	From	To	From	To	Temp	From	To	From	To	Temp	13/03/2018
V-29	8.00	10.00	19.00	21.00	24	7.00	9.00	21.00	23.00	24	6.00	8.00	21.00	23.00	20	7.00	9.00	16.00	18.00	22	All Dynamos currently off
V-59	7.00	9.00	18.00	20.00	22	7.00	9.00	19.00	21.00	20	7.00	9.00	18.00	20.00	20	7.00	9.00	19.00	21.00	22	Bed 2 and living room off
V-39	8.00	10.00	19.00	21.00	20	6.00	8.00	21.00	23.00	20			20.00	22.00	18	7.00	9.00	17.00	19.00	18	Bed 1 and living room off
V-37	8.00	10.00	19.00	21.00	24	9.00	11.00	20.00	22.00	24	8.00	10.00	20.00	22.00	22	8.00	10.00	19.00	21.00	24	All Dynamos currently off
V-34	9.00	11.00	16.00	18.00	24	6.00	8.00	17.00	19.00	20	7.00	9.00	20.00	22.00	16			16.00	18.00	20	Bed 2 off

It is of note that both V-29 and V-37 had already turned all VCharge dynamos (and presumably storage heaters) off by this date – it is unknown when this occurred, but as the "beast from the east" cold snap hit the UK between 22nd Feb and 5th March 2018 and another cold snap on 17th-18th March, it is possible that heating may have been turned back on again. All flats had at least one area of heating turned off. Both flats V-29 and V-37 had set temperatures high at 24°C, which would increase their costs, particularly if they were not used to paying for their heating costs before correction of the wiring as part of this installation. Flat V-34 set the living room temperature very warm compared to other areas, given the dynamo in bedroom 2 is turned off, but this household was used to using electric panel heaters and spot-heating.

Comments on the usefulness of this Switchee data to WHG were also requested, and the reply was received that: "*This is useful, but it is really only used when a customer requests support, as part of gathering evidence about what is going on in their property, as we do not have the resources to contact a customer every time an alert is raised via the [Switchee] dashboard.*"

Switchee is also able to send / display messages to householders from the landlord e.g. regarding maintenance visits to their property. This function did not work initially. WHG reported that: "*We did get this to work, but customers did not respond to the messages*" so unfortunately that function was not found to be as useful as expected.

3.7 Current clamp data

TinyTag View2 and Lascar ACT current clamps were fitted onto the peak and off-peak electricity cables in each property where available - if no split in circuits was visible at the meter in the flat, one current clamp was fitted onto a cable into the household circuit fuse-box, and another on a cable into the heating & hot water fuse-board (often unknown whether this was live or neutral). 5 households which received each new heating type also received Landis & Gyr electricity sub-meters wired into the heating circuit, with Omega CP-101 pulse loggers wired into them. We did not know which households would receive these, so in some properties there was duplication, with households having both a current clamp and a sub-meter fitted on their heating circuit – this was a useful check, and where it occurred, the current clamp data is marked with a * on Figure 3.15. Given the wiring issues in this block, we did not compare the consumption against meter readings, since not all meters measured both circuits.

Analysis periods were selected of 23rd Nov – 12th Dec 2017, a period of 20 days immediately after installation of the new heating, but before those in the VCharge group had smart meters fitted. Period 2 was 23rd – 29th January 2018, after exchange of any faulty Switchees, and installation of the last monitoring equipment, but before any properties received Evohome or VCharge. Period 3 ran from 7th – 25th March, after 3 households in the Tempergreen group had received Evohome, and many of the VCharge group households had VCharge installed, but before householders turned heating off for the spring. Households V-18 and V-44 had not yet received VCharge by this point (only fitted late March-April, after many had turned their heating off), and households V-06 and V-07 never received it, due to withdrawal of the technology by Ovo during the project period.

As not all VCharge group households had switched to Economy 10 (the 4 just referred to remained on Economy 7 electricity profile during period 3, as they had not had VCharge fitted), it was not possible to analyse usage by time period, so 24hr energy usage is analysed for each circuit type.

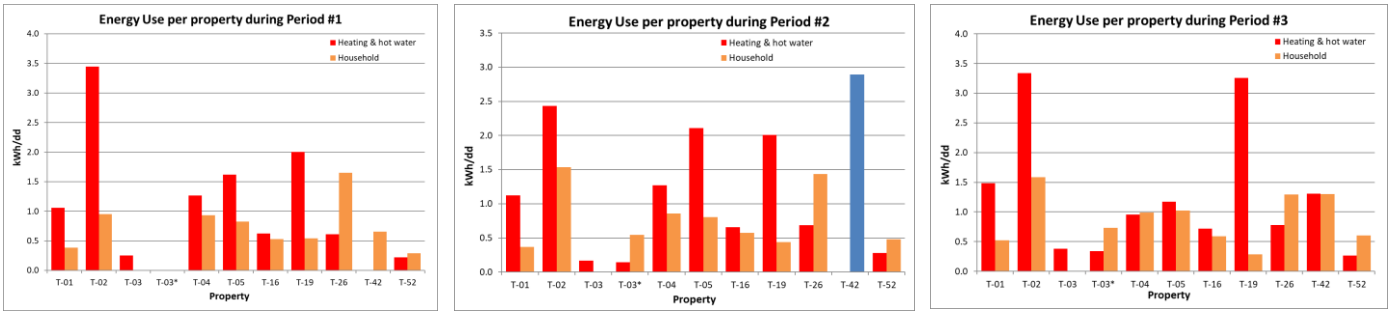
In charts of Figure 3.15, all heating circuits are coloured red, and household use in peach. Bars coloured blue show where current clamps were placed on the whole live (or neutral) circuit, hence no split was possible between household and heating circuits. In all other cases, if a whole live and another sub-circuit were monitored, these were used to calculate the current on the sub-circuit that was not monitored – this may introduce higher error in the calculated usage. This was the case for flats T-26 and T-42, where the live was monitored – it was corrected at the interim visit for T-42 (and an additional current clamp was added to monitor the heating circuit separately) – but T-26 was unavailable on this date, so household usage was calculated for the whole period.

For property C-09, no usage was recorded on the heating circuit in period 3 when it was monitored – this suggests that the hot water immersion tank was not used, and the residents report only using supplementary heating. The household circuit usage shown is therefore the flat's total electricity usage, including supplementary heating.

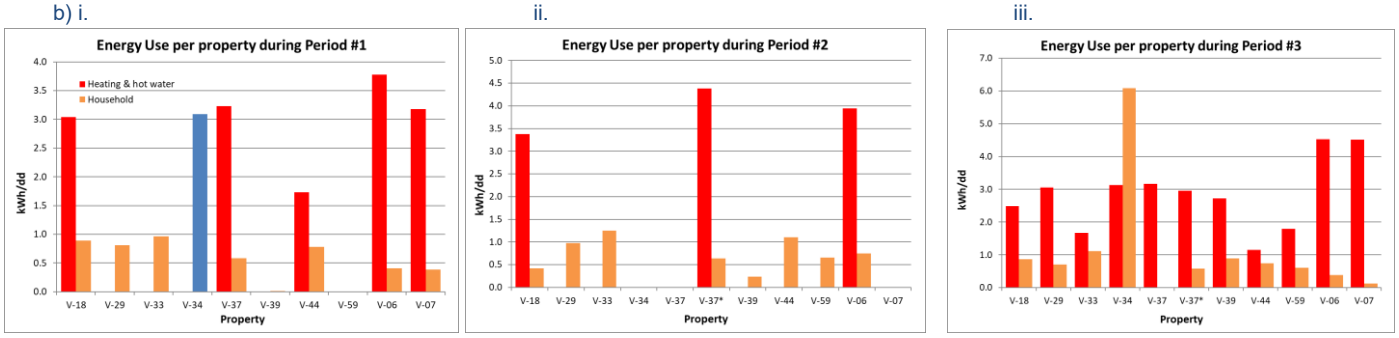
This shows that most VCharge households use more energy for heating and hot water on average, varying from 1.5 – 4.5 kWh/dd for VCharge (average 2.98 - 3.9 kWh/dd in different periods), than Tempergreen flats, at 0.25 - 4 kWh/dd (average of 1.02 – 1.58 kWh/dd for the different periods). Only T-02 (sometimes T-05,) and T-19 use more than 2 kWh/dd of heating in the Tempergreen group, whereas only V-33, V-44 and V-59 use less than 2 kWh/dd for heating in the VCharge group. In comparison, control properties which used storage heating used 2 - 5 kWh/dd (average 2.74 - 4.42 kWh/dd for the different periods), and control household C-09 which used only supplementary heating used 1.36 – 2.38 kWh/dd total energy use.

Figure 3.15 – Comparison of electricity use for (a) Tempergreen (b) VCharge and (c) control groups in Periods (i) 1, (ii) 2 and (iii) 3

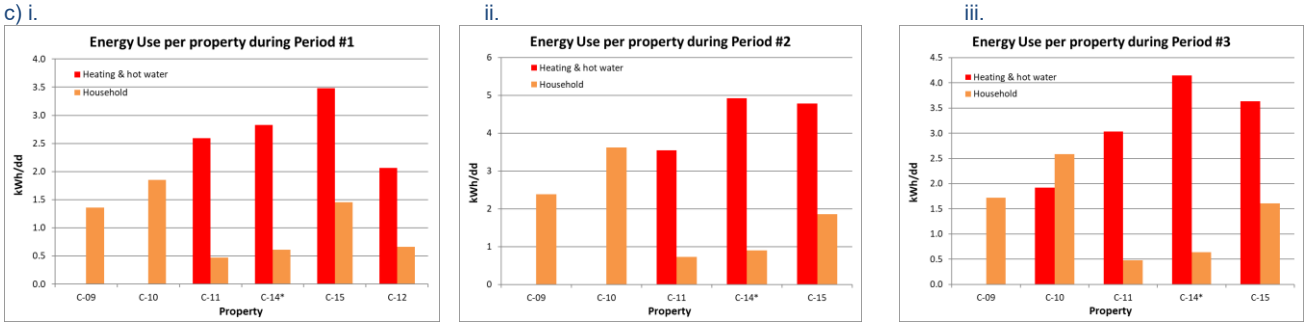
a) i. ii. iii.



b) i. ii. iii.



c) i. ii. iii.



In flat V-34 the current clamp was initially monitoring the whole circuit, but was detached during period 2 after installation of the smart meter. It was refitted on the household circuit at the interim visit in Feb 2018, and shows very high household circuit electricity usage in period 3. This would have increased costs, and may explain the household's dissatisfaction with "the heating cost" if they don't realise that the source is (a) high-powered item(s) plugged into a socket, not heating.

Comparing periods 2 and 3 for Tempergreen properties T-05, T-26 and T-42 which had received an EvoHome controller in the interim, shows a slight reduction in heating use per degree day for T-05, and possibly a small decrease for T-42 (though heating and household circuits were not monitored separately before period 3), but T-26 shows no detectable change, and household usage is higher than the heating contribution to bills. There is less information for VCharge group properties which had VCharge fitted between these periods (all but V-06, V-07, V-18 and V-44), as sub-meters were only fitted when VCharge was installed, whilst some current clamps were not fitted on the heating circuit initially, or had been detached due to works to the meter. Property V-37 is therefore the only comparison, which saw a reduction in energy use between the two periods. Other properties which had not received VCharge also saw reductions in energy use. For both groups, this may also be due to increased degree days from 7.7 per day in period 2 to 9.9 per day in period 3.

For households where both heating and household circuits were monitored, the proportion of total usage that heating made up was calculated. These are presented, for all periods for which it was available, in Tables 3.16 (a – c), and indicates that heating generally makes up a higher proportion of energy usage for the VCharge and control group properties than the Tempergreen group.

Table 3.16 – Comparison of electricity use for (a) Tempergreen, (b) VCharge and (c) control groups

a)

% heating	Period 1	Period 2	Period 3
T-01	58.7%	74.6%	73.9%
T-02	77.7%	50.4%	67.8%
T-03	-	25.8%	31.6%
T-04	58.7%	54.8%	49.2%
T-05	63.9%	74.4%	53.4%
T-16	48.5%	56.1%	54.8%
T-19	74.8%	70.5%	92.0%
T-26	17.4%	35.7%	37.5%
T-42	-	-	50.2%
T-52	42.0%	38.2%	30.4%

b)

% heating	Period 1	Period 2	Period 3
V-18	77.4%	89.1%	74.2%
V-29	-	-	81.4%
V-33	-	-	59.9%
V-34	-	-	34.0%
V-37	84.8%	87.4%	83.6%
V-39	-	-	75.3%
V-44	68.9%	-	60.7%
V-59	-	-	74.6%
V-06	90.3%	84.0%	92.1%
V-07	89.3%	-	97.4%

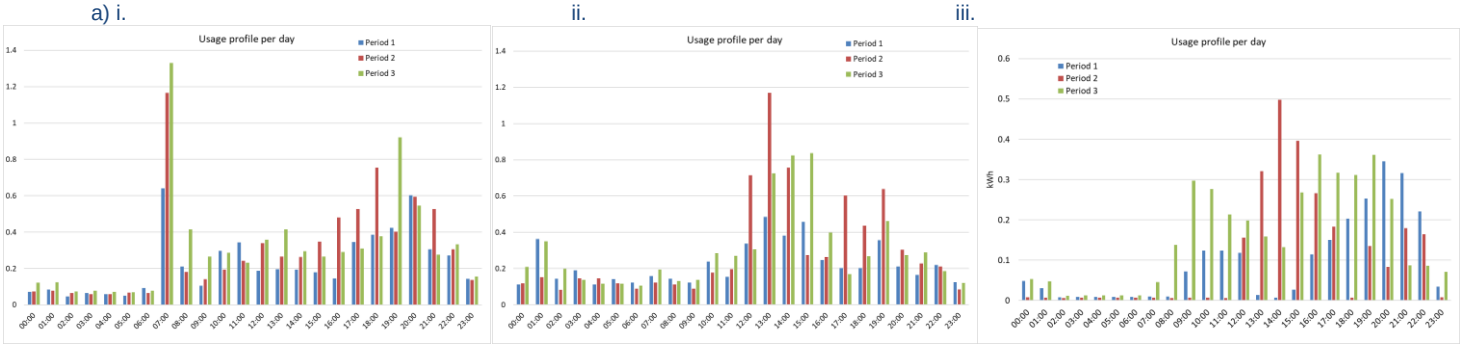
c)

% heating	Period 1	Period 2	Period 3
C-09	-	-	0.0%
C-10	-	-	42.7%
C-11	84.6%	83.0%	86.3%
C-14	82.2%	84.4%	86.6%
C-15	70.5%	72.0%	69.4%
C-12	75.7%	-	-

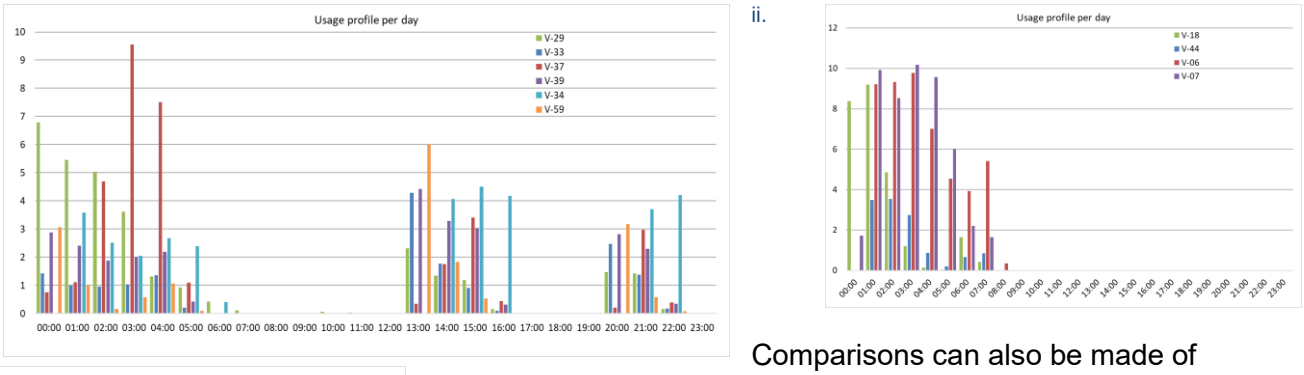
This suggests that households using both supplementary heating and Tempergreen may either be restricting heating use to ensure affordability, or are used to using only spot-heating - attaining cooler temperatures on average. This block is also highly insulated on the external face, so some households – particularly those resident in the middle floors - do not feel the need for much heat.

Figure 3.17 – Comparison of electricity usage profiles during a 24hr period for (a) Tempergreen (b) VCharge and (c) control groups

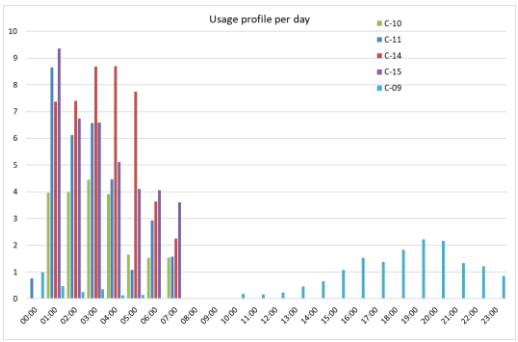
a) i. ii. iii.



b) i. ii.



c)



Comparisons can also be made of when households use electricity for heating, and how much, as shown in Figure 3.17. Tempergreen households had the most variable usage, given it is on-demand heating e.g. flat T-26 (Fig. 3.17 (a) i.) uses a short sharp peak of morning heating followed by a low steady usage peaking at 7-8pm, whereas property T-16 (Fig. 3.17 (a) ii.) uses most heating in the middle of the day. As usage in all periods 1, 2 and 3 are shown for this group, changes in shift pattern between the periods can be seen for property T-03 (Fig. 3.17 (a) iii.).

In period 3, the 6 properties with VCharge fitted show Economy 10 usage profiles, see Fig. 3.17 (b) i., varying depending on their temperature set points and times. However, 4 properties, V-18 and V-44 which had yet to receive VCharge, and V-06 and V-07 which would never receive it, had an Economy 7 profile, Fig. 3.17 (b) ii. This was also the case for the control properties, apart from flat C-09 which only uses supplementary heating (for this home, the full peak circuit is displayed, not only heating but also appliance use).

4. Conclusions and recommendations

4.1 Conclusions

The project's aims were to:

- Replace the existing storage heaters with either Elnur storage heaters coupled with Ovo's VCharge technology on an Economy 10 (time-of-use) tariff, or Enviroheat's lower-energy on-peak EconoRads and EconoCylinder, on a flat-rate energy tariff.
- Assess any change in residents' comfort – as reported in questionnaires, and measured using temperature and humidity monitors – after the new heating, any solar PV and coupled system,
- Quantify any change in electricity use and costs for heating, and general household use, following the measures, compared to the period prior to installation, and the control properties
- Report any change in ease of use of the heating system with the new measures fitted,
- Compare these two energy solutions in terms of cost, comfort / temperatures achieved, ease of control by the tenants, in comparison to control properties,
- Determine the effectiveness and cost-effectiveness of these measures to reduce fuel poverty in off-gas developments of flats, and whether either solution is more suitable or effective - information relevant to many social housing (and private) owners in many areas of the country.

Summary of Findings

- Residents' feedback indicated a marked improvement in comfort, with numbers saying they could keep comfortably warm at home increasing from only 2 of the 9 initially interviewed in the Tempergreen group up to all 10 interviewed at the end of the study. In the VCharge group, this increased from 7 out of 9, up to all 10 by the end of the study. In the control group, all felt they could keep warm enough. Numbers reporting that they needed to wear extra clothes at home to keep warm enough decreased from 7, and 6 out of 9 households in the Tempergreen and VCharge groups respectively, to only 3, or 4 of 10 in the same two groups by the end of the study. Only 2 of the 6 control group reported needing to wear warm clothing at home.
- 5 of the 10 Tempergreen group said they could now heat and comfortably use (more of) the home, as did 6 of the 10 VCharge group. Before the new heating, 3 of the 10 Tempergreen group had only heated one room, and 2 rarely heated the flat at all. Only 3 heated the majority of rooms, but none heated the whole flat. By the end of the study, whilst 3 still reported heating only the living room, none used no heating, and 4 of the 10 stated they could now heat the whole flat. For the VCharge group, 2 of the 10 had previously heated only the living room, and only one heated the whole flat, whereas after the new heating, 7 of 10 said they heated the whole flat and only one heated just the living room.
- The households did not have thermostats previously so residents' prior ideas of their heating temperatures would not be accurate. At the end of the study, all 10 Tempergreen group said they heated their flat to 18-21°C or higher (7 to over 21°C). In the VCharge group, 9 of the 10 heated to 18-21°C or higher (4 to over 21°C) and only one heated to 17°C by preference.
- Supplementary heating use on a daily basis decreased from 12 of the 20 households (7 of these instead of storage heaters) to 2 of the 10 Tempergreen group, and these used it only briefly to heat rooms quickly on getting up / bathing children. In the VCharge group, only 3 of 10 now needed to use supplementary heating daily, 2 in evenings and one resident's young son liked to turn the living room fire on – this was reported to WHG to fit a child-proof lock.
- Notable benefits identified included: the heating being easier to use / control, the flat being warmer and more comfortable, and the new radiators looking better than the old ones. 8 of the

Tempergreen group also felt that their home kept the heat in better – as no insulation work was done, we believe this question was interpreted as being able to have heat later in the evening than was previously possible. Many said the new heating improved the quality of the home, and the house gets warmer faster. However, few felt they were saving energy or money on bills. Parents of young children in both groups commented that the new heaters were cooler to the touch than the old storage heaters - less likely to burn children - so safer to use.

- Residents' behaviour also changed – few previously adjusted the controls of their storage heaters, but after the new heating, 9 of the 10 Tempergreen group adjusted the heater controls if they were too hot/cold rather than putting on/taking off clothes or opening windows. However, only 3 of the 10 VCharge group would log onto the VCharge website to adjust the settings if too cold/hot, so a few still resorted to supplementary heating and extra clothes.
- In both groups, 4 residents felt their hot water use was easier / better than previously, and 4 felt it was the same as before (2 did not answer in each group). 5 of 8 households in the Tempergreen group who had previously suffered damp / mould issues said it was improved, and all 3 in the VCharge group who'd had damp issues felt it was better (though not gone).
- Satisfaction with all aspects of the heating improved, especially for the Tempergreen group, particularly relating to how much control they had over the heating and how easy it was to use, which had both been very low before. The VCharge group stayed on average a little dissatisfied with costs of the heating: this is likely to link to historic wiring issues being rectified, so they had to pay for their heating costs for the first time. In many aspects, satisfaction increased above that for the control group – for both new heating systems in amount of control over their heating, and for the Tempergreen group with the cost of running the system. Both groups were now on average satisfied with how warm their flat gets when it's cold outside, how easy the system is to use, and how well the home keeps the heat in.
- In terms of ease of use, most householders in the Tempergreen group felt the new heaters were easier to use than their old ones, and knew as much as they needed to about how the system worked and how best to use it. They only slightly agreed that it didn't require too much input, as most were actively turning the heating on and off as needed. For the VCharge group, there was more agreement that the new heating didn't require their active input, and on average agreed that the measures were easy to use. However their responses fell exactly between agree and disagree for both knowing enough about how the new heating worked and understanding how best to use it, indicating that many were unsure. 5 VCharge group residents commented that they were unsure how to control the system, needed assistance to set up VCharge via phone or internet, or to log in, and others also wanted a reminder of how to use the system in the autumn.
- For support needs, most in the Tempergreen group agreed that they were clearly shown how to use the system, and received instructions, a manual or guide, they knew who to contact about any issues, and received prompt & effective support if needed. Despite one householder being unsure that they'd received paper instructions, all 10 felt they knew how to control their system adequately. However, in the VCharge group respondents only slightly agreed with these statements on average. 7 of the 10 said they were shown how to use the new controls for the system sufficiently clearly but only 5 said they received paper instructions to refer to, and 4 felt they cannot control their system adequately for their needs, showing that lack of knowledge, dissatisfaction / confusion and outstanding issues remain with this more complex system - particularly to access and control the system via the VCharge app / website.
- Half of the Tempergreen group had suffered breakdowns or reliability issues with the new

heating since it was fitted: 3 related to room thermostats losing connection with the radiators, all of which had been resolved quickly (though it reportedly recurred) and 2 related to the Switchee “freezing” – one had rectified itself, but the other had never been resolved – the household had received an EvoHome but it reportedly also lost connection from the system, so residents were controlling the heaters manually using room thermostats only. 4 of the 10 VCharge group reported reliability issues where heating had stopped working: all were fixed within a few days, but in one case the issue rectified itself before the resident had reported it.

- 16 of 19 initial respondents reported general maintenance issues which caused them concern with keeping warm or increased their bills. At the final questionnaire, 4 out of 10 Tempergreen respondents and 7 of 10 VCharge group householders highlighted issues. These included draughty windows and front doors, mould above the living room window, a major roof leak, insufficient hot water, assistance required with using the VCharge website, and with billing issues related to the project. These should be fixed / resolved to maximise benefits from the new heating. All issues reported were passed to WHG for action.
- Householders’ comments about the installation were mixed, with some reporting that the Enviroheat installs didn’t take long, but some negative aspects were also reported: leaving a resident’s hot water on boost - which used up all the credit on their meter, so they had to turn everything off and stay elsewhere until it was resolved – and a disorganised installer who used offensive language, making a resident feel uncomfortable. In the VCharge group, half felt the installation was fine, with installers being helpful, explaining everything, one said the first installers were careful but another who came later to fit Switchee and VCharge was very rude. 3 of the 10 said they got rather confused with lots of visits to install and fix different parts of the system, and the whole installation period went on for too long. Residents’ views about the project organisation were generally good, agreeing that installers were careful and respectful, they were told in advance when installers were coming and had been given all the info needed before they agreed to take part. Those in the Tempergreen group also agreed that they were kept informed of any delays or changes, and that they’d been given details of a contact for any issues they had, but the VCharge group agreed less with both these aspects – unsurprising as it is known that this was a long and complicated install process with various installers involved.
- All residents in the VCharge group had received support to ensure they switched to Ovo’s Economy 10 tariff, as VCharge only works with this, but there was some confusion, with a type of smart meter only compatible with Economy 7 initially installed in some flats. 2 which never received VCharge would be free to switch to any supplier of their choice. Most Tempergreen group residents were aware that they should switch to a flat rate tariff, and had done so (some discovering that they were already on one), with some requesting support to do this, but 2 residents were found to still be on an Economy 7 tariff at the final interview. One was assisted to switch to a flat rate at that time, the other was referred to WHG for this support.
- 5 of 9 Tempergreen group residents recalled receiving energy advice as part of the project, though only 2 had made changes as a result. For the VCharge group, 6 of 8 who responded to the question recalled receiving energy advice, and 4 had made changes as a result: fitting low energy light bulbs, doing washing late at night, and understanding the heating controls better.
- One difference noted was that 7 of the 10 in the Tempergreen group stated they did not know who to go to for energy advice, and 6 wouldn’t consider changing how they used / paid for energy to help save money. In contrast, 8 of 9 in the VCharge group said they knew where to go for energy assistance, and 5 of 8 would consider making changes to save them money. This difference in engagement was visible in behaviour around energy bills/statements with 7

of the 10 Tempergreen group never receiving or checking any information from their supplier, whereas only 2 of the 10 in the VCharge group said they hadn't had any statements, with more checking to see if they were in credit/debit, if they'd made savings, or against meter readings.

- In terms of affordability perception, residents' statements about their energy payments resulted in estimates that the Tempergreen group paid £1,084 per year on average at the start of the study (varying between £390-2,340), and £1,160 per year (varying from £480-£3,120) after the measures. The VCharge group's estimates were £863 (varying from £348-£2,080) at the start of the study and £1,234 (varying between £480 and £2,860) at the end of the study. Energy prices increased during the study, and winter 2017-18 was very cold, which will affect the responses, as would the wiring issues experienced mainly but not only by the VCharge group. In comparison, control properties paid £1,108 (between £480 and £1,825) at the start and £1,029 (from £360 to £1,820) at the end of the monitoring period, changing very little.
- By the end of the study, 3 of the 10 Tempergreen households felt that their bills were cheaper, 2 said this had reduced their money worries a little, and one reported it had reduced financial concerns a lot. 5 felt that they were paying about the same as before, but 2 felt that their energy bills were a little bit more expensive. Some commented that they were heating the flat for longer for the same cost. In the VCharge group, of the 8 residents who responded, only 1 felt their energy bills were cheaper, 1 said they were about the same, but the remaining 6 said their bills were more expensive. This is highly likely to be due to having the heating circuit wired through their household meter for the first time. Whilst 2 households felt the new heating had reduced money worries a little, and 1 felt they were the same as before, the remaining 5 felt the measures / project had made their money worries worse (3) or a lot worse (2).
- Previously, whilst the control group showed low levels of concern about energy affordability, both groups due to receive new heating showed more concern. On average there was slight agreement that they worried about paying fuel bills, and they have the heating on lower or less often than they'd like so their bills weren't too high. All these concerns had reduced markedly by the end of the study for the Tempergreen group, but whilst concerns over their ability to keep warm (and its impacts on health) had reduced in the VCharge group, their worries over affordability of energy and rationing strategies had not reduced much: half of respondents still agreed that paying for energy meant buying less of other essentials e.g. food, and they had the heating on lower or less often than desired to keep the bill down.
- Most residents in the Tempergreen group said they felt more in control of their energy bills, though they neither agreed nor disagreed that they'd seen savings on their energy payments, or reduced unneeded heating, and few said they'd specifically tried to save energy / money on energy. Their general money worries had changed little since the start of the study. In comparison, the VCharge group disagreed that they'd seen savings on their energy payments, and slightly disagreed that they'd reduced unneeded heating in their home (most felt there hadn't been any unneeded heating previously), and that they felt more in control of their energy bills. Again, this latter can be linked to the financial effects of correcting previous wiring issues. There was slight agreement that they had tried to save energy more, and understood more about how to save energy. However, this group's general money worries had decreased slightly since the start of the study.
- Taking into account electricity use (kWh) and costs:
  - Small savings of 2.2% in energy use and 2.8% costs were calculated for the Tempergreen group if flats T-03 (little energy use in previous year) and T-19 (faulty PPM, not paying for energy) are excluded, but these were not statistically significant as 2 householders made

savings, and 2 increased both their costs and energy use. Usage averaged 2.4 kWh/dd, and normalised costs were calculated to average £810 for this group.

  - The VCharge group flats saw increases in energy use – again linked to many having the heating wired through their household meter for the first time. The two households which did not previously have this wiring issue, V-18 and V-44 saved 17% and 33.6% on heating respectively when normalised for the colder winter in 2017-18, although V-44 used 28% more energy, as their living room storage heater did not previously work. (V-34 may also not have had the previous wiring issues, but high household i.e. non-heating energy use in this flat would have increased costs, so was excluded.) Average energy use was 4.1 kWh/dd for this group, and their degree day-normalised costs were calculated to average £837.
  - For the control group, savings were not expected as no measures were received. Their energy usage was 4.6 kWh/dd, and average normalised costs were £1,053.
  - Cost intensity for heating is therefore calculated at £339/kWh/dd (normalised for this period) for the Tempergreen group, and £206/kWh/dd for the VCharge group. This compares to £230/kWh/dd for the control properties.

- Plotting performance lines of electricity use against degree days of heating need suggest that only a few Tempergreen properties saw better control of energy consumption after installation of the new heating system, with points closer to the best-fit line (higher R^2 values) and/or lower slope or intercept. As this is an on-demand heating system with manual, residents are likely to use it as required to achieve comfort when they are at home – which may not correlate with external temperature / heating need. More information was available from VCharge properties as smart meters were fitted as part of the project, but not all had previous usage information to compare against. The properties with previously correct wiring showed improved efficiency for V-18 and increased energy use (from use of an extra storage heater) but better correlation with heating need for V-44. Households which were previously only paying for their household circuit electricity use showed an almost flat line before install with no correlation with degree days, and a slope relatively well correlated with degree days after the wiring was corrected.
- Temperature monitoring showed that living room temperatures for the Tempergreen group were cooler on average than for the VCharge group after their new heating was fitted, however both groups were cooler than the control properties. All but one property, V-06 achieved the 18-21°C recommended temperature range for comfort and good health before installation, and all did after the new heating was installed. Bedroom temperatures were more variable, with properties T-16 and C-09 clearly hardly heating the bedroom, T-01 increased heating in the bedroom during the study, but V-34 evening bedroom temperature decreased during the study period. 3 households heated their flat significantly warmer than the recommended range (one control, C-15, and 2 VCharge properties, V-18 and V-33) which would increase their costs. No change in temperature can be noted after properties received EvoHome or VCharge.
- Humidity levels were not well controlled, with some households (generally but not always those with high temperatures) having lower than the recommended range of 40 - 60% rh, but others having higher levels than this, approaching 80-90% in bedrooms. These were generally properties with identified leaks or water ingress / cold bridging, or under-heating issues (C-09). High humidity in property T-01 which was previously under-heated was brought under control once temperatures increased with the new heating. However, no general trends were detected in humidity levels during the study.
- Temperature and humidity data from Switchee – located in the hall - again shows that Tempergreen properties were on average cooler, and their humidity levels higher, than

VCharge and Control group homes. No notable effect can be seen of installing either EvoHome or VCharge in those which received them, compared to those which did not. Again, households with known leaks or other issues were more likely to show up with higher humidity.

- Current clamp monitoring of electricity consumption gave an indication of changes in peak and off-peak (or heating circuit for Tempergreen group properties) energy use This shows that:
  - Tempergreen properties generally used a lower amount, and proportion, of their electricity use on heating than those in the VCharge group.
  - A small reduction in heating energy use was detected for 2 Tempergreen properties which received EvoHome in addition, but another showed no saving. Less information was available for VCharge group properties, so only one could be compared, which made a small saving after receiving VCharge, however other properties which had not received VCharge also saw a small saving over the same period – it is possible that apparent savings may be linked to more severe weather (hence higher degree days) in March.
  - Patterns of usage show that the Tempergreen system is easily adaptable to the resident's heating demand, with distinct patterns of use for some households and irregular usage in others. Energy usage in off-peak periods shows the effect of VCharge, tailoring charging to set heating periods and temperatures. The properties which had yet to receive VCharge, and control properties all had an Economy 7 profile, apart from one control property which used supplementary heating only.
- SAP values of flats varied widely (58 (D) to 77 (C)), averaging 67.6 (D) before the measures. No EPCs were done since the works were completed, so no changes can be reported. Whilst thermostatic charge control would increase the SAP rating of a property, installing on-peak heating would decrease the SAP rating due to the high per-unit cost of the electricity.

4.2 Recommendations for potential future installations

For any improved heating system and controls – to prevent energy being lost via draughts and heat loss, maximise resident comfort, energy and carbon savings and minimise resident disruption - NEA recommends that heating upgrades should be carried out alongside a wider property thermal improvement programme. This should address all other heat loss issues evident in the home such as insulation, draughty windows and doors, adequate and controlled ventilation etc. Take-up of energy efficiency improvements is increased if works are done on a whole-house, rather than individual technology, basis. Such works should ideally be carried out prior to new heating installation, so it runs most efficiently, the householder sees the benefits, and they can be supported in its set-up / use only once, without having to change behaviour / set-points again later.

It should be ascertained at the feasibility stage of any project whether ancillary works – such as Internet availability is present, or its installation should be programmed into the project. It should never be assumed that households have broadband connections. Also, if mobile networks are to be relied on (GPRS, 3 or 4G), signal strength for the chosen network should be verified on site, in the location where communications devices will be installed.

Advice and ongoing support should always be provided to all residents at installation of any measures: as well as specific information on how to best use the measures and their controls, this should also cover how - and when, to make best use of the Economy 10 rates - to use energy most cheaply and efficiently in the home, to reduce expensive supplementary heating use in favour of whole-house heating, ensure residents are claiming all benefits for which they are eligible, that they are on the best energy tariff for their use, and to resolve any billing issues found, especially if

they are linked to changes of metering as part of the project. Greater support is also recommended to assist residents to switch electricity tariff type when this is advised – this opportunity should be taken to offer a full tariff check to ensure that they switch to the best tariff available for their usage patterns if they are on a poor-value or inappropriate tariff.

Particularly for these 2 types of heaters - which are more complicated than those they replace - greater support and “Quick-start guides” are recommended (laminated next to the controls, or in an airing cupboard, so they cannot get lost) as a reminder to explain simply to residents how to set key parameters, such as temperature; how to use the Switchee, room thermostats, EvoHome controller or VCharge website (as appropriate for the system installed, and whichever is the overall controller of the system) to set different temperatures at different times of day and in different rooms if desired, hot water heating times / frequency; and details of when to run high electricity-using equipment to make best use of the Economy 10 periods for those in the VCharge group.

With a small proportion of monitored homes suffering issues with their system, generally due to lack of knowledge / recollection of how to set it up for their needs, follow-up checks are required a few weeks after installation, by a competent officer trained in the technology. This is also recommended at the beginning of the subsequent winter, to pick up on teething problems and remind residents who have forgotten how to use the system over the summer. These should cover the above-mentioned advice and checking that the settings of the heaters match the timing and temperature needs stated by the resident. They should also cover other aspects of the heating and hot water system such as checks for mould, appropriate timing/control of the immersion tank for residents’ needs / property and advice / repairs as needed. Some residents – particularly those with memory or other issues – will be unable to set up their heating system so will require an installer or energy champion to do it for them. Development of more accessible and intuitive control methods for the VCharge system (or any replacement) would be recommended as some residents were not online.

Better training of contractors is recommended to ensure that they are able to look out for issues such as residents being on the wrong type of electricity tariff, and provide enhanced support for residents, or flag this up to housing association staff. Training must also be provided to housing association staff so they are aware how to maintain the heating systems installed, can provide ongoing support to residents, including any new tenants who move in, and know who to contact for further assistance if required, especially now that the VCharge technology is no longer available.

New tenants of properties which have received modern heating systems which are different from standard types must be provided with details of a department within housing associations which can visit to provide help / information, instructions / quick-start guide or manual, and contact information for any parties required to be contacted to set up e.g. the necessary Ovo tariff and VCharge registration set-up. However, this would also be advisable for any new tenant moving into a property with a standard type of heating system as there are many variants so they may never have come across the specific type installed, and poor knowledge and control of any heating type can result in extra financial cost, discomfort and fuel poverty.

4.3 Impact on fuel poverty

These measures appear to aid efforts against fuel poverty:

- Reductions in electricity bills of c. 25% for 2 VCharge properties which had not had previous wiring issues rectified. For properties where this issue meant they had to pay for heating for the first time, the cost increase was relatively small once the harsh winter of 2017-18 (resulting in increased heating need) was taken into account. However, there were issues of residents not understanding how to control their heating, potentially increasing costs or dissatisfaction.
- The majority of residents receiving the Enviroheat heaters liked them, and understood how to use them to heat their home when they wanted, more evenly distributed in the flat using the electric room fire. Many felt they now got more heat and comfort later in the evening than before, for the same cost, or only a slight increase.
- However, those using Enviroheat heaters used a lot less heating than those with VCharge, potentially limiting their use to maintain affordability, or habituated to lower temperatures. An off-peak solution would be more cost-effective, although VCharge – which ties residents to a specific company's energy tariff, controlled via a website - is unlikely to be the best solution.
- Marked improvement in comfort:
  - All 10 of 10 households in each group could now keep comfortably warm, compared to only 2 of 9 in the Tempergreen group, and 7 of 9 in the VCharge group before,
  - Residents in only 3 and 4 flats (of 10) now need to wear extra warm clothes in the home to keep warm for the Tempergreen and VCharge groups respectively, whereas 7 and 6 out of 9 said they needed to previously.
  - 5 and 6 of 10 in the Tempergreen and VCharge groups respectively said they could now heat and/or comfortably use more of their home, with 4 and 7 of 10 in the two groups respectively now reporting that they are able to heat their whole flat.
  - The main benefits identified in both groups were: the flat was warmer and more comfortable, and the heating was easier to use / control. 8 of 10 in the Tempergreen group said the flat retained heat better (assumed to mean they could have heating later in the evening if desired, as no insulation was done);
  - Some improvements were seen in ease of hot water use, with 4 of 8 who responded in each group saying it was better (and the remainder seeing no change)
  - 5 of 8 Tempergreen group households which had suffered with damp/mould felt it was improved, as well as all 3 in the VCharge group with damp issues.
  - Improved satisfaction with the heating system, especially the amount of control residents had over the system, how easy it was to use, and now satisfied with how warm the home gets when it's cold outside, and how well the home keeps the heat in. The VCharge group remained a little dissatisfied with the costs of running the system – likely to be due to previous wiring issues present in the block, rectified as part of this study, meaning they had to pay for their heating for the first time with obvious increase in costs.
  - Other benefits identified included the new storage heaters looking nicer than old ones, and the cooler surface temperature of the heaters made parents of young children more confident to use them, as would not burn their children if they bumped into them.
  - Residents' behaviour also changed – Tempergreen group residents were more likely to adjust the controls if too hot or cold (wasting less heat), rather than putting on/off extra clothes, supplementary heating or opening windows; a few in the VCharge group adjusted settings via the website (but knowledge / incidence of this was only 3 of 10).

- 3 of the 10 Tempergreen group felt their energy bills had reduced. This had reduced money worries a little for 2 respondents, and a lot for another. However, 2 felt their bills were a little more expensive than previously. Some commented that they were able to heat the flat for longer for the same cost. In the VCharge group, only one household thought their bills were cheaper, one said they were the same, but all others said they were more expensive – this is due to the previously mentioned wiring issues.
- On average, approx. half had concerns about affording energy bills previously - with slight agreement that residents worried about paying their fuel bills, and heated the home less than desired to save money. About half reported cutting back on essentials to afford their energy bills, and suffering negative health impacts due to cold homes. These were no longer issues of concern, on average in the Tempergreen group, after the new heating. In the VCharge group, though residents reported now being able to keep warm (so reduced impact on health), worries about affording bills remained – linked to increased costs from rectifying wiring issues.
- There was a reduction in expensive supplementary heating need from 12 households (of the full 20) having to use it initially, to 2 and 3 of 10 after measures were fitted in the Tempergreen and VCharge groups respectively, and most only for short periods, when weather was particularly cold, or in autumn before storage heating had been turned on.
- Temperatures achieved during the evening period were within the recommended 18-21°C range for all groups after install of the new heating – some households heated to higher than this, which would increase costs. Average temperatures in Tempergreen properties were lower than those in VCharge properties, which were slightly lower than those in control properties. Bedroom temperatures were much more variable, some households clearly not heating the bedroom at all while others heated it to high temperatures.
- Humidity levels were very variable, with some households with high temperatures having lower humidity than the recommended 40-60% RH range, and others with low heating temperatures or known leak issues which increased humidity – especially in bedrooms, some of which reached 80-90% RH. A few homes which were previously under-heated had their humidity levels brought under control.
- Current clamp and sub-meter monitoring of heating energy usage show that Tempergreen group properties used less energy for heating - and a lower proportion of total energy use - than those in the VCharge group on average. Households using Enviroheat heaters (Tempergreen group) may have either restricted heating to ensure affordability, or be used to using only spot-heating, attaining cooler temperatures on average. VCharge group properties used more energy but at lower cost, due to the majority being on the lower cost off-peak rate.
- It is notable that this block is highly insulated on the external face, so some households – particularly flats in the middle floors - do not feel the need for much heat. Enviroheat heaters may be most suitable here so heat is available on-demand as needed. But for households which require daily heating, an off-peak (i.e. storage heater) solution would allow a greater level of comfort for a cheaper cost. However, the VCharge website was not easily accessed & understood - more easily accessible and intuitive controls would be recommended.
- The impact of these measures could be improved in any future wider roll-out by providing greater assistance in their best use, and pairing them with other efficiency measures including improving insulation, replacing draughty windows and doors and other draught proofing.
- The ease and satisfaction with use of time-of use tariffs could be improved by opening technologies like VCharge up so residents can choose any supplier’s Economy 10 tariff, rather

than being restricted to only Ovo/Boost. One resident had not realised they were permanently tied so switched away to another supplier, and their heating & hot water stopped working until VCharge was “wired around”. Price rises also occurred during the project, which may normally may trigger switching behaviour, but it was not possible here. The ethics of tying vulnerable households to a specific supplier must therefore be considered, as it is not recommended.

4.4 Performance comparison against manufacturer’s claims

The only claims made about the Enviroheat heaters were their reported savings made against regular electric panel heaters, which were not tested here, so no comparison can be made.

The VCharge system claims to result in lower energy bills – as well as improved comfort - due to householders no longer having to use plug in supplementary heating. The 2 flats in this group which did not have wiring issues rectified as part of the study saw 25.4% cost savings on average, however this is only indicative as this sample size is too small to be statistically significant.

It is important to note that savings calculated in this study are likely to be lower than might be seen in more affluent households: the study targeted residents in a localised geographical urban area (exposed tower block, though with a well-insulated exterior surface), and who were in - or at risk of - fuel poverty. Many were in the home much of the day due to unemployment, having young children, and/or suffered health issues which means they would need to keep their home warm for longer in the day than a working household. However, many were clearly using less heating than needed in the period before installation of the new heating due to energy-rationing behaviour i.e. under-heating the home, so reducing their potential for cost savings.

Most residents reported improved comfort, being more likely to attain the recommended 18-21°C temperature range or higher (even with the colder outdoor temperatures of winter 2017-18), and/or able to heat or comfortably use more of the flat than previously. This improvement in comfort would also have reduced apparent financial savings as a result of the measures installed. These findings are therefore not necessarily transferable to other situations, or geographical areas of the UK.

4.5 Economic business case for installation of measures

Table 4.1 below shows the business case for installation of the two systems:

Measure	Capital cost	Installation costs	Total	Annual energy saving (from this study)	Indicative annual payback	Assumptions
Enviroheat (Tempergreen) & Switchee	£5,424		£5,424	No saving can be reported	N/A	• Households able to use more heating, at desired times of day (often for same cost).
Enviroheat, Switchee & EvoHome	£5,716		£5,716	No saving can be reported	N/A	• Households can use more heat, at desired times of day (often for same cost), with zoning function.
Elnur storage, VCharge & Switchee	£2,223		£2,223	25.4% (£125 - £423)	5.25 - 17.7 yrs	• Based only on 2 homes with no prior wiring issues. Small sample size not statistically significant.

Table 4.1 Summary of business case, all costs listed are per property

Costs per property reported are for this small study installing systems to 10 homes for each type of heating system – cost per property could be expected to be lower for larger volume installations.

As for all new technology, it is expected to continue to develop, and costs to reduce further.

No savings were expected for the Control group. As samples were small and variable, once those with wiring, data or other issues were excluded, it was not possible to report savings for the Tempergreen group (including the sub-group which received EvoHome), and that reported for the VCharge group is based on only 2 properties – an indication only.

It should be ensured that residents are confident in the use of the measures installed (or if unable to do it themselves, that the system is set up for them as they require) otherwise there is a danger of appliances being turned off, not achieving safe temperatures, or extra heating costs (supplementary or over-heating through lack of knowledge how to control heating).

Savings will always be greatest if also combined with other measures to improve insulation and controllability of ventilation where needed – especially measures which attract government ECO funding – replacing windows and front doors with more insulated ones when these require replacement, and insulating walls which adjoin unheated & externally ventilated areas of the block. Flats in top, ground and first floors (above unheated areas) would benefit from ceiling and floor insulation respectively, to reduce heat loss and heating need further.

Appendix 1: Glossary of Terms

DD (or dd)	*Degree Days*
DHW	*Domestic hot water*
ECO	Energy Company Obligation (scheme requiring energy companies to fund energy efficiency improvements)
EPC	*Energy Performance Certificate*
ESH	*Electric storage heating*
HIP	*Health and Innovation Programme*
HHR	*High heat retention*
IMD	*Indices of Multiple Deprivation – a measure of the level of deprivation in an area*
kWh	*kilowatt hour – unit of energy consumption*
LSOA	*Lower super-output area – the smallest area for which statistics are available*
NEA	*National Energy Action – the National Fuel Poverty Charity*
PPM	*Pre-payment meter (for electricity)*
RH	*Relative Humidity*
SAP	*Standard Assessment Procedure (for assessing home energy efficiency)*
TIF	*Technological Innovation Fund*
WHG	*Previously known as Walsall Housing Group but now expanding beyond the Walsall area, so rebranded to use the initials only – owner of the social housing in this study*

Appendix 2: Health and Innovation Programme 2015 – 2017

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

The programme comprised 3 funds

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

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

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

What it involved

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

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

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

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

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