TECHNICAL INNOVATION FUND

CP754

Solar Thermal & Biomass / Multi-fuel

Ceredigion County Council

Technical Evaluation Report

Tomos Davies, Bryony Holroyd & Michael Hamer
November 2017

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Ceredigion County Council

Number of households assisted	16
Number of households monitored	10

Background

About National Energy Action

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

About the Technical Innovation Fund

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

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

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

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

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

Technical monitoring and evaluation

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

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

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

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

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

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

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

Acknowledgements

With grateful thanks to our project partners:

Graeme Lane, Ceredigion County Council
Tai Ceredigion
Tai Cantref (later Wales and West Housing Association)

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October 2017

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Executive summary

Overview

This project was delivered by Ceredigion County Council. It had the following aims;

- To install and evaluate the effectiveness of combining solar thermal and multi-fuel stove and back-boiler systems as replacement space and hot water heating in rural off-gas properties; compared to those receiving solar thermal only
- To determine the energy-saving benefits and acceptability to householders of using these technologies
- To provide evidence as to the appropriateness of these systems for other areas and partners.

Background

Ceredigion comprises of a series of isolated rural communities, with 82.4% of homes not connected to mains gas – the highest number of off-gas properties in Wales. Tregaron, the area targeted for the project, falls within the top 30% most deprived, and the rural areas around it fall within the top 10%, in terms of access to services.

It is unlikely that any significant proportion of these rural Welsh homes will receive new gas connections in future, as this would not be cost-effective given the distances involved. Efficient non-gas heating methods must therefore be assessed to address fuel poverty; and renewable technology options explored to help reduce reliance on fossil fuels in this region.

The technology

The partners had originally intended to test biomass (wood-pellet) room-stoves with back boilers, combined with solar thermal panels, in homes not connected to the mains gas grid, but they changed the specification to multi-fuel stoves - for burning logs and solid fossil fuels - instead of biomass. The stoves provide heat in the main living room, and the back boiler also heats both domestic hot water and central heating radiators. Solar thermal uses energy from the sun to heat domestic hot water.

The idea of the combination of technologies was that the solar thermal panels could provide all the household's domestic hot water (DHW) need in the summer months, as well as reducing the energy need for DHW during the winter, and the stove could provide some of the winter space and hot water-heating needs, to reduce these households' dependence on expensive electric storage heating.

The project

The project involved the installation of multi-fuel stoves with back-boilers and solar thermal systems to heat domestic hot water and central heating radiators. The stoves replaced solid fuel room fires, other solid fuel-heated systems, or electric storage heating. The solar thermal aimed to reduce reliance on electric immersion hot water heaters.

Solar thermal and multi-fuel stoves were installed in 4 properties, and solar thermal panels fitted to 12 properties, to compare the technologies for space and hot water heating and test how they worked in combination. The properties were a mix of 19th Century terraced solid-wall properties and modern cavity wall properties. Of these, 10 households were monitored between January 2016 and May 2017, with a further multi-fuel stove property added to the monitoring in November 2016.

Findings

Satisfaction

- Prior to the intervention, 20% of households said that they were only able to heat their lounge. As a result of the measures all properties were able to use a variety of whole-house heating, and 36% said they are able to heat/use more rooms.
- The proportion of households feeling that they can keep warm enough at home increased from 45 to 60%.
- In homes that received **both** the multi-fuel stove and solar thermal systems the residents reported an increase in satisfaction with the level of control, cost and ease of use of their heating systems. 67% reported that their home gets warmer faster, is warmer and more comfortable, and keeps the heat in better.
- For **solar thermal-only** properties, 70% reported that the house gets warmer faster. 58% said they have more control over the heating and the home keeps the heat in better.
- 73% of all households said that their hot water system is easier / better to use, 18% said it had not changed, and only one resident thought it had become worse (this was referred to partners to provide further support).

Energy affordability

- Energy affordability concerns reduced slightly, with a reduction in the number of people reporting that they had the heating on lower or less often than they would like to keep bills affordable.
- One household that received a multi-fuel stove reported increased financial concerns (worry about paying all bills on time and reporting being behind with energy bills). The residents did not link this to the heating system, and said that they had seen savings as a result of the measures, so it may be due to other life circumstances (health, unemployment), un-resolved financial issues, or billing issues.
- 70% of recipients stated that their bills were cheaper; the remainder said there was no change.
- Cost savings on electricity as a result of installing multi-fuel stoves **and** solar thermal, varied from -39% to 51%. In one of the households which did not make savings, the resident became unemployed, but reasons for the increase in use in the other are not clear and may be due to a number of factors. The householder who saved around 50% on his electricity costs is very happy with the system.
- One household which switched from electric storage heating saved 75% on their electricity costs. Savings of 13.1% ± 12% were seen where just solar thermal systems were installed (where known factors were excluded). Savings were more variable at different times of year, depending on whether or not residents previously used hot water in summer, and whether solar heated hot water displaced electricity or solid fuel use.
- 29% of the fuel used in the multi fuel stoves in terms of kWh output was renewable biomass in the form of logs.

Temperature and thermal comfort

- No clear change in temperature was visible as a result of the measures – whilst those homes receiving multi-fuel stoves tended to have higher temperatures, this seems more likely to be due to the construction of these homes. The one home of an older construction type shows lower temperatures than the other multi-fuel stove and solar thermal homes.
- Many households still struggled to achieve the recommended 18-21°C for good health, particularly those which were of older solid-walled construction. Such homes also experienced high levels of relative humidity, of over 60%.
- No changes in humidity were noted as a result of the installation of measures.
- Limited data could be collected from heat meters, but the few fitted gave an indication of proportions of heat from stoves or solar thermal respectively. Interestingly, there was significant variation between heat meter readings of two properties fitted with solar thermal.
- In terms of cost effectiveness, data suggests that for the type of households in this study, solar thermal has a long payback period of c.19 yrs.

Conclusions and recommendations

- The project was successful in reducing costs for some participants, primarily those receiving solar thermal only. Some households which received both multi-fuel stoves and solar thermal increased their expenditure on energy, hence conclusions cannot be drawn for this aspect – these will be referred to partners to discover and resolve any issues.
- A significant proportion of residents felt that their energy bills had reduced and ease of hot water use had improved. The overwhelming view was that homes heated up faster when the central heating was turned on, probably due to pre-heating of water in the tank.
- Some comments were made that older homes still could not be kept adequately warm due to lack of radiators in certain rooms, poor insulation and/or draughts, and this is backed-up by temperatures monitored during the study. For future projects, fitting insulation at the same time as a more efficient new heating system is recommended to prevent the heat from being quickly lost from the home, so reducing total heat need.
- Most households were satisfied with the stoves; however this depended on resident expectations and previous experience of using similar types of heating systems. 1 resident had been hoping for a biomass boiler, and may have had trouble managing the multi-fuel stove. Testing of biomass pellet boilers for their performance and resident acceptance (a fuel which tends to be smaller, cleaner, lower carbon, and may therefore be easier to manage) would be recommended for future projects.
- Whilst solar thermal dramatically improved quality of life for some, others did not use much DHW, due to having electric showers and cold-feed washing machines / dishwashers. This implies that solar hot water projects are best targeted to those who do require hot water year-round, particularly those who may require more frequent warm baths due to health issues. Also, mains showers could be installed to properties along with solar thermal to allow residents to make better use of the free hot water.
- It is recommended that in any project involving heating system changes, advice and guidance on how to make best use of the technology is provided, along with ensuring that residents are on the correct electricity tariff for their needs. This ensures residents engage with their new technology, are able to make the expected savings on their energy bills, and that any issues requiring assistance are also resolved.

Potential impact on fuel poverty

Multi-fuel stoves may help to reduce fuel poverty in areas where people are already used to, and physically capable of, operating solid fuel fires However, as solid fuel stoves are generally less efficient than electric heating, account must be taken of the associated inefficiencies when considering these systems.

Such stoves are likely to be unsuitable for the elderly, infirm, disabled etc. who may be unable to manage solid fuels to top up the stove. It may be that other new and cleaner (both physically and environmentally) renewable technologies would be easier to manage and more cost and energy-efficient in the long run.

Solar thermal panels helped to reduce bills, and/or financial concerns for those who required hot water year-round. They also helped to improve quality of life where they relied on expensive electric immersion heating for their hot water. However, careful targeting is required, as those who do not use domestic hot water at all, for example those who wash hands using the cold tap, don't have a bath but use an electric shower (which heats its own water), and are in the habit of boiling a kettle for their hot water for washing up etc., will not benefit from it. Such people may be helped to make greater savings through education and behaviour change, and/or installing a mains shower with the solar thermal system.

Despite only providing domestic hot water, when combined with another space heating system, solar thermal does help to reduce both energy required by the main system, but also the time taken to heat up the home - due to hot / warm water already being present in the tank – making homes cheaper and easier to heat to a comfortable temperature.

All new heating systems should be fitted in conjunction with improving the insulation of the property, so the heat produced does not rapidly escape from the fabric of the building.

1. Project overview

1.1 Introduction

This project, delivered by Ceredigion County Council, sought to reduce costs and fuel poverty in rural off-gas areas by providing more efficient space and hot water heating to hard-to-treat homes. It involved installing multi-fuel stoves with back boilers, to provide space and water heating in winter, and solar thermal panels. Four properties received both multi-fuel stoves and solar thermal panels, and 12 properties received solar thermal panels only.

1.2 Aims

- To install and evaluate the effectiveness of combining solar thermal and multi-fuel stove and back-boiler systems as replacement space and hot water heating in rural off-gas properties; compared to those receiving solar thermal only
- To determine the energy-saving benefits and acceptability to householders of using these technologies
- To provide evidence as to the appropriateness of these systems for other areas and partners.

1.3 Background

Rural Wales has very low levels of connection to the mains gas network, and Ceredigion Council has the lowest levels with only 9000 connections – mainly around Aberystwyth and Lampeter.

The Tregaron area and its hinterland was targeted as it is an isolated rural community, with 95% of properties in this area not having access to mains gas[1]. As seen in Figure 1.1, over 95% of properties in this area do not have access to mains gas Housing in this area also suffers from poor SAP ratings, high energy costs and property build types regarded as "hard to treat" (solid wall etc.). Non-gas methods of heating must therefore be assessed in order to address fuel poverty in this type of area, and ideally renewable energy to reduce dependence on fossil fuels.

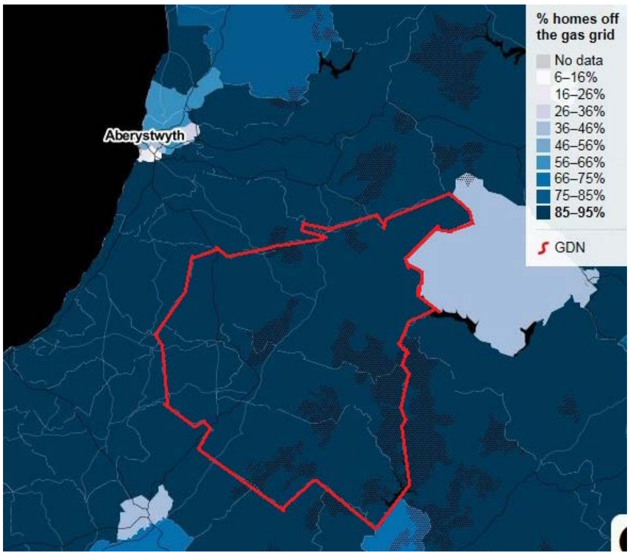

Figure 1.1 Map of areas without access to mains gas for the Tregaron area (outlined red)

[1] www.nongasmap.org.uk, The non-gas map for the UK, [accessed 9/10/2017]

Whilst the Tregaron area does not rank highly in the overall indices of deprivation, unsurprisingly in terms of access to services, Tregaron itself falls within the top 30% most deprived, and the rural areas around it fall within the top 10% most deprived[2]. The Lledrod lower super-output area (LSOA, the smallest area for which population statistics are available) to the north of Tregaron also falls within the top 20% most deprived for housing. Tregaron and its hinterland (Llangeitho, Tregaron and Lledrod LSOAs) suffer from 18-19.9% fuel poverty as modelled from 2001 UK census data[3].

1.4 Attracting beneficiaries and establishing the monitored group

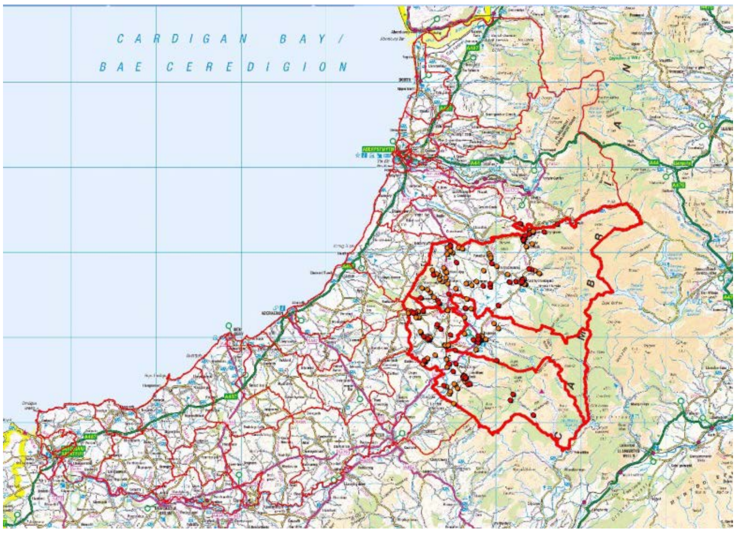

Figure 1.2 Map of potential project beneficiaries used during participant identification in the Tregaron area

Beneficiaries for the project were drawn from privately-owned properties and tenants of Tai Ceredigion and Tai Cantref housing associations. Potential recipients were identified (with suitable south-facing roofs) and contacted by Ceredigion County Council staff, working with the two local housing associations.

The type of system offered depended upon the characteristics of the property, and the existing heating system installed. Consideration was also given to the rurality of properties and potential access problems (to install solar hot water tanks, as well as to purchase and store solid fuels). Figure 1.2 shows how properties identified as potentially suitable were identified across the Tregaron area as having a suitable south-facing roof. Three households in Tregaron received both multi-fuel stoves and solar thermal, as did one household in Pontrhydygroes. All other households received solar thermal only.

The 4 older solid-walled households recruited in Pontrhydygroes and one in Pontrhydfendigaid had very low SAP values of 14-29, averaging 21. One of these received both multi-fuel stove and solar thermal, and the other three received solar thermal only. The more modern cavity-walled properties had SAP ratings varying from 55 – 71, averaging 60.8. Two of these properties received multi-fuel stoves plus solar thermal, and the remainder solar thermal only. One relatively modern property with a lower SAP rating of 40 also received both a stove and solar thermal.

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[2] http://wimd.wales.gov.uk/explore, Welsh indices of Multiple Deprivation [accessed 9/8/2017]
[3] http://gov.wales/docs/desh/policy/090129fuelmapceredigionen.pdf, Ceredigion fuel poverty map 2008, [accessed 10/8/2017]

Solar Thermal only

Evacuated tube solar thermal hot water systems[4] only were installed on 12 properties. These are a series of glass tubes – the vacuum within minimises heat loss from the solar collector, particularly in colder conditions. No liquid passes through the tubes themselves, rather the heat is transferred through a heat exchanger fixed to the top of the tubes, which takes the heat generated to the household's hot water tank. Evacuated tube systems tend to be more efficient than flat panels, but are also more expensive. Solar thermal was offered to residents of properties with a good aspect for solar collection, ideally with south facing roofs, such as in Figure 1.3. One property had its solar thermal panel mounted on their south-south east facing gable wall. Many of these properties already had multi-fuel stoves which they used for heating and hot water, sometimes in addition to electric storage heaters, and all also had electric immersion heaters for hot water. Only 2 properties used electric storage heaters as their main form of heating prior to the start of the study.

Figure 1.3(a) left, solar thermal panels on south facing roofs at New Row and (b) right, wall-mounted solar thermal panel

Biomass and Solar Thermal

This project originally bid to test biomass (wood-pellet) room-stoves with back boilers, combined with solar thermal panels, in properties distant from the mains gas network. However, the project managers changed the specification to multi-fuel stoves - for burning logs and solid fossil fuels – as shown in Figure 1.4 (a), and these were installed instead of biomass-only stoves. This was only discovered after the installations were complete. At that point it was decided to continue to monitor the households to gain information on this combination of technologies, as well as social learning i.e. whether residents found the measures effective and easy to use.

When lit, the stoves provide heat in the main living room, but the back boiler also heats both domestic hot water and can also heat central heating radiators (water being circulated using a pump). Solar thermal uses energy from the sun to heat water in the domestic hot water tank. A schematic of the central heating system is shown in Figure 1.4 (b).

The idea of this combination of technologies was that the solar thermal panels could provide all the household's hot water needs in the summer months - without having to light the stove or turn on the electric immersion tank - as well as reducing the energy need for DHW during the winter, and the stove could provide the winter space-heating needs, to reduce these households' dependence on expensive electric storage heating.

[4] http://www.alternative-energy-tutorials.com/solar-hot-water/evacuated-tube-collector.html [accessed 2/11/2017]

Both multi-fuel stoves with back boilers and solar thermal systems were installed in 4 properties. These were chosen as they had sufficient space to combine both systems. Some of these homes previously had solid fuel room fires - with no back-boiler - so they benefited from the addition of whole-house central heating in the winter, rather than just heating the room containing the stove. Charnwood LA 45 UW stoves were installed in the majority of these properties, but due to multiple installers involved in this project, another brand of stove was fitted in one of the 4 properties. We have been unable to obtain information from the householder / housing association as to the brand or model of the stove, but it was a commercially available model and functions identically.

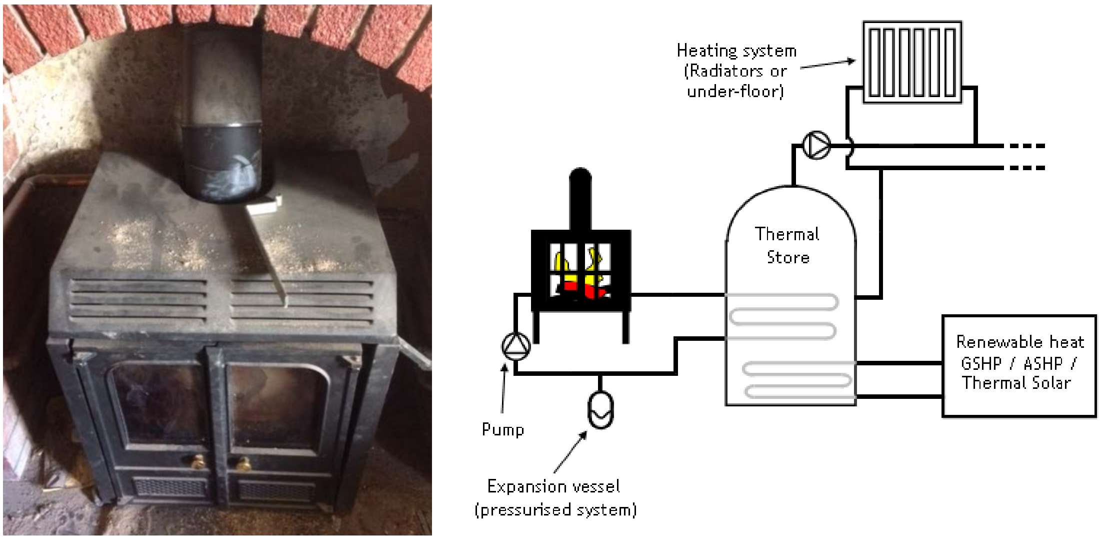


Figure 1.4 (a) – Solid / multi-fuel stove with back boiler installed in this project, (b) schematic of how this integrates with the central heating system (hot water system has separate pipes and is gravity fed)

Further details of the technologies installed are provided in Appendix 3.

1.5 Project timeline

This timeline shown in Figure 1.5, below, sets out the timescales of the project: the monitoring and technologies being installed, monitored, data collection and reporting process.

Properties mainly had their measures fitted in April – June 2016, however, 1 property had delayed installation (October 2016) due to logistical issues of fitting the large tank into the home.

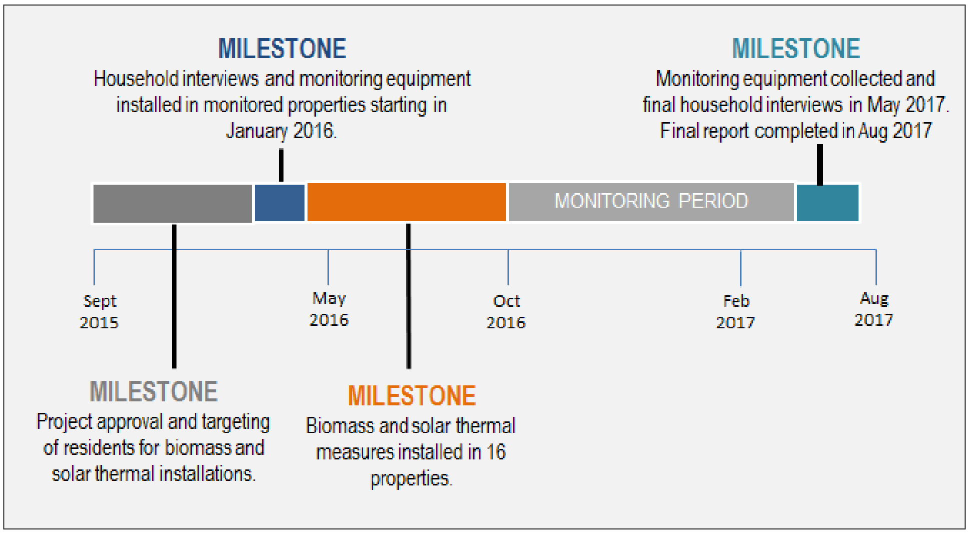


Figure 1.5 - Project timeline

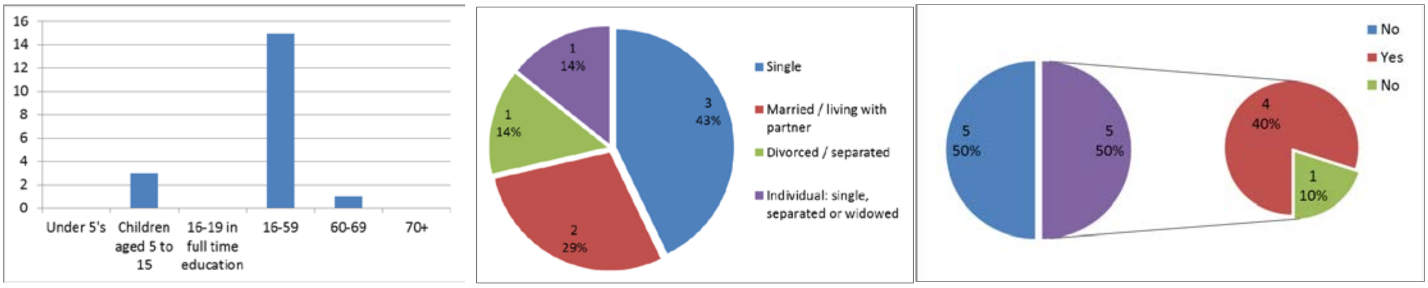
2. Social impact evaluation

Householders were interviewed at the start of the monitoring period, and again at the end of the project to identify key aspects of the property's type, occupancy and resident behaviour which could affect energy use; and to identify any changes and benefits at the end of the project.

2.1 Householder demographics and property type

This section sets out the results of the questionnaires regarding residents' views, acceptance of the technology etc. and any immediate findings. 10 householders were interviewed at the outset of the project, and 11 at the end of the study period.

Figure 2.1 – Resident (a) age, (b) marital status and (c) health issues present and worsened by cold



As shown in Figure 2.1(a), the majority (79%) of residents were working age, 16-59; with only 16% being children aged 5-15. Only 1 resident (5%) was aged over 60 at the start of the study. Marital status is a useful guide to vulnerability to high energy costs – only 29% of residents were married or living with a partner, and able to call on two incomes to pay their bills. The remainder (71%) are single so are solely responsible for household bills. 50% of properties contained no residents with health issues, but the remainder was made up of 40% with a health issue linked to cold which required the home to be kept warm, while only 10% had a health issue unaffected by temperature.

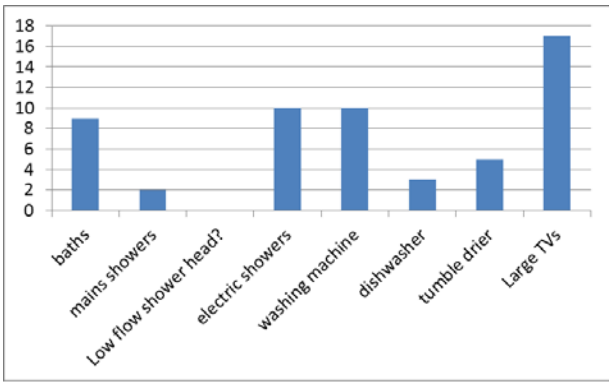


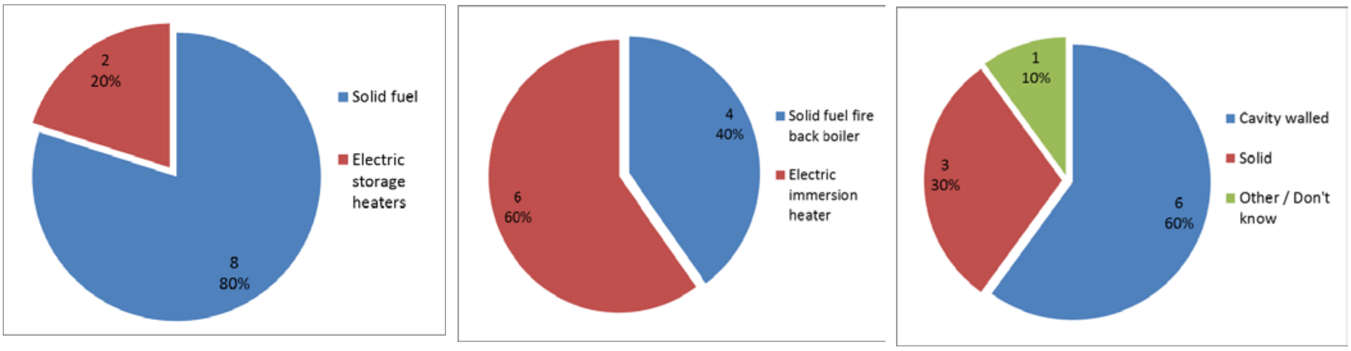
Figure 2.2 – Energy-using appliances present

Of the 10 properties where an initial questionnaire was completed, all but 1 contained a bath; all contained an electric shower and washing machine. Few residents had a tumble drier, dishwasher, or mains shower.

9 of the properties were 3-bedroom homes with only one 2-bedroom house (10%). 80% were semi-detached, with only 20% being mid-terraced (which are likely to experience lower heat loss).

Prior to the start of this study, the majority (80%) of households used solid fuel for their space heating, with only 20% using electric storage heating. Some also used electric supplementary heating, and 1 also used a multi-fuel stove. For hot water, 40% used a solid fuel fire with back boiler as their main water heating, whereas the remaining 60% used an electric immersion heater.

Figure 2.3 - (a) Main space heating, (b) main water heating (c) wall construction type



The home construction type was reasonably well-known, with residents correctly reporting those homes which were solid-wall construction. One of the householders in the cavity walled properties did not know the construction type, but it is likely that the 10% "other/don't know" is also cavity walled. Knowledge on wall and loft insulation levels was not as good, those in solid walled homes knew they were not insulated, and 4 of the 7 cavity-walled properties' residents thought their walls were insulated, but 3 did not know if the walls were insulated or not. For loft insulation, only 8 of the residents responded, with 50% of these thinking they had the full 250-270mm standard of loft insulation, 2 (25%) thought that they had some insulation, but only around 5-15cm thick. 1 householder reported a polystyrene pitched roof (which may aid insulation) and another did not know their home's insulation status.

Only 1 household reported having single glazing, although 3 others reported that their double glazing was draughty or suffered condensation. All but 1 said they had relatively modern external doors, although 4 reported that theirs were draughty.

2.2 Qualitative feedback given in questionnaire, before and after periods

For many of the properties, space and water heating methods changed due to the installations. One property switched its main space heating method from electric storage heating to solid fuel, whereas another household – previously noted as using solid fuel – now reports using both solid fuel and electric storage heaters. More also report using supplementary heating. For hot water, 8 of the 11 householders (73%) now use a combination of a multi-fuel stove, solar thermal and immersion heating. The remaining 3 (27%) use solar thermal plus electric immersion heating.

As shown in Figure 2.4(a), at the start of the study the majority (63%) of residents did not know their normal living room temperature as there was no thermostat present. It is unclear whether those who responded had a thermostat, a thermometer, or guessed. By the end of the project, whilst 2 households still reported low living room temperatures, most now felt that their living rooms achieved the recommended 18-21°C range, and only 1 resident still did not know the room temperature. 70% of residents initially reported heating the whole house, see Figure 2.4(b), and 1 reported heating selected areas, however 2 properties were still only able to afford to heat the living room. Investigating further in Figure 2.4(c) whether any rooms were unheated in winter, 2 properties again reported that all rooms but the living room were unheated. Others had some limited rooms which were unheated, but no explanation was provided whether this was by choice or through lack of heating in that location. By the end of the project, 73% of households were able to heat the whole house, a further 18% heated a variety of selected rooms (mainly excluding unused rooms), and only 1 property reported heating only the living room and bedroom. 64% of respondents now said no rooms were unheated in winter, with only 4 (36%) saying they did not heat some rooms – these were mainly spare bedrooms, an increase from 45% at the start of the study.

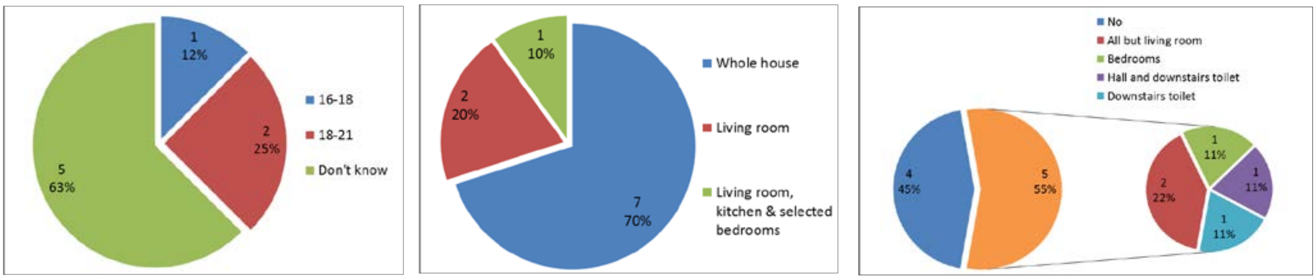


Figure 2.4 (a) normal living room temperature, (b) areas of the home heated and (c) whether any rooms are unheated in winter, for before installation (above) and after (below).

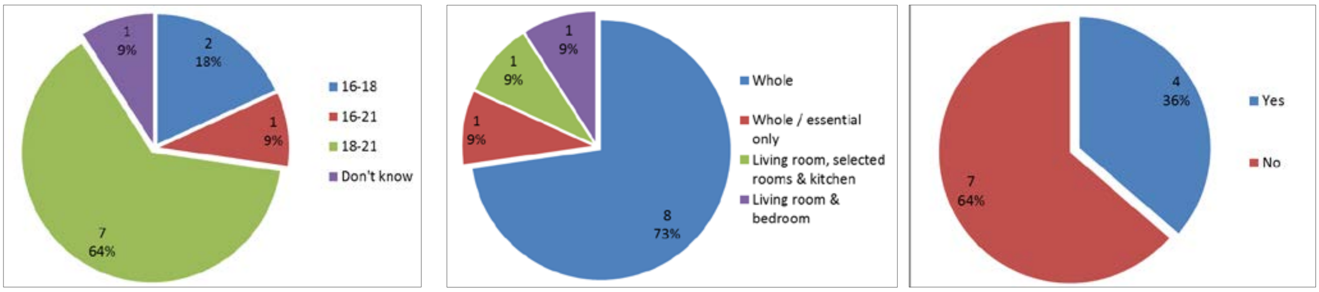


Figure 2.4 (d), above right, Ability to heat or use more rooms since the new measures fitted

Householders were asked whether they were able to heat or use more rooms as a result of the new measures which had been fitted to their property.

As shown in Figure 2.4(d), 4 householders (36%) reported that they were able to heat or use more rooms, be that for physical (e.g. radiators where none were previously present) or financial reasons.

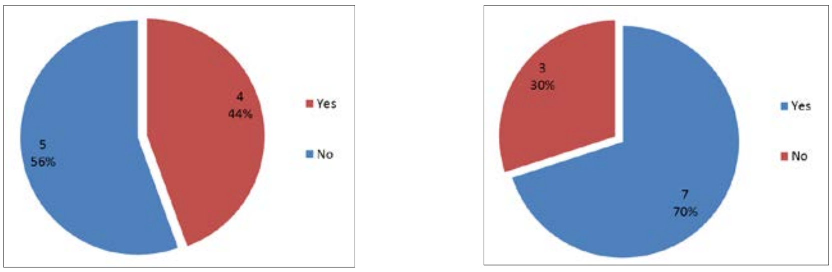
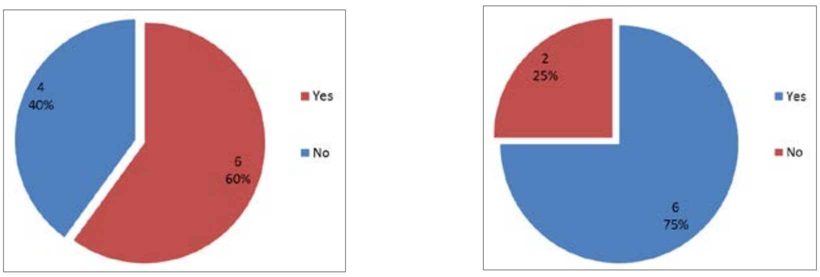


Figure 2.5 (a) can residents mostly keep warm enough at home, and (b) need to wear extra warm clothing at home to keep warm before installation (above) and after (below).



As shown in Figure 2.5(a), only 44% of residents felt they could mostly keep warm enough in their homes before installation of the measures – 5 people reported that this was due to the cost, and one said it was not possible to keep the home comfortably warm due to its construction. By the end of the study, the proportion who did mostly feel warm enough increased to 60%. Those who could not reported that it was not possible to heat the house to a comfortable level due to draughts, no radiator/heating in a particular room, or the property's construction, as well as the cost. However, Figure 2.5(b) also shows that 75% of residents now reported that they needed to wear extra warm clothing in the home i.e. multiple jumpers, a dressing gown, coat or blanket over clothes in order to stay warm enough – this may be due to changes in the respondent group: some did not answer this question in the final questionnaire, and the additional householder added during the monitoring period also reported the need to wear extra warm clothes.

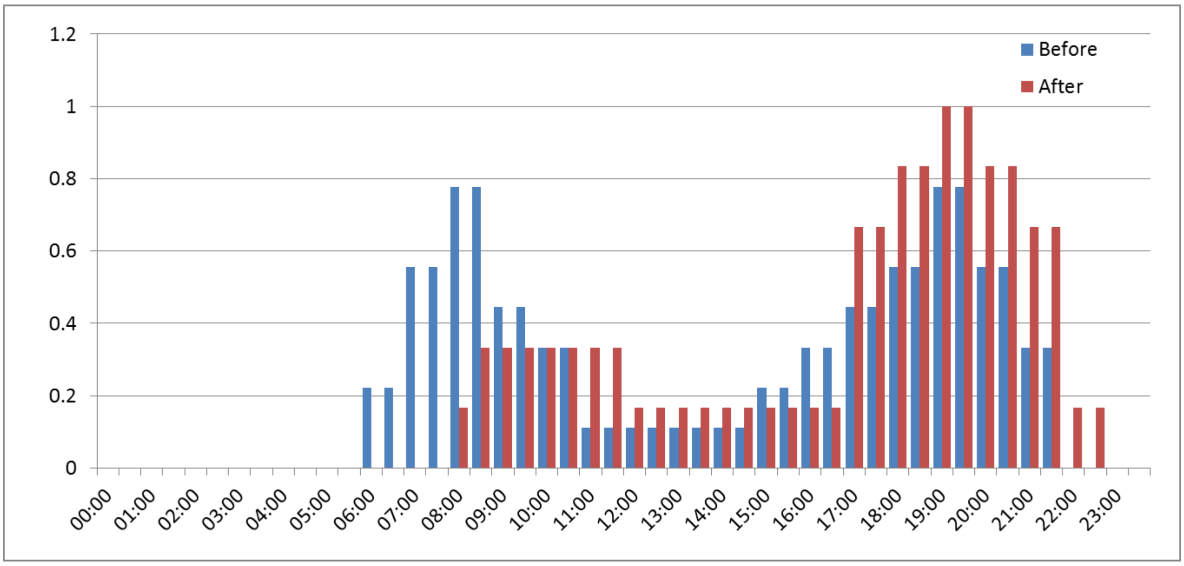


Figure 2.6 – Heating desire profile

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, Figure 2.6, over a 24hr time period, was used in the technical monitoring to assess whether homes achieved warm and safe temperatures during the required peak time period(s), in this case 5-10pm.

2.3 Resident acceptance and satisfaction

Householders were asked a series of questions about their satisfaction with their home heating, both before and after installation of their measures. Comparing their responses can tell us whether the measures have improved satisfaction. A compound "score" was allocated to responses, with "very satisfied" scored at 100, "satisfied" rated at 75, neither (satisfied nor dissatisfied) rated at 50, dissatisfied rated at 25, and very dissatisfied scored as 0. Scores for each property were then averaged across the group. Results are compared in Figure 2.7, below.

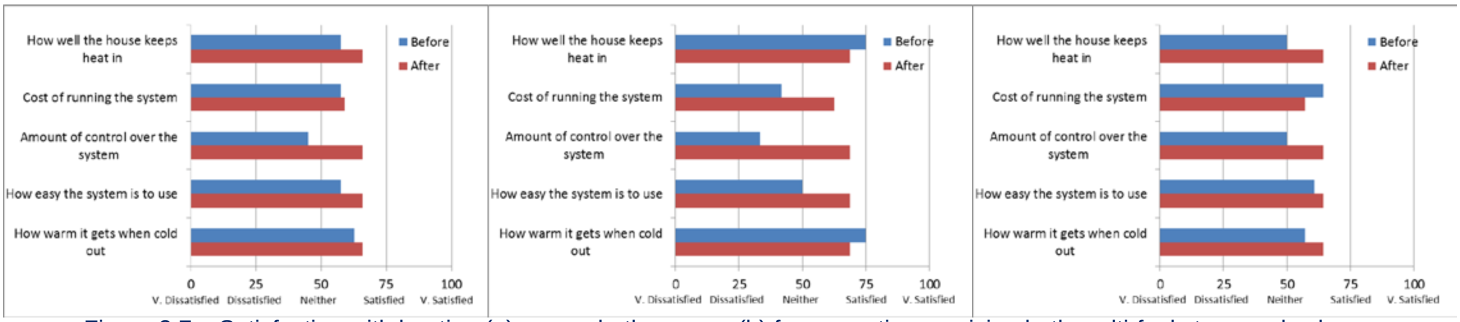


Figure 2.7 – Satisfaction with heating (a) across both groups, (b) for properties receiving both multi-fuel stove and solar thermal systems and (c) those receiving solar thermal only

Overall, satisfaction improved slightly in all aspects, with a significant jump in improvement in the amount of control over the system. Separating out the 2 groups, there was a large improvement in satisfaction with the cost of running the system for those properties which received both solar thermal and a multi-fuel boiler (Figure 2.7(b)), as well as in their amount of control over the system, and how easy the system was to use. Satisfaction with how well the house kept the heat in, and how warm it gets when it's cold outside decreased slightly, but it is unclear if this is a significant difference. For properties receiving solar thermal only (Figure 2.7(c)), smaller differences were seen. This is to be expected as the questions mostly relate to heating, whereas solar thermal provides domestic hot water only. Small increases were seen in satisfaction with how well the house kept the heat in, and the amount of control the householder has over the system.

Householders were asked to state whether they agreed or disagreed with a series of statements relating to managing energy costs, and financial concerns. A score of 1 was allocated to "strongly disagree", 2 to "disagree", 3 to "agree" and 4 to "strongly agree", and scores were again averaged across all respondents to give an average group score. These were used to compare the periods before and after installation of the measures, in Figure 2.8.

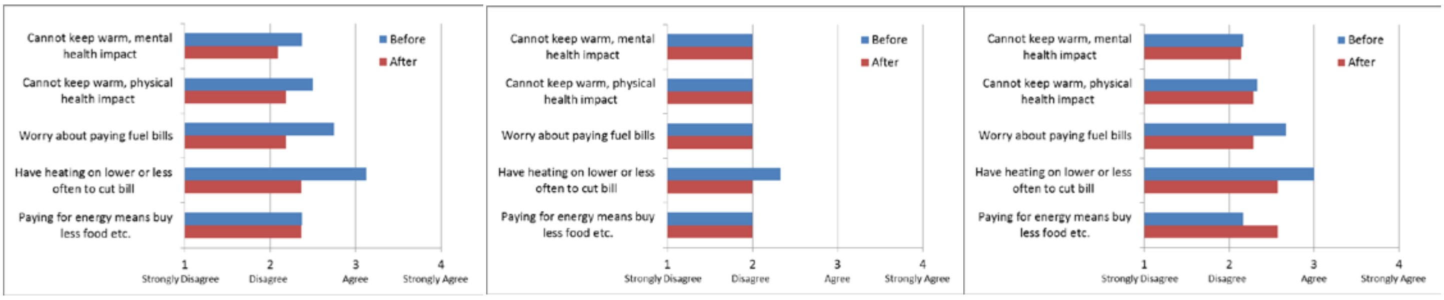


Figure 2.8 – Energy affordability concerns (a) across both groups, (b) for properties receiving multi-fuel stove & solar thermal systems and (c) those with solar thermal only

There were generally low levels of agreement with these negatively worded statements – the most agreement was seen around having the heating on lower, or less often than the resident would like, so that the bills are not too high, and worrying about fuel bills. Worries were lower amongst those who received both technologies than for those who only had solar thermal fitted, but this may not be linked to the project/technology as it could be due to the life situation of the householders.

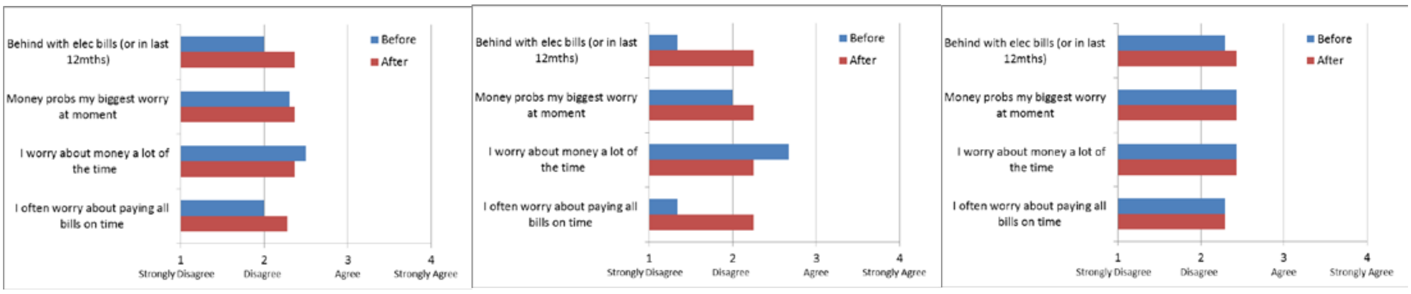


Figure 2.9 – Financial concerns (a) across both groups, (b) for properties receiving multi-fuel stove & solar thermal systems and (c) those with solar thermal only

Responses to questions about financial concerns are displayed in Figure 2.9. These show very little change, but an increase in worries about paying bills on time, and being behind with energy bills. Examining the individual responses, this appears to be as a result of 1 householder who was having financial/affordability issues at the end of the project period, and who may require some additional assistance.

2.4 Qualitative feedback given post installation of measures

Participants were asked whether they had found any benefits – or problems – as a result of the measures installed in/on their properties. Figure 2.10 shows the main benefits identified by the study participants. Responses are normalised by the number of properties in each group, for ease of comparison.

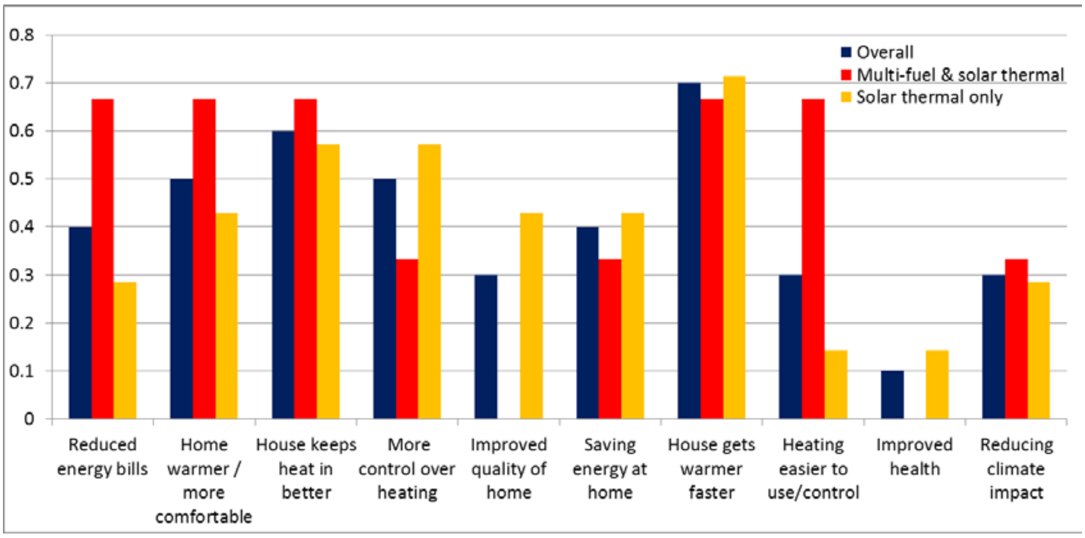
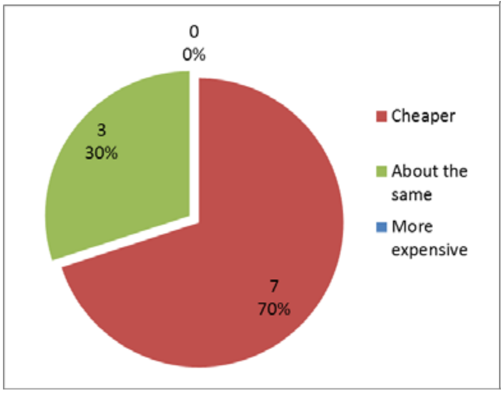


Figure 2.10 – Benefits of installations

Overall, most participants felt the measures helped their home to get warmer faster – even for those with solar thermal only. This was explained by the fact that central heating systems heats up hot water first. Hence when they used a multi-fuel stove (either installed via this project or already present in their home), there was already some pre-warmed/hot water in the tank provided by the solar thermal so it did not take as long to heat this up before it started to heat up the central heating. A high proportion across both groups also felt that their home kept the heat in better – as no additional insulation was fitted. This may mean that heat is (able/affordable to be) distributed more evenly through the house, but this is cannot be proven. Distinguishing between the 2 groups, those receiving both the multi-fuel stoves and solar thermal were more likely to feel that it had reduced their energy bills, that their home was warmer and more comfortable, and that their heating was easier to use or control. Those receiving solar thermal only felt that it gave them more control over their heating and that it saves energy in, and improves the quality of, the home.

Residents were also asked about ease of hot water use, the impact on the cost of bills – shown in Figure 2.11 – as well as damp/condensation, and any other impacts.



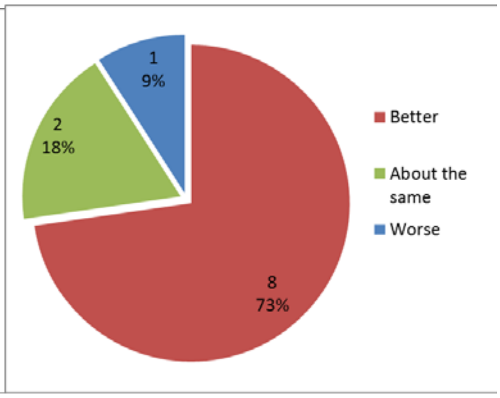
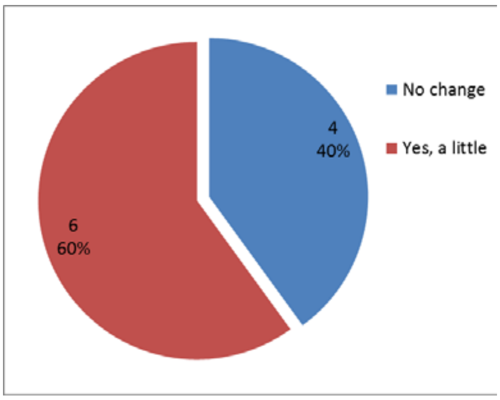


Figure 2.11 – Impact of installations on (a) ease of hot water use and (b) cost of energy bills

One householder reported problems with the temperature of her hot water with the new system, therefore finding that the water system was harder to use, and 2 householders (18%) found it about the same. However, 8 of the householders find the hot water much better. Comments were made that "it is a luxury to have hot water year-round without having to turn on the immersion heater". Three participants (30% of respondents to this question) felt their energy bills were about the same as before, and 7 (70%) thought they were cheaper. Comments were also made by residents of perhaps not having made cost savings, but highlighting the quality of life improvement of having hot water at no cost, or concern about cost.

Energy cost estimates are notoriously inaccurate (due to rounding, misremembering, accounts in credit / debt, delays in updating direct debit amounts etc.), however, householders were asked to estimate their energy bills at the start, and at the end of the project. Sufficient information was only gathered on recipients of the solar thermal panels only, but this indicates that some households saw small increases in costs, but also others saw significant savings. Overall, an average saving of around £500 was seen across the group. Again, such estimates should be viewed with caution, but do suggest that solar thermal panels are helping to save these participants money on electricity bills overall.



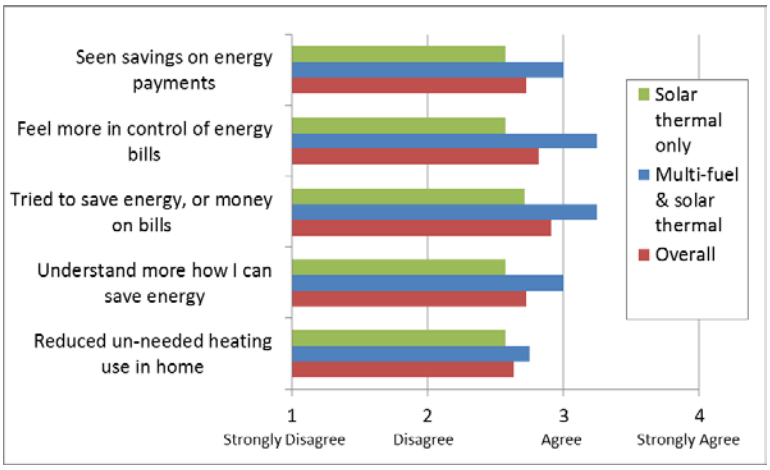


Figure 2.12 (a) Impact of installations on any money worries (b) impact of overall participation in the project

Residents were asked whether the measures had helped to reduce any financial concerns, and about the overall energy efficiency impact of their participation in this project, see Figure 2.12. Ten people responded to the first question (Fig 2.11(a)), of whom 4 felt there had been no change to any money worries, but 6 felt the measures had helped reduce financial concerns a little. In terms of improving engagement with energy efficiency, those who had received both multi-fuel stoves and solar thermal agreed more strongly with the statements. Those receiving solar thermal only were split almost 50:50 as to whether or not they had done any of these activities. Multi-fuel boiler recipients felt they understood more about how to save energy, had tried to save energy on bills more, felt more in control of their bills, and had seen savings on their energy payments. Least agreement was with the statement about reducing un-needed heating, as many households were under-heating their homes.

2.5 Satisfaction with installation process and customer service aspects

Changes to heating and hot water systems can be disruptive, and learning and adaptation is required in order to use new systems to their best potential. Lack of sufficient support can mean that recipients fail to engage with new technology, are more likely to use it wrongly, and hence experience problems which can reduce the effectiveness of the technology. It is therefore important to assess whether residents felt they received adequate information and support, are confident to use their new technology, and know who to contact should they require assistance.

Figure 2.13(a) shows that residents of most properties agree that they know how to use the measures, find them easy to use, and know enough about how they work. Surprisingly – given that multi-fuel stoves do require very active input from the resident to work – the majority of residents also agreed with the statement that their measures did not need any active input, both overall (red bar) and when separated into groups receiving the multi-fuel stoves and solar thermal; and solar thermal only. Participants also broadly agreed, see Figure 2.13(b), that they had received adequate support in using their new system – again recipients of multi-fuel stoves and solar thermal felt more positive about the support received than those who received solar thermal only. Two solar thermal recipients said they were not shown, and did not receive information or instructions on how to use their new system – these will be referred to the partners to resolve.

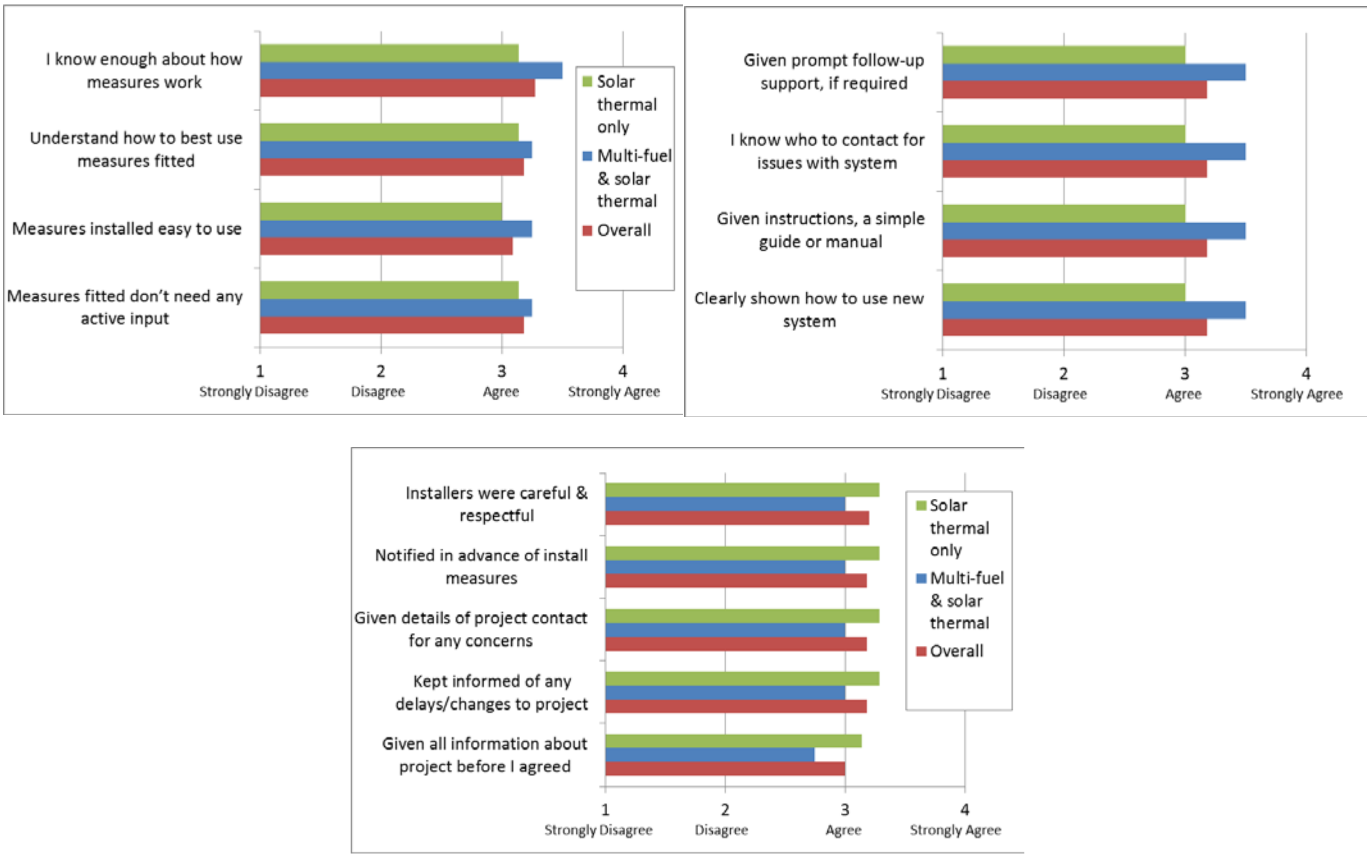


Figure 2.13 (a) Understanding of and (b) support received on the new measures fitted, and (c) thoughts on communications & customer service issues relating to the project

Those receiving solar thermal only were slightly more positive about the project communications than those also receiving a multi-fuel boiler, however most agreed that they were kept well informed about the project. The only aspect where participants disagreed with this was in the matter of receiving all information about the project before they agreed to take part – 1 person stated that he had not received this information, but only because he got involved in the project at the last-minute.

No residents reported any reliability issues or breakdowns of their new measures, however 1 person commented about the temperature of the hot water (it not being hot enough) – this matter was referred to the project partners to try to resolve directly or with their other partners/contractors.

One resident expressed disappointment that the stove received was a multi-fuel one, not a biomass/wood pellet boiler as initially planned – other comments suggest this participant did not like managing a solid fuel stove.

3. Technical evaluation methodology

3.1 Introduction

Ten properties were identified by Ceredigion County Council and their partners, to be monitored for over a year, between January 2016 and May 2017, to assess the effectiveness of their new heating systems. This monitoring period enabled NEA to capture a year of data, including a winter-spring period prior to installation of the measures, and both a summer and a winter heating period after installation of the measures. Due to changes in measures installed in properties after the monitoring equipment had been placed, it was discovered that 1 of the 4 properties which received a multi-fuel stove was not being monitored – this resident agreed to have monitoring equipment fitted so was also added to the monitored group in November 2016. The selected householders were chosen due to their willingness to have monitoring equipment fitted, and their ability to take regular meter readings.

NEA staff conducted questionnaire interviews with households at the start of the monitoring equipment installation period in January 2016 to the end of the monitoring period in May 2017 – resulting in the data in the previous section.

During the initial household interviews in January 2016, NEA installed automated data loggers which gathered temperature and humidity data from the room in which they were located, to determine the residents' comfort levels over the whole monitoring period; and thermal probes on the radiators of 2 households due to receive multi-fuel boilers. It was planned to install heat meters through the appointed contractors as part of the installation of measures, as these needed to be plumbed in. In many cases this was not done, see section 3.3.

All participants were asked to take regular household energy meter readings approximately every 2 weeks during the whole study, and to provide any previous energy bills or meter readings where possible in order to compare their current usage back against their previous energy use. NEA provided a small financial incentive – of £20 in shopping vouchers - for doing this. NEA also visited the properties in November 2016 to check on monitoring equipment, and take meter readings from the monitored properties. Residents were also reminded to take their regular meter readings over the winter.

In order to protect the privacy of the participants, all data has been anonymised in this report, with reference numbers allocated to each property, T-xx.

3.2 Technical monitoring

In the 4 homes which received multi-fuel stoves and solar thermal systems, the monitoring involved placing temperature and humidity loggers in the main living area and main bedroom. Thermal probes were fixed onto the living room radiator in 2 of these properties, to monitor when heating was in use and the radiator temperatures achieved. A heat meter - with attached pulse data logger – was also due to be installed at the same time as the stove system, to monitor its heat output (ideally all hot water output to both domestic hot water and the central heating circuit, or if this were not possible due to a gravity-fed system, on the pumped central heating circuit only). It was assumed that solar thermal output would either be logged via the solar thermal system's own controller, or that the heat output would be similar to that in the solar thermal only properties, so this aspect was not specifically monitored in these homes. All loggers collected data for analysis by

NEA's technical team at the end of the project. See Figure 3.1 (a) and (b) for monitoring diagrams.

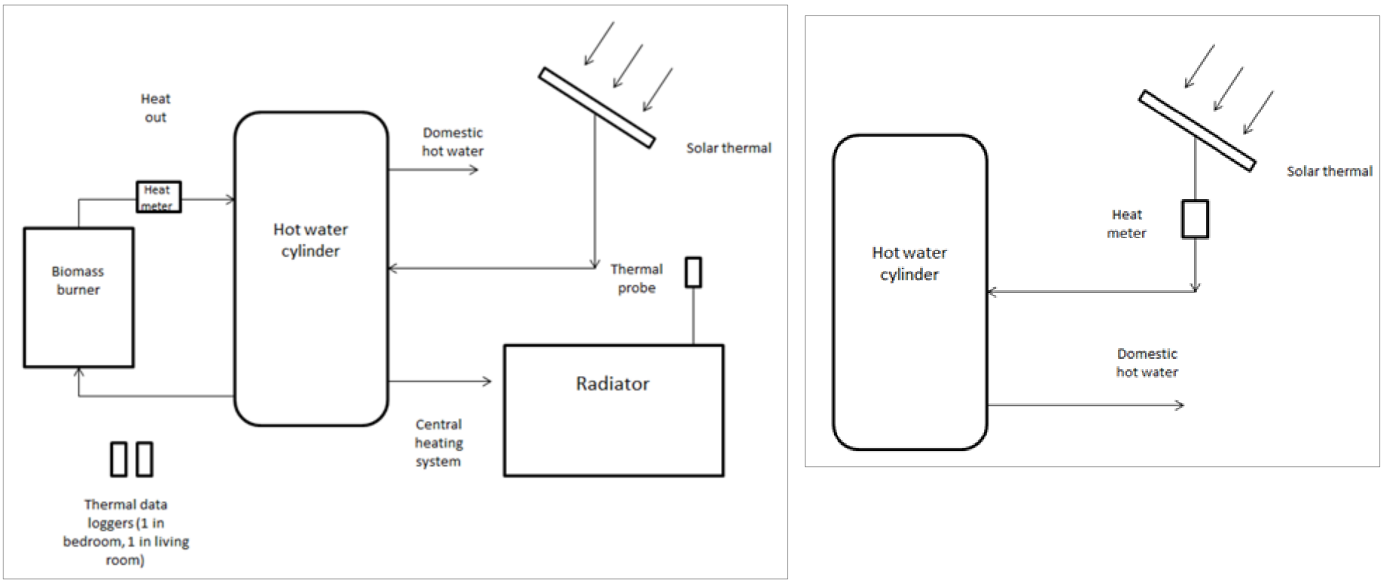


Figure 3.1 – Schematic diagrams of monitoring equipment placed in properties receiving (a) multi-fuel stove and solar thermal, and (b) solar thermal only, installations

In homes receiving solar thermal systems only, heat meters – with attached pulse loggers - were due to be attached to the output of the solar thermal system, to provide information on their heat output at different times of year. (As a result of concerns by installers that this would affect MCS certification, only 2 proprietary display units were fitted, later in the monitoring period, which show total heat output since installation – but to which a pulse logger could not be attached.)

Monitoring equipment

The following monitoring equipment was used in this project:

Thermal & humidity data loggers

Two Lascar EasyLog USB-2 loggers[5] were installed per home which was due to receive a multi-fuel stove - 1 in the main living room, and 1 in the main bedroom - to record the temperature and humidity every hour. These were placed in a background location, between sitting and head height, and away from direct sources of heat, cold or draughts.

Figure 3.2 - Thermal & humidity logger placed in a living room

[5] Lascar USB-2 product details: www.lascarelectronics.com/easylog-data-logger-el-usb-2, accessed 13/06/2017

Thermal probes

One Lascar EasyLog TP-LCD logger's[6] metal probe was attached (using electrical tape) to the back of the main living room radiator in 2 of the properties which were due to receive multi-fuel boilers. The logger records the temperature of the radiator every 30 minutes.

Pulse loggers

Lascar EasyLog USB-5 pulse data loggers[7] were attached to the heat meters due to be fitted with the multi-fuel stoves or solar thermal systems. These record the timing of each unit of heat output, to assess when in the year heat is being obtained from the systems.

Ultrasonic heat meters

VuHeat VHU-20 ultrasonic heat meters[8] were given to contractors, with instructions to install these on the hot water outlet pipes at the same time as the multi-fuel stove or solar thermal system was installed, see Figure 3.3(a). These monitor the heat which flow through them in kWh, and have an electronic pulse output so that a pulse data logger can be connected to record the timing of each unit of heat output. Unfortunately, as described in section 3.3, installers were wary of fitting these to systems, so only 2 were fitted.

Figure 3.3 (a) left, heat meter installed on a multi-fuel stove system and (b) right, a solar thermal display unit.

Solar hot water smart display units

Some controllers for the solar thermal units recorded heat energy produced by the solar panels in kWh, but did not display this. In order to extract this information, 2 Resol DS3 smart display units[9]

[6] Lascar thermal probe details: www.lascarelectronics.com/easylog-data-logger-el-usb-tp-lcd, accessed 13/06/2017
[7] Lascar USB-5 product details: www.lascarelectronics.com/easylog-data-logger-el-usb-5, accessed 13/06/2017
[8] VuHeat VHU20 Ultrasonic heat meter data sheet, www.heatcombustion.co.uk/downloads/VHU20.pdf [accessed 11/8/2017]
[9] Smart Display SD3 product details, www.resol.de/index/produktdetail/id/16/sprache/en-us [accessed 11/8/2017]

were therefore purchased to attach to the solar hot water controllers, as shown in Figure 3.3(b). These cannot accept pulse logger connection, hence we had to rely on the NEA member of staff conducting the final home visit to record the total heat units produced by the system at that date – and potentially ask residents in these properties to also note down the heat reading in addition to their regular electricity meter readings.

Property Type	Monitoring Equipment	Number of properties
Multi-fuel and solar thermal	USB Thermal data loggers – two for each property	4
Multi-fuel and solar thermal	Thermal USB probes – 1 in 2 properties.	2
Multi-fuel and solar thermal	Heat Meters & pulse loggers – one in each property on stove hot water outflow	4
Solar thermal	Heat Meters & pulse loggers – one in each property on output of solar thermal	6

Figure 3.4 Summary of monitoring equipment

In order to obtain a period of temperature and humidity data prior to the installation of the measures, monitoring equipment was installed in January 2016. However, there were changes to the measures to be installed, for example, some participants who were initially interested in receiving a biomass/multi-fuel stove system withdrawing from this element of the project between January and April-June 2016 when the installations of the measures were carried out. Monitoring equipment was not moved around to account for this, hence why elements monitored in each type of property do not always match the summary table above.

3.3 Factors affecting the evaluation methodology

Issue	Description and mitigation
Staffing and Time Management	Over the timespan of the project delivery phase, resources of the lead partner organisation were reduced, resulting in impacts on project delivery.
Installation of monitoring equipment	Due to changes in which participants were receiving which measures after initial fitting of the monitoring equipment, there was an issue with understanding where data loggers and thermal probes were located. The project lead visited each monitored property in October-November 2016 to check whether loggers were present, their locations within the home, and take household meter readings. Where loggers were not present as expected, new ones were placed at this time. However, not all equipment initially placed was able to be located.
Installation of measures	There were a number of issues with installation of the measures. Ceredigion County Council used its procurement framework to install measures in privately owned properties, whilst partner housing associations used their own contractors in their housing.

Issue	Description and mitigation
	This resulted in 4 different contractors working on this relatively small project, which compromised delivery as there was no central contact to train in fitting the monitoring equipment, the solar thermal systems differed from each other (particularly the controllers), and differing opinions of contractors on the effect of a heat meter on the system performance meant inconsistent installation of heat meters across the sample monitored. Critically, the boilers fitted were multi-fuel systems which burnt logs or coal, not wood pellet biomass models as described in the project specification. It is unknown how this occurred as NEA was not party to the procurement of the measures. Many such issues were only discovered after installation of the measures, when less could be done to resolve the issue without increased cost to the partner and inconvenience to residents to carry out further works. Despite the reduction in technological innovation and renewable energy elements, it was decided to continue to fund this project, due to the novelty of pairing these 2 technologies, and the social learning which would result.
Heat Meter Installation – multi-fuel stoves	As part of the monitoring of the project, the properties with multi-fuel stoves were meant to have heat meters installed to measure the amount of heat produced and distributed in the households. However, due to installer and contractual issues, only 2 heat meters were fitted as part of the project. Contractors appointed by Ceredigion County Council were reluctant to install the heat meters onto the stove systems in monitored households, stating that the systems were gravity fed and any obstruction to the pipes could compromise their function. NEA requested that heat meters instead be placed on the pumped circuit which circulates water around the central heating system – where a loss of pressure due to the heat meter would not occur due to the pump - so that heat output to central heating could be measured. NEA was not alerted to this issue until after the measures had been commissioned. However at that stage, extra costs and inconvenience for residents were introduced in having to drain the system to fit the meters, so again contractors were reticent to do this, and ‘stage 2’ heat meters were never fitted.

Issue	Description and mitigation
Heat Meter Installation – solar thermal	As for the multi-fuel stove systems, contractors were resistant to fitting heat meters to the solar thermal systems, fearing it would impact on the MCS certification of the system. As previously mentioned, different types/brands of solar thermal system were fitted by the 4 different contractors. Few of these included controllers which measured/displayed total heat output from the panels since fitting, hence a compromise was agreed to install a smart display unit to 1 brand of control unit which was capable of accepting it, in 2 properties to display the heat produced by the solar thermal systems. However, these were installed very late in the monitoring period – on an unknown date - and it is hence unclear whether useful heat data was collected.
Failure of monitoring equipment	Unfortunately, 1 of the thermal probes failed for unknown reasons during the monitoring period, as did 3 of the thermal and humidity loggers. Data can only therefore be reported for periods and (rooms of) properties where loggers were functioning.
Meter readings	The collection of meter readings for this project was mixed. Many residents were diligent in taking regular meter readings throughout the monitored period. For those who did not, and for energy consumption prior to the start of the monitoring, it was possible to obtain current and historic meter reading data from most households' energy companies, but in a few cases there were only 2 actual meter readings per year. A few households used prepayment meters which recorded frequent meter reads on top-up, providing very detailed data.

4. Monitoring results

4.1 Cost

As these homes are not connected to mains gas, electricity is their only metered fuel, however, we do not always know if electricity was the main fuel used for heating and hot water as some also had solid fuel stoves. This may limit the impact of the measures on electricity use. Meter readings from before the start of the study were used to calculate previous electricity usage – these were able to be obtained for all householders except 1. This previous usage was compared against usage for the period after the measures were installed, to see if the measures had helped the householders to make savings. The results are displayed in Figure 4.1. A full year's data was not always available: for entries marked *, meter readings for only a certain part of the year were available in either the before or after period. Usage from a similar time of year was used in the comparison period where possible, for best comparison. Homes marked purple received both solar thermal and multi-fuel stoves, rows marked gold received only solar thermal installations.

20 year average degree-day comparison of savings — Region: Wales — 20-yr average degree days: 1953.1

	"Before" period							"After" period							Comparison	
Tech Ref	Period	Days	Total Period (kWh)	Cost per year	Degree days	kWh per Degree Day	Estimated annual cost#	Period	Days	Total Period (kWh)	Cost per year	Degree days	kWh per Degree Day	Estimated annual cost#	Annual saving (uncorrected)	Estimated D/D corrected Saving#
T-05	21st May 2015 - 27th Apr 2016	342	3,626.0	£619.18	1,894.8	1.914	£598.00	26th May 2016 - 9th May 2017	348	4,979.0	£835.56	1,872.4	2.659	£830.96	-34.95%	-38.96%
T-01	18th Sept 2015 - 2nd Mar 2016*	166	2,180.0	£766.94	1,105.4	1.972	£616.28	18th Sept 2016 - 9th May 2017*	233	4,235.0	£1,061.48	1,739.9	2.434	£760.62	-38.40%	-23.42%
T-04	25th Feb 2015 - 25th Mar 2016	394	5,854.0	£867.70	2,263.8	2.586	£808.08	11th June 2016 - 9th May 2017	332	3,530.5	£621.03	1,842.4	1.916	£598.81	28.43%	25.90%
T-03	1st Aug 2015 - 31st May 2016	304	2,204.5	£423.50	1,859.1	1.186	£370.55	30th Jun 2016 - 30th Apr 2017	304	1,071.7	£205.88	1,776.6	0.603	£188.51	51.38%	49.13%
Average		302	3,466.1	£669.33	1,780.8	1.914	£598.23		304	3,454	£680.99	1,807.8	1.903	£594.73	1.62%	3.16%
T-15	30th Apr 2015 - 29th Apr 2016	365	4,885.0	£781.60	2,032.5	2.403	£751.06	13th May 2016 - 10th May 2017	362	4,769.5	£769.44	1,936.4	2.463	£769.69	1.56%	-2.48%
T-09	10th Oct 2015 - 10th May 2016*	213	1,385.0	£379.74	1,585.7	0.873	£272.94	9th Oct 2016 - 10th May 2017*	213	1,179.0	£323.26	1,682.6	0.701	£218.96	14.87%	19.78%
T-02	27th Nov 2014 - 11th May 2016	531	5,731.0	£630.30	3,535.4	1.621	£506.56	19th May 2016 - 10th May 2017	356	3,863.0	£633.71	1,909.5	2.023	£632.19	-0.54%	-24.80%
T-21	27th Nov 2015 - 4th May 2016*	159	6,218.0	£2,283.84	1,312.9	4.736	£1,479.99	10th Oct 2016 - 7th May 2017*	209	1,954.0	£546.00	1,660.1	1.177	£367.82	76.09%	75.15%
T-17	9th May 2015 - 13th May 2016	370	2,591.2	£408.99	2,037.2	1.272	£397.47	13th May 2016 - 10th May 2017	362	2,416.8	£389.89	1,936.4	1.248	£390.01	4.67%	1.88%
T-25	30th Aug 2015 - 15th Apr 2016	229	2,063.0	£526.11	1,566.5	1.317	£411.54	2nd July 2016 - 8th May 2017	310	2,775.7	£522.90	1,804.9	1.538	£480.56	0.61%	-16.77%
T-07	6th May 2015 - 19th Feb 2016	289	10,969.0	£1,467.94	1,359.6	8.068	£1,669.64	19th Aug 2016 - 9th May 2017	263	10,439.0	£1,388.61	1,762.1	5.924	£1,109.00	5.40%	33.58%
Average		308	4,834.6	£925.50	1,918.5	2.899	£784.17		296	3,913.8	£653.40	1,813.1	2.153	£566.89	14.67%	12.33%
Overall Average						2.541	£716.56						2.062	£577.01		9.00%

12 month estimated costs based on 20 year degree-day value for the region stated

Figure 4.1 - Analysis of electricity costs before and after the measures were fitted

Normally, for calculations relating to space heating, a process called "degree day correction" is used. In order to properly analyse energy use for space heating, account must be taken of the weather, as it is poor practice to compare the heating costs for two periods without compensating for different outdoor temperatures during those periods. An external temperature of 15.5°C is accepted by energy professionals as the outside temperature below which heating is normally required, and above which no heating is needed. Degree days (DD) are the heating requirement i.e. the number of degrees below 15.5°C that the average temperature falls, for each day. For example, when the average outside temperature drops to 14.5°C, this is classed as 1 degree-day. Degree days are added together over the required period, to give a total number of degree days in that period. Different periods can then be compared for their energy consumption and the results used to predict energy consumption on a normalised basis, taking into account the outside temperature for those different periods[10]. Degree day data was obtained from weather station Trawscoed, (3.95W,52.34N)[11] as this is relatively close to the area in which the properties are located and had good quality data for many years. 20-year average degree day values are only available on a regional basis: the Wales region experiences 1953.1 degree days per year on average.

[10] www.carbontrust.com/resources/guides/energy-efficiency/degree-days [Accessed 20/03/2017]

[11] Degree Days.net: www.degreedays.net [Accessed 20/06/2017]

As highlighted earlier, it was not always clear whether electricity was used in each household for heating and hot water, or simply for lighting and powering appliances. Hence, both degree day-corrected, and un-corrected, values are displayed. Homes where some use of electric heating was mentioned in questionnaire responses are marked in pale yellow in the right-hand column, as these values may be more appropriate. The home T-07, marked in bright yellow, was the only property using electric storage heating at the end of the study, where degree-day corrected figures should definitely be used. This home also had an Economy 7 electricity tariff, so standardised costs of 7p/kWh off peak and 18p/kWh peak rate are used for cost calculations (highlighted in bright orange) are used. The remainder – marked in pale orange in the second-to-last column – do not mention any aspect of electric heating, so for these homes, non-degree day corrected figures may be more appropriate. For all homes but T-07, standardised electricity costs of 16p/kWh were used for cost calculations.

For the properties which received both multi-fuel stoves and solar thermal, 2 appear to have used more electricity than previously, no matter whether measured per day or per degree day. These were the more modern cavity-walled homes. In one of these properties, T-05, the resident had become unemployed, so may be at home more than the previous year to require heating, but it is also possible that residents could not manage the stove so used more electric storage heating. However, properties T-03 (older solid-walled house) and T-04 (modern but low SAP-rated property) saved approx. 50% and 25% respectively on electricity costs following the measures. On average, it cannot be stated that savings were made as a result, due to this variability in savings (or otherwise) and the small sample size. The differences seen may be as a result of the different property types, different comfort expectations of their residents, or insufficient information about how to best use this combination of technologies for cost-effective heating and hot water.

Homes which received only solar thermal installations generally made overall savings, particularly property T-21 which switched from electric storage heating and saved around 75%. Of the 2 properties which did not make savings, T-02, stated that a son had returned to live at home and was now unemployed, so was now usually at home all day – this would be likely to increase electricity usage. The other, T-25, stated that they did not use electricity for either heating or hot water, so this must be linked to a change in other appliance usage and not linked to the solar thermal panels. Even when these homes are included in the calculations, an 11% saving on degree day-corrected electricity costs is seen. This rises to a 24% saving when properties T-02 and T-25 are excluded. If comparing non degree-day corrected figures, a saving of 13.2% is seen across all properties, and this rises to 16.2% if the household which is known to use electric storage heating is excluded (as degree day correction should definitely be used for that property). Household T-17 also commented that they previously had to be very frugal with hot water use to keep it affordable, whereas now they could afford to use hot water – and heat the home – more, which would explain their low level of savings.

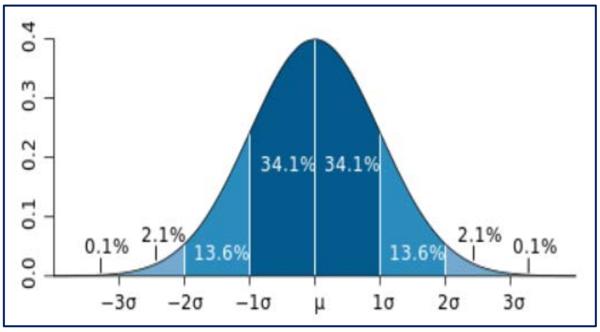


Figure 4.2 Illustration of mean (μ) and standard deviation (σ) in a normal distribution

To assess the significance of these results, the standard deviation of the savings is calculated – this measures the spread around the average, as displayed in Figure 4.2 above. A result is significant with 68.2% certainty when savings are greater than zero ±σ, significant with 95.4% certainty when savings are greater than zero ±2σ. In social studies, it is rare to be able to meet the 3σ requirement for a 99.6% level of significance. Given that only household T-21 completely switched heating type from electric storage heating, hence its 75% savings on electricity bills, this must be dealt with separately, as well as properties T-02 and T-25 already highlighted. If averaging the degree day corrected savings for T-07 and T-09 (as these households mention using all or partly electric heating), with the non-degree day corrected figures for T-13 and T-17, this gives an average saving of 13.1% ± a standard deviation of 12%. These savings are therefore significant to 1 σ, or 68.2% confidence level. Clearly property T-21 switching from electric storage heating has made enormous savings in electricity, however, they may be buying large amounts of solid fuel instead which may reduce these financial savings to the householder.

In order to compare performance over different times of year, summer and winter electricity usage was separated out where possible. Figure 4.3 shows results of the analysis for the summer period.

Tech Ref	Before Period	Days	kWh per day	30-day Cost	After Period	Days	kWh per day	30-day Cost	% saving
T-05	21st May - 24th Aug 2015	95	9.18	£44.06	26th May-20th Sept 2016	146	10.07	£48.33	-9.69%
T-01					6th June-18th Sept 2016	104	13.63	£65.40	
T-04	8th Jul - 19th Sept 2015	73	10.40	£49.91	11th June - 7th Nov 2016	149	10.66	£51.16	-2.51%
T-03	1st Aug - 30th Sept 2015	60	7.50	£35.98	30th Jun-30th Sept 2016	92	4.06	£19.48	45.87%
Average		76	9.02	£43.32		123	9.60	£46.09	11.23%
T-15	7th June - 11th Sept 2015	96	17.14	£82.25	28th May-16th Sept 2016	111	18.90	£90.72	-10.30%
T-09					30th May-17th Sept 2016	110	3.07	£14.75	
T-02					1st June-11th Sept 2016	102	9.38	£45.04	
T-21	4th May - 10th Oct 2016~	159	10.09	£48.42					
T-17	9th May - 4th Sept 2015	118	7.32	£35.15	30th May-14th Sept 2016	107	5.95	£28.58	18.67%
T-25	30th Aug - 10th Oct 2015	41	8.61	£41.33	15th Jun-11th Sept 2016	88	9.20	£44.16	-6.86%
T-07	6th May - 6th Aug 2015*	92	47.65	£138.63	19th Aug-19th Oct 2016*	61	16.64	£39.34	71.62%
Average		101	18.16	£69.15		97	10.53	£43.77	45.14%

* = costs calculated using Economy 7 tariff rates (as this property uses electric storage heating & immersion)
~ = due to late installation of measures, this is summer 2016 where all others are 2015

Figure 4.3 – Comparison of summer-period only electricity costs before and after measures

Degree day correction is not used in summer as space heating (and use of the multi-fuel stove by those properties which received one) is not expected. This shows that property T-05 did not make savings even in summer, which suggests that the resident's unemployment did indeed contribute to increased electricity usage. Another multi-fuel stove and solar thermal property, T-03 made 46% savings over their previous year's use, and T-04 used 2.5% more, but for a period included up until November (when heating is expected to be on) which could explain slightly higher use. For solar-thermal only properties, again T-25 reported that they do not use electricity for heating hot water, which would explain that household's lack of cost savings, and in property T-15, the resident had health issues and was in hospital for a period during the summer of 2016, though is unclear why this would have increased the electricity usage. Homes T-17 and T-07 made significant savings on their electricity bills, the latter – the only electrically storage heated home – apparently made a huge 72% saving (though different months are compared due to meter reading availability, and May-August can sometimes be cold). Monthly electricity costs reduced from £69 to £43 when averaged across the whole solar thermal sample group, a 45% saving.

Examining savings over winter months only (Figure 4.4), for properties with multi-fuel stoves and solar thermal: significant savings were seen for properties T-03 and T-04, but even assuming they used some electric heating (hence using the degree day corrected savings column), properties T-01 and T-05 still saw a 20%+ increase in electricity usage. This is concerning, and follow-up may be required to ascertain the cause of this increase and how it could be resolved.

	"Before" period							"After" period							Comparison	
Tech Ref	Before period	Days	kWh per day	30-day cost	Degree days	kWh per degree day	30-day d/d corrected cost	After period	Days	kWh per day	30-day cost	Degree days	kWh per degree day	30-day d/d corrected cost	Estimated 30-day saving	Estimated D/D corrected saving
T-05	24 Aug 2015 - 27th Apr 2016	247	11.15	£53.52	1,670	1.650	£42.37	1st Oct 2016 - 9th May 2017	220	16.30	£78.26	1,708	2.100	£53.94	-46.23%	-27.30%
T-01	18th Sept 2015 - 20th Mar 2016	166	13.13	£63.04	1,105	1.972	£50.65	18th Sept 2016 - 9th May 2017	233	18.18	£87.24	1,740	2.434	£62.52	-38.40%	-23.42%
T-04	19th Sept 2015 - 25th Mar 2016	188	17.57	£84.33	1,328	2.488	£63.90	7th Nov 2016 - 9th May 2017	183	10.61	£50.95	1,486	1.308	£33.58	39.58%	47.44%
T-03	31st Oct 2015 - 31st April 2016	182	7.35	£35.27	1,424	0.939	£24.12	30th Sept 2016 - 30th April 2017	181	3.34	£16.02	1,517	0.398	£10.23	54.57%	57.58%
Average		196	12.30	£59.04	1,382	1.76	£45.26		204	12.11	£58.12	1,613	1.56	£40.07	2.38%	13.57%
T-15	17th Oct 2015 - 29th Apr 2016	195	11.82	£56.71	1,478	1.559	£40.03	10th Oct 2016 - 10th May 2017	212	9.68	£46.47	1,677	1.224	£31.44	18.06%	21.45%
T-09	10th Oct 2015 - 10th May 2016	213	6.50	£31.21	1,586	0.873	£22.43	30th Sept 2016 - 10th May 2017	222	5.45	£26.18	1,720	0.704	£18.09	16.11%	19.38%
T-02	19th Jan - 11th May 2016	113	10.58	£50.80	970	1.232	£31.66	10th Oct 2016 - 10th May 2017	212	11.89	£57.06	1,677	1.503	£38.61	-12.31%	-21.96%
T-21	27th Nov 2015 - 4th May 2016	159	39.11	£187.71	1,313	4.736	£121.64	10th Oct 2016 - 7th May 2017	209	9.35	£44.88	1,660	1.177	£30.23	76.09%	75.15%
T-17	12th Oct 2015 - 13th May 2016	214	6.92	£33.20	1,578	0.938	£24.09	1st Oct 2016 - 10th May 2017	221	7.10	£34.06	1,716	0.914	£23.47	-2.57%	2.55%
T-25	10th Oct 2015 - 15th Apr 2016	188	9.10	£43.66	1,413	1.210	£31.07	2nd Oct 2016 - 8th May 2017	218	8.87	£42.57	1,697	1.139	£29.26	2.49%	5.83%
T-07	6th Aug 2015 - 19th Feb 2016*	197	33.43	£115.15	1,086	6.066	£98.40	19th Oct 2016 - 9th May 2017*	202	46.65	£177.89	1,619	5.822	£86.57	-54.48%	12.02%
Average		183	16.78	£74.06	1,346	2.37	£52.76		214	14.14	£61.30	1,681	1.78	£36.81	6.20%	16.35%
	* = costs calculated using Economy 7 tariff rates (as this property uses electric storage heating & immersion)													Whole group average savings:	17.23%	30.23%

Figure 4.4 – Comparison of winter-only electricity costs before and after measures

For properties with solar thermal only, savings were seen in all properties except T-02, where 1 additional, unemployed family member had returned home and was in most of the time. If this property is excluded, the average saving was around 22% (whether calculated using degree day-corrected or non-corrected figures). The household which used electric storage heating (highlighted in bright yellow) shows less saving than during the summer, as hot water heating made up a lower proportion of the energy use, but 12% is still a significant saving. Small savings were seen in properties T-17 and T-25 who report they were previously very frugal with heating, and do not use electricity for heating and hot water, respectively. Household T-21 again had very large savings due to their fuel switch. When averaged across the whole sample group, uncorrected monthly energy costs reduce from £74 to £61, a saving of 17%; and degree day corrected monthly costs (calculated across the whole year, equivalent of a monthly direct debit sum) reduce from £53 to £37 per month – a 30% saving. Due to the high variability within the sample, it is uncertain if these savings are achievable over the longer term. Average winter savings were 10.9% ± 8.1% if properties T-21 and T-02 are excluded due to known changes in their use.

Solid fuel usage/costs

Many homes in this area – with its tradition of coal mining and forestry - use solid fuels to heat their homes, and newly installed multi-fuel boilers will require the purchase of solid fuel to fire them. As well as taking regular meter readings, residents were asked to record when they opened each new bag of solid fuel, its type (logs, coal, anthracite or other), and its weight. Many also recorded its cost, or if they obtained wood for free. In practise, residents recorded when they bought solid fuel.

	Logs		Coal	Anthracite	Other solid fuels	% Renewable	Total	kWh/day	Cost
Tech Ref	Softwood	Hardwood							
T-05	1,896			9,066		17.3%	10,962	59.90	£350.00
T-01	1,896		6,512			22.6%	8,408	45.94	£394.00
T-04			7,544			0.0%	7,544	41.22	£364.80
T-03	6,883		794		2,073	70.6%	9,750	53.28	£329.40
Average							9,166	50.09	£359.55
T-15			3,573			0.0%	3,573	19.53	£162.00
T-09						-	-	-	-
T-02	4,740		1,112			81.0%	5,852	31.98	£392.00
T-21	1,422	10,831	5,162			70.4%	17,415	95.16	£617.50
T-17					5,399	0.0%	5,399	29.50	£240.00
T-25	1,896			4,986		27.5%	6,882	37.61	£220.00
T-07						-	-	-	-
Average							7,824	42.76	£326.30

Figure 4.5 – Analysis of solid fuel use & costs

Total usage over a winter period was calculated in kWh for comparison; see Figure 4.5, using data on calorific values of fuels from DUKES[12] and different types of wood logs from RenSMART wood fuel cost calculator[13]. For properties T-05 and T-25, householders obtained wood for free; amounts used were not known, and could not be estimated by the householders: a conservative estimate of 2 x 1 m^3 bags of logs per year was used in calculations for these homes.

These records only include solid fuel bought from November 2016 – May 2017; however some properties may have continued to use solid fuel during the summer months. Most residents who had previously used solid fuel heating had not noticed any significant change in the amount they needed to buy since the previous year, so we were unable to calculate any change in energy content of fuel purchased between the monitored winter and the previous one.

One householder, in property T-07, uses only electric storage heating with no solid fuel present over the monitoring period, and another in property T-09 did not provide information on solid fuel use - although this is reported as the main space heating for the property. As can be seen, assuming the records we obtained date from between our visits on 7th Nov 2016 and 8th-10th May 2016 (9th May used as an average), the kWh per day can be calculated for comparison with household electricity usage. N.B. values reported are energy content of fuels purchased, and do not take into account the efficiency of boilers or closed room fires at 70% and 60% respectively.

Given that multi-fuel stoves were fitted, instead of the originally proposed 100% renewable biomass (i.e. wood pellet or chip), it is encouraging that in terms of kWh heat content, 3 properties are using 70-81% wood fuel, 3 more are using 17-27.5% wood, and only 3 use entirely fossil fuels to provide their heating (and/or hot water). Of the 4 properties in which multi-fuel stoves were installed through this project, 29% of fuel used in terms of its kWh heat content was wood.

4.2 Analysis of heat output

Limited heat meter data is available due to the previously described issues (see section 3.3). Some heat meters were fitted late, but there is uncertainty as to when and on which hot water pipe they were fitted (output from solar thermal or multi-fuel stove), so no analysis of this data was possible.

For the 2 properties which had solar thermal heat output displays, these were fitted on 11th February 2017. On the final visit to properties, the reading displayed at property T-02 on 10th May

[12] Digest of UK Energy Statistics, BEIS, www.gov.uk/government/collections/calorific-values [accessed 27/7/2017]
[13] Wood Fuel Cost Calculator, www.rensmart.com/Tools/FuelCostCalculator/WoodFuelCostCalculator [accessed 27/7/2017]

2017 was 222 kWh, and at property T-25 on 8th May 2017 was 1358 kWh. This equates to a heat output of 2.5 kWh/day, and 15.8 kWh/day for properties T-02 and T-25 respectively. Following enquiries to obtain further meter readings for property T-25, the householder emailed an additional photo showing a reading of 3667 kWh on 20th July 2017. This equates to an output of 23 kWh/day since the display was fitted and 31.6 kWh/day since the final household visit in May. Clearly solar thermal systems produce most of their heat output in the summer, and readings have increased significantly since the final visits in May. It seems that either the aspect for solar gain is better at T-25 than T-02, particularly during the early part of the year, or some other issue is reducing the output for T-02 e.g. the immersion heater could be programmed to run every night so little top-up from the solar panels is needed/possible.

4.3 Temperature and thermal comfort

Temperature and humidity loggers were placed in the main living room/area and the main bedroom of each of the monitored homes, in position between January 2016 and May 2017. An additional property joined the project at the last minute before the installation of the measures, hence their thermal loggers were installed in May 2016, and further loggers were added in properties which we discovered did not have them, in October and November 2016. Therefore we do not have temperature data from prior to installation of the measures for all the monitored properties, only properties T-01 and T-05 which both received multi-fuel stoves and solar thermal, and properties T-02 and T-09 which received solar thermal only. The last of these temperature loggers was placed on 20th January 2016, and the first measures were installed in early May 2016, hence 21st January – 1st May 2016 is used as the 'before' temperature analysis period. The last thermal loggers were placed on 30th November 2016, and one logger stopped recording on 1st April 2017, hence the period to 1st December 2016 - 31st March 2017 is used as the 'after' winter temperature analysis period. Data is presented in Figure 4.6.

Before period		Living Room							Bedroom						
Property ref.	Measure	5-10pm	24hr	Median	Mode	Min	Max	SD	5-10pm	24hr	Median	Mode	Min	Max	SD
T-01	Multi-fuel & solar thermal	18.45	18.67	18.00	17.00	12.50	39.50	3.94	17.25	17.34	17.50	17.50	14.00	23.50	1.33
T-05	Multi-fuel & solar thermal	17.07	16.63	16.50	15.50	13.00	23.50	1.74	-	-	-	-	-	-	-
T-02	Solar-thermal	16.44	15.87	16.00	15.00	11.00	21.00	1.82	14.32	14.85	15.00	15.00	10.00	19.50	1.55
T-09	Solar-thermal	13.09	13.24	13.50	13.50	10.50	20.50	1.23	16.35	15.66	15.00	14.50	12.00	24.50	2.32
Average	Multi-fuel & solar thermal	17.76	17.65	17.25	16.25	12.75	31.50	2.84	17.25	17.34	17.50	17.50	14.00	23.50	1.33
	Solar-thermal	14.76	14.55	14.75	14.25	10.75	20.75	1.53	15.33	15.26	15.00	14.75	11.00	22.00	1.94

Figure 4.6 Temperatures in properties (a) above, in winter before (21st Jan – 1st May 2016) and (b) below, after (1st Dec 2016 – 31st Mar 2017) installation of the measures

After period		Living Room							Bedroom						
Property ref.	Measure	5-10pm	24hr	Median	Mode	Min	Max	SD	5-10pm	24hr	Median	Mode	Min	Max	SD
T-01	Multi-fuel & solar thermal	16.26	16.29	16.00	15.50	12.50	22.50	1.67	16.37	16.59	16.50	16.50	13.00	21.50	1.43
T-03	Multi-fuel & solar thermal	14.87	15.19	15.50	15.50	10.50	20.50	1.91	-	-	-	-	-	-	-
T-05	Multi-fuel & solar thermal	19.87	19.23	19.00	19.00	14.00	28.50	2.24	-	-	-	-	-	-	-
T-04	Multi-fuel & solar thermal	23.11	22.26	22.00	20.00	14.00	27.50	2.18	21.16	21.25	21.50	21.50	13.00	24.00	1.31
T-02	Solar-thermal	15.97	15.28	15.00	15.00	10.50	20.50	1.78	15.37	15.27	15.00	15.00	10.00	19.50	1.55
T-09	Solar-thermal	12.76	12.87	13.00	13.00	10.00	17.00	1.15	16.11	15.70	15.00	14.50	12.00	24.50	2.32
T-07	Solar-thermal	-	-	-	-	-	-	-	19.07	19.07	19.00	18.50	15.50	23.50	1.55
Averages	Multi-fuel & solar thermal	18.53	18.24	18.13	17.50	12.75	24.75	2.00	18.77	18.92	19.00	19.00	13.00	22.75	1.37
	Solar-thermal	14.36	14.08	14.00	14.00	10.25	18.75	1.46	16.85	16.68	16.33	16.00	12.50	22.50	1.81

Before the measures were fitted, properties T-01 and T-05 which would receive multi-fuel stoves and solar thermal (purple rows in the tables), used solid fuel fires with back boilers for space and water heating. Households T-02 and T-09 – due to receive solar thermal panels only (gold rows in the previous tables), used solid fuel for space heating, and electric immersion for water heating. Those properties which would receive multi-fuel stoves and solar thermal achieved temperatures closer to, or within, the recommended 18-21°C temperature range for comfort and good health, whereas T-02 and T-09 are very cold by comparison. This may be due to the type of heating used, or the fact that these properties are more modern cavity-walled ones which retain heat better. There appears to be no general rule for bedroom temperatures, with 2 being cooler than the respective property's living room, and 1 being warmer. All are cooler than the recommended 18-21°C temperature range. (The logger in the bedroom of home T-05 failed, hence no data here.)

In the period after the measures were fitted, when data is available for more properties, average temperatures in both the living room and bedroom of property T-01 have reduced by 1-2°C – again this is concerning that the resident appears not to be able to keep as warm as previously, with their average temperature no longer falling within the 18-21°C comfort range. Property T-03 achieves lower temperatures – this is likely to be because it is a poorly insulated solid-walled property, similar to T-02 and T-09. The maximum temperatures of both T-01 and T-03 are acceptable, but it is unlikely that these are achieved for long. Properties T-04 and T-05 are both relatively modern properties – the temperature of home T-05 has increased and whilst this may be due to the new heating system, this may also be due to the fact that the householder became unemployed during the study period so is likely to be at home for longer, requiring heating. Both properties are able to maintain their temperatures within the comfort 18-21°C temperature range, indeed, property T-04 heats the living room to an average of 23 °C during the evening heating period. Again, the older properties T-02 and T-09 which received solar thermal only, are much colder than most of the homes which also received multi-fuel stoves, but similar to temperatures in property T-03 which received a multi-fuel stove but is of similar construction-type. Living room temperatures in these 2 properties have decreased slightly, however as solar thermal would not influence the heating temperature (other than potentially making it more affordable to heat the home more), this is not a failing of the technology installed. Property T-07's living room logger failed, but the bedroom logger gives an indication that temperatures in this property are maintained within the 10-21°C range for comfort and health, with very little temperature variation. As this is an electric storage heated home, plus electric heaters for top-up as the householder in this property is 60+ and has health issues, it was stated that the home had to be kept warm for health reasons.

4.4 Humidity

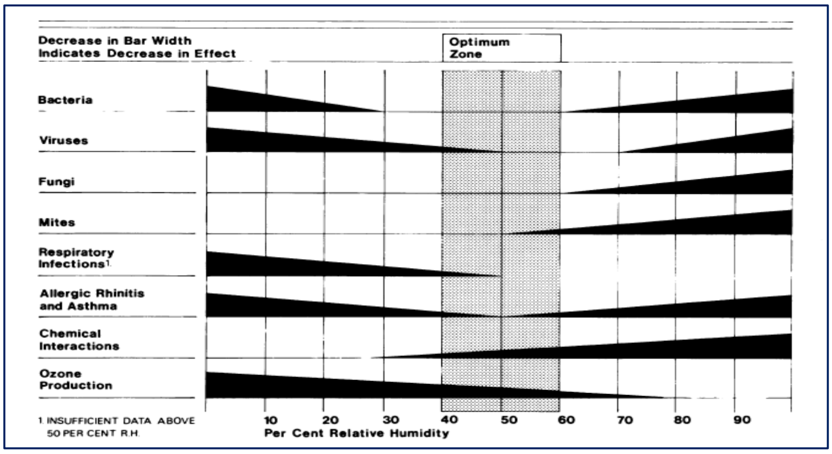


Figure 4.7 Optimum humidity levels to reduce indirect effects from pathogenic organisms or chemicals

Water vapour is not usually considered to be an indoor contaminant or a cause of health problems. In fact, some level of humidity is necessary for comfort. On the other hand, the relative humidity of indoor environments (over the range of normal indoor temperatures of 19 to 27°C), has both direct and indirect effects on health and comfort. The direct effects are the result of the impact of relative humidity on physiological processes, whereas the indirect effects result from the effect of humidity on pathogenic organisms or chemicals. Figure 4.7 illustrates the optimum humidity levels as cited by Anthony Arundel et al[14]. The study concludes that maintaining relative humidity levels between 40% and 60% would minimise adverse health effects relating to relative humidity. The indirect health effects of relative humidity increase in importance as a result of the construction of more energy efficient sealed buildings with low fresh air ventilation rates, but this subject is beyond the scope of this study.

Humidity data for the properties before and after installation of the measures is presented in Figure 4.8. Prior to installation of the measures, properties T-01 and T-05 had lower humidity than T-02 and T-09: again, this is more likely to be associated with their better insulation and higher temperatures than any humidity resulting from their type of heating. Properties T-01 and T-05 had relative humidity levels within the recommended 40-60% range to minimise adverse health effects, whereas properties T-02 and T-09 have average humidity levels above 60% and may therefore have been more likely to suffer from allergies, mites, bacteria and fungi. Two homes' bedrooms had higher humidity than the living rooms, but the bedroom in property T-09 had a lower relative humidity level than the living room. Comparing back to Figure 4.6, this is likely to be because it is heated to a warmer temperature than the living room.

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

TECHNICAL INNOVATION FUND

Before period		Living Room							Bedroom						
Property ref.	Measure	5-10pm	24hr	Median	Mode	Min	Max	SD	5-10pm	24hr	Median	Mode	Min	Max	SD
T-01	Multi-fuel & solar thermal	48.82	46.19	47.00	47.00	19.00	72.50	8.75	60.76	60.28	60.00	60.00	43.50	83.50	5.70
T-05	Multi-fuel & solar thermal	53.10	51.53	51.50	50.50	27.50	70.00	5.47	-	-	-	-	-	-	-
T-02	Solar-thermal	64.00	63.74	63.50	63.00	53.50	72.50	2.79	69.70	76.53	70.00	70.00	60.00	81.00	3.57
T-09	Solar-thermal	79.45	80.77	81.00	80.50	68.00	93.00	4.21	62.30	60.17	61.50	63.00	48.00	76.50	4.28
Average	Multi-fuel & solar thermal	50.96	48.86	49.25	48.75	23.25	71.25	7.11	60.76	60.28	60.00	60.00	43.50	83.50	5.70
	Solar-thermal	71.73	72.25	72.25	71.75	60.75	82.75	3.50	66.00	68.35	65.75	66.50	54.00	78.75	3.93

Table 4.8 - Relative humidity in the monitored properties (a) above, before (21st Jan – 1st May 2016) and (b) below, after (1st Dec 2016 – 31st Mar 2017) installation of the measures

After period		Living Room							Bedroom						
Property ref.	Measure	5-10pm	24hr	Median	Mode	Min	Max	SD	5-10pm	24hr	Median	Mode	Min	Max	SD
T-01	Multi-fuel & solar thermal	54.42	52.50	53.00	51.50	30.50	73.50	7.61	58.34	58.15	59.00	63.00	36.00	72.00	6.72
T-03	Multi-fuel & solar thermal	58.47	57.02	57.50	55.00	42.50	71.50	5.63	-	-	-	-	-	-	-
T-05	Multi-fuel & solar thermal	50.97	49.90	50.50	52.00	34.50	68.00	6.27	-	-	-	-	-	-	-
T-04	Multi-fuel & solar thermal	40.39	39.47	39.00	40.00	26.00	66.50	5.95	45.14	44.04	44.00	46.00	33.50	65.00	4.65
T-02	Solar-thermal	66.74	66.27	66.50	67.00	55.00	77.00	4.36	76.22	76.93	77.00	79.50	66.00	85.00	3.13
T-09	Solar-thermal	77.27	78.22	78.00	77.50	68.50	88.00	3.28	60.43	60.04	60.50	61.50	44.50	72.00	5.13
T-07	Solar-thermal	-	-	-	-	-	-	-	54.92	55.70	56.00	56.50	45.50	66.00	2.92
Averages	Multi-fuel & solar thermal	51.06	49.72	50.00	49.63	33.38	69.88	6.37	51.74	51.10	51.50	54.50	34.75	68.50	5.68
	Solar-thermal	72.01	72.25	72.25	72.25	61.75	82.50	3.82	63.86	64.23	64.50	65.83	52.00	74.33	3.73

No significant patterns or change in humidity can be identified as a result of the installation of the measures, other than that in general humidity is inversely proportional to temperature in the home, so those homes experiencing lower temperatures tend to have higher relative humidity. All those properties with multi-fuel stoves and solar thermal have average humidity levels of between 40-60%, whereas properties T-02 and T-09 which received solar thermal panels only have higher humidity averaging over 60%. Property T-07, the electric storage heated home, also has lower humidity, probably due to its warmer temperature. Bedrooms tend to have higher humidity than living rooms, but this is not always the case. Neither multi-fuel stoves nor solar thermal panels are designed to influence or reduce home humidity, so this does not represent any failing on their part.

4.5 Thermal probe data

Unfortunately, only 1 of the 2 thermal probes fitted functioned for the monitoring period, and this was installed on the bedroom radiator of property T-02, which received only solar thermal panels, which would not have influenced the central heating function.

From the data available, we can see that this property tends to use the heating for a variable number of hours, generally later in the evening. Their average radiator temperature for the most recent winter (1st Dec 2016 – 23rd March 2017) over the 5-10pm evening heating period is 24.65°C, however this household tend to heat this radiator from 7 or 8pm at the earliest, until midnight or later. Over the same date period, looking at the time range 7pm – 11:30pm, the radiators achieved an average of 27.3°C. Comparing this back to the previous winter, before the solar thermal was fitted to this property, between 21st January and 10th March 2016, the radiator achieved an average temperature of 21.86°C between 5-10 pm, and 25.7°C between 7-11:30 pm.

This suggests that the solar thermal may be helping the central heating to achieve higher temperatures as domestic hot water is already pre-warmed, so less energy needs to be diverted to heat it before the central heating warms up, however, it could also indicate that the winter was milder so less heating was required. Also, as this was a bedroom radiator, this may not be indicative of the whole house, if TRVs or manual valves are adjusted to turn the radiator on only approaching the time that the household would use the room.

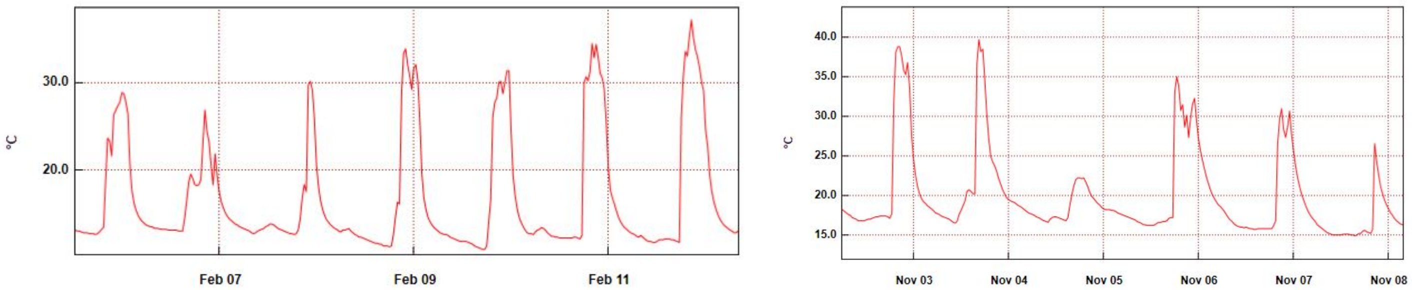


Table 4.9 – Thermal probe data from (a) before and (b) after install of solar thermal

Figure 4.9 shows snapshots from the thermal probe data from before and after install of the solar thermal system. As can be seen, the peaks in Figure 4.9(a) have a slow response time of the radiator to the central heating turning on, probably as heat is being diverted to heat up the hot water tank. Following solar thermal installation, Figure 4.9(b), the temperature peaks have much more vertical fronts showing radiators get hot much more quickly after the central heating is turned on. This supports residents' perception that their homes heat up faster since the solar thermal was installed. Hence, despite solar thermal only providing domestic hot water, the result of this pre-heating of the hot water tank clearly improves the performance of the central heating system.

4.6 Performance comparison against manufacturer's claims

Evacuated tube solar collectors can collect approximately 450-550kWh/m^2 per year[15]. Therefore, a typical 4 m^2 system could provide an annual solar yield of 2,200kWh. If this amount of energy had previously been provided by electricity at 16p per kWh, it would save £352. If previously provided by coal (typical purchase price £9 per 25kg bag, energy content 7.94 kWh/kg[12], it would save £100. Average savings seen by participants in this study of around £230 on electricity bills are therefore in line with expectations, given a mixture of electricity and solid fuels are used to provide hot water, plus households may not have needed the maximum amount of hot water that panels can provide.

No claims of savings are made by multi-fuel stove manufacturers, plus it was unclear whether savings were made in this study as a result of stove installation, so no comparisons can be made for this aspect of the measures.

4.7 Economic business case for installation of measures

The table below examines the cost of the measures themselves, together with the costs of installation, compared against the anticipated savings to the resident. This can therefore be used to suggest a basic pay-back period and demonstrate value for money.

[15] German Solar Society (2005) Planning and Installing Solar Thermal Systems

Measure	Capital cost	Indicative installation costs	Total	Annual energy saving from study	Indicative annual payback (years)	Assumptions
Multi-fuel stove and solar thermal	£7,200	£2,600	£10,000	Could not be determined	Unknown	• Not eligible for RHI as not exclusively renewable. • Social evaluation suggests residents were under-heating homes previously, so cost savings will be lower than anticipated. • Solid fuel costs were not taken into account as no increase was noted.
Solar thermal	£2,500	£1,800	£4,300	£230	18.7 yrs	• Hot water is used: but social evaluation suggests few residents previously used hot water in summer, so cost savings will be lower than expected. • Solid fuel costs were not taken into account as no saving was noted.

The cost-benefit analysis table assumes that the multi-fuel stoves, as installed, are not eligible for the government's Renewable Heat Incentive (RHI) since the stoves do not burn exclusively renewable fuels. It also assumes that the stove is operated as the main central heating system rather than as an occasional room heater providing a top-up of hot water and heating.

For the solar thermal panels, it assumes that residents previously did use hot water in the summer, which would otherwise have had to be heated at some cost by the immersion tank and that the heating system is operated in such a manner that the solar thermal pre-heats the tank in winter prior to the multi-fuel stove or immersion heater topping up the temperature. Solid fuel costs have not been taken into account in this calculation, as residents had not noted any change in their purchases compared to the previous winter, however, for a household newly switching to a multi-fuel stove from electric storage heaters (i.e. solid fuels had not been used previously) this additional cost should be taken into account.

5. Conclusions and recommendations

The initial aims of the project were:

- To install and evaluate the effectiveness of combining solar thermal and multi-fuel stove and back-boiler systems as replacement space and hot water heating in rural off-gas properties; compared to those receiving solar thermal only
- To determine the energy-saving benefits and acceptability to householders of using these technologies
- To provide evidence as to the appropriateness of these systems for other areas and partners.

5.1 Findings and conclusions

Resident satisfaction

Those receiving multi-fuel stoves and solar thermal felt that it improved their control over their heating/hot water system, as well as reducing costs.

- The majority (73%) of householders felt that their **energy costs were the same or cheaper**, and this had reduced any money worries a little – worries about affording fuel bills decreased. 70% also felt that their ease of using hot water was the same or better. 1 householder felt her hot water was not hot enough – this will be referred to the partner. **General financial concerns had increased** over this period amongst the group receiving multi-fuel stoves & solar thermal; however residents did not indicate that this was linked to the measures. 1 householder became unemployed, so it is likely to be linked to other live circumstances

- The majority of householders felt that **their homes warmed up faster**, as even in winter the water in the tank was pre-warmed by the solar thermal so did not take so long to heat up before heat was directed around the central heating circuit. Those receiving multi-fuel stoves particularly felt their house was warmer and more comfortable.

- 36% felt that they could **use more rooms in the house** – even for those who received solar thermal only, the reduction in cost to heat hot water allowed them to afford to put the central heating on for longer/in extra rooms. There was an increase in the proportion who felt they could mostly keep warm enough at home.

- Householders reported anecdotally on **improved quality of life** from having hot water available in the summer, where this was not previously the case – particularly those with health issues which may require frequent (warm) baths.

Energy costs

- Mixed results were seen from the solar thermal combined with the multi-fuel stoves, with 2 properties increasing their electricity use, where the other saved around 45%. This could have been due to changes in resident habits, problems managing the stove to meet their needs, type of house construction, or resident expectations of the system.

- Solar thermal panels alone made more clear-cut savings on electricity bills, where immersion heating was displaced by the solar hot water. This was less clear in winter when other solid fuels were displaced for heating water.
- Whilst the model of stove installed could burn both logs and fossil fuels, on average 29% of fuels burned in stoves fitted as part of this project were renewable biomass (logs), and some properties used up to 70% logs. Some households had access to a local supply of logs, which enabled them to source free fuel.

Temperature and thermal comfort

- No clear change in temperature was visible as a result of the measures – whilst those homes receiving multi-fuel stoves tended to have higher temperatures, this seems more likely to be due to the construction of these homes. The 1 home of an older construction type shows lower temperatures than the other multi-fuel stove and solar thermal homes.
- Many households still struggled to achieve the recommended 18-21°C for good health, particularly those which were of older solid-walled construction. Such homes also experienced high levels of relative humidity, of over 60%.
- No changes in humidity were noted as a result of the installation of measures.
- Limited data could be collected from heat meters, but the few fitted gave an indication of proportions of heat from stoves or solar thermal respectively. Interestingly, there was significant variation between heat meter readings of two properties fitted with solar thermal.
- In terms of cost effectiveness, results of this project suggest that solar thermal has a long payback period of approx. 19 yrs. As few residents previously used hot water in the summer, whilst quality of life was improved, low financial savings were made.

5.2 Recommendations for potential future installations

- Whilst installation of these measures may have reduced costs, temperatures in many of the properties remained worryingly low. It is recommended for future heating system installations that draught proofing and insulation levels of the homes are also improved, to help keep the resulting heat in.
- Whilst most householders accepted the stoves, many being previously used to heating their home using a multi-fuel stove with back-boiler, 1 expressed disappointment that they did not receive a biomass stove as expected. It would be interesting to investigate biomass stoves in future, as far as performance and resident acceptance of a fuel which tends to be smaller, cleaner, lower carbon, and may be easier to manage.
- Solar thermal makes most financial saving to those who use hot water in the summer anyway and would otherwise have to heat it using an electric immersion heater. Homes which have electric showers, cold-feed appliances and do not use significant amounts of hot water from the taps will see very little benefit. In such properties it may be of benefit to

fit a mains shower at the same time as solar thermal, so the resident can take more advantage of the free hot water. Those with health issues could also be targeted, who may benefit in terms of quality of life, from availability of plenty of hot water.

- Provision of resident advice is recommended to ensure householders know how to operate the system, and how to use it to best effect to make savings – e.g. having a bath instead of an electric shower, or using water from the tap instead of boiling a kettle to wash up, if free solar hot water is available.
- At any change of heating fuel, particularly if switching from electric storage heating on an Economy 7 tariff, advice is always recommended to ensure residents are on the correct energy tariff for their needs, and how they may need to change their energy-use behaviour. E.g. some householders appear to retain immersion tanks/storage heaters, but no longer have an Economy 7 tariff so this would be very expensive to use.

5.3 Impact on fuel poverty

In rural areas which are not connected to mains gas, solar thermal - particularly where there is a year-round need for hot water - can make a contribution to reducing the costs of heating hot water, and therefore reducing fuel poverty. As described, this reduction in hot water costs and improved heating speed of the heating system may mean that those at risk of fuel poverty are able to (afford to) keep their homes warmer and more comfortable.

The combination of multi-fuel stoves and solar thermal could unfortunately not be well-characterised due to the small sample size, issues with obtaining previous meter readings and changes to participant life circumstances adding confounding factors. In areas where such a heating type is traditional and fuels are readily available to purchase or have delivered these were generally accepted, were not felt too onerous to control, and users felt that they were helping to save money on bills. However, acceptance may depend on resident expectations and prior experience.

Appendix 1: Glossary of terms

DD	Degree Days (for heating, using a 15.5 °C baseline)
DHW	Domestic hot water
EPC	Energy Performance Certificate
HDD	Heating Degree Days
HIP	Health and Innovation Programme
IMD	Indices of Multiple Deprivation – the nationally defined method of assessing deprived areas in the UK
LSOA	Lower super-output area (the smallest area over which demographic statistics are available)
MCS	Micro-generation Certification Scheme
NEA	National Energy Action – the National Fuel Poverty Charity
OFGEM	Office of Gas and Electricity Markets (the Energy Regulator)
PDC	Programme Development Coordinator
RH	Relative Humidity, measured in % saturation, and dependent on temperature
RHI	Renewable Heat Incentive
SAP	Standard Assessment Procedure (for assessing home energy efficiency)
σ or SD	Standard Deviation
TIF	Technical Innovation Fund
TRV	Thermostatic Radiator Valve

Appendix 2: Comments from householders following installations

Multi-fuel stove & solar thermal recipient comments

Household reference	Comments
T-01	Work is needed to top up the multi-fuel boiler. It's not a biomass boiler but a multi-fuel boiler. I was hoping for a biomass one.
T-03	I have found the process and project useful and have saved a significant amount of money – it's approximately halved my electricity bills. However, there is still no heating in the kitchen.
T-04	It's definitely saved me money on electricity.
T-05	Happy to take part, and happy to benefit.

Solar thermal only recipient comments

Household reference	Comments
T-02	Glad we took part - 100% pleased. However, it is still not possible to heat the house to a comfortable standard due to the fact that it's an old property with insufficient insulation, and the type of heating system fitted - the multi-fuel stove - only heats when it's fired up.
T-07	Happy to take part in project, but as I don't use hot water (electric shower, and only cold-feed washing machine), I'm not sure whether, or how much, it is benefiting me financially, and would be interested to know if it is helping me make savings.
T-09	Good to take part and receive the solar thermal.
T-15	Saving a little money and the home heats up faster.
T-17	Very happy: unsure if it'll save me money on coal but it's brilliant to have the hot water there, especially in spring & autumn when I wouldn't normally have the fire on – I previously had to use the immersion. I have health issues, and sometimes have to have bath a lot: I can do this now without having to worry about the cost. So this project has been life-changing in terms of giving choices & financial freedom, improving quality of life etc.
T-21	Hot water available continually has been a massive help!
T-25	We're really pleased with the system, it works fantastically. It's a luxury, and so much cheaper now we have plenty of free hot water throughout the year – we didn't use it before as have an electric shower & cold-feed washing machine etc. Just used cold water from taps, but now we can use hot. When we do light the fire in the colder months, the central heating heats up much more quickly as there is already some hot water in the tank.

Appendix 3: Details of technologies

Solar Thermal

Solar Thermal panels

Evacuated tube panel system installed. MCS certificates were produced and are available for inspection for all properties if required.

Solar thermal cylinders

Gledhill Stainless Lite Plus solar cylinder

The majority of households in the project were installed with open vented Gledhill Stainless Lite Plus solar cylinders[16].

The Gledhill Stainless Lite Plus solar cylinders are a cylinder specifically for solar applications to provide an efficient way of providing domestic hot water. Each model features a high performance solar coil, transferring the maximum amount of heat from the solar circuit to the stored water.

The cylinders are compatible with a wide range of solar systems available and have been designed to maximise the dedicated solar volume. The open vented Gledhill Stainless Lite Plus solar cylinder is designed for use for use with a conventional boiler including gas, oil and biomass. Cylinders are available in 8 different sizes ranging from 90 litres to 400 litres. The indirect range has a high efficiency corrugated tube coil which is connected to a conventional boiler to heat the cylinder of water. The coils corrugated design gives much faster recovery times than can be achieved with plain tube coils. All models have a temperature and pressure relief valve which is factory set at 6 bar and 95 degrees Celsius.

Solar thermal controllers

The solar controller is the brains of a solar thermal system. It measures the temperature of the collectors and compares this with the temperature of the store. If the collectors are hotter than the store, it turns on the pumping station. Once the store is the same temperature as the collectors it stops the pump. There is additional functionality that can be incorporated and controlled by the controller and could be used in conjunction with other heat requirements such as a swimming pool or central heating.

Four different brands of solar controllers were installed as part of this project:

Resol

Joule Deltasol C4

Grant solar Controller

Regula Primos 250

16 StainlessLite Plus Solar product info, www.gledhill.net/products/alternative-energy/stainlesslite-solar

Multi-fuel stoves with back-boiler

Charnwood LA 45 UW

The majority of properties installed with multi-fuel boilers as part of the project were installed with Charnwood LA 45 UW models[17].

The Charnwood LA 45 features a thermostatically controlled, integral boiler that delivers a heat output sufficient to power 8 - 9 radiators and domestic hot water. Because it is fitted with a water temperature sensitive thermostat, heating controls can be fitted, to give heat precisely when and where it is needed.

The Charnwood LA 45 UW is able to use multiple fuels to heat the stove including and not exclusively, Anthracite Large Nuts, Centurion, Cosycoke, Extracite, Maxibrite, Phurnacite, Sunbrite Doubles, seasoned dry wood and peat.

Specifications of the Charnwood LA 45

Heat Output to Room	SLX 45i+fs - 6.0kW (wood) (range 2-7kW) SLX 45i+fs - 4.6kW (anthracite) (range 2-5kW)
Boiler Output	SLX 45i+ fs - 6.3kW (wood) SLX 45i+ fs - 9.7kW (anthracite)
Flue Outlet	Top or Rear 150mm (6”) diameter
Maximum Log Length	370mm (14.5 inches)
Weight	135kg

Due to issues with multiple contractors working on this project (section 3.3), in property T-04, a different model of multi-fuel stove was installed. We have been unable to identify the brand / model from the contractor, housing association, resident, or from the image of it, left.

However, similar to the Charnwood model above, this also has a back boiler, with two sets of flow and return pipes: the domestic hot water system is gravity-fed, while there is a pump to circulate hot water around the central heating circuit, see image, right.

[17] Charnwood LA range product information, www.charnwood.com/range/stove/la-stove.aspx#

Appendix 4: 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

NEA Technical
October 2017

Action for Warm Homes