CP1025
Q-Bot Application of Under-floor Insulation
London Borough of Camden

Technical Evaluation Report

Before:

After:

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April 2018

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

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Jacob Davies, Sustainability Officer, London Borough of Camden Borough Council
Maddie Clifford, Product Manager, Q-Bot

NEA team:

David Crookes, initial Project Development Co-ordinator
Bryony Holroyd, Technical Project Development Co-ordinator
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Executive summary

Project overview

This project used Q-Bot's novel "SprayBot" to install a 12.5cm thick layer of Elastospray® 1629/1 foam insulation to the under-side of suspended timber ground floors in properties in the London Borough of Camden (LBC). The robot was inserted into the floor void via either an air vent or by removing only a small hatch in the floorboards. This allowed the work to be completed more quickly, cheaply and less disruptively than would normally be the case for under-floor insulation, as there was no need to remove the floorboards. The properties were owned by LBC Council. In one property, the ground floor treated was at the basement level. Some properties were ground-floor flats, others were the lowest floor of multiple-storey terraced properties.

The project had the following aims:

- Insulate the ground floor of hard-to-treat (HTT) properties in Camden borough – these were older terraced, semi-detached or detached properties, all with solid-wall construction. They were Victorian with large rooms and large windows, some of which were single glazed.
- Assess any change in residents' comfort – both reported in questionnaires, and measured using temperature and humidity monitors – as a result of the under-floor insulation,
- Quantify any change in energy use for heating, as a result of the insulation,
- report any change in air quality i.e. carbon monoxide levels in homes, to see if reducing ventilation by sealing up draughty floorboards might worsen air quality,
- Determine the effectiveness and cost-effectiveness of under-floor insulation to reduce fuel poverty in HTT properties - information relevant to all social housing (and private) owners.

Context

The London Borough of Camden (LBC) contains 7 lower super-output areas (LSOAs) which fall into the 10% most deprived in the country. Many properties in the Borough are of older Victorian-era construction, with solid walls, large rooms and (often single glazed) windows, and many also have rooms in the roof so there is no loft space to insulate. This means the properties are naturally hard to heat affordably, so those in social housing are at risk of fuel poverty: likely to struggle to keep their homes adequately warm or afford their energy bills. LBC suffers 9.9% fuel poverty.

These properties are also defined as hard-to-treat (HTT) as their construction means the cheapest and most easily applied insulation methods are not relevant. Of the more expensive measures, fitting internal wall insulation is disruptive, and external wall insulation and double glazing are often not possible due to the presence of conservation areas (or listed status). LBC Council owns over 2,000 such HTT street properties (and additional HTT estate properties) and is seeking alternative cheaper options to improve energy efficiency of these properties. The EST's Energy Saving House suggests an average 15% of heat loss is through a property's floor, so this novel technology to enable easier and cheaper application of under-floor insulation was a good target for testing.

There are approx. 6.6 million dwellings in the UK built before 1919, mainly solid-wall construction with suspended timber ground floors. Including later 1930s' homes, there could be up to 10 million dwellings with suspended timber ground floors in the UK. As cost-effective under-floor insulation has not previously been available, most are untreated, so significant numbers of homes nationally, both social housing and privately owned, could benefit if this trial were to prove successful and cost-effective.

The technology: Q-Bot

Q-Bot's SprayBot is a 4-wheeled robot that applies under-floor insulation onto timber, to reduce heat loss through ground floors. It applies spray foam insulation in 4 stages:

1. Access – SprayBot is inserted into the floor space via an air brick / vent in the wall or hatch in the floor,
2. Survey – a 3D map of the floor-space to be treated is built up to identify issues, obstacles etc.,
3. Apply – the robot sprays the under-side of the floorboards with insulating foam,
4. Verify – the robot re-scans & photographs the space to check the floor is sufficiently insulated.

The project

LBC Council contacted tenants in properties believed to be suitable, asking for volunteers to take part, and properties were surveyed to verify suitability. 39 ground-floor properties were selected for treatment, comprising ground floor flats and larger 3-storey properties, some of which had previously been identified. These were all gas central-heated properties.

7 properties were monitored: 4 ground floor flats and 3 larger 3-storey houses from Sept 2016. They were monitored for temperature and humidity, and a sample were also analysed for carbon monoxide levels in the first year (all were in the second year), in various rooms on the ground floor of the property. Residents were asked to record their electricity and gas meter readings every 2 weeks for the duration of the study, and if possible to provide bills detailing previous consumption. Pre-installation questionnaires were carried out with residents to gather information on household occupancy, energy using behaviours and costs, and satisfaction with the heating and insulation.

Installations of the under-floor insulation took place between October 2016 and January 2017, Dec 2016-Jan 2017 for these monitored properties. One of each type of property withdrew from the monitoring between May-December 2017, these were replaced by a similar-type property at visits in December 2017. Interim questionnaires were carried out with properties which continued with monitoring in May-June 2016. Monitoring continued until February 2018 when all equipment was collected, and a final questionnaire was carried out to gauge resident satisfaction with their heating and insulation now they had experienced a whole winter with the new under-floor insulation fitted.

Summary of findings:

Energy use and costs

- Properties saw an average saving of 13.39 % per year, ± (3 x 3.28%) i.e. savings are significant to 99.6% level of confidence (excluding the largest property which was quite different to the others with bedrooms on the treated ground floor, and a very low consuming energy-rationing property). This represents a cost saving of £88 per year on gas costs.
- Given the two types of property were quite different in size, separating them results in a saving of 13.7% (£92 per year) on average for the smaller ground-floor flats, and 13% (£82 per year) for the larger 3-storey houses. The slightly higher savings for the smaller properties may be due to variations in this small sample, or the fact that under-floor insulation treats a larger proportion of the external envelope of a small flat than of a large multi-storey home where heat can rise to higher floors to potentially escape. [outside scope of study]
- No electricity savings could measurably be linked to the under-floor insulation. Only one property saw savings which may or may not be linked.

Thermal comfort

- Average temperatures during the evening heating period (7-10pm) were generally slightly higher than 24hr average temperatures, though this was not always the case. Most fell into the recommended range of 18-21°C for comfort and good health. Two properties' temperatures were above this range, so residents could save money by reducing heating (one is an elderly household with health conditions so may need it warmer). Two properties experienced average temperatures of 14-15.5°C – one was a fuel poor household where the property was empty 3 days per week and heating was used only for short periods. The other property had basement bedrooms which they found hard to heat. However, maximum temperatures in both these properties (when heating is on, possibly electric heaters) are reasonable (17.5-20°C).
- Following installation of the under-floor insulation, temperatures in most households remained comparable to pre-install levels. One property saw a decrease in temperature – this must be due to a reduction in heating in the property (relative to external temperatures), as under-floor insulation would not reduce temperatures. Another sees a slight reduction in average temperature, but from a relatively high start point, so was not a cause for concern and is likely to have resulted from advice provided at visits. A possible slight increase was seen in temperature in property T-13 with basement bedrooms, but no change was seen for property T-15 (fuel poor) - the heated periods may be minimal compared to the unheated periods.

Damp and humidity

- Most properties' humidity levels fell within the recommended 40-60% humidity range for good health except for T-13, T-15 and an unheated bedroom in property T-08.
- Whilst a reduction was seen in average humidity between the before and immediately after period, levels had risen again in some propertied by early in the following winter, so this may be a seasonal variation between autumn-early winter and mid-late winter rather than as a result of the insulation. However, humidity levels had reduced in property T-15 (fuel poor) to around 60%. In one property with high average temperatures, humidity was now lower than the recommended 40%, another reason to reduce heating to prevent negative health impacts.

Air quality: carbon monoxide

- Carbon monoxide levels were generally low, and not likely to cause health issues in monitored properties. No increase was seen as a result of the installation of under-floor insulation. Some of the possible causes of spikes in levels (e.g. use of a multi-fuel stove) appeared to be reduced after the insulation was installed. Some properties did see spikes in levels after installation, but these are unexplained (may be from (burnt) cooking, smoking etc.) and they were not repeated regularly so it does not suggest an ongoing issue of concern in the property.

Resident satisfaction and comfort

- Residents had poor satisfaction with their home heating, comfort and insulation before under-floor insulation - whilst this improved after installation, they were still not satisfied on average. Greatest increases in satisfaction were seen with the cost of running the heating system, how well the property keeps the heat in, and how warm it gets when it's cold outside. 7 of the 9 residents said the home was now warmer and/or more comfortable, 5 said the house got warmer faster, kept the heat in better, and the measures had improved the quality of the home.
- 4 of the 9 felt their energy bills had reduced. However, there was a split into those who were relatively satisfied, and a group who did not feel the under-floor insulation had made a noticeable difference: with 2 of the 9 feeling there was no change in their energy bills (though

one of these felt they were retaining more heat in the property for the same money), and 3 feeling their energy bills had increased. This reduced money worries a lot for 2 of the 9 residents questioned, and a little for 2 more.

- 5 of the 9 householders could now mostly keep warm enough at home, compared to only 2 of at the outset, and 2 of 9 said they could comfortably heat / use more rooms in the property.
- 3 of the 9 felt that any damp, condensation or mould issues were better after the measures were installed.
- Issues remaining which caused discomfort included single glazed windows, old & draughty windows / doors, uninsulated rooms in the roof (if present), and uninsulated external walls.
- Householders were very satisfied with the installation of the measures, giving the installers glowing reviews, saying how helpful, knowledgeable and good workers they were.

Thermal Imaging

- Floor temperatures were quite even, other than areas unable to be treated, or with hot or cold pipe runs (the latter may be cold-bridging from a supporting wall, cannot confirm from image).
- However, plenty of remaining cold spots / heat loss points were identified in these homes – unrelated to the under-floor insulation – which would still cause comfort issues.

U-values, and EPCs

- Measurements by Q-Bot on one home indicate that the U-value of the floor improved, reducing from 0.99 W/m^{2}K before installation of the under-floor insulation to 0.27 W/m^{2}K afterwards. EPCs carried out before and after install showed an improvement of 3 SAP points on average.

Conclusions and recommendations

- Installation of under-floor insulation by this method was far less disruptive than would normally be the case for manual installation, and the install itself was overwhelmingly liked by residents.
- This measure does reduce heat loss through floors, with a more significant impact on heating bills of ground floor flats, where the floor makes up a larger proportion of the external envelope of the property. However, from this study, the pay-back period appears to be quite long.
- Despite some residents feeling they had not saved money due to the measures, all but one household had reduced their gas consumption once external temperature was taken into account. Average normalised savings measured in this study were not as high as Q-Bot's stated savings, which are based on SAP assessments and resident-reported savings.
- The measures improved residents' satisfaction with heating their property overall, though not all felt the difference was noticeable.
- This may result from other issues that remain in these properties, which may reduce savings as heat can still be lost via other pathways, and cause discomfort: single glazed windows, old & draughty windows / doors, uninsulated rooms in the roof, and uninsulated external walls.
- In future projects, consideration should be given to installing other complimentary measures to ensure maximum benefits are achieved, e.g. draught proofing and other insulation measures.
- Provision of advice to residents - at the time of installation - on the most effective and efficient use of energy in the home is always advised, to ensure residents are on the best energy tariff for their use, and that they are claiming all benefits for which they are eligible.

1. Project overview

1.1 Introduction

This project undertook the installation of insulation to the underside of suspended timber ground floors in properties in the London Borough of Camden (LBC) – in one property, this was at the basement level. The properties were owned by LBC Council. Some properties were ground-floor flats, others were the lowest floor of multiple-storey terraced properties.

Q-Bot's novel "SprayBot" was used to apply a 12.5cm thick layer of Elastospray® 1629/1 spray foam (see Appendix 3) to the under-side of suspended timber floors. The robot was inserted into the floor void via either an air vent or by removing only a small hatch in the floorboards. This allowed the work to be completed more quickly, cheaply and less disruptively than would normally be the case for under-floor insulation, as there was no need to remove the floorboards.

1.2 Aims

The project had the following aims, to:

- Insulate the ground floor of hard-to-treat (HTT) properties in Camden borough – these were older terraced, semi-detached or detached properties, all with solid-wall construction. They were Victorian with large rooms and large windows, some of which were single glazed.
- Assess any change in residents' comfort – both reported in questionnaires, and measured using temperature and humidity monitors – as a result of the under-floor insulation,
- Monitor any change in energy use for heating, as a result of the insulation,
- Monitor any change in carbon monoxide levels in homes, to see if reducing ventilation by sealing up draughty floorboards might worsen this health & safety issue,
- Determine the effectiveness and cost-effectiveness of under-floor insulation to reduce fuel poverty in HTT properties - information relevant to all social housing (and private) owners.

1.3 Context

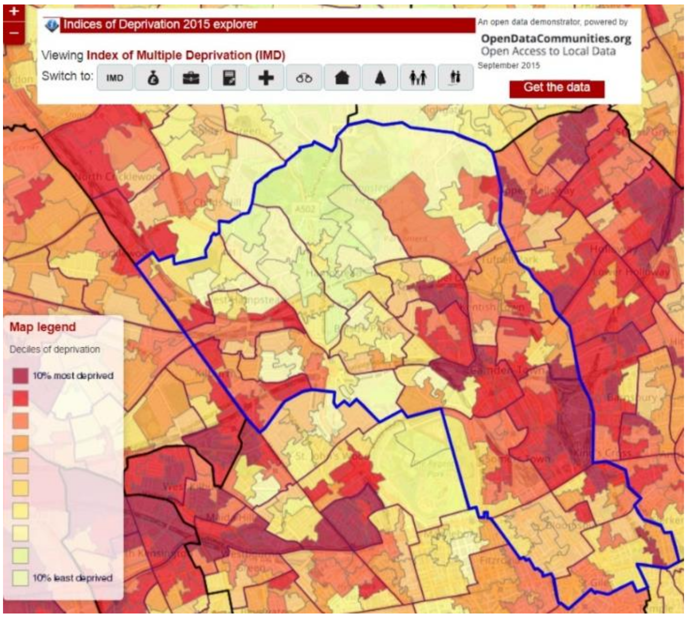


Figure 1.1 Map of Indices of Multiple Deprivation in Camden

The LBC contains 7 lower super-output areas (LSOAs) – the smallest area for which population statistics are available – in the 10% most deprived in the country as defined by indices of multiple deprivation (IMD)[1]. Many properties in this Borough are of older Victorian-era construction, with solid walls, large rooms and (often single glazed) windows, and many also have rooms in the roof so there is no loft space to insulate. This means the properties are naturally hard to heat affordably, so those in social housing are at risk of fuel poverty: likely to struggle to keep their homes adequately warm or afford their energy bills. LBC suffers 9.9% fuel poverty.

[1] 2015 English IMD Explorer: http://dclgapps.communities.gov.uk/imd/idmap.html, [Accessed 04/04/2018]

These properties are defined as hard-to-treat (HTT) as their Victorian era construction means the cheapest and most easily applied insulation measures (cavity wall and loft insulation) are not relevant to them. External wall insulation (EWI) would be costly and cover up the historic brick façade. Internal wall insulation fitted on the inside surface of external walls, and walls and ceilings of rooms in the roof, would also be costly, and intrusive as it would require residents to move out of rooms to carry out the work. Double glazing could be fitted in single glazed properties, but whilst this improves comfort by reducing draughts, it does not pay back from an energy efficiency point of view over the lifetime of the windows, so is usually only done when existing windows require replacement. Many properties treated also were in conservation areas (or were listed), which limits or prohibits some external works to insulate walls and replace original glazing with double glazing. Secondary glazing – a possible alternative – is more expensive to install than simple replacement of single glazing with double glazed units.

LBC Council owns over 2,000 such HTT street properties (and additional HTT estate properties) from which to select those which would most benefit from this measure. The Council is therefore seeking cost-effective options to improve energy efficiency of these properties. Given up to 15% of heat loss from the average uninsulated property escapes through the floor, this novel technology to enable easier and cheaper application of under-floor insulation was a worthwhile target for testing.

There are approximately 6.6 million dwellings in the UK built before 1919, predominantly of solid-wall construction with suspended timber ground floors. Including later 1930s' homes, there might be as many as 10 million dwellings with suspended timber ground floors in the UK[2]. As cost-effective under-floor insulation has not previously been available, most of these are untreated, so significant numbers of homes nationally, both social housing and privately owned, could benefit if this trial were to prove successful and cost-effective.

1.4 Project timeline

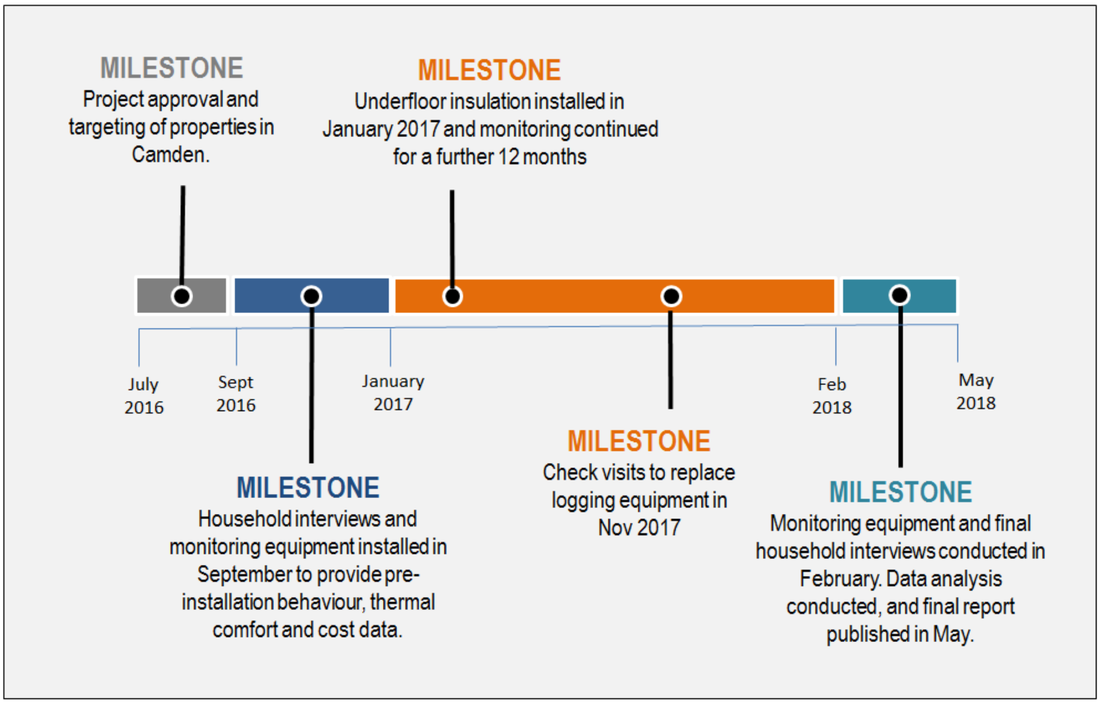


Figure 1.2 Project timeline

[2] Suspended timber ground floors: measured heat loss compared with models, S. Pelsmakers; B. Croxford & C.A. Elwell, Building Research & Information, Published 26 Jun 2017. https://doi.org/10.1080/09613218.2017.1331315, [Accessed 06/04/2018]

This project was agreed in July 2016, and LBC Council attempted to identify suitable properties they own and contacted their tenants to request participants for the study. These were inspected by Q-Bot to see if the treatment was possible. Installation at each property took 1 day, involving inserting the robot, surveying the floor void, spraying the insulating foam, then verifying complete coverage. Installations were carried out between October 2017 and January 2018. 40 households were planned to be treated as part of this project, 8 of which were due to be monitored. However, one monitored property could not be treated due to insufficient clearance in the floor void, hence only 39 properties were treated, and 7 monitored.

1.5 Attracting beneficiaries and establishing a monitored group

Initial engagement with householders was done by the LBC Council and Q-Bot:

- LBC Council identified poor-performing potentially suitable ground floor properties,
- Q-Bot completed a desktop and drive-by study to identify the most promising streets i.e. vents for suspended timber-floor construction visible from the street,
- LBC Council sent residents a letter to invite them to express interest in having the under-floor insulation installed, including some previously identified residents.
- Q-Bot contacted interested residents to arrange survey work - as to whether the property was suitable to receive the under-floor insulation – followed by installation.

40 households were identified, to receive insulation and from this sample tenants of 8 properties were willing to receive monitoring equipment and record meter readings. Unfortunately, one of these properties could not ultimately be treated due to insufficient floor-void clearance, which reduced the sample treated to 39, and the monitored group to 7: a mixture of 4 ground floor flats, plus larger 3-storey properties, 2 terraced and 1 semi-detached. Details of the properties monitored are shown in Table 1.3, and example photographs of property types treated are shown in Figure 1.4. EPCs were not available for many properties as they had been rented long-term since before EPCs were required. Of those we could obtain, the SAP values of the 3-storey properties varied from 54 (E) to 69 (C). The only ground floor flat with an EPC had a SAP value of 66 (D).

After it was decided to extend the monitoring over a further winter, NEA wrote to all monitored properties explaining this, and visited during May-June 2017 to either exchange or collect the data loggers. Two properties withdrew from the monitoring – one at this visit, and another in Dec 2017. Replacements were sought from other willing households who had received under-floor insulation as part of this project – one terraced property replaced a semi-detached property which withdrew, and a ground floor flat / maisonette replaced another which withdrew. Monitoring equipment was placed in these replacement properties at the visits in Dec 2017, when carbon monoxide loggers were also exchanged / fitted in all monitored properties, and any issues from the summer visits were resolved. Whilst we do not have thermal, humidity or carbon monoxide data from the replacement properties for the first winter of monitoring – particularly the period prior to installation of the insulation – we did request meter reading records from the residents' energy suppliers from back before the measures were installed, so energy bill costs can be compared, and monitoring will determine whether they now attain comfortable temperatures and safe carbon monoxide levels.

In order to maintain anonymity for study participants, all properties are reported using allocated Technical reference numbers, as shown in Figure 1.3.

Technical ref.	Property type	Storeys	Approx floor area	Bedrooms	Supplementary heating used
T-02	Mid-terrace house	3	100	4	Yes
T-07	Mid-terrace house	3	100	3	Yes
T-13	Semi-detached house	3	191	6	Yes
T-66	Mid-terrace house	3	119	4	Yes
T-08	Ground floor flat / Maisonette	1	60	3	-
T-15	Ground floor flat / Maisonette	1	40	1	Yes
T-18	Ground floor flat / Maisonette	1	51	2	-
T-19	Ground floor flat / Maisonette	1	50	1	-
T-61	Ground floor flat / Maisonette	1	52	1	-

Table 1.3 – Type and size details of monitored properties

All monitored participants completed an initial questionnaire at the outset of the project – before installation of the under-floor insulation – about their household occupancy, energy-using behaviours, and experiences of heating their home: their costs and satisfaction with their heating, insulation, and comfort. A short intermediate questionnaire was carried out at the visits in summer 2017, to ask about the installation process of the measures and initial feedback. This was completed for any properties which NEA had been unable to visit in summer, at the December visit, and at this point pre-installation questionnaires were carried out with the residents of the 2 newly monitored properties, although this was after their insulation had been fitted. Final questionnaires were carried out for all properties in February 2018 at the final visit to collect the data loggers.

Figure 1.4 – Types of properties treated: (a) ground floor flats in terraced properties (b) ground floors of 3-storey homes

1.6 Factors affecting the planned evaluation methodology

Issue	Description and mitigation
Identification of sufficient suitable properties for install	Difficult to find suspended timber floor properties alongside suitable install conditions (void space etc.) – construction can vary from house to house on one street. Identifying a sufficient sample to treat took longer than expected and required assessment by Q-Bot for viability of install.
Size of monitoring group	A group of 8 properties agreed to take part in the monitoring, however one was unable to receive under-floor insulation due to insufficient clearance in the floor pit. 7 properties were therefore monitored during the first winter. Prior to the second winter, two of these properties withdrew, but these were replaced by 2 additional similar properties. All 9 properties are assessed in terms of their questionnaire responses.
Start of monitoring	Monitoring equipment was placed into the initial 8 properties in September 2016. As CO loggers only record data for 3 months, these were replaced at regular intervals throughout the project. Equipment was collected from the properties which withdrew in May and December 2017. Monitoring was newly placed in replacement properties in Dec 2017.
Monitored group	2 of the 7 monitored properties withdrew from the monitoring prior to the second winter, hence 2 further properties were identified where residents were willing to receive monitoring, however data from these properties will be limited as no thermal, humidity or CO monitoring was in place prior to installation of the measures, for comparison.
Meter readings	Meter readings could be obtained for all properties from energy log books, bills or energy company records for the period prior to and after install, including for those properties which did not have monitoring equipment installed during the first winter.
Monitoring equipment	One of the properties monitored had a gas meter with pulse output, however, a wire in the pulse logger fitted became detached, so no data was recorded. We therefore had to rely on the householder taking regular meter readings, and obtaining readings from their energy supplier, as for all other properties.
Other factors	This sample contains 2 very different property types: the larger homes – many of which had large single glazed windows and no loft insulation – would only be likely to see improvements on the ground floor. These should be considered as a different sub-group to the smaller ground floor flats. This will be taken into account when analysing impacts on both bills and questionnaire feedback about the measures.

Table 1.5 - Issues experienced which may affect the monitoring and evaluation of this project

2. Social evaluation and impacts

2.1 Qualitative feedback from initial – pre-installation – questionnaire

The 7 monitored householders were interviewed at the start of the monitoring period, 5 completed a short interim questionnaire in the middle of the study (June 2017, after the measures were installed), while the 2 which withdrew completed a final questionnaire at this time. The 2 "replacement" monitored households were asked an initial "pre-install" questionnaire in December 2017 (although this was after the measures were installed) and residents of all the remaining 7 monitored households were interviewed 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, benefits and any other effects at the end of the project. Questionnaire responses are resident opinions, so are not necessarily correct. This section sets out the questionnaire results regarding the residents' views, acceptance of the technology etc. and any immediate findings.

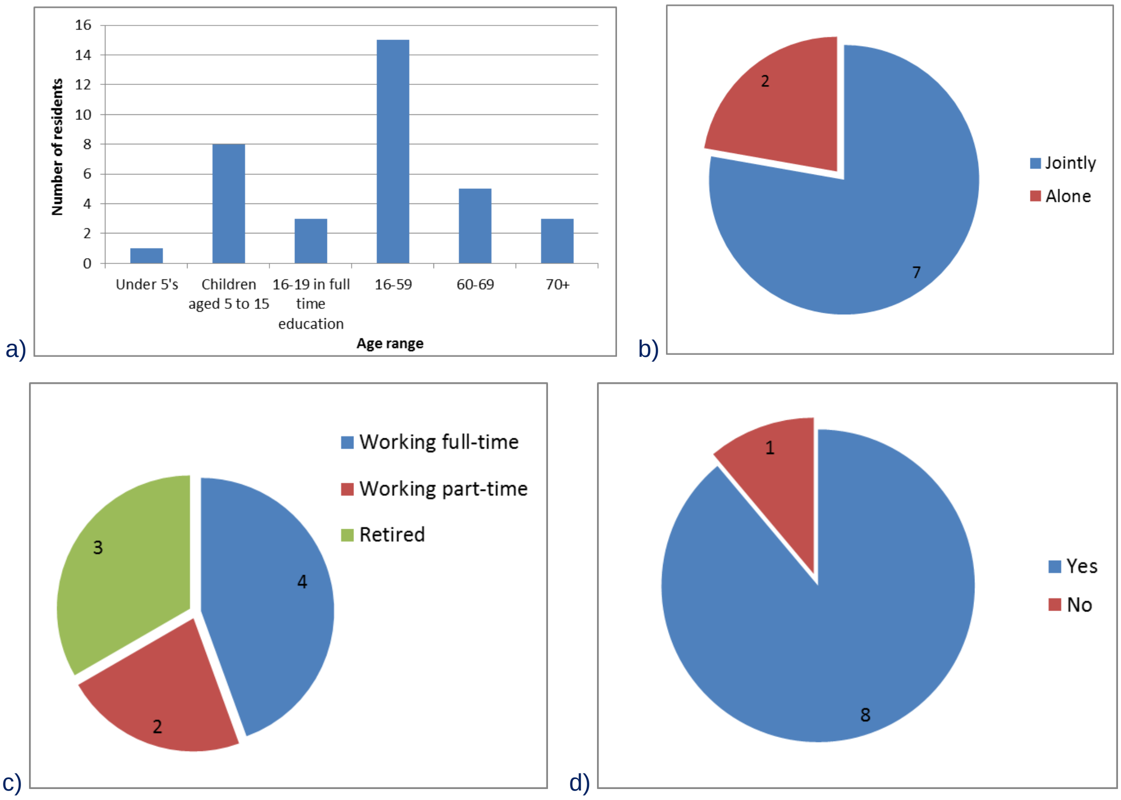


Figure 2.1 (a) Household age distribution, (b) How the bills are managed / paid, (c) Occupation, (d) Health conditions

Figure 2.1(a) shows that there was a wide distribution of resident ages in the monitored properties – the majority were of working age, but there were a significant number of children (though mainly older than 5), and also older people. Whether householders are able to share responsibility for energy bills can be a useful guide to vulnerability to high energy costs. Figure 2.1(b) shows that residents in 7 of the 9 households were able to share responsibility for energy bills with another household member – only 2 of the householders reported that they managed their bills alone. 4 of the 9 households reported that the main bill payer was working full-time (Fig 3.1(c)), whereas 3 were retired and 2 were working part-time, which may indicate a more limited income. Figure 2.1(d) shows that 8 of the 9 households contained at least one resident with health issues, all of these were reported to be made worse by living in a cold home (so for best health they needed to keep the home warm). Health issues present included arthritis, COPD, asthma, eczema, allergies, diabetes, depression, heart condition (requiring pacemaker) and multiple sclerosis.

All properties were heated by gas central heating. Two properties reported having a standard gas boiler with a tank for hot water, but all others reported having combi boilers. 5 of the properties reported also using supplementary heating: one household had a multi-fuel fire fitted and used this 3-4 times per week instead of the main heating system, whereas 4 other households used a variety of plug-in electric heaters. 2 households used these as well as the main heating system for when they required additional heat in the evenings, whereas 2 others used these instead of the main heating in order to only heat one room, or between periods of using the main system.

a) b) c)

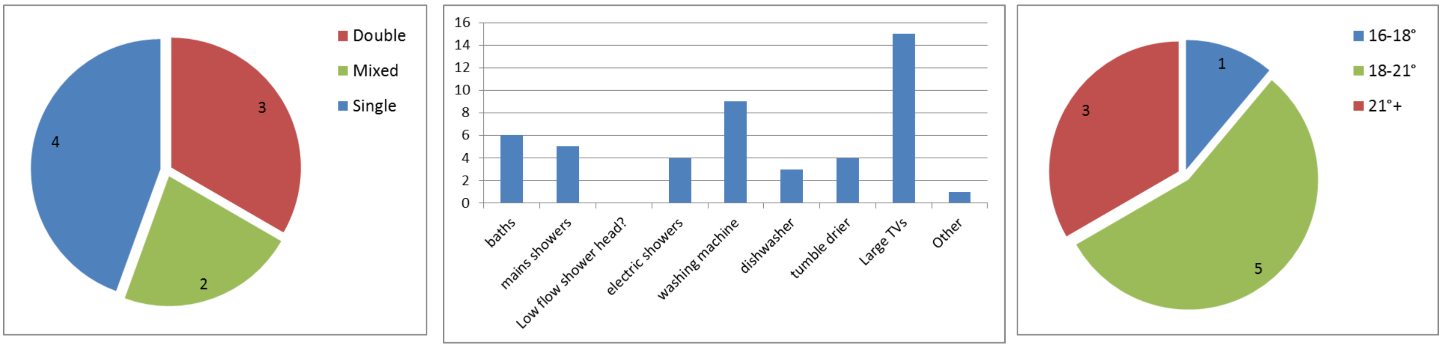


Figure 2.2 (a) Glazing type, (b) Energy using appliances present, (c) Normal living room temperature

A significant problem with this type of property is that a large proportion of them still had single-glazed windows, or a mixture of single and double glazing, as shown in Figure 2.2 (a). The energy-using appliances present in the households are shown in Figure 2.2 (b) – as seen, all had a washing machine fitted, and all had a shower, either mains or electric. 6 of 9 had a bath fitted, but only 4 had a tumble drier present, and 3 had a dishwasher. The most frequent appliances were large TVs, with an average of 1.7 per property – the small one-bedroom flats tended to have only one, those which had multiple were the larger properties with 2 or more bedrooms. One property – identified as in fuel poverty – said they kept their temperatures cooler than 18°C in order to save money, whereas respondents in 5 of the properties reported normally keeping their living rooms in the recommended 18-21°C range, and 3 said they kept temperatures higher than this, at more than 21°C.

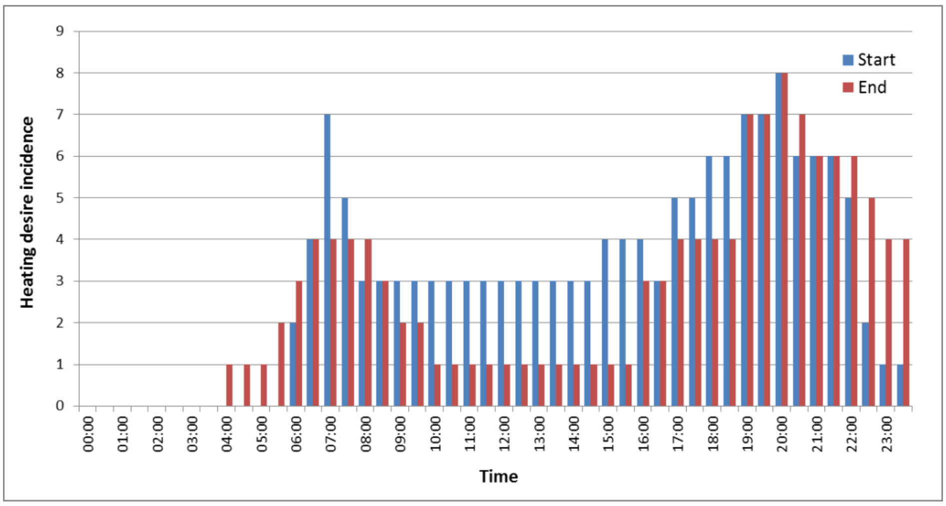


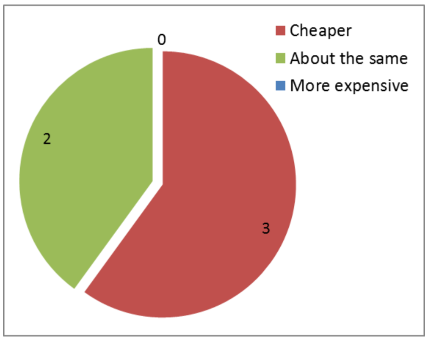
Figure 2.3 Times when residents stated it was important for them to have a warm home

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” over a 24hr time period, as shown in Figure 2.3, 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 7-10pm.

2.2 Affordability of energy bills

In each questionnaire, residents were asked to estimate how much they paid for energy, and at what interval. This was used to estimate an annual total. Whilst this is inaccurate (due to incorrect recollection, rounding, accounts in debt / credit, delays in energy companies amending direct debit payments) it is useful as a measure of residents' perception of their heating costs. Not all residents knew their bill payments. Initially, 6 of the 9 residents reported their payments, which averaged at £1,063 per year, varying between a minimum of £357 and a maximum of £1,654. Separating out the two property types, for the 1- 2 bedroom flats the average was £655 per year; and for the larger 3-bed flats and houses, £1,470 per year. At the interim questionnaire, fewer respondents reported their payments, so it is not useful to make comparisons. At the end of the study, payments reported averaged at £1,280 per year, varying between £480-£2,080. This corresponds to an average for the smaller 1-2 bedroom properties of £1,016; and for the larger 3+ bed properties of £1,740. Energy price rises occurred during the study period which will confound estimates, and winter 2017-18 was particularly cold, so more heating was required, which may explain the increase.

We also asked residents for their perception of whether their energy bills had reduced or not, as shown in Figure 2.4. At the interim questionnaire (summer 2017), 3 of the 5 respondents felt that their bills were cheaper. However, by the end of the study (February 2018), of the 9 respondents, 3 felt that their bills were more expensive, 2 felt they had not changed, and 4 felt they were saving money. Two did comment that their bills had probably gone up because it had been so cold, and another stated that whilst his bills had not dropped he now got the benefit of more heat for the same money.

a) 

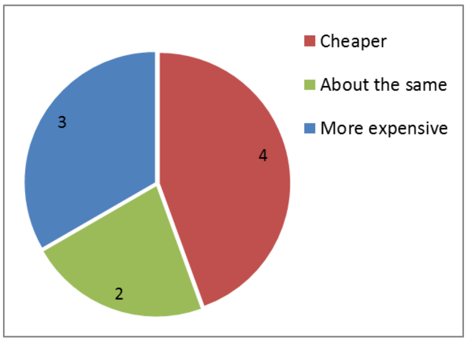
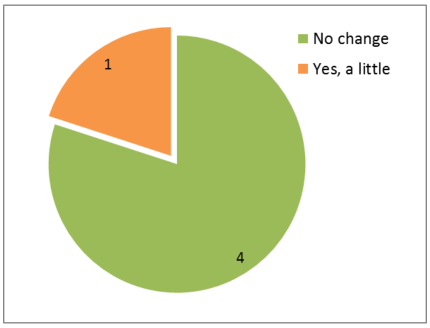
b) 

Figure 2.4 Reported effect of measures on heating bills (a) at interim questionnaire, (b) at end of monitoring period.

a) 

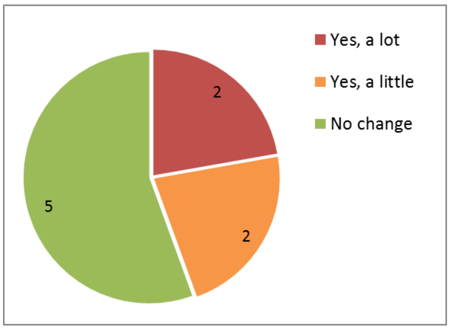
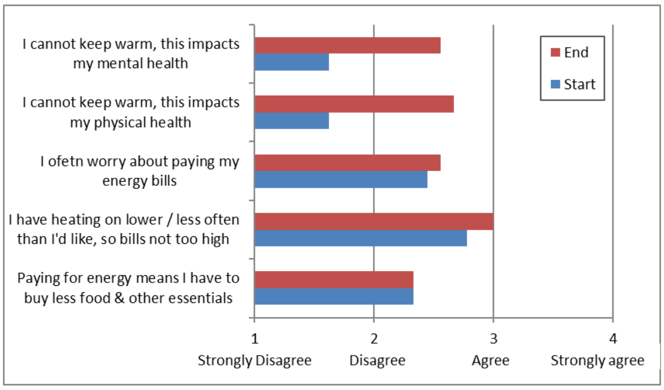
b) 

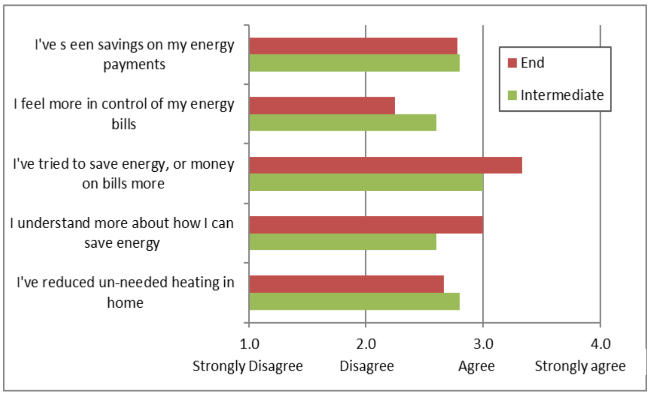
Figure 2.5 Reported effect of measures on money worries (a) at interim questionnaire, (b) at end of monitoring period.

Figure 2.5 shows residents' views on whether the measures had reduced any money worries they had. At the interim visit, only one respondent reported that the under-floor insulation had reduced their money worries a little, however by the end, of 9 respondents, 2 felt the measures had reduced their worries a little, and 2 felt the insulation had reduced their money worries a lot.

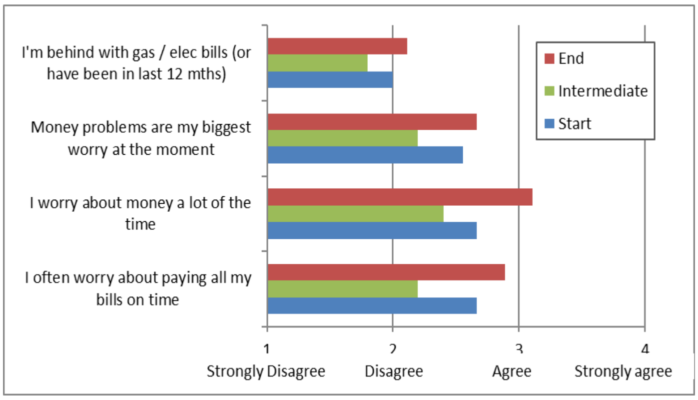


a)

Figure 2.6 Impact of the study on (a) energy affordability concerns, (b) energy saving issues, (c) general money worries.



b) c)



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

Fig 2.6 (a) shows that concerns and actions to reduce energy bills have changed little between the start and end of the study period, however, an increase was seen in householders' agreement with the statements about health impacts of not being able to keep warm, with the average response at the end of the study approximately half way between agree and disagree. This may be due to the particularly harsh winter emphasising any health effects, advice provided at the visits leading to increased awareness about the impact of cold on health, and also residents gaining trust in NEA staff during the study to report such issues.

There was little change in respondents' views on the influence of the measures or their behaviour over their energy bills, Fig 2.6 (b), between the interim and end questionnaires – variations are likely to be due to only 5 respondents to the interim questionnaire compared to 9 for the final questionnaire. Overall, residents generally agreed that they had tried to save money on energy more. Lowest agreement was seen with the suggestion that they felt more in control of their energy bills. It should be mentioned that some households could not report improvements in control as they felt they had no issues of lack of control of energy bills at the outset. Overall, views were only slightly towards the "agree" side of the chart that residents had seen savings on their energy payments.

General affordability issues, Fig 2.6 (c) showed concerns around general money worries and paying all bills on time. There was general disagreement with the idea of being behind with energy bills – many residents used prepayment meters so this was not possible. The slightly more positive average response seen in the interim questionnaire is likely to be linked to the fact that this was carried out over the summer, when energy bills in particular are not likely to be as high, and also the difference in respondents – only 5 for the interim questionnaire, and 9 for the start and end questionnaires.

2.3 Perceived comfort and benefits

In the initial questionnaire, participants were asked about their comfort with their existing heating & insulation arrangements, before installation of the under-floor insulation. The same questions were asked as part of the final questionnaire in order to see whether there had been any improvement. Figure 2.7 shows the number of respondents who felt they could mostly keep comfortably warm enough at home, both (a) before and (b) after receiving under-floor insulation. Before insulation, only 2 of the 9 householders felt they could mostly keep warm enough, whereas after install, 5 of the 9 respondents said they could now mostly keep warm enough in the home. Whilst the measures have not solved all issues, they have resulted in an overall improvement in comfort.

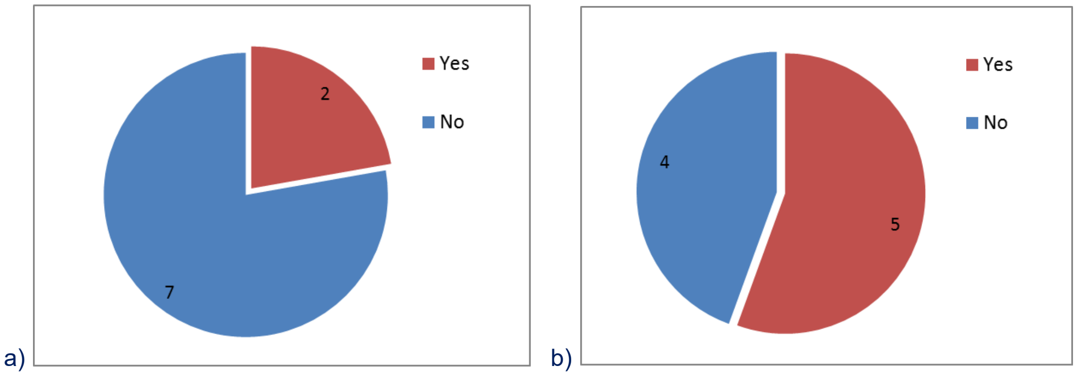


Figure 2.7 Householders reporting they could mostly keep comfortably warm at home in winter / when it was cold outside, (a) before, and (b) after installation of the under-floor insulation

Respondents were asked about whether they ever needed to wear extra warm clothes in the home e.g. blankets, dressing gown, coat or multiple jumpers over clothes, in order to keep warm. This appeared to be more of a cultural issue / habit as there, with 4 out of 9 reporting that they needed to wear extra warm clothes in the home to keep warm at both the start and end of the study period.

Residents were also asked whether they felt they could heat or comfortably use more rooms since the measures were fitted, at both the intermediate and end questionnaires, shown in Figure 2.8.

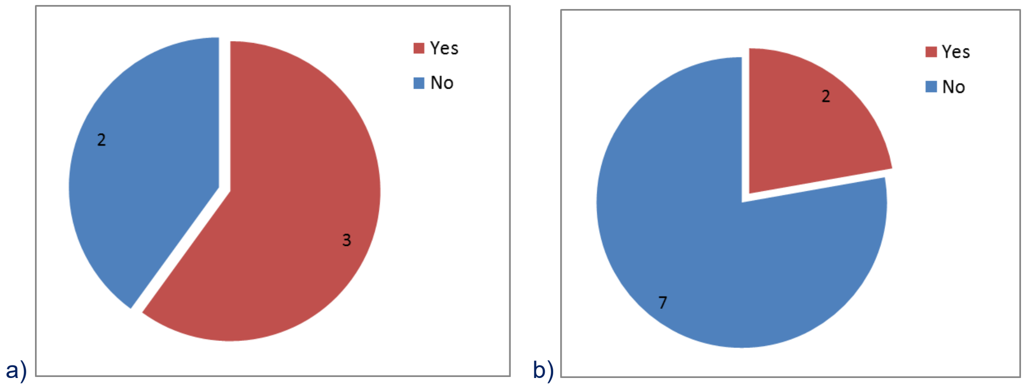


Figure 2.8 Householders reporting that they could heat or comfortably use more rooms at (a) the intermediate and (b) the final questionnaire

Two said that they could now use the home more comfortably – one stating that their small bedroom (previously unused) was now warm enough for the husband to use as a work room, and another saying they had used all the rooms previously, but each one was now more comfortable. Two further of those who responded negatively stated that their ground floor rooms were warmer (even though in one case they reported that they were still not warm enough).

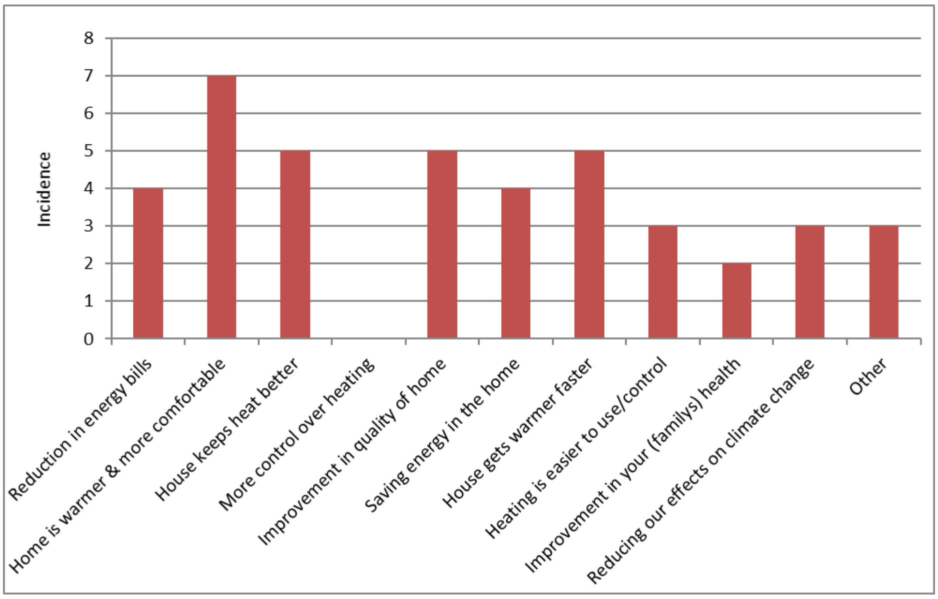


Figure 2.9 Benefits perceived by residents after installation of the under-floor insulation

Figure 2.9 shows the number of householders identifying benefits as a result of the under-floor insulation in the final questionnaire (9 respondents). 7 stated that their home was now warmer and more comfortable by the end of the study, and 5 also reported that their home now keeps the heat in better, gets warmer faster, and that it has improved the quality of the home. 4 report a reduction in energy bills and that the measures are saving them energy in the home. Other comments made included noise – both improved acoustics in the home and muffling of the noise of mice living under the house – and that venturing downstairs in bare feet was not as unpleasant as it had been as the floor was not so cold now!

Other benefits identified related to damp, condensation and mould in the home, if this was present. Householders were asked whether the measures had made any change to it, with the results displayed in Figure 2.10. 2 properties did not report suffering any damp issues, and 4 which did have moisture issues had seen no improvement, but 3 did report that mould problems had improved (even if not completely gone), or not recurred after the last treatment.

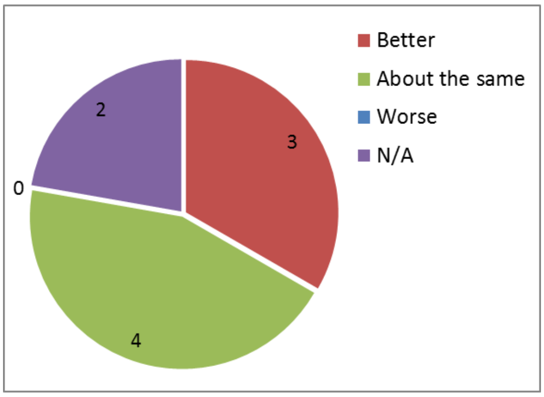


Figure 2.10 Impact of the measures on damp / condensation / mould

Only one dis-benefit was identified by a resident who used the under-floor / basement area for storage – they were disappointed at the reduction in space in the cellar, and reported that the insulation "looked messy", especially as they felt it had not made too much difference to their heating bills/comfort.

2.4 Resident acceptance and satisfaction

Most residents accepted the under-floor insulation in the sense that they understood how it was meant to work. Only one householder mentioned negative issues around its presence, taking up space and that it did not look tidy, but most did not use the under-floor space at all, so it caused them no negative issues (even for those who did not feel it had made much/any difference to their heating costs or comfort).

All residents were asked about their satisfaction levels with different aspects of their home heating and insulation in the start, interim and end questionnaires. As for those questions where residents were asked how much they agreed or disagreed with statements, a response of very satisfied was allocated a value of 100, satisfied with 75, neither satisfied nor dissatisfied with 50, dissatisfied with 25, and very dissatisfied was valued at zero. These values could then be averaged across all respondents in order to see whether overall opinions changed during the course of the study. Results are displayed in Figure 2.11. This shows that there was little change in the amount of control and ease of use of the system before and after installation of the insulation measures, unsurprising as the heating system itself had not changed so they continued to use it in the same way as before. However, there was improvement in satisfaction with how warm the home got when it was cold outside, from being dissatisfied on average prior to the installation, to being on the satisfied side of "middling" afterwards. Clearly under-floor insulation alone has not solved all the heating and insulation related issues with these HTT properties so many are still not satisfied, but this has improved satisfaction somewhat.

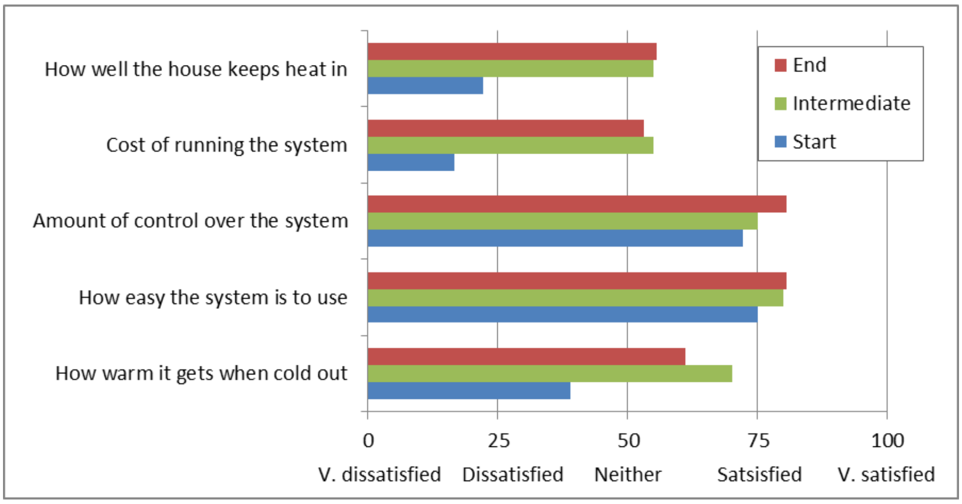


Figure 2.11 Resident satisfaction with aspects of their heating system & insulation

Householders were generally dissatisfied to very dissatisfied with the cost of running their heating system, and how well the property kept the heat in before installation of the measures, and again whilst they are only "neither satisfied nor dissatisfied" by the end of the study, this still shows a marked improvement from previously.

Resident comments about their satisfaction mentioned that they were "more comfortable and not using as much gas", that they "needed the heating on for shorter periods now" to keep adequately warm, and that the property "stays warm for longer" after they've had the heating on.

However, some didn't feel it had made any significant difference, generally those in the larger properties (where under-floor insulation would only reduce heat loss through the ground floor which makes up a smaller proportion of the home’s surface area, its comfort and heating costs), those with large single glazed and/or draughty wood-framed windows – particularly if they did not hang thick curtains over these to provide insulation, and properties with un-insulated rooms in the roof. Areas of the property which were unable to be treated with under-floor insulation due to the presence of solid concrete floors were also highlighted as an issue of concern, as these still felt cold, and increased disparities in warmth within the property (causing comfort issues). Also, as winter 2017-18 was so cold, some residents may not have perceived that the insulation made a difference to their comfort or heating costs (despite our energy monitoring potentially indicating that they were not having to spend as much per degree day of heating required - see section 3.3).

From comments made, the interviewer was asked to rank each respondent's feelings out of 5 (with 1 being very negative, 3 being indifferent, and 5 being very positive) and their involvement / engagement with their heating system now the measures were installed. As these measures are fitted under the floor with no new controls, residents' involvement was limited to their engagement with their heating / energy use. Results are shown in Figure 2.12.

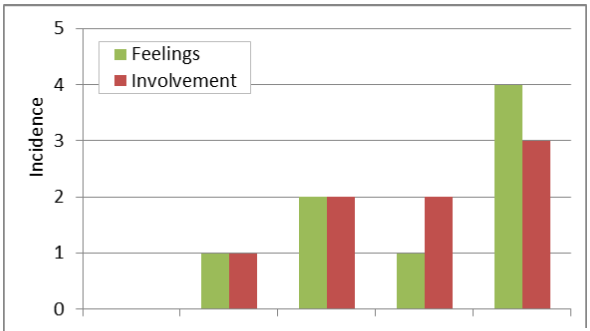


Figure 3.12 Ranking of householders' feelings and involvement / engagement with their new measures

4 of the 9 respondents' comments suggested that they felt very positive about using their heating since the new measures were fitted, one was mildly positive. Two who felt that they had not seen any improvement were indifferent about the insulation / heating, and only one felt negatively about it – that it had taken up storage space in the cellar and "looked messy", whilst not making a noticeable difference to their heating bills / comfort – these residents said they felt their heating and energy bills were higher / more out of their control than previously, which is more likely to be linked to the very cold winter rather than the new insulation.

2.5 Ease of use and reliability

Given that these measures were installed under the ground floor of the property, they were not physically "used" by the residents, it is the property's heating system which is used as normal. There were no reported reliability issues with the measures themselves.

7 of the 9 residents reported general maintenance issues in the initial pre-installation questionnaire related to their heating, insulation, moisture or mould and which caused them concern with keeping warm or increased their bills. 5 of 9 also reported such issues at the final questionnaire. These covered issues such as thermostats not working / the numbers on them being rubbed off, inadequate central heating systems for the larger properties to get them warm enough on all but the middle floor, a very old standard boiler, draughty doors/windows and lack of insulation. All issues were reported to LBC Council.

2.6 Customer service and installation issues

Comments about the installation process were requested and all residents gave glowing reports of how courteous, knowledgeable, helpful and good workers the installers were, involving residents in the installation process if desired, and explaining to them how the insulation and the process worked. In one property, a hatch had to be cut in a floor to insert the SprayBot, and the resident commented that new lino had been fitted afterwards, which had been put down perfectly.

Residents were asked about their satisfaction with various aspects of the project communications and installation process. As previously, the responses were averaged across each questionnaire period to see if there had been any change in opinions. The results are displayed in Figure 2.13. It is clear that householders' opinions of the communication and installation aspects of this project are very good – there was some minor change in opinion about whether residents were given details of a contact for if they had any concerns - this may be due to respondents forgetting about this aspect by the end of the study, or just the different (numbers of) respondents to each questionnaire, 5 for the interim one, and 9 for the final one.

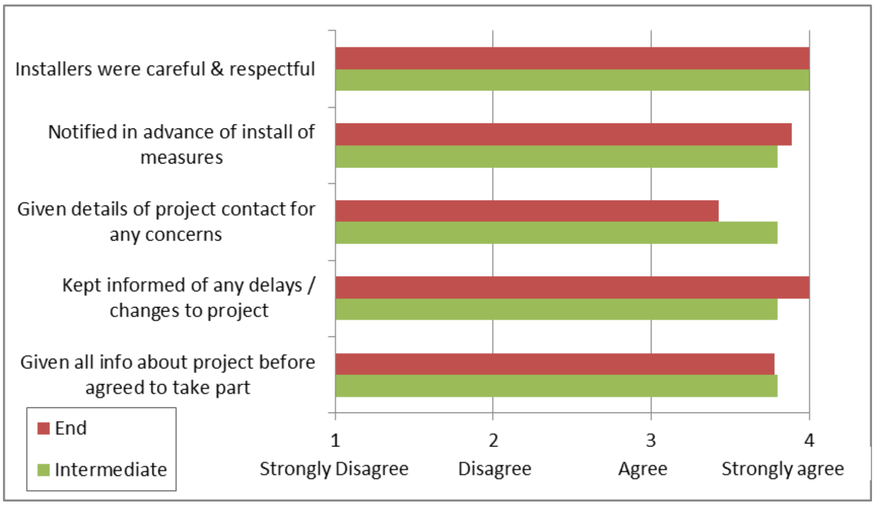


Figure 2.13 Resident satisfaction with aspects of their heating system & insulation

Residents were asked about whether they were shown how to use their measures, whether they knew how the system worked etc. Given the nature of under-floor insulation measures, most of these questions were not relevant. The few residents who responded said that they understood how the measures worked, and that their measures did not require any active input.

3. Technical evaluation and results

3.1 Overview of technology

Q-Bot's SprayBot is a 4-wheeled robot that applies under-floor insulation onto timber, to reduce heat loss through ground floors.

Figure 3.1 (a) – The Q-Bot SprayBot (right)

The Q-Bot installation is delivered over four stages. The survey takes 45 minutes, and if the property is suitable a convenient date for installation was arranged, which takes 1 day:

a) Access – The robot is folded and inserted through an external air vent or by removing a few bricks, or via an access hatch made in the floor within the property. In several of the properties, there was an existing access hatch that was used to insert the robot into the under-floor void.

Figure 3.1 (b) Q-Bot being inserted into the under-floor space

b) Survey – A detailed 3D map was built up of the under-floor space, allowing the operator to assess whether the property was suitable for installation, identify any obstacles and plan the insulation route. Examples of 3D maps displaying different sets of information are below, Fig 3.1(c).

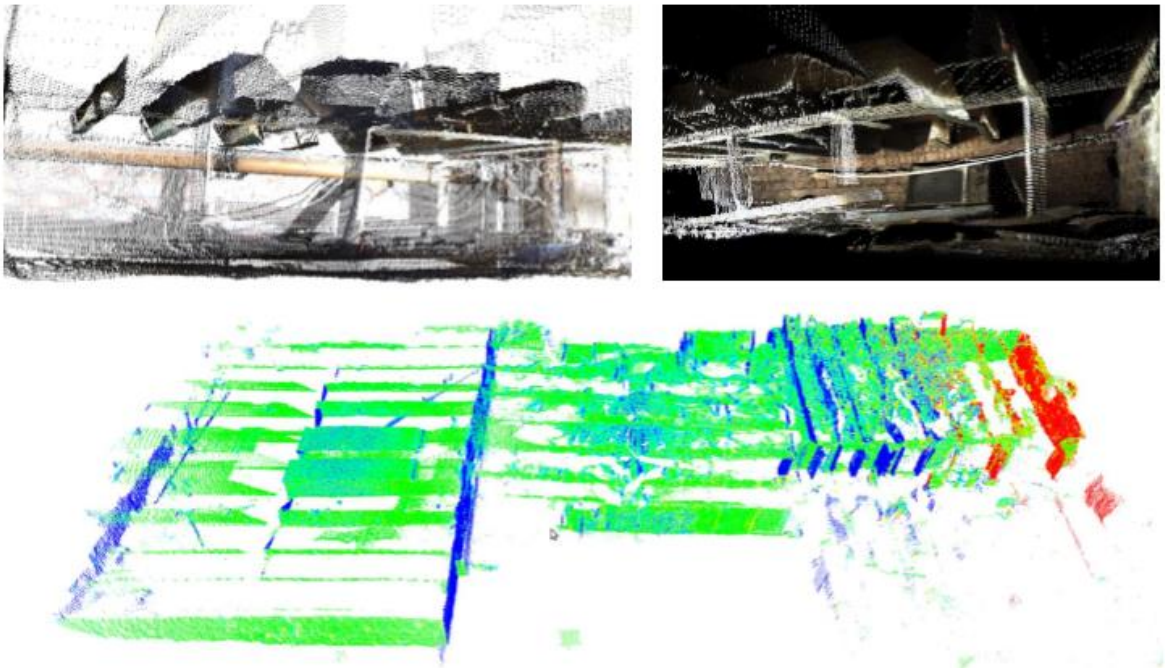


Figure 3.1 (c) 3D map of under-floor space resulting from the surveying phase

c) Apply – Insulation is applied by the robot to the underside of the floorboards to an average depth of 125mm. The remaining free space will keep the timber on the warm dry side of the insulation yet maintain the ventilation of the ground below (venting moisture and gases outside).

Figure 3.1 (d) Application of insulating spray foam to the under-side of floorboards using the SprayBot

d) Verify – The installation is verified using the 3D scanning system and the data sent to Q-Bot. This allows Q-Bot to remotely validate the control quality of each install.

Figure 3.1 (d) Images of the resulting spray foam insulated floorboards from the under-side

If there is an obstruction in the floor space, more than one access point may be required for the SprayBot. Further information and details about the technology can be found on the Q-Bot website[3], including a link to a video about this Camden project.

According to the grant agreement, costs were £3,000 per property, across all 39 properties which had these measures installed – some properties with smaller floor areas treated were cheaper.

According to the Energy Saving Trust (EST)'s Energy Saving Home, in a typical home, an average of 15% of heat loss is through the floor. Q-Bot claim[4] that their floor insulation (i) reduces heat loss through the floor by up to 90% resulting in warmer, drier floors, and (ii) that it improves the air-tightness of a property by up to 50% resulting in fewer cold draughts. They state that an average reduction in heat loss through the floor of 80% and a reduction in air permeability by 1/3 results in annual bill savings of £150 and lifetime carbon savings of 21.6 tonnes of CO_{2e}. Also, that Q-Bot is normally the cheapest option to achieve improvement in the EPC score, with an average gain of 5.7 points.

[3] Q-Bot website, www.q-bot.co [Accessed 10/4/2018]

[4] Q-Bot Service page of website, www.q-bot.co/service.html [Accessed 27/04/2018]

3.2 Technological monitoring

In order to assess the performance of the underfloor insulation, the following monitoring equipment was placed in the properties, and displayed in Figure 3.2 below:

Thermal & humidity data loggers

These record temperature and humidity in the property every hour. Two or three Lascar EasyLog USB-2 loggers[5] were placed (as relevant) in different rooms on the ground floor in each monitored property. They were positioned in a background location, away from direct heat, cold or draughts.

CO data loggers

Used to record carbon monoxide levels inside the property every 5 minutes. With a 3-month data capacity, these were changed regularly throughout the study period. One Lascar EasyLog USB-CO logger[6] was installed on the ground floor of a sample of monitored properties in the first winter, and in every property during the second winter – usually in the living room.

Event Logger – 1 x

One property's gas meter had an RJ11 socket to allow fitting of a Lascar EasyLog USB-5 pulse logger[7], which records a pulse when a unit of gas is consumed. However, a wire on this logger detached so it did not record data, and we had to rely on the householder's regular meter readings.

Energy meter readings

In addition to monitoring equipment, residents were requested to record their electricity and gas meter readings regularly during the study period, usually every 2 weeks, in a log book provided. They were also requested to retain energy bills or statements received during the winter prior to, and during the monitoring period. Many allowed NEA staff to phone their energy company during the initial visit to obtain previous meter readings, or signed consent forms to allow us to contact their energy company to request meter readings held on their account.

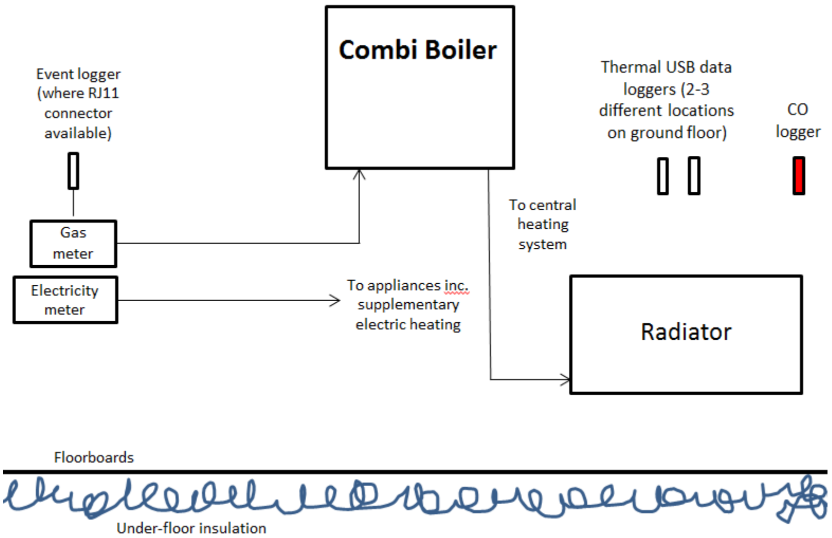


Figure 3.2 – Schematic diagram of monitoring equipment placed in properties receiving under-floor insulation

5 Lascar USB-2 product details: www.lascarelectronics.com/easylog-data-logger-el-usb-2, [Accessed 11/04/2018]
6 Lascar USB-CO product details: www.lascarelectronics.com/easylog-data-logger-el-usb-co, [Accessed 11/04/2018]
7 Lascar USB-5 product details: www.lascarelectronics.com/easylog-data-logger-el-usb-5, [Accessed 11/04/2018]

3.3 Cost

This analysis uses the meter reading information obtained from householders writing down their regular meter readings, and others obtained from bills or energy suppliers. Meter readings from before the start of the study were used to calculate previous energy usage – it was possible to obtain these for all householders for gas, and all but two for electricity costs. This previous usage was compared against usage for the period after the measures were installed (generally studying only the winter heating period), to see if the measures had helped the householders to make savings. Electricity costs were also analysed, as questionnaire responses indicated that many households used supplementary electric heating in addition to (or instead of during some periods of the day) their main gas central heating, so insulation might impact on electricity usage as well as gas. Gas volume used (in m^3 or ft^3) was converted to kWh by multiplying by:

- (only if in ft^3) the conversion factor of 2.83 to convert to m^3,
- an industry figure to take account of atmospheric pressure: 1.02264
- a standard calorific value for gas of 39.5,
- gas measurement is joules, so convert to kWh by dividing by 3.6

Imperial meters measure in hundreds of cubic feet (100 ft^3). If such a meter shows a usage of 1, the resident has actually used 100 ft^3. For all homes, standardised gas costs of 5p/kWh, and electricity costs of 16p/kWh were used for calculations – these are slightly higher than common tariff rates as they include a small element for standing charges etc. Cost comparisons are displayed in Table 3.3 (a) and (b) on the next page.

To properly analyse energy use for space heating, account must be taken of weather conditions over the monitoring period, as it is poor practice to compare the heating costs for two periods without compensating for different outdoor temperatures during the periods – particularly as winter 2017-18 was so cold. An external temperature of 15.5°C is the commonly-used base temperature that energy specialists assume below which heating is normally required inside a building, and above which no heating is normally needed. Degree days (dd) are a measure of heating demand of a building relative to the external weather i.e. the number of degrees below 15.5°C that the average temperature falls, for each day. For example, if the average outside temperature is 14.5°C, this is recorded as 1 degree-day. Degree days are summed together over the required period, to give a total number in the period. Different periods can then be compared in terms of energy consumption per degree day, so accounting for different external temperatures, to determine if savings have been made as a result of installation of energy efficiency measures[8].

Degree day data was obtained - for 3 years prior to, and during the monitoring period - from weather station ILondon9, Hampstead, London (0.16W,51.56N)[9] 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 Thames Valley region experiences 1771 degree days per year on average, which was used to normalise our data.

For gas costs, Fig 3.3 (a), all but one household, T-13, made a saving. T-13 is a very large 6-bedroom household, with the entrance and reception rooms on the middle floor, up high steps, and (naturally cooler) bedrooms on the lowest / ground floor of the property which was insulated. Given the large size of the house, and the fact that insulation would have less effect on rooms which are cooler anyway, it is likely that this increase in usage is due to other factors, and should be excluded

8 www.carbontrust.com/resources/guides/energy-efficiency/degree-days [Accessed 11/04/2018]

9 Degree Days.net: www.degreedays.net [Accessed 06/03/2018]

a)

20 year average degree-day comparison of savings — Region: Thames Valley — 20 year average: 1771

Tech Ref	"Before" period: Period	Days	Total Period (kWh)	Cost per 30 days	Degree days	kWh per Degree Day	Estimated annual cost#	"After" period: Period	Days	Total Period (kWh)	Cost per 30 days	Degree days	kWh per Degree Day	Estimated annual cost#	Comparison: Estimated Saving#
T-08	19/9/15-31/3/16 + 14/10/16-4/1/17	276	10,244.4	£55.68	1,821.40	5.624	£498.05	20/1-16/4/17 + 24/10/17-13/2/18	198	7,449.9	£56.44	1,606.80	4.636	£410.56	17.57%
T-15	6/9/15-31/3/16 + 3/10/16-17/1/17	313	1,526.0	£7.31	2,018.00	0.756	£66.96	17/1-18/5/17 + 16/9/17-14/2/18	272	1,352.5	£7.46	1,875.00	0.721	£63.87	4.61%
T-18	1/9/15-13/5/16 + 24/9-16/12/16	338	19,176.1	£85.10	1,968.10	9.743	£862.78	16/12/16-29/3/17 + 18/10-20/12/16	166	11,445.0	£103.42	1,381.30	8.286	£733.70	14.96%
T-19	23/10/15-19/4/16 + 14/10/16-13/1/17	270	18,544.6	£103.03	1,908.20	9.718	£860.56	13/1-19/5/17 + 13/10/17-12/2/18	248	16,041.7	£97.03	1,847.50	8.683	£768.87	10.65%
T-61	25/9/15 - 7/5/16	225	8,561.3	£57.08	1,431.80	5.979	£529.48	9/10/16-22/4/17 + 4/10/17-12/2/18	326	13,050.4	£60.05	2,465.70	5.293	£468.68	11.48%
Average for ground floor flats						6.364	£563.57						5.524	£489.14	11.86%
T-02	15/5/15-14/5/16 + 30/9-27/11/16	423	17,706.3	£62.79	1,919.90	9.223	£816.65	4/12/16-23/4/17 + 24/9/17-9/2/18	278	16,991.0	£91.68	2,072.20	8.199	£726.06	11.09%
T-07	4/1 - 21/12/16 (heating on in summer)	352	9,462.8	£40.32	1,625.50	5.821	£515.49	21/12/16-24/12/17 + 2/1/18-13/2/18	410	10,207.4	£37.34	2,130.40	4.791	£424.27	17.70%
T-13	4/9/15-14/5/16 + 19/9/16-12/1/17	368	17,021.7	£69.38	2,211.50	7.697	£681.56	20/1-15/5/17 + 14/10/16-3/1/18	196	12,926.2	£98.92	1,353.10	9.553	£845.92	-24.11%
T-66	28/2-25/5/15 + 19/10/15-29/5/16	309	13,015.9	£63.18	1,855.80	7.014	£621.06	21/12/16-27/5/17 + 2/10/17-13/2/18	291	13,322.1	£68.67	2,116.40	6.295	£557.40	10.25%
Average for 3-storey houses						7.439	£658.69						7.210	£638.41	3.73%
Average (overall)						6.794	£601.62						6.198	£548.85	8.24%

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

b)

20 year average degree-day comparison of savings — Region: Thames Valley — 20 year average: 1771

Tech Ref	"Before" period: Period	Days	Total Period (kWh)	kWh / day	Cost per 30 days	Degree days	kWh per Degree Day	Estimated annual cost#	"After" period: Period	Days	Total Period (kWh)	kWh / day	Cost per 30 days	Degree days	kWh per Degree Day	Estimated annual cost#	Comparison: Estimated saving (uncorrected)	Estimated Saving (dd corrected)#
T-08	16/10/2016 - 20/1/2017	96	1,965.0	20.5	£98.25	767.40	2.561	£725.57	20/1-25/5/17 + 6/12/17-13/2/18	194	3,552.0	18.3	£87.88	1,444.20	2.459	£696.92	10.6%	3.95%
T-15	2/11/15-7/5/16 + 26/9/16-17/1/17	300	1,083.0	3.6	£17.33	2,086.40	0.519	£147.09	17/1-30/4/17 + 1/10/17-14/2/18	239	1,014.0	4.2	£20.36	1,788.60	0.567	£160.64	-17.5%	-9.22%
T-18	9/9 - 16/12/16	98	1,005.0	10.3	£49.22	484.70	2.073	£587.53	16/12/16 - 17/1/17	32	392.0	12.3	£58.80	305.50	1.283	£363.59	-19.5%	38.12%
T-19	22/1/15-28/7/16 + 26/10/16-13/1/17	632	5,809.0	9.2	£44.12	2,748.00	2.114	£598.99	13/1-1/5/17 + 6/12/17-12/2/18	176	1,779.0	10.1	£48.52	1,450.00	1.227	£347.65	-10.0%	41.96%
T-61	25/9/15 - 23/4/16	211	1,732.0	8.2	£39.40	1,341.50	1.291	£365.84	12/10/16-29/4/17 + 27/9/17-24/2/18	349	2,422.0	6.9	£33.31	2,631.10	0.921	£260.84	15.5%	28.70%
T-02	16/9 - 1/12/16	76	894.0	11.8	£56.46	377.80	2.366	£670.52	1/12/16-30/4/17 + 24/9/17-9/2/18	288	3,127.0	10.9	£52.12	2,148.90	1.455	£412.34	7.7%	38.51%
T-07	4/1 - 21/12/16	352	7,008.0	19.9	£95.56	1,625.50	4.311	£1,221.65	21/12/16-25/5/17 + 6/12/17-13/2/18	387	5,774.5	14.9	£71.62	2,196.40	2.629	£744.97	25.1%	39.02%
T-13									4/9 - 6/12/17	93	1,630.0	17.5	£84.13	412.60	3.951	£1,119.43		
T-66									10/1/-28/6/17 + 6/12/17-13/2/18	238	2,611.3	11.0	£52.66	1,573.50	1.660	£470.25		
Average							2.177	£616.74							1.795	£508.52	1.69%	25.86%

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

Table 3.3 Analysis of (a) gas and (b) electricity costs before and after the under-floor insulation was fitted from the analysis. When this property is included in calculations of average savings, an 8.24% normalised energy (and cost) saving is seen across the whole sample (£53 per year). However, if it is excluded, the sample shows an overall 12.29% saving (£77 per year). The other property of note is T-15 – this household is in fuel poverty and clearly under-heating their home, using only 0.7 kWh of gas per degree day compared to 5-9 kWh/dd for all other households. It is also unoccupied – and unheated - for 3 days per week which also reduces heating usage. This householder reported at the final interview that they suspected analysis of their energy bills would not show savings, as they had felt it was worth heating the flat more since the insulation was installed, since heat was retained for longer. However, even this householder showed some small saving in gas bills. If that property is excluded, savings average 13.39% (£88 per year) across the whole sample.

Separating the two very different property-types monitored for further energy-saving analysis results in the following: small 1-3 bedroom flats had a calculated average saving of 11.9% (£74 per year, from £564 down to £489), or 13.67% (£92 per year, from £688 down to £595) if T-15, the extremely low gas user in fuel poverty, is excluded. For the larger 3-storey homes, savings were 3.7% or £20 per year saving (from £659 down to £638 per year total) if T-13 is included, or 13% (£82 per year) if this is excluded. It is logical that savings might be lower in the larger properties as the under-floor insulation has treated a smaller proportion of the home's external surface, plus there is more opportunity for heat to escape through other locations higher in the building. However, heating temperature, duration (which may or may not be related to occupancy periods), and other behavioural aspects also play a large part in energy use, so this is not always the case.

To assess the significance of these, the standard deviation (SD or σ) of the savings was calculated – this measures the spread around the average, as displayed in Figure 3.4. A result is significant with 68.2% certainty when savings are always greater than zero when σ is added to or subtracted from it (denoted ±σ), significant with 95.4% certainty when savings are greater than zero ±2σ. In social studies, it is rare to meet the 3σ requirement for a 99.6% level of significance. The standard deviation of the gas savings, if households T-13 and T-15 are excluded for reasons discussed above, is 3.28%. The average saving of 13.39% ± (3 x 3.28%) would always be above zero, so we can say that these savings are therefore significant to 3σ, or 99.6% confidence level.

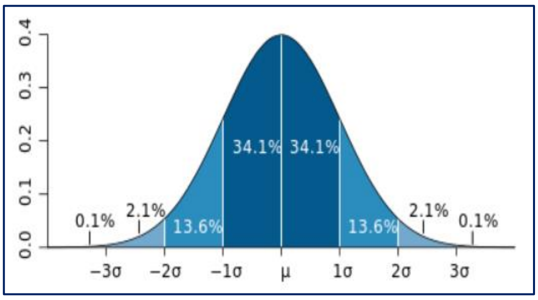


Figure 3.4 Illustration of mean (μ) and standard deviation (σ) in a normal distribution

One property, T-07, had a multi-fuel stove fitted. They could not estimate their wood use, nor if this had changed during the study, but said that they needed to use the stove less often than before the insulation was fitted. We did not ask about the amount of bottled gas (stove) use in the properties.

Those households which did not report using electric supplementary heating in Table 1.3 (p. 12) had electricity use per day compared directly, highlighted pale yellow in the first "uncorrected" comparison column of Table 3.3(b). This shows that some of these properties made a saving, others increased their electricity use. Overall a 0.9% increase in electricity use was seen for these homes, but given this is not used for heating, it is not linked to the under-floor insulation.

Households which did use supplementary electric heating had electricity costs analysis carried out using degree-day correction – these are all large 3-storey properties, plus T-15 (a ground floor flat). These homes are highlighted in bright yellow in the final degree-day corrected column of Table 3.3(b) – we only have electricity use information from before the measures were installed for 3 of these to compare. Properties T-02 and T-07 made savings of around 39%. However, the householders of property T-07 only reported using electric heating in the upper floors of the house (spot-heating at desks whilst working) so we cannot definitively link this to ground floor insulation. The insulation would have improved ground floor airtightness, by filling gaps between floorboards and so reducing draughts, potentially reducing air movement and leakage and improving perceived comfort. Property T-02 reported that they had needed more heat as it had been colder, but that it had been costly to do so. As mentioned above for gas, they may therefore have increased usage by less than theoretically expected by degree day correction due to affordability (i.e. energy rationing), hence an apparent saving. Some of the saving may be linked to the under-floor insulation – since they state that the electric bar fire is used in the living room - but their electricity use was only very weakly related to heating need (dd) so we could not justify any such conclusions. No statistically significant conclusions can be drawn about electricity savings for the whole sample group from these 2 properties. Property T-15, which saw an increase in electricity use, contains a household in fuel poverty, who reported increasingly using electric spot-heating in one room they were in, instead of the central heating. They have been advised that this is likely to cost more than using the central heating, due to electricity being 3 times the cost of gas, despite more energy being used overall. In any case, only a very small increase in usage was seen – again, this household uses only 0.57 kWh/dd compared to 1.3 – 4 kWh/dd for others.

Savings in electricity costs were not necessarily expected. In general, supplementary heating is only normally used when residents feel their main heating system doesn't get their home warm enough or believe it to be cheaper to run than central heating, so with better thermal efficiency, this cost may reduce. However, it must also be highlighted that any electrical savings may not (only) be due to the insulation but may be down to normal variation in household behaviour. Advice was given by NEA staff on most efficient energy-using behaviour at all interview visits, so some savings unrelated to heating might result.

It is also interesting to see that heating need - in terms of total energy usage per degree day - fell for all but property T-13, despite actual costs per 30 days increasing for some properties: T-02, T-18 (and T-13) saw significant increases in actual gas costs, while others saw small increases. The colder winter in 2017-18 could explain the perception that bills have gone up despite the insulation, as more heat was needed to keep the home adequately warm (18-21°C).

This data can sometimes be used to investigate whether energy costs in the properties are better controlled, in terms of being more closely related to heating need i.e. degree days, following insulation. Meter readings taken by householders were used to plot energy usage against degree days for the periods before and after installation of the measures, see examples in Appendix 4. However, as the periods between meter readings were often irregular in length, no conclusions could safely be drawn. In many cases there was also a lack of frequent meter reads from the period prior to the start of the study, so few points available to plot before the insulation was fitted.

In addition, poor correlation may be expected as many residents indicated in their questionnaire responses that they manually controlled (rather than programmed) their heating, so its energy use is more related to whether they were at home or not, and personal heating preferences. Many householders also reported rationing energy use (heating) for cost reasons, so delayed turning on heating if it was very cold.

3.4 Temperature and thermal comfort

Temperature and humidity loggers were placed - to see whether the property was able to achieve recommended temperatures (18-21°C) for comfort and good health - in 2-3 locations as appropriate on the ground floor of the monitored properties, generally the main living room/area and the main bedroom of ground floor flats, different areas of the living room and/or hallway in the larger 3-storey houses, and in 2 lower floor bedrooms in property T-13 where the main entrance was into the middle floor. Data loggers were in position from autumn 2016 to February 2018. One property, T-18, withdrew from the monitoring during summer 2017, when loggers were collected, and a further property, T-13, withdrew from monitoring in December 2017. Two additional properties, T-61 and T-66, joined the monitoring in Dec 2017, when their thermal loggers were installed. Therefore, we do not have temperature data from prior to installation of the measures for all the monitored properties. Most loggers installed over the first winter were exchanged in summer 2017, a few in Dec 2017. Some loggers did not start, or stopped logging sometime during the monitoring period, for unknown reasons.

4 different periods were selected over which to analyse temperatures, to account for this variation. The "Before" period in winter 1 covered 18/10 – 30/11/16, after which the measures started to be installed in properties. This was a period of 43 days, during which 307.1 degree days of heating need were experienced, an average of 7.14 dd/day. The "After" period in winter 1 started the day after the last under-floor insulation measures were installed and ran until the weather started to warm up in the spring i.e. 19/1 – 30/4/17, a period of 101 days during which 701.8 degree days were experienced, averaging 6.95 dd/day. Winter 2 was separated into 2 periods so that the household which withdrew at the December visit and those which had thermal loggers newly installed could both be included in the analysis over the relevant period. The periods selected were therefore from when the weather started to get cold for the winter until the day prior to the NEA visit i.e. 2/11 – 5/12/17, a period of 33 days with 278.8 degree days, 8.45 dd/day, and the day after the visits until mid-January when one logger was posted back to us, 7/12/17 – 22/1/18, a period of 46 days with 465.7 degree days, 10.12 dd/day. Note that winter 2017-18 was much colder than 2016-17 with a higher average number of degree days per day i.e. early winter temperatures 1.3°C colder per day than the previous year, and later winter temperatures more than 3°C colder per day on average. Table 3.6(a) & Figure 3.6(b) display indoor temperatures recorded over these periods.

The letters after the property codes indicate the type of room in which the data logger was placed: L for living room; B is a bedroom; H is a hallway, and K is a kitchen. For property T-15, a bedsit, the kitchen was also used as the bedroom. In the larger homes with large living rooms, two loggers were placed at either end, marked (a) and (b) to differentiate them. For logger positions where no data was available for that period, "-" is shown. The first two columns show average (mean) temperature: for the 7-10pm heating period – from questionnaire responses, the times when most of the monitored households desired heating (see Figure 2.3) - and the whole 24hr period average. SD is the standard deviation which measures the variability around the mean.

The before-installation data shows that temperatures in the evening heating period are generally slightly higher than the 24hr average temperatures, though this is not always the case. Most average temperatures fall into the recommended range of 18-21°C. Properties T-18 and T-19 are warmer than this so could save money by reducing their heating temperatures. Property T-19 contains elderly residents with health conditions, hence their need for higher temperatures. The bedroom of property T-08 is slightly cooler than the recommended range, but the householder kept the radiator there turned off by choice, as they prefer a cool bedroom. Temperatures in property T-15 are very low at 14°C, as are those in one of the bedrooms of property T-13 at 15°C.

Table 3.6 (a) Temperature and thermal comfort in monitored properties

Before, winter 1

18/10 - 30/11/16	Temperature analysis						
Property ref.	7 - 10pm	24hr	Median	Mode	Min	Max	SD
T-02 L(a)	20.88	20.17	20.00	19.50	14.50	24.00	1.53
T-02 L(b)	21.55	20.69	20.50	20.00	15.50	25.00	1.51
T-07 L(a)	19.65	18.77	18.50	20.00	13.00	24.00	1.79
T-07 L(b)	-	-	-	-	-	-	-
T-66 L	-	-	-	-	-	-	-
T-66 H	-	-	-	-	-	-	-
T-13 B(a)	-	-	-	-	-	-	-
T-13 B(b)	15.50	15.39	15.50	14.00	13.00	18.50	1.29
T-18 L	24.18	23.97	24.00	24.50	20.00	26.00	1.08
T-18 B	25.16	24.87	25.00	25.00	21.50	28.50	0.92
T-19 L	23.10	22.85	23.00	23.00	19.50	24.50	0.81
T-19 B	23.82	23.69	23.50	23.50	21.00	25.50	0.74
T-61 L	-	-	-	-	-	-	-
T-61 B	-	-	-	-	-	-	-
T-08 L	19.70	20.06	20.00	20.50	16.00	23.50	1.48
T-08 B	17.55	17.13	17.00	18.00	13.00	20.50	1.29
T-08 K	-	-	-	-	-	-	-
T-15 L(a)	14.16	14.23	14.50	14.50	9.50	20.50	1.76
T-15 L(b)	-	-	-	-	-	-	-
T-15 K	14.01	14.04	14.50	14.50	9.50	20.50	1.64
Average	19.94	19.66	19.67	19.75	15.50	23.42	1.32

After, winter 2 (early)

2/11 - 5/12/17	Temperature analysis						
Property ref.	7 - 10pm	24hr	Median	Mode	Min	Max	SD
T-02 L(a)	19.17	19.00	19.00	18.50	15.00	23.00	1.50
T-02 L(b)	20.74	20.18	20.00	20.00	16.00	25.00	1.74
T-07 L(a)	18.59	18.10	18.00	17.00	14.50	21.50	1.56
T-07 L(b)	17.16	17.00	17.00	16.00	13.50	20.00	1.27
T-66 L	-	-	-	-	-	-	-
T-66 H	-	-	-	-	-	-	-
T-13 B(a)	17.13	16.98	17.00	16.50	14.50	20.00	0.91
T-13 B(b)	15.10	15.01	15.00	15.00	12.50	17.50	0.96
T-18 L	-	-	-	-	-	-	-
T-18 B	-	-	-	-	-	-	-
T-19 L	-	-	-	-	-	-	-
T-19 B	23.52	23.62	23.50	24.00	21.50	25.50	0.70
T-61 L	-	-	-	-	-	-	-
T-61 B	-	-	-	-	-	-	-
T-08 L	19.22	19.45	19.50	19.00	17.00	21.50	0.85
T-08 B	-	-	-	-	-	-	-
T-08 K	22.82	21.29	21.50	22.50	17.00	25.00	1.40
T-15 L(a)	14.20	14.25	14.00	13.50	10.50	18.00	1.31
T-15 L(b)	13.53	13.71	13.50	13.00	10.00	20.50	1.55
T-15 K	-	-	-	-	-	-	-
Average	18.29	18.05	18.00	17.73	14.73	21.59	1.25

After, winter 1

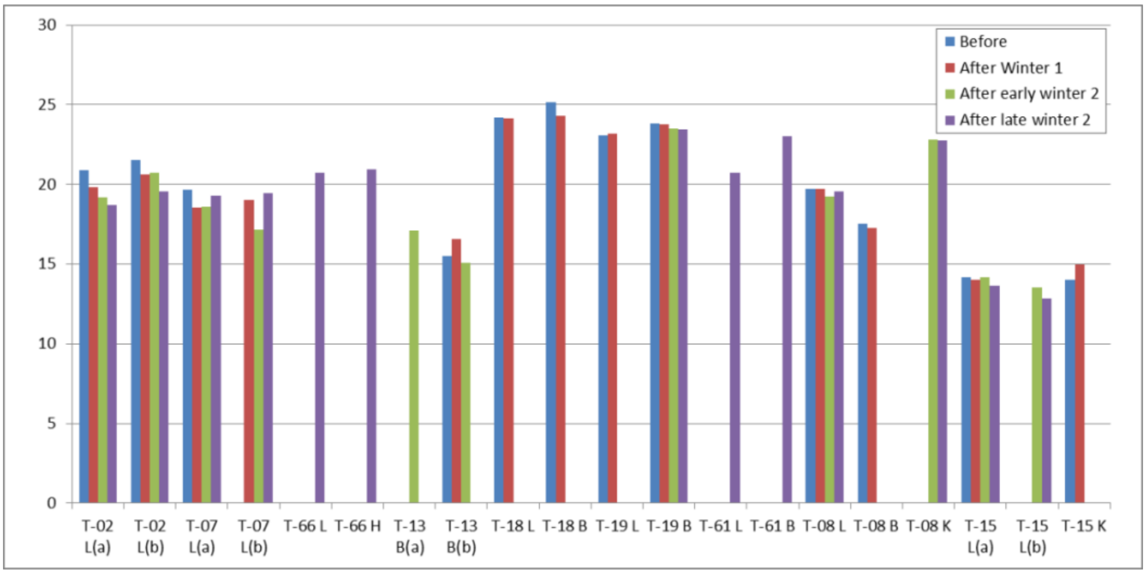
19/1 - 30/4/17	Temperature analysis						
Property ref.	7 - 10pm	24hr	Median	Mode	Min	Max	SD
T-02 L(a)	19.82	19.60	19.50	19.00	15.00	24.00	1.45
T-02 L(b)	20.60	20.38	20.50	20.00	16.00	25.00	1.46
T-07 L(a)	18.55	18.30	18.00	18.50	14.00	27.50	1.95
T-07 L(b)	19.05	18.20	18.00	18.50	13.50	24.00	1.62
T-66 L	-	-	-	-	-	-	-
T-66 H	-	-	-	-	-	-	-
T-13 B(a)	-	-	-	-	-	-	-
T-13 B(b)	16.56	16.30	16.00	16.00	12.50	24.50	1.47
T-18 L	24.12	24.15	24.00	24.00	21.50	26.50	0.89
T-18 B	24.32	24.48	24.50	24.50	22.00	28.00	0.73
T-19 L	23.19	23.22	23.00	23.00	20.50	25.50	0.71
T-19 B	23.78	24.19	24.50	24.50	21.50	26.50	0.84
T-61 L	-	-	-	-	-	-	-
T-61 B	-	-	-	-	-	-	-
T-08 L	19.73	19.84	20.00	20.50	16.50	23.50	1.41
T-08 B	17.28	16.79	17.00	16.50	11.50	19.50	1.40
T-08 K	-	-	-	-	-	-	-
T-15 L(a)	14.03	14.06	14.00	13.00	8.00	20.00	1.85
T-15 L(b)	-	-	-	-	-	-	-
T-15 K	14.99	14.84	15.00	14.50	8.50	20.00	1.70
Average	19.69	19.56	19.54	19.42	15.46	24.19	1.34

After, winter 2 (later)

7/12/17 - 22/1/18	Temperature analysis						
Property ref.	7 - 10pm	24hr	Median	Mode	Min	Max	SD
T-02 L(a)	18.69	18.49	18.25	17.50	14.50	24.00	1.88
T-02 L(b)	19.54	19.27	19.00	18.50	15.00	25.00	2.01
T-07 L(a)	19.30	18.50	18.50	19.00	14.00	23.00	1.86
T-07 L(b)	19.43	18.41	18.50	18.50	14.00	24.50	1.85
T-66 L	20.74	19.79	20.00	20.00	16.00	23.50	1.37
T-66 H *	20.96	20.88	21.50	21.50	10.50	24.50	2.67
T-13 B(a)	-	-	-	-	-	-	-
T-13 B(b)	-	-	-	-	-	-	-
T-18 L	-	-	-	-	-	-	-
T-18 B	-	-	-	-	-	-	-
T-19 L	-	-	-	-	-	-	-
T-19 B	23.45	23.72	23.50	23.50	22.00	25.00	0.59
T-61 L	20.71	20.23	20.50	20.50	17.50	22.50	0.92
T-61 B	23.05	22.38	22.50	23.00	19.00	25.50	1.25
T-08 L	19.58	19.30	19.50	19.50	15.50	23.00	1.28
T-08 B	-	-	-	-	-	-	-
T-08 K	22.78	21.15	21.00	21.50	17.50	26.50	1.59
T-15 L(a)	13.64	13.62	13.50	14.00	9.50	20.00	1.79
T-15 L(b)	12.86	13.00	13.00	13.50	7.50	19.00	2.21
T-15 K	-	-	-	-	-	-	-
Average	19.59	19.13	19.17	19.27	14.81	23.54	1.64

* logger stopped on 9/1/18

Figure 3.6 (b) Graph based on Table 3.6 (a) for the 7-10pm heating period average temperatures



The median temperature is the middle of a list when sorted into size order, and the mode is the most frequently recorded temperature – comparing these different types of averages can identify whether a property's temperature is relatively even, or if it is skewed towards warm or cold. For most homes, the three types of average are similar. The mode in the bedroom of property T-13 indicates that the most frequently recorded temperature is 14°C, suggesting that the mean is pulled upwards by spikes of higher temperatures.

Looking at the maximum and minimum temperatures, the minima are very low for property T-15, due to its limited heating (unoccupied 3 days per week), however the maxima show reasonable temperatures can be achieved when the heating is on. For properties T-18 and T-19 the minimum temperatures are warm. Again, T-19 is permanently occupied by elderly residents so the heating is always on, but property T-18 is inhabited by a working family, so they could save money on their bills by turning the heating off, or down to 13-15°C, when they are out of the house. The very high maximum in this property was a one-off (one day) occurrence, but temperatures regularly reached 26°C at around 11pm – again, money could be saved by putting on a jumper instead of turning up the thermostat up beyond 23°C.

Following installation of the under-floor insulation, temperatures in most households remain fairly consistent, similar to those before insulation. Only property T-02 sees a decrease in temperature – this must be due to a reduction in heating in the property relative to outdoor temperature, as under-floor insulation cannot reduce temperatures. T-19 also sees a slight reduction in average temperature, but from a relatively high start point, so is not a cause for concern. Of the 2 properties, T-13 and T-15, previously unable to achieve safe and comfortable temperatures, whilst an increase in temperature was seen in some of the rooms during the period immediately after install of the measures, this was not continued into the following winter for one of the bedrooms in T-13, though the other maintained a higher average temperature of 16.5°C. Loggers in this home were mixed up by the householder on collection in Dec 2017, so it is not known which bedroom each was from, so T-13 B(b) may be from the same bedroom that saw the average temperature of 17.13°C shortly after installation. In that latter case, the improvement has been somewhat maintained, but the other bedroom is still too cold.

3.5 Humidity

Water vapour in the air is usually measured as relative humidity (RH) which quantifies the percentage of water vapour held by the air compared to the saturation level (the highest quantity of water able to be supported by the air at a given temperature). The saturation amount is dependent on temperature, as warmer air can hold more moisture, so relative humidity is a function of both moisture content and temperature. Humidity is not usually considered to be an indoor contaminant or a cause of health problems. In fact, some level of humidity is necessary for comfort. Conversely, the relative humidity of indoor environments (over the range of normal indoor temperatures of 19 to 27°C), has both direct and indirect effects on health and comfort. The direct effects are the result of the effect of relative humidity on physiological processes, whereas the indirect effects result from the impact of humidity on pathogenic organisms or chemicals which may affect health. High values of RH are problematic as they can cause damage to building fabric and furnishings, mould growth and associated health problems. From the Building regulations part F[10]; the suggested average monthly maximum humidity for domestic dwellings during the heating season is 65%, weekly is 75% and daily is 85%.

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

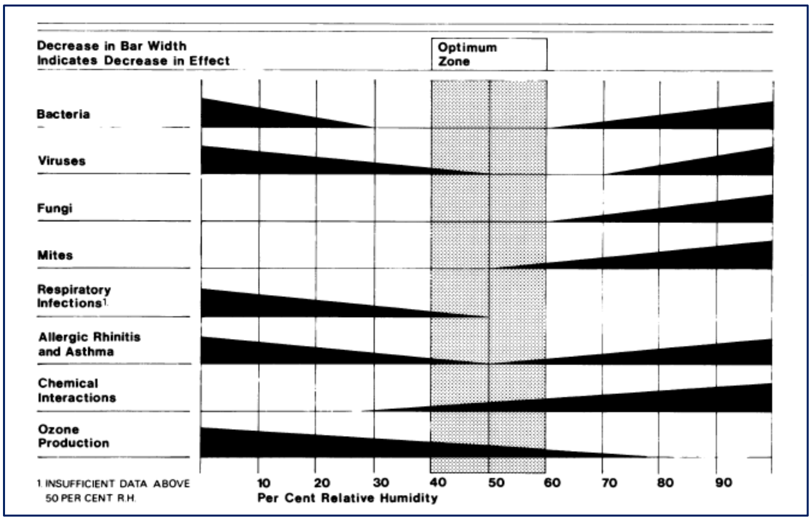


Figure 3.7 Optimum humidity levels to reduce indirect effects from pathogenic organisms or chemicals

Figure 3.7 illustrates the optimum humidity levels as cited by Arundel et al[11]. The study concluded that maintaining relative humidity levels between 40% and 60% would minimise adverse health effects relating to relative humidity.

Humidity data for the properties, over the same analysis periods as for the thermal loggers (as explained in section 3.4), is shown in Table 3.8(a) and presented in graph form in Figure 3.8(b). There is a complex relationship between humidity and the evening heating period – as relative humidity is inversely proportional to temperature, in some rooms the humidity decreases probably due to an increase in heating, whereas in others, presumably those which are occupied and where moisture releasing activities such as cooking or bathing is taking place, humidity increases. The whole 24-hour average is therefore the best period to use for humidity analysis. This shows that most of the properties' average humidity levels before installation of the under-floor insulation are within the recommended 40-60% range for good health. Those properties which have the highest average temperatures tend to be at the lower end of this range. Properties with humidity outside the recommended range include T-13 where the cold bedroom has very high average humidity (72.2 %), both rooms of property T-15 which is known to be under-heated (62.5-64 % RH), and the bedroom of property T-08 which the residents do not heat by choice (61.4 % humidity).

Immediately after installation of the measures (winter 1), an overall small reduction in relative humidity levels was seen, with 24hr average humidity levels now falling within the recommended range except for the bedroom in property T-13 which is slightly over 60%, and property T-18 where the humidity levels are now lower than recommended. Even property T-15 achieved RH of 55-56%.

By winter 2, relative humidity levels in bedrooms of property T-13 had increased to approx. 73%. This property withdrew from monitoring for the second winter, so we do not know whether humidity decreased again later in the winter 2 heating period. However, humidity levels in property T-15 did decrease and remained just within the recommended levels, at around 60% RH. The minimum humidity increased for most homes early in winter 2 to an average of 44.5% across the whole group, then decreased again to an average of 35.6% later that same winter, so this may be linked to damp autumn and drier winter weather (but external humidity was not monitored), residents not turning heating on / up until later in the winter, or other physical cycles in properties which cause a decrease over winter-time. The reduction in humidity to within the recommended range in property T-15 suggests that under-floor insulation can help to bring excess humidity under control.

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

Before, winter 1

18/10 - 30/11/16	Humidity analysis						
Property ref.	7 - 10pm	24hr	Median	Mode	Min	Max	SD
T-02 L(a)	53.28	51.49	51.50	52.50	34.50	76.50	5.67
T-02 L(b)	50.03	48.67	49.00	51.50	30.00	74.50	6.00
T-07 L(a)	51.97	52.49	53.00	56.00	34.50	68.50	6.00
T-07 L(b)	-	-	-	-	-	-	-
T-66 L	-	-	-	-	-	-	-
T-66 H	-	-	-	-	-	-	-
T-13 B(a)	-	-	-	-	-	-	-
T-13 B(b)	71.83	72.18	72.00	72.00	48.00	83.00	4.91
T-18 L	43.15	42.20	42.00	41.00	25.50	59.50	5.69
T-18 B	40.28	40.38	40.00	37.50	28.00	54.00	5.51
T-19 L	48.29	47.17	47.00	41.00	32.50	65.00	6.59
T-19 B	45.20	44.25	43.50	38.50	30.50	60.00	6.14
T-61 L	-	-	-	-	-	-	-
T-61 B	-	-	-	-	-	-	-
T-08 L	52.91	52.04	52.50	51.00	38.50	65.50	4.55
T-08 B	65.20	61.39	61.00	61.00	40.50	84.00	7.49
T-08 K	-	-	-	-	-	-	-
T-15 L(a)	63.12	62.28	62.50	60.00	47.00	76.50	6.23
T-15 L(b)	-	-	-	-	-	-	-
T-15 K	64.49	64.18	64.00	62.00	53.00	74.50	4.48
Average	54.15	53.23	53.17	52.00	36.88	70.13	5.77

After, winter 2 (early)

2/11 - 5/12/17	Humidity analysis						
Property ref.	7 - 10pm	24hr	Median	Mode	Min	Max	SD
T-02 L(a)	55.77	55.26	54.50	52.50	49.00	71.00	3.60
T-02 L(b)	47.09	46.61	45.50	43.00	36.00	66.50	5.30
T-07 L(a)	51.38	50.98	51.00	50.00	37.50	66.50	5.94
T-07 L(b)	54.19	53.01	52.50	51.00	40.00	67.00	5.35
T-66 L	-	-	-	-	-	-	-
T-66 H	-	-	-	-	-	-	-
T-13 B(a)	71.82	72.65	73.50	74.00	63.50	79.00	3.32
T-13 B(b)	73.71	72.81	74.00	76.50	60.50	84.00	4.61
T-18 L	-	-	-	-	-	-	-
T-18 B	-	-	-	-	-	-	-
T-19 L	-	-	-	-	-	-	-
T-19 B	44.76	44.91	45.00	45.50	32.00	57.00	3.68
T-61 L	-	-	-	-	-	-	-
T-61 B	-	-	-	-	-	-	-
T-08 L	55.79	53.58	53.50	52.50	42.50	68.50	4.39
T-08 B	-	-	-	-	-	-	-
T-08 K	56.37	52.03	51.50	50.00	35.00	79.50	5.66
T-15 L(a)	59.36	59.05	58.00	56.00	46.50	80.50	5.83
T-15 L(b)	61.37	60.74	59.50	69.50	46.50	78.50	6.61
T-15 K	-	-	-	-	-	-	-
Average	57.42	56.51	56.23	56.41	44.45	72.55	4.94

After, winter 1

19/1 - 30/4/17	Humidity analysis						
Property ref.	7 - 10pm	24hr	Median	Mode	Min	Max	SD
T-02 L(a)	48.57	47.14	47.00	49.00	33.50	75.50	4.99
T-02 L(b)	44.79	43.56	43.50	45.00	31.00	74.00	5.03
T-07 L(a)	48.58	47.90	48.50	51.50	27.50	66.50	5.95
T-07 L(b)	46.96	46.43	47.00	47.50	28.00	65.50	6.03
T-66 L	-	-	-	-	-	-	-
T-66 H	-	-	-	-	-	-	-
T-13 B(a)	-	-	-	-	-	-	-
T-13 B(b)	59.30	60.21	60.50	57.00	39.50	75.00	5.77
T-18 L	39.39	38.95	39.00	36.50	28.00	53.50	4.51
T-18 B	38.39	38.83	39.00	39.50	26.00	52.00	4.31
T-19 L	42.96	43.01	43.00	39.50	26.50	66.50	4.99
T-19 B	41.28	42.23	42.50	43.50	29.50	57.50	4.37
T-61 L	-	-	-	-	-	-	-
T-61 B	-	-	-	-	-	-	-
T-08 L	48.76	48.14	48.00	48.00	33.50	68.50	5.08
T-08 B	60.90	57.35	57.00	54.00	34.00	83.50	8.01
T-08 K	-	-	-	-	-	-	-
T-15 L(a)	56.63	55.97	56.00	54.50	39.00	73.00	6.76
T-15 L(b)	-	-	-	-	-	-	-
T-15 K	55.93	55.07	55.00	54.00	35.00	82.50	6.22
Average	48.65	48.06	48.15	47.65	31.62	68.73	5.54

After, winter 2 (later)

7/12/17 - 22/1/18	Humidity analysis						
Property ref.	7 - 10pm	24hr	Median	Mode	Min	Max	SD
T-02 L(a)	52.68	51.73	51.50	53.50	42.50	75.50	4.39
T-02 L(b)	46.36	45.45	45.50	48.50	34.50	66.50	5.13
T-07 L(a)	45.07	44.91	44.50	42.50	32.00	61.00	5.09
T-07 L(b)	45.70	46.08	45.50	43.50	34.00	59.00	4.95
T-66 L	47.48	47.05	47.00	41.00	31.50	75.50	6.49
T-66 H *	35.46	36.34	35.00	33.50	26.00	54.50	5.67
T-13 B(a)	-	-	-	-	-	-	-
T-13 B(b)	-	-	-	-	-	-	-
T-18 L	-	-	-	-	-	-	-
T-18 B	-	-	-	-	-	-	-
T-19 L	-	-	-	-	-	-	-
T-19 B	41.67	41.94	41.50	40.00	31.00	54.50	4.43
T-61 L	53.10	52.64	53.00	55.00	38.00	66.00	5.18
T-61 B	43.74	44.22	44.00	42.00	31.50	57.00	4.61
T-08 L	52.67	49.40	50.00	50.00	35.00	66.50	4.29
T-08 B	-	-	-	-	-	-	-
T-08 K	57.82	51.77	51.00	54.00	39.50	82.50	5.67
T-15 L(a)	59.08	58.43	57.50	55.50	43.50	84.00	6.28
T-15 L(b)	61.04	60.07	60.00	60.50	44.00	76.00	6.51
T-15 K	-	-	-	-	-	-	-
Average	49.37	48.46	48.15	47.65	35.62	67.58	5.28

* logger stopped on 9/1/18

Table 3.8 (a) Table showing relative humidity (RH) in properties

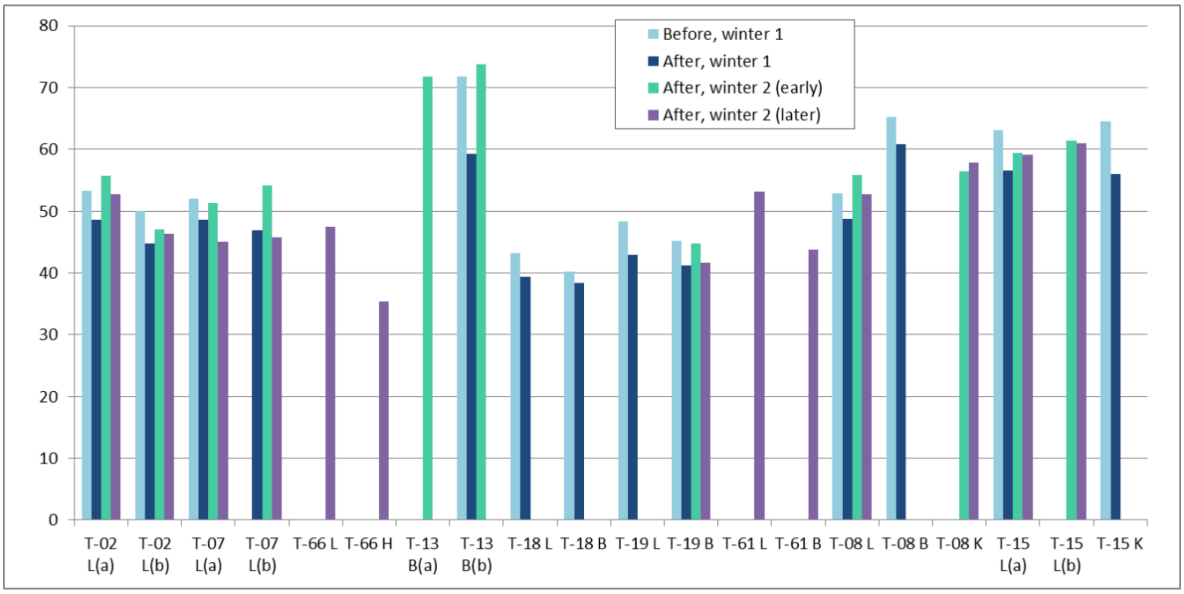


Figure 3.8 (b) Graph based on Table 3.8 (a), for the 24-hour average relative humidity

3.6 Air quality and carbon monoxide levels

Carbon monoxide (CO) is the toxic product of incomplete combustion of carbon-containing fuels. This can occur where appliances such as stoves, ovens, water heaters and boilers malfunction, or are inadequately ventilated so insufficient oxygen reaches them e.g. blocked flues. The health effects of different levels of CO are shown in Table 3.9.

Level of CO	Health Effects, and Other Information
0.1 PPM	Natural atmospheric levels in normal, fresh air.
0.5-5 PPM	Average level in homes without indoor sources.
5-15 PPM	Near properly adjusted gas stoves in the home.
9 PPM	Maximum recommended prolonged indoor CO level (ASHRAE).
10-24 PPM	Possible health effects with long-term exposure.
25 PPM	Max TWA Exposure for 8 hour work-day (ACGIH).
50 PPM	Maximum permissible exposure in workplace (OSHA) and safety level specified by HSE in the UK
100 PPM	Slight headache after 1-2 hours.
200 PPM	Dizziness, nausea, fatigue, headache after 2-3 hours of exposure.
400 PPM	Headache and nausea after 1-2 hours of exposure. Life threatening in 3 hours.
800 PPM	Headache, nausea, and dizziness after 45 minutes; collapse and unconsciousness after 1 hour of exposure. Death within 2-3 hours.
1000 PPM	Loss of consciousness after 1 hour of exposure.
1600 PPM	Headache, nausea, and dizziness after 20 minutes of exposure. Death within 1-2 hours.
3200 PPM	Headache, nausea, and dizziness after 5-10 minutes; collapse and unconsciousness after 30 minutes of exposure. Death within 1 hour.
6400 PPM	Death within 30 minutes.
12,800 PPM	Immediate physiological effects, unconsciousness. Death within 1-3 minutes of exposure.

Table 3.9 Health effects of various levels of carbon monoxide (from detectcarbonmonoxide.com)

As draughty floorboards provide uncontrolled ventilation which could reduce danger should high carbon monoxide levels be present, it was important to verify that reducing such ventilation in a treated property did not exacerbate any problems. Questionnaire responses indicated that all homes contained potential sources of carbon monoxide: all had gas central heating, one also had a multi-fuel stove fitted, some had gas room fires, and others used bottled gas heaters. Other indoor sources of carbon monoxide included gas cookers / ovens, burning of candles and smoking.

The CO loggers record carbon monoxide concentrations at minimum of 5-minute intervals, giving a maximum capacity for 3 months of monitoring data. These therefore required changing at various times during the monitoring period, and periods were selected within this when all loggers were installed and recording data:

- Period 1: 15/10 – 28/11/16, before under-floor insulation installed
- (Period 2a: 25/05/17 – August 2017, excluded from analysis as not during heating period)
- Period 2: 18/01 – 30/04/17, after measures installed, winter 1
- Period 3: 07/01 – 08/02/18, after measures installed, winter 2

Table 3.9 shows various levels of carbon monoxide which may cause concern, both individual spikes of high CO concentrations over 50 ppm, and long-term average exposure of above 9 ppm. Both average levels, Table 3.10, and plots of levels in homes over time, Figure 3.11, are presented.

Table 3.10 shows the average levels experienced suggest no cause for concern for resident safety. Table (a) shows property T-08 experienced the highest CO concentrations over the period before installation of the under-floor insulation. Regular peaks can be seen for this property in Figure 3.11. These tend to occur in the early hours of the morning. It is not known why this could be the case, but this property contains a gas living room fire, and the residents are smokers. For example, if the

Analysis Period #1	
Start Date	15 October 2016
End Date	28 November 2016
Number of Days	44
Start Time	00:00:00
End Time	23:59:00
Hours per day	23:59:00
Property	**Average CO levels (ppm)**
T-08	2.18
T-02	0.04
T-18	0.30
T-07	0.01
Count	4
Maximum	2.18
Minimum	0.01
Average	0.63
Median	0.17
Std Dev	1.04

Analysis Period #2	
Start Date	18 January 2017
End Date	30 April 2017
Number of Days	102
Start Time	00:00:00
End Time	23:59:00
Hours per day	23:59:00
Property	**Average CO levels (ppm)**
T-08	-
T-02	0.01
T-18	0.28
T-07	0.01
Count	3
Maximum	0.28
Minimum	0.01
Average	0.10
Median	0.01
Std Dev	0.15

Analysis Period #3	
Start Date	07 January 2018
End Date	08 February 2018
Number of Days	32
Start Time	00:00:00
End Time	23:59:00
Hours per day	23:59:00
Property	**Average CO levels (ppm)**
T-08	0.44
T-02	0.05
T-18	-
T-07	0.01
T-15	0.11
T-19	0.09
T-61	1.52
T-66	0.11
Count	7
Maximum	1.52
Minimum	0.01
Average	0.33
Median	0.11
Std Dev	0.54

Table 3.10 Average carbon monoxide concentrations in properties over (a) Period 1, (b) Period 2 and (c) Period 3

residents stayed up late, perhaps they used the living room fire instead of the central heating, but we cannot identify the behaviour which causes the carbon monoxide levels recorded. Another property, T-07, whilst having low overall CO concentrations, also sees sudden spikes of high concentrations (lasting only 5 minutes). As this is the property with the multi-fuel stove fitted, these spikes may result from the resident opening its door to fuel it while it is alight but again we cannot state this categorically.

Levels seen over Period 2 were generally lower, although this may result from the logger in property T-08 not recording data. Concentrations in the other properties monitored for CO during this period did not changed significantly compared to before the measures were fitted. Regular peaks in property T-02 are more noticeable in this graph, where a Calor gas heater is reportedly used "rarely", or these peaks may result from cooking.

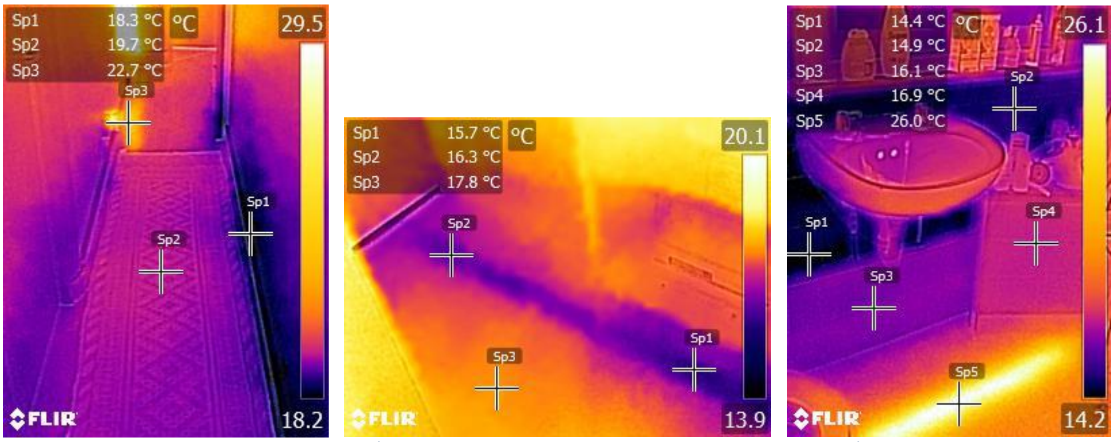
During the third period, average levels seen in properties that were monitored prior to the installation of measures are similar or lower (for property T-08) in winter 2 after the under-floor insulation was installed. The other properties monitored in winter 2 show average levels which indicate no cause for concern. The highest concentrations were seen in property T-61, a ground floor flat where the room heater in the living room is electric (and is reportedly not used).

Properties which show spikes of high carbon monoxide levels are T-07, T-66 and T-15. For T-07 the spikes are fewer than before, adding to the theory that they result from opening the multi-fuel fire door, since the householder reported in the final questionnaire that they'd had to use it less often than previously. T-66 sees regular relatively low levels of CO, but also experienced 3 peaks of 10-22ppm CO of 15-30-minute duration. No explanation for this can be definitively determined – but it was reported by residents that a Calor gas heater is used in the property, which could cause this. Spikes in CO levels in property T-15 may be caused by cooking, as this logger was in the kitchen.

Figure 3.11 Carbon monoxide concentrations in individual properties over (a) Period 1, (b) Period 2 and (c) Period 3

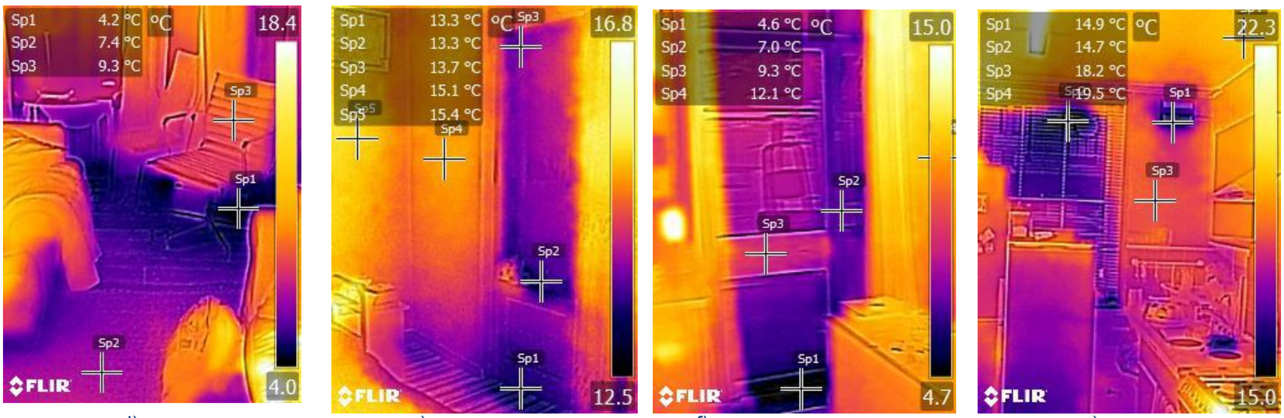
3.7 Thermal Imaging

On visits to the monitored properties in December 2017, a thermal imaging camera was used to assess the floor temperatures for evenness, and also for any remaining cold spots. This also showed up other cold spots which may affect comfort: from doors, windows, walls, draughts etc.

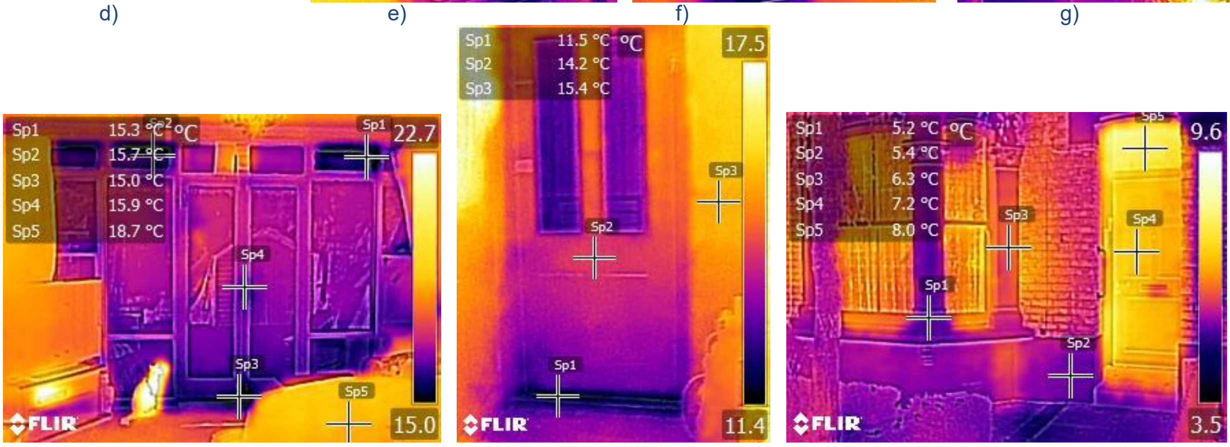


a) b) c)

Figure 3.12 Thermal images from properties showing examples of heat loss & thermal comfort issues after under-floor insulation.



d) e) f) g)



h) i) j)

Figure 3.12 shows how floor temperatures were relatively even in treated properties (a), however on occasion cold (b) or hot spots (c) could be seen, presumably where hot or cold water pipes run under the floor, or (b) could be due to an under-floor supporting wall forming a cold bridge.

These thermal images show examples of colder areas where solid concrete floors meant areas of properties could not be treated (d), and other remaining issues included cold (spots on) external walls (c & e), cold metal-framed single glazed windows (f), uncontrollable vents in kitchens (g) and large areas of single glazed draughty windows (h) and doors (i) still cause heat to be lost, and variations in temperature throughout the property, resulting in poor comfort levels. Thermal image (j) shows an external view of one property, with significant heat apparently leaking from the front door, windows, and some areas of the external walls.

3.8 Q-Bot monitoring to determine U-values

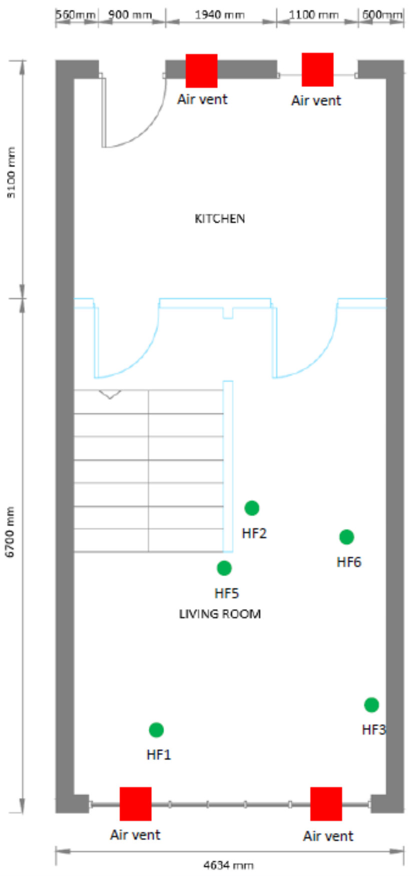


Figure 3.13 Schematic of heat flux sensors installed in property T-07 to measure u-value of the floor

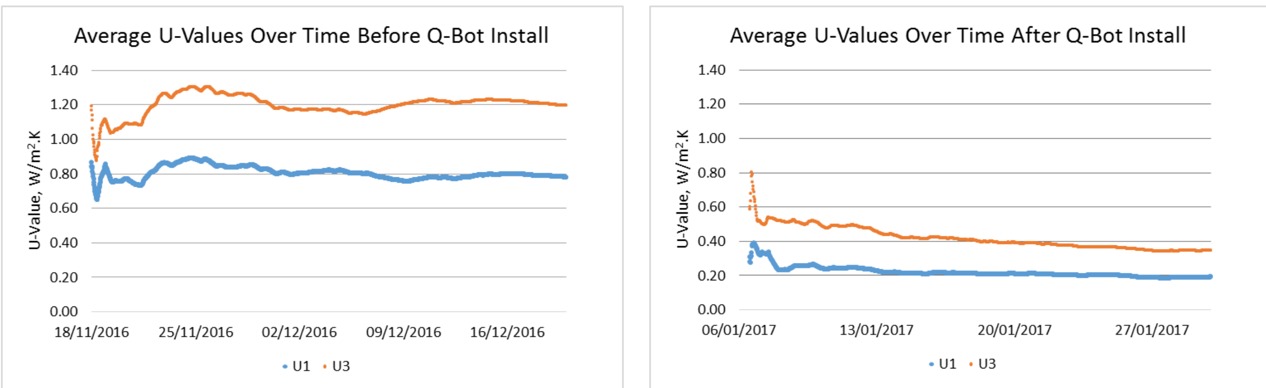
Q-Bot carried out their own detailed monitoring of two properties, T-07 and T-08, to determine the U-value of the floors before and after insulation. As this monitoring was invasive - requiring heat flux sensors to be fitted on the ground floor of the property - it was only carried out over a short period of 4 weeks before and 3 weeks after installation of the under-floor insulation. The periods used for calculating the U-values were 18/11 – 19/12/16, before install, and 13/1 – 21/1/17 (a period of just over 1 week), after install). Monitoring of property T-08 proved inconclusive so U-values could not be calculated here.

Figure 3.13 shows the heat flux sensors installed on the ground floor surface in the 3-storey property T-07 from December 2016 - January 2017. This measured the u-value of the floor using ISO 9869 procedures[12]. U was calculated at 2 different locations (U1 and U3), and the resulting value averaged.

Graphs of the U-values over time at the two different locations and over the two monitoring periods are shown in Figure 3.14. The measured U-values before under-floor insulation was installed averaged 0.78 and 1.20 W/m^{2}K over this period, resulting in an overall average of 0.99 W/m^{2}K.

After the under-floor insulation was installed, the two U values were calculated as 0.19 and 0.34 W/m^{2}K, resulting in an overall average of 0.27 W/m^{2}K. This is a significant improvement, reducing the heat loss via this floor.

Figure 3.14 Average U-values over time (a) before and (b) after installation of the under-floor insulation



EPCs (drafts) were generated by Q-Bot before and after install of the under-floor insulation, showing that the theoretical improvement varied from 2 to 5 SAP points.

[12] www.iso.org/standard/59697.html, ISO 9869-1:2014, Thermal insulation - Building elements - In-situ measurement of thermal resistance and thermal transmittance - Part 1: Heat flow meter method [Accessed 23/04/2018]

4. Conclusions and recommendations

4.1 Conclusions

The project's aims were to insulate the ground floor of HTT properties in Camden and:

- Assess any change in residents' comfort – both reported in questionnaires, and measured using temperature and humidity monitors,
- Monitor any change in energy use for heating,
- Monitor any change in carbon monoxide levels in homes, to ensure reducing ventilation by sealing up draughty floorboards does not worsen this health & safety issue,
- Determine the effectiveness and cost-effectiveness of under-floor insulation to reduce fuel poverty in HTT properties.

Comfort

- Residents' feedback indicated a general improvement in comfort overall from a low starting point in terms of the costs of running their heating system, and how well the property keeps the heat in, and how warm it gets when it's cold outside. More householders said they could now mostly keep warm enough at home, and 2 of 9 reported they could comfortably heat or use more rooms in the property.
- However, after insulation the monitored group were still not satisfied with their comfort levels, on average. Issues remaining included large areas of single glazing, old & draughty windows / doors, uninsulated rooms in the roof (if present), and cold external walls.
- Floor temperatures were generally quite even using thermal imaging techniques, apart from solid concrete floor areas which could not be treated, and locations with hot or cold pipe runs. However, the above-mentioned issues were also identified as cold spots / points of heat loss.
- Householders were very satisfied with the installation of the measures, giving the installers glowing reviews, saying how helpful, knowledgeable and good workers they were.
- There was a split into those who were relatively satisfied with the impact of the under-floor insulation, and a group who did not feel it had made a noticeable difference: 4 of 9 said their bills had reduced, 2 felt it had made no difference, but 3 said bills had increased. However, 2 of 9 said the measures had reduced money worries a lot, and 2 more said it had reduced them a little.
- Gas use, and therefore heating costs, decreased after installation of the measures. The largest property, T-13 – the only one to see an increase in gas use per degree day – was excluded due to it being the only one to have bedrooms on the treated ground-level floor, as was T-15, a severely energy-rationing ground-floor flat household in fuel poverty.
  - The average saving in gas usage (and therefore costs) after under-floor insulation was 13.39%. With a standard deviation (σ) of 3.28%, the savings are significant to a 3σ, or 99.6% confidence level.
  - This resulted in an average saving of £88 per year across all properties. Given the very different property types, this equates to an average saving of £92 per year (from £688 to £595) for the small 1-3 bedroom flats, and £82 per year saving (from £651 to £569) for the larger 3-storey homes – the slightly lower saving in larger homes may be due to under-floor insulation treating a smaller proportion of the home's external surface, and as heat can more easily escape upstairs to be lost from the higher floors.

  - Only the larger properties and one flat reported using electric supplementary heating. No significant saving in electricity use & costs was found: only two of the large homes made a saving, only one of which may be linked to the measures. It is important to note that advice was given by NEA staff on efficient energy-using behaviour at visits, and electricity prices increased so householders may have been more careful with their use, so some savings unrelated to heating might be expected.
- Temperature monitoring showed most properties achieved the recommended range of 18-21°C, apart from rooms in two with average temperatures of 14-15°C. These tended to be heated for only a short time, but maximum temperatures achieved were reasonable (17.5-20°C), presumably when heating was on. Temperatures did not improve significantly as a result of the under-floor insulation, though anecdotal feedback indicated that residents felt they needed to use their central heating less often / for shorter periods to achieve the same temperatures. For homes where thermostats were used, the heating would turn off once the set temperature was reached, saving on fuel bills rather than increasing temperature. The slight reduction seen in average temperatures is likely to be a result of the particularly hard winter in 2017-18, with some householders rationing heating for affordability reasons.
- Humidity levels were better controlled after installation of under-floor insulation, with more properties' humidity levels falling within the recommended 40-60% relative humidity range. Humidity was higher early in the winter (before December) than later, for unknown reasons. One home still had high humidity levels after the measures, which may be due to a structural issue with the property. One property which is heated to very high temperatures now falls below the recommended minimum 40% humidity.
- There were no concerns identified from the monitored carbon monoxide levels in the homes. None of the properties experienced average levels of more than 9 ppm above which long term effects may occur - so installation of under-floor insulation does not appear to worsen this. One property which saw regular high spikes in concentration – possibly due to opening a lit multi-fuel stove – saw these spikes reduce in frequency after the measures as their stove use reduced. Other properties saw lower spikes in CO concentration, but reasons for these are unknown, and do not suggest any long-term issue in the property.
- Measurements by Q-Bot indicate that the U-value of the floor improved, reducing from 0.99 W/m^2K before installation of the under-floor insulation to 0.27 W/m^2K afterwards. This resulted in an average improvement in EPC rating of 3 SAP points after installation.

4.2 Recommendations for potential future installations

Identifying suitable properties was a difficult process due to variability in construction within a street – it may be best to use EPCs to target suitable homes, verified by Google street-view and drive-by visits, if installs of this measure are to be ramped up. If residents use under-floor areas e.g. for storage, it may be best to avoid treating these properties, as this will reduce the available space.

Were this measure to be rolled-out more generally - as always for any insulation measure – to prevent the insulating effects being reduced by draughts and heat loss elsewhere in a property, to maximise resident comfort, energy and carbon savings and minimise resident disruption, NEA recommends that it should ideally be carried out as part of a wider property thermal improvement programme. This should address other heat loss issues evident in the property such as single-glazing, draughty windows / doors, cavity wall and loft insulation, insulation of rooms in the roof and external solid walls at the same time. Take-up of energy efficiency improvements is increased if works are done on a whole-house basis rather than individual technology-by-technology basis.

Advice should always be provided to all residents at installation of any measures: as well as specific information on how to best use the measures (if necessary, unlikely to be required for this measure), this should also cover how to use energy most cheaply and efficiently in the home, to reduce supplementary heating use in favour of whole-house heating, ensure residents are claiming all benefits for which they are eligible, that they are on the best energy tariff for their use, and to resolve any billing issues being experienced.

4.3 Impact on fuel poverty

This measure appears to aid efforts against fuel poverty:

- Reducing gas bills by £88 per year on average: £92 per year for small ground floor flats and £82 per year for larger multi-storey homes;
- A reduction was seen in electricity bills for 2 properties but one cannot be categorically linked to the under-floor insulation. For the other we cannot say how much of this was due to a reduction in supplementary electric heating need, and how much due to other behavioural changes;
- 7 of the 9 residents said their home was now warmer and/or more comfortable, 5 said the house gets warmer faster, keeps heat in better, and the work had improved the quality of the home;
- 4 of the 9 felt their energy bills had reduced, and one further felt they were retaining more heat in the property for the same money. This had reduced money worries a lot for 2 of the 9 residents questioned, and a little for 2 more;
- 5 of the 9 householders could now mostly keep warm enough at home, compared to only 2 of the 9 at the outset;
- 3 of the 9 felt that any damp, condensation or mould issues were better after the measures were installed;
- The impact of these measures could be improved in any future wider roll-out by pairing them with other improvement measures to reduce draughts, insulate cavity walls and lofts, rooms-in-roof and solid walls, replace large single glazed windows or fit secondary glazing.

4.4 Performance comparison against manufacturer's claims

Q-Bot states that under-floor insulation reduces heat loss from the floor by up to 90% (average 80%) based on U-values[13], and cold draughts by up to 50% (average 1/3 improvement) based on air-pressure testing, however heat losses are beyond the scope of our monitoring. We can however compare against Q-bot's claimed average saving of £150 per year – based on SAP assessments (theoretical) and previous resident-reported savings. This study found average normalised savings in energy consumption of £88 per year, for a year with average heating need (degree days) – which is 41% less than Q-bot's reported savings. Savings seen in this study varied from £60-129 per year and were in fuel poor households who often have different energy habits than other households[14].

SAP assessments are theoretical calculations, rather than actual measured savings, and resident-reported savings are notoriously inaccurate (due to rounding, mis-remembering, accounts being in

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[13] https://q-bot.co/service.html [Accessed 20/07/2018]

[14] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/332122/understanding_behaviours_households_fuel_poverty_review_of_research_evidence.pdf [Accessed 20/07/2018]

debt/credit, delays in changing direct debits etc.). Q-Bot also report that their data is based on a wide range of properties in a variety of locations, including exposed rural properties where greater savings would be expected. It is therefore unsurprising that different situations and calculation methods result in differing findings / savings.

The reduced savings calculated in this study are likely to be linked to the fact that the study targeted residents in a localised geographical urban area (southern UK), and who were in - or at risk of - fuel poverty. They may have been using less heating initially due to energy-rationing behaviour i.e. under-heating the home, so reducing their potential for cost savings. Some residents reported improved comfort, being more likely to attain the recommended 18-21°C temperature range (even with the colder outdoor temperatures of winter 2017-18), and/or able to heat or comfortably use more areas of the home than previously. This would reduce apparent savings as a result of under-floor insulation. Conversely, as the cold winter in 2017-18 required increased energy use to attain the same indoor temperatures, some residents in could not afford to increase heating use as much as theoretically expected, which would appear to increase savings following the insulation. These findings are therefore not necessarily transferable to other situations.

4.5 Economic business case for installation of measures

Table 4.1 below shows the business case for installation of under-floor insulation:

Measure	Capital cost	Installation costs	Total	Annual energy saving (from this study)	Indicative annual payback	Assumptions
Q-Bot under-floor insulation	£3,000 per property	Included	£3,000 per property	£92 (1-3 bed ground floor flat) £88 (average) £82 (3-storey)	32.6 years 34 years 36.6 years	• Electricity savings not included: Any savings seen cannot be linked to under-floor insulation. • No savings were noted in solid fuel or bottled gas costs by households which use these.

Table 4.1 Summary of business case

The cost per property reported is for this small study installing under-floor insulation to only 40 homes. It is expected that costs per property would be lower for larger volumes of installations. As for all new innovations, the technology is expected to continue to develop, with aims to increase speed and reduce installation costs further.

The gas cost savings – based on fixed gas prices - were slightly lower for the larger properties, hence the smaller value used in the cost benefit analysis table. This is likely to be because under-floor insulation treats a smaller proportion of the external building envelope, compared to a smaller home with only a ground floor, however under-floor insulation still improves airtightness of the whole building.

No electricity savings were identified that could be measurably linked to the under-floor insulation. Even when electric supplementary heating was used, it was impossible to calculate what proportion of the electricity cost savings seen might result from fitting the under-floor insulation. We will therefore not include these, or savings in any other fuel type such as bottled gas or wood, but only state that savings could be greater in properties where supplementary heating is used to increase ground-floor temperatures to satisfactory levels.

Savings would be greater if also combined with other measures to improve the insulation, and controllability of ventilation, of these HTT properties – especially those which may attract government ECO funding – or replacing windows with more insulated ones where these require replacement anyway, or adding secondary glazing where replacement is not possible for historic building / conservation-area reasons.

Appendix 1: Glossary of Terms

CO Carbon monoxide, toxic gas, product of incomplete combustion of carbon fuels
DD (or dd) *Degree Days*
ECO Energy Company Obligation (scheme requiring energy companies to fund energy efficiency improvements)
EPC *Energy Performance Certificate*
EWI *External Wall Insulation*
HIP *Health and innovation Programme*
HTT *Hard-to-treat – properties for which the easiest and cheapest insulation measures are unsuitable / cannot be applied.*
IMD *Indices of Multiple Deprivation – a measure of the level of deprivation in an area*
LBC *London Borough of Camden*
LSOA *Lower super-output area – the smallest area for which statistics are available*
NEA *National Energy Action – the National Fuel Poverty Charity*
RH *Relative Humidity*
SAP *Standard Assessment Procedure (for assessing home energy efficiency)*
TIF *Technological Innovation Fund*
TRV *Thermostatic Radiator Valve*

Appendix 2: Health and Innovation Programme 2015 – 2017

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

The programme comprised 3 funds

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

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

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

What it involved

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

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

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

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

Appendix 3: Technical Data Sheet for Elastospray 1629/1 product

Technical Data Sheet

Elastospray® 1629/1

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Application:

The Elastospray 1629/1 system was developed as a sprayed (in-situ) thermal insulation. This system was particularly formulated to insulate and prevent condensation on a wide range of applications including roofs, walls, floors and soffits

Intended use: Thermal insulation of buildings

Aside from its excellent properties as an insulation material, Elastospray 1629/1 has following advantages;

- Excellent compression strength values
- Good values of compressive creep.
- Excellent adhesion to the substrate. The spray foam bonds to most surfaces without the need for primers or mechanical fasteners.

The spray process is especially suitable for insulating large areas, including irregularly shaped surfaces such as profiled roofs.

Chemical Characteristics:

Component A:	**Elastospray 1629/1**	Mixture of polyols and additives (Catalysts, Surfactants and blowing agents (HFC). Product does not contain HCFC.
Component B:	**IsoPMDI 92140**	MDI (diphenylmethane diisocyanate)

The product contains fluorinated greenhouse gases according to regulation (EC) No 517/2014. Product contains the following components: Propane, 1,1,1,3,3-pentafluoro- (HFC-245fa); 1,1,1,3,3-Pentafluorobutane (HFC-365mfc); 1,1,1,2,3,3,3-Heptafluoropropane (HFC-227ea)

Supply:

Steel drums: 240kg Component A, 250kg Component B

Storage, Preparation:

Polyurethane components are moisture sensitive. Therefore they must be stored at all times in sealed, closed containers. More detailed information should be obtained from the separate data sheet entitled "Information for in-coming material control, storage, material preparation and waste disposal" and from the component data.

Possible Hazards:

The B-component (Isocyanate) irritates the eyes, respiratory organs and the skin. Sensitization is possible through inhalation and skin contact. MDI is harmful by inhalation. On processing these, take note of the necessary precautionary measures described in the Material Safety Data Sheets (MSDS). This applies also for the possible dangers in using the A-component (Polyol) as well as any other components.

See also our separate information sheet "Safety- and Precautionary Measures for the Processing of Polyurethane Systems. Use our Training Program "Safe Handling of Isocyanate."

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Waste Disposal:

More detailed information is provided in our country -specific pamphlet.

Consumer articles, medical products:

There are national and international laws and regulations to consider if it is intended to produce consumer articles (eg articles that necessitate food or skin contact, toys etc.) or medical objects out of BASF products. Where these do not exist, the current legal requirements of the European Union for consumer articles as well as medical products should be sufficient. Consultation with our Sales Office and our Ecology and Product Safety Department is strongly recommended.

Handling and installation instructions:

See our "Guide for the Application of Elastospray systems".

Component data:

The following properties were obtained at a temperature of 20 °C and correspond to the typical values.

Property	Unit	Comp. A	Comp. B	Method
Viscosity at 20°C	mPa.s	200	220	G133-07*
Density at 20°C	g/cm³	1.21	1,23	G133-08*
Shelf Life	Months	6	6	

* BASF methods

Reaction Profile and Free Rise Density: (components at 20°C and the indicated mixing ratio)

Property	Unit	Elastospray 1629/1	Method
Mixing ratio (weight)		100:103	G132-01*
Cream Time (CT)	s	4	G132-01*
Gel time (GT)	s	8	G132-01*
Tack Free Time (TFT)	s	9	G132-01*
Beaker Free Rise Density (FRB)	kg/m³	31.5	G132-01*

* BASF method in accordance with the method described in standard EN 14315-1

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Process:

The spraying process consists of projecting an impinged mixture of the two components onto the surface which is meant to be insulated. The mixture reacts on the surface, adhering to it instantaneously, and expanding into a rigid foam.

The following conditions should be observed for the correct application of the system:

Machine Conditions		
Mixing Ratio of Components:		1:1 (volume)
Component Temperatures:		30 – 55 °C
Component Pressure:		50 – 80 Bar
Environmental Conditions		
Ambient Temperature:		Between +5 and +40 °C
Relative Humidity:		< 85 %
Wind speed:		≤ 30 km/h
Substrate Conditions		
Substrate Temperature:		Between +5 and +40 °C
Substrate moisture content	Porous substrates	≤ 20 %
	Nonporous substrates	No surface condensation

The thickness of each applied layer should be between 1 and 4 cm. In order to maintain an adequate dimensional stability, it is not recommended to apply thicker layers.

The distance from the spray gun to the substrate is recommended to be approx. 80 cm.

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CE Marking:

CE

0836
0832

BASF plc

Wimsey Way, Alfreton, Derbyshire, DE55 4NL

14

DoP-No.: **3G04-0001-01-CPR-14**
www.elastospray.eu/dop

EN 14315-1:2013

In-situ formed sprayed rigid polyurethane (PU) foam system

ThIB – Thermal Insulation for Buildings

Reaction to fire – **E (valid for all thicknesses)**

Thermal conductivity: **see performance chart**

Water permeability (expressed as short term water absorption by partial immersion): **NPD**

Water vapour transmission (expressed as water vapour resistance factor μ): **NPD**

Compressive strength: NPD

Continuous glowing combustion: **no harmonized test method available**

Durability of reaction to fire against ageing/degradation: **reaction to fire does not decrease with time**

Durability of thermal resistance against ageing/degradation: **see performance chart**

Durability of compressive strength against ageing/degradation: **compressive strength does not decrease with time**

PU EN 14315-1-CCC4-CT4(20)-GT8(20)-TFT9(20)-FRB32.1(20)

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Performance Chart:
(in accordance with EN 14315-1):

Type of facing: None or diffusion open		
Thickness	Declared aged thermal conductivity (λ_D) W/m·K	Thermal resistance level (R_D) m^2·K/W
30 mm	0,028	1,10
35 mm	0,028	1,25
40 mm	0,028	1,45
45 mm	0,028	1,65
50 mm	0,028	1,80
55 mm	0,028	2,00
60 mm	0,028	2,20
65 mm	0,028	2,35
70 mm	0,028	2,55
75 mm	0,028	2,75
80 mm	0,026	3,05
85 mm	0,026	3,25
90 mm	0,026	3,45
95 mm	0,026	3,65
100 mm	0,026	3,85
105 mm	0,026	4,00
110 mm	0,026	4,20
115 mm	0,026	4,40

Type of facing: None or diffusion open		
Thickness	Declared aged thermal conductivity (λ_D) W/m·K	Thermal resistance level (R_D) m^2·K/W
120 mm	0,025	4,80
125 mm	0,025	5,00
130 mm	0,025	5,20
135 mm	0,025	5,40
140 mm	0,025	5,60
145 mm	0,025	5,80
150 mm	0,025	6,00
155 mm	0,025	6,20
160 mm	0,025	6,40
165 mm	0,025	6,60
170 mm	0,025	6,80
175 mm	0,025	7,00
180 mm	0,025	7,20
185 mm	0,025	7,40
190 mm	0,025	7,60
195 mm	0,025	7,80
200 mm	0,025	8,00

Declared aged thermal conductivity value (λ_D) at 10 °C calculated with statistical procedure 90/90 and rounded upwards to the nearest 0,001 W/m·K.

Thermal resistance value (R_D) calculated with aged thermal conductivity at 10 ° C and rounded downwards to the nearest 0,05 m^2 K / W.

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Foam Physical Properties declared in the CE Marking:			
The foam expansion is made by the action of HFC and CO2 (coming from the chemical reaction between water and isocyanate), in such a way that the HFC gases proportion inside the closed cells of the unaged foam is greater than 30%.			
Property	**Elastospray 1629/1**	**Unit**	**Standard**
Thermal conductivity at 10°C Aged value	See Performance Chart	W/(m·K)	EN 14315-1
Reaction to Fire (naked foam)	Class E (valid for all thicknesses)	-	EN 13501-1

Suitable substrates:

Under favorable weather conditions, the rigid spray polyurethane foam Elastospray has a good adhesion to most construction materials (concrete, brick, wood, steel). They must be clean (without dust or grease), dry and, in case of metallic substrates, free of rust. If the adhesion is not acceptable under these conditions, priming may be necessary.

Nevertheless, due to the wide range of substrates and primers used in construction, it is not possible to guarantee perfect adhesion of this system to all surfaces. It is therefore recommended to test adhesion in each case.

See our "Guide for the application of Elastospray Systems" for more detailed information about the general installation process and the suitable substrates.

Complementary Information:

- **Guide for the application of Elastospray Systems.**

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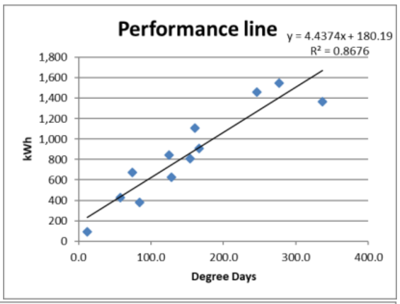
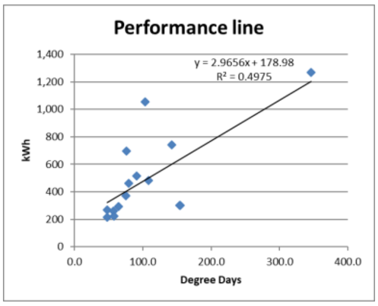
Appendix 4: Examples of degree day analysis & regression

Meter readings taken by householders at frequent intervals during the study were plotted for the winter periods before and after install of under-floor insulation to see if any improvement could be discerned. However, most meter readings were taken at irregular intervals for ALL graphs below, rather than the exactly regular intervals required for degree day analysis, so no conclusions can safely/properly be drawn. However, comments are included to the right for each property.

Property: Before: After: Comments:

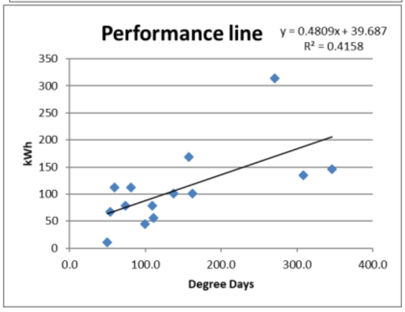
T-08

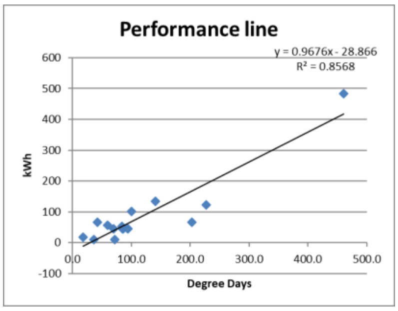




Correlation has notably worsened, improved graph slope

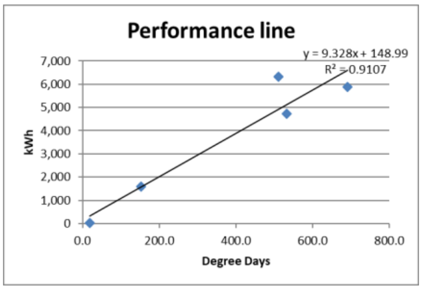
T-15

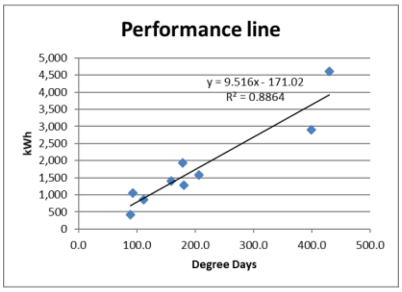




Correlation improved, increase in gas use but under-heating

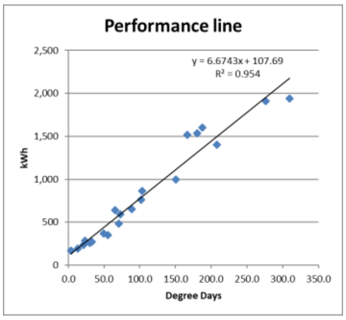
T-19

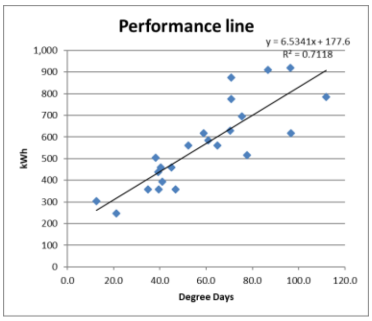




No apparent improvement, intercept now below zero

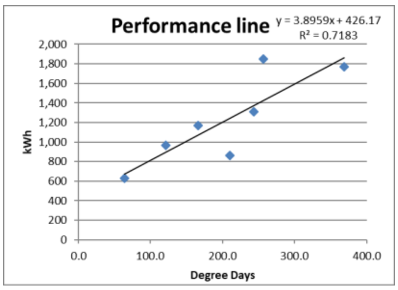
T-13

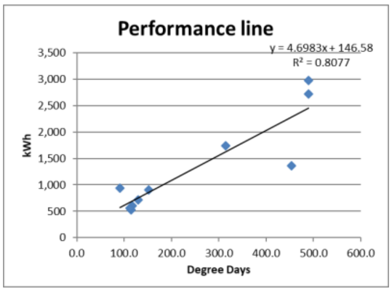




Correlation slightly worse, slightly reduced slope, intercept increased

T-61





Improved correlation, increased slope, reduced intercept

NEA Technical
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