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Solid wall heat losses and the potential for energy saving

Closing the gap. Pre, post-insulation field trial

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Notes

This report is part of a collection of outputs from the BEIS research project investigating the savings achieved with the installation of solid wall insulation. These will be made available on the project web site where a summary of the project can also be found (see http://www.bre.co.uk/swi).

The lead authors for this report were Andrew Gemmell and Matthew Custard of BRE.

Executive Summary

Insulating the solid wall housing stock is one of the greatest challenges for energy efficiency policy. Solid wall insulation is significantly more expensive and intrusive to install than other forms of insulation, making it much less attractive to households and funding organisations. Uncertainties exist around the assumptions used when predicting savings typically achieved following the installation of solid wall insulation. Previous research has identified a gap between calculated savings and actual realised energy savings following the application of solid wall insulation. Typically, the actual savings achieved are less than predicted. This gap affects the potential savings to energy, cost and carbon thereby making solid wall insulation a less cost-effective measure to install than predicted by the energy models.

To quantify the savings achieved by installing solid wall insulation and explain the gap between predicted and actual savings, BRE conducted a pre- and post-insulation field trial spanning two and a half years.

The objectives of the field trial were to;

1. Gather data to improve our understanding of the key factors affecting savings achieved by installing solid wall insulation
2. Improve our knowledge of changes in heating patterns and behaviours as well as the physical movement of heat before and after solid wall insulation
3. Use the knowledge gained to improve modelling assumptions such as U-values, heating patterns, and internal temperature patterns
4. Evaluate changes in energy use attitudes and behaviours pre- and post-refurbishment, with particular focus on heating behaviour
5. Monitor case study solid wall homes before and after insulation to assess the intended and unintended consequences of installing solid wall insulation

The report outlines the size of the discrepancy between the assumed values used in energy models and measured values, as well as the relative impact each variable has on the size of the gap between modelled and measured annual energy consumption. The key findings of the research were;

- On average, *winter* gas consumption for insulated households was found to be 31% lower after the insulation was installed than the year before, saving on average £121 over the winter period alone.
- The measured total *annual* energy savings (2,982 kWh) were found to be, on average, 27% lower than the modelled savings (4,079 kWh) (n=16).
- The gap between modelled and measured savings was attributed to a significant overestimation of energy consumption both before and after insulation. Annual measured consumption was 30% lower than modelled before insulation (n=50) and 32% lower than modelled after insulation (n=16).
- The two variables that had the biggest influence on the size of the gap were external temperature and heating hours.
- When modelling total annual energy consumption, substituting just the measured number of heating hours for the assumed values improved the accuracy of the modelled consumption estimate by 53% for uninsulated dwellings and 61% for insulated cases.

Glossary of key terms

Term	Meaning
Cold bridge	Also referred to as a thermal bridge, a cold bridge is a part of a building with a significantly higher thermal transmittance than the surrounding area. This differential can increase the risk of condensation and mould problems. Cold bridges are more likely around openings such as windows and at junctions such as between the wall and floor of a building.
Comfort taking or Rebound effect	Some of the potential financial and energy savings associated with the insulation are taken back by the occupants as increase comfort.
Dry lining	Plasterboard applied to the internal surface of an external wall, usually fixed with wet plaster dabs or wood studwork.
EFUS	The Government's Energy Follow Up Survey was conducted in 2010 and revisited dwellings and households first contacted as part of the English Housing Survey (EHS). See link for more details: https://www.gov.uk/government/statistics/energy-follow-up-survey-efus-2011
Heating Zones 1 and 2	The SAP methodology divides the dwelling into two zones, zone 1 refers to is the main living area and zone 2 is the rest of the dwelling. The living area is normally the lounge/living room together with any rooms not separated from the lounge by doors. The living area does not, however, extend over more than one storey, even when stairs enter the living area directly.
RdSAP	Reduced Data SAP is a system developed for use in existing dwellings when the full SAP input dataset is not available. It consists of a system of data collection which, when combined with default values and inferences, can be used to generate a full SAP input dataset. That SAP calculation is then run in the standard way.
SAP	The Government's Standard Assessment Procedure for the energy rating of dwellings. A cost based measure, SAP is expressed on a scale of 1-100 (scores greater than 100 are achievable)
Secondary heating	A heating appliance or system used in addition to the main heating system.
U-value	U-value is a measure of the thermal transmittance of a surface. The higher the U-value, the more heat is being transferred through the wall.
Year 1 and Year 2	In the findings section 'year one' refers to the period between May 2014 and April 2015 and 'year two' refers to May 2015 to April 2016.

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1 Introduction

Insulating the solid wall housing stock is one of the greatest challenges for energy efficiency policy. Solid wall insulation can be significantly more expensive and intrusive to install than other forms of insulation, making it much less attractive to households and funding organisations. Uncertainties exist around the assumptions used when predicting savings typically achieved following the installation of solid wall insulation. Previous research has identified a gap between calculated savings and actual realised energy savings following the application of solid wall insulation. Typically, the actual savings achieved are lower than predicted. This gap affects the potential energy, cost and carbon savings from solid wall insulation which makes the intervention a less cost-effective measure to install, with potentially significant impacts on Government policy.

Energy models used to predict savings typically use standard assumptions about the performance of the dwelling and the behaviour of the occupants both before and after insulation. The principle methodology used for calculating savings from the Energy Company Obligation (ECO) is Reduced Data SAP (RdSAP). A number of recent studies have suggested that the actual savings from solid wall insulation may be lower than anticipated by modelling using RdSAP. The over-estimation of the savings is addressed in programmes such as ECO by the application of ‘in-use factors’[1]. These factors apply a simple percentage reduction in savings after the calculations have been made.

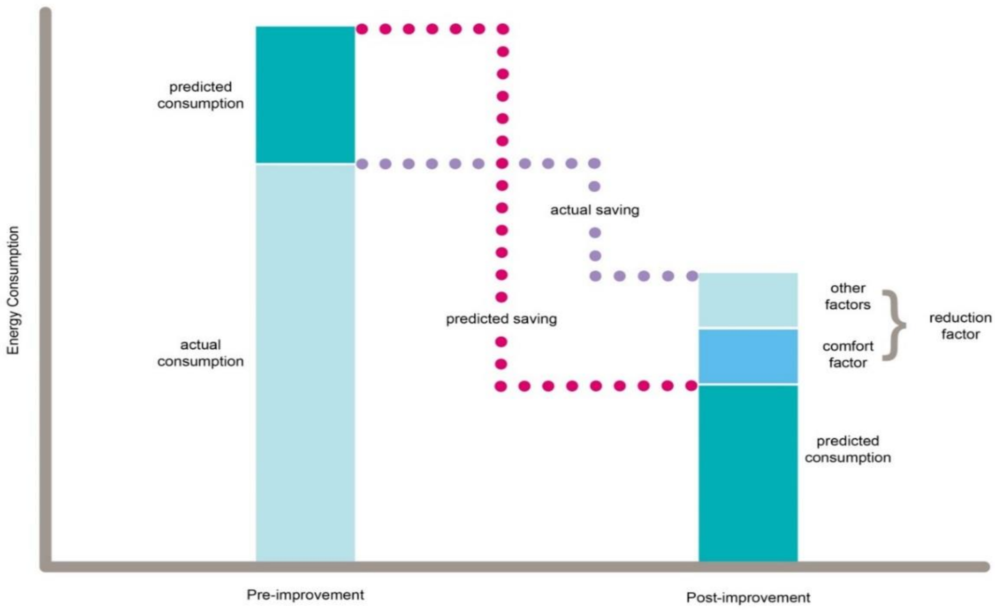

Figure 1 - The gap between predicted and actual energy savings post insulation

[1] https://www.ofgem.gov.uk/ofgem-publications/83100/energycompaniesobligation-measures-pdf

Figure 1 above shows a visual representation of the gap between actual and predicted consumption prior to and following insulation and savings achieved (based on the findings of previous research). A literature review conducted as part of the solid wall insulation research programme[2] identified that the primary reasons for the gap between the predicted and actual savings are likely to be;

- Inaccurate assumptions regarding the baseline performance of the building envelope and the temperatures in the homes prior to installation;
- Errors in the installation of the insulation and poor workmanship;
- Changes in occupant energy use behaviour once the insulation has been installed.

Research examined as part of the literature review suggests that assumptions used in energy models may be outdated in respect of occupant behaviour, heating hours and typical internal temperatures. In addition, changes in occupant behaviour following energy efficiency improvements have been estimated to typically account for between 30% and 60% of the reduction in the predicted space heating savings. All of these factors lead to uncertainty in estimates of energy, carbon and cost savings from this measure, hampering policymakers' and industry's efforts to roll out an effective programme of installation.

The field trial conducted here is part of a work package within the wider research programme which examined in detail the properties of solid walls, the measurement of heat loss and the intended and unintended consequences of installing solid wall insulation. The aim of this work package was to quantify exactly what savings are achieved by improving the thermal performance of solid walls, explain the gap between predicted and actual savings, and assess what other consequences (positive and negative) result from the improvements.

The objectives were to improve our knowledge of changes in heating patterns and occupant energy use behaviours, as well as the physical movement of heat before and after solid wall insulation, and explore whether improving energy model inputs (either through more measurement or improved assumptions) could lead to more accurate predictions of energy consumption both before and after insulation.

To meet these aims BRE conducted a two and a half year pre- and post-insulation field trial to study in detail how the performance of solid wall dwellings changes following insulation as well as any changes in the occupants' behaviours. The objectives of the field trial were to;

1. Gather data to improve our understanding of the key factors affecting savings achieved by installing solid wall insulation
2. Improve our knowledge of changes in heating patterns and behaviours as well as the physical movement of heat before and after solid wall insulation
3. Use the knowledge gained to improve modelling assumptions such as U-values, heating patterns, and temperature profiles (internal and external)
4. Evaluate changes in energy use behaviours pre- and post-refurbishment, with particular focus on heating behaviour and comfort taking
5. Monitor case study solid wall homes before and after insulation to assess the intended and unintended consequences of installing solid wall insulation

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[2] https://www.bre.co.uk/filelibrary/pdf/other_pdfs/Solid-wall-insulation-literature-review.pdf

This report summarises the key findings of the field trial, specifically;

- Pre-insulation energy consumption and comparisons with data collected from the Energy Follow Up Survey (EFUS)
- Post-insulation measured energy consumption
- Assessing the gap between the assumed/estimated values from energy models and the actual measured values in the field
- Quantifying the gap between measured and predicted savings
- Closing the gap by substituting measured values for assumed values in the energy model
- Identifying the key variables that have the greatest effect on the accuracy of the energy model
- Assessing measured changes to the physical properties, heating periods, internal conditions and energy consumption post-insulation
- Evaluating the quality of installations based on observations

The report also contains detailed information regarding the changes observed at each individual case study dwelling.

2 Description of the project

2.1 The sample

At the beginning of the project (summer 2013) BRE identified a number of social housing providers from across England and Wales who were engaged in, or beginning the process of, insulating their solid wall housing stock. BRE worked with these providers to identify suitable dwellings to include in the sample for the pre-, post-insulation field trial. These dwellings were due to be insulated in the summer of 2014. From these cases, 48 households were recruited to participate in the field trial. The dwellings were spread across England and Wales as shown in Table 1 and Figure 2. Households were given £100 in high street vouchers per year as an incentive for taking part.

In the original sample 40 dwellings were due to be insulated, five were dedicated control dwellings (not due to be insulated) and there were three that may or may not have been insulated. The original aim was to monitor these dwellings for two heating seasons; one prior to insulation and one after. The systems used to insulate the dwellings were selected by the housing providers and so varied between locations. These are described in the information pages in section 2.7.

Due to issues faced by the housing providers (described in Appendix A), only one dwelling was insulated before winter 2014/15. The decision was taken to extend the monitoring for another year to give the housing providers time to complete their insulation programmes and for sufficient post-insulation monitoring to be undertaken. To ensure a large enough sample of insulated dwellings was achieved, BRE worked with two additional housing providers (in Hertfordshire) and added a further 15 dwellings to the sample in winter 2014/15.

Table 1 - Location of field trial dwellings (* indicates added in Winter 2014/15)

Location	Number in sample
Wales	17
London	11
Cambridgeshire	7
Liverpool	5
Oxfordshire	3
Warwickshire	3
Control dwellings (Hertfordshire and Bedfordshire)	3
Hertfordshire*	15

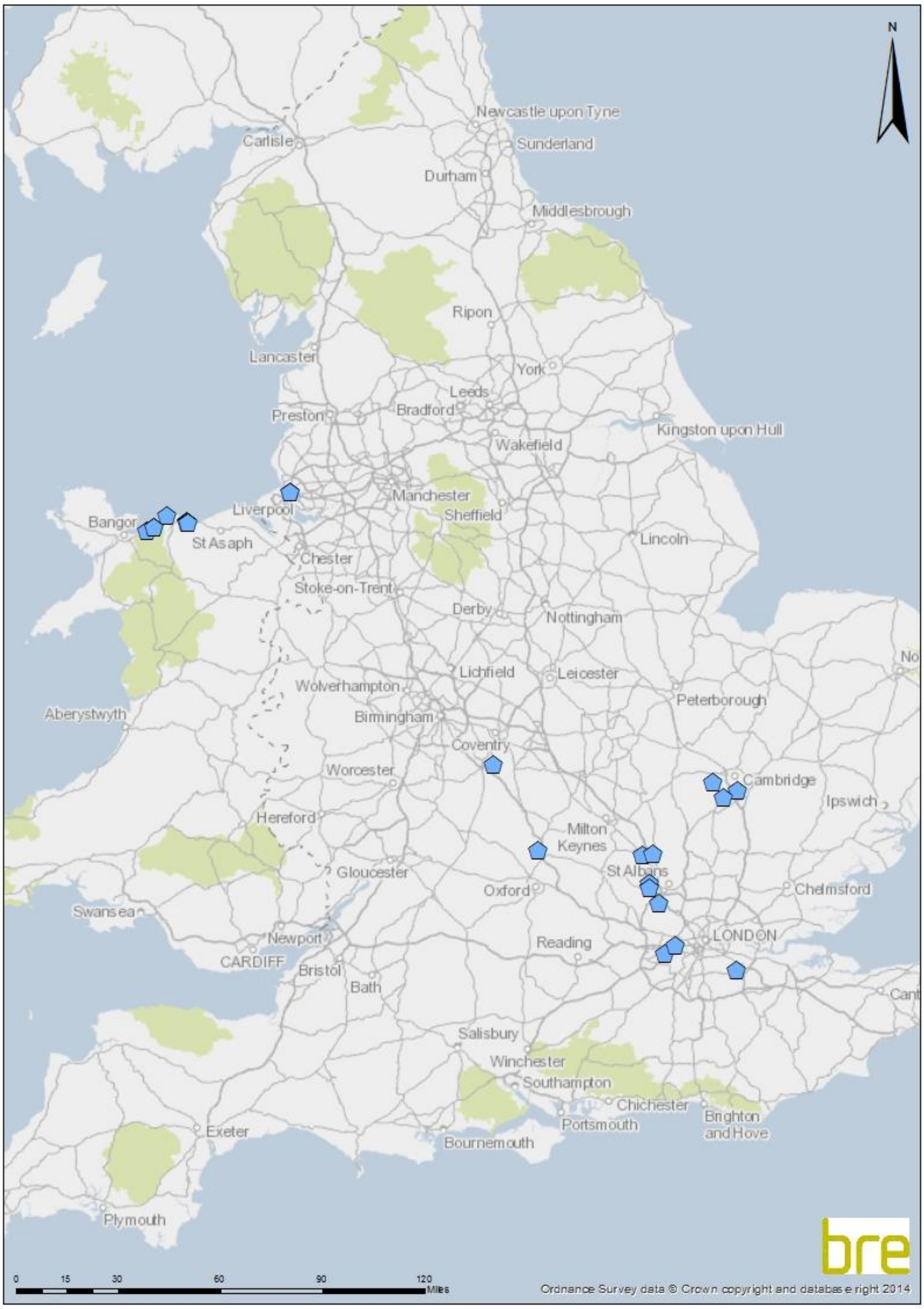

Figure 2 - Geographic location of field trial dwellings

2.2 Monitoring

The dwellings and households recruited for the study were monitored in a number of ways prior to and following insulation being installed. The monitoring was designed to provide accurate information that could be substituted into the energy models in place of the standard default assumptions in order to close the gap between predicted and actual performance both before and after installation and by extension to close the gap between predicted and actual savings for solid wall insulation. The total monitoring period ran from October 2013 to April 2016. Table 2 below lists all of the physical and occupant monitoring conducted at the field trial dwellings.

Table 2 **-** Monitoring undertaken at field trial dwellings

Physical monitoring	Occupant interview
Air tightness	Household demographics and income
U-value	Occupancy times
RdSAP survey	Use of heating system and heating patterns
Measured heating period (radiator monitor)	Energy use behaviour
Temperature and humidity	Perception of environmental conditions
Gas and electricity meter readings	Ventilation and cooling behaviours
Damp and mould assessment	Energy spend and method of payment
Timber moisture (at 7 insulated dwellings)	Attitudes toward energy saving and wall insulation

Air tightness tests and U-value measurements were conducted during the first year of monitoring at all dwellings with the exception of the original five dedicated control dwellings. These were then repeated after the insulation was installed at those dwellings that were insulated. The air tightness test could not be conducted at one of the dwellings due to an unusual design of front and back door which meant the testing equipment could not be installed. In addition, the post-insulation U-value test could not be conducted at one other dwelling due to a change in the internal layout of furniture between years.

Temperature and humidity were monitored in the living room, hallway and bedroom in all dwellings and readings were taken every hour. Gas and electricity readings were taken at the start (October) and end (April-May) of each heating season.

Household interviews were conducted in February of each year. The interviews comprised a mix of qualitative and quantitative questions. The same core questions were asked each year to enable differences between years to be assessed. The interview questions were developed alongside BEIS social research experts and were conducted by trained members of BRE's social research team. The majority of interviews were conducted over the telephone. Despite extensive efforts there was a small number of dwellings that could not be reached in each year. A copy of the occupant interview which was used each year can be found in Appendix C. The additional post-insulation questions asked in the final winter can be found in Appendix D.

As well as asking the occupants what their heating hours were for weekdays and weekends, periods of heating were also measured using a temperature monitor which was attached to one of the living room radiators in each house. Changes in temperature were detected as hot water was pumped around the central heating system. This method was not a direct measure of heating hours (as the boiler does not run throughout the heating hours), and was therefore used to validate the reported heating hours obtained from the occupants.

Damp and mould assessments and timber moisture monitoring were not in the original monitoring specification, but were added later. A formal damp and mould assessment was added at the end of the first winter of monitoring as the occupant interviews identified that some form of damp, mould and/or condensation issues were present in the majority of dwellings. Documenting and measuring these issues before insulation ensured that changes post insulation could be quantified. Monitoring the moisture content of timbers in the roof space was added to the programme as a growing body of evidence suggests an increase in roof timber moisture content could be an unintended consequence of installing solid wall insulation. Timber moisture probes were installed in the loft beams of seven of the dwellings being insulated to allow the moisture content to be tracked after the insulation was installed.

A more detailed description of the physical monitoring methods used can be found in Appendix B.

2.3 Installation of insulation

Table 3 below shows when the insulation was installed in each area. As can be seen in the table only seven of the 25 dwellings were insulated prior October 2015, which is the beginning of the SAP assumed heating season (SAP assumes that space heating is only required between the months of October and May inclusive).

Table 3 - Insulation installation dates

Insulated	Total for each period	Cumulative total
Oct 2014	1 (Cambridgeshire)	1
May 2015	2 (Liverpool)	3
June 2015	4 (Hertfordshire)	7
Oct 2015	8 (Oxfordshire 3, Hertfordshire 5)	15
November 2015	6 (Hertfordshire 2*, Wales 4)	21
Dec 2015	4 (Hertfordshire*)	25

**Insulation boarding installed but final rendering work not complete until as late as Feb 2016*.

External solid wall insulation was installed at each of the dwellings. The insulation material used in each location is specified in Table 4. More detail regarding the insulation at the individual dwellings can be found in the information sheets in section 2.7.

Table 4 - Insulation used in each region

Site	External Insulation used
Cambridgeshire	90mm Jablite EPS 70 e with a k of 0.032
Wales	85mm of SPS Lambdatherm k value 0.032
Hertfordshire	90mm Wetherby Epsitherm k value 0.032
Liverpool	90mm Wetherby Epsitherm k value 0.032
Oxfordshire	Unknown

2.3.1 Observation of installation and timber moisture monitoring

In addition to the monitoring of dwellings, the process for the installation of the external wall insulation was observed. The observation was undertaken without interference or comment to the workforce to ensure the behaviours of the workforce were not influenced. The workforce were told the observations were simply to learn about how insulation was applied. All site visits were undertaken by the same BRE expert to allow comparison to be made and site specific issues to be identified.

The sites observed were in;

- Cambridgeshire
- Hertfordshire
- Wales

The methodology for the observations was as follows.

- A copy of the specification for the works was provided by the housing providers and reviewed prior to the site visit. This included a review of the specification for any key requirements and the site activity profile.
- A minimum of three site visits were conducted at each site during the installation process. Observations took place at three key stages
    - Basecoat and/or boarding out
    - Scrim mesh and topcoat
    - Finish coat and sealing
- In addition to the information collected at the visits themselves, site records were inspected to assess procedures followed for inclement weather and other stoppages.
- General discussions were conducted with site manager/agent when possible.

The observations were recorded and photos taken at key points. Site records were inspected for any delays in work due to inclement weather. Finally, provisions for storage on site were inspected.

2.4 Energy modelling

When considering the performance of energy efficiency measures; and particularly for the major government programmes such as ECO, estimates of savings tend to be made using SAP and RdSAP methodologies. SAP is the Standard Assessment Procedure approved by Government for the demonstration of compliance with Part L1A of the Building Regulations. The SAP methodology (the latest edition of which was SAP 2012 at the time of writing) contains a methodology for collecting and inferring information to allow a SAP calculation to be made on an existing dwelling. This is referred to as RdSAP (Reduced Data SAP) and is used for the production of Energy Performance Certificates (EPCs) and for assessments of suitability for Government carbon reduction schemes (such as ECO).

SAP is a constrained version of the BRE Domestic Energy Model (BREDEM). This reflects SAP's original purpose as a tool for demonstrating compliance with regulations whereby it is necessary to 'test' a dwelling's performance under standard conditions of operation. BREDEM is a more flexible tool for estimating annual consumption, however it requires more information in order to predict consumption accurately. Key areas in which SAP differs from BREDEM are:

- SAP incorporates fuel costs and so is a price index. BREDEM only produces estimates of annual energy consumption. Prices can be applied to these if required.
- SAP does not include energy for appliances and cooking whereas BREDEM does.
- SAP always assumes that a dwelling is located in the East Pennines region of the UK. This is to allow dwellings built in any part of the UK to be compared on a like-for-like basis. BREDEM allows dwellings to be located in different regions of the UK and therefore takes more realistic account of solar gains and external temperatures.
- External temperatures in SAP are based on long term averages for the East Pennines region of the UK. BREDEM can use any external temperatures such as contemporary averages or future projections.
- SAP assumes a standard number of occupants based on the floor area of the dwelling. Again, this is to allow comparison of dwellings on a like-for-like basis.
- SAP makes assumptions about occupants' behaviour such as the hours of heating and the temperatures to which they heat the home. BREDEM allows this to be varied.

The assumptions and inferences built into the RdSAP methodology are based on a combination of empirical data, requirements of regulations and expert judgement. These assumptions have to be applied to all existing dwellings subject to an EPC, ECO or other energy assessment. This inevitably adds further restrictions to an already constrained calculation.

For this project BREDEM was used to generate an estimate of consumption for all dwellings monitored in the study. When assessing the relative influence key variables had on the accuracy of the modelled annual energy consumption, a combination of RdSAP assumed values and recorded values were entered into the model each time. The model was run a number of times using different combinations of actual recorded values and RdSAP assumed/estimated values to establish which variables have the biggest impact on the accuracy of modelled energy consumption. Version 9.92 of RdSAP has been used for all modelling described in this report.

For the base run, only values derived from the RdSAP survey were entered into the model for each variable. No measured values were used other than those which would be recorded in a standard RdSAP assessment. This formed the base modelled energy consumption. For each of the subsequent runs of the model, the actual recorded values were entered for a single variable at a time, SAP values were used for all other variables. All values, other than for the single variable being examined, were reset to the SAP values each time. This allowed the relative impact of each variable to be assessed, rather than the cumulative effect of adding the actual values for each variable. Finally, the measured values for all the variables were used in the model to create the 'Realistic modelled scenario'.

2.5 Comparison with EFUS data

As part of the analysis, some of the data collected in the 2011 Energy Follow Up Survey (EFUS) were compared with the data collected from the first full year of this field trail (May 2014 – May 2015). Energy usage and internal temperatures in households from the field trial cases were analysed alongside households of a similar type from the 2011 EFUS. The aim was to assess how representative the results from the current field trial dwellings were and how comparable they were to the results from previous studies. The EFUS sample was selected to be representative of the English housing stock. The data from the current sample was compared with all available comparable dwellings and households in the EFUS sample. The energy consumption and internal temperatures were studied for social housing dwellings with solid walls, from both the EFUS and field trial, and the results compared.

The Energy Follow Up Survey was carried out in 2011 and included more detailed monitoring of households originally visited for the 2010 English Housing Survey (EHS). As well as interviews on heating behaviours, meter readings were obtained from 1,345 households and internal temperatures were monitored in 823 dwellings.

For datasets containing meter readings and internal temperatures, the following methodology was used to select relevant cases for further analysis. For all datasets, cases that had household or dwelling changes since the 2010 EHS were removed, as well as those with communal systems. Households with solid walls and social housing were then selected.

The EFUS collected initial and final gas and electricity meter readings between April 2010 and November 2012. Thereafter, each case was normalised, using degree-day data to adjust for variability in temperatures across the year. Gas and electricity consumption values were then reported for the period 15th November 2010 – 14th November 2011 and validated.

Of the original EFUS households, the 38 households selected were Social Housing tenants living in solid wall dwellings. The gas and electricity consumption was adjusted using the total number of degree-days between Nov 2010 and Nov 2011, and May 2014 and May 2015, so that comparisons could be made with the current field trial cases.

In the EFUS, internal temperatures were measured in the living room, bedroom and hallway from December 2010 to January 2012. The same method used in the EFUS was adopted for this field trial. The internal temperatures measured in the EFUS sample and the field trials were compared. To analyse the internal temperature in the winter periods, temperatures from November to April were selected to use in the analysis. So as to select the largest sample from the EFUS, temperatures were obtained from February 2011, March 2011, April 2011, November 2011, December 2011 and January 2012. The average temperatures, in zone 1 and zone 2 of the dwelling, were calculated for each month and cases with missing values were removed. This left 23 EFUS cases with solid walls in social housing.

The results of the comparison can be found in section 3.1.

2.6 Annualising consumption figures and estimating costs

With the exception of the EFUS comparisons analysis, all annual data comparisons (both modelled and measured) were based on the 12-month period between the 1st May and 31st April each year. To ensure exactly the same period was being compared for all dwellings, measured gas and electricity consumption was annualised to these dates using degree day data. All comparisons of winter energy use were based on the period between the 1st November and 31st April. As with the annual consumption data, the measured consumption data were normalised for this period to ensure precise comparisons were made and modelled estimates were based on the same time period.

To ensure consistency in the way estimated energy spend was calculated across the monitoring years, all figures were based on 2014 unit prices for gas and electricity taken from the quarterly domestic energy price tables in the BEIS 'Annual domestic energy bills' statistical data set[3]. Electricity was assumed to be a standard tariff and no corrections were made for inflation, or the change in fuel prices between 2014 and 2016. This was done to ensure any observed changes could be attributed to changes at the dwellings themselves rather than other variables such as changes in fuel prices.

2.7 Information sheets

Individual case study information sheets for each of the insulated dwellings can be found below.

Each case study provides information on (where available);

- The dwelling and household characteristics (size, type, heating system, number of occupants, etc.)
- Results from the monitoring both pre- and post-insulation
- Annual energy consumption and estimated spend (gas, electric and total)
- Information regarding any damp and mould issues
- Feedback from the occupants
- Percentage of solid walls insulated
- Any other relevant additional information regarding changes between monitoring years

In addition, the information sheets show measured and modelled total annual energy consumption pre- and post-insulation. Each information sheet shows the modelled consumption based just on the SAP inputs and a BREDEM model run that includes all the measured values for each of the monitored variables.

Eight of the 25 insulated dwellings had new boilers installed at, or around, the time of the insulation. To ensure that the modelled scenario reflected the monitored reality as closely as possible the change in wall U-value and any change in boiler was input into the model. The modelled energy period matched the measured period (May-April) and the point during the year that the insulation was installed was also mirrored in the model. For example, if the insulation was installed in October the uninsulated U-value was used up until this month and the new post insulation U-value was used after this point. The same was true of the boilers; for example, if a new boiler was installed in November, the details of the old boiler were used in the model up to the point of insulation and the new boiler details were used post installation.

[3] https://www.gov.uk/government/statistical-data-sets/annual-domestic-energy-price-statistics

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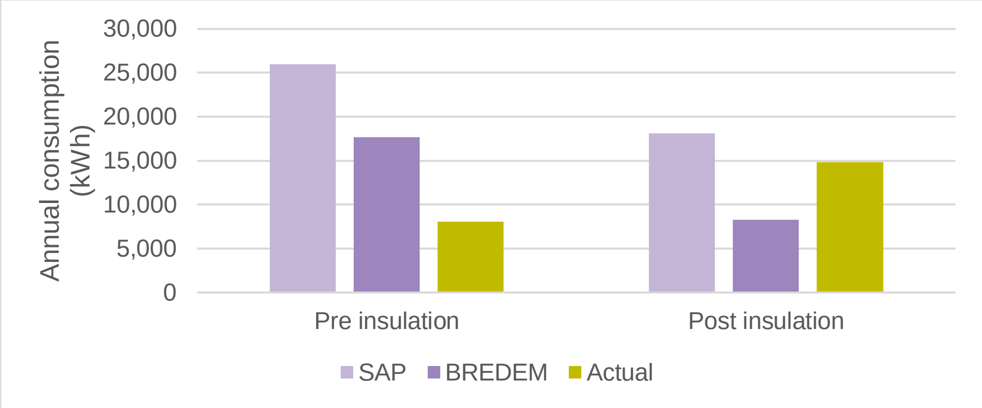
Case ID	35
DWELLING TYPE	End-terrace house
FLOOR AREA	85 m^2
HABITABLE ROOMS	4
HEATING SYSTEM	Gas CH, combi/condensing combi
OCCUPANTS	Pre: 1 Post: 2
RENDERED	No
DRY-LINED	No
INSULATION DATE	May 2015
% OF SOLID WALL INSULATED	~70%

	SAP		Actual		
	Pre	Post	Pre	Post	Percent change
SAP RATING (RdSAP)	49	64	n/a	n/a	n/a
INFILTRATION RATE (ach)	0.55	0.55	0.57	0.70	24%
U-VALUE (W/m^2K)	2.10	0.60	0.96	0.24	-75%
REPORTED HEATING HOURS (WEEKDAY)	9	9	n/a	~8	n/a
REPORTED HEATING HOURS (WEEKEND)	16	16	n/a	~8	n/a
REPORTED HEATING HOURS (TOTAL)	77	77	n/a	~8	n/a
DEMAND TEMPERATURE (°C)	21.0	21.0	n/a	14.0	n/a
PERCENT ZONE 2 HEATED	100	100	100	100	0%[4]
EXTERNAL TEMPERATURE (°C)	6.0	6.0	7.2	7.8	8%
ZONE 1 TEMPERATURE (°C)	17.7	18.6	16.5	21.8	32%
ZONE 2 TEMPERATURE (°C)	15.6	16.8	12.6	19.8	57%
WINTER HUMIDITY (%)	n/a	n/a	61	46	-25%
GAS CONSUMPTION (kWh/yr)	21,117	13,744	1,797	8,835	392%
GAS SPEND (£/yr)	£1,059	£689	£90	£443	392%
ELECTRICITY CONSUMPTION (kWh/yr)	4,901	4,385	6,264	5,974	-5%
ELECTRICITY SPEND (£/yr)	£763	£683	£976	£931	-5%
TOTAL CONSUMPTION (kWh/yr)	26,018	18,129	8,061	14,809	84%
TOTAL SPEND (£/yr)	£1,822	£1,372	£1,066	£1,373	29%

[4] The percentage of zone 2 heated for case W35 was assumed to be 100%, pre- and post-insulation. This was due to uncertainty with the response to interview question 21.

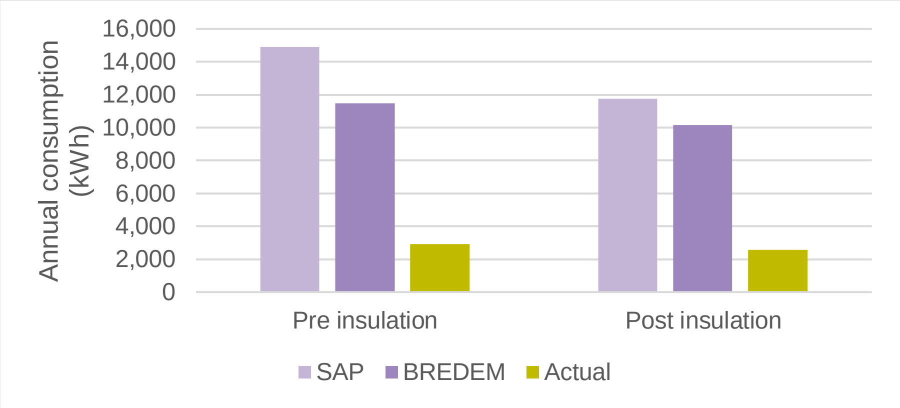
Case ID	35


Annual consumption (kWh)
30,000
25,000
20,000
15,000
10,000
5,000
0
Pre insulation
Post insulation
SAP
BREDEM
Actual

Case ID	38
DWELLING TYPE	Semi-detached flat
FLOOR AREA	92.34m^2
HABITABLE ROOMS	4
HEATING SYSTEM	Gas CH, condensing combi
OCCUPANTS	Pre: 1 Post: 1
RENDERED	No
DRY-LINED	Yes
INSULATION DATE	May 2015
% OF SOLID WALL INSULATED	100%

	SAP		Actual		
	Pre	Post	Pre	Post	Percent change
SAP RATING (RdSAP)	73	78	n/a	n/a	n/a
INFILTRATION RATE (ach)	0.40	0.40	0.56	0.38	-32%
U-VALUE (W/m^{2}K)	1.55	0.60	1.25	0.48	-61%
REPORTED HEATING HOURS (WEEKDAY)	9.0	9.0	5.5	6.5	18%
REPORTED HEATING HOURS (WEEKEND)	16.0	16.0	5.5	6.5	18%
REPORTED HEATING HOURS (TOTAL)	77.0	77.0	38.5	45.5	18%
DEMAND TEMPERATURE (°C)	21.0	21.0	25.0	25.0	0%
PERCENT ZONE 2 HEATED	100	100	100	100	0%
EXTERNAL TEMPERATURE (°C)	6.0	6.0	7.2	7.8	8%
ZONE 1 TEMPERATURE (°C)	19.2	20.1	12.0	n/a	n/a
ZONE 2 TEMPERATURE (°C)	17.8	19.1	13.1	14.9	13%
WINTER HUMIDITY (%)	n/a	n/a	65	64	-1%
GAS CONSUMPTION (kWh/yr)	10,575	7,716	2,105	1,653	-21%
GAS SPEND (£/yr)	£530	£387	£105	£83	-22%
ELECTRICITY CONSUMPTION (kWh/yr)	4,328	4,041	811	912	12%
ELECTRICITY SPEND (£/yr)	£674	£630	£126	£142	12%
TOTAL CONSUMPTION (kWh/yr)	14,903	11,757	2,917	2,565	-12%
TOTAL SPEND (£/yr)	£1,204	£1,016	£232	£225	-3%

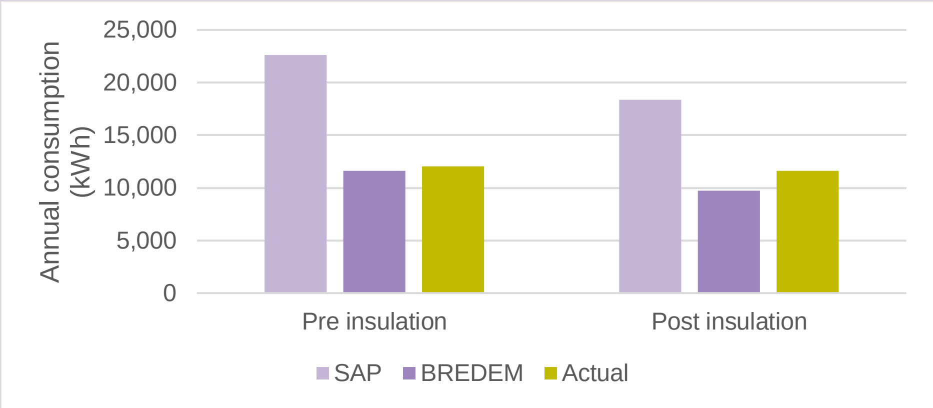
Case ID	38


Annual consumption (kWh)
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
Pre insulation
Post insulation
SAP
BREDEM
Actual

Case ID	40
DWELLING TYPE	Semi-detached house
FLOOR AREA	92.88 m2
HABITABLE ROOMS	4
HEATING SYSTEM	Gas CH, condensing combi
OCCUPANTS	Pre: 2 Post: 2
RENDERED	Yes
DRY-LINED	No
INSULATION DATE	November 2015
% OF SOLID WALL INSULATED	100%

	SAP		Actual		
	Pre	Post	Pre	Post	Percent change
SAP RATING (RdSAP)	58	70	n/a	n/a	n/a
INFILTRATION RATE (ach)	0.55	0.55	0.38	0.27	-30%
U-VALUE (W/m^{2}K)	2.10	0.60	1.89	0.50	-73%
REPORTED HEATING HOURS (WEEKDAY)	9	9	7	5	-29%
REPORTED HEATING HOURS (WEEKEND)	16	16	7	5	-29%
REPORTED HEATING HOURS (TOTAL)	77	77	49	35	-29%
DEMAND TEMPERATURE (°C)	21.0	21.0	18.0	18.0	0%
PERCENT ZONE 2 HEATED	100	100	100	100	0%
EXTERNAL TEMPERATURE (°C)	6.0	6.0	7.3	7.8	7%
ZONE 1 TEMPERATURE (°C)	18.1	19.0	16.3	18.1	11%
ZONE 2 TEMPERATURE (°C)	16.1	17.5	16.0	n/a	n/a
WINTER HUMIDITY (%)	n/a	n/a	55	n/a	n/a
GAS CONSUMPTION (kWh/yr)	17,832	13,916	9,801	9,549	-3%
GAS SPEND (£/yr)	£894	£698	£491	£478	-3%
ELECTRICITY CONSUMPTION (kWh/yr)	4,816	4,424	2,214	2,085	-6%
ELECTRICITY SPEND (£/yr)	£750	£689	£345	£325	-6%
TOTAL CONSUMPTION (kWh/yr)	22,647	18,340	12,016	11,634	-3%
TOTAL SPEND (£/yr)	£1,644	£1,387	£836	£803	-4%

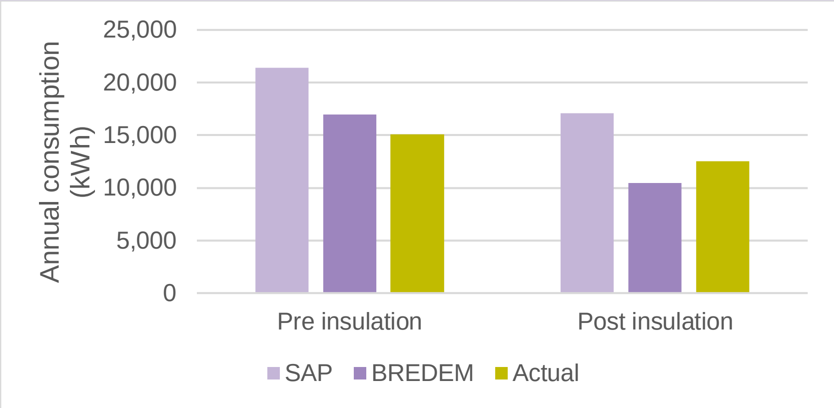
Case ID	40


Annual consumption (kWh)
25,000
20,000
15,000
10,000
5,000
0
Pre insulation
Post insulation
SAP
BREDEM
Actual

Case ID	41
DWELLING TYPE	Semi-detached house
FLOOR AREA	80.86 m^2
HABITABLE ROOMS	4
HEATING SYSTEM	Gas CH, condensing combi
OCCUPANTS	Pre: 3 Post: 3
RENDERED	Yes
DRY-LINED	No
INSULATION DATE	November 2015
% OF SOLID WALL INSULATED	100%

	SAP		Actual		
	Pre	Post	Pre	Post	Percent change
SAP RATING (RdSAP)	56	68	n/a	n/a	n/a
INFILTRATION RATE (ach)	0.55	0.55	0.32	0.27	-15%
U-VALUE (W/m^{2}K)	2.10	0.60	2.06	0.43	-79%
REPORTED HEATING HOURS (WEEKDAY)	9	9	10	8	-20%
REPORTED HEATING HOURS (WEEKEND)	16	16	10	10	0%
REPORTED HEATING HOURS (TOTAL)	77	77	70	60	-14%
DEMAND TEMPERATURE (°C)	21.0	21.0	21.0	17.0	-19%
PERCENT ZONE 2 HEATED	100	100	100	100	0%
EXTERNAL TEMPERATURE (°C)	6.0	6.0	7.3	7.8	7%
ZONE 1 TEMPERATURE (°C)	18.0	19.0	17.8	18.7	5%
ZONE 2 TEMPERATURE (°C)	16.0	17.3	18.0	19.9	11%
WINTER HUMIDITY (%)	n/a	n/a	55	52	-5%
GAS CONSUMPTION (kWh/yr)	16,801	12,857	10,680	8,514	-20%
GAS SPEND (£/yr)	£842	£645	£535	£427	-20%
ELECTRICITY CONSUMPTION (kWh/yr)	4,588	4,230	4,370	4,026	-8%
ELECTRICITY SPEND (£/yr)	£715	£659	£681	£627	-8%
TOTAL CONSUMPTION (kWh/yr)	21,389	17,087	15,050	12,540	-17%
TOTAL SPEND (£/yr)	£1,557	£1,304	£1,216	£1,054	-13%

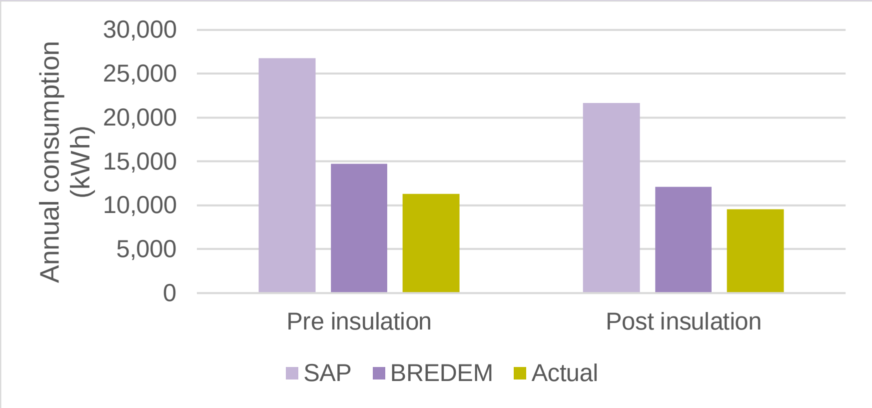
Case ID	41


Annual consumption (kWh)
25,000
20,000
15,000
10,000
5,000
0
Pre insulation
Post insulation
SAP
BREDEM
Actual

Case ID	43
DWELLING TYPE	Semi-detached house
FLOOR AREA	102.8m2
HABITABLE ROOMS	5
HEATING SYSTEM	Gas CH, combi boiler
OCCUPANTS	Pre: 2 Post: 2
RENDERED	Yes
DRY-LINED	No
INSULATION DATE	November 2015
% OF SOLID WALL INSULATED	100%

	SAP		Actual		
	Pre	Post	Pre	Post	Percent change
SAP RATING (RdSAP)	55	67	n/a	n/a	n/a
INFILTRATION RATE (ach)	0.55	0.55	0.29	0.20	-32%
U-VALUE (W/m^{2}K)	2.10	0.60	1.85	0.47	-74%
REPORTED HEATING HOURS (WEEKDAY)	9	9	5	4	-20%
REPORTED HEATING HOURS (WEEKEND)	16	16	8.5	4	-53%
REPORTED HEATING HOURS (TOTAL)	77	77	42	28	-33%
DEMAND TEMPERATURE (°C)	21.0	21.0	20.0	20.0	0%
PERCENT ZONE 2 HEATED	100	100	100	100	0%
EXTERNAL TEMPERATURE (°C)	6.0	6.0	7.3	7.8	7%
ZONE 1 TEMPERATURE (°C)	18.1	19.0	14.1	15.9	12%
ZONE 2 TEMPERATURE (°C)	16.2	17.5	16.2	17.4	7%
WINTER HUMIDITY (%)	n/a	n/a	62	63	2%
GAS CONSUMPTION (kWh/yr)	21,552	16,858	8,249	6,609	-20%
GAS SPEND (£/yr)	£1,080	£845	£413	£331	-20%
ELECTRICITY CONSUMPTION (kWh/yr)	5,199	4,784	3,081	2,954	-4%
ELECTRICITY SPEND (£/yr)	£810	£745	£480	£460	-4%
TOTAL CONSUMPTION (kWh/yr)	26,751	21,642	11,330	9,562	-16%
TOTAL SPEND (£/yr)	£1,890	£1,590	£893	£791	-11%

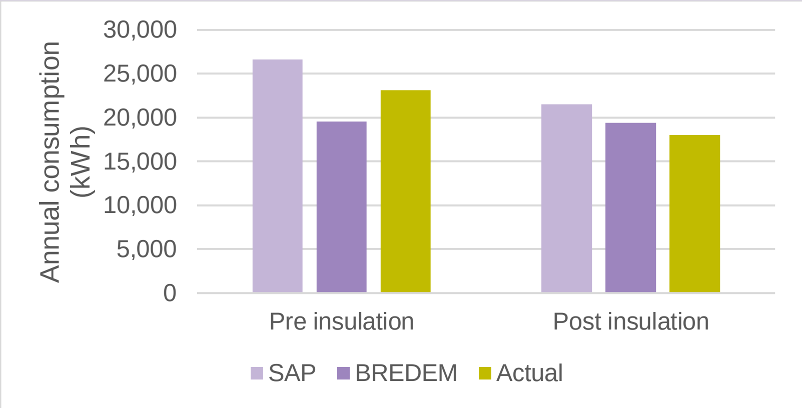
Case ID	43


Annual consumption (kWh)
30,000
25,000
20,000
15,000
10,000
5,000
0
Pre insulation
Post insulation
SAP
BREDEM
Actual

Case ID	48
DWELLING TYPE	Semi-detached house
FLOOR AREA	92.88 m^2
HABITABLE ROOMS	5
HEATING SYSTEM	Gas CH, combi boiler
OCCUPANTS	Pre: 3 Post: 3
RENDERED	Yes
DRY-LINED	No
INSULATION DATE	November 2015
% OF SOLID WALL INSULATED	100%

	SAP		Actual		
	Pre	Post	Pre	Post	Percent change
SAP RATING (RdSAP)	58	69	n/a	n/a	n/a
INFILTRATION RATE (ach)	0.63	0.63	0.38	0.28	-25%
U-VALUE (W/m^{2}K)	2.10	0.60	1.88	0.38	-80%
REPORTED HEATING HOURS (WEEKDAY)	9	9	12	8	-33%
REPORTED HEATING HOURS (WEEKEND)	16	16	12	8	-33%
REPORTED HEATING HOURS (TOTAL)	77	77	84	56	-33%
DEMAND TEMPERATURE (°C)	21.0	21.0	20.0	25.0	25%
PERCENT ZONE 2 HEATED	100	100	100	100	0%
EXTERNAL TEMPERATURE (°C)	6.0	6.0	7.3	7.8	7%
ZONE 1 TEMPERATURE (°C)	18.0	19.0	20.8	20.2	-3%
ZONE 2 TEMPERATURE (°C)	16.0	17.4	19.5	19.6	1%
WINTER HUMIDITY (%)	n/a	n/a	49	51	4%
GAS CONSUMPTION (kWh/yr)	23,142	18,035	16,526	11,135	-33%
GAS SPEND (£/yr)	£1,160	£904	£828	£558	-33%
ELECTRICITY CONSUMPTION (kWh/yr)	3,467	3,467	6,614	6,854	4%
ELECTRICITY SPEND (£/yr)	£540	£540	£1,030	£1,068	4%
TOTAL CONSUMPTION (kWh/yr)	26,609	21,503	23,140	17,989	-22%
TOTAL SPEND (£/yr)	£1,700	£1,444	£1,858	£1,626	-12%

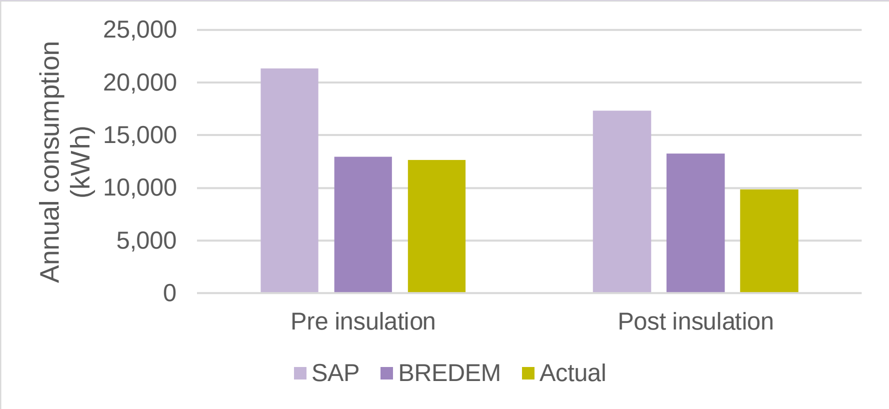
Case ID	48


Annual consumption (kWh)
30,000
25,000
20,000
15,000
10,000
5,000
0
Pre insulation
Post insulation
SAP
BREDEM
Actual

Case ID	49	
DWELLING TYPE	Semi-detached house	
FLOOR AREA	68.74 m^2	
HABITABLE ROOMS	3	
HEATING SYSTEM	Gas CH, condensing boiler	
OCCUPANTS	Pre: 4	Post: 4
RENDERED	Yes	
DRY-LINED	No	
INSULATION DATE	November 2015	
% OF SOLID WALL INSULATED		100%

	SAP		Actual		
	Pre	Post	Pre	Post	Percent change
SAP RATING (RdSAP)	54	66	n/a	n/a	n/a
INFILTRATION RATE (ach)	0.75	0.75	0.43	0.43	0%
U-VALUE (W/m^{2}K)	2.10	0.60	1.50	0.92	-38%
REPORTED HEATING HOURS (WEEKDAY)	9	9	4	1	-75%
REPORTED HEATING HOURS (WEEKEND)	16	16	4	1	-75%
REPORTED HEATING HOURS (TOTAL)	77	77	28	7	-75%
DEMAND TEMPERATURE (°C)	21.0	21.0	18.0	20.0	11%
PERCENT ZONE 2 HEATED	100	100	100	100	0%
EXTERNAL TEMPERATURE (°C)	6.0	6.0	7.2	7.4	2%
ZONE 1 TEMPERATURE (°C)	17.9	18.9	16.6	18.4	11%
ZONE 2 TEMPERATURE (°C)	15.9	17.2	14.1	17.5	24%
WINTER HUMIDITY (%)	n/a	n/a	59	63	8%
GAS CONSUMPTION (kWh/yr)	17,376	13,680	8,161	6,068	-26%
GAS SPEND (£/yr)	£871	£686	£409	£304	-26%
ELECTRICITY CONSUMPTION (kWh/yr)	3,965	3,621	4,486	3,786	-16%
ELECTRICITY SPEND (£/yr)	£618	£564	£699	£590	-16%
TOTAL CONSUMPTION (kWh/yr)	21,342	17,301	12,647	9,854	-22%
TOTAL SPEND (£/yr)	£1,489	£1,250	£1,108	£894	-19%

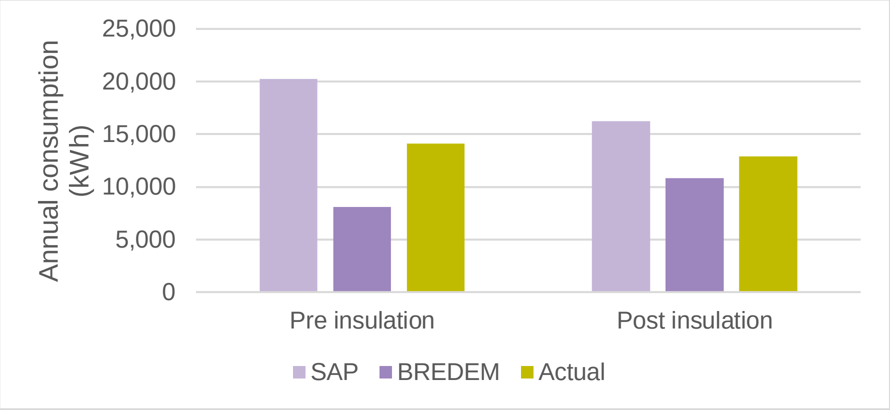
Case ID	49


25,000
20,000
15,000
10,000
5,000
0
Annual consumption (kWh)
Pre insulation
Post insulation
SAP
BREDEM
Actual

Case ID	50
DWELLING TYPE	Semi-detached house
FLOOR AREA	66.72 m^2
HABITABLE ROOMS	4
HEATING SYSTEM	Gas CH, regular/condensing boiler
OCCUPANTS	Pre: 3 Post: 3
RENDERED	Yes
DRY-LINED	Yes
INSULATION DATE	October 2015
% OF SOLID WALL INSULATED	100%

	SAP		Actual		
	Pre	Post	Pre	Post	Percent change
SAP RATING (RdSAP)	61	70	n/a	n/a	n/a
INFILTRATION RATE (ach)	0.75	0.75	0.25	0.27	11%
U-VALUE (W/m^{2}K)	1.55	0.60	0.79	0.43	-45%
REPORTED HEATING HOURS (WEEKDAY)	9	9	8	9	13%
REPORTED HEATING HOURS (WEEKEND)	16	16	8	9	13%
REPORTED HEATING HOURS (TOTAL)	77	77	56	63	13%
DEMAND TEMPERATURE (°C)	21.0	21.0	12.0	17.5	46%
PERCENT ZONE 2 HEATED	100	100	100	100	0%
EXTERNAL TEMPERATURE (°C)	6.0	6.0	7.2	7.4	2%
ZONE 1 TEMPERATURE (°C)	18.2	18.9	19.1	18.5	-3%
ZONE 2 TEMPERATURE (°C)	16.8	17.2	17.8	19.2	8%
WINTER HUMIDITY (%)	n/a	n/a	51	55	8%
GAS CONSUMPTION (kWh/yr)	17,488	13,483	10,683	9,112	-15%
GAS SPEND (£/yr)	£877	£676	£535	£457	-15%
ELECTRICITY CONSUMPTION (kWh/yr)	2,772	2,772	3,438	3,769	10%
ELECTRICITY SPEND (£/yr)	£432	£432	£536	£587	10%
TOTAL CONSUMPTION (kWh/yr)	20,259	16,254	14,121	12,882	-9%
TOTAL SPEND (£/yr)	£1,309	£1,108	£1,071	£1,044	-3%

Case ID	50

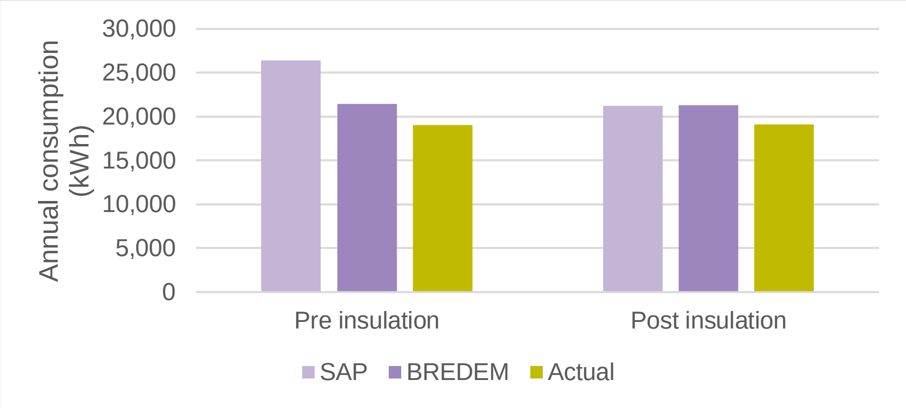

25,000
20,000
15,000
10,000
5,000
0
Annual consumption (kWh)
Pre insulation
Post insulation
SAP
BREDEM
Actual

bre

Case ID	51	
DWELLING TYPE	Semi-detached house	
FLOOR AREA	117.3 m^2	
HABITABLE ROOMS	6	
HEATING SYSTEM	Gas CH, condensing combi	
OCCUPANTS	Pre: 6	Post: 6
RENDERED	Partially	
DRY-LINED	No	
INSULATION DATE	June 2015	
% OF SOLID WALL INSULATED		100%

	SAP		Actual		
	Pre	Post	Pre	Post	Percent change
SAP RATING (RdSAP)	60	69	n/a	n/a	n/a
INFILTRATION RATE (ach)	0.75	0.75	0.24	0.23	-4%
U-VALUE (W/m^{2}K)	2.10	0.60	1.56	0.52	-67%
REPORTED HEATING HOURS (WEEKDAY)	9	9	8	4.5	-44%
REPORTED HEATING HOURS (WEEKEND)	16	16	8	4.5	-44%
REPORTED HEATING HOURS (TOTAL)	77	77	56	31.5	-44%
DEMAND TEMPERATURE (°C)	21.0	21.0	21.0	27.0	29%
PERCENT ZONE 2 HEATED	100	100	100	100	0%
EXTERNAL TEMPERATURE (°C)	6.0	6.0	7.2	7.4	2%
ZONE 1 TEMPERATURE (°C)	18.3	19.0	18.5	20.3	10%
ZONE 2 TEMPERATURE (°C)	16.5	17.5	17.7	19.6	11%
WINTER HUMIDITY (%)	n/a	n/a	61	64	5%
GAS CONSUMPTION (kWh/yr)	20,583	15,868	15,436	15,032	-3%
GAS SPEND (£/yr)	£1,032	£796	£773	£753	-3%
ELECTRICITY CONSUMPTION (kWh/yr)	5,809	5,337	3,609	4,056	12%
ELECTRICITY SPEND (£/yr)	£905	£831	£562	£632	12%
TOTAL CONSUMPTION (kWh/yr)	26,392	21,205	19,045	19,088	0%
TOTAL SPEND (£/yr)	£1,937	£1,627	£1,336	£1,385	4%

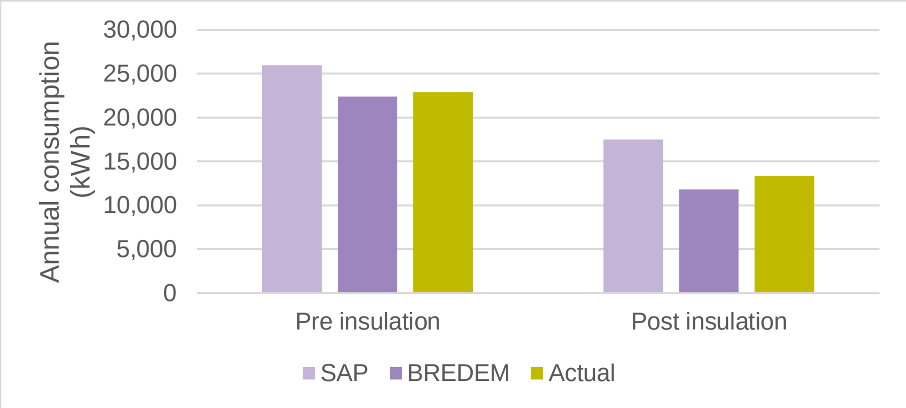
Case ID	51


30,000
25,000
20,000
15,000
10,000
5,000
0
Annual consumption (kWh)
Pre insulation
Post insulation
SAP
BREDEM
Actual

Case ID	52
DWELLING TYPE	Semi-detached house
FLOOR AREA	68.32 m^2
HABITABLE ROOMS	3
HEATING SYSTEM	Gas CH, regular/condensing boiler
OCCUPANTS	Pre: 3 Post: 3
RENDERED	Yes
DRY-LINED	No
INSULATION DATE	December 2015
% OF SOLID WALL INSULATED	100%

	SAP		Actual		
	Pre	Post	Pre	Post	Percent change
SAP RATING (RdSAP)	50	69	n/a	n/a	n/a
INFILTRATION RATE (ach)	0.86	0.86	0.39	0.38	-3%
U-VALUE (W/m^2K)	2.10	0.60	1.96	0.76	-61%
REPORTED HEATING HOURS (WEEKDAY)	9	9	n/a	4.5	n/a
REPORTED HEATING HOURS (WEEKEND)	16	16	n/a	6.5	n/a
REPORTED HEATING HOURS (TOTAL)	77	77	n/a	35.5	n/a
DEMAND TEMPERATURE (°C)	21.0	21.0	21.0	20.5	-2%
PERCENT ZONE 2 HEATED	100	100	83	83	0%
EXTERNAL TEMPERATURE (°C)	6.0	6.0	7.2	7.4	2%
ZONE 1 TEMPERATURE (°C)	17.8	18.8	19.7	20.6	5%
ZONE 2 TEMPERATURE (°C)	16.2	17.1	17.6	19.3	9%
WINTER HUMIDITY (%)	n/a	n/a	50	55	10%
GAS CONSUMPTION (kWh/yr)	23,350	14,909	19,782	10,746	-46%
GAS SPEND (£/yr)	£1,171	£747	£991	£538	-46%
ELECTRICITY CONSUMPTION (kWh/yr)	2,624	2,624	3,112	2,582	-17%
ELECTRICITY SPEND (£/yr)	£409	£409	£485	£402	-17%
TOTAL CONSUMPTION (kWh/yr)	25,974	17,533	22,893	13,328	-42%
TOTAL SPEND (£/yr)	£1,579	£1,156	£1,476	£941	-36%

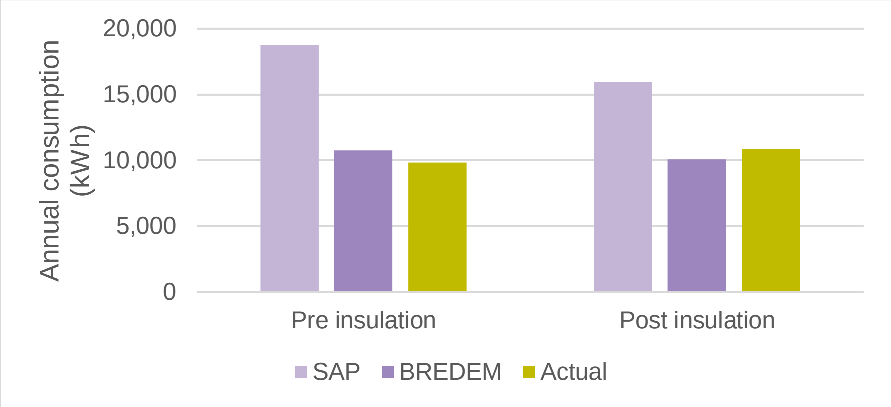
Case ID	52


Annual consumption (kWh)
30,000
25,000
20,000
15,000
10,000
5,000
0
Pre insulation
Post insulation
SAP
BREDEM
Actual

Case ID	53
DWELLING TYPE	Semi-detached house
FLOOR AREA	66.72 m^2
HABITABLE ROOMS	3
HEATING SYSTEM	Gas CH, condensing boiler
OCCUPANTS	Pre: 3 Post: 3
RENDERED	Yes
DRY-LINED	Yes
INSULATION DATE	October 2015
% OF SOLID WALL INSULATED	100%

	SAP		Actual		
	Pre	Post	Pre	Post	Percent change
SAP RATING (RdSAP)	61	67	n/a	n/a	n/a
INFILTRATION RATE (ach)	0.75	0.75	0.28	0.30	6%
U-VALUE (W/m²K)	1.55	0.60	0.97	0.71	-27%
REPORTED HEATING HOURS (WEEKDAY)	9	9	3.5	5	43%
REPORTED HEATING HOURS (WEEKEND)	16	16	3.5	5	43%
REPORTED HEATING HOURS (TOTAL)	77	77	24.5	35	43%
DEMAND TEMPERATURE (°C)	21.0	21.0	17.0	15.0	-12%
PERCENT ZONE 2 HEATED	100	100	100	100	0%
EXTERNAL TEMPERATURE (°C)	6.0	6.0	7.2	7.4	2%
ZONE 1 TEMPERATURE (°C)	18.2	18.9	n/a	18.5	n/a
ZONE 2 TEMPERATURE (°C)	16.8	17.2	n/a	18.2	n/a
WINTER HUMIDITY (%)	n/a	n/a	n/a	62	n/a
GAS CONSUMPTION (kWh/yr)	15,971	13,174	7,072	7,842	11%
GAS SPEND (£/yr)	£801	£660	£354	£393	11%
ELECTRICITY CONSUMPTION (kWh/yr)	2,804	2,804	2,745	2,996	9%
ELECTRICITY SPEND (£/yr)	£437	£437	£428	£467	9%
TOTAL CONSUMPTION (kWh/yr)	18,775	15,978	9,817	10,838	10%
TOTAL SPEND (£/yr)	£1,238	£1,097	£782	£860	10%

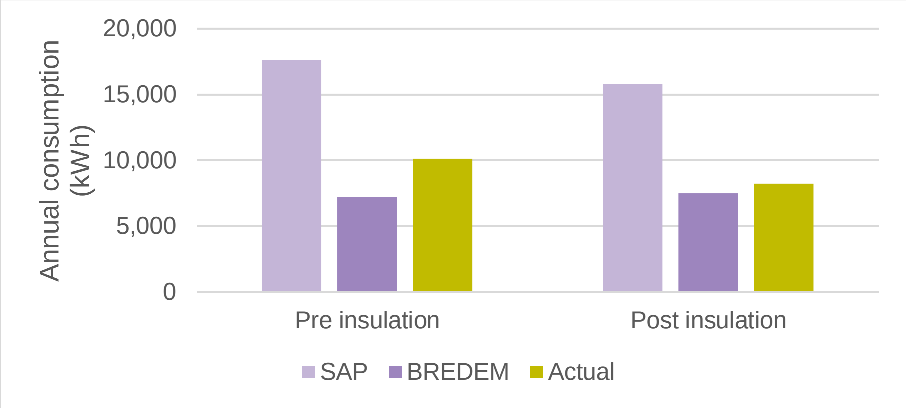
Case ID	53


Annual consumption (kWh)
20,000
15,000
10,000
5,000
0
Pre insulation
Post insulation
SAP
BREDEM
Actual

Case ID	54	
DWELLING TYPE	Semi-detached house	
FLOOR AREA	68.32 m^2	
HABITABLE ROOMS	3	
HEATING SYSTEM	Gas CH, condensing boiler	
OCCUPANTS	Pre: 1	Post: 1
RENDERED	Yes	
DRY-LINED	Yes	
INSULATION DATE	December 2015	
% OF SOLID WALL INSULATED		100%

	SAP		Actual		
	Pre	Post	Pre	Post	Percent change
SAP RATING (RdSAP)	64	69	n/a	n/a	n/a
INFILTRATION RATE (ach)	0.75	0.75	0.38	0.34	-9%
U-VALUE (W/m^{2}K)	1.55	0.60	0.97	0.56	-43%
REPORTED HEATING HOURS (WEEKDAY)	9	9	4.3	5.25	22%
REPORTED HEATING HOURS (WEEKEND)	16	16	5.3	5.5	4%
REPORTED HEATING HOURS (TOTAL)	77	77	32	37.25	16%
DEMAND TEMPERATURE (°C)	21.0	21.0	16.0	17.0	6%
PERCENT ZONE 2 HEATED	100	100	100	100	0%
EXTERNAL TEMPERATURE (°C)	6.0	6.0	7.2	7.4	2%
ZONE 1 TEMPERATURE (°C)	17.9	18.9	n/a	16.6	n/a
ZONE 2 TEMPERATURE (°C)	15.8	17.2	n/a	16.3	n/a
WINTER HUMIDITY (%)	n/a	n/a	n/a	56	n/a
GAS CONSUMPTION (kWh/yr)	14,683	12,920	7,006	5,300	-24%
GAS SPEND (£/yr)	£736	£648	£351	£266	-25%
ELECTRICITY CONSUMPTION (kWh/yr)	2,903	2,903	3,104	2,944	-5%
ELECTRICITY SPEND (£/yr)	£452	£452	£484	£459	-5%
TOTAL CONSUMPTION (kWh/yr)	17,586	15,823	10,110	8,243	-18%
TOTAL SPEND (£/yr)	£1,188	£1,100	£835	£724	-13%

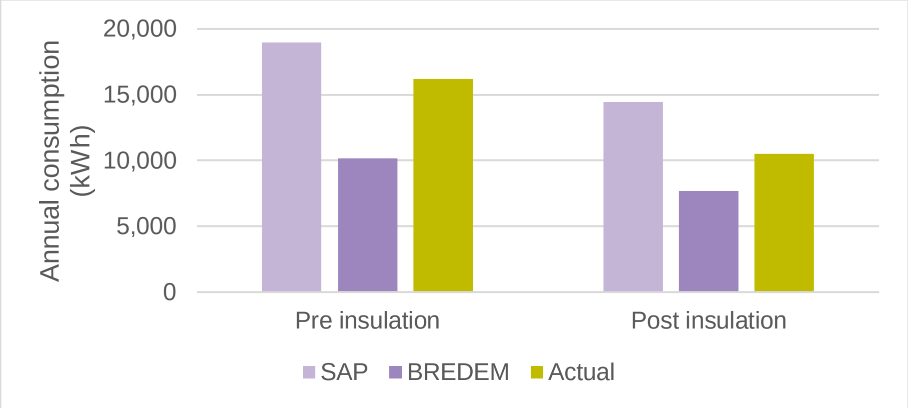
Case ID	54


Annual consumption (kWh)
20,000
15,000
10,000
5,000
0
Pre insulation
Post insulation
SAP
BREDEM
Actual

Case ID	55	
DWELLING TYPE	Semi-detached house	
FLOOR AREA	67.52 m^2	
HABITABLE ROOMS	4	
HEATING SYSTEM	Gas CH, regular/ condensing boiler	
OCCUPANTS	Pre: 1	Post: 1
RENDERED	Yes	
DRY-LINED	Yes	
INSULATION DATE	October 2015	
% OF SOLID WALL INSULATED		100%

	SAP		Actual		
	Pre	Post	Pre	Post	Percent change
SAP RATING (RdSAP)	56	67	n/a	n/a	n/a
INFILTRATION RATE (ach)	0.75	0.75	0.36	0.37	5%
U-VALUE (W/m^2K)	1.55	0.60	2.13	0.56	-74%
REPORTED HEATING HOURS (WEEKDAY)	9	9	2	1	-50%
REPORTED HEATING HOURS (WEEKEND)	16	16	2	1	-50%
REPORTED HEATING HOURS (TOTAL)	77	77	14	7	-50%
DEMAND TEMPERATURE (°C)	21.0	21.0	20.0	20.0	0%
PERCENT ZONE 2 HEATED	100	100	100	100	0%
EXTERNAL TEMPERATURE (°C)	6.0	6.0	7.2	7.4	2%
ZONE 1 TEMPERATURE (°C)	18.2	18.9	n/a	20.8	n/a
ZONE 2 TEMPERATURE (°C)	16.8	17.2	n/a	16.1	n/a
WINTER HUMIDITY (%)	n/a	n/a	n/a	62	n/a
GAS CONSUMPTION (kWh/yr)	15,178	10,876	8,341	4,270	-49%
GAS SPEND (£/yr)	£761	£545	£418	£214	-49%
ELECTRICITY CONSUMPTION (kWh/yr)	3,793	3,553	7,880	6,252	-21%
ELECTRICITY SPEND (£/yr)	£591	£554	£1,228	£974	-21%
TOTAL CONSUMPTION (kWh/yr)	18,971	14,429	16,221	10,522	-35%
TOTAL SPEND (£/yr)	£1,352	£1,099	£1,646	£1,188	-28%

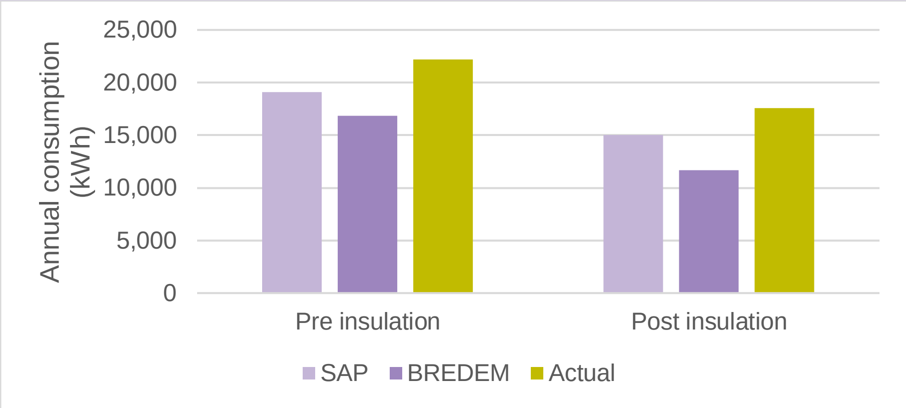
Case ID	55


20,000
15,000
10,000
5,000
0
Annual consumption (kWh)
Pre insulation
Post insulation
SAP
BREDEM
Actual

Case ID	56	
DWELLING TYPE	Semi-detached house	
FLOOR AREA	68.32 m^2	
HABITABLE ROOMS	4	
HEATING SYSTEM	Gas CH, condensing boiler	
OCCUPANTS	Pre: 4	Post: 4
RENDERED	Yes	
DRY-LINED	No	
INSULATION DATE	October 2015	
% OF SOLID WALL INSULATED		100%

	SAP		Actual		
	Pre	Post	Pre	Post	Percent change
SAP RATING (RdSAP)	62	71	n/a	n/a	n/a
INFILTRATION RATE (ach)	0.75	0.75	0.38	0.26	-31%
U-VALUE (W/m^2K)	2.10	0.60	2.62	0.71	-73%
REPORTED HEATING HOURS (WEEKDAY)	9	9	24	24	0%
REPORTED HEATING HOURS (WEEKEND)	16	16	24	24	0%
REPORTED HEATING HOURS (TOTAL)	77	77	168	168	0%
DEMAND TEMPERATURE (°C)	21.0	21.0	17.5	16.5	-6%
PERCENT ZONE 2 HEATED	100	100	100	89	-11%
EXTERNAL TEMPERATURE (°C)	6.0	6.0	7.2	7.4	2%
ZONE 1 TEMPERATURE (°C)	17.9	18.9	n/a	19.8	n/a
ZONE 2 TEMPERATURE (°C)	15.8	17.1	n/a	20.1	n/a
WINTER HUMIDITY (%)	n/a	n/a	n/a	49	n/a
GAS CONSUMPTION (kWh/yr)	16,489	12,373	18,987	14,589	-23%
GAS SPEND (£/yr)	£827	£620	£951	£731	-23%
ELECTRICITY CONSUMPTION (kWh/yr)	2,632	2,632	3,202	2,996	-6%
ELECTRICITY SPEND (£/yr)	£410	£410	£499	£467	-6%
TOTAL CONSUMPTION (kWh/yr)	19,121	15,005	22,189	17,586	-21%
TOTAL SPEND (£/yr)	£1,237	£1,030	£1,450	£1,198	-17%

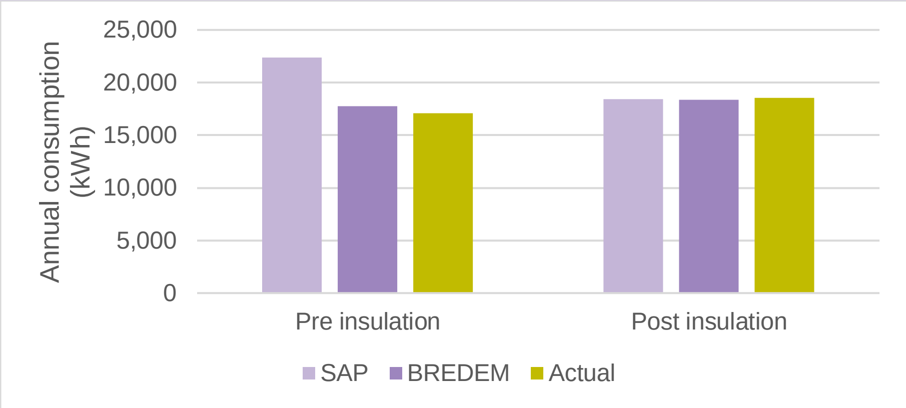
Case ID	56


Annual consumption (kWh)
25,000
20,000
15,000
10,000
5,000
0
Pre insulation
Post insulation
SAP
BREDEM
Actual

Case ID	57	
DWELLING TYPE	Semi-detached house	
FLOOR AREA	67.12 m^2	
HABITABLE ROOMS	4	
HEATING SYSTEM	Gas CH, condensing boiler	
OCCUPANTS	Pre: 5	Post: 5
RENDERED	Yes	
DRY-LINED	Yes	
INSULATION DATE	December 2015	
% OF SOLID WALL INSULATED		100%

	SAP		Actual		
	Pre	Post	Pre	Post	Percent change
SAP RATING (RdSAP)	61	66	n/a	n/a	n/a
INFILTRATION RATE (ach)	0.92	0.92	0.53	0.62	16%
U-VALUE (W/m^2K)	1.55	0.60	1.20	0.38	-69%
REPORTED HEATING HOURS (WEEKDAY)	9	9	7	7.5	7%
REPORTED HEATING HOURS (WEEKEND)	16	16	7	7.5	7%
REPORTED HEATING HOURS (TOTAL)	77	77	49	52.5	7%
DEMAND TEMPERATURE (°C)	21.0	21.0	21.0	25.0	19%
PERCENT ZONE 2 HEATED	100	100	100	89	-11%
EXTERNAL TEMPERATURE (°C)	6.0	6.0	7.2	7.4	2%
ZONE 1 TEMPERATURE (°C)	17.8	18.5	n/a	23.3	n/a
ZONE 2 TEMPERATURE (°C)	15.7	16.6	n/a	22.7	n/a
WINTER HUMIDITY (%)	n/a	n/a	n/a	51	n/a
GAS CONSUMPTION (kWh/yr)	19,578	15,617	8,430	8,000	-5%
GAS SPEND (£/yr)	£982	£783	£422	£401	-5%
ELECTRICITY CONSUMPTION (kWh/yr)	2,823	2,823	8,680	10,567	22%
ELECTRICITY SPEND (£/yr)	£440	£440	£1,352	£1,646	22%
TOTAL CONSUMPTION (kWh/yr)	22,401	18,440	17,111	18,657	9%
TOTAL SPEND (£/yr)	£1,421	£1,223	£1,775	£2,047	15%

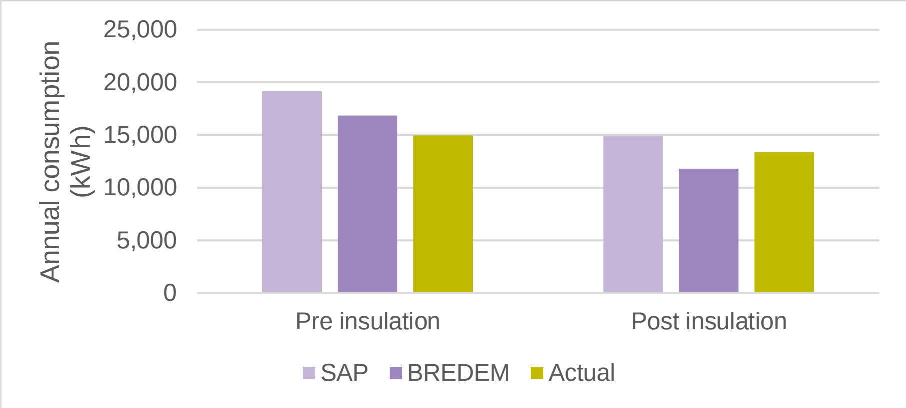
Case ID	57


Annual consumption (kWh)
25,000
20,000
15,000
10,000
5,000
0
Pre insulation
Post insulation
SAP
BREDEM
Actual

Case ID	58
DWELLING TYPE	Semi-detached house
FLOOR AREA	67.52 m^2
HABITABLE ROOMS	4
HEATING SYSTEM	Gas CH, regular/ condensing boiler
OCCUPANTS	Pre: 3 Post: 3
RENDERED	Yes
DRY-LINED	Yes
INSULATION DATE	October 2015
% OF SOLID WALL INSULATED	100%

	SAP		Actual		
	Pre	Post	Pre	Post	Percent change
SAP RATING (RdSAP)	61	71	n/a	n/a	n/a
INFILTRATION RATE (ach)	0.75	0.75	0.37	0.38	2%
U-VALUE (W/m^{2}K)	1.55	0.60	1.97	1.21	-39%
REPORTED HEATING HOURS (WEEKDAY)	9	9	6	4	-33%
REPORTED HEATING HOURS (WEEKEND)	16	16	16	4	-75%
REPORTED HEATING HOURS (TOTAL)	77	77	62	28	-55%
DEMAND TEMPERATURE (°C)	21.0	21.0	22.0	20.5	-7%
PERCENT ZONE 2 HEATED	100	100	100	100	0%
EXTERNAL TEMPERATURE (°C)	6.0	6.0	7.2	7.4	2%
ZONE 1 TEMPERATURE (°C)	18.2	18.9	n/a	18.5	n/a
ZONE 2 TEMPERATURE (°C)	16.3	17.2	n/a	17.4	n/a
WINTER HUMIDITY (%)	n/a	n/a	n/a	54	n/a
GAS CONSUMPTION (kWh/yr)	16,452	12,190	10,683	9,250	-13%
GAS SPEND (£/yr)	£825	£611	£535	£463	-13%
ELECTRICITY CONSUMPTION (kWh/yr)	2,700	2,700	4,270	4,110	-4%
ELECTRICITY SPEND (£/yr)	£421	£421	£665	£640	-4%
TOTAL CONSUMPTION (kWh/yr)	19,152	14,890	14,953	13,360	-11%
TOTAL SPEND (£/yr)	£1,245	£1,032	£1,201	£1,104	-8%

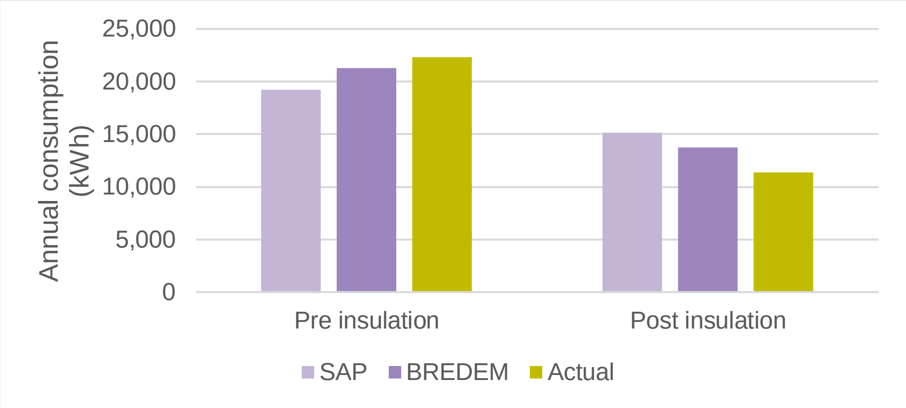
Case ID	58


25,000
20,000
15,000
10,000
5,000
0
Annual consumption (kWh)
Pre insulation
Post insulation
SAP
BREDEM
Actual

Case ID	59	
DWELLING TYPE	Semi-detached house	
FLOOR AREA	67.72 m^2	
HABITABLE ROOMS	4	
HEATING SYSTEM	Gas CH, condensing boiler	
OCCUPANTS	Pre: 5	Post: 5
RENDERED	Yes	
DRY-LINED	Partial	
INSULATION DATE	October 2015	
% OF SOLID WALL INSULATED		100%

	SAP		Actual		
	Pre	Post	Pre	Post	Percent change
SAP RATING (RdSAP)	64	69	n/a	n/a	n/a
INFILTRATION RATE (ach)	0.75	0.75	0.30	0.34	14%
U-VALUE (W/m^{2}K)	2.10	0.60	2.34	0.74	-68%
REPORTED HEATING HOURS (WEEKDAY)	9	9	11	7.5	-32%
REPORTED HEATING HOURS (WEEKEND)	16	16	6	7.5	25%
REPORTED HEATING HOURS (TOTAL)	77	77	67	52.5	-22%
DEMAND TEMPERATURE (°C)	21.0	21.0	25.0	20.0	-20%
PERCENT ZONE 2 HEATED	100	100	100	100	0%
EXTERNAL TEMPERATURE (°C)	6.0	6.0	7.2	7.4	2%
ZONE 1 TEMPERATURE (°C)	18.2	18.9	n/a	18.7	n/a
ZONE 2 TEMPERATURE (°C)	16.2	17.1	n/a	18.3	n/a
WINTER HUMIDITY (%)	n/a	n/a	n/a	62	n/a
GAS CONSUMPTION (kWh/yr)	16,301	12,244	16,854	7,171	-57%
GAS SPEND (£/yr)	£817	£614	£844	£359	-57%
ELECTRICITY CONSUMPTION (kWh/yr)	2,917	2,917	5,445	4,213	-23%
ELECTRICITY SPEND (£/yr)	£454	£454	£848	£656	-23%
TOTAL CONSUMPTION (kWh/yr)	19,219	15,161	22,299	11,384	-49%
TOTAL SPEND (£/yr)	£1,272	£1,068	£1,693	£1,016	-40%

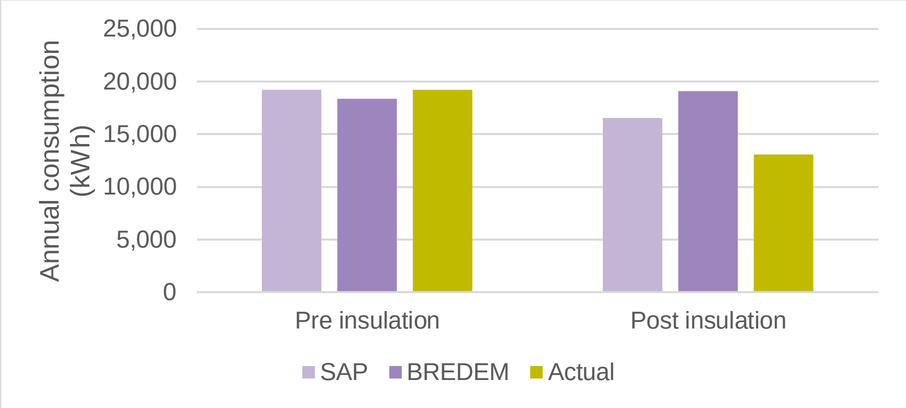
Case ID	59


Annual consumption (kWh)
25,000
20,000
15,000
10,000
5,000
0
Pre insulation
Post insulation
SAP
BREDEM
Actual

Case ID	60	
DWELLING TYPE	Semi-detached house	
FLOOR AREA	68.32 m^2	
HABITABLE ROOMS	4	
HEATING SYSTEM	Gas CH, condensing combi	
OCCUPANTS	Pre: 6	Post: 6
RENDERED	Yes	
DRY-LINED	No	
INSULATION DATE	December 2015	
% OF SOLID WALL INSULATED		100%

	SAP		Actual		
	Pre	Post	Pre	Post	Percent change
SAP RATING (RdSAP)	62	70	n/a	n/a	n/a
INFILTRATION RATE (ach)	0.75	0.75	0.46	0.46	0%
U-VALUE (W/m^{2}K)	2.10	0.60	1.88	0.75	-60%
REPORTED HEATING HOURS (WEEKDAY)	9	9	9	9	0%
REPORTED HEATING HOURS (WEEKEND)	16	16	9	9	0%
REPORTED HEATING HOURS (TOTAL)	77	77	63	63	0%
DEMAND TEMPERATURE (°C)	21.0	21.0	22.5	25.0	11%
PERCENT ZONE 2 HEATED	100	100	100	100	0%
EXTERNAL TEMPERATURE (°C)	6.0	6.0	7.2	7.4	2%
ZONE 1 TEMPERATURE (°C)	17.8	18.7	n/a	20.4	n/a
ZONE 2 TEMPERATURE (°C)	15.7	17.0	n/a	19.7	n/a
WINTER HUMIDITY (%)	n/a	n/a	n/a	56	n/a
GAS CONSUMPTION (kWh/yr)	16,334	13,655	11,592	6,356	-45%
GAS SPEND (£/yr)	£819	£685	£581	£318	-45%
ELECTRICITY CONSUMPTION (kWh/yr)	2,885	2,885	7,606	6,748	-11%
ELECTRICITY SPEND (£/yr)	£449	£449	£1,185	£1,051	-11%
TOTAL CONSUMPTION (kWh/yr)	19,219	16,540	19,198	13,103	-32%
TOTAL SPEND (£/yr)	£1,268	£1,134	£1,766	£1,370	-22%

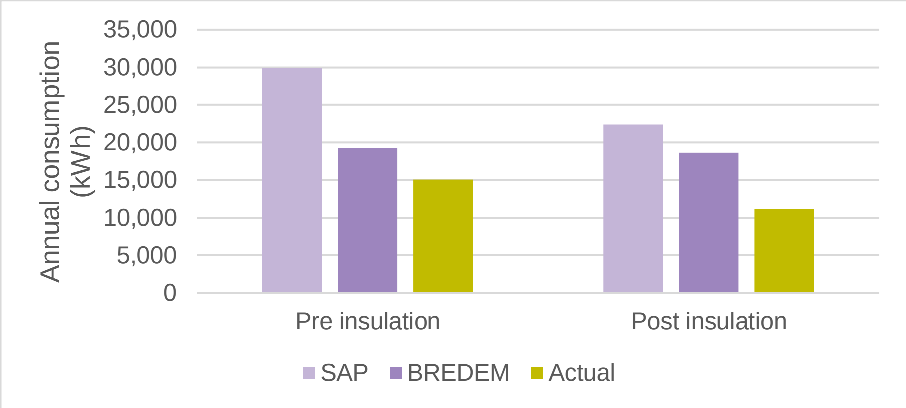
Case ID	60


Annual consumption (kWh)
25,000
20,000
15,000
10,000
5,000
0
Pre insulation
Post insulation
SAP
BREDEM
Actual

Case ID	61
DWELLING TYPE	Semi-detached house
FLOOR AREA	89.37 m^2
HABITABLE ROOMS	5
HEATING SYSTEM	Gas CH, combi boiler
OCCUPANTS	Pre: 4 Post: 4
RENDERED	Partially
DRY-LINED	No
INSULATION DATE	June 2015
% OF SOLID WALL INSULATED	100%

	SAP		Actual		
	Pre	Post	Pre	Post	Percent change
SAP RATING (RdSAP)	54	66	n/a	n/a	n/a
INFILTRATION RATE (ach)	0.75	0.75	0.26	0.27	3%
U-VALUE (W/m^2K)	2.10	0.60	1.39	0.44	-68%
REPORTED HEATING HOURS (WEEKDAY)	9	9	8.5	5.5	-35%
REPORTED HEATING HOURS (WEEKEND)	16	16	7.5	5.5	-27%
REPORTED HEATING HOURS (TOTAL)	77	77	57.5	38.5	-33%
DEMAND TEMPERATURE (°C)	21.0	21.0	21.0	25.0	19%
PERCENT ZONE 2 HEATED	100	100	78	78	0%
EXTERNAL TEMPERATURE (°C)	6.0	6.0	7.2	7.4	2%
ZONE 1 TEMPERATURE (°C)	17.8	18.8	n/a	19.5	n/a
ZONE 2 TEMPERATURE (°C)	15.8	17.1	n/a	19.3	n/a
WINTER HUMIDITY (%)	n/a	n/a	n/a	61	n/a
GAS CONSUMPTION (kWh/yr)	26,315	18,819	10,372	6,677	-36%
GAS SPEND (£/yr)	£1,319	£943	£520	£335	-36%
ELECTRICITY CONSUMPTION (kWh/yr)	3,583	3,583	4,715	4,479	-5%
ELECTRICITY SPEND (£/yr)	£558	£558	£735	£698	-5%
TOTAL CONSUMPTION (kWh/yr)	29,898	22,402	15,087	11,156	-26%
TOTAL SPEND (£/yr)	£1,877	£1,502	£1,254	£1,032	-17%

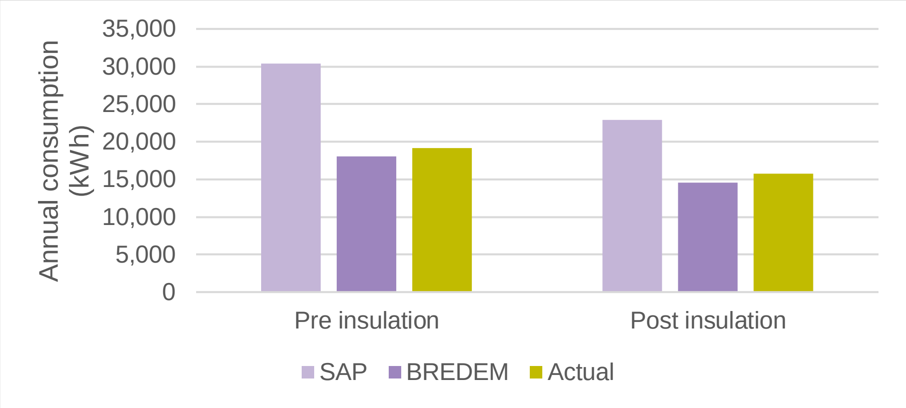
Case ID	61


Annual consumption (kWh)
35,000
30,000
25,000
20,000
15,000
10,000
5,000
0
Pre insulation
Post insulation
SAP
BREDEM
Actual

Case ID	62	
DWELLING TYPE	Semi-detached house	
FLOOR AREA	89.24 m^2	
HABITABLE ROOMS	5	
HEATING SYSTEM	Gas CH, combi boiler	
OCCUPANTS	Pre: 2	Post: 2
RENDERED	Partially	
DRY-LINED	No	
INSULATION DATE	June 2015	
% OF SOLID WALL INSULATED		100%

	SAP		Actual		
	Pre	Post	Pre	Post	Percent change
SAP RATING (RdSAP)	49	62	n/a	n/a	n/a
INFILTRATION RATE (ach)	0.78	0.78	0.22	0.21	-1%
U-VALUE (W/m^{2}K)	2.10	0.60	1.66	0.61	-63%
REPORTED HEATING HOURS (WEEKDAY)	9	9	9	9	0%
REPORTED HEATING HOURS (WEEKEND)	16	16	10	10	0%
REPORTED HEATING HOURS (TOTAL)	77	77	65	65	0%
DEMAND TEMPERATURE (°C)	21.0	21.0	20.0	19.0	-5%
PERCENT ZONE 2 HEATED	100	100	89	89	0%
EXTERNAL TEMPERATURE (°C)	6.0	6.0	7.2	7.4	2%
ZONE 1 TEMPERATURE (°C)	17.8	18.8	n/a	20.6	n/a
ZONE 2 TEMPERATURE (°C)	15.7	17.1	n/a	20.8	n/a
WINTER HUMIDITY (%)	n/a	n/a	n/a	50	n/a
GAS CONSUMPTION (kWh/yr)	25,169	18,249	15,830	12,262	-23%
GAS SPEND (£/yr)	£1,262	£915	£793	£614	-23%
ELECTRICITY CONSUMPTION (kWh/yr)	5,221	4,650	3,356	3,464	3%
ELECTRICITY SPEND (£/yr)	£813	£724	£523	£540	3%
TOTAL CONSUMPTION (kWh/yr)	30,390	22,899	19,185	15,726	-18%
TOTAL SPEND (£/yr)	£2,075	£1,639	£1,316	£1,154	-12%

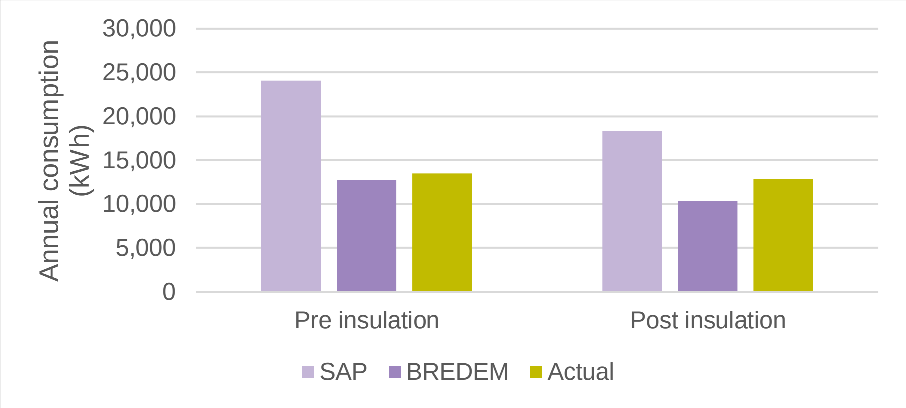
Case ID	62


Annual consumption (kWh)
35,000
30,000
25,000
20,000
15,000
10,000
5,000
0
Pre insulation
Post insulation
SAP
BREDEM
Actual

Case ID	63
DWELLING TYPE	Semi-detached house
FLOOR AREA	89.24 m^2
HABITABLE ROOMS	5
HEATING SYSTEM	Gas CH, condensing boiler
OCCUPANTS	Pre: 3 Post: 3
RENDERED	Partially
DRY-LINED	No
INSULATION DATE	June 2015
% OF SOLID WALL INSULATED	100%

	SAP		Actual		
	Pre	Post	Pre	Post	Percent change
SAP RATING (RdSAP)	60	69	n/a	n/a	n/a
INFILTRATION RATE (ach)	0.75	0.75	0.18	0.29	57%
U-VALUE (W/m^{2}K)	2.10	0.60	1.94	0.45	-77%
REPORTED HEATING HOURS (WEEKDAY)	9	9	9	7	-22%
REPORTED HEATING HOURS (WEEKEND)	16	16	9	7	-22%
REPORTED HEATING HOURS (TOTAL)	77	77	63	49	-22%
DEMAND TEMPERATURE (°C)	21.0	21.0	16.0	15.0	-6%
PERCENT ZONE 2 HEATED	100	100	100	100	0%
EXTERNAL TEMPERATURE (°C)	6.0	6.0	7.2	7.4	2%
ZONE 1 TEMPERATURE (°C)	17.9	18.9	n/a	19.1	n/a
ZONE 2 TEMPERATURE (°C)	15.9	17.3	n/a	18.2	n/a
WINTER HUMIDITY (%)	n/a	n/a	n/a	55	n/a
GAS CONSUMPTION (kWh/yr)	20,680	14,912	6,814	5,771	-15%
GAS SPEND (£/yr)	£1,037	£748	£341	£289	-15%
ELECTRICITY CONSUMPTION (kWh/yr)	3,419	3,419	6,675	7,041	5%
ELECTRICITY SPEND (£/yr)	£533	£533	£1,040	£1,097	5%
TOTAL CONSUMPTION (kWh/yr)	24,099	18,331	13,489	12,813	-5%
TOTAL SPEND (£/yr)	£1,569	£1,280	£1,381	£1,386	0%

Case ID	63


30,000
25,000
20,000
15,000
10,000
5,000
0
Annual consumption (kWh)
Pre insulation
Post insulation
SAP
BREDEM
Actual

Case ID	20
DWELLING TYPE	Bungalow – End terrace
FLOOR AREA	53.21 m^2
HABITABLE ROOMS	2
HEATING SYSTEM	Oil CH
OCCUPANTS	Pre: 1 Post: 1
RENDERED	No
DRY-LINED	Yes
INSULATION DATE	October 2015
% OF SOLID WALL INSULATED	~ 60%

	SAP		Actual		
	Pre	Post	Pre	Post	Percent change
SAP RATING (RdSAP)	43	47	n/a	n/a	n/a
INFILTRATION RATE (ach)	0.95	0.95	0.48	0.45	-6%
U-VALUE (W/m²K)	1.55	0.60	0.64	0.24	-62%
REPORTED HEATING HOURS (WEEKDAY)	9	9	6	7	17%
REPORTED HEATING HOURS (WEEKEND)	16	16	6	7	17%
REPORTED HEATING HOURS (TOTAL)	77	77	42	49	17%
DEMAND TEMPERATURE (°C)	21.0	21.0	17.0	17.5	3%
PERCENT ZONE 2 HEATED	100	100	100	100	0%
EXTERNAL TEMPERATURE (°C)	6.0	6.0	6.1	7.1	16%
ZONE 1 TEMPERATURE (°C)	18.1	18.3	20.7	21.7	5%
ZONE 2 TEMPERATURE (°C)	16.0	16.4	20.3	20.8	3%
WINTER HUMIDITY (%)	n/a	n/a	50	51	1%
GAS CONSUMPTION (kWh/yr)	14,019	13,115	n/a	n/a	n/a
GAS SPEND (£/yr)	n/a	n/a	n/a	n/a	n/a
ELECTRICITY CONSUMPTION (kWh/yr)	2,274	2,274	3,008	3,098	3%
ELECTRICITY SPEND (£/yr)	£354	£354	£469	£483	3%
TOTAL CONSUMPTION (kWh/yr)	16,293	15,389	n/a	n/a	n/a
TOTAL SPEND (£/yr)	n/a	n/a	n/a	n/a	n/a

Case ID	20

[Measured annual consumption could not be calculated as the central heating was oil powered and oil consumption was not monitored.]

Case ID	21
DWELLING TYPE	Bungalow - mid-terrace
FLOOR AREA	84.85 m^2
HABITABLE ROOMS	4
HEATING SYSTEM	Oil CH
OCCUPANTS	Pre: 1 Post: 1
RENDERED	No
DRY-LINED	Yes
INSULATION DATE	October 2015
% OF SOLID WALL INSULATED	< 25%

	SAP		Actual		
	Pre	Post	Pre	Post	Percent change
SAP RATING (RdSAP)	45	49	n/a	n/a	n/a
INFILTRATION RATE (ach)	0.58	0.58	0.39	0.33	-15%
U-VALUE (W/m^2K)	1.55	0.60	0.65	0.37	-43%
REPORTED HEATING HOURS (WEEKDAY)	9	9	12	13	8%
REPORTED HEATING HOURS (WEEKEND)	16	16	12	13	8%
REPORTED HEATING HOURS (TOTAL)	77	77	84	91	8%
DEMAND TEMPERATURE (°C)	21.0	21.0	20.0	20.0	0%
PERCENT ZONE 2 HEATED	100	100	87.5	87.5	0%
EXTERNAL TEMPERATURE (°C)	6.0	6.0	6.1	7.1	16%
ZONE 1 TEMPERATURE (°C)	18.4	18.6	21.3	n/a	n/a
ZONE 2 TEMPERATURE (°C)	16.5	16.8	23.4	n/a	n/a
WINTER HUMIDITY (%)	n/a	n/a	39	n/a	n/a
GAS CONSUMPTION (kWh/yr)	12,517	11,355	n/a	n/a	n/a
GAS SPEND (£/yr)	n/a	n/a	n/a	n/a	n/a
ELECTRICITY CONSUMPTION (kWh/yr)	7,032	6,926	2,474	2,256	-9%
ELECTRICITY SPEND (£/yr)	£1,095	£1,079	£385	£352	-9%
TOTAL CONSUMPTION (kWh/yr)	19,549	18,281	n/a	n/a	n/a
TOTAL SPEND (£/yr)	n/a	n/a	n/a	n/a	n/a

Case ID	21

[Measured annual consumption could not be calculated as the central heating was oil powered and oil consumption was not monitored.]

Case ID	22
DWELLING TYPE	Bungalow – End terrace
FLOOR AREA	39.45 m^2
HABITABLE ROOMS	2
HEATING SYSTEM	Oli CH, condensing combi
OCCUPANTS	Pre: 1 Post: 1
RENDERED	No
DRY-LINED	Yes
INSULATION DATE	October 2015
% OF SOLID WALL INSULATED	< 25%

	SAP		Actual		
	Pre	Post	Pre	Post	Percent change
SAP RATING (RdSAP)	47	53	n/a	n/a	n/a
INFILTRATION RATE (ach)	0.84	0.84	0.65	0.63	-3%
U-VALUE (W/m^{2}K)	1.55	0.60	1.3	n/a	n/a
REPORTED HEATING HOURS (WEEKDAY)	9	9	12	9	-25%
REPORTED HEATING HOURS (WEEKEND)	16	16	12	9	-25%
REPORTED HEATING HOURS (TOTAL)	77	77	84	63	-25%
DEMAND TEMPERATURE (°C)	21.0	21.0	20.0	20.0	0%
PERCENT ZONE 2 HEATED	100	100	67	67	0%
EXTERNAL TEMPERATURE (°C)	6.0	6.0	6.1	7.1	16%
ZONE 1 TEMPERATURE (°C)	17.7	18.1	15.5	17.7	15%
ZONE 2 TEMPERATURE (°C)	15.6	16.0	14.4	16.7	16%
WINTER HUMIDITY (%)	n/a	n/a	62	58	-6%
GAS CONSUMPTION (kWh/yr)	10,853	9,806	n/a	n/a	n/a
GAS SPEND (£/yr)	n/a	n/a	n/a	n/a	n/a
ELECTRICITY CONSUMPTION (kWh/yr)	1,963	1,963	1,788	1,963	10%
ELECTRICITY SPEND (£/yr)	£306	£306	£279	£306	10%
TOTAL CONSUMPTION (kWh/yr)	12,817	11,769	n/a	n/a	n/a
TOTAL SPEND (£/yr)	n/a	n/a	n/a	n/a	n/a

Case ID	22

[Measured annual consumption could not be calculated as the central heating was oil powered and oil consumption was not monitored.]

3 Results

3.1 Pre insulation comparison with EFUS data

Energy usage and internal temperatures in all the field trial dwellings were analysed alongside cases of a similar type from the 2011 Energy Follow Up Survey (EFUS). The aim was to assess how representative the results from the current field trial homes were and how comparable they were to the results from previous studies (a full description of the method used can be found in section 2.5). The methodology used to monitor the temperatures was exactly the same for both studies. All sensors were calibrated by the manufactures before going out into the field. Consumption data was adjusted, based on degree day data, to allow for comparison between years.

The median gas consumption for the EFUS cases was 9,004 kWh/year and the median electricity consumption was 2,900 kWh/year (both normalised to the 2014-2015 year using degree-day data). These values were not found to be significantly different from the results from the SWI field trial, with a median gas consumption of 9,700 kWh/year, and electricity consumption of 3,400 kWh/year (see Table 5), based on Mann-Whitney non-parametric tests at the 0.05 level (Gas: p = 0.281, Elec: p = 0.213).

Table 5 - Gas and electricity consumption for EFUS and SWI field trial cases

	Median gas consumption (kWh/year)	Cases	Median electricity consumption (kWh/year)	Cases
EFUS (normalised to 2014-15)	9,004	37	2,921	38
SWI field trial (2014-15)	9,745	51	3,359	57

The median internal temperatures for the period are shown in Figure 3 (based on average of heating months) and Figure 4 (monthly). Averages for all the months are comparable between the EFUS and this field trial: the median temperatures for the EFUS cases as 19.3°C in zone 1 and 18.4°C in zone 2; for this field trial the median values were 19.3°C in zone 1 and 18.4°C in zone 2, as illustrated in Figure 3.

The averages of the median internal temperatures in the period February 2011 to April 2011 (19.7°C zone 1, 18.9°C zone 2) were slightly higher than the period February 2015 to April 2015 (19.2°C zone 1, 18.4°C zone 2), due to a warmer February and April in 2011, with an estimated UK average external temperature of 7.7°C compared with 6.8°C in 14/15 (based on degree day data). In addition, internal temperatures in the period November 2011 to January 2012 were slightly lower than the 2014-15 period, which is likely due to regional fluctuations in temperature, as illustrated in Figure 5. Over 70% of the SWI cases were from London or Wales, which were areas with warmer external temperatures compared with the UK average, contributing to the higher internal temperatures in the period November 2014 to January 2015.

The consistency of findings across the two studies, especially where the energy consumption was not found to be significantly different based on non-parametric analysis, suggests the current sample is representative of other solid wall social housing properties.

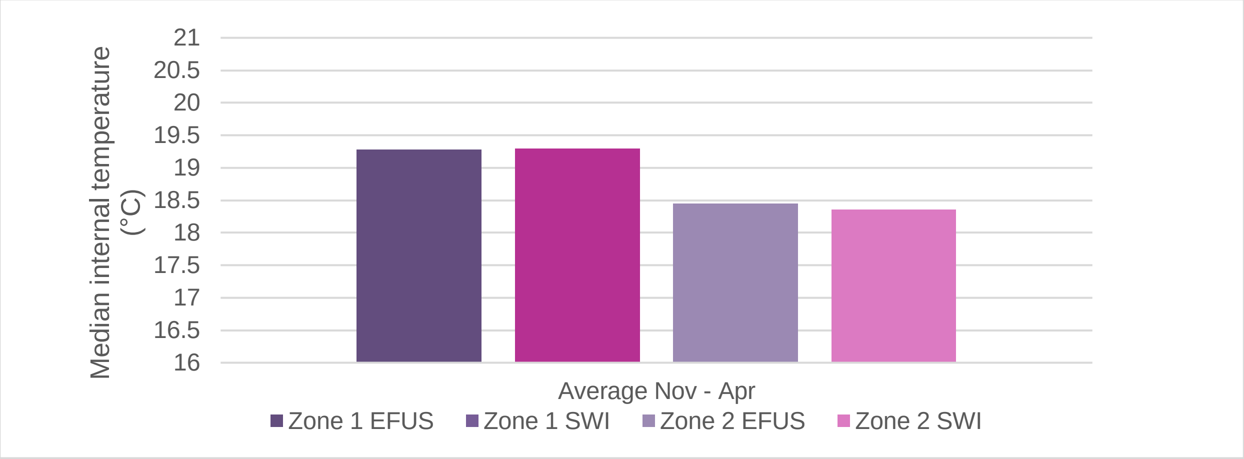


Figure 3 - Average internal temperatures for zone 1 and zone 2, for EFUS and SWI cases

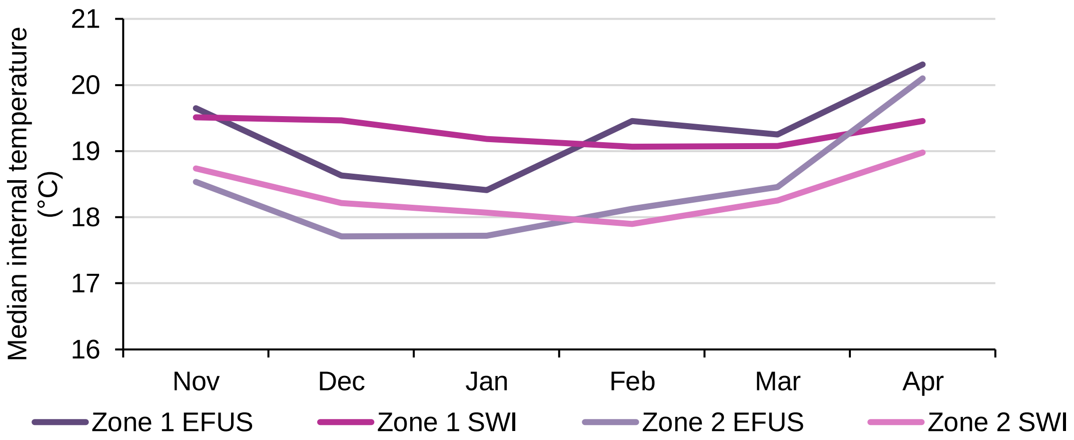


Figure 4 - Internal temperatures (°C), for zone 1 and zone 2, November to April, for EFUS and SWI cases

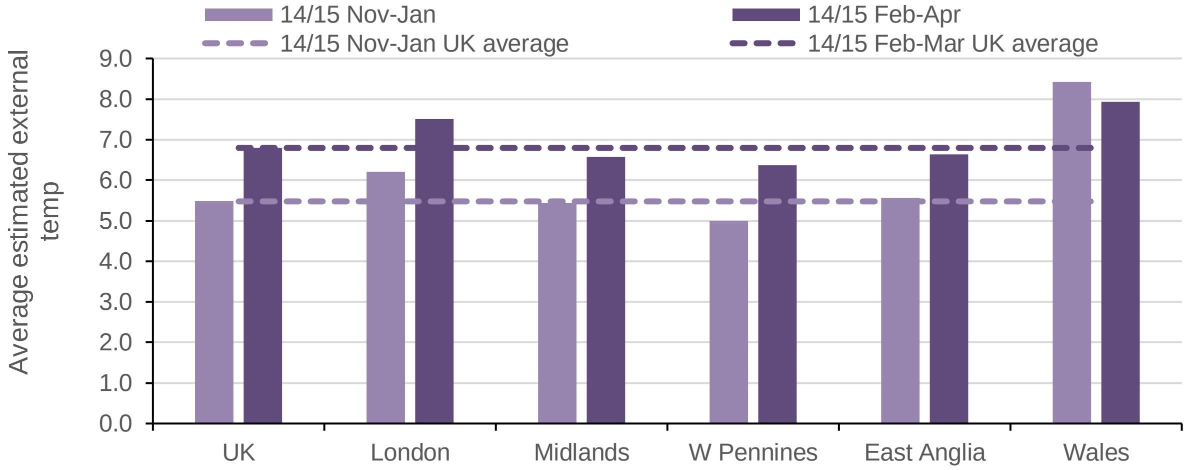


Figure 5 - Estimated average regional external temperatures, for SWI, based on degree day data

3.2 Reporting field trial findings

The total monitoring period ran from October 2013 to April 2016, however, the analysis reported in the findings section focuses on the final two complete years of data collected. This was done because the SAP methodology calculates the annual consumption of a dwelling. The final two years' data were selected because the monitoring of some of the dwellings did not start until December 2014 and, in addition, at most of the dwellings the insulation was not installed until the end of 2015, so in order to maximise the amount of pre- and post-insulation data available for analysis the final two years were selected.

In the findings section below 'year one' refers to the period between May 2014 and April 2015 and 'year two' refers to May 2015 to April 2016 (Figure 6). The findings of the report are split into two sections, the first focuses on the dwellings in their uninsulated state. One dwelling was insulated in year 1 so this was not included in the year 1 analysis, or the comparisons between years one and two. The 'winter period' refers to the period between the 1st November and 31st April each year.

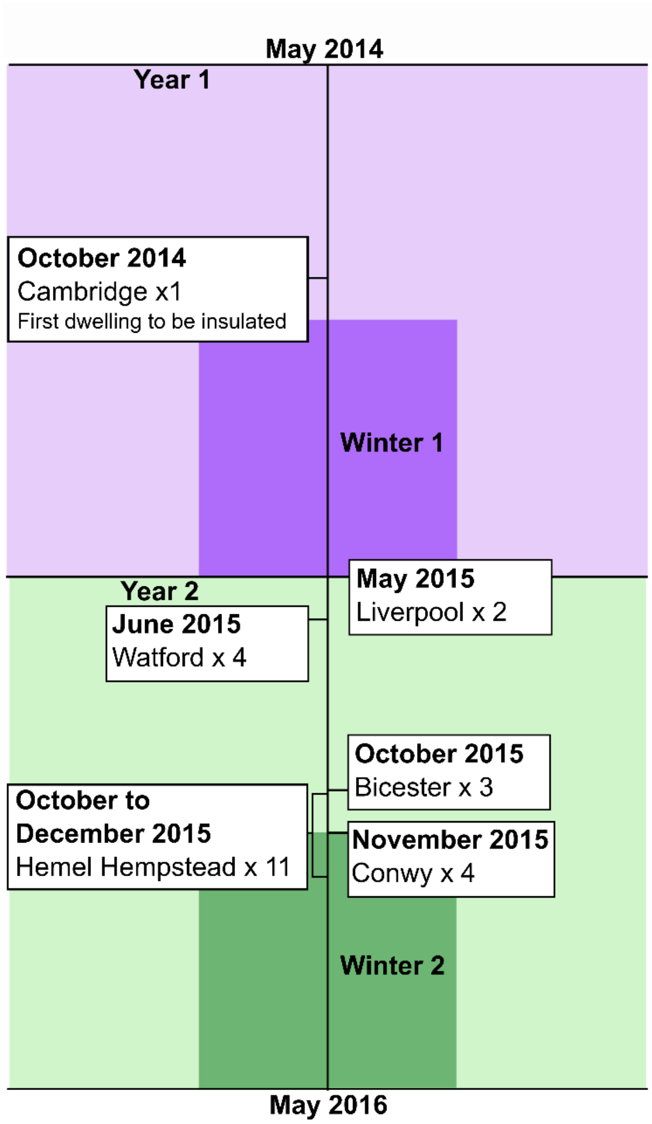


Figure 6 – Insulation timeline showing the annual and winter period for year 1 (purple) and year 2 (green).

The majority of the data used in the analysis was found to be normally distributed (or at least not significantly abnormal). However, due to the small sample sizes, particularly when looking at just the insulated dwellings, some of the data were found to be not suitable for parametric testing (which assumes a normally distributed population). To ensure consistency in analysis and reporting, medians have been used as the main measure of central tendency when comparing groups (e.g. modelled vs measured, comparison between pre and post, etc.). Mann-Whitney U tests have been used to test the significance of any differences between groups throughout the report.

3.3 Uninsulated solid wall dwellings

The following section examines the size of the gap between modelled and measured energy consumption in uninsulated dwellings, the reasons for the gap, and how the gap can be closed by substituting actual values for modelled assumptions. All monitored dwellings that were not insulated in year one were included in the analysis (50 cases).

3.3.1 Gap between modelled and measured consumption for uninsulated dwellings

The total annual energy consumption was modelled for all of the uninsulated dwellings in year one and compared with the measured consumption over the same period. Figure 7 below shows the gap between the two. A Mann-Whitney test showed that SAP significantly overestimated the total energy consumption ($n=50$, $Z=5.55$, $p<0.001$). The median measured annual consumption was 30% lower than the median modelled consumption using SAP assumptions, and SAP was found to overestimate the total annual consumption for 92% of the dwellings. Figure F1 in Appendix F compares the distribution of both modelled and actual consumption.

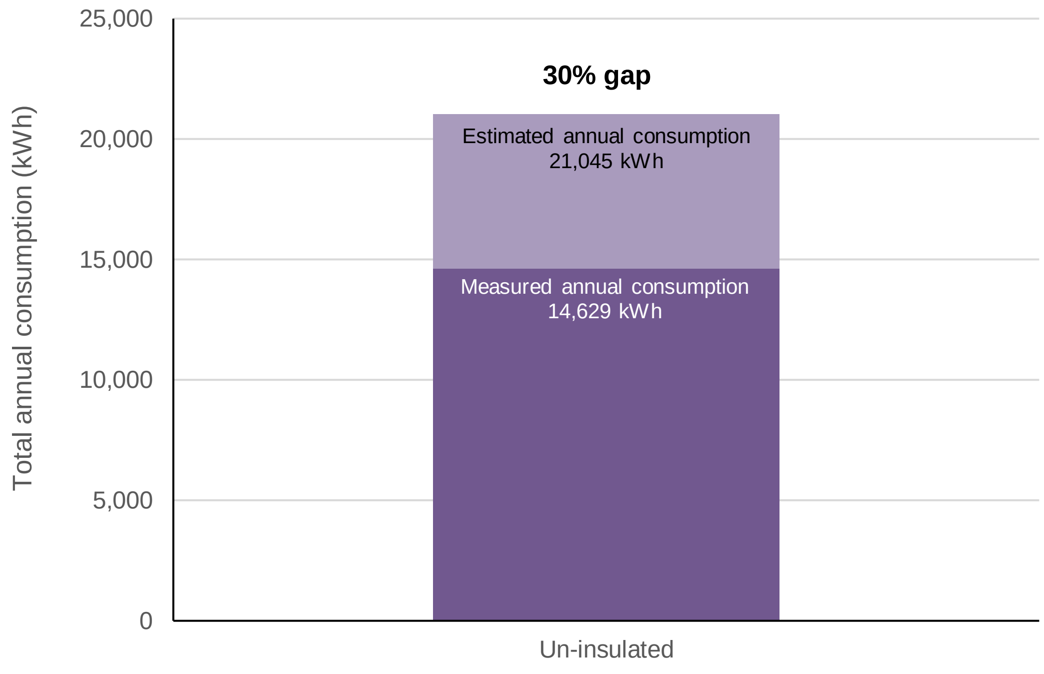


Figure 7 - The gap between the median modelled and measured consumption for all uninsulated cases (n=50) in year one.

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3.3.2 The gap between modelled and measured dwelling characteristics

In order to understand why SAP overestimated the annual energy consumption for the majority of uninsulated dwellings, the gap between the assumed and measured dwelling characteristics was examined. When calculating total annual energy consumption SAP makes certain assumptions about the dwelling and how it is heated, it also estimates values for other variables based on the data entered.

Table 6 compares the median SAP assumed/estimated figures and the measured results for the key variables assessed as part of the field trial. The maximum number of cases available were used for each measurement. To help visualise for which variables the SAP average is furthest away from the measured average, Figure 8 shows the average percentage difference between SAP and measured for each of the variables.

Table 6 - Average SAP assumed values vs measured values uninsulated dwellings

Variable	Number of dwellings	SAP	Measured	Median % difference between SAP & Measured	SAP over- or under-estimation	Per cent of cases over- or under-estimated
Infiltration rate (ach*)	54	0.75	0.38	-49%	overestimated	94%
U-Value (W/m²K)	56	2.10	1.78	-15%	overestimated	84%
Zone 1 temp (°C)	47	17.97	19.05	6%	underestimated	68%
Zone 2 temp (°C)	47	16.05	18.02	12%	underestimated	83%
External temp (°C)	63	5.98	7.22	21%	underestimated	100%
Demand Temp (°C)	58	21.00	20.00	-5%	overestimated	59%
Reported Heating hrs (weekday)	56	9.00	8.50	-6%	overestimated	54%
Reported Heating hrs (weekend)	56	16.00	9.00	-44%	overestimated	77%
Reported Heating hours (total)	56	77.00	62.5	-19%	overestimated	68%

*Air changes per hour

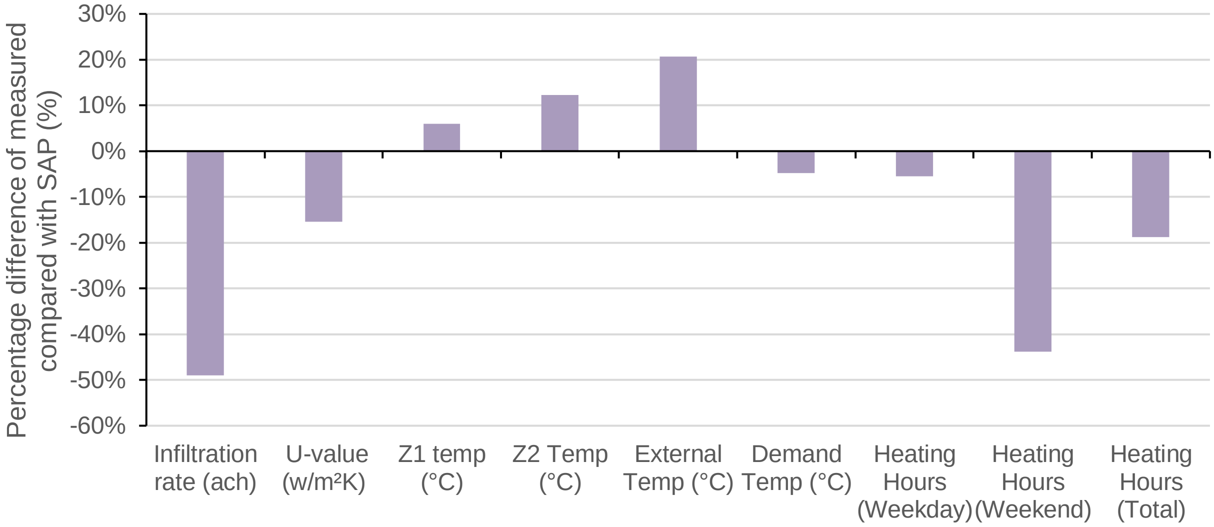

Figure 8 - Percentage difference between median measured values and median SAP values, for all uninsulated cases in 2014/15.

Air tightness - Infiltration rate (ach)

The air infiltration rate, expressed in air changes per hour (ach), is a measure of the structural air tightness of the dwelling (which excludes the impact of window opening and chimneys for example). An overestimation of the air infiltration rate can lead to an overestimation of the annual energy consumption as the model assumes more energy is required to heat a home that is less air tight. Table 6 shows the median measured value for uninsulated dwellings (0.38 ach), which was almost 50% lower than the median SAP value (0.75 ach). A Mann-Whitney test showed this difference was statistically significant ($n=54$, $Z=7.01$, $p<0.001$). The SAP estimate was found to be higher than measured for 94% of the dwellings in their uninsulated state. Figure F2 in Appendix F shows the distribution of both modelled and actual air infiltration rates (ach).

U-value (W/m²K)

U-value is a measure of the thermal transmittance of a surface (in this case a wall). The higher the U-value, the more heat is being transferred through the wall. SAP currently assumes an uninsulated solid wall has a U-value of 2.1 W/m²K and a lower value of 1.55 W/m²K for uninsulated solid walls with dry-lining. The median measured U-value in this study was 1.84 W/m²K for walls without dry-lining, and 0.97 W/m²K for dry-lined walls. The SAP assumed values were found to be greater than measured for 84% of the sample, and on average (median) the measured value was found to be 15% lower. As SAP uses a single value for the U-value a one-sample Wilcoxon signed rank test was used to compare the measured distribution against the model's assumed values. The tests showed that the SAP assumed values for both the non-dry-lined ($n=45$, $Z= 4.88$, $p<0.001$) and dry-lined ($n=11$, $Z= 2.05$, $p=0.040$) solid walls were significantly higher than measured. Figure F3 in Appendix F shows the distributions of the measured wall U-values. An overestimation of the U-value can lead to an overestimation of the annual energy consumption as the model assumes more energy is required to heat a home that is less thermally efficient (i.e. heat is escaping more easily through the walls).

Internal temperatures

The SAP methodology divides the dwelling into two zones and produces a monthly mean internal temperature for both zones. Zone 1 is the main living area and zone 2 is the rest of the dwelling. The living area is normally the lounge/living room together with any rooms not separated from the lounge by doors, and including any cupboards directly accessed from the lounge or living room. Living area does not, however, extend over more than one storey, even when stairs enter the living area directly.

The measured mean monthly internal temperatures were calculated for each individual dwelling and compared with the SAP estimates across the winter period in year one. In zone 1 the median measured internal temperature across the sample (19.05°C) was found to be significantly higher than the modelled temperature (17.97°C) (n=47, Z=3.13, p=0.002). An even greater difference was found in zone 2, where the median SAP value for the sample was 16.05°C and the measured value was 12% higher at 18.02°C (n=47, Z=4.87, p<0.001).

In both zones the range of measured temperatures between dwellings was much greater than assumed in SAP. For example, there was just a 2-3 degree range in the SAP estimates (zone 1; 17°C to 19°C, zone 2; 15°C to 18°C), however, in reality a 14 degree range was observed from measured temperatures, with average measured zone 1 temperatures ranging from 12°C to 26°C and 13°C to 25°C in zone 2. Figure F4 and Figure F5 in Appendix F show the distribution of both modelled and actual temperatures for zones 1 and 2.

External temperatures

External temperature readings were taken once every 30 minutes at one of the monitored dwellings in each location and the mean recorded temperature over the winter period in year one (November 1st to April 30th) was then calculated for each of these regions. The median winter temperature across all sites was 7.22°C, which was 21% higher than the 20-year historical average figure used in the SAP methodology over the same winter period (5.98°C). The mean measured external temperature was higher than assumed in SAP in all the areas of England and Wales included in the sample. An underestimation of the winter external temperatures will lead to an overestimation of household energy consumption as the model will assume more energy is required to heat the dwelling to the demand temperature when the external temperature is lower.

Demand temperatures

The measured demand temperature was derived from the thermostat set point which was obtained during the occupant interview (see Q19 in the occupant interview in Appendix C). SAP assumes a demand temperature of 21°C, the median reported demand temperature was 20°C. A one-sample Wilcoxon signed rank tests showed that the SAP assumed value was significantly higher (n=58, Z=2.6, p=0.009) than measured. The SAP assumed figure was found to be higher than measured in 59% of the sample and only 19% of the sample heated to a higher temperature than 21°C. Figure F6 in Appendix F shows the distributions of the measured demand temperature, with the observed median and SAP assumed value. An overestimation of the demand temperature can lead to an overestimation of the annual energy consumption as the model assumes the home is heated to a higher internal temperature which requires more energy.

Reported heating hours

The assumed heating hours used in the SAP calculation are 9 hours a day on weekdays and 16 hours a day on weekends. The reported heating hours were collected via the occupant interview (see questions 15 (a) and (b) in Appendix C). No significant difference was found between the SAP assumed (9 hours) and measured (8.5 hours) values for weekday heating hours (n=56, Z=.51, p=0.607), the distribution of which is shown in Figure F7 in Appendix F. These results suggest that for uninsulated dwellings the SAP assumption is close to the reality. Although the average was very close there was a wide range in the number of hours householders heated for, ranging from just one hour a day to 24 hours a day. Of dwellings with reported heating hours, 54% heated for fewer than 9 hours per day, 5% heated for 9 hours and 41% heated for more than 9 hours. The median value is inflated due to a number of households who heat for 24 hours a day. If these cases are removed (on the basis that they are controlling their heating by other means) the median value drops to 8 hours and a significant difference is found between the SAP assumed value and the measured values (n=46, Z=2.23, p=0.026).

Whilst the median number of reported heating hours was close to the SAP assumed value for weekdays, the SAP assumed value of 16 hours a day on weekends was found to be significantly higher than the

9 hours a day reported by the householders (n=56, Z= 3.81, p<0.001), with the distribution shown in Figure F8 of Appendix F. The median reported number of heating hours was 44% lower than assumed in SAP. As with weekday heating, a wide range of heating hours was reported (between 2 and 24 hours a day on weekends), however, for weekends SAP was found to overestimate the number of heating hours for 77% of the sample and only 21% of the sample heated for more than 16 hours per day. An overestimation in the number of heating hours will lead to an overestimation of the total household energy consumption as the model assumes more energy is required to heat a home for a greater number of hours.

It should be noted that the majority of households reported that their heating hours were very similar on weekdays and weekends. This was found to be the case over the duration of the field trial and this finding is consistent with the results of the EFUS. This suggests that the assumption in SAP regarding weekend heating hours could be revisited.

The discrepancy in weekend heating hours resulted in an overestimation of the total weekly heating for over two thirds of the sample (68%). SAP assumes 77 hours of heating a week whereas the median reported figure was 62.5 hours (19% less than SAP). This difference was not found to be statistically significant (Wilcoxon signed rank test n = 56, Z=1.2, p=0.23). This is due to the small sub sample of 10 households that heated their home for 24 hours a day (168 hours a week) see Figure 9 below. If these cases are removed a significant difference is found (n=46, Z=5.91, p<0.001) and the median number of heating hours drops to 56.

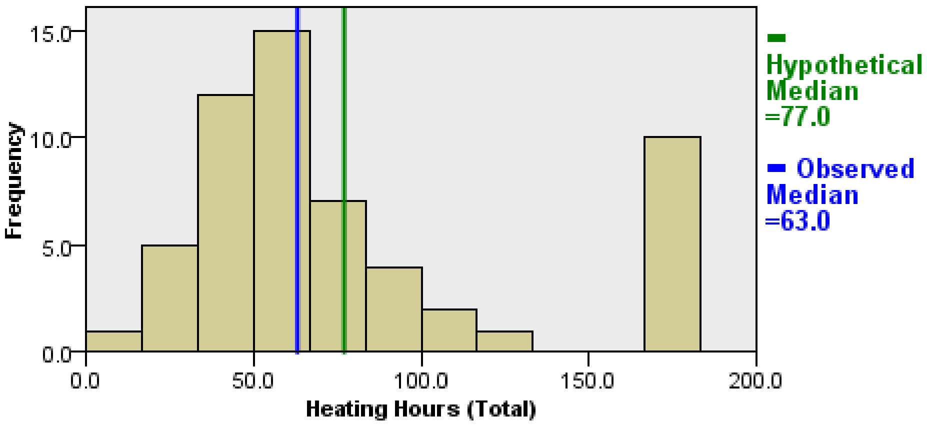

Figure 9 - Distribution of total weekly heating hours

3.3.3 Closing the gap – Using measured values in the energy model

In order to identify the key variables that have the greatest effect on the accuracy of the model estimates, the annual energy consumption was modelled under a number of scenarios using BREDEM. The model was run repeatedly using different combinations of actual recorded values and SAP assumed/estimated values to establish which variables have the biggest impact on the accuracy of modelled energy consumption.

For the base run, only values derived from RdSAP were entered into the model for each variable. No measured values were used other than those which would be recorded in a standard RdSAP assessment. This formed the base modelled energy consumption. For each of the subsequent runs of the model, the actual recorded values were entered for a single variable at a time. SAP assumed values were used for all other variables. All values, other than for the single variable being examined, were reset to the RdSAP values each time. This allowed the relative impact of each variable to be assessed, rather than the cumulative effect of adding the actual values for each variable. Finally, the measured values for all the variables were used in the model to create the ‘Realistic modelled scenario’.

Table 7 and Figure 10 show the relative impact of key variables on the size of the gap between predicted and actual consumption for all the uninsulated dwellings in year 1. Only cases with actual measured energy use, full RdSAP assessments, and full interview surveys were included. These values differ from those quoted in Figure 7 because one case has been excluded as a full interview was not achieved. The estimated total annual energy consumption using just the RdSAP values was found to be significantly higher (n=49, Z=5.57, p<0.001)) than the measured consumption figures at 21,342 kWh/year compared with 14,953 kWh/year. The distribution is shown in Figure F9 of Appendix F. The actual energy consumed was lower than estimated by the model for 92% of uninsulated dwellings.

Table 7 - Gap between modelled and measured annual energy consumption for uninsulated dwellings

Variable	Number of dwellings	BREDEM (Median) (kWh/year)	Measured (Median) (kWh/year)	% difference of measured from modelled	% closer to measured consumption	BREDEM over- or under-estimation	Per cent of cases over- or under-estimated
Base	49	21,342	14,953	-30%		over	92%
No of occupants	49	21,972	14,953	-32%	-10%	over	92%
Fraction of zone 2 heated	49	21,342	14,953	-30%	0%	over	92%
Air tightness	44	20,535	14,953	-27%	13%	over	89%
U-value	46	20,504	14,953	-27%	13%	over	87%
Thermostat temp	49	20,084	14,953	-26%	20%	over	90%
External Temp	49	19,124	14,953	-22%	35%	over	88%
Heating hours	46	17,941	14,953	-17%	53%	over	83%
All measured	49	16,728	14,953	-11%	72%	over	55%

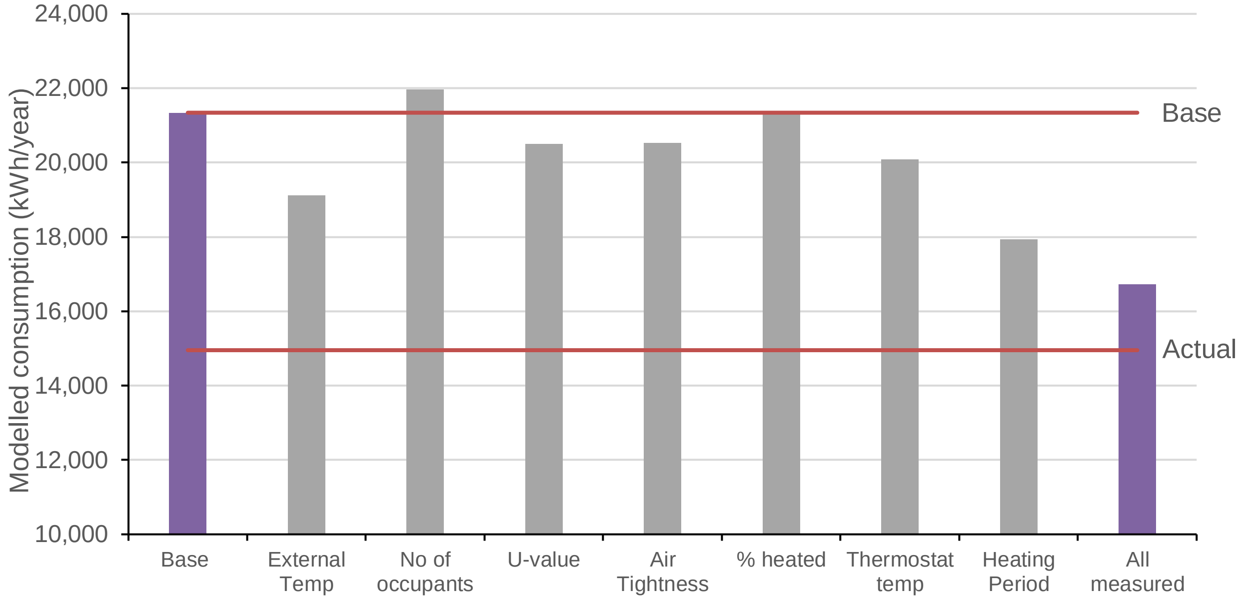

Figure 10 - The gap between actual and modelled energy consumption for uninsulated dwellings (Individual changes are highlighted in grey).

The impact of substituting each measured value for the default assumed value is summarised below;

- Entering the actual number of people in each household did not reduce the estimated annual energy consumption. In fact it produced a slight increase in consumption. The model overestimated the consumption for 92% of the sample.

- It is assumed in SAP that 100% of zone 2 is heated and for the vast majority of the sample this was found to be the case, therefore, adding the actual percentage of zone 2 that was heated did little to improve the modelled estimate.

- Individually entering the measured wall U-values and air tightness closed the gap between modelled and actual consumption by 13% for each. Despite the improvements, the modelled energy consumption was still found to be significantly higher than measured (Mann-Whitney test, U-values: $n=46$, $Z=4.63$, $p<0.001$, Air tightness: $n=44$, $Z=4.99$, $p<0.001$).

- Using the recorded thermostat set point as the demand temperature improved the modelled estimate by 20%. This is a relatively large effect given that the median measured demand temperature was found to be just one degree lower than assumed in SAP. This result illustrates that the demand temperature has a marked effect on the predicted annual energy consumption.

- Entering the actual recorded external temperatures closed the median gap by 35%. SAP uses a 20-year average figure based on one location in the East Pennines region. In year one the median external winter temperature was found to be 1.24°C (21%) higher than the median value assumed in SAP. Using actual average external temperatures for a particular heating season and in a particular location would lead to more accurate estimates of consumption.

- The most significant single variable was found to be the number of heating hours. Inputting just the reported heating periods improved the modelled estimate by 53% alone. As highlighted in the previous section, the reported heating hours were found to be very similar on weekdays and weekends. No significant difference was found between the SAP assumed and measured value for weekdays, but the SAP assumed value for weekends (16 hours per day) was found to be significantly higher than measured (median = 9 hours per day). This pattern was found to be the consistent with the results of the EFUS. The result suggests that the SAP assumption about the number of heating hours at weekends needs to be revisited and that dropping the assumed number of heating hours, particularly at weekends would significantly improve the accuracy of the estimated total energy consumption.

The modelled energy consumption was found to be significantly higher than measured for each of the model runs above, suggesting that substituting the actual measured values for any one variable in isolation does not sufficiently close the gap. However, when all the measured values were added and the model was re-run, no significant difference was found between the modelled and measured consumption ($n=49$, $Z=0.79$, $p=0.432$). Adding in all the measured values into the model in one go closed the gap by 72%. Distributions for the 'base' and 'all measured' BREDEM results are compared with the actual values in Figure F9 and Figure F10, in Appendix F.

It must be noted that actual measured values could only be included in this analysis for the variables that were monitored as part of the field trial. There are other variables, not measured as part of the monitoring, that have an effect on the accuracy of the modelled consumption and therefore entering measured values for these variables would have an effect on the size of the gap (for example the U-value of floors and roofs, detailed information about the windows, etc.). However, the variables selected for inclusion in field trial design were those which were thought to have the biggest influence on the modelled consumption levels.

3.4 Insulated dwellings

Of the 63 homes monitored, 25 were insulated during the monitoring period. The following section outlines what impact the insulation had on the physical dwellings, the heating behaviours of the occupants and the savings achieved. In addition, it covers the size of the gap between modelled and measured energy consumption post insulation, the reasons for the gap and how the gap can be closed.

Eight of the 25 insulated dwellings had new boilers installed at or around the time of the insulation. Whilst the majority of the new boilers installed were more efficient than the old boilers they replaced, in three cases the new boiler had the same efficiency as the old boiler (design efficiency as reported in the Products Characteristics Database). In order to isolate the effect of the wall U-value and control for the effects of new boilers, the five homes which had more efficient boilers installed were removed from the analysis.

Three of the remaining 20 dwellings were not on the mains gas grid and as a result, accurate measurements of total household energy consumption could not be taken. These dwellings have therefore been removed from the following analysis.

All but one of the 25 dwellings were insulated in year two. As described in the methodology section, one of the dwellings was insulated during year one. As the focus of the following analysis was to establish what effect the wall insulation had, this case was also removed from the comparisons of year one and two consumption, spend, heating hours, internal temperatures and demand temperature. This left a residual sample of 16 cases. However, reporting of the measured U-value and air tightness before and after included this case and it was also included when comparing SAP's post insulation assumptions with the measured data, giving a total of 17 cases. It is important to note the base (n) when considering the results presented in the following sections.

3.4.1 Changes in energy consumption between years one and two

Figure 11, Table 8 and Table 9 show the change in annual and winter median energy consumption between years for both the insulated (experimental group) and uninsulated (control group) dwellings. The year two consumption data were weather corrected to ensure that any changes attributable to differences in external temperature were controlled for. This was done by adjusting 2015/16 gas consumption values, according to the difference in the number of degree days between 2014/15 and 2015/16, based on regional data.

Weather correcting the year two consumption data allowed for direct comparison of household energy usage between the two years. It should be noted that doing so results in consumption figures for year two (and resulting differences between year one and year two consumption) that differ from the uncorrected figures presented in Figure 14 and Table 11 and used in the Executive Summary and in Section 5 – Conclusions and recommendations.

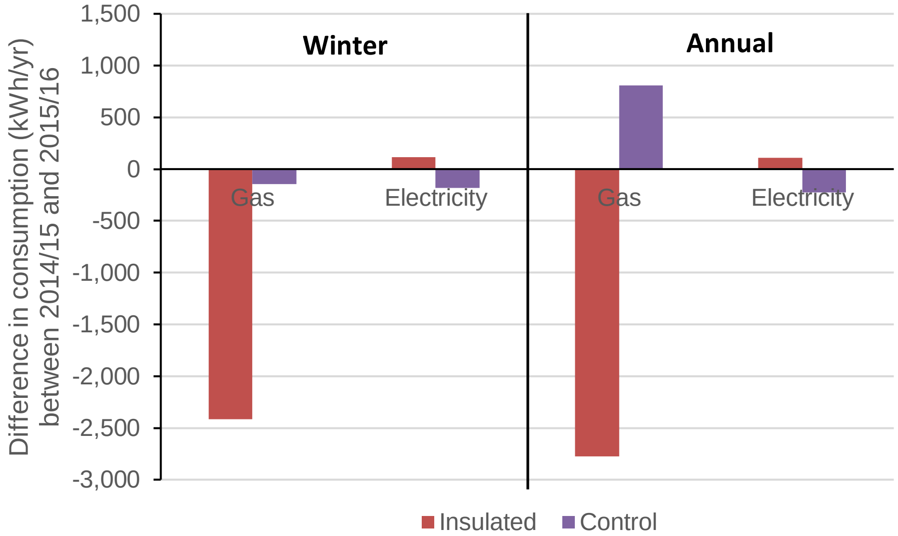

Figure 11 - Changes in weather corrected gas and electricity consumption for insulated and uninsulated dwellings

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Table 8 - Change in weather corrected annual energy consumption between years for insulated and uninsulated control dwellings

	Dwellings	2014/15 (pre insulation)		2015/16		Difference between years		
	Type and number	Consumption (kWh/yr)	Spend	Consumption (kWh/yr)	Spend	Consumption (kWh/yr)	%	Spend
Annual gas consumption	Insulated n=16	10,087	£506	7,309	£366	-2,778	-28%	-£139
	Control n=28	9,713	£487	10,524	£528	811	8%	£41
Annual electricity consumption	Insulated n=19	3,356	£523	3,464	£540	108	3%	£17
	Control n=29	3,463	£539	3,237	£504	-226	-7%	-£35
Total annual consumption	Insulated n=16	15,069	£1,285	11,429	£1,028	-3,640	-24%	-£257
	Control n=26	13,584	£1,118	12,653	£1,116	-931	-7%	-£2

Table 9 - Change in weather corrected annual energy consumption between years for insulated and uninsulated control dwellings

	Dwellings	2014/15 (pre insulation)		2015/16		Difference between years		
	Type and number	Consumption (kWh/yr)	Spend	Consumption (kWh/yr)	Spend	Consumption (kWh/yr)	%	Spend
Winter gas consumption	Insulated n=16	7,799	£391	5,385	£270	-2,414	-31%	-£121
	Control n=28	8,247	£413	8,104	£406	-143	-2%	-£7
Winter electricity consumption	Insulated n=19	1,690	£263	1,807	£282	117	7%	£18
	Control n=28	1,798	£280	1,615	£252	-183	-10%	-£29
Total winter consumption	Insulated n=16	10,117	£793	8,172	£665	-1,945	-19%	-£128
	Control n=26	9,329	£739	9,728	£708	398	4%	-£31

For the control dwellings, no statistically significant differences were found in gas, electricity, or total consumption levels between years or winter periods. However, for the insulated dwellings both winter and annual gas consumption were found to be significantly lower in year two than year one (Annual: n=16, Z=2.26, p=0.023, Winter: n=16, Z=2.19, p=0.029), with the distributions shown for both years in Figure F11 and Figure F12 in Appendix F. In year two (the year the insulation was installed) the median annual gas consumption was found to be 28% lower than year one, and the median winter gas consumption was 31% lower than year one (before the insulation was installed). The median annual financial saving in gas spend alone was £139. In addition, a marked effect was also found in terms of the total annual and winter energy consumption, with a 24% fall in the median total annual consumption between years. It should be noted that for the majority of the cases the insulation was not installed before the beginning of the year two winter period (i.e. the heating season), so this is likely to be an

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underestimate of the true effect of installing solid wall insulation. Figure 12 shows a comparison of the winter gas consumption between 2014/15 and 2015/16, for all control households (red) and all insulated households (purple). The control households show almost a 1:1 relationship, indicating little difference between the two years of the study, however, the insulated group show a decrease in the overall gas consumption in 2015/16.

A reduction in both annual and winter gas consumption was observed in all but one of the insulated dwellings. H53 showed a slight increase (of 12%) in both annual and winter gas consumption. In the post insulation interview the householders said they had made a conscious decision to make the house more comfortable rather than taking the energy and financial savings. The householders were aware the consumption had risen slightly. The interviewee said they could not afford to heat their home to a comfortable level in year one and so were happy to ensure the house was more comfortable rather than take any financial savings for now, but they also said it was “early days” and they may change how they heat in the future. In addition, their gas consumption was lower than the median of the insulated group, both pre- and post-insulation.

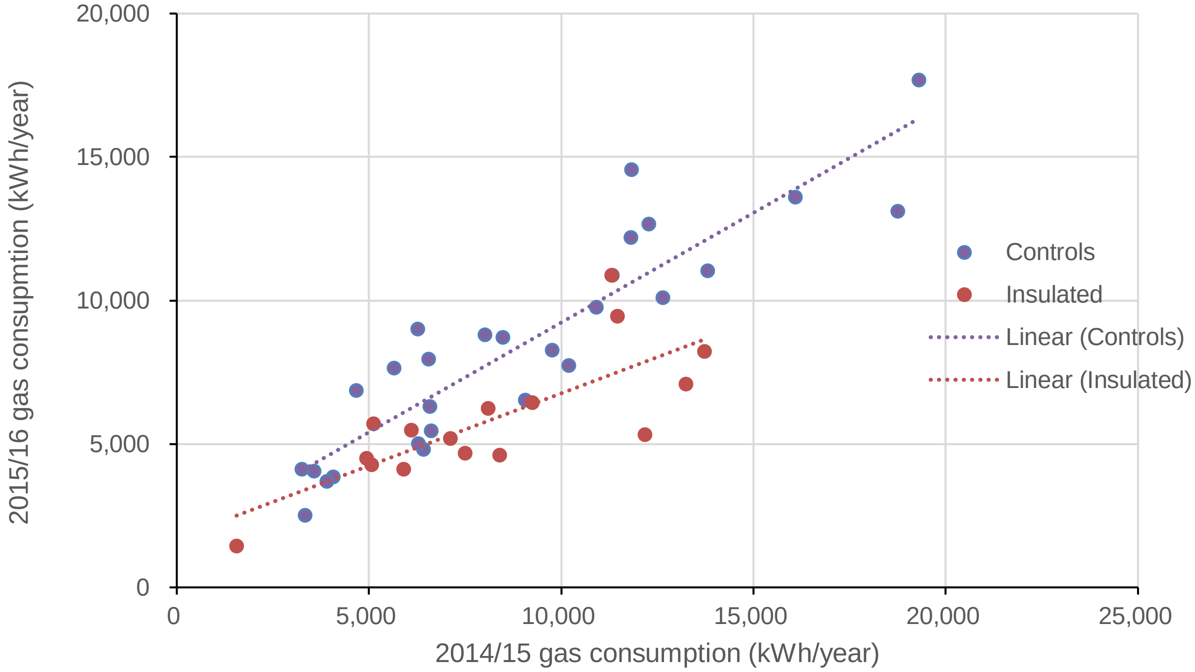

Figure 12 - Distribution of winter gas consumption changes for control and insulated dwellings

3.5 Changes to the dwelling and heating behaviours between years

Table 10 and Figure 13 below show the changes observed between years on key measured variables for both the control and insulated dwellings.

Table 10 - Measured changes between years

	n	2014/15	2015/16	Per cent change	n	2014/15 (Pre-insulation)	2015/16 (Post-insulation)	Percent change
	Control group				Experimental group (insulated dwellings)			
Air Infiltration (ach)	29	0.44	0	0%	20	0.38	0.29	-23%
U-value (w/m²K)	31	1.82	1.82	0%	19	1.66	0.48	-71%
External Temp. (°C)	38	7.02	7.82	11%	20	7.22	7.35	2%
Demand Temp.	32	20	20	0%	19	20	20	0%
Z1 Temperature (°C)	30	19.54	19.69	1%	8	17.18	18.56	8%
Z2 Temperature (°C)	32	18.55	18.36	-1%	8	16.94	18.54	9%
Heating Hours (weekday)	30	9.0	8.0	-11%	19	8.5	7	-18%
Heating Hours (weekend)	30	10.75	9.5	-12%	19	8	7	-13%
Heating Hours (Total)	30	67.75	59.5	-12%	19	57.5	49	-15%
Winter gas consumption (kWh) WA*	28	8,247	8,104	-2%	16	7,799	5,385	-31%
Total Annual Consumption (kWh) WA*	26	13,584	12,654	-7%	16	15,069	11,429	-24%

* Weather Adjusted

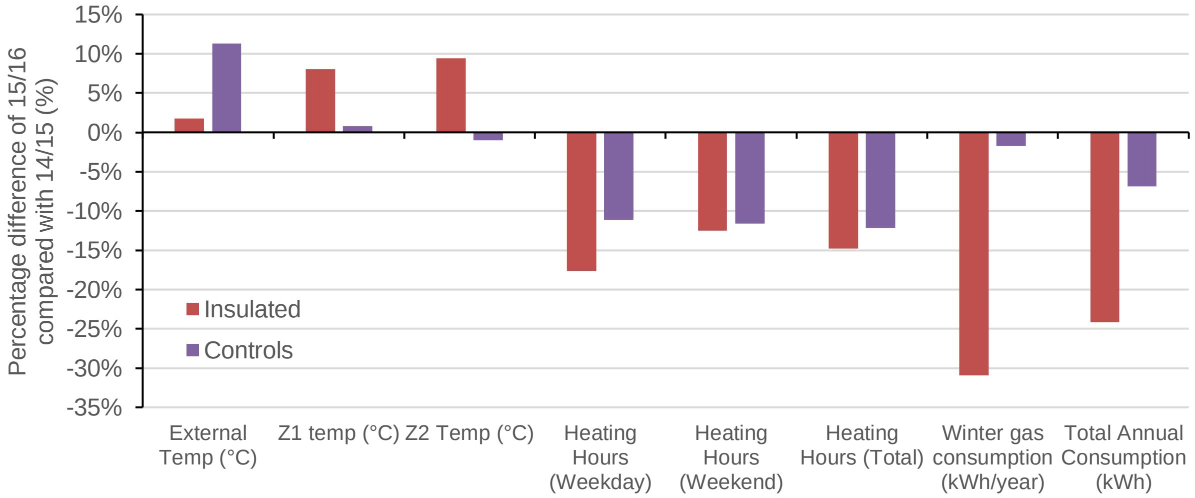

Figure 13 - Percentage change between years on key measured variables for control and insulated dwellings

For the control group no statistically significant changes were found between years on any of the measures. A slight increase in the average winter external temperature was measured between years, however, the sample size was too small to test if the difference was statistically significant.

For the insulated group, the insulation had a significant effect on the measured wall U-value (n=19 Z=4.98, p<0.001). The median U-value dropped from 1.66 to 0.48 (W/m²K) and all dwellings saw a drop in wall U-value. The measured U-value prior to the installation ranged from 0.64 to 2.62 (W/m²K) and post insulation ranged from 0.24 to 0.92 (W/m²K). Figure F13 in Appendix F shows the distribution of U-values for pre-insulation and post-insulation dwellings.

The reported heating hours were found to be lower in year two at both the insulated and control dwellings. A larger drop in the median total heating hours was observed for the insulated group (-15%) than the control group (-12%). Over half (53%) of the insulated households reduced their total weekly heating hours and 16% kept them the same in year two. Almost a third (32%) increased their heating hours.

The median demand temperature in both the control and insulated dwellings remained the same across the monitoring years, yet 58% of the insulated households reduced their typical thermostat set point or kept it at the same level after the insulation was installed, whereas 42% increased the demand temperature. In contrast only 31% of control households increased their demand temperature in year two. The increase in demand temperature and heating hours are examples of rebound effects, where some of the potential energy savings are taken back to increase comfort. For full details of how the heating behaviours changed in each household see the information sheets in section 2.7.

As reported in 3.4.1 for the insulated dwellings both winter and annual gas consumption (weather corrected) were found to be significantly lower in year two than year one (Annual: n=16, p=0.023, Winter: n=16, p=.029), a change not seen in the control group.

3.5.1 Measured vs modelled savings

For each of the insulated homes the total annual energy consumption before and after insulation was modelled using SAP. Figure 14 and Table 11 show the median modelled and measured consumption in each year and the change in annual consumption between years. Note, unlike the comparisons shown in in tables 8 and 9, the measured winter two consumption has not been weather corrected here as SAP does not take into account changes in external temperature between years and this is one of the factors being assessed when understanding the gap.

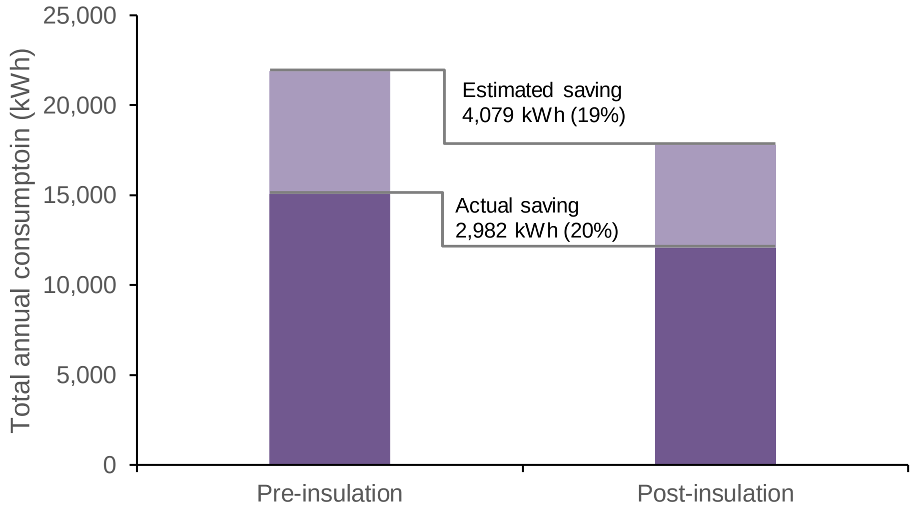

Figure 14 - Modelled and measured changes in annual energy consumption before and after insulation (n=16).

Table 11 - Modelled and measured changes in annual energy consumption before and after insulation

n=16	Pre-insulation consumption (kWh)	Post-insulation consumption (kWh)	Saving (kWh)	Saving (Percent)
SAP estimated	**21,895**	**17,816**	**4,079**	**19%**
Actual	**15,069**	**12,087**	**2,982**	**20%**
Gap	-6,826 (-31%)	-5,729 (-32%)	-1,097 (-27%)	
% of cases overestimated	88%	88%	69%	

The SAP model was found to significantly overestimate the annual energy consumption before (n=16, Z=3.32, p=0.001) and after insulation (n=16, Z=3.17, p=0.001). The median measured annual energy consumption was found to be 31% lower than modelled for the dwellings in their uninsulated state and 32% lower when insulated. For 88% of the sample SAP overestimated the annual consumption before and after insulation. The saving, from pre-insulation to post-insulation, for both modelled and actual consumption, was ~20% but SAP was found to overestimate the saving in 69% of cases. Figure F14 and Figure F15 in Appendix F show the distribution of both modelled and actual consumption for years one and two.

3.5.2 Explaining the gap between measured and predicted savings

In order to understand why the energy model overestimated the annual energy consumption for the majority of dwellings when insulated, the gap between the assumed and measured insulated dwelling characteristics were examined. Table 12 compares the median assumed/estimated figures and the measured results for the key variables measured as part of the field trial. Figure 15 shows the median percentage difference between SAP and measured for each of the variables.

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Table 12 - Median SAP assumed values vs measured values insulated dwellings.

Variable	Number of dwellings	Modelled	Measured	% difference of measured from modelled	Modelled over- or under-estimation	Per cent of cases over- or under-estimated
Infiltration rate (ach)	20	0.75	0.29	- 61%	overestimated	100%
U-Value (W/m²K)	19	0.60	0.48	- 19%	overestimated	68%
Zone 1 temp (°C)	18	18.87	19.51	2%	underestimated	56%
Zone 2 temp (°C)	18	17.17	19.3	11%	underestimated	83%
External temp (°C)	20	5.98	7.35	23%	underestimated	100%
Demand Temp (°C)	20	21	20	-5%	overestimated	65%
Reported Heating hrs (weekday)	20	9	7	-22%	overestimated	75%
Reported Heating hrs (weekend)	20	16	7	-56%	overestimated	95%
Reported Heating hours (total)	20	77	49	-36%	overestimated	90%

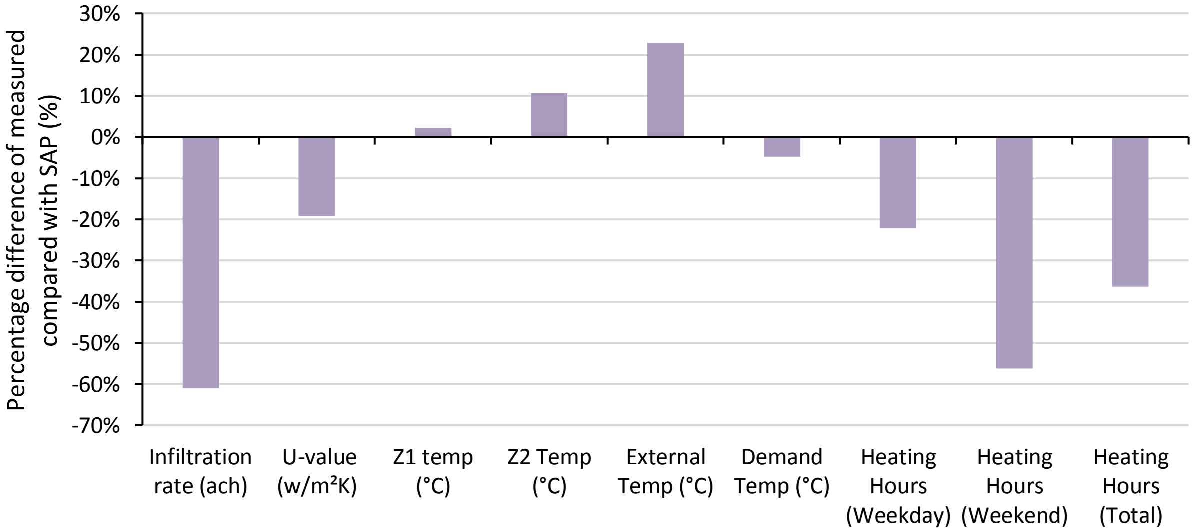

Figure 15 - Median percentage difference between SAP & Measured

Air tightness - Infiltration rate (ach)

For the insulated dwellings, the median measured infiltration rate (0.29 ach) was found to be significantly lower than the SAP estimated value of 0.75 (n=20, Z=5.03, p<0.001). The distribution of modelled and measured values is shown in Figure F16 in Appendix F. The median measured value was found to be 61% lower than the SAP assumed value. The SAP estimate was also found to be higher than measured for all of the dwellings in their insulated state.

U-value (W/m²K)

SAP assumes an insulated solid wall has a U-value of 0.6 W/m²K (regardless of the presence of dry-lining). The median measured U-value (0.48 W/m²K) was not found to be significantly different from the SAP assumed value. Whilst the SAP value was found to be higher than measured for over two thirds of the sample (68%), the differences were relatively small for most cases. The distribution of measured values can be found in Figure F17 in Appendix F.

Internal temperatures

No significant difference was found between the modelled and measured internal temperatures in zone 1 for insulated dwellings, whereas for uninsulated dwellings, the measured internal temperature was found to be significantly higher than modelled (Section 3.3.2). The SAP model does assume the internal temperature will be higher after insulation is installed and on the median measured value was found to be only 2% higher than modelled for the insulated dwellings.

A significant difference was found between modelled and measured zone 2 temperatures (n=18, Z=3.23, p<0.001). The median measured temperature over the winter period was 11% higher than modelled in SAP. The model assumes that zone 2 (median 17.17°C) will be heated to a lower temperature than zone 1 (median 18.87°C). However, in reality very little difference was found between the measured zone 1 (median 19.3°C) and zone 2 (19°C) temperatures. As found with dwellings in their uninsulated state in both zones the measured range of temperatures between dwellings was much greater than assumed in SAP. Figure F18 and Figure F19 in Appendix F show the distribution of both modelled and actual temperatures for zones 1 and 2.

Heating

No significant difference was found between the SAP assumed demand temperature (median 21°C) and the occupant reported value (median 20°C), however, the SAP assumed value was found to be higher than measured for almost two thirds of the sample.

The assumed heating hours used in the SAP method are 9 hours on weekdays and 16 hours a day on weekends. As shown in Table 10, the installation of insulation led to a drop in the reported heating hours, from 8.5 (median) to 7 hours on weekdays, and 8 hours to 7 hours at the weekend. This drop in weekday heating hours resulted in a significant difference between SAP assumed and measured weekday heating hours (n=20, Z=2.30, p=.022), whereas before insulation there was not. The distribution of weekday heating hours for insulated dwellings is shown in Figure F20 of Appendix F.

As with the uninsulated dwellings in year 1, there was a significant difference between the SAP assumed weekend heating hours and those reported by the occupants (n=20, Z= 3.68, p<0.001), shown in Figure F21 in Appendix F. The median reported number of heating hours (7 hours) was 56% lower than the 16 hours assumed in SAP and SAP overestimated the number of hours for all but one of the insulated dwellings. This particular household continued to heat their home 24 hours a day after the insulation was installed. It should be noted that, as with the uninsulated dwellings in year 1, the majority of households reported that their heating hours were very similar on weekdays and weekends.

A significant difference (n=20, Z=3.06, p=0.002) was found between the SAP assumed total weekly heating hours (77 hours) and the measured heating hours (median = 49 hours). The distribution is shown in Figure F22, in Appendix F. The discrepancy in weekend heating hours resulted in an overestimation of

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the total weekly heating for 90% of cases. This difference was found to be larger for insulated dwellings (median = 49 hours, 36% less) than for the uninsulated dwellings in year 1 (median= 62 hours, 19% less).

The winter external temperature in year 2 for the insulated homes (7.35°C) was found to be 23% higher than the SAP assumed value of 5.98°C. This difference is very similar to the difference observed for the uninsulated dwellings in year 1 where the average measured winter temperature (7.22°C) was 21% higher than assumed in SAP.

3.5.3 Closing the gap – Using measured values in the energy model – insulated dwellings

Annual energy consumption was modelled under a number of BREDEM scenarios using the same methodology employed for the uninsulated dwellings (see section 3.3.3). The aim was to identify the variables that have the greatest effect on the accuracy of the predictions for insulated dwellings and explore how the findings differ from the uninsulated dwellings. This analysis is based on the maximum number of cases available for which there was measured post-insulation data. Seventeen cases were used. This excludes the cases where a more efficient boiler was installed (five) and cases that did not use mains gas as the main heating fuel (three) but includes the one case that was insulated in year one as the timing of the installation did not make a difference for the purposes of this analysis. Consequently, the results differ slightly from those presented in section 3.5.1, for which the base is sixteen dwellings.

As before, the model was run repeatedly using different combinations of actual recorded values and RdSAP assumed values. The base run used exclusively the default RdSAP values and each subsequent run replaced one default or assumed value at a time, setting all previously altered values back to the RdSAP values.

Figure 16 and Table 13 show the relative impact of key variables on the size of the gap between predicted and actual consumption for the insulated dwellings in year 2. The median measured total annual energy consumption was found to be 28% lower than the modelled consumption figures, using just SAP values (median modelled = 17,301 kWh/year, median measured = 12,540 kWh/year). The actual energy consumed was lower than estimated by the model for 82% of insulated dwellings, and the distribution of modelled and measured values is shown in Figure F23 in Appendix F.

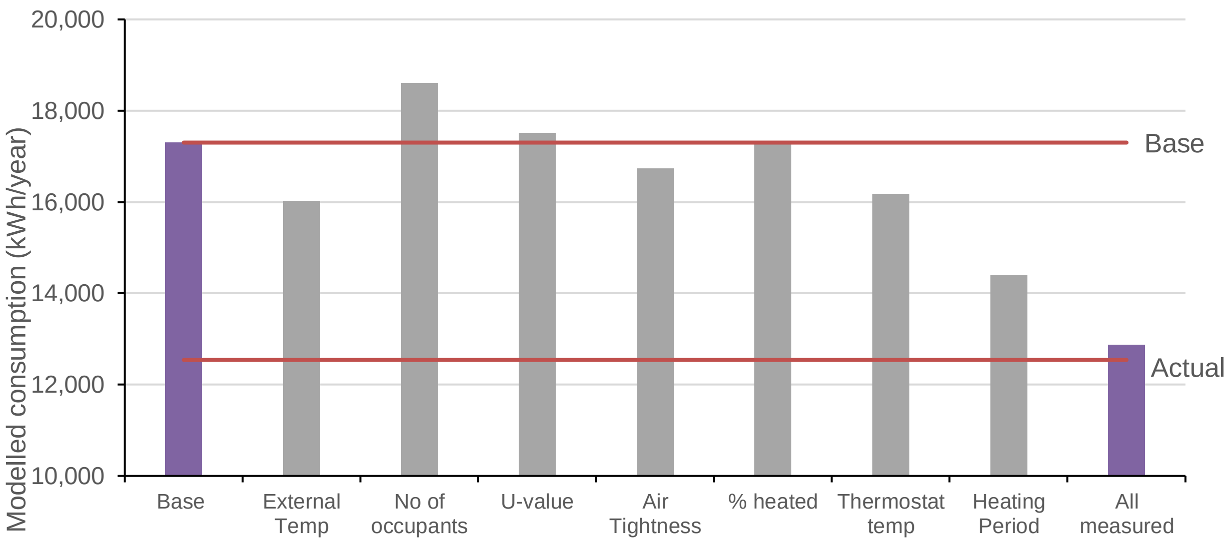

Figure 16 - Gap between modelled and measured annual energy consumption for insulated dwellings (n=17)

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Table 13 - Gap between modelled and measured annual energy consumption for insulated dwellings

Variable	Number of dwellings	BREDEM (Median) (kWh/year)	Measured (Median) (kWh/year)	% difference of measured from modelled	% closer to measured consumption	BREDEM over- or under-estimation	Per cent of cases over- or under-estimated
Base	17	17301	12540	-28%		overestimated	82%
No of occupants	17	18603	12540	-33%	-27%	overestimated	94%
U-value	17	17512	12540	-28%	-4%	overestimated	82%
% heated	17	17301	12540	-28%	0%	overestimated	82%
Air Tightness	17	16732	12540	-25%	12%	overestimated	82%
Thermostat temp	17	16179	12540	-22%	24%	overestimated	82%
External Temp	17	16019	12540	-22%	27%	overestimated	82%
Heating hours	17	14405	12540	-13%	61%	overestimated	71%
All measured	17	12876	12540	-3%	93%	overestimated	47%

The impact of substituting each measured value for the default assumed value is summarised below:

- As with uninsulated dwellings, entering the actual number of people in each household did not reduce the estimated annual energy consumption. In fact it produced a slight increase in the estimated consumption. The model overestimated the consumption for 94% of the sample.
- In contrast to uninsulated dwellings, entering the measured wall U-values for insulated walls did not (on average) improve the accuracy of the model. This is likely to be due to the fact that the SAP assumed wall U-values for insulated dwellings were not significantly different from measured, therefore substituting the actual values does not significantly change the accuracy of the model.
- It is assumed in SAP that 100% of Zone 2 is heated and for all of the insulated dwellings this was found to be the case, therefore adding the actual percentage of zone 2 that was heated did not change the modelled estimate.
- Individually entering the measured air infiltration rate closed the gap between modelled and actual consumption by 12%. The relative effect of this variable was similar for insulated dwellings (12%) to uninsulated dwellings (13%), as the difference between modelled and measured values was significant for both insulated and uninsulated dwellings, with measured values 50-60% lower than modelled
- Using the recorded thermostat set point improved the modelled estimate by almost a quarter (24%). As found with the uninsulated dwellings, this is a relatively large effect given that the median measured demand temperature was found to be just one degree lower than assumed in SAP. This result illustrates that the demand temperature has a marked effect on the predicted annual energy consumption.

- As with the uninsulated dwellings entering the actual recorded external temperatures had the second greatest effect on closing the gap (on average the gap was closed by 27%). The results show the relative importance of this variable. A difference of just one degree has a large effect on the accuracy of the model. Using actual average external temperatures for a particular heating season and in a particular location would lead to more accurate estimates of consumption, however this is not an option using SAP as using standardised external temperatures enables comparability between dwellings. Given the global average temperature increase over the past few years it may be pertinent to look at increasing the estimated external temperature value currently used in SAP or enable users to input a more accurate value. In the case of ECO or other assessments of improvement options, it may be necessary to consider using future projections of temperature.

- The most significant single variable was found to be the number of heating hours. Inputting just the reported heating periods improved the modelled estimate by 61% alone. Unlike all the previous model runs above, no significant difference was found between the measured and the modelled consumption when the recorded values for this variable alone were entered ($n=17$, $Z=0.913$, $p=0.375$), the distribution for modelled and measured consumption is shown in Figure F24 in Appendix F. This demonstrates the importance of using accurate heating time estimates when modelling energy consumption.

Finally, adding in all measured values into the model in combination closed the gap by 93%, based on median values. No significant difference was found between the modelled and measured consumption ($n=17$, $Z=0.534$, $p=0.610$). The median difference between the modelled and measured consumption was just 3%. It should be noted that whilst no significant difference was found and the median consumption values were similar, there was a relatively large spread in the measured consumption figures (see Figure F25 in Appendix F) and in several cases the measured and modelled consumption figures were considerably different (see information sheets in section 2.7).

It must also be noted that actual measured values could only be included in this analysis for the variables that were monitored as part of the field trial. There are other variables, not measured as part of the monitoring, that have an effect on the accuracy of the modelled consumption and therefore entering measured values for these variables would have an effect on the size of the gap (for example the U-value of floors and roofs, detailed information about the windows etc.). However, the variables selected for inclusion in field trial design were those which were thought to have the biggest influence on the modelled consumption levels.

3.6 Evaluating the quality of the insulation installations

An important part of the overarching project is the consideration of unintended consequences from the installation of SWI. In addition to the monitoring of dwellings, the process for the installation of the external wall insulation was observed. The observations were undertaken without interference or comment to the workforce by the same BRE expert on all sites to allow for comparison between sites. This work allows key characteristics of the installation to be recorded and quantified in order to gauge their potential impact. The observations were undertaken in;

- Cambridgeshire
- Hertfordshire
- Wales

A full description of the method used and the findings from the observations work can be found in Appendix E. The key issues identified through the observation were as follows:

Cold bridging	Thermal bridging at junctions or around openings is an important issue as it can give rise to additional (unaccounted for) heat loss and can also result in an increased risk of internal mould growth and/or condensation at adjoining areas. The risks can be considered and modelled using specific software prior to doing the work to calculate temperature factors and mould risk. If the additional heat loss is ignored (i.e. assumed to be zero) when calculating the total heat loss through the fabric of the building, it is likely that the overall heat loss will be underestimated by a greater or lesser degree, depending on the level of thermal bridging that exists at junctions. Thus, if buildings are improved through insulation of the plane building elements (such as the wall) but thermal bridging at the junctions is either ignored or not properly determined, the heat loss may be significantly higher than intended. Cold bridging should be considered at the outset of any project and this was found to be lacking at the majority of sites visited. Bespoke details should be created to minimise the risk of cold bridging and mould growth. Key areas where cold bridges were typically introduced; • Around soil pipes, canopies and connections of fences • Geometric junctions, joints and penetrations • Where the insulation stopped at damp proof course rather than going down to ground level • Incoming services It was found that in many cases there was a lack of upfront design and that greater attention to the potential issues at the surveying stage could have prevented the introduction of the cold bridges.
Adjoining dwellings	In some instances, the insulated dwellings were attached to adjoining uninsulated homes. Previous research suggests this can lead to problems at the uninsulated dwellings. Internally, these problems can include mould growth on the adjoining internal walls caused by cold bridging, and an increased risk of condensation along adjoining habitable spaces. Externally, problems can include increased risk of moisture penetration along the party wall. If the introduction of insulation requires alterations to original metal gutters, or finlock gutters, their profile (shape) may not match that of any new gutters, increasing the risk of leakage and water leaking onto the façade in concentrated areas. However, there appeared to be a lack of awareness of this particular issue and the risks were not sufficiently considered. In addition, not enough consideration was given to the detailing of the insulation at the point at which it meets the adjoining dwelling to minimise moisture penetration behind the insulation.
Issues with weather	Another issue identified at multiple sites was related to the weather and in particular problems that arise when it rains. At most sites materials due to be attached to the dwellings were protected from the rain prior to being installed, however, in some cases the materials were left out meaning moisture could be trapped between the insulation and the wall when installed. At one site the work was delayed meaning the insulation had to be installed in the winter. This lead to problems with the application of the final coats of render as it was slow to dry and in some cases washed off in the rain. Issues such as this added significantly to the overall timetable and cost of the works.

3.7 Occupant perceptions of the insulation

The occupants of the insulated dwellings were asked a series of questions about the insulation and the effects it had (see Appendix D). The post insulation interviews took place in February 2016. The majority were conducted face to face, however where this was not possible they were done over the telephone. The same trained interviewer conducted all interviews. For each topic they were asked, on a scale of 1-5, to rate the size of the effect the installation had (from 1. Very little, to 5. A great deal) and how the size of the effect compared to what they were expecting (from 1. Significantly less than expected, to 5. Significantly more than expected). Using bipolar scale questions allowed the team to quantify the occupant perceptions and examine across the sample the views of the householders. The questions were developed by BRE's social research team in conjunction with social research experts at BEIS.

Figure 17 and Figure 18 below show the householder responses to all the scale questions regarding their perception of the insulation. Figure 17 shows on a scale of 1-5 the perceived size of effect the insulation had and Figure 18 shows the extent to which the effect was any more, or less, than expected.

The occupants were asked, "How much disruption did the work cause to you and the others living in the house?" The highest proportion of households (28%) said the installation caused 'very little' disruption, however, the experiences of the occupants varied greatly from case to case and therefore there was a fairly even distribution of responses across the scale. 42% of respondents said the level of disruption was more than they expected, 29% said it was about what they had expected and 29% said it was less than expected.

The occupants were asked, "How big an effect has the insulation had on your energy bills?" 39% of interviewees said they had noticed very little change in their energy bills, rating the difference as either a 1 or 2 on the scale. However, many said it was too early to tell what effect the insulation was having as for the majority the insulation had only been installed a few months prior to the interview. 39% said they had already noticed a marked reduction in their bills, rating the difference as a 4 or 5 on the scale. The majority (53%) said the change to their bills was at the level they had expected.

The occupants were asked, "How big an effect has the insulation had on the amount of time you need the heating on?" A large proportion of the sample said it had had very little effect (35%), however, for another group (39%) the insulation had had a marked effect on the amount of time they heated for. For almost half the sample the size of the effect was about what they expected, for 38% the effect was greater than expected and for 15% it was less.

Next householders were asked, "How big an effect has the insulation had on how warm the house feels?" The majority felt the insulation had had a significant effect, with 72% scoring either a 4 or a 5 on the scale. The majority also reported the effect was greater than expected (53%), only two households said the effect was less than they expected.

Occupants were asked, "How big an effect has the insulation had on the speed at which the temperature drops after the heating is turned off?" As with the warmth of the house, the majority felt the insulation had had a significant effect on the speed at which the temperature drops, with 68% scoring either a 4 or a 5 on the scale. Two thirds reported the effect was greater than expected and only three households said the effect was less than they expected.

The areas in which the householders had noticed the biggest change were the effect the insulation had on how warm the house felt and the speed at which the temperature dropped after the heating was turned off. Most said that the house generally felt much warmer and was much slower to cool down after the insulation was installed. On average the size of the effect was much higher than expected for the majority of householders.

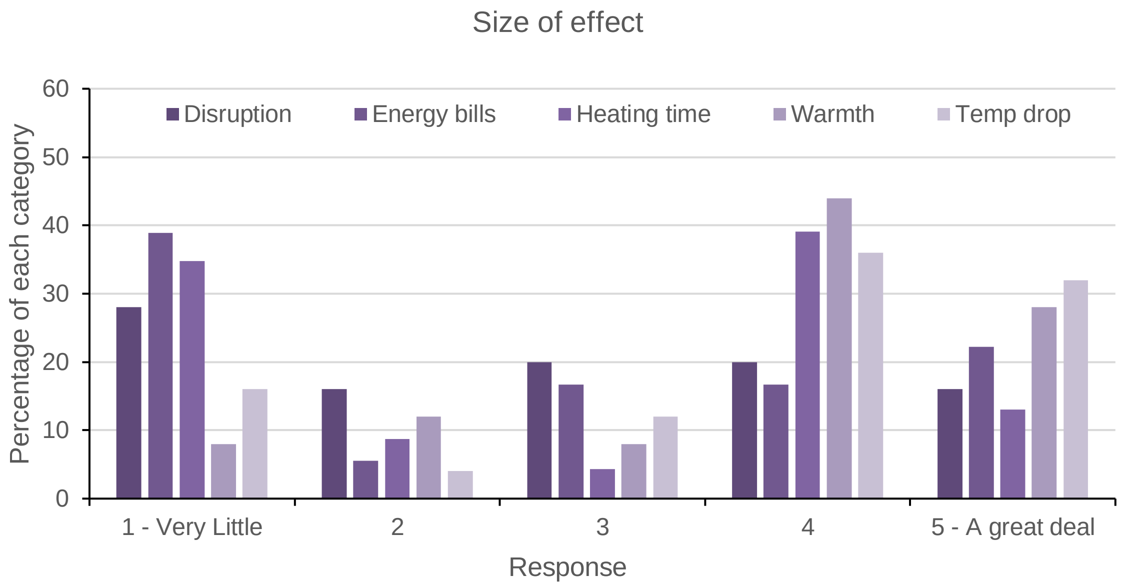

Figure 17 - Perceived size of effect of insulation on different aspect of occupation

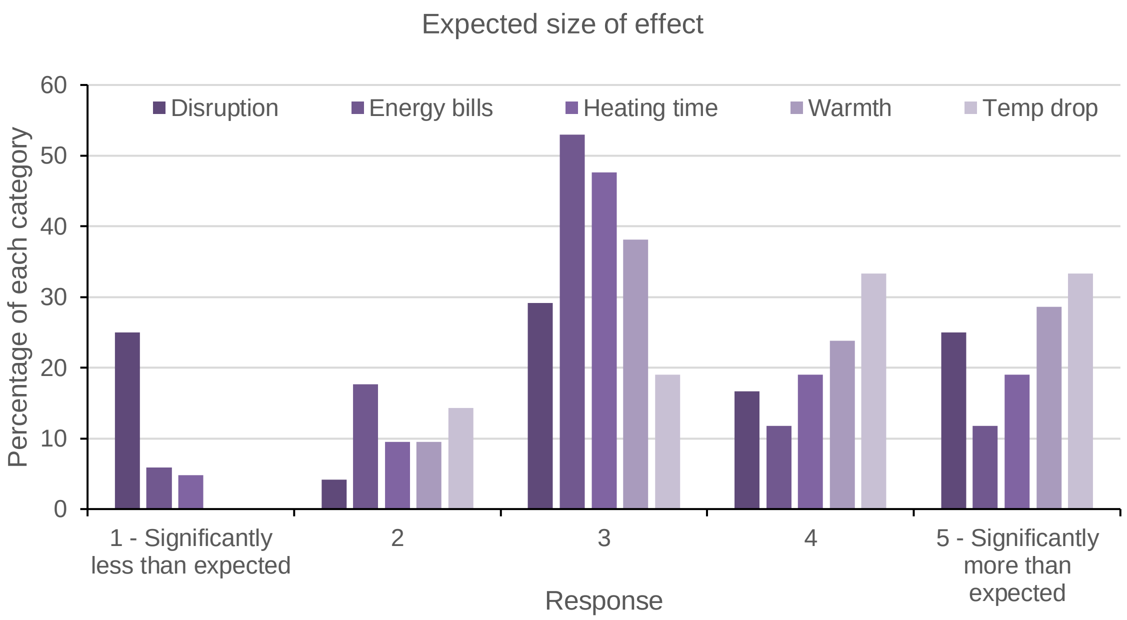

Figure 18 - The extent to which the insulation effects were more or less than expected

Householders were asked how long the insulation had taken to install and whether installation time was any longer or shorter than expected. Figure 19 shows that for the majority (54%) the installation had taken longer than expected. However, despite the levels of disruption and longer than expected install duration, Figure 20 shows that the majority of householders were happy or very happy with the appearance of the dwelling when the work was complete (72%) and 80% said that overall they were happy with the insulation that had been installed.

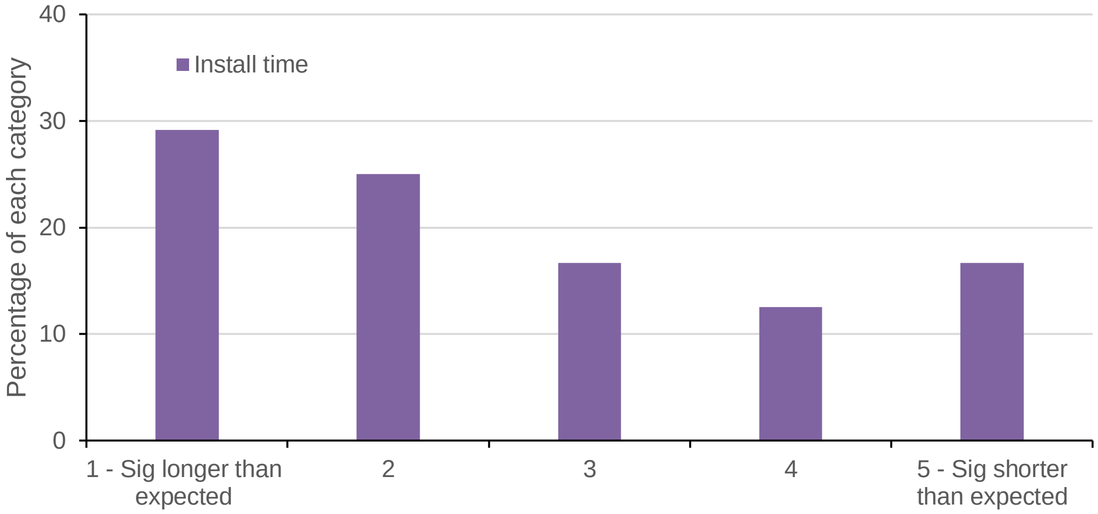

Figure 19 - The extent to which the time taken to install was more or less than expected

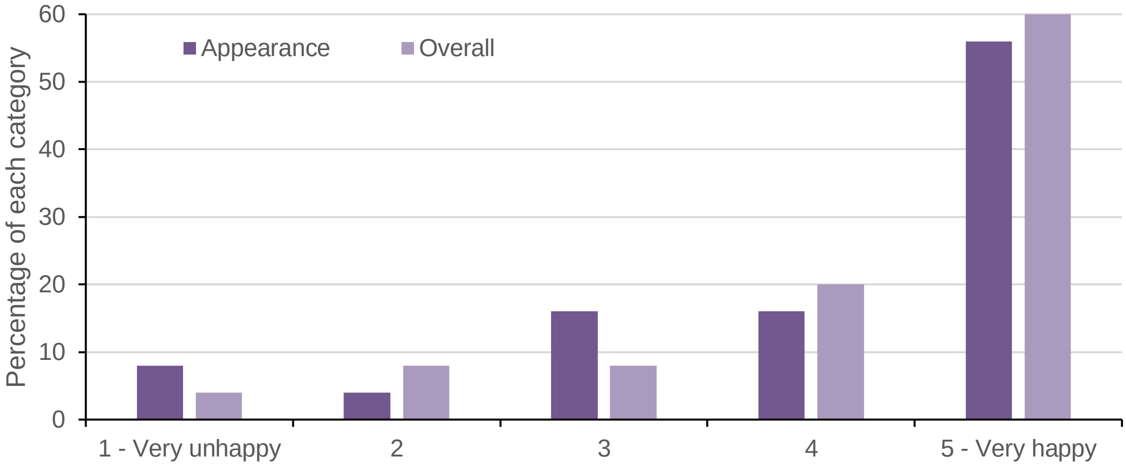

Figure 20 - How happy the occupants were with the insulation overall and the appearance of the dwelling

3.8 Damp and mould incidence and severity

Levels of damp and mould were tracked over the monitoring period. Occupants were asked about the levels and location of any damp and mould in the annual interview (see question 37 in Appendix C) and there was also an objective assessment undertaken annually at each of the monitored dwellings. The assessments were conducted at the end of each winter by trained BRE staff. It looked for and measured visible areas of surface damp and/or mould on the walls or ceilings. In addition, photographs were taken of the affected areas so that changes between years could be assessed and tracked.

Figure 21 shows the changes in the levels of damp and mould between year one and year two in the insulated and control dwellings which reported having issues.

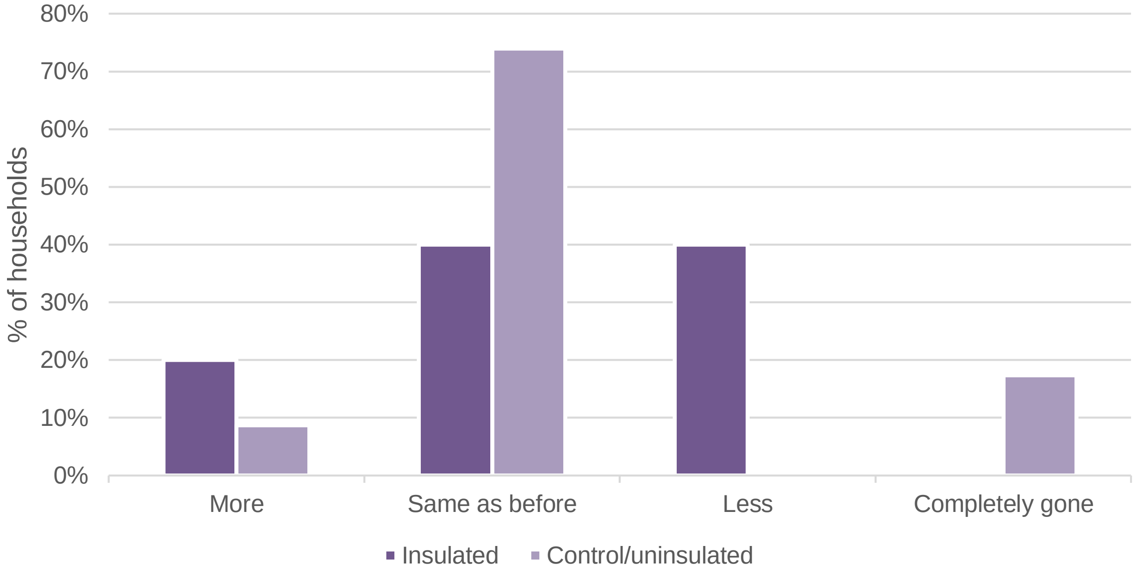

Figure 21 - Changes in the levels of damp and mould between 2014/15 and 2015/16

The results showed that in 40% of insulated homes, there had been either a reported or observed reduction in the levels of damp and mould after the insulation had been installed. In 40% of homes there had been no change, and in 20% an increase was observed.

In contrast, at the majority (74%) of uninsulated dwellings there was no change in damp and mould levels. A small proportion of the uninsulated homes showed an increase (9%) in levels. In 17% of the uninsulated dwellings problems had been completely resolved. This was typically due to remedial works carried out by either the housing provider or householders themselves.

It is not surprising that damp and mould levels had not greatly changed for the control dwellings (other than where remedial action had been taken) because there was no change to the fabric of the dwelling and the interview survey found that behaviours had not altered significantly between the two years. The most significant change for these dwellings was the severity of the winter (in other words, the average external temperatures). The results suggest that for the majority of insulated dwellings the insulation had not led to any increase in the levels of damp and mould and for half of these had led to a reduction, however, 20% of cases reported an increase and while they were outnumbered by those noticing a reduction by a ratio of 2:1, this could indicate potential for problems to emerge in the future. Many of the householders said it was too early to confidently say as the insulation had only been installed a few months prior to the interview. Longitudinal research currently being conducted by BRE has also shown that damp and mould levels can fluctuate over time after solid wall insulation is installed, so, whilst encouraging, these early results should be treated with caution. A follow-up interview and assessment towards the end of the subsequent heating season would provide a better indication once the early changes associated with insulation have had a chance to settle down.

4 Discussion

4.1 What impact did the solid wall insulation have?

In order to quantify the effect that the insulation had on household energy consumption, both the winter and annual consumption in year two (the year the insulation was installed) were compared with year one (the year before insulation was installed). To control for other factors which may contribute to the observed changes, the consumption and spend data were weather corrected to account for differences in external temperatures and any insulated dwellings which were fitted with new more efficient boilers were removed from the comparisons. In addition, the changes between years observed for the insulated dwellings were compared with the changes observed for the uninsulated control dwellings.

The findings indicate that the installation of solid wall insulation results in a significant reduction in both winter and annual gas consumption. This reduction was observed in all but one of the insulated dwellings and on average a 31% drop in winter gas and 28% drop in annual gas consumption was recorded. The median annual financial saving in gas spend was £139. In contrast no significant change was observed between years for the control dwellings which on average showed just a 2% drop in winter gas consumption and an 8% drop in annual gas consumption.

In addition, a marked effect was also found in terms of the total annual energy consumption. It should be noted that for the majority of the cases the insulation was not installed before the beginning of the year two winter period, so this effect is likely to be greater the following winter (2016-17).

As expected the insulation had a significant effect on the measured wall U-value. A reduction was observed at the insulated dwellings and on average (median) the U-value dropped from 1.66 W/m²K to 0.48 W/m²K. A slight increase in the average winter external temperature was measured between years. On average (median) the winter temperature was 0.8°C higher at the control dwellings and 0.13°C higher at the insulated dwellings. The reported heating hours were found to be lower in year two at both the insulated and control dwellings. However, on average a slightly larger drop was observed for the insulated group than the control group. For the insulated dwellings the significant (weather corrected) drop in winter gas consumption was achieved despite (on average) no change in demand temperature and higher internal temperatures across the majority of the dwelling.

Comfort taking/rebound effect

A reduction in both annual and winter gas consumption was observed in all but one of the insulated dwellings. Case H53 showed a slight increase in both annual (11%) and winter (7%) gas consumption. In the post insulation interview the householders said they had made a conscious decision to make the house more comfortable rather than taking the energy and financial savings. The householders were aware the consumption had risen slightly. This is an example of a conscious rebound effect and in this case it led to what Madlener and Alcott[4] refer to as 'backfire', where more energy is consumed after the intervention than before.

The majority of insulated householders kept their thermostat temperatures and heating hours at the same level or lower after the insulation was installed, however, almost a third increased their heating hours and

[4] Madlener, R. and Alcott, B. (2009). Energy rebound and economic growth: A review of the main issues and research needs. Energy, 34(3), 370-376.

42% increased their demand temperatures. Some of these changes were very small and the figures are reported estimates from the householder meaning these findings should be treated with caution, however, the results do suggest that a rebound effect was observed at some of the insulated homes, meaning some of the potential energy savings were taken back to increase comfort. On average (median) the recorded internal temperatures for zone 1 remained the same although an increase in zone 2 temperature was measured. This increase is likely to be due to the improved thermal efficiency of the walls rather than a change in heating behaviour.

4.2 The gap between measured and modelled energy consumption

To fully understand the gap between modelled and measured savings we must first understand the gap observed for dwellings in their uninsulated state. To do this the total annual energy consumption was modelled for 50 of the uninsulated dwellings in year one and compared with the measured consumption over the same period. The SAP model was found to significantly overestimate the annual energy consumption. The median measured consumption (14,629 kWh) was found to be 30% lower than the median SAP estimate (21,045 kWh) and the model was found to overestimate the total annual consumption for 92% of the dwellings.

For those dwellings that were insulated the SAP model was found to significantly overestimate the annual energy consumption following insulation as well as prior to installation and therefore also the change in consumption between years. In summary;

- On average (median), the measured annual energy consumption was found to be 31% lower for these dwellings in their uninsulated state and 32% lower when insulated.
- For 88% of the sample SAP overestimated the annual consumption before and after insulation.
- The saving, from pre-insulation to post-insulation, for both modelled and actual consumption, was ~20% but SAP was found to overestimate the saving in 69% of cases and the median modelled saving was 4,079 kWh compared with a median measured saving of 2,982 kWh.

4.3 Explaining the gap between measured and predicted savings

When calculating total annual energy consumption SAP makes certain assumptions about the dwelling and how it is heated. It also estimates values for other variables based on the data entered. To understand why the SAP model overestimated the annual energy consumption for the majority of uninsulated dwellings in year one and insulated dwellings in year two, the differences between the assumed and measured dwelling characteristics were examined.

Air tightness - Infiltration rate (ach)
The air infiltration rate, expressed in air changes per hour, is a measure of the structural air tightness of the dwelling (which excludes the impact of window opening and chimneys for example). The SAP model assumes the infiltration rate of a dwelling will not change as a direct result of being insulated. The measured infiltration rate was found to be significantly lower than modelled for both insulated (61% lower) and uninsulated dwellings (49% lower). The SAP estimate was found to be higher than measured for 94% of the dwellings in their uninsulated state and all insulated dwellings. An overestimation of the air infiltration rate can lead to an overestimation of the annual energy consumption as the model assumes more energy is required to heat a home that is less air tight.

U-value
U-value is a measure of the thermal transmittance of a surface (in this case a wall). The higher the U-value, the more heat is being transferred through the wall. SAP assumes an uninsulated solid wall has a U-value of 2.1 W/m²K (1.55 W/m²K for dry-lined walls) and an insulated wall (dry-lined and non-dry-lined) has a value of 0.6 W/m²K. The measured U-values for uninsulated walls were found to be significantly lower (i.e. meaning less of the heat is being transferred through the wall) than assumed. The median measured U-value was 1.78 W/m²K (0.97 W/m²K for dry-lined walls). The SAP assumed values were found to be greater than measured for 84% of the sample and on average (median) the measured

value was found to be 15% lower. An overestimation of the U-value can lead to an overestimation of the annual energy consumption as the model assumes more energy is required to heat a home that is less thermally efficient (i.e. more of the heat is escaping through the walls).

For insulated walls however, no significant difference was found. The median measured U-value (0.48 W/m²K) was found to be similar to the SAP assumed value (0.60 W/m²K) and whilst the SAP value was still found to be higher than measured for over two thirds of the sample (68%), the differences were relatively small for most cases.

External temperatures

External temperature readings were taken once every 30 minutes at one of the monitored houses in each area and the mean recorded temperature over the winter period in each year (November 1st to April 30th) was then calculated. SAP estimates the external temperature using 20-year average data based on the temperature in the East Pennines. The median recorded winter temperature across all sites in year one was 7.22°C, which was 21% higher than the than the figure used in SAP for the same winter period (5.98°C). At the insulated dwellings in year two a similar figure was recorded (7.35°C) which was 23% higher than assumed in SAP. The mean measured external temperature was higher than assumed in SAP in all the areas of England and Wales included in the sample for both years. Assuming lower winter external temperatures can lead to an overestimation of household energy consumption as the model will assume more energy is required to heat the dwelling to the demand temperature when the external temperature is lower.

Demand temperatures

The observed demand temperature was derived from the thermostat set point which was obtained during the occupant interview. SAP assumes a demand temperature of 21°C. The median reported demand temperature at both the insulated and uninsulated dwellings was 20°C. The reported demand temperature was found to lower than the SAP assumed value for 59% of the uninsulated dwellings in year one and 65% of the insulated dwellings in year two. An overestimation of the demand temperature can lead to an overestimation of the annual energy consumption as the model assumes more energy is required to heat a home to a higher internal temperature.

Reported heating hours

The assumed heating hours used in the SAP method are 9 hours on weekdays, 16 hours a day on weekends and 77 hours a week in total. SAP assumes the heating hours are the same for insulated and uninsulated dwellings. The reported heating hours were collected via the occupant interview conducted each winter. An overestimation in the number of heating hours can lead to an overestimation of the total household energy consumption as the model assumes more energy is required to heat a home for a greater number of hours.

No significant difference was found between the SAP assumed weekday heating hours (9 hours) and the reported heating hours (median = 8.5 hours) for the uninsulated dwellings in year one. However, for the insulated dwellings, weekday heating hours dropped on average from 8.5 hours to 7 hours after the insulation was installed. This drop resulted in there being a significant difference between SAP assumed and measured weekday heating hours post insulation.

Whilst the median number of reported heating hours was close to the SAP assumed value for weekdays, the SAP assumed value of 16 hours a day on weekends was found to be significantly higher than the reported for both the uninsulated (9 hours) and insulated dwellings (7 hours). The SAP assumed value was found to be higher than measured for 77% of the uninsulated dwellings in year one and 95% of the insulated dwellings in year two.

It should also be noted that the majority of households reported their heating hours were very similar on weekdays and weekends. This was found to be the case over the duration of the field trial, for both insulated and uninsulated dwellings, and this finding is consistent with the results of the EFUS. This suggests that the assumption regarding weekend heating hours should be revisited and potentially adjusted.

4.4 Closing the gap

In order to identify the key variables that have the greatest effect on the accuracy of the model estimates, the annual energy consumption was modelled under a number of scenarios using BREDEM. The model was run repeatedly using different combinations of actual recorded values and SAP assumed/estimated values to establish which variables have the biggest impact on the accuracy of modelled energy consumption.

The measured total annual energy consumption was found to be significantly lower than the modelled consumption (using just the SAP values) for both the uninsulated and insulated dwellings. On average (median) the modelled consumption was found to be 30% lower for the uninsulated homes and 28% lower for insulated dwellings. The model overestimated the actual consumption for 92% of the uninsulated and 82% of the insulated dwellings.

Using the measured rather than assumed U-values in the model did not significantly improve the accuracy of the modelled consumption. On average (median), using the measured U-values for the uninsulated dwellings did result in a 13% improvement in accuracy, however, for the insulated dwellings it resulted in a small increase in the overestimation of modelled consumption. This is likely to be due to the fact that, unlike the uninsulated dwellings, the SAP assumed wall U-values were not significantly different from measured, therefor substituting the actual values did not improve the accuracy of the model.

Individually entering the measured air infiltration rate closed the gap between modelled and actual consumption for both the uninsulated (13%) and insulated dwelling (12%). The improvement in the accuracy of the modelled consumption was relatively small given the large discrepancy between the estimated and measured air infiltration rate described above. This suggests that knowing the actual infiltration rate of a dwelling alone may not substantially improve the accuracy of modelled energy consumption.

Using the recorded thermostat set point improved the modelled estimate by 20% for the uninsulated dwellings and 24% for the insulated dwellings. This was found to a relatively large effect given that the median measured demand temperature was found to be just one degree lower than assumed in SAP. This result illustrates that the demand temperature alone has a marked effect on the predicted annual energy consumption. The relative effect of this variable was greater for insulated dwellings (24% improvement) than uninsulated dwellings (20% improvement). This is likely to be because the SAP assumed value was found to higher than measured for 58% of the uninsulated dwellings but 82% of the insulated dwellings.

The two variables that had the biggest influence on the size of the gap for both uninsulated and insulated dwellings were external temperature and heating hours.

Using the actual recorded external temperatures made a marked difference to the accuracy of the modelled energy consumption, on average (median) closing the gap by almost 35% for the uninsulated and 27% insulated dwellings. The average external temperature was found to be higher than assumed in SAP in all regions for both years. The results show the relative importance of this variable. Minor differences in external temperature have a relatively large effect on the on the accuracy of the model. Using actual average external temperatures for a particular heating season and in a particular location would lead to more accurate estimates of consumption, however this is not an option within SAP as using a single value enables comparability between dwellings. Given the trend of global average temperature increases it may be pertinent to look at increasing the estimated external temperature value currently used in SAP or enable users to input a more accurate value. In the case of ECO or other assessments of improvement options, it may be necessary to consider using future projections of temperature.

Finally, the most significant single variable for both insulated and uninsulated dwellings was found to be the number of heating hours. Substituting just the reported heating periods for the SAP assumed values alone improved the modelled estimate, on average (median), by 53% for the uninsulated and 61% for the insulated dwellings. For the insulated cases no statistically significant difference was found between the measured and the modelled consumption when the recorded values for this variable alone were used. This demonstrates the importance of using accurate heating time estimates when modelling energy consumption. Dropping the assumed number of heating hours, particularly at weekends, would significantly improve the accuracy of the estimated total energy consumption.

When all the SAP assumed/estimated values were substituted with the available measured values and the model was re-run, no significant differences were found between the modelled and measured consumption for either the uninsulated or insulated cases. Adding in all the measured values into the model in one go closed the gap on average (median) by 72% for the uninsulated dwellings and 93% for the insulated homes.

It must be noted that actual measured values could only be included in this analysis for the variables that were monitored as part of the field trial. There are other variables, not measured as part of the monitoring, that have an effect on the accuracy of the modelled consumption and therefore entering measured values for these variables would have an effect on the size of the gap (for example the U-value of floors and roofs, detailed information about the windows etc.). However, the variables selected for inclusion in field trial design were those which were thought to have the biggest influence on the modelled consumption levels.

5 Conclusions and recommendations

The measured impact of the insulation

Despite a relatively short period of monitoring post insulation (typically 4-6 months for the majority of insulated homes), the results of the field trial showed that the introduction of insulation resulted in a significant reduction in gas consumption over the winter period (correcting for changes in external temperature). This reduction was observed in all but one of the insulated dwellings. The size of the change varied between dwellings with, on average, a 31% drop in winter gas consumption being observed. This was achieved despite (on average) no change in demand temperature and higher internal temperatures across the majority of the dwellings. In contrast, no significant changes were observed between years for the control dwellings which on average (median) showed just a 2% drop in winter gas consumption.

The insulation had a significant effect on the measured wall U-value, a reduction was observed at all the insulated dwellings and on average (median) the U-value dropped from 1.66 W/m^2K to 0.48 W/m^2K. RdSAP (9.92) assumes a pre-insulation U-value of 2.10 W/m^2K and post insulation value of 0.6 W/m^2K.

The size of the gap

In order to assess the size of the gap between modelled and measured consumption, the total annual consumption for each dwelling was modelled using the RdSAP assumptions and compared with the measured values.

For all the monitored dwellings in their uninsulated state (n=50), actual energy consumption was found to be significantly lower (by 30% on average – section 3.3.1) than predicted by modelling and the model was found to overestimate the consumption for 92% of the sample (section 3.3.3).

For those dwellings that were insulated, the actual post-insulation consumption was also found to be significantly lower (on average 32% lower) than modelled and the model was found to overestimate the consumption for 88% of the sample (Table 11, section 3.5.1).

The actual measured decrease in consumption (2,982 kWh) was, on average, 27% lower than the modelled savings (4,079 kWh) (n=16) and the SAP consumption estimate was higher than measured for 69% of the sample (Table 11, section 3.5.1).

Understanding the gap

When calculating total annual energy consumption SAP makes certain assumptions about the dwelling and how it is heated, it also estimates values for other variables based on the data entered. To understand why the SAP model overestimated the annual energy consumption for the majority of uninsulated and insulated dwellings, the differences between the assumed and measured dwelling characteristics were examined.

The SAP model was found to significantly over-estimate the;

- Air infiltration rate, both before and after insulation
- Wall U-value prior to insulation (no significant difference was found post insulation)
- Number of heating hours, particularly at weekends

The model was also found to significantly under-estimate the external temperature for each year of monitoring.

Overestimation of the air infiltration rate, U-values and heating hour's leads to an overestimation of the annual energy consumption as the model assumes more energy is required to heat a home that is less air tight, less thermally efficient and heated for longer periods of time.

Closing the gap

In order to identify which of the measured variables had the greatest effect on the accuracy of the model estimates, the annual energy consumption was modelled under a number of scenarios using BREDEM. The model was run repeatedly using different combinations of actual recorded values and SAP assumed/estimated values to establish which variables have the biggest impact on the accuracy of modelled energy consumption.

The two variables that had the biggest influence on the size of the gap for both uninsulated and insulated dwellings were external temperature and heating hours.

Using the actual recorded external temperatures made a marked difference to the accuracy of the modelled energy consumption, on average (median) closing the gap by almost 35% for the uninsulated and 27% insulated dwellings. The average external temperature was found to be higher than assumed in SAP in all regions for both years. The results show the relative importance of this variable. Minor differences in external temperature have a relatively large effect on the accuracy of the model. Using actual average external temperatures for a particular heating season and in a particular location would lead to more accurate and relevant estimates of consumption.

Substituting just the reported heating periods for the SAP assumed values improved the modelled estimate, on average (median), by 53% for the uninsulated and 61% for the insulated dwellings. For the insulated cases no statistically significant difference was found between the measured and the modelled consumption when the recorded values for this variable alone were used. This demonstrates the importance of using accurate heating time estimates when modelling energy consumption. Dropping the assumed number of heating hours, particularly at weekends, would significantly improve the accuracy of the estimated total energy consumption.

It must be noted that actual measured values could only be included in this analysis for the variables that were monitored as part of the field trial. There are other variables, not measured as part of the monitoring, that have an effect on the accuracy of the modelled consumption and therefore entering measured values for these variables would have an effect on the size of the gap. However, the variables selected for inclusion in field trial design were those which were thought to have the biggest influence on the modelled consumption levels.

5.1 Recommendations

SAP modelling assumptions

The evidence collected suggests that the SAP/RdSAP assumed values for the following variables should be revisited. The data collected indicate that if these variables were amended, SAP would more accurately reflect the performance of the UK housing stock, external conditions and the way households heat their homes. The changes would also improve the accuracy of modelled energy consumption and the potential for savings. It is recommended that the following variables should be reviewed;

- Weekend heating hours
- External temperatures
- Uninsulated solid wall U-values

In addition, the data collected in this study suggest that the SAP assumed air infiltration rate for solid wall dwellings should be amended. However, more research is needed with a larger and broader sample as the majority of the dwellings monitored were well-maintained social housing dwellings with double glazing and uPVC doors.

Quality of installation

The observations of the installation identified a number of issues with the quality of the design and workmanship which could potentially lead to negative unintended consequences in the future. As part of the wider solid wall insulation research programme a report[5] has been produced that looks at the potential unintended consequences, recommendations for how they can be avoided, and a roadmap for change. The report recommends;

- Further research to better understand how the insulation performs in situ and improvements to modelling
- Changes to standards and policies
- Greater training and information for the surveyors, installers and occupants

In addition, this field trial suggests the quality of the installation can have an effect on the measured air tightness of the dwellings. More research, with a larger sample, is recommended to explore this further.

Future research

The findings of the current research are based on a relatively short period of post insulation monitoring. Further data collection is required to measure longer term changes in;

- Energy consumption
- Heating behaviours
- Timber moisture levels
- Damp and mould levels
- Negative consequences of poor installation

The findings of this study are based on a relatively small number of households and there was a great deal of variation between the dwellings on some variables. In addition, all the insulated dwellings were social housing and the majority were houses rather than flats or maisonettes. Where possible, future studies should recruit a bigger and broader sample of dwellings and households.

5 https://www.bre.co.uk/filelibrary/pdf/projects/swi/UnintendedConsequencesRoutemap_v4.0_160316_final.pdf

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Appendix A Issues faced by housing providers leading to delays in insulating

During the first year of the project all of the housing providers experienced problems that meant the dwellings could not be insulated in the summer of 2014 as planned. These problems fell into four main areas;

1. **Financial.** The change in ECO funding in spring 2014 meant that several providers lost their primary funding source for the works. All of the providers found it hard to obtain alternative external funding and so had to seek internal funding. Some of the providers (particularly those connected to or part of local authorities) had to put the planned works on hold due to council wide internal financial reviews. A lack of funding meant that some providers had to shelve their programmes indefinitely.

2. **Planning.** Several providers experienced much greater difficulties gaining planning permission than they had expected. For many the process was far more involved and took a great deal longer than they had planned for when targeting a summer 2014 installation. The picture was mixed across the country and the approach of the local authorities to planning appears very inconsistent. Some providers were able to complete the works under permitted development rights meaning they did not have to go through formal planning application procedures. Some of the dwellings being monitored were in conservation/heritage areas. Gaining planning permission to do the works in these areas proved particularly difficult, sometimes requiring long consultation periods and the production of heritage statements. Changing the appearance of the dwelling is a key issue, not just for planners but also for occupants and housing providers aiming not to adversely transform the appearance of an area.

3. **Dwellings found to be difficult to insulate.** In many cases the dwellings earmarked for external solid wall insulation were found to consist of different wall types to those expected. Often the dwellings were made up of more than one wall type. In one case several dwellings that had been specified as solid walled by external surveyors were found to be cavity walled. In some cases the true wall construction was not discovered until work had started. Some dwellings were found to have structural problems which delayed the work and/or made them prohibitively expensive to treat.

4. **Procurement**. Procuring sub-contractors to do the works often took considerably longer than expected for some housing providers, sometimes requiring the running of competitions, or going through framework agreements to meet the housing providers' or local authorities' procurement rules.

In addition to these issues, the installations themselves often took significantly longer than anticipated due to unforeseen problems. For example, at one dwelling in Cambridge early investigations identified that the upper gable construction was of an original timber frame with render applied, not solid wall as assumed. This resulted in an alteration to the approach taken, huge delays in the works and significantly increased costs. In total, the cost to insulate that one dwelling alone was £17,000 and the works took almost a year to complete. These problems and planning issues led to the council postponing all other planned solid wall insulation works for the foreseeable future.

In Hemel Hempstead (one of the areas added to the study after the first heating season) delays in starting the installations meant the works did not begin until October 2015. Bad weather resulted in further delays to the works and at one dwelling the render was entirely washed off the walls during a particularly strong downpour of rain three days after it was applied. The work was also delayed as one of the workman drilled into a live cable meaning all work had to be stopped while all dwellings were scanned. These problems meant that while the insulation boards were installed by Christmas 2015 the rendering works weren't complete until the end of February 2016.

Appendix B Monitoring Methodology

Airtightness test

The airtightness test method used was a standard method recommended in the air tightness guidance within Approved Document L of the Building Regulations. To ensure the test only measures unintentional air movement all trickle vents, air bricks, chimneys and any other vents are covered or blocked prior to the test.

The air permeability test involves connecting a fan, to a suitable aperture in the building envelope (usually the front door opening, see Figure B1) and pressurising it over a range of pressure differences. The fan speed is increased in steps up to a maximum and then decreased in steps. Air volume flow rate through the fan (equal to the air leaking through the building envelope) and the pressure difference across the building envelope are recorded at each fan speed. In calculating air permeability, corrections are made for temperature and barometric pressure.

Figure B1 - Air permeability test rig mounted in the front entrance to a dwelling

U-value measurement

To measure the U-value of the walls before and after insulation four heat flux plates were applied to each wall and held in place with poles which ran from floor to ceiling. The plates were positioned on a north facing external wall at each dwelling and were positioned as far away from junctions (such as windows, doors, and wall joins) as possible within the confines of the room and the furniture layout. For the second measurement after the wall insulation was installed the plates were positioned as close as possible to their original pre-insulation positions to ensure the differences could be measured as accurately as possible.

The U-value measurements took place in winter period as a difference between the inside and outside temperatures of at least 10°C is required to give the most accurate reading possible. The plates stayed in place for two weeks.

To ensure a good thermal connection (i.e. no air gaps) between the heat flux plate and the wall, Vaseline was added to each plate which was then covered with Clingfilm so as not to mark the wall and to keep the Vaseline in place.

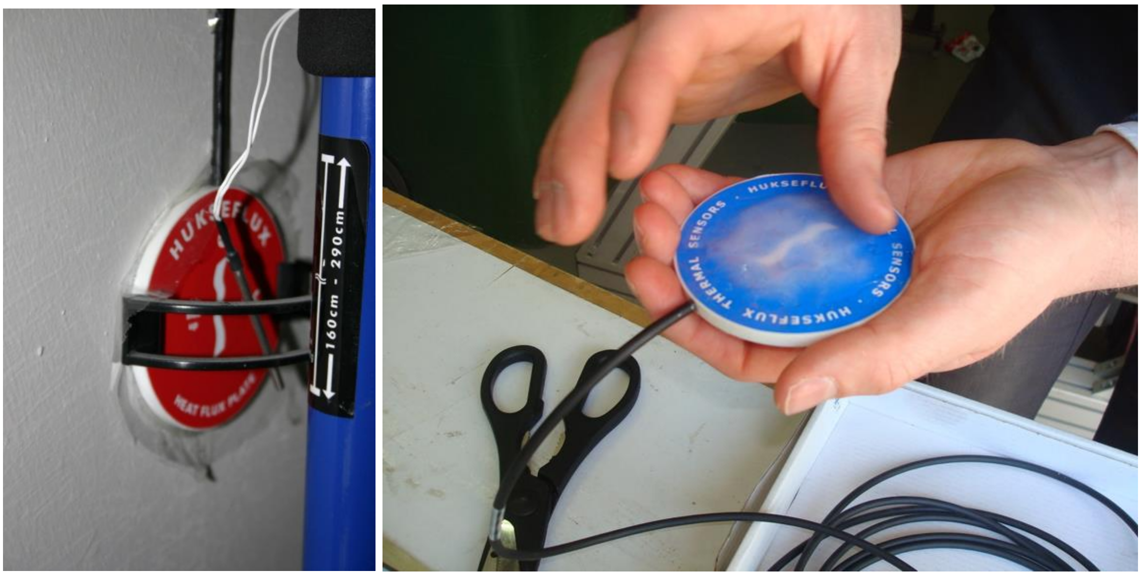


Figure B2 - Heatflux plate used to measure the wall U-value.

Internal temperature and humidity levels

The internal temperature and relative humidity levels in the living room, hallway/stairwell and bedroom were measured using Log Tag monitors like that shown in Figure B3. Readings were taken every hour and the data were downloaded from the monitors once a year. The Log Tags were installed at around head height on an internal wall in each room.

Figure B3 - LogTag temperature and humidity monitor

Several of these loggers were removed by occupants or went missing during the monitoring period and a small number of devices experienced a battery failure during the final year of monitoring, however, in general the monitors worked well and produced good data.

Periods of heating

As well as asking the occupants what their heating hours were for weekdays and weekends, periods of heating were also measured using a TinyTag temperature monitor which was attached to the inlet pipe of a radiator in the living room in each house. Changes in temperature were monitored as hot water was pumped around the central heating system. Readings were taken every 15 minutes. This method was not a direct measure of heating hours as the boiler does not run all the time during heating hours, but it did give an indication of when the heating was on. As with the LogTags, some of the loggers were removed and not re-attached by occupants or workmen when radiators were removed or repaired.

Figure B4 - TinyTag temperature logger

Appendix C Winter occupant interview schedule

House ID -

Occupant Interview

Intro

- How you heat your home and control the temperature
- When are people generally at home and when you normally heat your home
- How much energy you use and what your bills are like at the moment
- What difference you think the wall insulation will make

Demographics and basic information about occupancy

1. How many people are currently living at this address?	
2. Including yourself, how many adults (aged 18 and over) live in the house? (ask for ages)	
3. How many children (under 18) live in the house? (ask for ages)	
4. How long have you lived in this house?	

Typical occupancy patterns

5. On a typical week, when are you usually at home ON WEEKDAYS?

Most days and evenings	Mainly just in during the day	Mainly just in during the evening	No fixed pattern	People are out most of the time

6. Over a typical week, when are you usually at home ON WEEKENDS?

Most days and evenings	Mainly just in during the day	Mainly just in during the evening	No fixed pattern	People are out most of the time

7. Do you have anyone who lives in the house for part of the year and elsewhere for the rest of the year? (E.g. children who live elsewhere during university term times, or people who work away for periods of time?) a. If so when do they stay at the house?	
8. Where do you tend to spend most of your time when at home?	
9. Are there any rooms which you don't tend to use? a. Do you heat these rooms in the same way as the rest of the house?	

Temperature and heating

Heating systems

10. What is the main heating system you use to heat your home? (e.g. central heating, storage heaters) a. What fuel is used to power the heating? (Electricity, gas, other) b. If oil, roughly how much do you use each winter? (record spend if they don't know the volume used)	
11. Does this heating system alone provide enough heat to the house to a comfortable level?	
12. Do you use any other heating devices in any rooms in the house? (e.g. electric heaters) a. What rooms do you use it/them in? b. Do you use it/them instead of the main heating system, or in addition to? c. In a typical week in the winter, how many days would you have it/them on?	

Controlling the internal temperature

13. When you/someone's at home during the coldest months of the year do you tend to have the central heating on: a. Constantly (kept around the same temperature) b. Timed to come on at certain times c. Turn it on an off as you need it d. Constantly but turned on and off with the thermostat	

bre

14. If timed… a. When is it timed to come on and off? b. How often do you manually put the heating on outside of these times? (e.g. press the override, extra hour or boost button) i. Several times a day ii. Once a day iii. A couple of times a week iv. A couple of times a month v. Never	
15. Approximately, how many hours a day in the winter do you heat your home? *(help them work it out)* a. Hours per day at weekdays b. Hours per day on weekends	
16. When you are too cold in your home, what do you do to get warmer? *(use the list below as prompts only. Tick all that apply and record the order)* a. Increase temperature on the heating control b. Put on more clothes c. Use additional heating device (e.g. electric heater) d. Go to bed e. Do nothing f. Turn the heating on if it's off g. Other	
17. During the colder months of the year do you tend to wear more clothing, when in the house, than at other times of the year?	

bre

18. How do you control the temperature of your home? a. Using the thermostat b. Adjusting the temperature at individual radiators c. Use additional heating devices d. Turns the heating on and off at the boiler	
19. What temperature is your thermostat usually set to in the winter months?	
20. Do you generally have the thermostat set at one temperature, or do you turn it up and down depending on how you're feeling? a) What temperatures do you usually keep it between?	
21. Do you tend to heat the entire house, or just certain rooms? a. (If certain rooms aren't heated, find out why).	
22. Do you heat the house in the same way during the spring and autumn as you do in the winter, or do you change how you heat the house depending on the weather outside?	
23. On a scale of 1-5, how easy is it to control the temperature in the house and get the temperature to a comfortable level? 1=Very difficult to control – 5 Very easy to control	

Perception of the internal temperature

24. In the rooms where you spend most of your time in the winter, how would you describe the temperature? **Area 1** (specify) --- a. 1 Cold, 2 Cool, 3 comfortable, 4 warm, 5 hot. b. During the winter, how often are these rooms too cold? 1 Never, 2 Rarely, 3 Sometimes, 4 often, 5 All of the time. **Area 2** (specify) --- a. 1 Cold, 2 Cool, 3 comfortable, 4 warm, 5 hot. b. During the winter, how often are these rooms too cold? 1 Never, 2 Rarely, 3 Sometimes, 4 often, 5 All of the time.	
25. In the rooms where you spend most of your time in the summer, how would you describe the temperature? **Area 1** (specify) --- a. 1 Cold, 2 Cool, 3 comfortable, 4 warm, 5 hot. b. During the winter, how often are these rooms too hot? 1 Never, 2 Rarely, 3 Sometimes, 4 often, 5 All of the time. **Area 2** (specify) --- a. 1 Cold, 2 Cool, 3 comfortable, 4 warm, 5 hot. b. During the winter, how often are these rooms too hot? 1 Never, 2 Rarely, 3 Sometimes, 4 often, 5 All of the time.	
26. On a scale of 1 – 5, how quickly does the temperature in the house change when your heating goes off? 1 very slowly – 5 very quickly	
27. In the winter months are there any rooms which feel cold even when the heating is on?	

28. Overall, taking all of the above into account, how happy are you with the temperature in the home during the winter?

Area 1 (specify) ---

a. 1 Very unhappy, 2 Unhappy, 3 Neither happy nor unhappy, 4 Happy, 5 Very happy.

Area 2 (specify) ---

b. 1 Very unhappy, 2 Unhappy, 3 Neither happy nor unhappy, 4 Happy, 5 Very happy.

29. How happy are you with the temperature in the home during the summer?

Area 1 (specify) ---

a. 1 Very unhappy, 2 Unhappy, 3 Neither happy nor unhappy, 4 Happy, 5 Very happy.

Area 2 (specify) ---

b. 1 Very unhappy, 2 Unhappy, 3 Neither happy nor unhappy, 4 Happy, 5 Very happy.

Ventilation, cooling and air quality

30. During the hottest months of the year, how do you usually cool the house when it gets to hot?	
31. During the coldest months of the year, how do you usually cool the house if it ever gets too hot?	
32. Are there regular times when you have the windows open all year round? (e.g. generally have the windows open at night)	

33. How often have you had your windows open this winter?

Every day	Every other day	Once a week	Less than once a week
○	○	○	○

In how many rooms do you have them open?

Why do you open them?

34. How often did you have your windows open during the summer?

Every day	Every other day	Once a week	Less than once a week
○	○	○	○

In how many rooms do you have them open?

Why do you open them?

35. Do you use electric fans, air conditioning units, humidifiers / de-humidifiers?	

Perception of the ventilation and air quality

36. Are there any rooms in the house that are particularly…? a. Humid b. Stale c. Smelly d. Draughty	
37. Do you have any problems with the following in any rooms: (a) condensation on the windows / walls / (b) mold on the walls / ceilings? (c) damp patches on the internal walls? 37a. (if so find out) Where, how long it has been a problem and how they manage it	

Energy spend/underspend

38. How do you pay your energy bills? a. pre-pay, b. weekly, c. monthly, d. quarterly e. annually f. per bill
39. Approximately, how much do you spend on gas and electricity each period? a. Gas = b. Electricity = c. Both (duel fuel) = d. Oil e. Other (specify)

40. Which one of these best describes how well you and your household are keeping up with your energy bills at the moment? 1) I/we manage very well 2) I/we manage quite well 3) I/we get by alright 4) I/we have some difficulties 5) I/we have severe difficulties 6) Don't know 7) Prefer not to answer	
41. What if anything do you currently do to save energy/money (use below as prompts after they have said their own list) a. Switch off lights b. Turn appliances off instead of using stand-by c. Wash clothes at 30°C d. Shower instead of taking a bath e. Only boil as much water as I need when using f. Other	
42. Compared to other households like yours do you think you use: a. Less energy, b. About the same amount of energy, c. More energy d. No idea (similar sized homes, with the same number of occupants, in the house at similar times to you)	

Attitudes towards energy use, energy saving, and energy efficiency

43. To what extent does the cost of energy effect how you heat your home? a. Not at all b. Slightly c. A fair amount d. A great deal	
44. Do the environmental impacts of your energy use effect how you heat your home at all? a. Not at all b. Slightly c. A fair amount d. A great deal	

Perception of solid walls and solid wall insulation

45. Before being contacted about this study, did you know your home had solid walls, as opposed to cavity walls?	
46. How happy are you to be getting solid wall insulation? Very unhappy - Very happy	
47. What, if anything, appeals to you about the solid wall insulation and what differences do you think it will make? (e.g. saving money, being warmer, improve health conditions, being eco-friendly, etc. Let the answers come from them)	
48. What, if anything, puts you off the solid wall insulation?	
49. What difference do you think it will make to your energy bills, if any? No idea. 1 None at all – 5 substantial	

Participation in the study

50. Do you currently have any concerns or reservations about participating in the study?	
51. Do you feel you have received adequate information about the project and your involvement?	
52. Do they have any questions about the monitoring or what will happen next?	

Detailed demographic information

Finally, I would like to ask you some more detailed questions about those living in the house. Remember- If there are any questions you feel uncomfortable answering just let me know and we will move on to another question. All the information you give will be entirely confidential.

Questions	Answers recorded here	
1. What is the marital status of those living in the house?	1 Married/civil partnership, 2 Co-habiting, 3 Lone parent, 4 Other multi person arrangement, 5 Single person occupancy	
2. This card shows various possible sources of income. Can you please tell me which kinds of income occupants of this household receive?		Earnings from employment
		Earnings from self-employment
		Pension from former employer
		Personal pension
		State pension
		Child benefit
		Any means tested benefits? (E.G. Income support Universal Credit Housing/council tax benefit)
		Interest from savings
		Interest from investments
		Other kinds of regular allowance from outside the household
		Income from rent
		Other sources
		No source of income

3. Thinking of the household as a whole, roughly how much is the total income of the household before all deductions?

	WEEKLY	MONTHLY	ANNUAL
A	up to £199	up to £866	up to £10,399
B	£200 up to £399	£867 up to £1,732	£10,400 up to £20,799
C	£400 up to £599	£1,733 up to £2,599	£20,800 up to £31,199
D	£600 up to £799	£2,600 up to £3,466	£32,000 up to £41,599
E	£800 up to £999	£3,367 up to £4,332	£42,600 up to £51,999
F	£1000 or more	£4,333 or more	£52,000 or more

- Thank interviewee for their time.

- Explain when the next interview will be.

Appendix D Additional post insulation interview questions

Perception of solid walls and solid wall insulation

53. Approximately how long did the installation take to install in total? 54. On a scale of 1 – 5 how did that compare with what you expecting? Significantly longer than expected 1 – 5 Significantly shorter than expected	
55. On a scale of 1 – 5, how much disruption did the work cause to you and the others living in the house? Very little 1 – 5 A great deal 56. On a scale of 1 – 5 how did that compare with what you expecting? Significantly less than expected 1 – 5 Significantly more than expected 57. What were the most disruptive aspects of the work?	
58. Have you noticed any particular benefits of having the insulation? If so, what are they?	
59. Are there any particular downsides of having the insulation? If so, what are they?	
60. On a scale of 1-5 how big an effect has the insulation had on your energy bills? Very little 1– 5 A great deal 61. How does this compare with what you were expecting? Sig less than expected 1 – 5 Significantly more than expected	

62. On a scale of 1-5 how big an effect has the insulation had on you're the amount of time you need the heating on? Very little 1– 5 A great deal 63. How does this compare with what you were expecting? Sig less than expected 1 – 5 Significantly more than expected	
64. On a scale of 1-5 how big an effect has the insulation had on how warm the house feels? Very little 1– 5 A great deal 65. How does this compare with what you were expecting? Sig less than expected 1 – 5 Significantly more than expected	
66. On a scale of 1-5 how big an effect has the insulation had on the speed at which the temperature drops after the heating is turned off? Very little 1– 5 A great deal 67. How does this compare with what you were expecting? Sig less than expected 1 – 5 Significantly more than expected	
68. On a scale of 1 – 5, how happy are you with the appearance of the property after the insulation has been installed? Very unhappy 1 - 5 Very happy	
69. Overall, taking everything into account, how happy are you with the insulation? Very unhappy 1 - 5 Very happy	

Appendix E Observation of installation and timber moisture monitoring

In addition to the monitoring of dwellings, the process for the installation of the external wall insulation was observed. The observation was undertaken without interference or comment to the workforce to ensure the behaviours of the workforce were not influenced. Workers were told the observations were to learn about how insulation was applied. All site visits were undertaken by a BRE specialist to allow comparison to be made and site specific issues to be identified.

The sites observed were in;

- Cambridgeshire
- Three sites in Hertfordshire
- Wales

The methodology for the observations was as follows.

- A copy of the specification for the works was provided by the housing providers and reviewed prior to the site visit. This included a review of the specification for any key requirements and the site activity profile.
- A minimum of 3 site visits were conducted at each site during the installation process. Observations took place at three key stages
    - Basecoat and or boarding out
    - Scrim mesh and topcoat
    - Finish coat and sealing
- In addition to the information collected at the visits themselves, site records were inspected to assess procedures followed for inclement weather stoppages
- General discussions were conducted with Site Manager / Agent when possible

The observations were recorded and relevant photographs taken on key points and principles. Site records were inspected for any delays in work due to inclement weather, site storage inspected and general arrangements on site were assessed where appropriate.

Cambridgeshire

One dwelling in Cambridgeshire was the first installation to be undertaken, the dwelling in question was to be a trial installation for the housing provider on their approach to improving older dwellings within their district. The dwelling is a semi-detached brick built dwelling with rough cast render finish, and pan tile roof covering (see Figure E1 below)

Figure E1 – Front of the dwelling

Early investigations into the dwelling identified that the upper gable construction was of an original timber frame, with render applied. This resulted in a change to the approach to be taken, requiring a plywood board to be applied and the introduction of insulation (foil backed foam) into the floor joists to minimise the effects of cold bridging, there were no bespoke construction details created that could be identified, resulting in the workforce effectively creating the detail as they went along.

Figure E2 below shows the plywood boarding progressing during the construction phase, and the detail created to attempt to minimise cold bridging at the floor joist junction is shown in Figure E3.

Figure E2 – plywood boarding to timber frame

Figure E3 – floor joist detail

The rear of the dwelling had at some point been extended by means of a single storey structure, see Figure E4 below

Figure E4 – Single Storey extension to rear

Observations

During the installation process a number of specific issues were noted, in particular the materials (plywood, and insulation) were left exposed in the garden for a considerable period of time see Figure E5 below

Figure E5 – materials left exposed in front garden

All of the materials shown in the image above, were subsequently fixed to the dwelling, no observations were made of the plywood being checked for moisture content before fixing.

Thermal Bridging

Thermal bridging at junctions or around openings will give rise to additional (i.e. unaccounted for) heat loss. If this additional heat loss is ignored (i.e. assumed to be zero) when calculating the total heat loss through the fabric of the building, it is likely that the overall heat loss will be underestimated by a greater or lesser degree, depending on the level of thermal bridging that exists at junctions. Thus, if buildings are improved through insulation of the plane building elements (such as the wall) but thermal bridging at the junctions is either ignored or not properly determined, the heat loss may be significantly higher than intended.

Not fully understanding the effect of cold bridges being introduced can result in an increased risk of mould growth and or condensation at adjoining areas.

There was no attempt to minimise the risk of cold bridging at geometric junctions and details (ground floor slab, windows jamb and reveals, flat roof junctions) as shown in Figure E6 and E7 below

Figure E6 – uninsulated reveal

Figure E7 – uninsulated sill

Figure E8 – uninsulated window head

Figure E9 – Insulation stopped above floor slab

Not insulating below the floor slab can introduce a significant a cold bridge. If constructed of concrete the floor slab is the most significant area for cold bridging, when the external walls are insulated. The process of stopping the insulation above the DPC will create a significant cold bridge, this often results in mould growth, accelerated heat loss through the un-improved area, and an increased risk of condensation on adjacent areas.

In addition to not addressing the risk of cold bridging, there were also other observations made of poor workmanship and attention to detail, these are set out below.

Timber

During the site observations it was noted that rotten timber that should ideally have been removed was in fact covered up and left in place see Figure E10 below.

Figure E10 – rotten timber left in place

Expanding foam

The site monitoring and observations identified an over reliance on the use of expanding foam to make up for poor workmanship in the placement of insulation, and in some instances to level out the surface of the wall before the application of the insulation. See figures E11 and E12 below.

Figure E11 – window reveal

Figure E12- door detail with foam to pack out

Figure E13 – window packed out with foam

Figure E14 – inconsistent use of foam

Other observations

During the site visits, the site had been left unmanned for a period of prolonged rain, there had been no attempt to protect the timber, or exposed sub structure, resulting in an increased risk of moisture being trapped within the structure, see Figures E15 and E16 below.

Figure E15- Exposed sub structure and presence of moisture

Figure E16 - Exposed sub structure during rain

In situ timber moisture measurement

As part of the site observation works, in situ timber monitoring was undertaken, using multiple measurements at key locations in the roof space, to determine any potential impact on performance created by the failure to address cold bridging on rafter and joist ends.

Measurements are collected hourly and downloaded every 6 months for analysis. Although this monitoring was only conducted for a short period of time after insulation, the initial findings are as follows.

The first data download highlighted a significant rise in reported moisture content, which if prolonged would result in a high risk of decay and rot in the timbers see Figure E17 below.

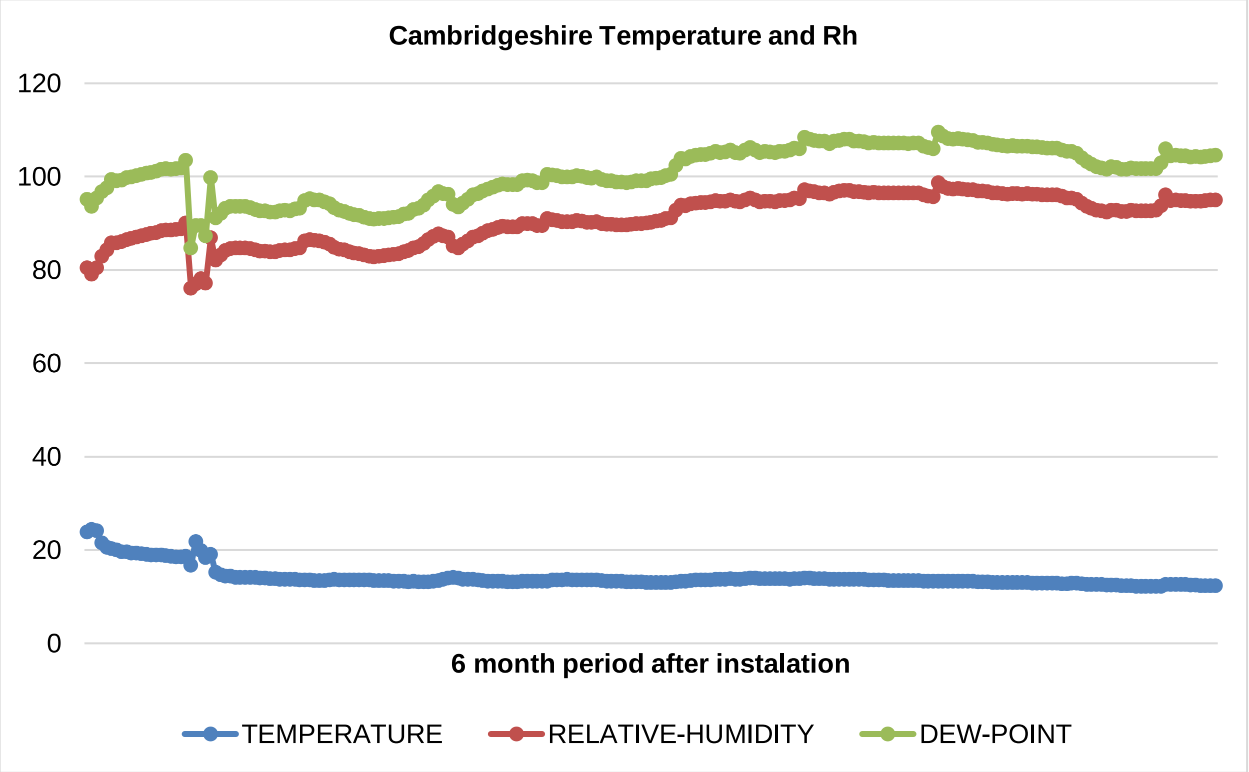


Figure E17 – Initial download of data with increase in moisture content

Subsequent to the identified increase in moisture content, a site visit was undertaken and the cause found to be blocked ventilation to the roof space and a minor leak, the latest readings from the monitoring indicate that a more conventional environment is being maintained following the correction of this defect.

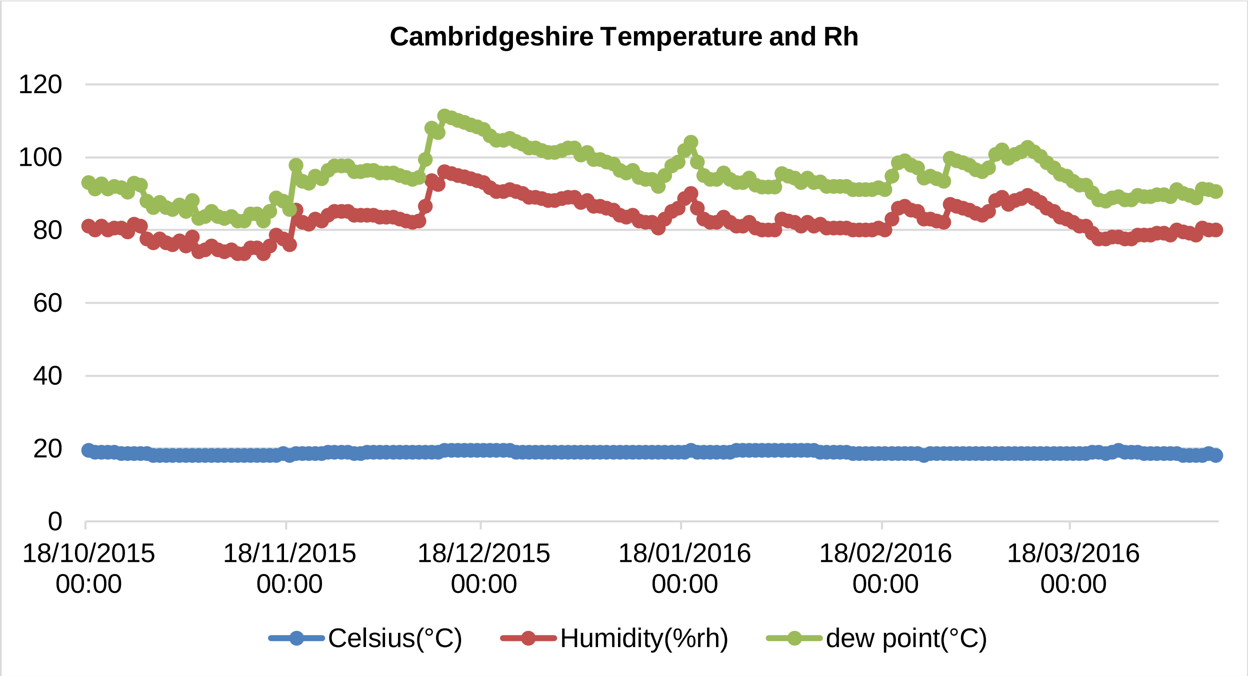


Figure E18 - Follow up data with reduction in moisture content

Summary

In summary, despite the insulation process in Cambridgeshire being a pilot (and therefore an exemplar), the level of attention to detail or care undertaken was not at the level expected. In particular, the following points are noteworthy, particularly from an improvement perspective:

- Cold bridging should be considered at the outset of any project
- Bespoke details should be created to minimise the risk of cold bridging and mould growth
- Materials should be protected both when stored on site and in periods of extended rainfall
- The over reliance of expanding foam to fill gaps in the structure should be reduced, and correct materials used instead to match the existing sub structure
- All rotten timbers with excess moisture content should be cut out and replaced with new timber from a sustainable source.

Hertfordshire 1 & 2

Three sites in Hertfordshire were inspected. The dwellings at the first two sites are semi-detached and of brick construction with render as shown in Figure E19 below.

Figure E19 – Front of one of the homes

Observations

The works undertaken were completed in very difficult weather conditions, with prolonged spells of heavy rain delaying the finishing of the works, resulting in the dwellings not having the final top coat applied for some months. This may or may not affect the long term performance of the solid wall insulation, and it would be prudent to undertake a prolonged monitoring period of the internal condition of the dwellings, to ensure that there has been no moisture penetration during the period between the commencement of works and completion.

The materials storage and general workmanship was good during the installation period, with the presence of a knowledgeable foreman during the process. There was also a good process for checking before progression to subsequent stages.

Thermal Bridging

As in all of the observations undertaken as part of this project there was no attempt to address the issue of cold bridging at junctions, joints and penetrations, see Figures E20, E21 and E22 below.

Figure E20 – Cold bridge at window detail

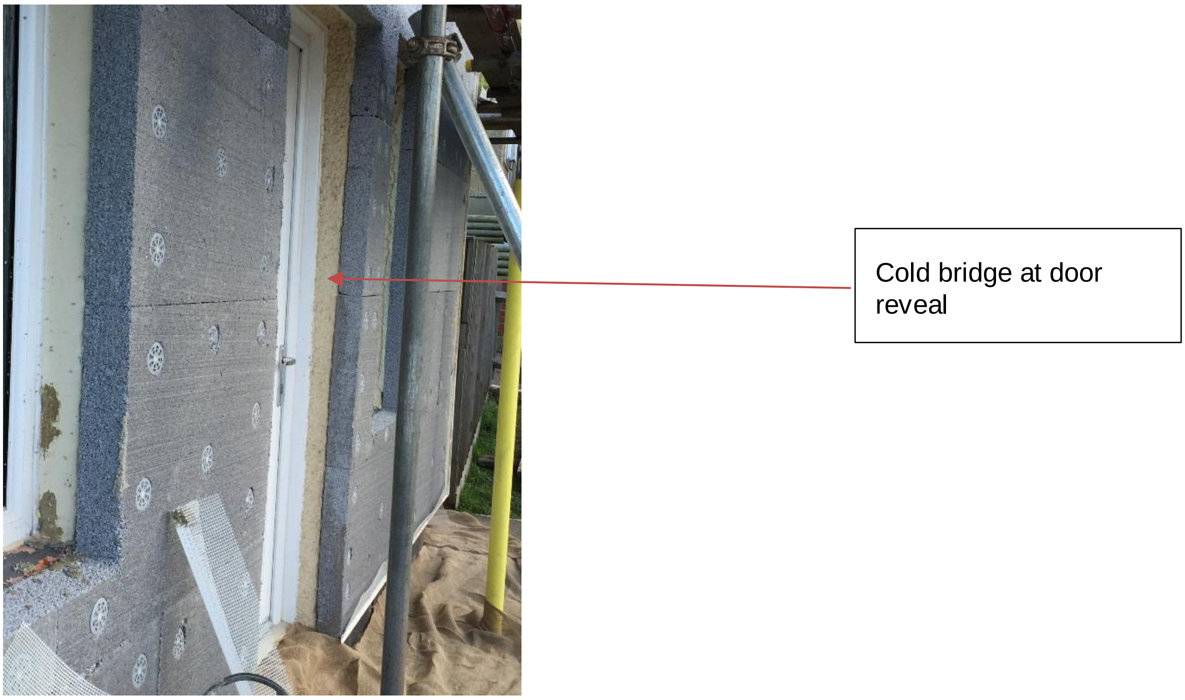


Figure E21 – Cold bridge at door reveal

Figure E22 – Cold bridge created by insulation stopped at DPC

Other observations

The dwellings in this location were not all owned by the housing provider, therefore the works resulted in adjoining dwellings not being insulated as a pair. This can lead to a raised level of risk by shifting the problems of poor performance to the uninsulated dwelling. It can also lead to a higher risk of moisture penetration at the boundary point where the insulation stops see Figure E23 below.

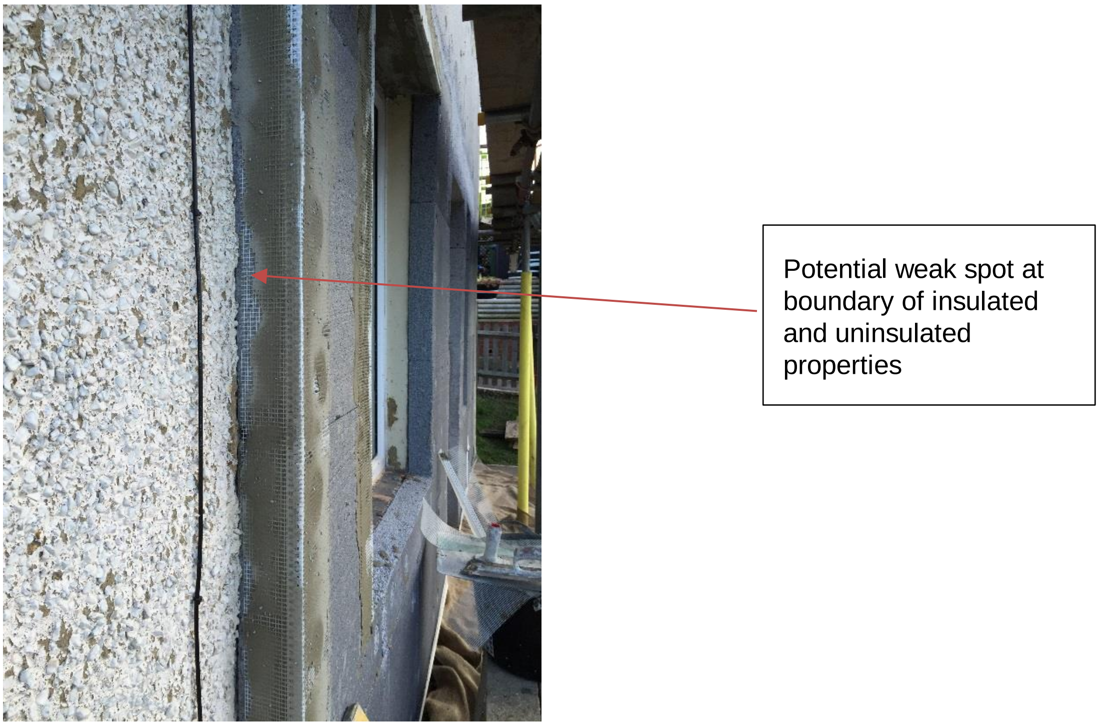


Figure E23 – boundary between insulated and uninsulated dwellings

If this junction had been considered at the design stage of the works, and appropriate details could have been used, such as the insulation being applied with adhesive and mechanical fixings, this would have reduced the risk of moisture penetration behind the insulation.

In addition there were inconsistencies in the depth of top coat applied to the mesh coat, resulting in poor covering. This may lead to movement in the top coat and the creation of micro cracks which could allow moisture ingress and delamination of the final coat. See Figure E24 below.

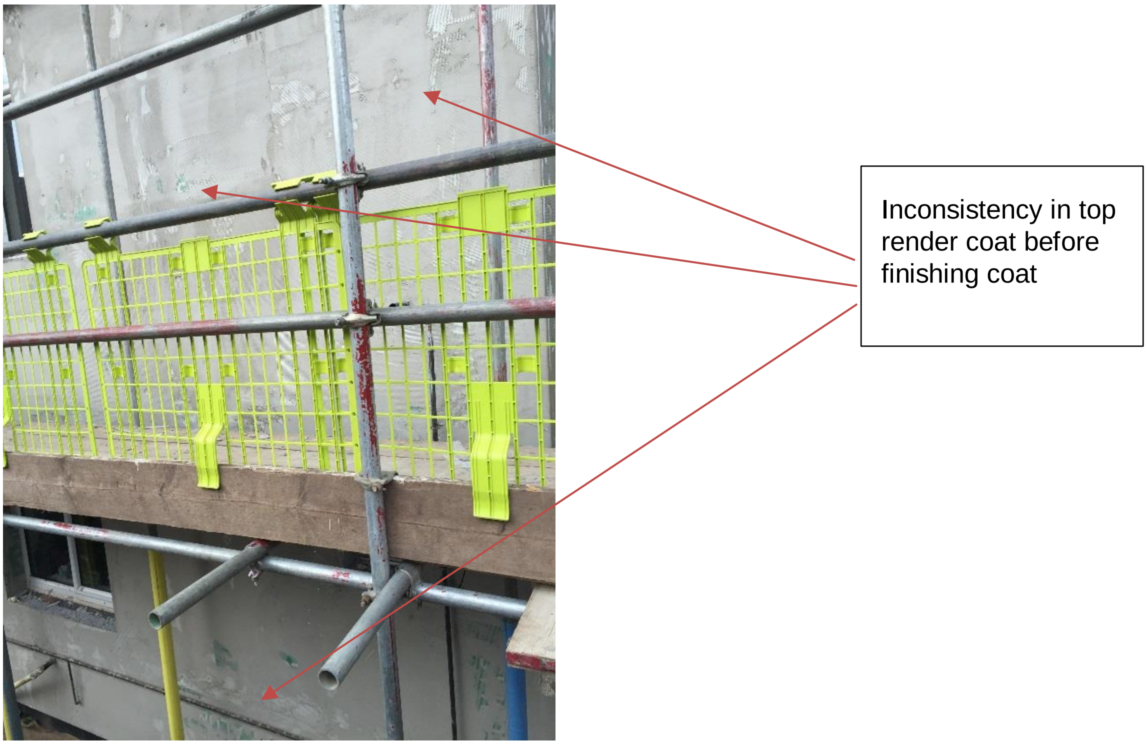


Figure E24. Inconsistency in top render coat before finishing coat

In situ timber moisture measurement

The initial download of data from the in situ monitoring indicated that the environment in the roof space and in particular the timber moisture content is relatively stable with a normal condition being maintained. See Figure E25 below.

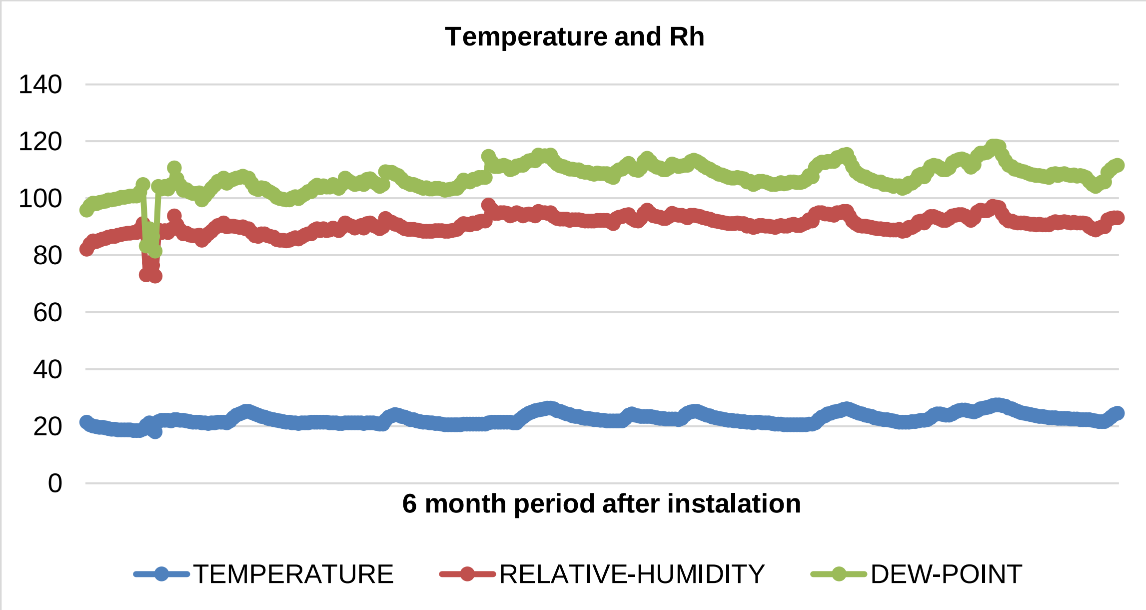


Figure E25 – Initial download of timber moisture data

Summary

In summary although the insulation process was reasonable, there were areas where the attention to detail or care were lower than the level expected. In particular, the following points are noteworthy, particularly from an improvement perspective:

- Cold bridging should be considered at the outset of any project
- Bespoke details should be created to minimise the risk of cold bridging and mould growth
- The risk of not insulating adjoining dwellings needs to be considered
- The detailing of adjoining dwellings to minimise moisture penetration behind the insulation needs to be considered
- The timing of works should be carefully planned to avoid where possible long periods of precipitation.

Hertfordshire 3

The dwellings at the third Hertfordshire location are traditionally constructed facing brick dwellings of 9" solid wall, brick soldier course heads, with rendered pine ends, and a brick band feature at first floor window sill level, as shown in Figure E26 below

Figure E26 typical dwelling elevation

Observations

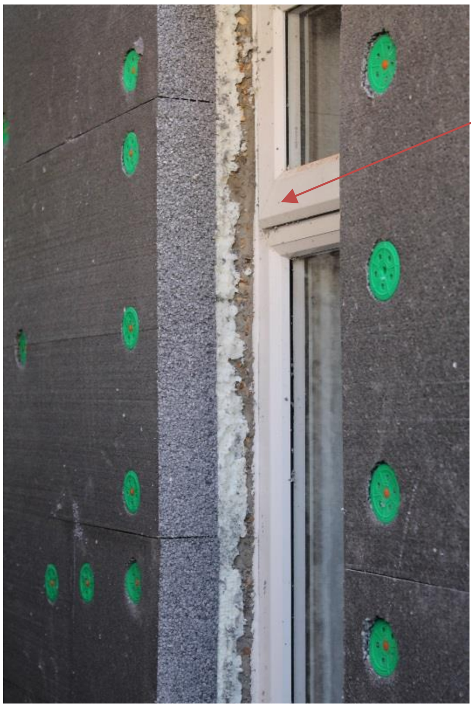
The site was one of the later sites in the programme to be observed and demonstrated a marked improvement in site practice. This included a dedicated site office and compound, correct storage and protection of materials, numerous levels of site supervision and in particular a clerk of works from the main contractor, the system provider and the housing manager. In reality this may be too onerous but clearly demonstrates an increased awareness of the importance of quality control in the installation process of solid wall insulation, which is to be commended.

Thermal Bridging

Although the process of quality control on site had without doubt improved the issue of addressing cold bridging had not, there was still no attempt to address the geometrical junctions that cause cold bridging, see Figure E27 below.

Figure E27 - Cold bridging at window junctions

Cold bridge at window junction



In addition the insulation was also not installed below the DPC, see Figure E28 below.

Figure E28 - SWI stopped short of DPC

Other observations

During the site observations it was apparent that the level of workmanship was improved compared with other sites, as can be seen in Figure E29 below, with closer placement of insulation board, minimal use of expanding foam, and correct fixing placement and numbers.

Figure E29 - Closer placement of insulation board, minimal use of expanding foam, and correct fixing placement and numbers

The general standard of workmanship and quality of fixings was significantly improved from previous observations made of installing solid wall insulation.

Although as previously stated the quality had significantly improved, there are still localised issues of attention that need to be addressed, see Figure E30, E31, E32 and E33 below.

Figure E30 - Soil pipe buried in the insulation

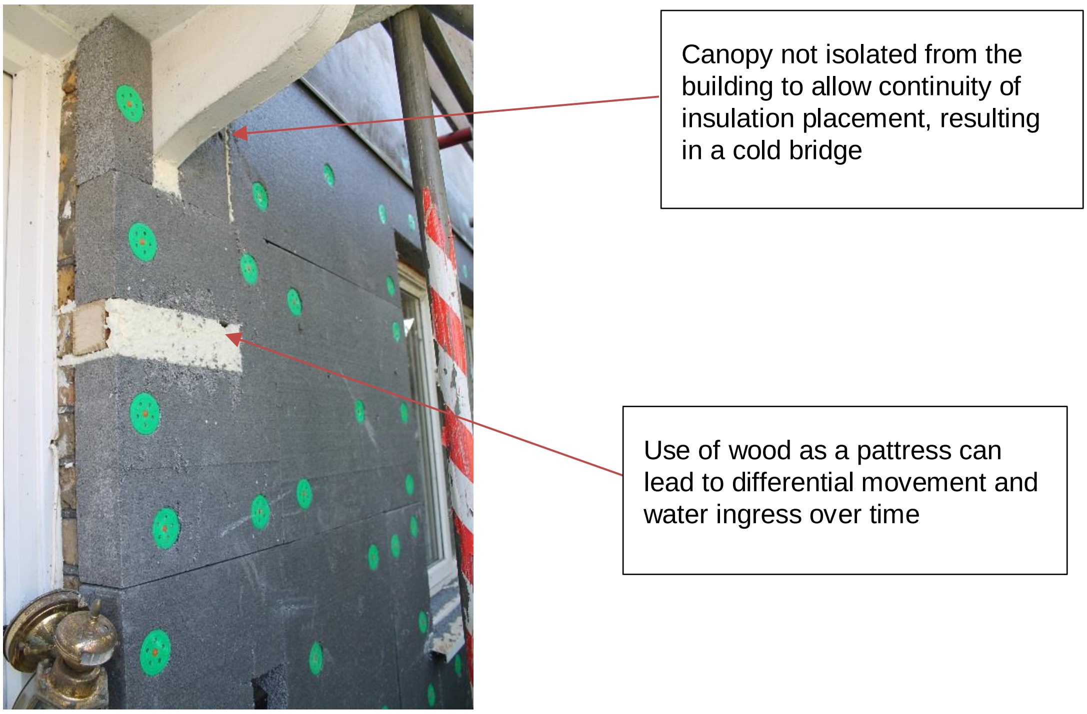


Figure E31 - Canopy not isolated from the building and se of wood as a pattress.

bre

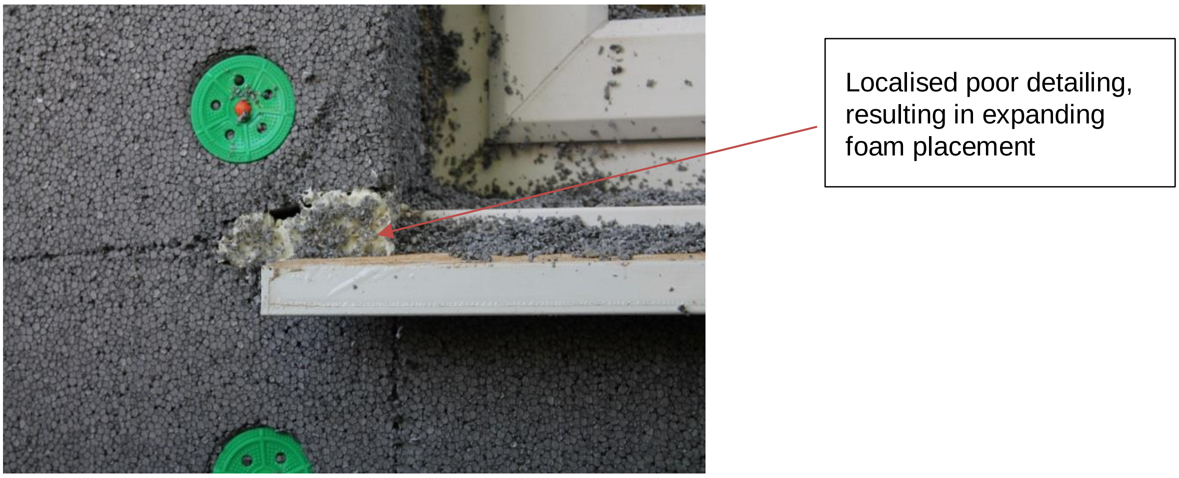


Figure E32 - Poor detailing

Figure E33 - Cold bridge introduced around gas flue

In situ timber moisture measurement

The initial download of data from the in situ monitoring indicated that the environment in the roof space and in particular the timber moisture content is relatively stable with a normal condition being maintained. See Figure E34 below

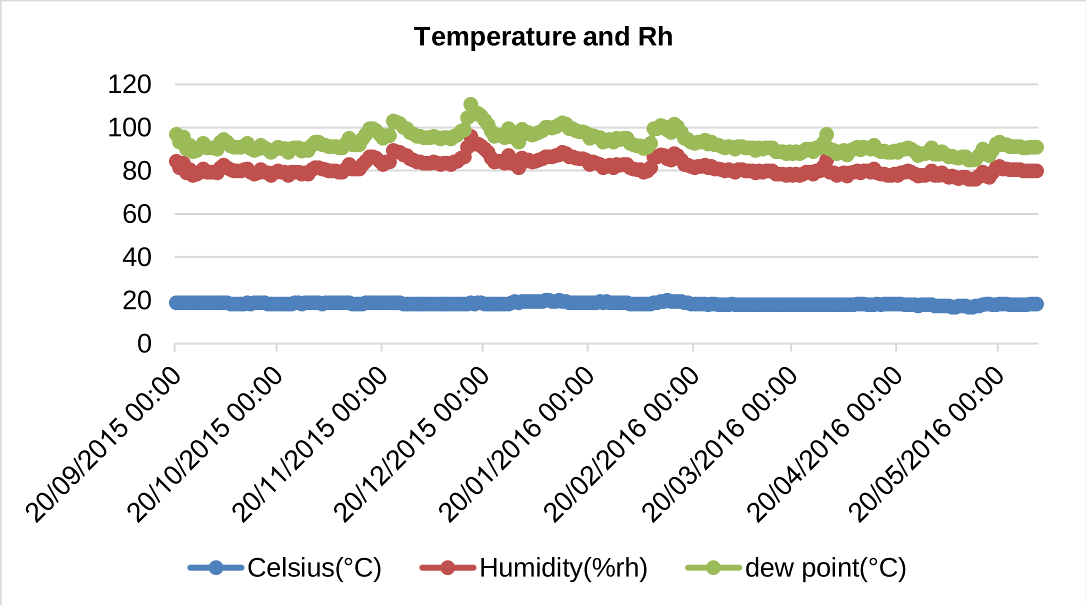


Figure E34 - Temperature and Rh

Summary

The installations at the third site in Hertfordshire are a better example of improved workmanship and levels of on-site supervision, however the lack of up front design process has resulted in the introduction of cold bridging and poor detailing. With greater attention to the surveying stage and understanding the challenges posed by the geometrical junctions and connections the installation, though good, could have been significantly better.

Attention to detail specifically around soil pipes, canopies and connections of fences could have improved the performance of the final finished project. Also the use of timber pattresses should be limited

Wales

The scheme in Wales was the last of the installations to be observed. The dwellings in question are of solid brick construction, with rendered finish and located in an exposed location. The dwellings are rendered with a substantial brick plinth of approximately 900mm in height.

The dwellings are located predominantly on sloping plots.

Figure E35 - Typical dwelling configuration.

Observations

The installation process for the solid wall insulation was interrupted over a period of time by extensive rain and poor weather conditions. The materials were stored appropriately during the installation process, and work put on hold in extreme weather conditions.

Thermal Bridging

Like all of the other observations there was no attempt to address the cold bridging around junctions and penetrations (see Figures E36 and E37 below) however the dwellings did benefit from a significant roof overhang, resulting in good protection at high level to the insulation, minimising the risk of cold bridging at roof level. See Figure E38 below.

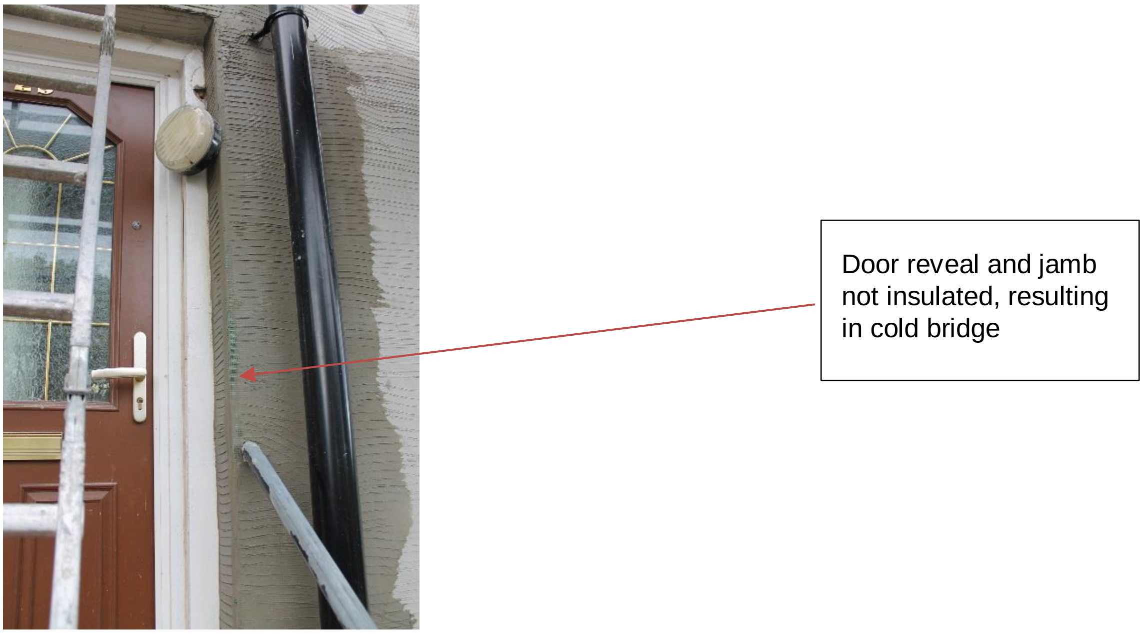


Figure E36 - Door reveal

Figure E37 – Insulation stopped at DPC

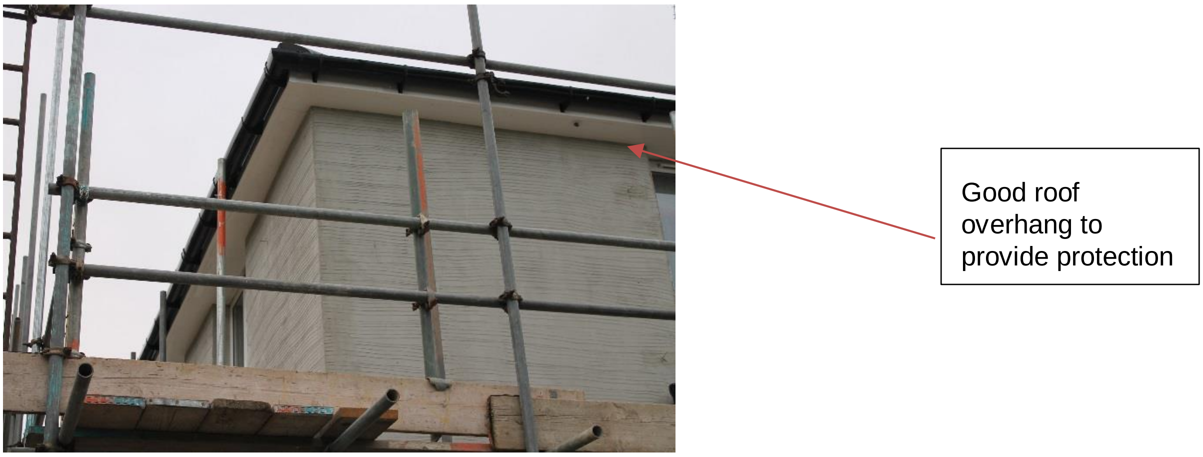


Figure E38 – Roof overhang

Other observations

In general the workmanship was of an acceptable standard, however close inspection did identify areas of inconsistency in top coat finish, where the mesh could be seen exposed; this was not covered up before the final coat was applied. See Figure E39 below. There were in addition other details which if considered up front could have been detailed more robustly, see Figure E40 below.

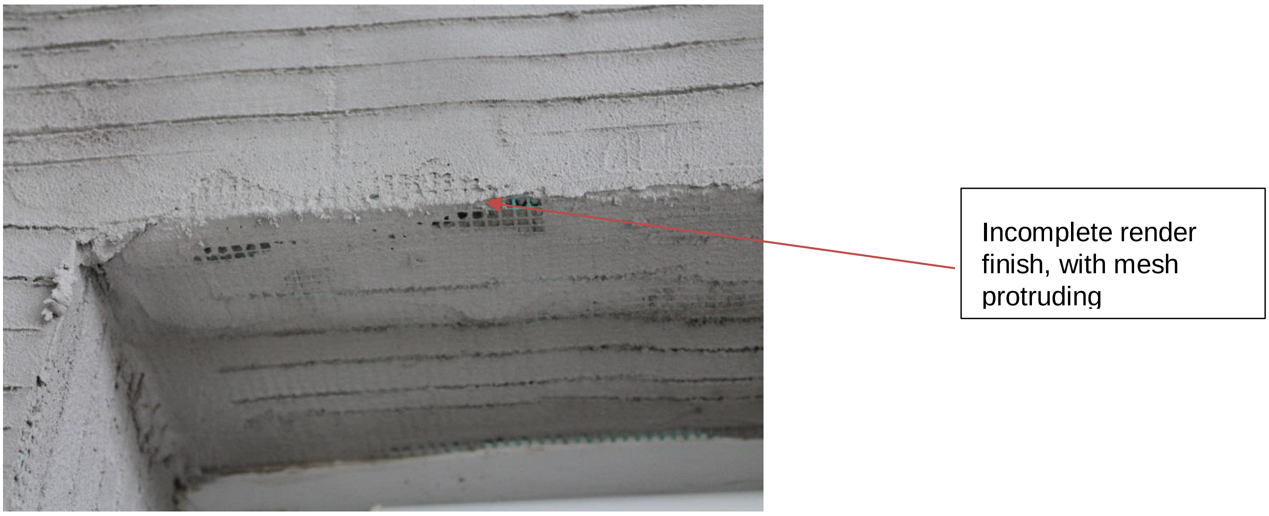


Figure E39 – exposed mesh

Figure E40 – Poor incoming services detail

In situ timber moisture monitoring

The initial download of the timber moisture monitoring indicated a gradual increase in Rh and potential risk. This has been brought to the attention of the housing provider, and may be linked to the issue of a lack of adequate ventilation to the roof space that was observed during the project. See Figure E41 below.

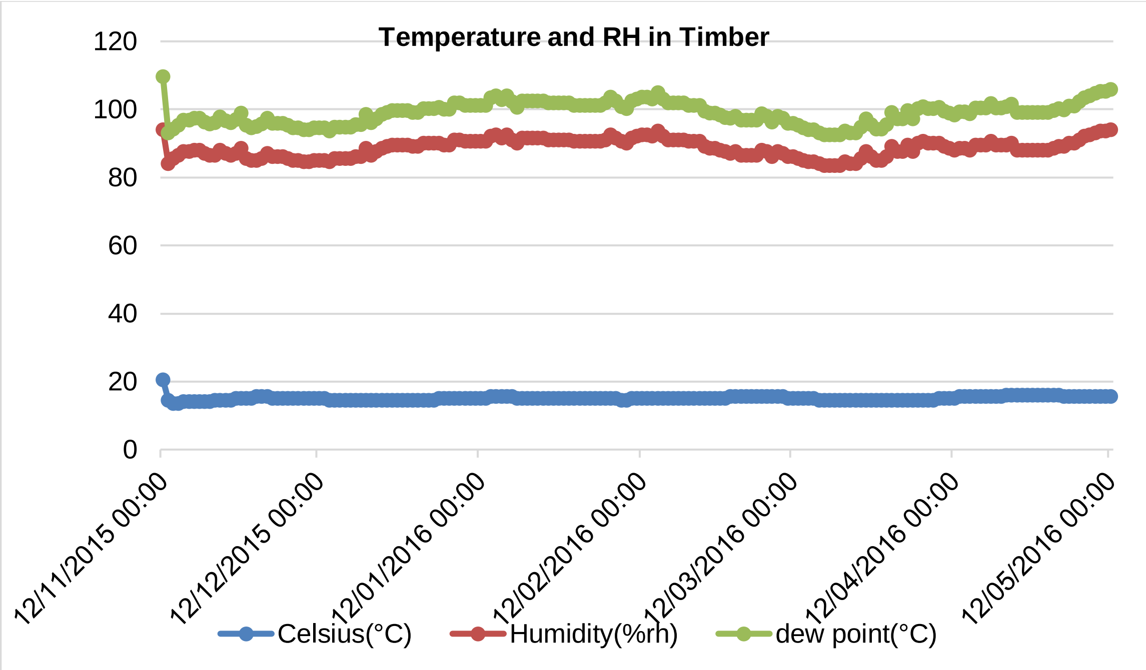


Figure E41 – Increase in Rh first data download

Summary

The installations at the Wales site are reasonable examples of workmanship and levels of on-site supervision however the lack of up-front design process has resulted in the introduction of cold bridging and poor detailing. With greater attention to the surveying stage and understanding the challenges posed by the geometrical junctions and connections, the installation, though good, could have been significantly improved. Attention to detail specifically around incoming services, and the DPC levels could have improved the performance of the final finished project.

Appendix F Distributions

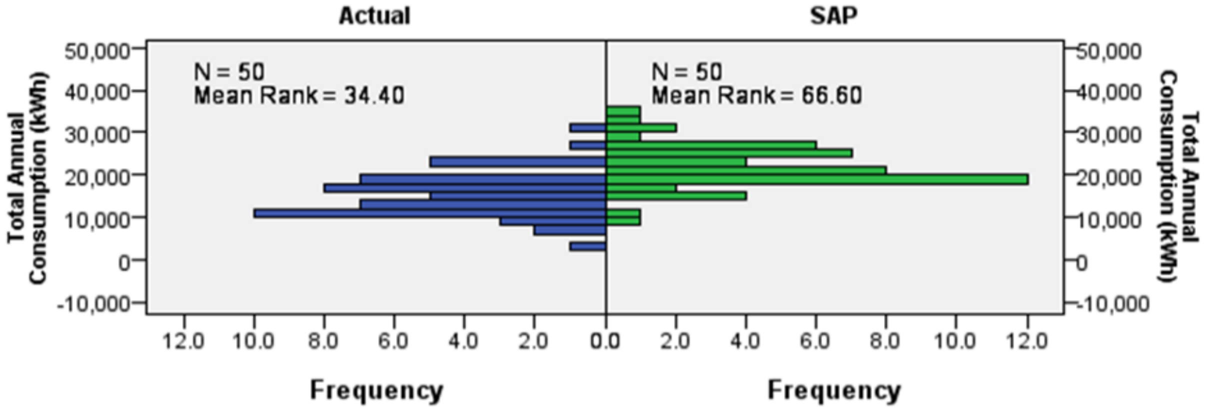


Figure F1 - Distribution of modelled and actual consumption

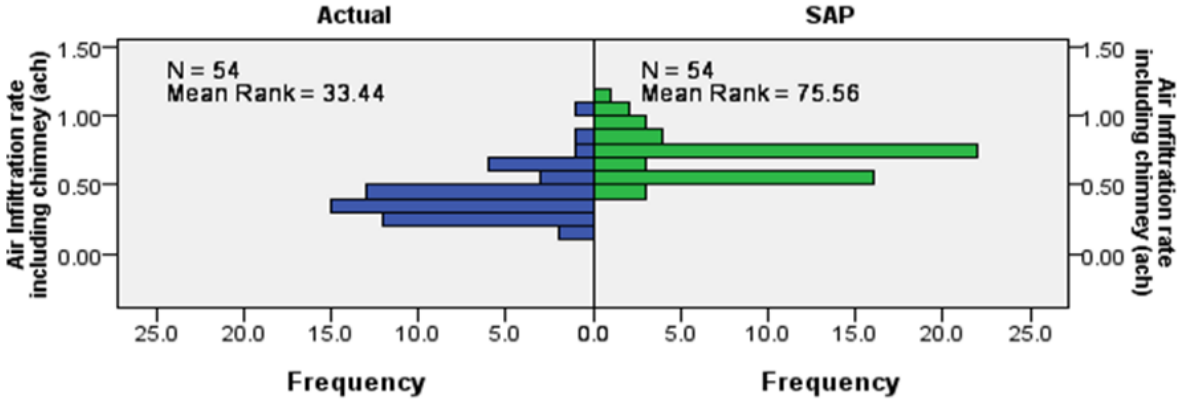


Figure F2 - Distribution of modelled and actual air infiltration rates (ach)

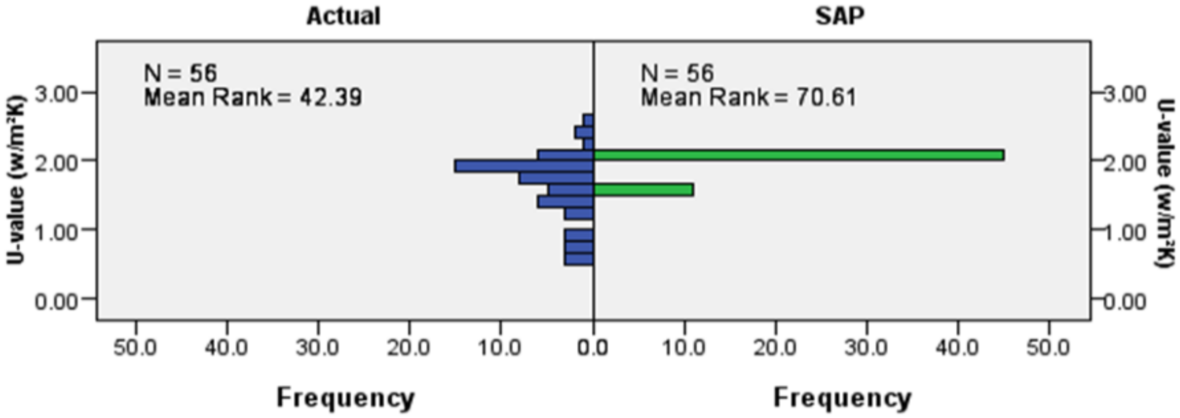


Figure F3 - Distribution of modelled and actual wall U-values

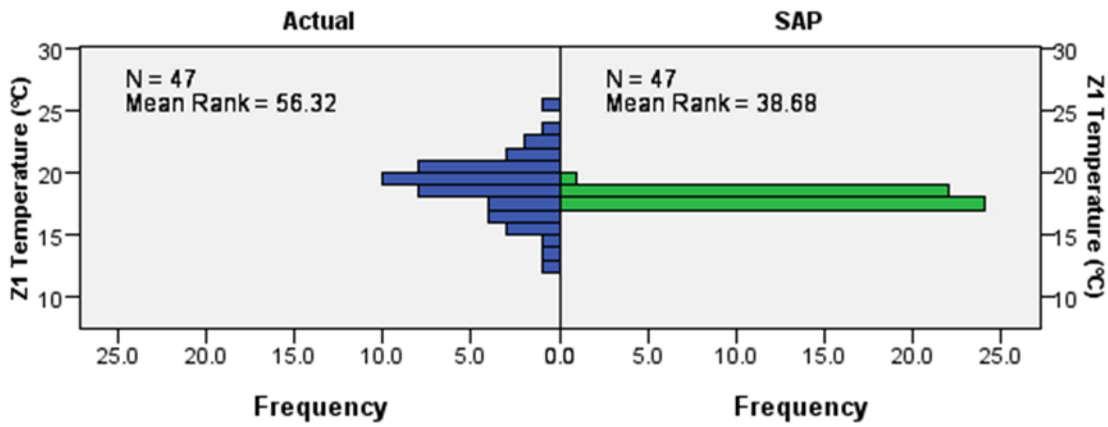


Figure F4 - Distribution of modelled and actual temperatures for zone 1

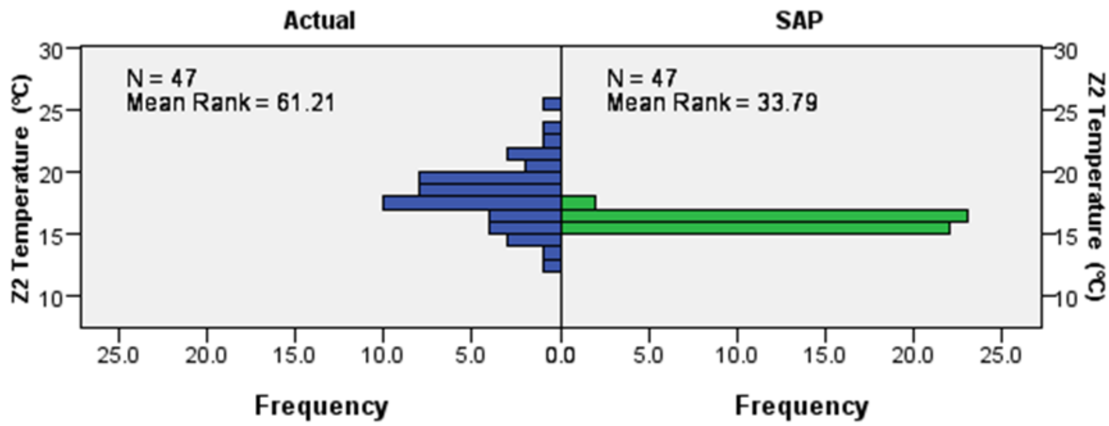


Figure F5 - Distribution of modelled and actual temperatures for zone 2

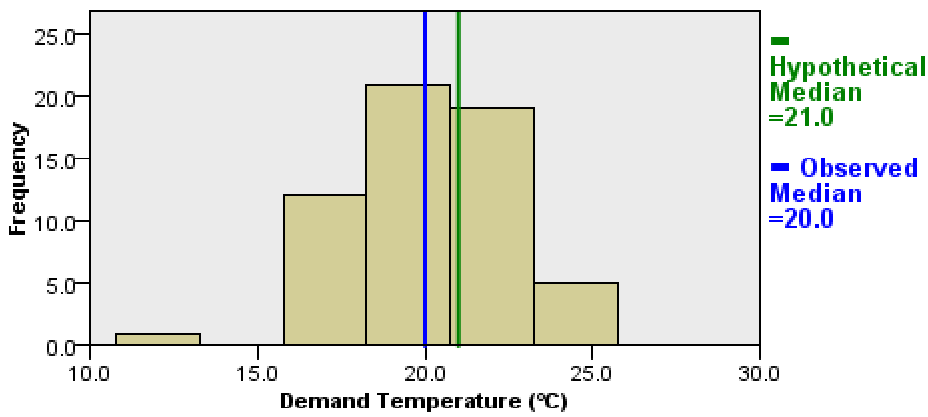


Figure F6 - Distribution of the measured demand temperature

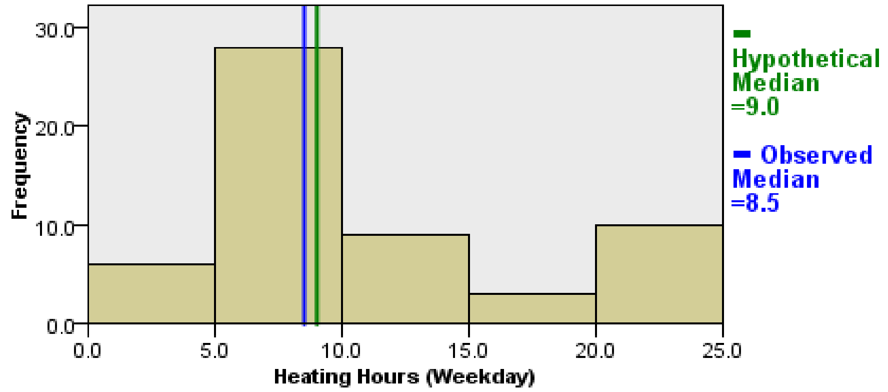


Figure F7 - Distribution of Weekday heating hours

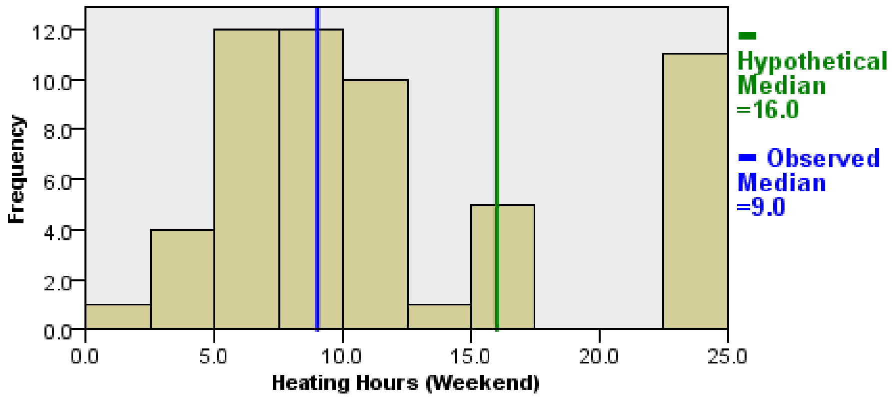


Figure F8 - Distribution of Weekend heating hours

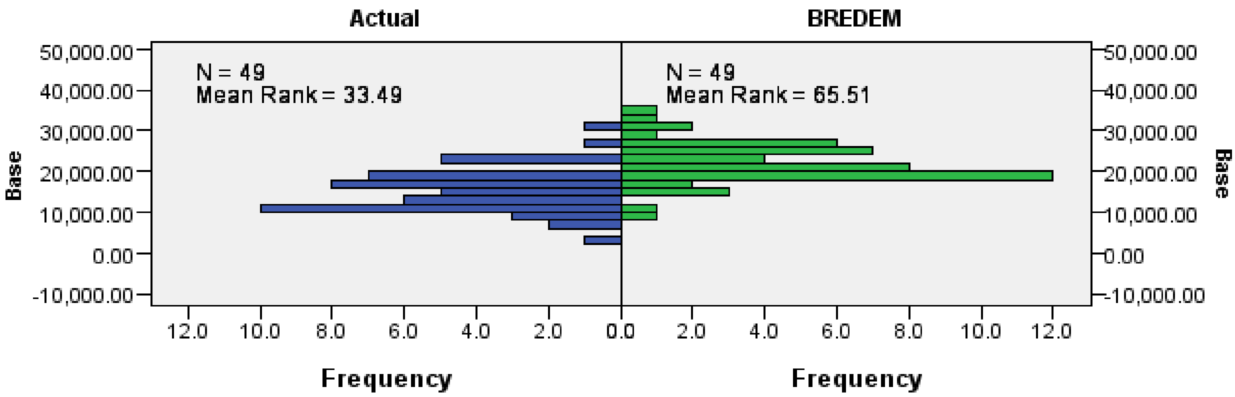


Figure F9 - Base modelled vs actual consumption, for all dwellings

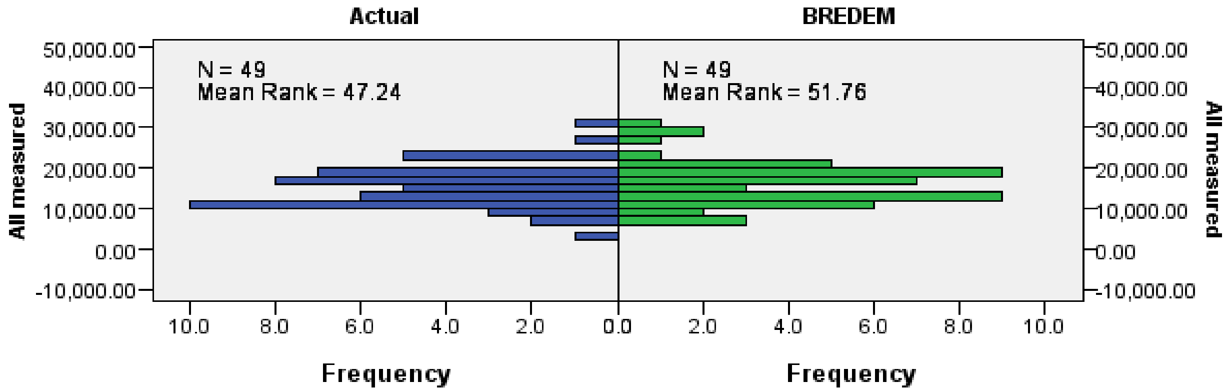


Figure F10 - Modelled with all measured values vs actual consumption, for all dwellings

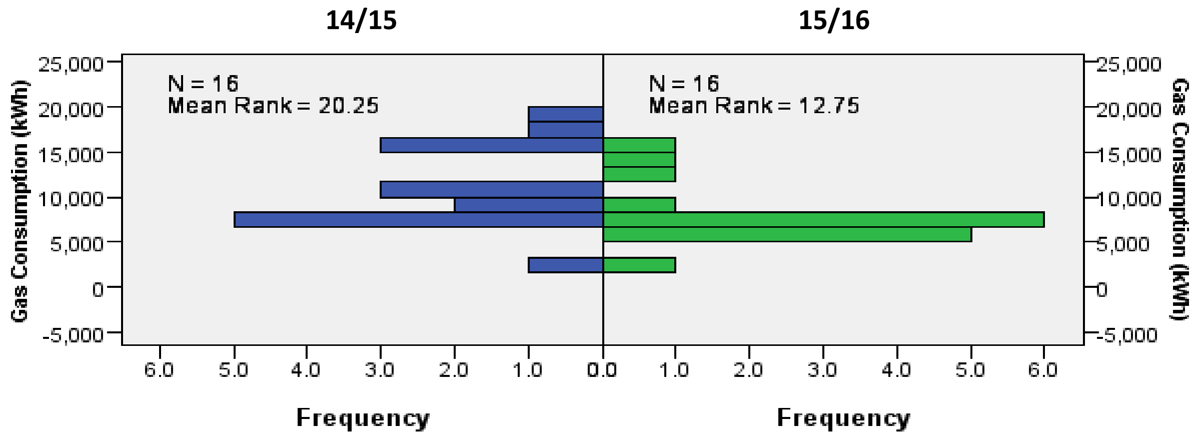


Figure F11 - Gas consumption

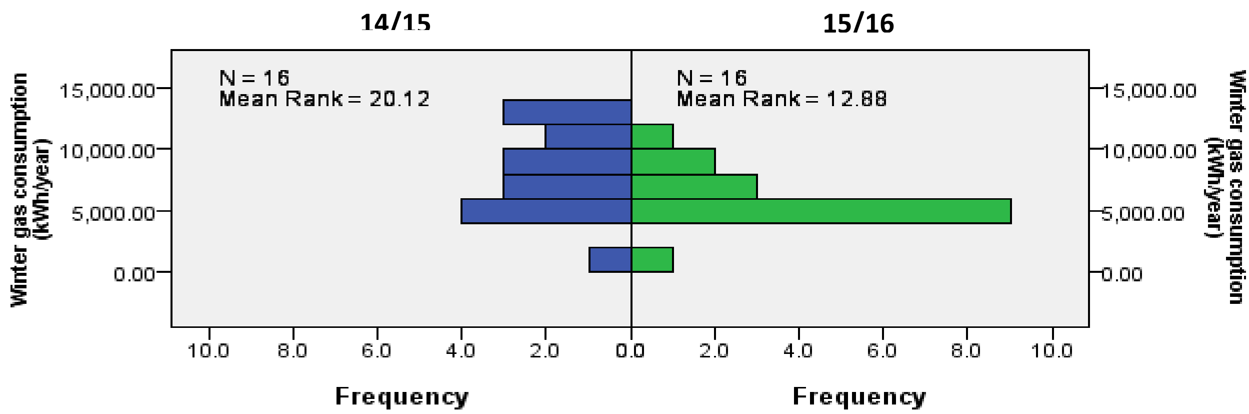


Figure F12 - Winter gas consumption

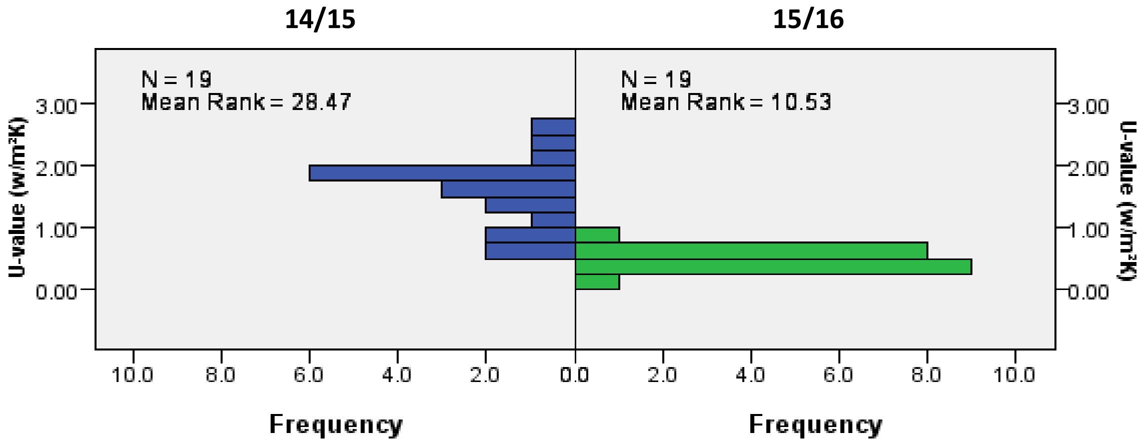


Figure F13 - Distribution of U-values for pre- and post- insulation

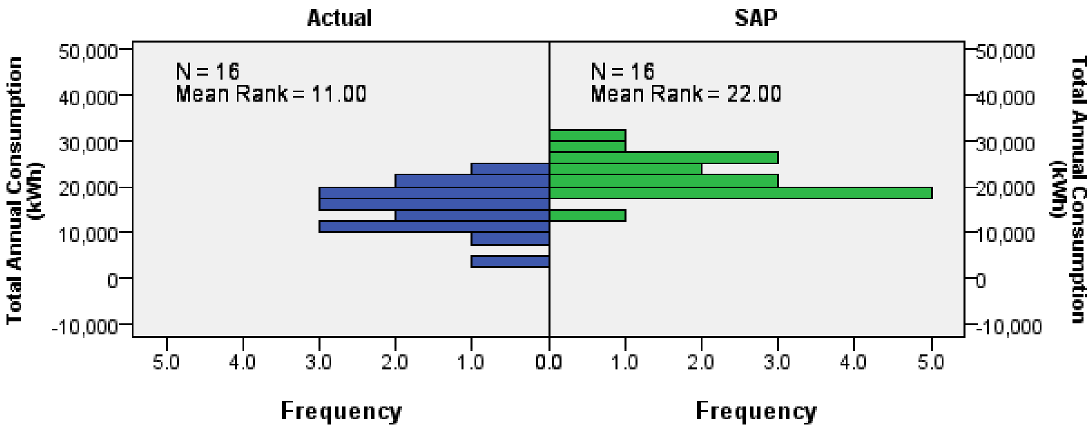


Figure F14 - Total annual consumption, 14/15 (Year 1)

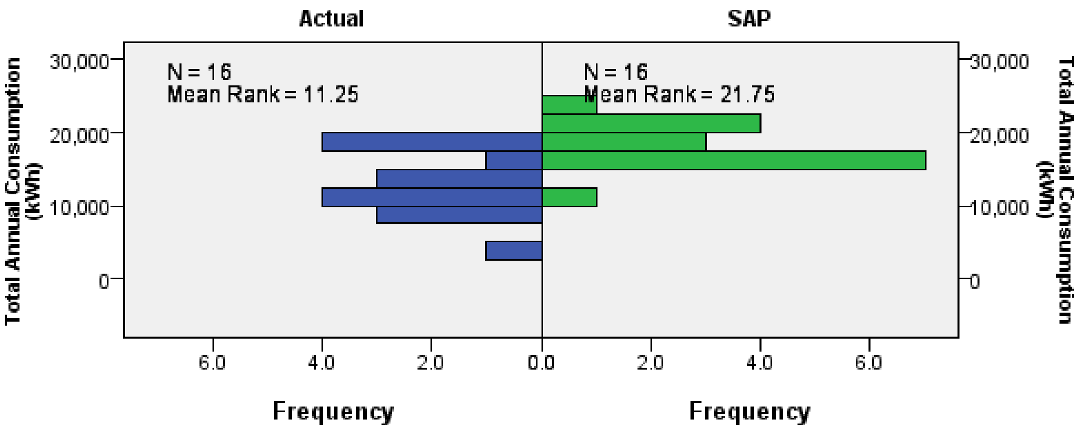


Figure F15 - Total annual consumption, 15/16 (Year 2)

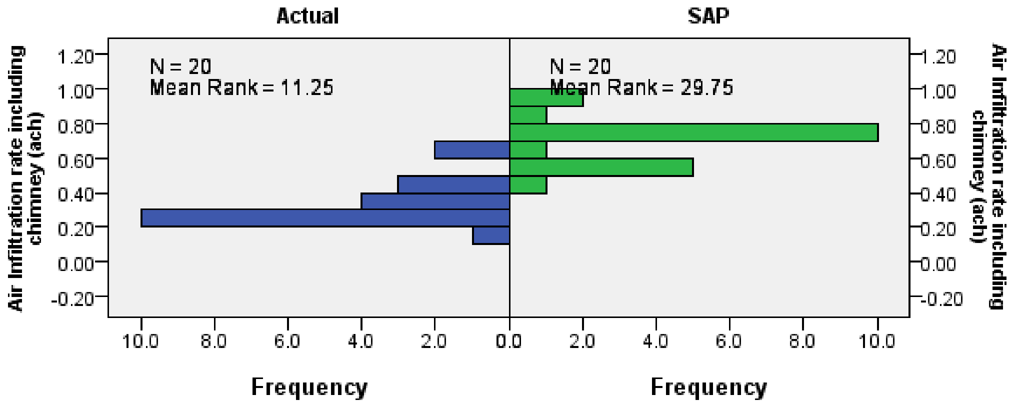


Figure F16 - Distribution of modelled and measured air infiltration rate, 15/16

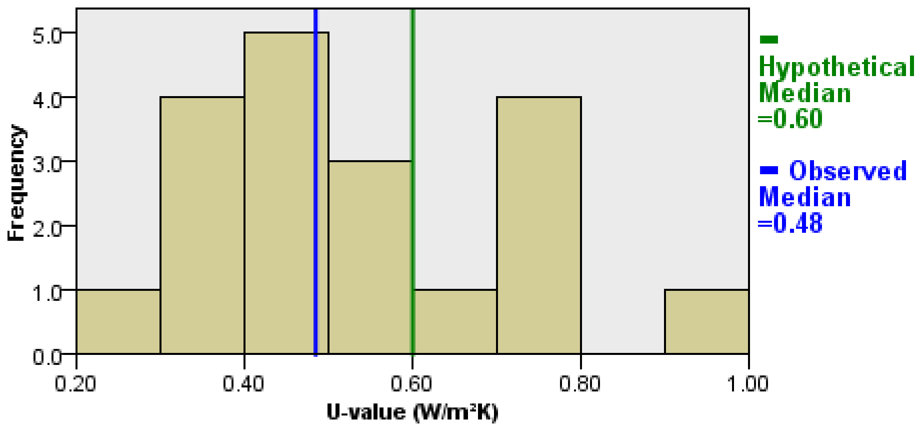


Figure F17 - Distribution of modelled and measured U-values, 15/16

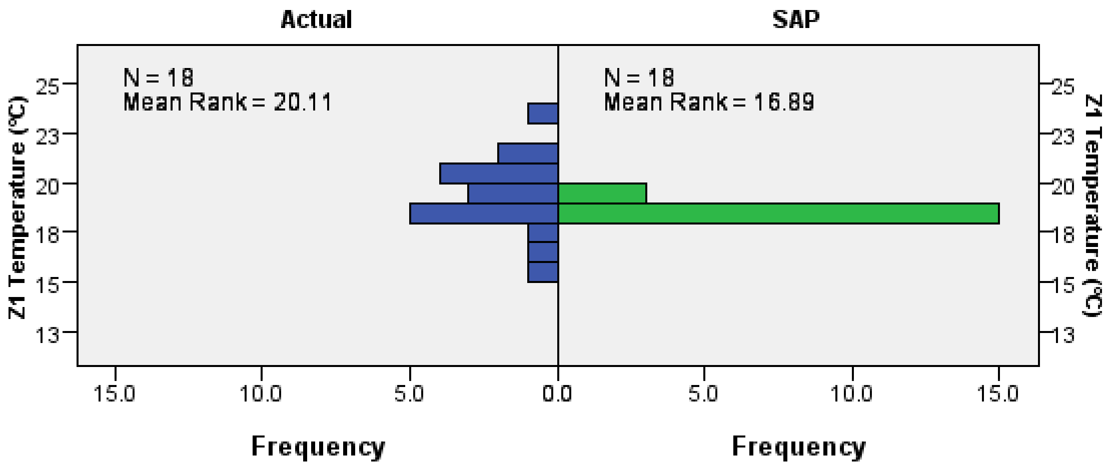


Figure F18 - Distribution of modelled and measured zone 1 temperatures, 15/16

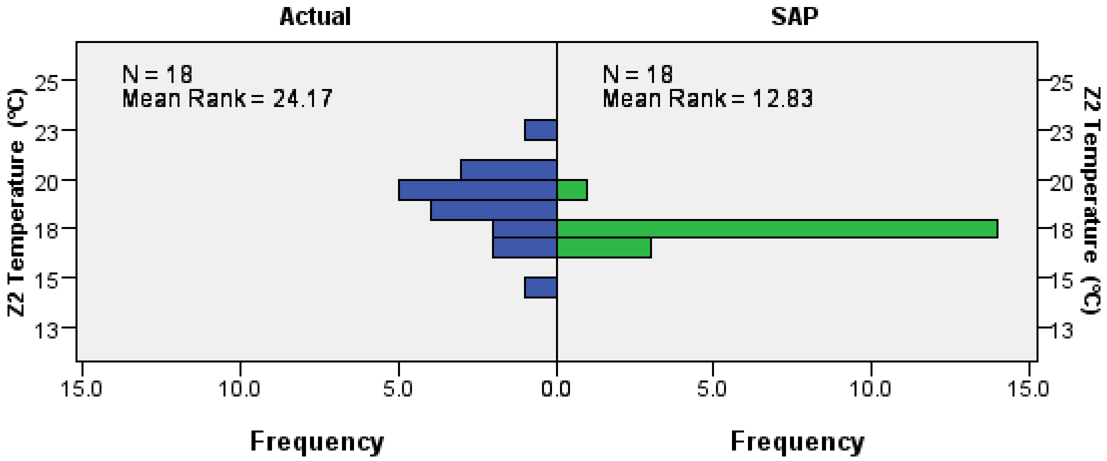


Figure F19 - Distribution of modelled and measured zone 2 temperature, 15/16

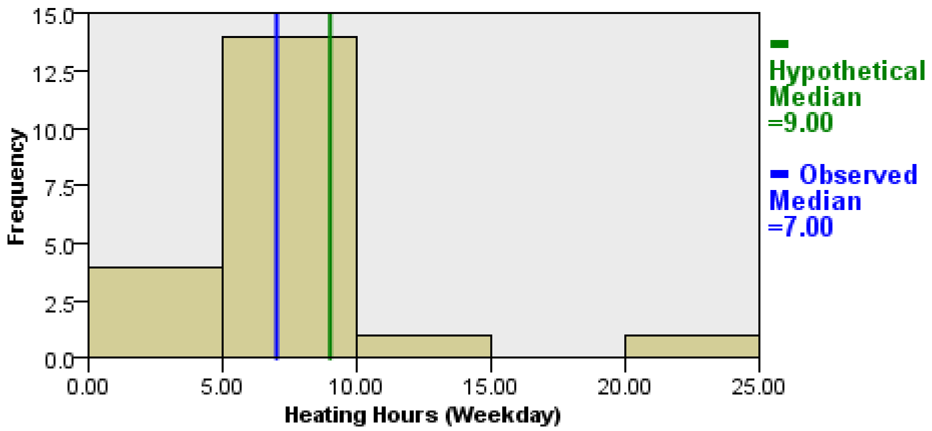


Figure F20 - Distribution of weekday heating hours, 15/16

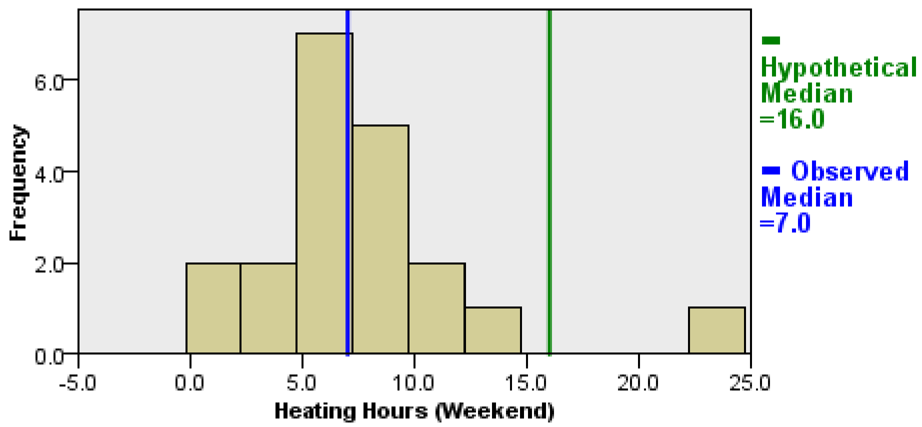


Figure F21 – Distribution of weekend heating hours, 15/16

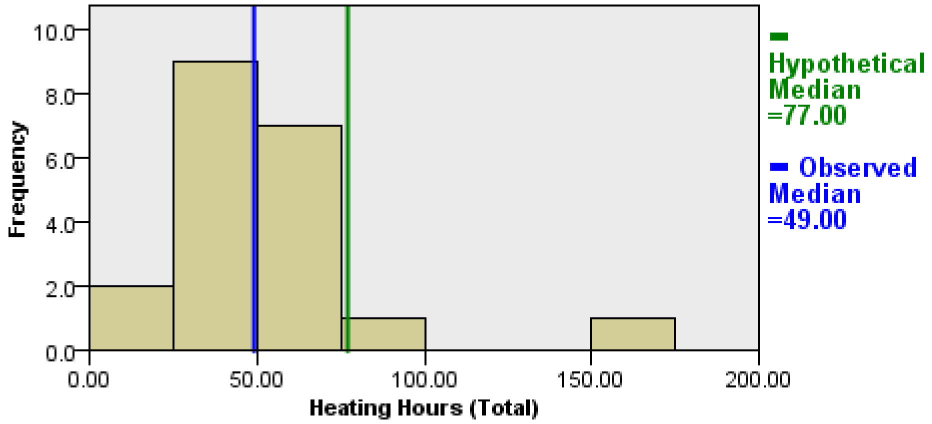


Figure F22 - Distribution of total heating hours, 15/16

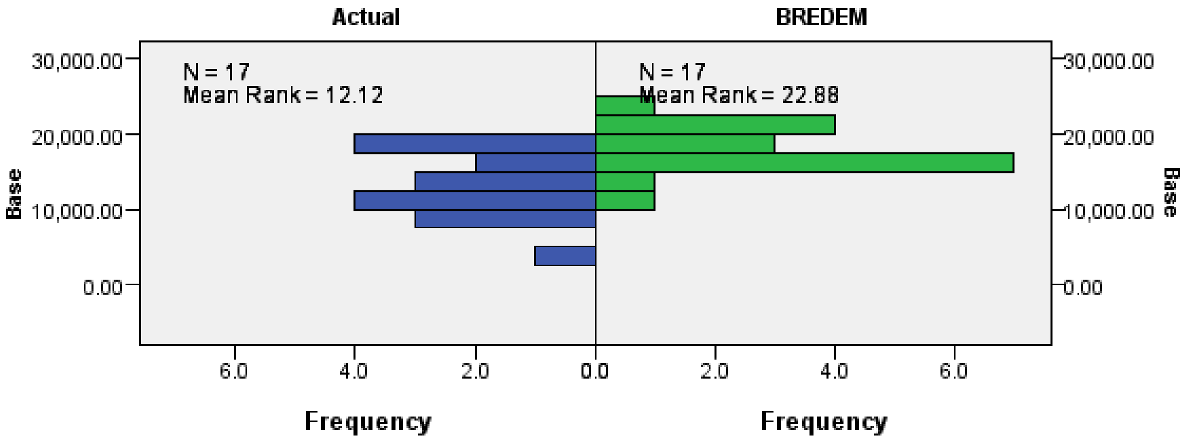


Figure F23 - Base modelled vs actual consumption, for insulated dwellings

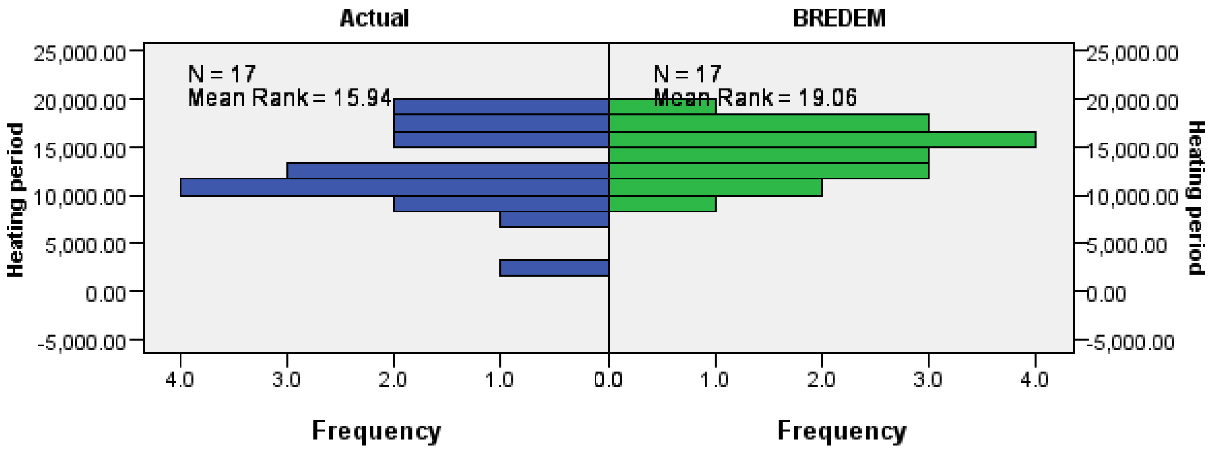


Figure F24 - Modelled with actual heating periods vs actual consumption, for insulated dwellings

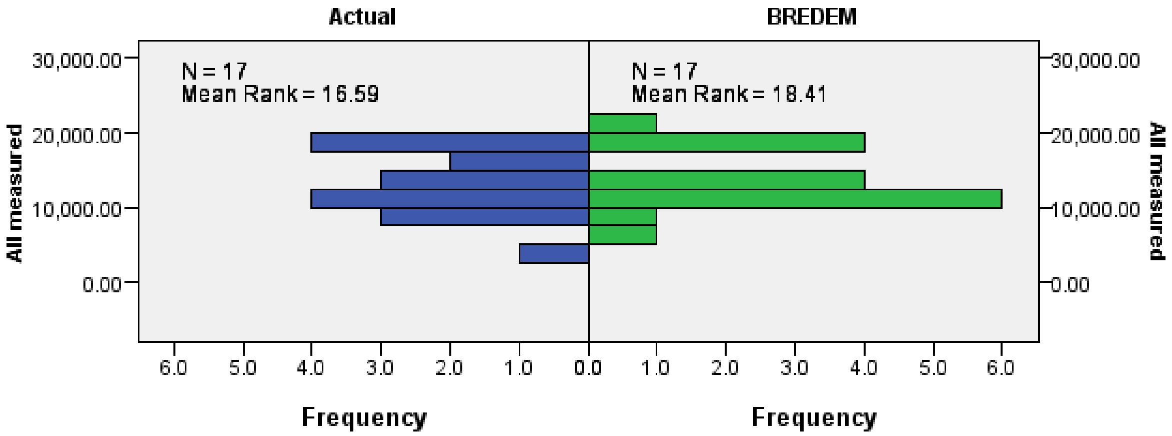


Figure F25 - Modelled with all measured values vs actual consumption, for insulated dwellings

Report Ends