Do U-value insulation? England's field trial of solid wall insulation

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Abstract

The Energy Saving Trust is completing the largest UK field trial to monitor the in-situ performance of solid walled properties and retrofit solid wall insulation. The field trial has gathered building performance data from 93 dwellings in England, including: environmental conditions; wall surface temperature; and gas and electricity usage all at 5 minute intervals. Thermal imaging, u-value and air tightness measurements have also been carried out, and all measurements have been taken before and after insulation.

U-value measurements show that pre-insulation thermal performance of solid walled dwellings in England varies widely. The average pre insulation U-value for the sample was 1.4 W/m^{2}K, well below the standard assumed value for a solid wall of 2.1 W/m^{2}K. Further, based upon temperature measurements, almost half of the dwellings in the trial were considered to be under-heated.

Partners from across the insulation industry committed to insulate up to 35 of the dwellings in the field trial. A number of challenges and barriers to installing solid wall insulation were identified, including technical, social and legal challenges encountered during the process of installation, which are discussed in further detail.

Early post-insulation data, presented for 11 dwellings, provides crucial insight into potential energy and carbon savings in the sample. Post insulation u-value measurements have also been investigated to reveal possible gaps in estimated performance of insulation systems based on lab testing and modeling versus observed performance.

This paper presents the baseline energy consumption measured at the 93 dwellings; demonstrates the measured u-values and thermal efficiency of the sample; presents modelled impacts to energy efficiency from installing insulation; and discuss the energy savings recorded at monitored dwellings as a result of the installation. Further, the paper introduces the barriers encountered to retrofitting solid wall insulation in the UK.

Introduction to the Field Trial

The Energy Saving Trust has a well-established reputation for developing and delivering projects to monitor the in-situ performance of energy-efficiency and low-carbon technologies. The Energy Saving Trust's field trial of residential solid wall dwellings is the most comprehensive exercise to determine the performance of this building type to date in the UK. This paper provides insight into the measured energy efficiency of existing solid walled dwellings in England including air tightness, thermal efficiency, and energy used for heating and provides a comparison to the UK's building regulations and standard assumptions for dwelling energy performance. Further, additional study was undertaken at a sample of dwellings where insulation was fitted, and preliminary findings of how insulation has impacted the dwelling's energy efficiency are discussed.

The field trial was developed and launched in 2009 to monitor the in situ performance of a representative sample of 93 solid wall homes in England. Too little is known about the actual in-situ performance of solid wall buildings in the UK. Previous studies of solid wall dwellings have been undertaken, including co-heating tests; thermal imagery; u-value measurements; and energy monitoring. None of the studies have combined all of

these different types of measurement or included monitoring of dwelling performance after insulation has been installed.

The Energy Saving Trust study, funded by the UK Department of Energy and Climate Change, combined a comprehensive year-long monitoring of existing dwellings to establish a 'baseline' energy performance, including the actual energy use and heating requirements, at the dwellings. Further, the u-values of the solid walls were measured and thermal imaging was undertaken to identify heat loss and to compare against standard UK assumptions for buildings. After a year of data collection, dwelling performance was modelled, using the UK Government's Standard Assessment Procedure (SAP) for the Rating of Dwellings (BRE, 2011) to illustrate the theoretical improvements to the sample if solid wall insulation should be installed. Finally, solid wall insulation was installed at a sample of up to 35 dwellings to measure the improvements of the energy performance; internal temperature; and changes to energy demand of the dwelling.

The study therefore illustrates the actual performance of solid walls, including u-values and heat loss, in England. The paper and provides a comparison with generally-held assumptions such as the UK Building Regulations part 'L1B' conservation of fuel and power (existing dwellings) (HM Government, 2010) and SAP and identifies the potential energy savings, both theoretical and practical, from the installation of solid wall insulation.

The outcomes from the study will help UK policymakers and the supply chain understand the potential energy savings from the installation of SWI in the residential sector; identify the potential future uptake of the technology; and identify additional considerations including disruption to the householder and planning issues.

THE BACKGROUND

The UK has adopted the most ambitious target in Europe for reducing carbon emissions. By the year 2020 the UK is obliged to reduce greenhouse gas (GHG) emissions by 34 % (from 1990 emission levels) (DECC, 2008). 27 % of British carbon dioxide emissions come from the energy used in our homes, so around a quarter of this 34 % saving must also come from our home consumption. Solid wall insulation is considered to be an integral measure to help the UK meet its GHG reduction targets.

For a number of years, incentive programmes across the UK have provided support to householders to accelerate the uptake of a range of insulation and energy saving measures technologies. Cavity wall and loft insulation measures have been incentivised through the Carbon Emission Reduction Target (CERT) scheme and more recently the Energy Company Obligation (ECO) and the forthcoming Green Deal. Solid Wall Insulation is now being considered for incentives through ECO. In order to set appropriate incentives and identify the appropriate market for solid wall insulation it is necessary to understand how the measure performs in-situ. The Energy Saving Trust identified that undertaking pre and post-installation performance monitoring in dwellings is essential to determine the potential energy savings from installing insulation in solid wall properties in England. The field trial has provided an opportunity to monitor the performance at a sample of 93 solid wall dwellings of various types from the English housing stock through the collection of energy data and building performance.

The principle objectives of the analyses were to evaluate and compare the existing quality of construction and energy performance of the sample and estimate the potential benefits of solid wall insulation for the sample and solid wall houses in general. The secondary objective of the study was to extract any useful insights from the available data on building thermal performance, energy consumption and occupancy patterns.

The following measures were investigated for each dwelling including:

1. Thermal imaging inside and outside the dwellings.
2. In-situ U-value measurements using heat flux sensors.
3. Air permeability testing.
4. SAP calculations based on detailed site survey data.
5. Analysis of energy consumption and environmental data logged at 5 minute intervals for up to one year.

The methodologies used to collect these measurements are discussed in the following section, and the results of the investigations and implications for the UK stock of solid wall dwellings are presented in the Key Findings.

SITE SELECTION

There are approximately 9 million homes in the UK with solid wall construction. There is a significant potential to reduce energy consumption from this dwelling type and meet energy efficient standards by installing solid wall insulation (Energy Saving Trust, 2008). It is therefore essential that the in-situ performance of insulation is monitored and understood to allow the measure to be correctly specified.

Research of the English housing stock was undertaken to determine if the sample of properties was representative to England as a whole. The English Housing Survey (DCLG, 2012), carried out in 2010, provides insight into the English housing stock. There are approximately 22.4 million dwellings in England. Of these, Solid wall construction was found in 28 % of the dwellings.

The study identified 93 dwellings across England to participate in this study. The sample included detached and semi-detached houses; terraced houses; and flats. 65 of the properties were constructed before 1900, 22 were constructed between 1900 and 1929 and one property was built in the 1970's. The year of construction was unknown for the remaining 5 properties. All the properties included in this study were self-selected and most were owner occupied. All properties were least partially solid wall construction and heated by a variety of means including gas, electricity or oil. A pre-requisite for the study was that all properties had to be double glazed. Figure 1 illustrates the type of dwellings that were included in the study and Figure 2 illustrates their geographic locations.

Work commenced in January 2010, initially selecting a sample of homes then commencing the phase of baseline monitoring (i.e. before the installation of insulation), resulting in the data that forms the content of this paper.

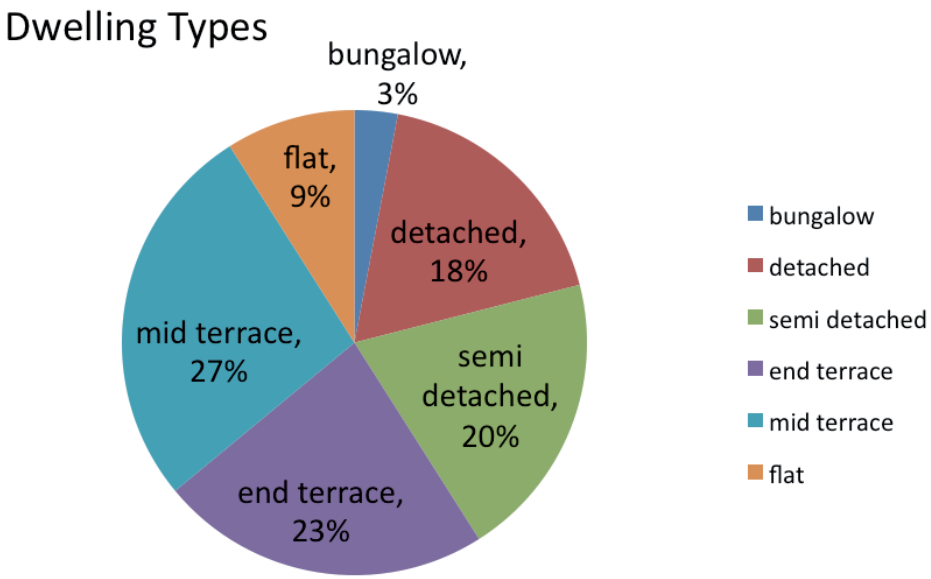


Figure 1. Distribution of monitored sites by dwelling type (n=93).

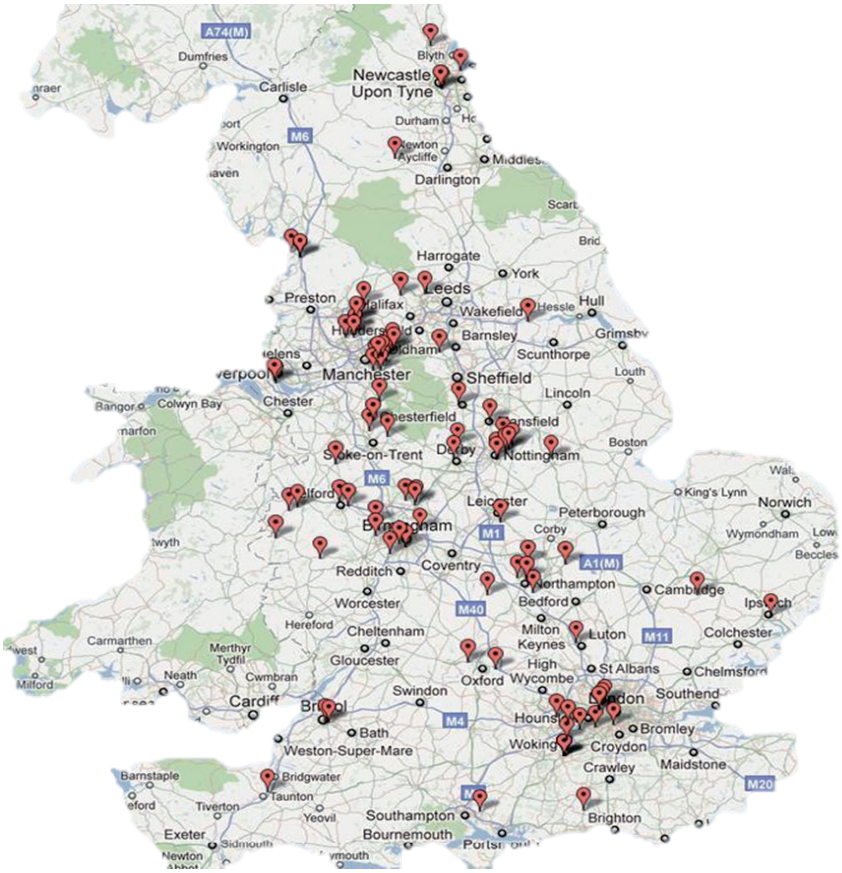


Figure 2. Distribution of monitored sites across England.

Monitoring Methodology

The field trial collected performance and environmental conditions data from the 93 dwellings for a continuous period of at least 12 months, until the property was insulated. A multiple-stage process was undertaken to determine the energy performance of the existing dwellings**.**

Thermal imaging. Thermal imaging was used to identify specific problems such as gross thermal bridging, air leakage paths, dampness and for "before and after" comparison. Images were obtained for every visible surface of external walls. In ideal conditions the surface temperature of a wall differs from the air temperature around it because of the boundary layer resistance. Boundary layer resistances are generally higher on the inside surface of a wall because the air movement is less on the inside.

U-value measurement. The U-value (thermal transmittance in W/m^2K) of a representative external wall was measured for each property. U-value measurement is often used for "before and after" comparison of improvement measures. Measured U-values have also been used in the SAP calculations and form part of the estimate of theoretical benefits from additional insulation later in this report. This data set also provides what is possibly the largest single collection of U-value results for older properties in the UK.

The U-value of the wall was measured in accordance with ISO 9869 using a method similar to that used by the UK's BRE in their *Cavity Wall Insulation Study* of 2005-6. Ideally the measurement of U-values would be carried out under steady-state conditions but as these do not occur on site a procedure has been developed to allow the calculation of U-value from data obtained during non-steady state conditions over several weeks.

Two Hukseflux HFP01 heat flux sensors were installed close together on the inside surface of a representative external wall of each house to give two separate measurements of heat flow for nominally the same U-value. To maintain good thermal contact between the heat flux sensor and the wall surface silicon grease was used as the heat transfer compound, with a thin PVC film to protect the wall surface. Two thermistor temperature sensors were used to measure inside and outside air temperatures. The output of the heat flux sensors and temperature sensors was logged by measurement locations were chosen with reference to structural features and orientation. Ideally the sensors were located on a north facing wall away from local heat sources. The convenience of the occupants also needed to be considered as the measurement rig needed to be left in place without disturbance for two weeks or more in some cases. Thermal imaging was used to help place the heat flux sensors in a location with typical and spatially consistent surface temperature.

Air Permeability measurement. The air permeability was measured for each property. Measured air permeability data have been used in the SAP calculations later in this report. This data set also provides possibly largest single collection of air permeability results for older properties in the UK.

All new domestic buildings are required to meet certain levels of air permeability in an effort to improve the energy efficiency by minimising uncontrolled ventilation losses. Since changes were made to the Building Regulations in England & Wales in 2006 (HM Government, 2010), air-tightness testing has become mandatory for all new buildings. Compliance requires an air permeability result better than 10.0 m^3/m^2h at 50 Pa in new dwellings.

The air leakage characteristics of a building were measured using an air pressurisation/depressurisation technique. Airflow rates were recorded for a number of pressure differentials imposed on the building envelope by means of a fan. The airflow rate corresponding to 50Pa pressure differential was then calculated and divided by the envelope area to provide the permeability result.

The buildings were tested with all external doors, windows and window vents closed and with all internal doors wedged open. All mechanical ventilation ducts, flues, chimneys and dedicated ventilation openings for combustion appliances were also sealed. Using an electric fan capable of producing flow rates from 0.01 to 12.0 m^3/s at 50 Pa the flow was calculated by measuring the differential pressure across the fan system using a manometer(s). The differential pressure across the envelope was measured using another manometer. Internal and external temperatures were measured using calibrated probes with accuracy better than ±0.2 °C. Temperature measurements were averaged over the period of the test. All blower door systems used in the project were calibrated using UKAS accredited procedures.

SAP Calculation. The Standard Assessment Procedure (SAP) is the UK's methodology for assessing and comparing the energy and environmental performance of dwellings. SAP calculations were carried out for each dwelling based on survey data that was collected. Key outputs of the SAP calculations have been extracted from the SAP reports and analysed and presented by dwelling type. The SAP estimates of design heat load have been compared with actual heat load based on measured energy consumption for different outside temperatures.

After the baseline monitoring was completed, SAP calculations were then used to estimate of the theoretical improvement resulting from the addition of insulation or the reduction of air permeability in the sample of properties to compare the potential improvements to the dwelling energy efficiency.

Pre-installation energy& environmental conditions monitoring. Energy consumption (electricity and gas) and environmental conditions (temperature and humidity) were measured by "smart" utility meters at 5 minute intervals in each of the dwellings. Where sufficient data was available, degree-day correlations were used to establish the relevant split of heating and hot water energy consumption for each dwelling.

The following sensors were installed for each property:

1. Internal temperature and humidity: living room, bedroom and one other (often the 2nd bedroom or the office space).
2. Surface temperature: inside of external wall.
3. External temperature and humidity: north face of property.

Environmental conditions for each property were analysed and considered in conjunction with energy consumption data and consequent operating costs. The data have also been used to consider performance of the properties during the extreme cold weather of December 2010. The risks of condensation on cold walls leading to dampness have also been considered.

Findings from On-site measurements

Thermal imaging. Thermal imaging was carried out at all 93 properties. Uniformly cold walls occurred in some places in nearly all properties – as expected in solid wall construction. 24 of the properties (26 % of the properties within the sample) had a large number of cold patches and 31 had some cold patches (33 % of the sample).

U-values. U-value measurements were conducted at all 93 properties using the methodology described above. A small number of results are suspected to be anomalous and these have been discarded from this analysis. Measurements of 87 properties are considered to be sufficiently reliable. The median U-value of the sample was 1.40 W/m²K with a range of 0.36 W/m²K to 2.53 W/m²K as shown in Table 1. 90 % of the properties in the sample had measured U-values of less than 1.89 W/m²K. This is considerably better than the default value of 2.1 W/m²K based on solid brick construction and reflects the diversity of solid wall construction within the housing stock.

The average U-values by property type (Table 2) ranged from 1.31 W/m²K to 1.62 W/m²K. The average results for terraced properties were generally lower (better) than detached and semi-detached dwellings.

The results suggest that the UK assumption that solid wall housing has an average U-value of 2.1 W/m²K would be misleading. Over 90 % of the sample performed better than this. The finding does not suggest that solid walled dwellings would not benefit from solid wall insulation; rather suggests that wall construction should be carefully evaluated before investing in solid wall insulation.

Air permeability. The procedure for air permeability testing is set out in BS EN 13829:2001. The estimated uncertainty of the air permeability result is assumed to be 7 % of the measured value. The test measures the air flow required to generate a sequence of pressures up to 60 Pa. The air leakage for each property (m³/h.m² at 50 Pa) was then calculated from the data collected.

The median air permeability of the sample was 10.09 m³/m²hr at 50 Pa with a range of 3.33 m³/m²hr to 24.22 m³/m²hr at 50 Pa. The average air permeability of the properties tested was 10.50 m³/m²hr. Compliance with the Building Regulation requirements for new dwellings requires an air permeability result better than 10.0 m³/m²h at 50 Pa. Approximately 50 % of the properties within the sample have air-permeability results which are better than current Building Regulations. The reasons for the relatively good air permeability performance of the sample include that all the dwellings had been fitted with double glazing.

SAP calculations. The SAP rating is an energy cost indicator expressed on a scale of 1 to 100, with the higher numbers representing lower running costs. In England, the average SAP rating for traditional masonry cavity wall housing is 56. For solid wall dwellings a lower value of 42 has been reported. SAP evaluations were carried out on 92 of the properties. For the solid wall properties assessed in this study the average SAP rating is 53.7, considerably higher than the average SAP value for solid walls. The range of SAP calculations is presented in Table 3.

SAP calculations were being used to identify the space heating requirement of buildings presented as both kWh per year and kWh/m² per year. The average space heating requirement for all properties is 157.1 kWh/m²/year.

The average total CO_2 emissions from the properties within the sample were 5,684 kg CO_2/year, with minimum and maxi-

Table 1. Summary of the measured U-values.

Statistical Measure	Measured u-value (W/m2K)
Average	1.43
Median	1.40
Maximum	2.52
Minimum	0.64
Range	1.88
10th percentile	1.03
90th percentile	1.89
Standard Deviation	0.36
Sample size	87

Table 2. Summary of the measured U-values by property type.

Property type	Sample size	Average U-value (W/m²K)	Maximum U-value (W/m²K)	Minimum U-value (W/m²K)
Bungalow	3	1.62	2.52	0.80
Detached	16	1.44	2.21	0.80
Semi-Detached	17	1.59	2.30	0.76
End Terrace	19	1.37	1.90	0.70
Mid Terrace	24	1.37	2.25	0.64
Flat	8	1.31	1.50	0.98
Total	87	1.43	2.52	0.64

Table 3. Summary of SAP calculations.

Statistical measure	SAP rating
Average	53.7
Median	57.4
Max	74.3
Min	7.7
Range	66.7
10th percentile	38.3
90th percentile	67.5
Standard Deviation	14.053
Sample size	92

Table 4. Summary of SAP space heating requirements.

Statistical measure	Space heating requirement kWh/year	Space heating requirement kWh/m^2/year
Average	17375	157.1
Median	15456	155.3
Max	40955	259.9
Min	6610	82.4
Range	34346	177.5
10th percentile	9228	102.2
90th percentile	30314	214.6
Standard Deviation	8142.865	40.074
Sample size	92	92

mum values ranging from 2,559 kg CO_2/year to 14,745 kg CO_2/year. An average of 52.8 kg CO_2/m^2/year was calculated for all properties within the sample.

Pre-installation energy & environmental conditions monitoring. Energy consumption was recorded at 5 minute intervals. Electricity data was available for most of the properties for up to 9 months and gas for, on average, 7 months. Average weekly electricity consumption data was extrapolated to provide an estimated annual consumption. The median electrical consumption for the properties in the sample was 35.7 kWh/m^2/year.

Environmental data was collected and analysed to reveal the weekday heating pattern for each property during November 2010.The majority of properties (57 %) were heated according to the morning and evening pattern typical of working families while 19 % were heated continuously. The unexpected finding was 10 % of properties were heated only during the evening.

It was evident during initial examination of the data that many of the properties within the sample appeared to be heated to a lower temperature than might be expected of a modern dwelling, some as low as 14 °C during occupancy. It was also suspected from thermal imaging that some of the properties might be susceptible to internal condensation and dampness.

Key Findings

Installation of solid wall insulation is anticipated to reduce the heat loss from the dwelling; reduce energy costs; and provide improved thermal comfort. A modelling exercise was undertaken, using SAP, to identify the *theoretical* improvement to each dwelling from the installation of insulation including improvements to u-values and improved air permeability. In addition to the modelling of theoretical savings, actual savings were monitored in a sample of 10 dwellings once solid wall insulation was installed. These findings are presented in the following section.

Impact of installing SWI in the sample of properties: u-value improvements. The initial SAP assessment was based on the surveyed construction of the property using the results from the in-situ U-value measurements (or default U-values if measured data was unavailable). The calculations were then repeated for each property with the main wall U-value amended to 0.30 W/m^{2}K to assess the theoretical benefit of insulation measures. The theoretical benefits of improving the U-value from "as measured" to 0.3 W/m^{2}K, in terms of space heating requirements, are shown in Table 5.

The modelling exercise estimates the potential savings for properties in the study to range from 1,335 kWh/year to 22,272 kWh/year. The change in modelled SAP ratings is illustrated in Table 6 with a 25 % improvement in the average SAP rating.

Table 5. Comparison of dwelling space heating requirements using actual vs modelled SAP calculation.

Statistical measure	Current Space heating requirement kWh/year	Space heating requirement with U-value improvements kWh/year
Mean	17375	10149
Median	15456	8886
Max	40955	25340
Min	6610	3304
Range	34346	22036
10th percentile	9228	5649
90th percentile	30314	15563
SD	8143	4605

Table 6. Comparison of actual vs modelled SAP calculations.

Statistical measure	Current SAP rating	SAP rating with U-value improvements
Mean	53.67	67.50
Median	57.39	68.90
Max	74.31	79.85
Min	7.66	30.55
Range	66.65	49.30
10th percentile	38.26	58.04
90th percentile	67.46	75.64
Standard Deviation	14.05	8.52
Sample size	92	92

The primary energy use and design heat load for each property have also been calculated for the improved U-values. These results indicate an average 33 % reduction in primary energy and 27 % reduction in design heat load if U-value is improved to 0.3 W/m^{2}K.

Impact of installing SWI in the sample of properties: Air Permeability Improvement. A second set of calculations was carried to investigate how improved air permeability within the dwellings would improve the performance. In each case the air permeability was amended to a value of 10.00 m^3/m^{2}hour (the current level set in Building Regulations).

On average, improvements to the air permeability brought a modelled 1.7 % reduction in the design heat. This improvement was considerably less than the figures modelled for improved U-values, however the range of observed air permeability measurements was wide and included properties which already performed better than the Building Regulations requirements.

Post-insulation findings

Subsequent to the baseline energy monitoring and dwelling surveys, each property was visited by experienced surveyors to evaluate the most suitable method of insulation, taking account of the physical feasibility, views of the occupier and planning restrictions. The surveyors provided recommendations for the 93 properties within the study as shown in Figure 3.

Phase 2 of the study undertook to install solid wall insulation at 35 of the 93 dwellings followed by a second u-value assessment, thermal image, and second full year of energy and environmental monitoring This data would allow for a comparison of the actual improvements from the installation of solid wall insulation compared with the monitored data and modeled improvements in SAP.

The preliminary findings from 11 dwellings, where insulation was installed during the summer and autumn of 2012 are presented here.

Air permeability: The average improvement in air permeability was 8 % across the sample. A wide range of results was captured ranging from a 57 % improvement at IWI 1 to a 26 % increase in air permeability at hybrid 3 (Figure 4 and Table 7). IWI 1 was insulated internally with a phenolic foam backed plasterboard. Hybrid 3 utilised a mineral wool internal insulation on the front face of the house and rendered PIR foam to the rear. The marginal change in air tightness at most of the properties could be as a result of solid wall insulation contracts not concentrating on sealing the building. By contrast a whole house retrofit would be more likely to incorporate an air permeability strategy into the installation of solid wall insulation. As seen in the UK Retrofit for the Future program where in-

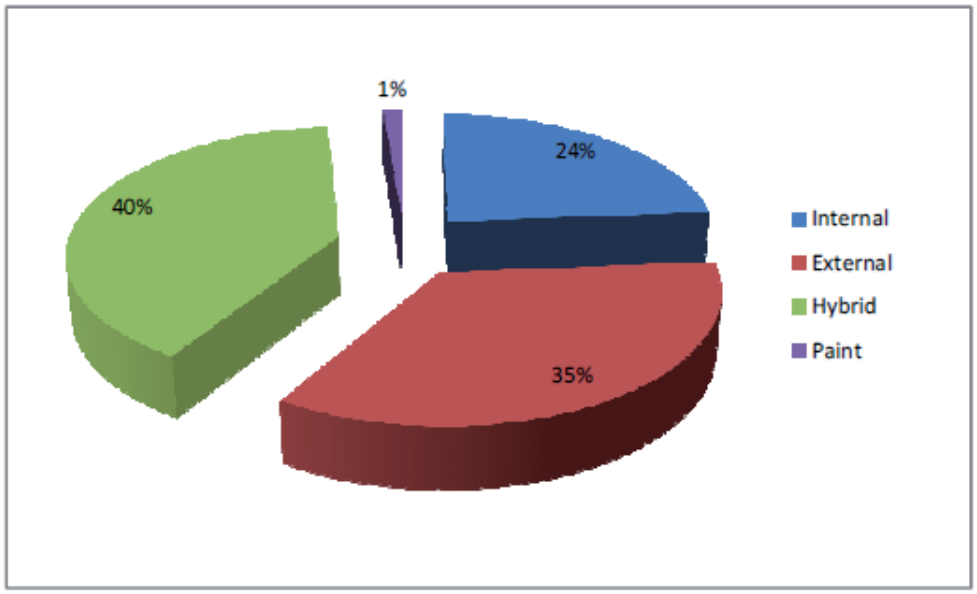


Figure 3. Recommended insulation methods (n=93).

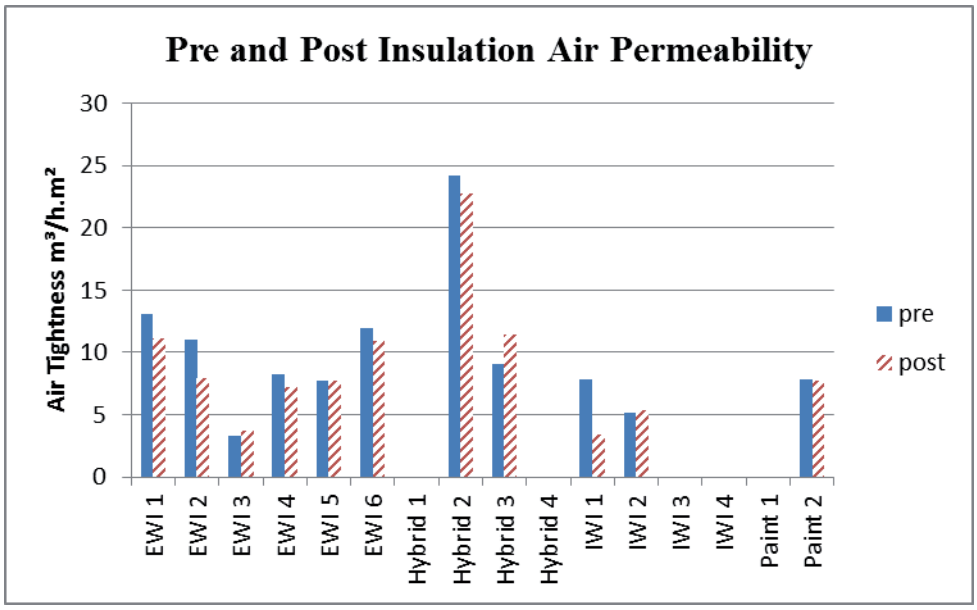


Figure 4. Air permeability pre and post solid wall insulation ($m^3/h.m^2$).

stallations carried out insulation and focused on creating an airtight envelope (A Technology Strategy Board whole-house retrofit programme of 119 social houses in the UK with the aim of achieving 80 % reductions in CO_2 emissions (Bradford, et al, 2013)).

U-Values: The average u-value post insulation was 0.44 W/m²K (Figure 5, Table 8), slightly short of the UK Building Regulations requirement of 0.3 W/m²K. This is surprising considering that the average pre-insulation u-value was already lower than the SAP standard estimate of 2.1 W/m²K. The installers in the trial encountered several issues that could have led to specifying a reduced level of insulation. These included the aesthetic and economic impacts of extending roof rafters and eves to accommodate thicker insulation. With internal insulation householders were not willing to accept the loss of space from thicker insulation.

The greatest u-value improvement of 89 % was achieved with internal insulation in IWI 1, which also had the greatest air tightness improvement. The smallest change in u-value was observed in property hybrid 5 which was insulated externally with a rendered EPS foam system.

Energy Use: Due to the limited time to capture energy use data from the 11 properties since summer 2012, data is only available for 7 properties. So far, measured reductions in heating fuel use range from 14 % to 37 %. Figure 6 illustrates the reduction in heating fuel use over 1 year before and after insulation. Reductions are normalised using degree days to compensate for differing external conditions. With the current small

Table 7. Change in Air permeability in 11 properties after insulation.

	Pre insulation	Post insulation	% change
Sample size	**11**		
Average (W/m^2K)	**9.96**	**9.01**	**8**
Maximum (W/m^2K)	24.22	22.67	57
Minimum (W/m^2K)	3.33	3.42	-26

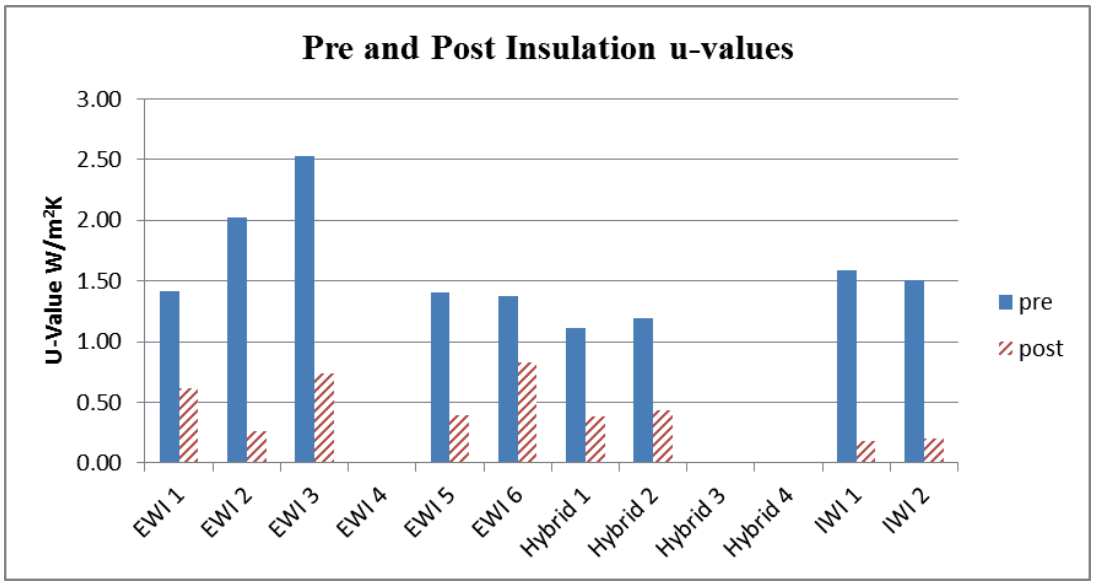


Figure 5. U-value measurements carried out according to BS EN ISO 6946 taken before and after installation of solid wall insulation.

Table 8. Change in u-values in 11 properties after insulation.

	Pre insulation	Post insulation	% change
Average (W/m2K)	**1.57**	**0.44**	**70**
Maximum (W/m2K)	2.52	0.82	89
Minimum (W/m2K)	1.11	0.18	40

sample size it is hard to draw conclusions on the differences in observed savings in the properties. The study will continue to collect measurements from these and additional properties during the next 1–2 years.

Qualitative findings: In addition to the measured energy performance, u-values, and air permeability in Phase 2 of the study, a number of important qualitative findings have been encountered. These challenges and barriers to installing solid wall insulation include technical, social and legal challenges encountered during the process of installation and are reasons why only 11 of the original 93 dwellings have completed installations of insulation.

One of the key challenges for external insulation (EWI) was the English planning system. Most installations were subject to planning applications and many local councils had different requirements. Requirements In many cases a full planning application was required including detailed site plans and design drawings. This process was time consuming, taking up to 3 months for a confirmation of permission. In some circumstances it was possible to fast track planning applications due to the nature of the housing to be insulated. It was found that including photographs of the property in applications allowed planners to make faster decisions based on the property.

Although less disruptive to householders EWI ran into some delays caused by the need to relocate mains power lines and problems with applying render in cold conditions. Some of these delays led to scaffolding being in place for several months.

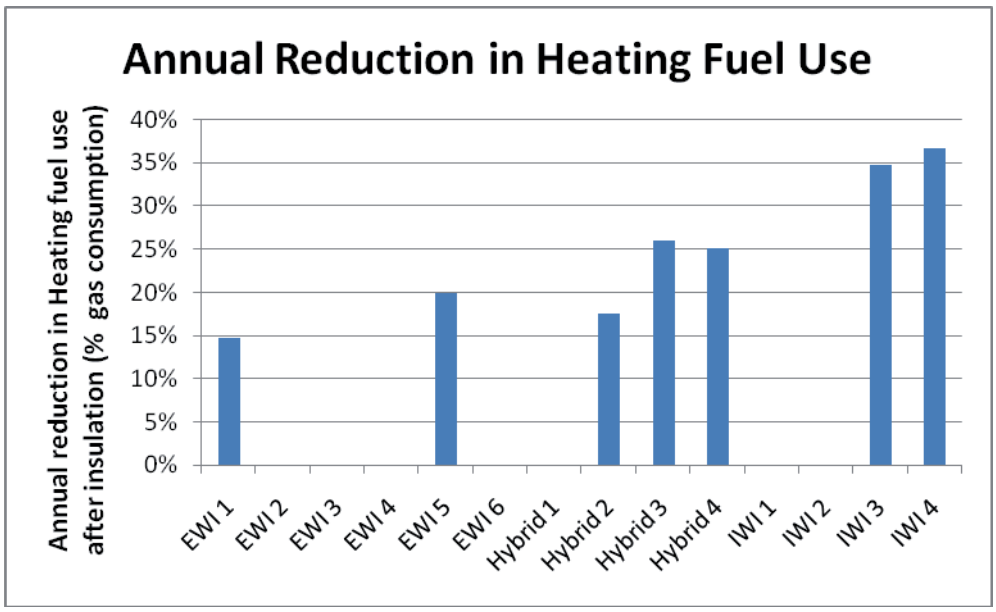


Figure 6. Monitored reduction in heating fuel use over 1 year before and after insulation, normalised using degree days.

The main problems encountered with internal insulation were the complexity of reinstating features such as cornicing, architraving, plumbing and electrics. In some cases kitchens and bathrooms were not insulated and householders had recently upgraded the fittings and were not prepared to remove them. This highlights that a trigger point approach to internal insulation may be appropriate. For example if a householder is refitting the kitchen or bathroom it would be a good opportunity to add internal insulation.

Finally, a review of thermal images highlights an issue that was observed in several externally insulated properties. It appears to be normal practise by some companies practice to not extend insulation below the ground level. This has led to an exposed thermal bridge at the bottom of the property that can be clearly seen in the images in Figures 7 and 8. It is too early to determine the impact on monitored performance but should be considered in subsequent installations.

Summary of Key Findings

The study's key findings provide useful guidance to inform additional research into the energy performance of solid walled properties both before and after the installation of insulation. Comprehensive thermal imaging, u-value assessments, air permeability and energy/environmental monitoring from a sample of 93 solid walled properties in England have identified the following key findings:

- The median U-value of the sample was found to be 1.4 W/m²K which is considerably better than the U-value of 2.1 W/m²K assumed by SAP for solid brick walls. This suggests that potential energy savings from solid walled dwellings might not be as significant as originally anticipated
- The thermal efficiency of solid wall dwellings is considerably worse than current UK building regulations
- The median air permeability of the sample was found to be 10.1 m³/h.m², which is also better than be expected for solid walled properties. However there was a considerable range across the sample. The current Building Regulations requirement for new houses is better than 10 m³/h.m².
- The theoretical benefit of improving the wall U-value to 0.3 W/m²K by means of additional insulation estimated for each property by before-and after SAP calculations, demonstrates a considerable potential for energy cost saving from solid wall dwellings.
- Although both u-value and air permeability improvement works would bring benefits in terms of reduced space heating requirements for the properties, the results showed that u-value improvements delivered greater benefits when compared to improvements in the air permeability alone.
- Analysis of the monitored energy data showed that heating energy consumption was generally in line with SAP estimates though a significant proportion of the houses were operated with internal temperatures below 18 °C during occupancy. It is estimated that 36 % of the houses were underheated generally rising to 46 % in very cold weather.
- Improvements to air permeability; u-values; and energy use have been achieved at the sample of 11 properties where solid wall installations have completed.

Conclusions

There are approximately 9 million homes in the UK with solid wall construction. This study suggests there is a significant potential to reduce energy consumption from this dwelling type and meet energy efficiency standards by installing solid wall insulation. Although little research has been undertaken to investigate the energy performance of solid walled dwellings, the results of the Energy Saving Trust's study provide useful

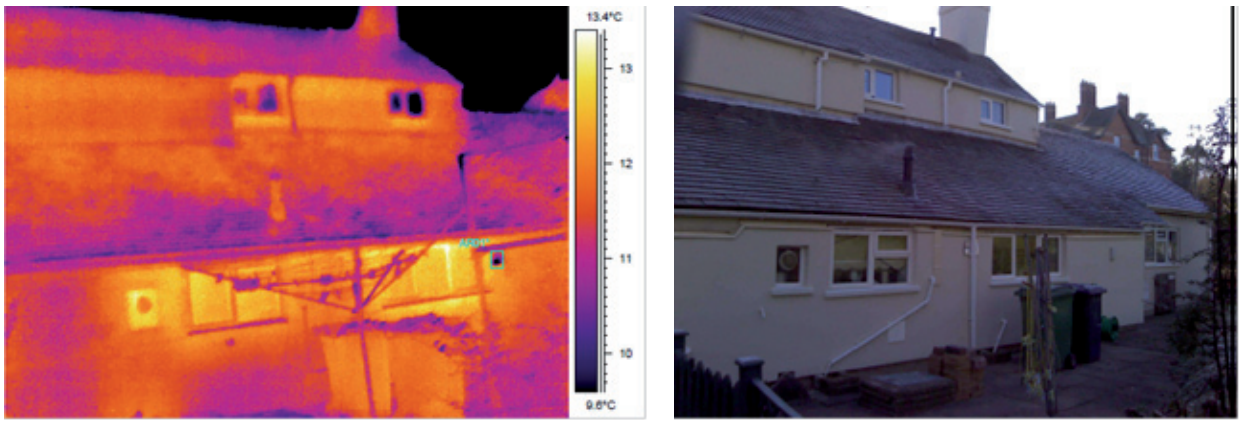


Figure 7. Pre-insulation thermal image of an EWI property.

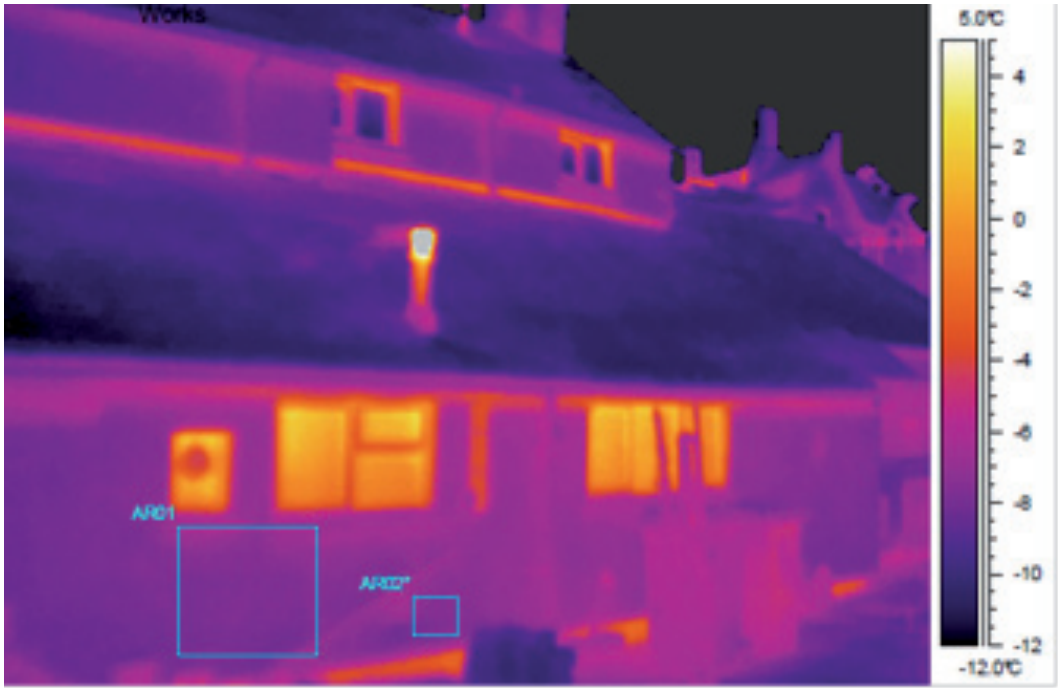


Figure 8. Thermal image of front of house post insulation, EWI property (ambient temp -8 °C, average temperature in box AR01: 7.5 °C).

insight into the thermal properties of these buildings and the potential to reduce energy and CO_2 emissions whilst improving the comfort of the occupants.

The study of u-values measured at the 93 dwellings – the largest of such studies undertaken to date in the UK – suggests that solid walled dwellings have potentially better thermal properties than assumed by SAP. This suggests that the UK Government's assumptions for potential energy savings from housing may need to be revised. These solid walled dwellings, however, are far below the energy efficiency standards set by current building regulations. Ambitious government-backed schemes such as ECO and the Green Deal are considering subsidies to support insulation in solid wall dwellings. Thus, it is important to understand the potential for energy and carbon savings starting from robust baseline data.

The year-long energy and environmental monitoring of the 93 dwellings provided a unique set of baseline data from which future energy savings can be calculated. Such comprehensive energy data did not exist before this study and the before-and-after approach of the field study provides a useful starting point to undertake study of additional technologies and efficiency measures in these homes.

A number of barriers, including the UK planning system; capital cost; and disruption to the householder have been identified through this study. A number of anticipated installations never completed due to these barriers, which must be addressed in order to undertake a mass refurbishment of UK solid walled homes.

The initial findings from 11 properties suggest that key variables such as air tightness; u-values; and energy consumption have improved since solid wall insulation has been installed. The UK government is committed to undertaking further research into the potential of insulation so further results will be forthcoming in the upcoming years.

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