

TEMPLE AVENUE PROJECT

ENERGY EFFICIENT REFURBISHED HOMES
FOR THE 21ST CENTURY



JRF JOSEPH
ROWNTREE
FOUNDATION

JRHT JOSEPH
ROWNTREE
HOUSING TRUST

FOREWORD



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This booklet is published just as the Government prepares for the launch of its major energy and carbon reduction initiative - the Green Deal. The scale of the problem with existing housing stock is well understood - but will Green Deal improvements deliver the savings we anticipate? An additional problem that is important to the Joseph Rowntree Foundation (JRF) and the Joseph Rowntree Housing Trust (JRHT) is fuel poverty. Fuel costs have effectively doubled in the last ten years and almost four million UK households are expected to be in fuel poverty this year (Department of Energy and Climate Change, 2012b, p. 78).

At 67 Temple Avenue, York, we have implemented and evaluated building fabric improvements from draught proofing to wholesale renovation, each with different effectiveness and potential payback. Designing the building fabric correctly must be the highest priority, as an efficient fabric will save energy for the whole life of the dwelling.

Many households are unlikely to contemplate wholesale renovation and will have to make do with standard, less intrusive upgrades. Although these would appear to be simple, we have found that a great deal of thought needs to go into their design and installation so that residents can be confident that 'as-built' performance will be similar to 'as-designed'.

FINDINGS AND RECOMMENDATIONS

The Green Deal, due to be launched in October 2012, will place intense pressure on the growing residential refurbishment industry

Government and regulators:

- If 'as-built' performance does not meet design predictions, then 'the golden rule' of the Green Deal is at risk of being broken;
- Green Deal Assessment must include tolerances or confidence factors in performance predictions and expected financial savings.

Asset managers and residents:

- Commission an intrusive condition survey of the house and any alterations or replacement fittings, to establish its bespoke status and appreciate the effectiveness of any improvements to be undertaken;
- Consider capital and revenue cost, carbon cost-effectiveness and the level of disruption of potential improvements;
- Seek professional design and installation advice.

Installers:

- Forensic observation and/or in-production testing should be used to check that improvements have been installed correctly;
- Education and training is needed to replicate experience and knowledge;
- On-site briefings are essential to ensure that everyone involved is sufficiently aware of the issues to do their job well.

The supply chain: Information provided by suppliers should include 'as-built' data and not simply rely on unrealistic laboratory performance.

OVERVIEW

Before refurbishment, 67 Temple Avenue was a fairly ordinary semi-detached house on the eastern edge of York. The surrounding neighbourhood is mainly composed of 1930s houses of a type that has been repeated in towns and cities all over the country. Homes built in this era and before make up the vast majority of our housing stock and rank amongst "the leakiest in the Western world" (Department of Energy and Climate Change 2011, p. 10). They are neither well insulated nor airtight and as a result are relatively expensive to heat. The refurbishment of 67 Temple Avenue by JRF and JRHT shows how a series of improvement measures can potentially generate substantial savings to the occupier of over £650 per year and cut carbon emissions by 66 per cent (Sustainable Energy Academy, n.d.).

Overall, the project aimed to bring a 1930s house up to the advanced energy and carbon standard of JRF and JRHT's neighbouring new-build prototype houses, described in the sister publication, 'Temple Avenue Project: 54 & 69' (Richards Partington Architects, 2012). This was not an easy task and some of the alterations were significant - probably too intrusive to undertake in an occupied dwelling. By making the improvements in stages and measuring the results, the project also looked at the relative effectiveness of standard improvements and of more radical alterations.

The improvement works were implemented after a review had been made of the existing condition of the building and after the ease and cost-effectiveness of each improvement had been assessed. The details necessary for each improvement and the sequencing of works were largely left to the expertise of the contractors and JRHT's project manager, much as they would be on a typical domestic refurbishment project where consultants' input and extensive detailed analysis is usually limited. Leeds Metropolitan University, Centre for the Built Environment (Leeds Met) undertook a substantial programme of design and construction observation and involvement, as well as testing and evaluation. This report is underpinned by Leeds Met's detailed technical findings (Miles-Shenton et al., 2012).

Although the improvements were substantial, many of the predicted performances were not fully achieved when the house was measured. 'As-built' measurements revealed that following all of the improvements Number 67 achieved 71 per cent of the predicted reduction in heat loss. The test results raise important questions about the reliability of both the modelling assumptions and construction techniques used in this kind of project.

PART 1.1

HOW TO USE THIS BOOKLET

We hope that this booklet will appeal to a wide audience. The following conventions have been adopted to highlight some of the important messages:

Key points are located at the top of pages and can be read independently;

The discursive text below expands upon the key points;

Text against a blue background gives further explanation of the technical information.

INTRODUCTION TO THE 67 PROJECT

Can existing houses be brought up to current new-build standards?
In the future will they become increasingly expensive to heat and maintain?
Can improvements to housing stock help to reduce national emissions?



The eco refurbishment (energy-efficient and low carbon footprint) of Number 67 Temple Avenue, York, was set up to answer some of these questions, using the same testing and evaluation techniques that were applied to JRF and JRHT's new-build Temple Avenue houses.

The 67 Project focuses on improvements to the building fabric followed by improvements to the heating and ventilation system, and then measures that offset the cost of hot water and energy use. This is a logical hierarchy of improvements, tackling firstly the biggest component of the energy budget, space heating, with robust measures that will be in place for a number of years and are not prone to alteration or replacement. These are called the 'fabric' measures.

The 67 Project aimed to test the efficacy and reliability of various improvement measures

With the Green Deal on the horizon, the question of whether an upgrade is cost-effective over its payback period will have a bearing on the decisions made by a householder and the return on investment. In this regard Number 67 reveals some unexpected challenges to conventional practice.

and also their cost-effectiveness, trying to give helpful information about where investment should be made. The renovation work is divided into two stages in order to test the relative effectiveness of standard and more radical improvements:

1. The first stage included standard repairs and energy saving measures that are within the scope and budget of an ordinary householder and in theory can be implemented while the house is in occupation.
2. The second stage looks at a more radical retrofit that aims to reach the advanced energy and carbon performance level of JRF and JRHT's neighbouring new-build prototype houses. The improvements involve high capital costs and significant disruption to the occupants, probably requiring them to move out during the works.

Heat loss from a house (described as whole-house heat loss) is a combination of conduction, convection and radiation through the dwelling's walls, floors and roofs (fabric heat loss) and via air leakage through gaps and joints (background ventilation heat loss).

In order to minimise heat loss it is necessary to improve the insulating effect (U-value) of each element of the fabric and airtightness. Good practice construction establishes continuous insulating and air barrier layers. It also addresses other construction issues that can increase heat loss, minimising thermal bridging (instances of extreme heat loss that 'bridge' the insulation) and thermal bypass (the movement of unheated outside air within cavities in the construction, which has bypassed the insulation layer) and avoiding out-of-sequence work, which can prevent other work stages from being completed properly, or damage work that has already been done.

Opposite. Number 67
following the radical retrofit

1.2

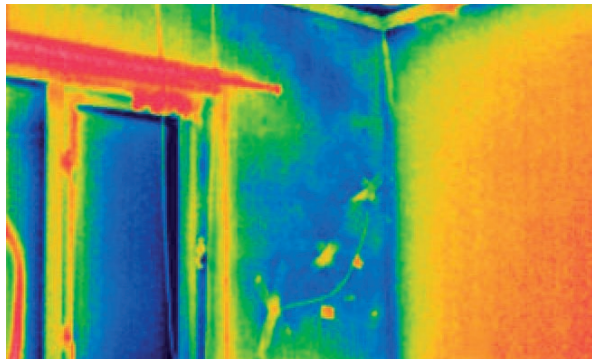
OBSERVATION AND TESTING

Leeds Metropolitan University, Centre for the Built Environment (Leeds Met) observed the improvement works, carrying out a forensic visual and thermographic survey, and also extensively tested the performance of the dwelling in its existing condition and following each stage of improvements.



Leeds Met assessed both the performance of the existing house, highlighting areas for enhancement, and also the impact of each stage of the renovation works, verifying the predicted performance improvements. The research team made 50 site visits between July 2009 and March 2010 and used a variety of testing and observational techniques.

Thermograms display surface temperatures in a range of colours. Thermograms of heated buildings can show comparative heat loss through different elements of the building envelope and thermal weaknesses.



Skilled interpretation of thermograms is needed as the displayed variations in surface temperature are also affected by a surface being in shade or in sunlight, or being wet or dry, or differences in infra-red emissivities of materials.

Every existing house is unique – as a result of alterations and extensions over time – and we need to understand whether the tools that are used to predict the effects of improvements are accurate enough and capable of dealing with this variety.

Air pressurisation testing measures the air permeability of the building envelope to determine airtightness. During pressurisation air leaks are more obvious and are found using smoke detection. During depressurisation air infiltration is more obvious. Thermograms showing cooler air being drawn in highlight particular areas for concern. Testing the house under pressurisation and depressurisation gives a clearer understanding of ventilation losses.

Coheating testing measures whole-house heat loss (a combination of fabric heat loss and ventilation heat loss). A coheating test involves heating the inside of the dwelling using electric fan heaters to an elevated internal temperature (typically 25°C) over a period of time (typically one to three weeks). The electrical energy required to maintain the internal temperature each day is recorded giving the daily heat input in watts. The daily heat input is plotted against

the daily difference in temperature between the inside and outside of the dwelling to give the heat loss coefficient in W/K. In order to obtain a sufficient temperature difference (generally ten degrees Kelvin or more), the coheating test should be carried out in late autumn/ winter months (between October/November and February/March). The house must be unoccupied and undisturbed throughout the test period to ensure accurate results. Once collected, the data is adjusted to compensate for solar gains (Wingfield et al., 2010).

Heat flux sensors measure the rate of heat loss through a material at a specific point giving an indicative U-value for a building element.

Borescope investigation uses a miniature video camera at the end of an articulated rod, inserted through small inspection holes drilled in the fabric, to remotely inspect building fabric voids.

Opposite top. Heat flux sensors measuring the rate of heat flux during coheating testing

Opposite bottom. Thermogram showing a thermal bridge through the external wall and the window lintel

2.1

SEMI-DETACHED

1930S CONSTRUCTION

UNINSULATED CAVITY WALLS

'SUSPENDED' GROUND FLOOR

MINIMAL LOFT INSULATION

DOUBLE-GLAZED WINDOWS

'LEAKY' FABRIC

GAS FIRED CENTRAL HEATING

PREDICTED FUEL COSTS PER YEAR

AUGUST 2009

HEATING = £612

HOT WATER = £136

LIGHTING = £55

CONDITION OF NUMBER 67 BEFORE REFURBISHMENT

Number 67 was a typical two-storey semi-detached house, originally constructed in the 1930s, which had been extended to the side and to the rear. It originally had open fireplaces and single-glazed windows. More recently double glazing and a central heating system have been installed.

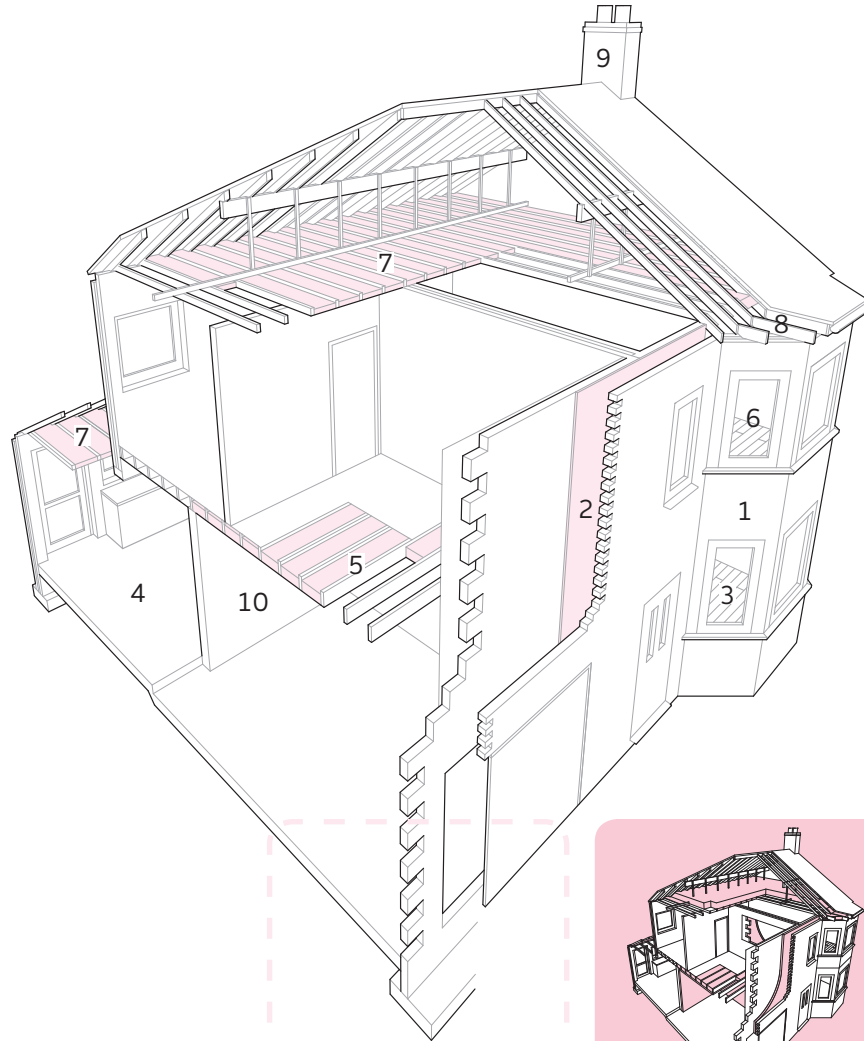
PREDICTED ENERGY EFFICIENCY RATING

	Current	Potential
Very energy efficient - lower running costs		
(92 to 100) A		
(81 to 91) B		89
(69 to 80) C		
(55 to 68) D	59	
(39 to 54) E		
(21 to 38) F		
(1 to 20) G		
Not energy efficient - higher running costs		

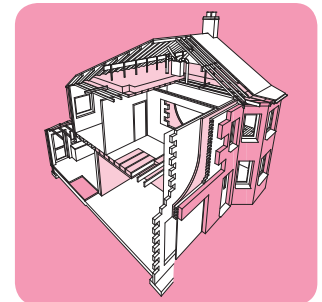
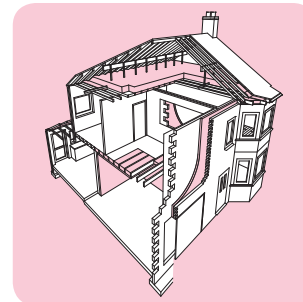
The Energy Efficiency Rating which appears on the EPC (Energy Performance Certificate) is an estimation of the overall efficiency of a home. The higher the rating (on a scale of 0-100) the more energy efficient the home is likely to be and the lower the fuel bills. The 'potential' column shows the score possible after all the improvements.

Energy efficiency and estimates of fuel cost were predicted using the Government's Standard Assessment Procedure (SAP). The calculation is based on the energy costs associated with space heating, water heating, ventilation and lighting, less cost savings from energy generation technologies. It is adjusted for floor area so that it is essentially independent of dwelling size for a given built form. The calculation does not account for the individual characteristics of the household occupying the dwelling.

1. Original uninsulated cavity walls
2. Extension cavity walls with 25 mm insulation
3. Original uninsulated timber ground floor
4. Uninsulated concrete floor in extension
5. Timber first floor above garage with 150 mm insulation between the joists
6. UPVC double-glazed replacement windows
7. 75 mm degraded insulation between the ceiling joists in the loft and in the rear extension roof
8. Uninsulated bay window roof
9. Ventilation via intermittent extract fans in wet rooms and via chimney flue
10. Boiler and hot water cylinder located outside of the heated envelope with uninsulated pipework



EXISTING



2.2

MEASURED
AIRTIGHTNESS =
 $\text{m}^3/(\text{h}\cdot\text{m}^2)\text{@}50\text{Pa}$

15.76

PREDICTED HEAT LOSS =
W/K

341.4

MEASURED HEAT LOSS =
W/K

324.7

EXISTING CONDITION PERFORMANCE

Predicted thermal performance proved to be reasonably accurate but underestimated the actual performance of the dwelling in its existing condition.

For the existing dwelling, predictions of the thermal performance were made using SAP. A measured survey and visual inspection of the existing dwelling along with an air pressurisation test were carried out to enable informed decisions and U-value calculations for fabric elements to be made. However, test results revealed that the measured performance of the existing property was better than the predicted performance. This inaccuracy may be due to an insufficient understanding of the existing construction, despite a detailed survey.

At present, a detailed survey, airtightness test and SAP calculation is the most accurate government approved tool for estimating thermal performance of existing dwellings. If it was not possible to conduct a detailed survey of the existing dwelling, then predictions of the performance would have to be made using the Reduced Data Assessment Procedure (RdSAP)

Airtightness is a measure of how successfully air leakage is prevented.

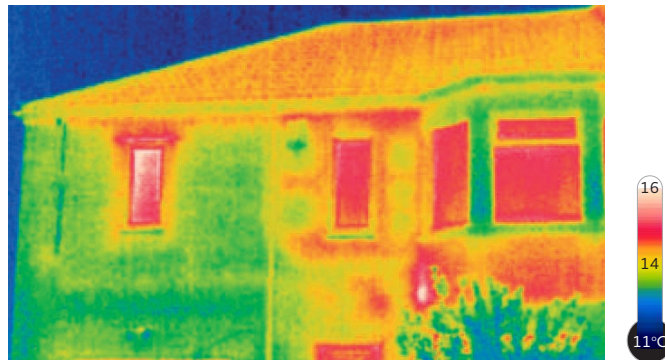
Total heat loss is equal to the amount of heat that escapes from a house as a whole, which includes both heat loss through the dwelling fabric (fabric loss) and via air leakage (background ventilation loss).

Predicted total heat loss takes into account measured airtightness and a combination of estimations: SAP, manufacturer's claimed U-values, and U-value calculations where no claimed values could be found (calculated using NHER U-value Calculator version 1.1.7).

"[Therefore] it can safely be assumed there were inaccuracies in the original heat-loss prediction due to an incomplete knowledge of the actual construction of the existing building" (Miles-Shenton et al., 2012, p. 57).

- the Government's approved calculation tool for undertaking an energy assessment on an existing property. This simplified version of SAP classifies dwellings by age bands, assigning default values for construction types and building systems typical for the period. For older properties especially, the impact of any previous upgrade measures that are not obviously visible may be excluded from calculations; this situation could potentially create a further gap between the predicted and measured performance.

Thermogram showing air and heat leakage through the existing uninsulated walls and windows



3.1

STANDARD RETROFIT

CAVITY WALL
INSULATION (CWI)

INSULATED AROUND
INTEGRAL GARAGE

INSULATED LOFT

IMPROVED
AIRTIGHTNESS

REDUCED THERMAL
BYPASSES

CONDENSING BOILER
AND BALANCED FLUE

100% LOW ENERGY
LIGHT FITTINGS

PREDICTED FUEL COSTS
PER YEAR
AUGUST 2009

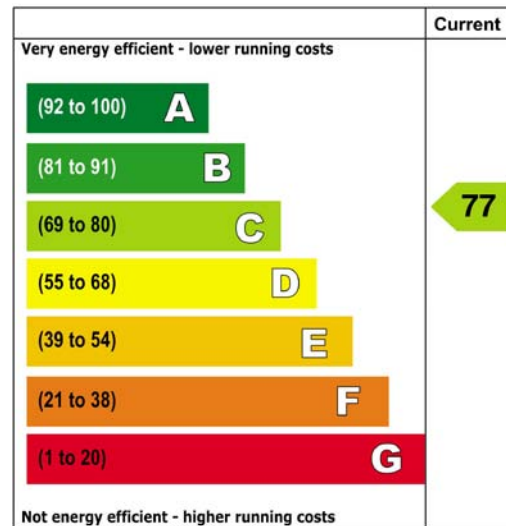
HEATING = **£285**

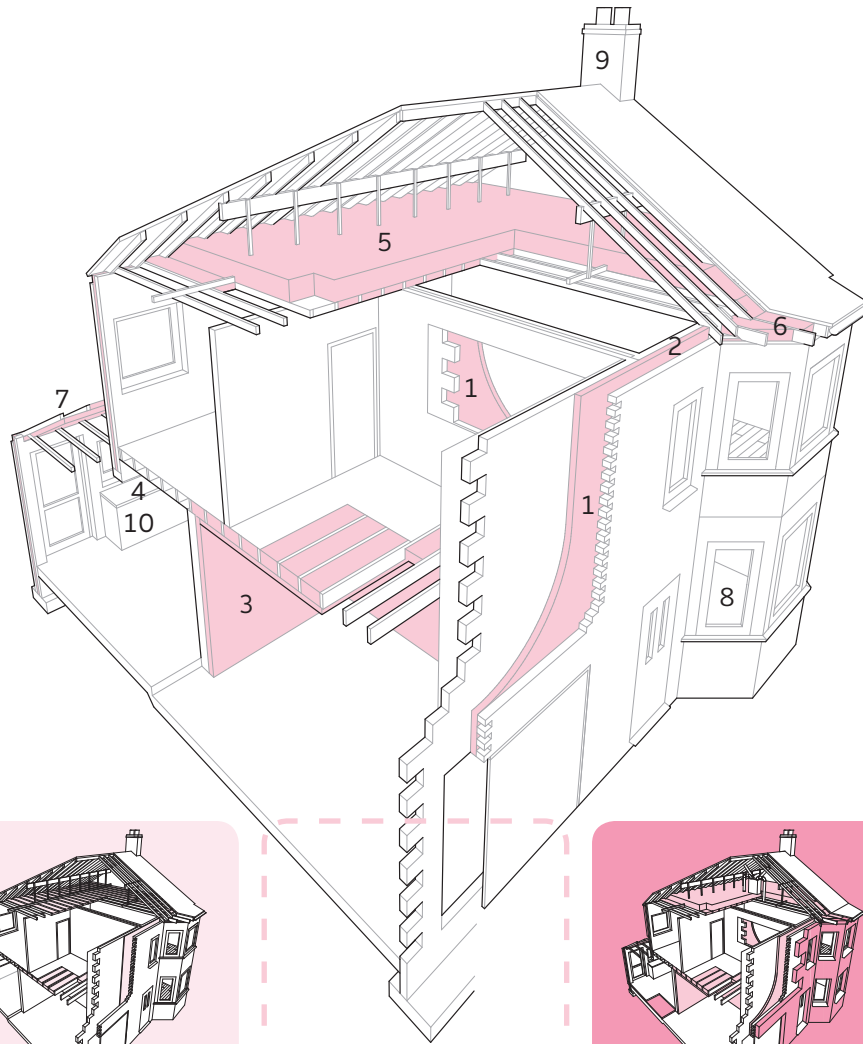
HOT WATER = **£84**

LIGHTING = **£54**

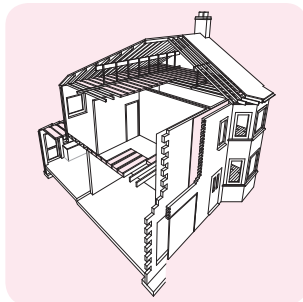
The first stage of improvements included standard repairs and energy saving measures that are within the scope and budget of an ordinary householder and can be implemented while the house is in occupation.

PREDICTED ENERGY EFFICIENCY RATING

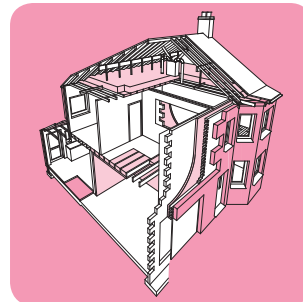




1. CWI added to all external walls and original side wall
2. Top of cavities packed with insulation to reduce thermal bypass
3. 75 mm rigid insulation lining to semi-external walls and first floor around integral garage
4. Service penetrations through external walls removed/ sealed
5. 400 mm insulation (100 mm between ceiling joists, 300 mm above) in the main loft
6. Insulation between bay window rafters
7. 75 mm rigid insulation below rafters in rear extension roof
8. Ground floor sealed with taped hardboard
9. Chimney blocked and insulated
10. Boiler, hot water cylinder and related plumbing moved inside the thermal envelope



STANDARD RETROFIT



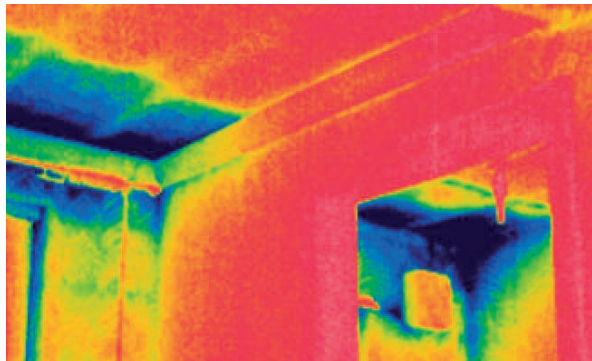
3.2

STANDARD RETROFIT OBSERVATIONS

"The CWI retro-filling of the brick-brick external walls was predicted to bring the U-value down from 1.68 W/m²K to 0.45 W/m²K, yet even after filling the measured U-values varied from a highest value of 1.93 W/m²K to a lowest of 0.70 W/m²K" (Miles-Shenton et al., 2012, p. 58).



Blown-in cavity wall insulation (CWI) was installed by an approved contractor who had carried out many similar installations over a number of years. However, thermograms showed that in some areas the installation had had very little effect on the thermal conductivity of the external walls, and had certainly not reduced it by the 73 per cent assumed in the design calculations.

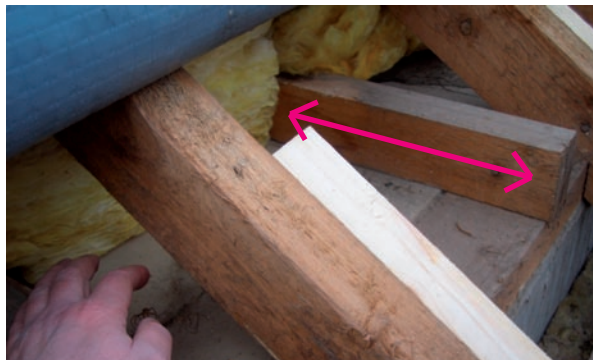


Borescope and heat flux investigations revealed that the CWI had not spread sufficiently through the cavity due to the poor quality of the inner leaf of brick and debris in the cavity. These obstructions are common but generally go undetected. In addition it was discovered that a vertical cavity brush had not been fitted at the party wall allowing the CWI to fall sideways into the neighbouring property's wall cavity.

Even though established industry procedures were followed carefully, the level of fill of cavity wall insulation was found to be very uneven throughout the dwelling with a number of areas having little, if any, insulation present.

Lifting the roof tiles at the eaves during the second stage of works revealed a gap between the CWI and roof insulation, compromising the continuous thermal barrier. It was also found that the insulation packing at the top of the cavities, proposed in order to reduce thermal bypass, had been omitted.

Most of the first stage of energy saving measures were inexpensive and would cause minimal disruption to occupants of the house. Sealing the suspended timber ground floor using a layer of hardboard with expanding foam edge sealing and taped joints was a particularly straightforward and cost-effective improvement measure.



Opposite. Thermogram of rear extension showing significant cold bridging at the eaves

Gap (shown by arrow) between the CWI and roof insulation at the eaves discovered when the tiles were lifted during the second stage of works

3.3

STANDARD RETROFIT PERFORMANCE

MEASURED
AIRTIGHTNESS
 $\text{m}^3/(\text{h}\cdot\text{m}^2)\text{@}50\text{Pa}$

9.83

PREDICTED HEAT LOSS
REDUCTION
W/K

102.7

MEASURED HEAT LOSS
REDUCTION
W/K

75.5

At higher levels of performance, assessment overestimated the benefits of the improvements undertaken.



The measured airtightness of $9.83 \text{ m}^3/(\text{h}\cdot\text{m}^2)\text{@}50\text{Pa}$ is a reasonable improvement on the existing house airtightness of around $16 \text{ m}^3/(\text{h}\cdot\text{m}^2)\text{@}50\text{Pa}$ and complied with current new-build standards at the time of the works.



The thermogram to the left indicates that the CWI may not have entirely filled the cavity, or that the cavity is 'bridged'. The CWI was predicted to reduce the U-value of the external walls from 1.68 to $0.45 \text{ W/m}^2\text{K}$. Yet heat flux sensors measured U-values that varied from a highest value of $1.93 \text{ W/m}^2\text{K}$ to a lowest value of $0.70 \text{ W/m}^2\text{K}$.

The thermogram overleaf suggests that there could be a gap between the cavity and roof insulation. However, what thermographic inspections cannot reveal is the extent of heat loss through the uninsulated ground floor.

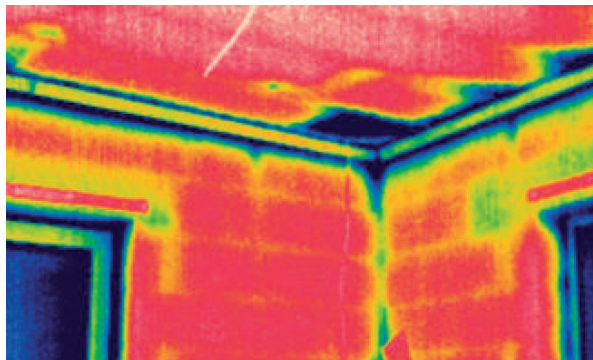


Although the first stage of works appeared successful to the untrained eye, the intrusive nature of the second stage of works revealed that many of the standard improvements may not have been installed adequately.

Thermal bridges or cold bridges are specific instances in the building envelope where heat loss is worse than through the main building elements. Consequently in a generally well insulated building thermal bridges can represent more than 30 per cent of all heat loss, due to their comparative difficulty to address.

Linear non-repeating thermal bridges that include items such as cills, lintels and jambs typically span between the inner and outer skins of a wall. Geometric thermal bridges occur at junctions between building elements (between walls and a roof) and at changes of geometry (a corner in a wall or a hip in a roof).

It is impossible to avoid all thermal bridging, but the effect can be lessened by detailing and carefully sequenced construction. It is more difficult to avoid thermal bridging caused by poor workmanship, as it will often be too late to avoid costly remedial works.



Opposite. Thermogram taken following CWI installation showing heat losses through the walls and around the bay window

Thermogram taken following the standard retrofit showing air infiltration and thermal bridging at the eaves

4.1

EXTERNAL WALL
INSULATION (EWI)

INSULATED GROUND
FLOOR

MVHR

TRIPLE-GLAZED
ARGON-FILLED
WINDOWS

FURTHER IMPROVED
AIRTIGHTNESS

SOLAR WATER
HEATING

PREDICTED FUEL COSTS
PER YEAR
AUGUST 2009

HEATING = £87

HOT WATER = £22

LIGHTING = £54

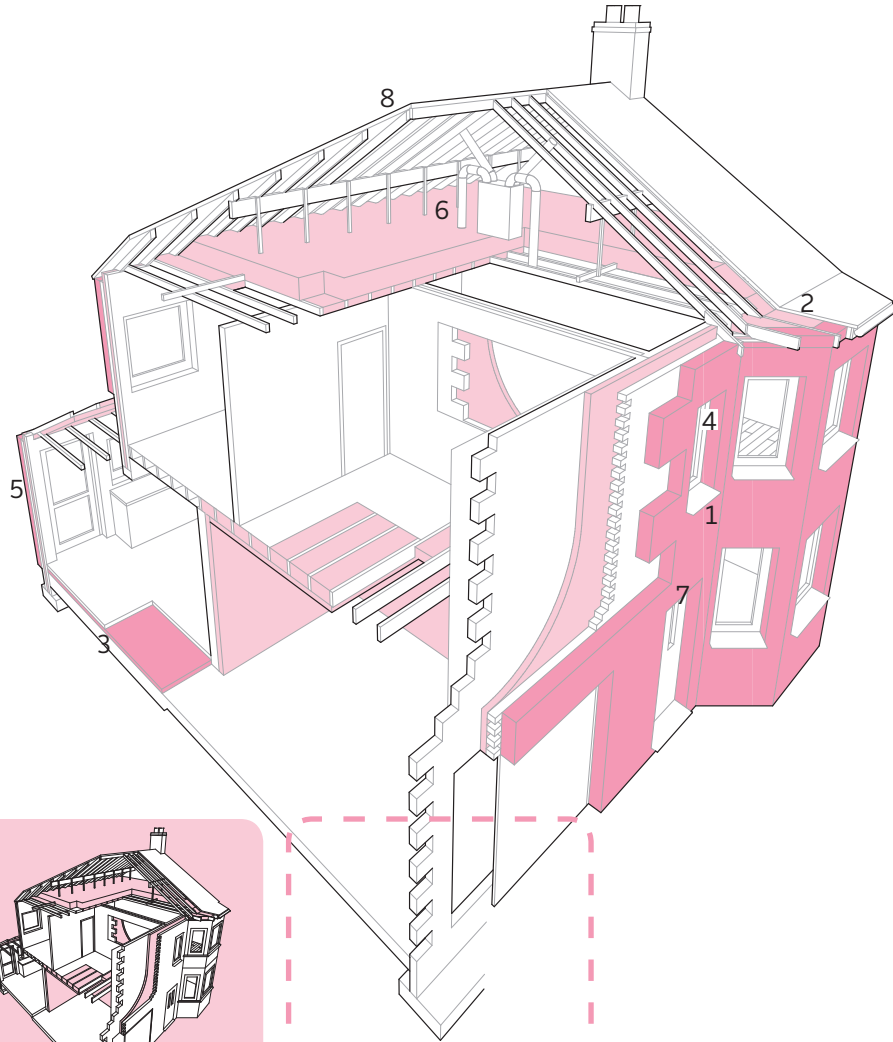
RADICAL RETROFIT

The radical retrofit aims to reach the performance level of JRF and JRHT's neighbouring new-build prototype houses. These are improvements that could be considered by affordable housing providers, but are probably beyond the scope of the private residential sector given the level of capital investment.

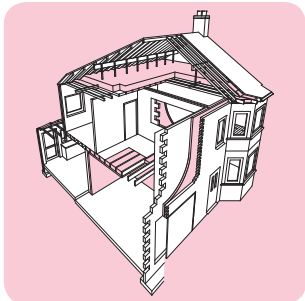
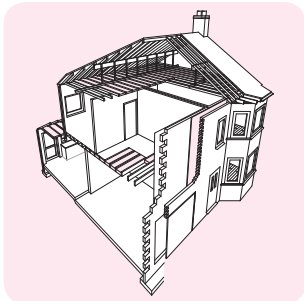
PREDICTED ENERGY EFFICIENCY RATING

	Current
Very energy efficient - lower running costs	
(92 to 100) A	89
(81 to 91) B	
(69 to 80) C	
(55 to 68) D	
(39 to 54) E	
(21 to 38) F	
(1 to 20) G	
Not energy efficient - higher running costs	





1. 175 mm EWI with render coating
2. Eaves extended and external water and waste pipes rerouted to accommodate EWI thickness
3. Existing concrete and timber ground floors removed and replaced with insulated concrete ground floor
4. New argon-filled, triple-glazed timber windows
5. New composite insulated external doors
6. MVHR (mechanical ventilation with heat recovery)
7. Airtightness improved as a result of solid ground floor; new windows; external wall insulation; and good workmanship
8. Solar hot water panels installed on the south side of the property



RADICAL RETROFIT

4.2

RADICAL RETROFIT OBSERVATIONS

A great deal of effort is required to bring a house of this period to the performance level of a new 2006 Building Regulation compliant dwelling.



The second stage of works involved high capital costs and significant disruption. The breaking and extraction of the solid concrete parts of the existing ground floor was also difficult and time consuming, with particular problems where internal masonry walls had been constructed on top of the old slab or the foundations and could not be disturbed. The most ambitious aspect of the renovation was the addition of 175 mm of insulation, with a render coating, to

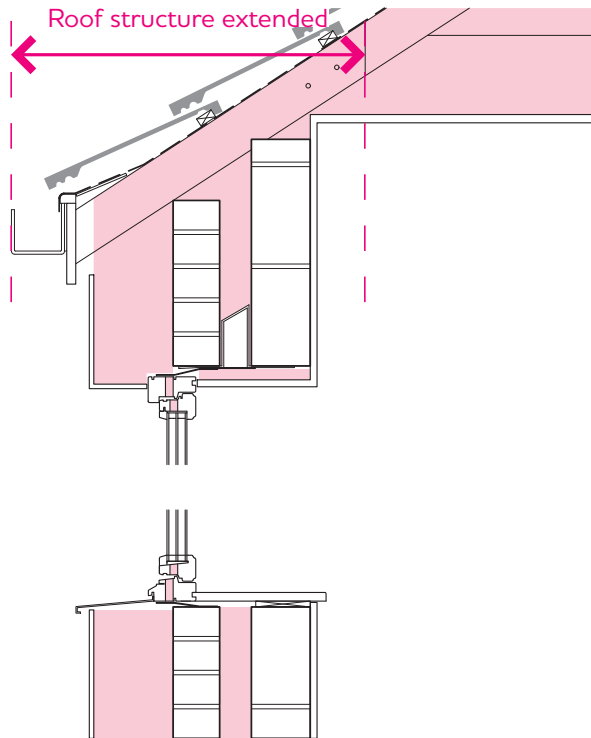


Improvement measures need to be carefully evaluated and designed by experienced practitioners.

the outer surface of all the external walls of the property. Ideally windows need to be positioned in line with the external wall insulation (EWI) to maintain thermal continuity. In practice the sill must also be supported by the structure.

The sizable increase in the thickness of the external walls provided plenty of challenges at the roofline. The contractor had to lift the bottom row of tiles, extend the rafters, and add extra rows of tiles. It was also necessary to replace and reroute gutters, downpipes, gulleys and external waste pipes.

The knock-on effects of EWI would vary with different houses. Houses with large overhanging roofs would be able to accept insulation more readily. However, houses with windows close to the underside of the roof would not be suitable for EWI application without significant modification to the window design.



Opposite. EWI installation
Detailed section showing
extended eaves and position
of window in relation to the
external wall insulation

4.3

RADICAL RETROFIT PERFORMANCE

MEASURED
AIRTIGHTNESS
 $\text{m}^3/(\text{h}\cdot\text{m}^2)\text{@}50\text{Pa}$

5.42

PREDICTED HEAT LOSS
REDUCTION
W/K

234.2

MEASURED HEAT LOSS
REDUCTION
W/K

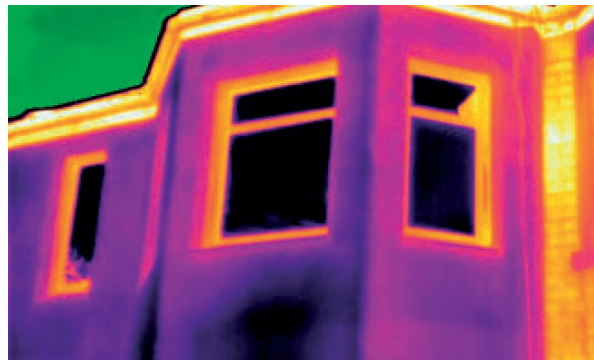
165.7

"In neither stage of improvements did the measured reduction in fabric heat loss achieve the design expectations" (Miles-Shenton et al., 2012, p. 57).



The final airtightness of $5.42 \text{ m}^3/(\text{h}\cdot\text{m}^2)\text{@}50\text{Pa}$, against a target of $5 \text{ m}^3/(\text{h}\cdot\text{m}^2)\text{@}50\text{Pa}$, was achieved with the dwelling not fully finished and some sealing still to be carried out.

The new triple-glazed windows achieved the manufacturer's specification of a centre pane U-value of $0.5 \text{ W/m}^2\text{K}$ and a vast improvement in airtightness.



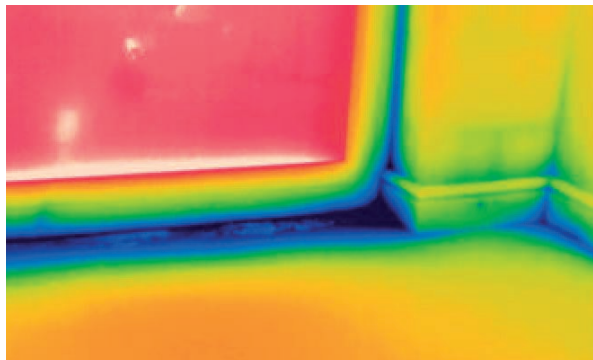
The EWI significantly improved thermal bridging, although the design value of $0.15 \text{ W/m}^2\text{K}$ was not met and values of $0.23\text{-}0.24 \text{ W/m}^2\text{K}$ were measured. Higher U-values were measured around openings suggesting thermal bypass heat losses as a result of air circulation in gaps behind the insulation. Thermal bypasses were also detected on the new-build project 54 and 69. Minor discontinuities in the EWI were difficult to avoid around the existing entrance and patio doors.

On-site measurements showed that some predicted values were achieved, with measured U-values for the triple-glazed windows and the new ground floor equivalent to the manufacturer's claims and design values.

Thermal bypass is the movement of unheated outside air within voids in the construction, particularly, in party wall cavities, underfloor voids and lofts, resulting in increased heat loss.

Until recently, thermal bypass was not widely recognised and there is still limited understanding of this heat loss mechanism operates. However, there are straightforward design measures that will help to limit or even eliminate thermal bypass heat loss. Ensuring cavity walls are sealed top and bottom is essential. In other situations such as roofs it is important that any airtightness barrier follows the line of the insulation to avoid creating unheated spaces between the two.

Before refurbishment there was a significant bypass in the original external cavity wall between the hall and the garage, which contained no insulation in the cavity and was open to the loft at the top.



Opposite. Thermogram taken following external wall insulation installation

Thermogram following EWI installation showing heat loss (blue area) through the patio door threshold where the external step bridges the insulation

5.1

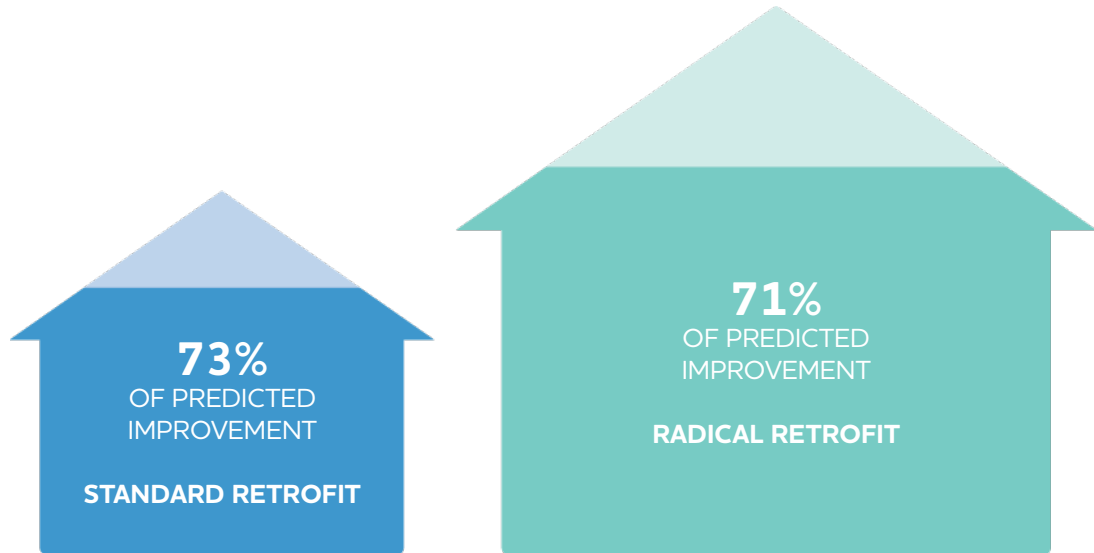
HOW SUCCESSFUL WERE THE IMPROVEMENTS?

A comparison of measured (as-built) versus predicted (as-designed) heat loss uncovers inaccuracies in the estimations. The inputs to SAP underestimated the performance of the dwelling in its existing condition; and at higher levels of performance overestimated the benefits of the improvements taken.

The 67 Project only covers issues related to the fabric performance, rather than any attempt to evaluate the full efficacy of the design including CO₂ reductions from technology, such as the solar hot water system. These are more user

dependent and can only be assessed through supplementary post occupancy monitoring.

It is clear that the predictions made for the performance of the house in its existing



condition were dependent on the accuracy of the initial survey and the standard assumptions made about the thermal performance of the construction. In this instance the initial investigation was conducted with minimal disruption to the then occupants. A more intrusive investigation could have led to a more accurate prediction.

The predictions of performance following the improvement works are also dependent on the accuracy of the data entered into the estimation software. Invariably the theoretical performance of elements, based on laboratory tested U-values and assuming ideal installation, will not be achieved in practice. In the first stage of works, the uneven filling of the cavity and the omission of insulation at the eaves and elsewhere contributed to the underperformance. However, even in areas where the cavity wall insulation was completed following rectification works, the estimated U-value was not achieved.

As in the first stage of works, the second stage external insulation was carefully installed in accordance with the manufacturer's

recommendations, but minor discontinuities were difficult to avoid around the existing entrance and patio doors. A full thermal simulation of these effects would have been prohibitively expensive and inappropriate as such techniques are not routinely used in housing refurbishment. Thermograms showed that the external wall insulation was extremely effective in reducing the thermal bridges through the external walls; however, heat flux sensors showed a large discrepancy between the predicted and measured average U-values for the walls (Miles-Shenton et al., 2012, p. 38). This may have been caused by warm air movement in the existing cavity, with heat escaping by means of a thermal bypass at the top of the cavity wall.

It is important to recognise, however, that the 67 Project benchmark of current new-build housing standards set by Numbers 54 and 69 aimed to achieve dwellings with very low levels of heat loss. Although the percentage difference between the target and the measured heat loss reduction following the radical retrofit may seem significant, in absolute terms, 68.5 W/K is a relatively small amount of heat.

Opposite. Achieved as-built heat loss reduction as a percentage of the predicted reduction

Lessons for Government and regulators:**If ‘as-built’ performance does not meet design predictions, then ‘the golden rule’ of the Green Deal is at risk of being broken**

– Number 67 benefited from a committed and knowledgeable team and intensive quality control. The input from the research organisation was invaluable, anticipating breaks in airtightness and thermal layers. Without this experience, the gap between predicted and actual performance discovered at Number 67 could widen with replication. The findings of the 67 Project have very significant implications for initiatives such as the Government’s Green Deal, which rely on the efficacy of improvement measures to give a return on investment.

Green Deal Assessment should consider ‘as-built’ performance and include tolerances in calculations of expected financial savings –

The heat loss mechanisms in an existing dwelling are very complex and require more analysis than a simple assessment of a property’s age and construction. The analysis tool used for Number 67, full SAP, is more sophisticated than the reduced version (RdSAP) used to generate

Energy Performance Certificates. However, even when using full SAP and inputting the usual conventions for product performance (U-values, systems performance, efficiencies, etc.) we found substantial discrepancies between the predicted and measured performance. As at the Temple Avenue new-build prototype project it is clear that more allowance needs to be made for the actual performance of products in-situ, which will, invariably, fall short of the laboratory-measured performance.

Lessons for asset managers and residents:**Commission a comprehensive survey of the house before any improvement work –**

The 67 Project was set up as a prototype for energy efficiency improvements to similar traditional cavity walled masonry dwellings. However, the improvements to Number 67 cannot be simply replicated as no two existing houses are the same and certain measures are not suitable for some houses or locations. A refurbishment project should not be undertaken without a comprehensive survey of the house and any alterations or replacement fittings.

Consider cost, carbon cost-effectiveness and disruption of improvements

– The financial and carbon cost-effectiveness of improvements needs to be considered as part of a balanced appraisal of the condition of a property, the ease of introducing measures and their likely effectiveness in reducing energy bills. The radical improvements at Number 67 required intrusive investigations to understand the home's construction – these are best undertaken in an unoccupied home. It would have been easier and cheaper to perform all the refurbishments in one go, but important observations would have been missed.

Seek professional advice – Any alteration or improvement of a home is an opportunity for introducing energy saving measures. However, good advice, based on a thorough understanding of the home's construction 'status', is necessary if the measures are to deliver predicted savings. Achieving the higher levels of performance that the 67 Project aimed for will probably require an inherent level of professional and design advice; and the qualifications of Green Deal Advisors should reflect this situation. Construction

and installation drawings and analysis of condensation risks will be necessary for the correct installation of some improvements. The installation of a measure such as EWI can have significant knock-on effects for the eaves and external drainage and requires careful detailing of openings and junctions to avoid thermal bridging.

Lessons for installers:

Forensic observation and/or in-production testing should be used to check that improvements have been installed correctly

– The efficiency of even the most standard improvements is highly dependent on the competence and thoroughness of the installers. At Number 67 we discovered that both the loft insulation and the CWI underperformed because the installation process had not delivered the expected results, even though CWI installation was carried out by a CIGA (Cavity Insulation Guarantee Agency) registered installer. Measured U-values revealed that the application of CWI had very little effect on the thermal conductivity of the external walls and had certainly not reduced it by the 73 per cent

assumed in the design calculations. Further advanced assessment of the state of the cavity might have minimised the uneven distribution.

Without the radical improvements and comprehensive testing, the lack of insulation in large areas of the walls, and subsequent thermal underperformance, might not have been detected. It is unlikely that this is a one-off occurrence and there could be many similar properties nationwide where 'fit and forget' installations fail to deliver anything like the benefits claimed. Indeed, research by the BRE undertaken during 2005 and 2006 into the thermal transmittance of walls of 70 dwellings before and after the application of CWI found that the improvement in thermal resistance is, on average, around 38 per cent less than expected (Doran & Carr, 2008). These findings suggest that if CWI installations are claiming and/or predicting certain outcomes, then these should be verified by thermographic, borescope and/or heat flux investigations, or other suitable methods of confirming performance.

Education and training is needed to replicate experience and knowledge –

Improvements should be made to education and training throughout the industry in order to replicate the design and construction skills, knowledge and experience gained in this and similar experimental retrofit projects.

On-site briefings are needed to ensure that everyone involved is sufficiently aware of the issues to do their job well –

Although improvement measures may have been installed correctly they are easily damaged or displaced by subsequent trades, who might not fully understand the consequences of their actions. The design intent needs to be communicated to all those in the supply chain who could potentially affect the air barrier or create a thermal bridge, and each link in the chain should 'sign-up' to this approach and understanding before commencing work.

5.3

CONSTRUCTION COSTS

TOTAL NET PROJECT COST =

£56k

£18,250

STANDARD RETROFIT

+£37,750

RADICAL RETROFIT

£400

CWI

£550

SEAL
CHIMNEY

£800

LOFT
INSULATION

£3,000

AIRTIGHTNESS

£6,000
REWIRE AND
REPLASTER

£4,000
INSULATION
AROUND
GARAGE

£3,500
NEW HEATING
& HOT WATER
SYSTEM

£2,000

AIRTIGHTNESS

£5,000
MVHR

£5,500
SOLAR HOT
WATER

£10,000
HIGH-PERFORMANCE
DOORS AND
WINDOWS

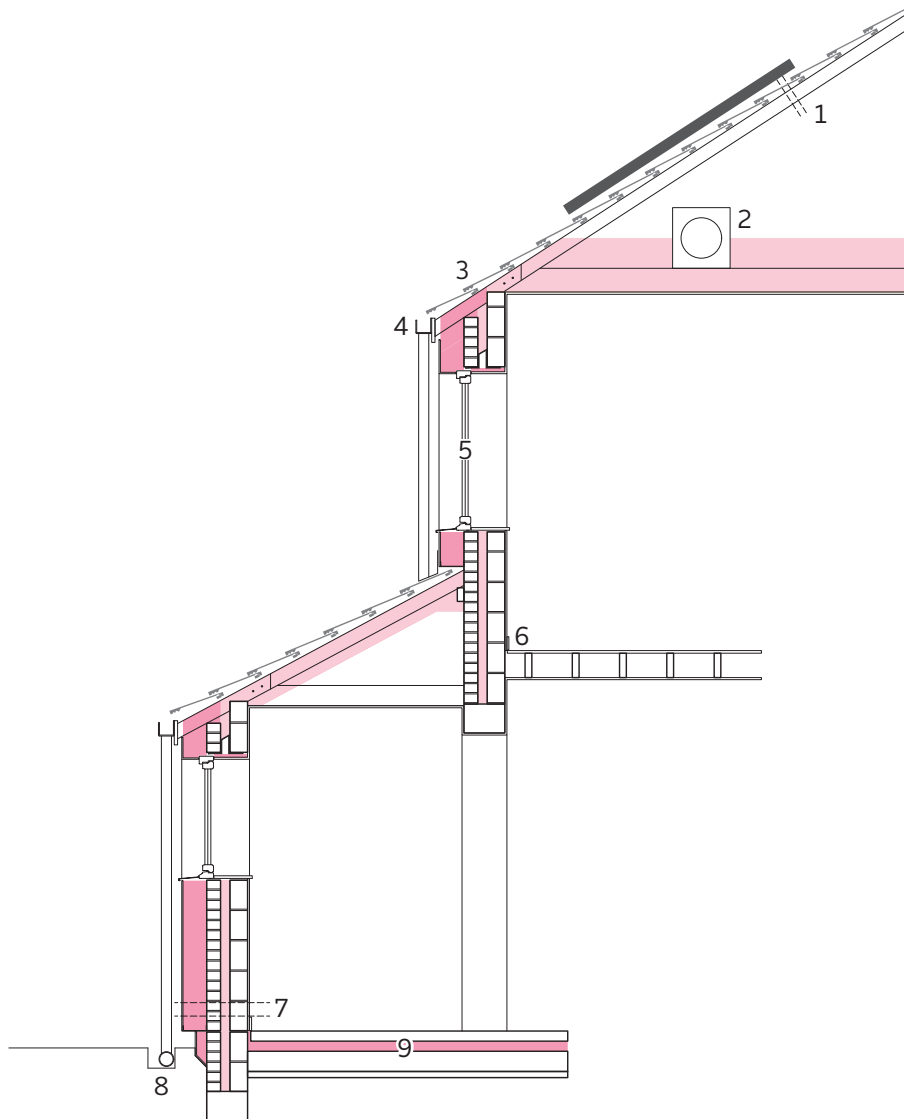
£9,250
EWI

£6,000
UNDERFLOOR
INSULATION

5.4

PROJECT SUMMARY

67 TEMPLE AVENUE	EXISTING CONDITION	STANDARD RETROFIT	RADICAL RETROFIT
ESTIMATED FUEL COSTS PER YEAR (DECEMBER 2009) £/yr			
HEATING	612	285	87
HOT WATER	136	84	22
LIGHTING	55	54	54
SAP BAND A-G	D	C	B
SAP SCORE 0-100	59	77	89
ESTIMATED CARBON DIOXIDE EMISSIONS PER YEAR kgCO ₂ /yr			
DWELLING EMISSION RATE (DER) kgCO ₂ /m ² /yr	62.22	30.69	13.11
PREDICTED HEAT LOSS W/K	341.4	238.7	107.2
PREDICTED HEAT LOSS REDUCTION W/K	n/a	102.7	234.2
PREDICTED HEAT LOSS PARAMETER W/m ² K	3.05	2.13	1.15
MEASURED AIRTIGHTNESS m ³ /(h.m ²)@50Pa	15.76	9.83	5.42
MEASURED HEAT LOSS W/K	324.7	249.2	159.0
MEASURED HEAT LOSS REDUCTION W/K	n/a	75.5	165.7
MEASURED HEAT LOSS PARAMETER W/m ² K	2.90	2.22	1.42



Section through the rear of the property following the radical retrofit, showing the extent of the works, issues for consideration and knock-on effects

1. Seal solar thermal panel penetrations through the roof
2. Pack insulation around MVHR
3. Extend rafters, batons and tiles to accommodate EWI
4. Reposition downpipes and gutters
5. Position windows in line with EWI
6. Lift floorboards to seal around built-in joists
7. Seal service penetrations through external walls
8. Reposition gully and kitchen wastepipe
9. Install insulated concrete slab

- By the end of the project the dwelling's measured performance was considerably improved, with heat losses reduced by slightly more than half. However, the radical retrofit involved high capital costs and significant disruption.
- Although possible, it is extremely difficult to improve a house of this period to achieve an 'as-built' performance equivalent to the advanced energy and carbon standard of JRF and JRHT's prototype houses.
- Although design calculations predicted that following both stages of improvements Number 67 would perform better than its newly-built neighbours (Numbers 54 & 69) in fact the measured heat loss was slightly greater.
- Neither the renovated nor the new-build houses performed as well as predicted. Measured heat losses revealed a 26.3 per cent increase over the design value for Number 67; a 20.5 per cent increase for the masonry prototype, Number 54; and a 10.6 per cent increase for the SIPS (Structural Insulated Panel System) prototype, Number 69.
- This gap between measured and predicted values is known as 'the performance gap' (Richards Partington Architects, 2012).

- Inputs used in the SAP calculation tool, such as U-values, thermal bridging values and efficiencies of building services, can be based on manufacturers' data, which is tested in specific laboratory conditions and does not account for variables of housing design and construction/working standards, the realities of building on-site, and the effects of the weather/orientation.
- Given the nature of the inputs, it is highly unlikely that the designed performance will ever be achieved in the majority of cases in mainstream construction. Therefore appropriate tolerances or confidence factors (based on quality of data available) should be included in all calculations.
- With refurbishments the performance gap is widened by SAP's unsophisticated model of the idiosyncrasies of an existing house. Inaccuracies may result from relying on Reduced Data SAP (RdSAP), an insufficient survey or imprecise inputs into SAP.
- The effectiveness of insulation improvements is highly variable and should ideally be verified by testing.
- The performance gap of a property will only increase as you include the performance of technologies, and the issue of user interaction (not using things correctly).

SPECIALIST TERMS

Air permeability: Is the unintended leakage of air through gaps and cracks in the external envelope of a building.

Air pressurisation testing: Measures the air permeability of the building envelope to determine airtightness, which is expressed as the volume of air leakage per hour per square metre of external building envelope ($\text{m}^3/\text{h.m}^2$) at a tested pressure of 50 pascals (Pa).

'As-built' performance: Describes performance measured post-construction.

Cavity wall insulation (CWI): Is installed by injecting a cavity wall with insulation. All CWI systems are approved by the British Board of Agrément (BBA) and British Standards Institution (BSI). Each system has a defined pattern of holes, which has been tested to verify that it results in a complete fill.

Cavity Insulation Guarantee Agency (CIGA): Provides independent 25-year guarantees for CWI installed by CIGA registered installers in the UK and the Channel Islands.

Coheating testing: Measures whole-house heat loss (a combination of fabric heat loss and ventilation heat loss). A coheating test involves heating the inside of the dwelling using electric fan heaters to an elevated internal temperature over a period of time, typically one to three weeks. In order to obtain a sufficient temperature difference (generally ten degrees Kelvin or more), the coheating test should be carried out in the winter months, usually between October/November and March/April.

Dwelling Emission Rate (DER): Is a measure of carbon dioxide emissions arising from energy use in homes calculated by SAP. It is expressed in kilograms of carbon dioxide per square metre of floor area per year and takes into account energy used for space heating, hot water, fixed internal lighting and fans and pumps.

External wall insulation (EWI): External wall insulation involves fixing a layer of insulation material to the wall, then covering it with a special type of render or cladding. The finish can be smooth, textured, painted, tiled, panelled, pebble-dashed, or finished with brick slips.

Green Deal: From autumn 2012 the new 'Green Deal' will offer consumers energy efficiency improvements to their homes, community spaces and businesses at no upfront cost, and to recoup payments through a charge in instalments as part of their energy bill. The repayment obligation will

sit with the property and transfer to any new occupier. The 'golden rule' of the Green Deal is that the expected financial savings must be equal to or greater than the cost of the work attached to the energy bill (Department of Energy and Climate Change, 2011).

Heat flux sensors: Measure the rate of heat loss through a material at a specific point giving an indicative U-value for a building element.

Heat loss parameter: Is a building's heat loss (fabric heat loss and ventilation heat loss combined) per unit floor area. The heat loss parameter is comparable with other buildings.

Housing stock: It is estimated that at the start of January 2012 there are 26.7 million homes in Great Britain. Of these 23.3 million have lofts, 18.9 million have cavity walls with the remaining 7.8 million having solid walls. 14.1 million homes had loft insulation of at least 125 mm - 60 per cent of homes with lofts. 11.2 million homes had cavity wall insulation - 59 per cent of homes with cavity walls. 122,000 homes had solid wall insulation - 2 per cent of homes with solid walls (Department of Energy and Climate Change, 2012a).

Mechanical ventilation: Is a system of fans and ducts used to extract stale air and bring fresh air into a building. Mechanical ventilation can include the recovery of waste heat from the outgoing air, which is used to pre-heat the incoming air - mechanical ventilation with heat recovery (MVHR).

SAP (Standard Assessment Procedure): Is the Government's nationwide approved method for calculating energy efficiency and carbon emissions from homes to demonstrate compliance with Building Regulations.

Solar gains: Are the build up of heat within a building due to direct sunlight.

Thermal bridging: Are weak instances in the building envelope where heat loss is greater than through the main building elements. There are four types of thermal bridge:

- 1. Repeating thermal bridges** follow a regular pattern and are evenly distributed over an area of a thermal element. Typical examples include: timber studwork and I-beams in timber frame construction and mortar joints in an insulating blockwork inner leaf. They are accounted for in U-value calculations;
- 2. Non-repeating or linear thermal bridges** are intermittent and occur at a specific point in the construction. They are often caused by discontinuities in the thermal envelope. They typically occur

around windows and doors and where internal walls or floors penetrate the thermal envelope;

3. **Point thermal bridges** are created by a small cross section element that has high conductivity and penetrates the thermal envelope. Typical examples include: wall ties and insulation fixing screws;
4. **Geometric thermal bridges** are a result of the geometry (or shape) of the thermal envelope. They can be two-dimensional (where two planes intersect) or three-dimensional (where three or more planes intersect). They occur at junctions between building elements, such as between the walls and roof, and at changes of geometry, for example, a corner in a wall or a hip in a roof.

Overall thermal bridging should be calculated by the SAP assessor.

Thermograms: Display surface temperatures in a range of colours. With skilled interpretation, thermograms of heated buildings can show comparative heat loss through different elements of the building envelope and thermal weaknesses.

Thermal bypass: Thermal bypass is the movement of unheated outside air within voids in the construction, particularly in party wall cavities, underfloor voids and lofts, resulting in increased heat loss.

Thermal performance: Each 'element' of the building envelope - a wall, a roof, a floor, a window or a door - has a role to play in minimising heat loss. The insulating effect of each of these elements is measured by its U-value.

U-value: Is the calculated rate at which heat is lost per unit area of a building element expressed in W/m^2K ; the lower the U-value, the better an element's thermal performance.

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