second edition, may 2014

an introduction to low carbon domestic refurbishment

construction products association

Foreword

The UK has made a commitment to reduce its carbon dioxide emissions by 80% by 2050 and the built environment is expected to account for about half of this reduction. Programmes are being put in place to ensure that the new buildings we create in the future meet the highest practical and cost effective standards for energy efficiency, but impressive as we expect this achievement to be, it will barely scratch the surface in terms of meeting the contribution that the built environment has to make to the overall carbon reduction target.

The real challenge is to improve the energy efficiency of the buildings that exist today, the vast majority of which will continue to exist in 2050. This will involve some form of refurbishment of each of the 26 million homes and 2 million non-domestic buildings – a programme that it is estimated will cost at least £500 billion over the next forty years. The scale of such a programme is unprecedented in both the challenge and opportunity it provides for the construction industry.

This Introduction to Low Carbon Domestic Refurbishment sets out the various ways in which homes can be upgraded. It begins with first principles and highlights what needs to be done before work starts, then focuses on the main elements of the home – the floor, walls, windows and roof, and the ventilation, heating, hot water, lighting and electrical systems. It concludes with a series of case studies that show the different scale of activity that can be undertaken, ranging from low cost work on walls, lofts and floors, through to radical whole-house renovations.

The information is presented in a way that will be of value to a wide audience – the informed householder trying to decide where to start on their property, the builder looking to advise their clients on the most cost effective solution for them, as well as regulators and politicians, who need to understand the challenges ahead.

Every household in the country needs to be engaged in this programme at some point over the next thirty-six years and it is imperative that the work undertaken is carried out in a cost effective and efficient manner, with least inconvenience to the owners and occupiers. Success will require everyone to play their part and understand the balance between costs and benefits.

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The aim of this guide

This guide is intended for builders who are carrying out refurbishment of existing houses and flats. It will also be of interest to householders who are planning to refurbish their homes, their professional advisors (architects, surveyors and energy consultants), politicians and regulators. The aim of the guide is to provide clear information about how to refurbish in a way that improves the energy efficiency of the building and therefore reduces carbon dioxide emissions from energy use for heating, hot water, lighting and domestic appliances. We deal first with basic principles and the preliminary considerations associated with planning a refurbishment project and then with each of the elements of a house (floors, walls, heating system) in turn. Each section of the guide includes references and links to sources of more detailed information. The case studies at the end of the guide provide examples of a variety of low carbon refurbishment projects.

Climate change

Climate change brought about by man-made emissions of greenhouse gases has been identified as the greatest challenge facing human society during the twenty-first century. In the UK, each person's share of our national greenhouse gas emissions is around ten tonnes per year. Stabilising global emissions at a sustainable level will involve reducing emissions to two tonnes per person per year. Every individual, every industry and every profession will have a part to play in meeting the challenge.

The complex mechanisms of climate change involve the balance of greenhouse gases in the atmosphere, in the oceans and in all living things. The main mechanism is the greenhouse effect, by which levels of greenhouse gases in the atmosphere affect the heat balance of the earth. The process is summarised in Figure 1.1.

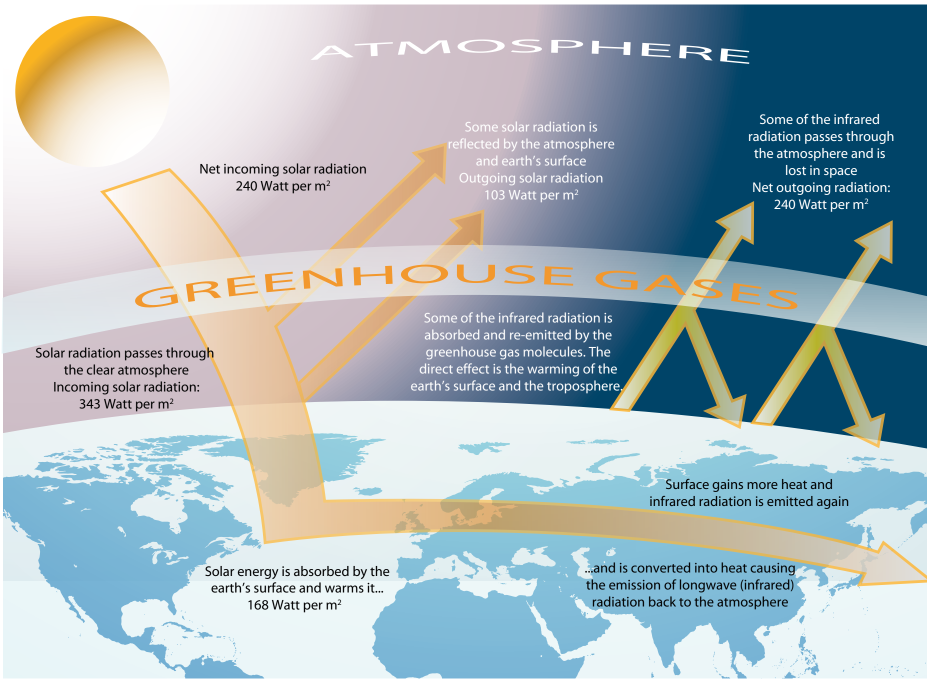


Figure 1.1 The process of global warming caused by greenhouse gases in the atmosphere. Adapted from 'Greenhouse effect', Philippe Rekacewicz, UNEP/GRID-Arendal Maps and Graphics Library. 2005

Fuel	Carbon dioxide emissions factor $kgCO_2/kWh$	Emissions factor relative to mains gas
Mains gas	0.216	1.00
LPG (bulk)	0.241	1.12
Oil	0.298	1.38
House coal	0.394	1.82
Grid electricity	0.519	2.40
Wood chips	0.016	0.07
Wood pellets	0.039	0.18
Wood logs	0.019	0.09

Table 1.1 Carbon dioxide emission factors for domestic fuels used in the UK (source: SAP 2012, Table 12)

The principal greenhouse gas is carbon dioxide, which is emitted when we burn fossil fuels including gas, solid fuel (such as coal) and electricity (which is currently generated mostly by burning gas and coal). Table 1.1 shows the carbon dioxide emissions factors for fuels used in the UK, i.e. the amount of carbon dioxide emitted (including power station emissions and emissions associated with processing and distribution) per unit of energy delivered to the building. The third column of the table indicates the relative size of the emissions factors, compared to mains gas. Note that the carbon dioxide emissions associated with the use of grid electricity are more than twice as large as the emissions associated with the use of the same amount of energy in the form of gas.

The European Union has adopted a policy to reduce carbon dioxide emissions by 20% and to obtain 20% of energy from renewable sources such as wind power and solar power, throughout the EU, by 2020. The UK government has set a target of reducing carbon dioxide emissions by 80% by 2050, with intermediate targets to be met during the next twenty years. As part of the process of meeting these targets, the government has developed the Green Deal, a mechanism by which householders may borrow the capital required to carry out low carbon refurbishment and repay it via a charge on their electricity bills, over a period of up to twenty years. The annual charge may not exceed the predicted annual fuel cost saving. The charge is attached to the electricity meter, not to the occupant, so when the occupant changes the charge is paid by the new householder. Thus occupants only pay the Green Deal charge while they are enjoying the benefits of the refurbishment. The government has also introduced the Energy Company Obligation (ECO), which obliges large energy retailers to spend approximately £650 million per year for at least four years (collectively) on reducing carbon dioxide emissions from buildings. ECO funding is available for 'hard to treat' homes (e.g. those with solid external walls) and for households in fuel poverty, as well as for community-scale refurbishment projects, but following changes in the autumn of 2013 much of the money seems likely to be spent on cheaper, basic measures such as loft insulation and cavity wall insulation. The government has also introduced a Feed in Tariff (FIT) to provide a financial incentive for the local generation of electricity from renewable sources such as photovoltaics and a Renewable Heat Incentive (RHI) to provide a financial incentive for the local generation of heat and hot water from renewable sources such as solar energy and biomass.

These programmes are just the start of an emerging national refurbishment programme on an unprecedented scale. The refurbishment of over 20 million homes in less than forty years implies that on average we must improve at least half a million homes every year – a rate of nearly one every minute! At an average cost of £25,000 per dwelling the domestic refurbishment programme will have a value of approximately £500 billion, presenting not only a funding challenge for all involved but also a significant business opportunity for the construction industry. Already, local authorities are promoting low carbon refurbishment through regional partnerships with industry such as Birmingham Energy Savers and Warm Up North. We can expect to see many similar schemes during the coming years.

Energy use in our homes

Carbon dioxide emissions associated with all energy use in the UK amount to more than 500 million tonnes each year (the exact amount depends on the weather). Almost half of these emissions are associated with energy use in buildings. Energy use in housing accounts for slightly more than half of the emissions associated with energy use in all buildings, amounting to 28% of the UK total – typically between 135 million and 150 million tonnes per year. Despite measures to improve the energy efficiency of dwellings, carbon dioxide emissions are rising, mostly because of a significant increase in the numbers of electrical appliances in homes. Increasing household numbers and a tendency to heat our properties to higher temperatures are also contributing to rising emissions.

There are approximately 26 million homes in the UK. The stock has grown from 18 million in 1976 and is expected to reach 27 million by 2020 – 50% growth in less than fifty years. From 2016 new dwellings will have to be 'zero carbon', but few new dwellings will replace existing ones; the average replacement rate of the housing stock, during the last fifty years, has been less than 1% per year. Because of this, in any one year, only 0.3% of carbon dioxide emissions are associated with the new homes built that year and 99.7% of emissions are associated with dwellings built in previous years. Over 80% of the current stock of homes will still be standing and occupied in 2050. Therefore the required 80% reduction in emissions associated with energy use in housing cannot be achieved without significant improvement in the energy efficiency of existing homes.

Since we refurbish our homes only rarely (at intervals of twenty or thirty years), it is important to seize every opportunity to improve energy efficiency. If you are improving your home, you should incorporate measures to improve its energy efficiency and reduce the carbon dioxide emissions associated with energy use. If you are advising homeowners on refurbishment projects, you should advise them to improve energy efficiency as much as possible. In an era of rising fuel prices this is sound advice, irrespective of the argument for reducing emissions. Benefits for homeowners include lower fuel bills and improved comfort, as well as helping to meet the challenge of climate change.

The energy efficiency of existing dwellings and their potential for improvement depends largely on their age. Before the 1930s, most buildings were built with solid brick walls, which are relatively expensive to insulate, and with single glazed windows and solid fuel heating. Since the 1930s most domestic buildings have been built with cavity walls, which are easy to insulate by filling the cavities; to date, approximately 40% of the originally empty cavity walls have been insulated. Roofs have been progressively improved since the 1970s by the installation of loft insulation. Since the 1960s, single glazed windows have slowly been replaced by new double glazed windows.

Gas-fired central heating is installed in nearly 90% of dwellings, but a significant number of dwellings have no gas supply. Boilers are replaced at 10-20 year intervals; and boiler efficiencies have increased, from 65% or less in the 1970s to around 90% for new condensing boilers today.

From 1976, regular improvements in the energy efficiency of new dwellings have been driven by the Building Regulations. Insulation standards were increased in 1982, 1990, 2002, 2006, 2010 and 2014. Overall energy efficiency standards for dwellings were first introduced in 1995 and increased in 2002, 2006, 2010 and 2014. Further changes are planned for 2016.

Today, an average 1930s semi-detached house of 90 m^2 floor area, with some insulation and gas-fired central heating, uses approximately 26,000 kWh of energy per year for heating, hot water, cooking, lighting and appliances. Fuel costs are approximately £4,100 per year (including 5% VAT) and carbon dioxide emissions are approximately six tonnes per year, of which 70% are associated with fossil fuel use (mostly for heating and hot

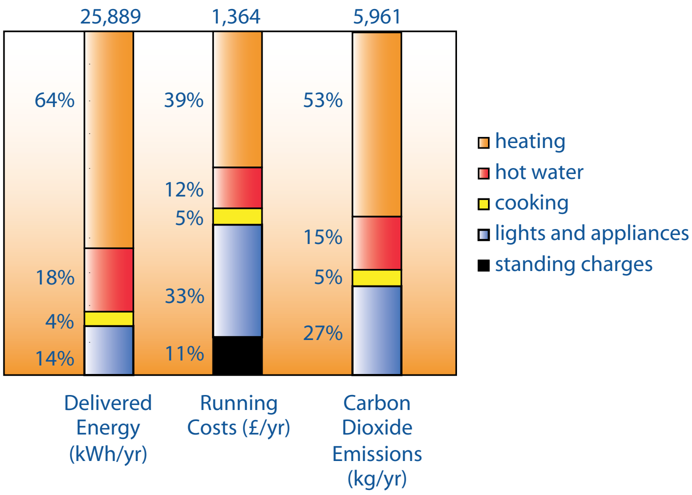


Figure 1.2 The breakdown of annual fuel use, fuel costs and carbon dioxide emissions for a typical 1930s semi-detached house of 90 m^2 floor area

water) and 30% are associated with electricity use. Figure 1.2 shows the breakdown of annual fuel use, fuel costs and carbon dioxide emissions for this typical house.[1]

Energy standards for refurbishment

In this guide, we have adopted two energy standards for housing refurbishment: a current 'good practice' standard, and an 'advanced' or 'low carbon' standard. These standards may be applied to individual elements (e.g. exposed floors, walls and roofs, heating systems) and to the dwelling as a whole:

- The good practice standard exceeds the current minimum standards required by the Building Regulations[2], and is consistent with guidance published by the Energy Saving Trust[3]. This standard is readily achievable using widely available materials and products with which builders and installers are familiar

- The advanced standard is the 'EnerPHit' standard developed by the Passive House Institute, which aims to reduce overall carbon dioxide emissions by 60% or more. Refurbishing a home to this standard will be more complicated and expensive, but will often be a more appropriate response to the challenge of climate change, especially if another improvement opportunity may not arise (or may not be affordable) for some time

Refurbishment strategies: the three-stage approach

There are two common approaches to improving the energy efficiency of a home during refurbishment: the 'measures-based' approach and the 'whole-house' approach:

- The measures-based approach involves the installation of individual improvement measures one-by-one at different times. Measures such as cavity wall insulation, loft insulation, new windows or a more efficient boiler are chosen because opportunities arise – for example, the offer of grant funding or the need to replace worn out window frames or a broken boiler

- The whole-house approach involves installing a 'package' of improvement measures embracing the building fabric (exposed floors, walls and roofs, and heating systems), the building services (heating, hot water, ventilation and lighting) and often renewable energy systems (e.g. solar water heating) at the same time

1 All of the figures quoted in this paragraph and presented in Figure 1.2 were calculated under SAP standard occupancy using BREDEM-12 based NHER Plan Assessor (SAP 2005) version 4.5 software.

2 See Building Regulations Approved Document L1B, 'Conservation of fuel and power in existing dwellings' (2013 edition), NBS.

3 For the Energy Saving Trust's online guidance see www.est.org.uk.

The measures-based approach has been adopted for many government-funded programmes such as the Energy Company Obligation (ECO) that obliges energy suppliers to reduce emissions associated with energy use by their customers. This approach is straightforward and affordable and minimises disruption of the household during installation, but it takes a long time and a lot of projects to achieve significant reductions in carbon dioxide emissions.

When a major refurbishment is being carried out, the whole-house approach should be adopted. This approach is often more expensive and disruptive, but it allows most of the work to be completed at once so that significant fuel cost savings and emissions reductions are obtained immediately.

In reality, few households can afford to adopt the whole-house approach, and many are unwilling to undertake work that may involve them moving out of their home while improvements such as internal wall insulation, floor insulation or whole-house ventilation are installed. Nevertheless, the challenge of climate change is significantly to improve the energy efficiency of most of our homes within the next forty years and there are at least 20 million dwellings to improve.

Therefore in this guide we recommend a three-stage approach, which involves having a plan for the dwelling (see Chapter 2) and implementing it progressively, as opportunities arise and funding becomes available, perhaps over many years. The three stages are as follows:

1. **Make 'quick fixes':** Improvement measures that are affordable, achievable with readily available materials and products by existing installers, and not too disruptive

2. **Exploit and preserve opportunities:** Options for improvement often arise while other work is being carried out. It is essential to exploit these opportunities because they may not arise again for some time. It is also important not to close down options for making improvements in the future. For example, it makes sense to insulate the roof when re-roofing and to replace windows when installing wall insulation. If external wall insulation is planned as a future improvement, it may be appropriate to allow for it by extending the eaves when re-roofing. If a hot water cylinder is replaced, it may be appropriate to specify a twin-coil cylinder ready for the later installation of solar water heating

   The Building Regulations require us to exploit some improvement opportunities: for example there are minimum efficiencies for replacement boilers and if you re-plaster or re-render more than a certain percentage of any external wall you must insulate the whole wall[4]. The Building Regulations are dealt with in more detail in Chapter 3.

4 See the guidance in Building Regulations Approved Document L1B, 'Conservation of fuel and power in existing dwellings' (2013 edition), NBS.

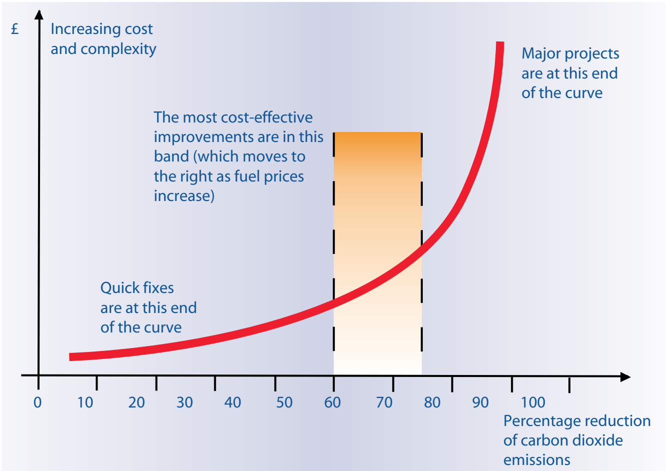


Figure 1.3 How the cost and complexity of refurbishment varies with emissions reduction

3 **Implement major projects:** Eventually, if we are to meet our national emissions reduction targets, major improvements to most homes are likely to be required. These are often best implemented when carrying out other work (replacing a kitchen or bathroom or having a loft converted), when funding becomes available, or before moving into a house for the first time

We will return to this three-stage process in Chapter 3.

The capital cost of a refurbishment project designed to reduce carbon dioxide emissions increases exponentially with the percentage by which emissions are to be reduced, as shown in Figure 1.3. The average capital cost of reducing emissions by 80% or more may be more than £50,000. A more practical target of reducing emissions by between 50% and 60% may cost only half as much. 'Quick fixes' (stage 1) lie along the left-hand end of the curve. Exploiting and preserving opportunities (stage 2) reduces the cost and disruption associated with some projects, making them more affordable. Major projects (stage 3) lie at the middle and towards the top of the curve.

Figure 2.1 A typical semi-detached house. Picture: John Willoughby

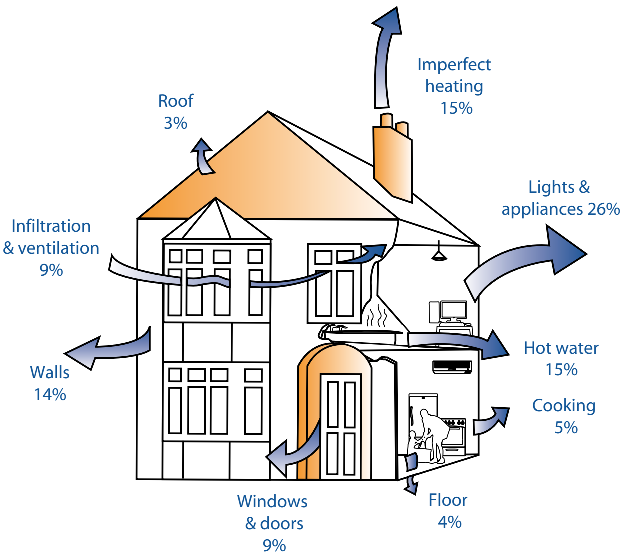


Figure 2.2 Breakdown of carbon dioxide emissions for a typical house[5]

Energy use and carbon dioxide emissions for a typical house

Figure 2.1 shows an average UK dwelling: a semi-detached house built in the 1930s, with average floor area of 90 m^2, some insulation, gas-fired central heating and average carbon dioxide emissions of just under six tonnes per year.

Figure 2.2[5] shows the breakdown of carbon dioxide emissions associated with fuel use in this average dwelling; the arrows represent the emissions associated with heat losses through the various elements of the building fabric, those incurred because of the inefficiency of the heating system and controls, and those incurred as a consequence of electricity use for lighting and appliances. The breakdown of emissions varies a little for dwellings of other types, e.g. larger detached houses and smaller flats. However, the approximate improvement costs and carbon dioxide figures quoted in this chapter always refer to the average house shown in Figure 2.1.

The biggest source of carbon dioxide emissions is space heating, which accounts for 54% of emissions. The heat losses through the building fabric (including windows and doors) make up 30% of the total emissions and these must be satisfied by the heating system. A further 15% of emissions are attributed to the inefficiency and poor control of the heating system (which uses more fuel than it would if more efficient) and 9% of emissions are attributed to infiltration and ventilation. Improved insulation and air tightness (including better windows) and efficient heating and controls are important components of any refurbishment.

The next largest source of carbon dioxide emissions is electricity use for lighting and appliances (26%). Fixed lighting accounts for 6% of emissions and portable lighting and appliances account for 20%. Using electricity makes a lot of carbon dioxide – more than twice as much as using the equivalent amount of gas[6]. This is why it is important to consider the efficiency of lighting and domestic appliances in a refurbishment project. Low energy compact fluorescent lamps (CFLs) use approximately a quarter of the electricity used by old-fashioned tungsten lamps, and the latest LED[7] lighting is even more efficient.

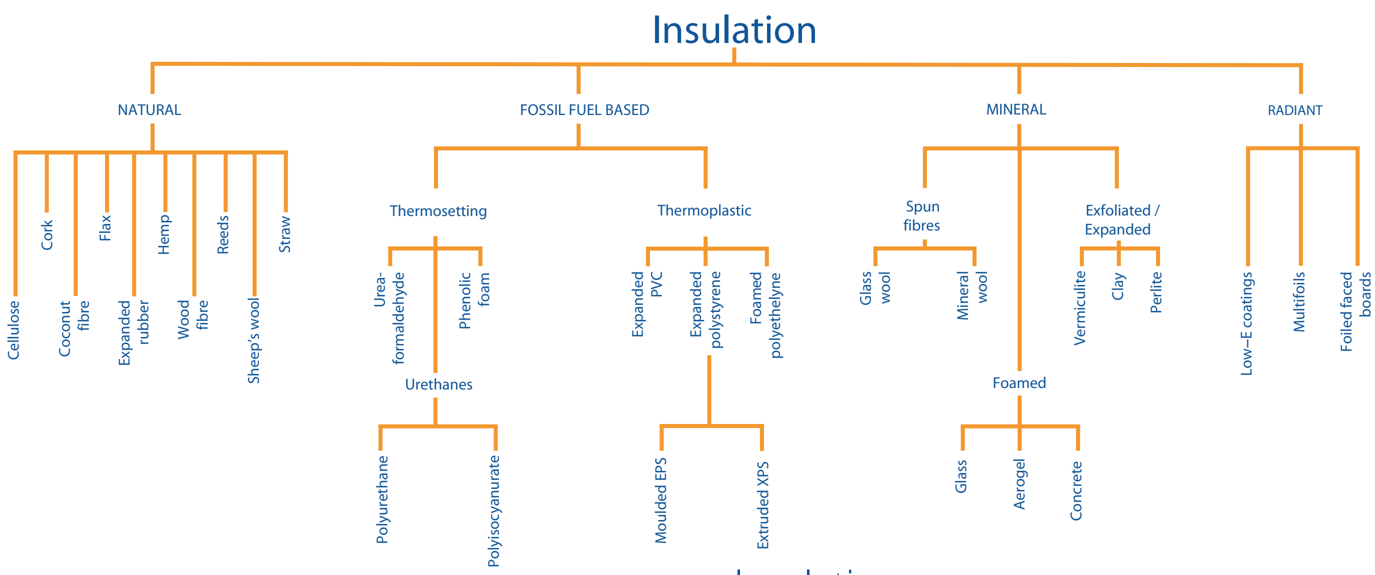
At least 15% of carbon dioxide emissions can be attributed to water heating; this depends on the efficiency of the boiler, how well the hot water system is controlled and how well the hot water cylinder is insulated. Finally, 5% of carbon dioxide emissions are attributed to cooking – this can be reduced by the use of a microwave oven and induction hob.

The building fabric is dealt with in Chapters 4 to 8 of this guide. Ventilation is dealt with in Chapter 9. Heating and hot water are dealt with in Chapters 10 and 11. Electric power is dealt with in Chapter 12. This guide does not deal with the energy used for cooking.

5 The percentages in Figure 2.2 have been calculated under SAP standard occupancy using BREDEM-12 based NHER Plan Assessor (SAP 2005) version 4.5 software.

6 The emissions factors (taken from SAP 2012) are 0.216 $kgCO_2/kWh$ for mains gas, and 0.519 $kgCO_2/kWh$ for grid electricity.

7 LED stands for light emitting diode.



Insulation

Insulation of the building fabric is a key component of any domestic refurbishment project. Insulating materials are built into the building fabric to impede the flow of heat from the warm interior to the cold exterior (during the heating season). The most important property of an insulating material is its thermal conductivity, which is measured in W/mK – that is, the rate of heat conduction through one metre of the material per K (or degree C) temperature difference across it. The lower the conductivity, the better, but insulation material must be suited to its application.

There are many types of insulation: Some are natural materials, some are highly processed and many of those with the best thermal performance are derived from oil. Figure 2.3 shows the 'family tree' of insulating materials. Table 2.1 shows the approximate thermal conductivities of some common insulating materials. Figure 2.3 and Table 2.1 do not show the latest vacuum insulation panels (because a vacuum is not strictly a material!), which have thermal conductivity of approximately 0.08 W/mK.

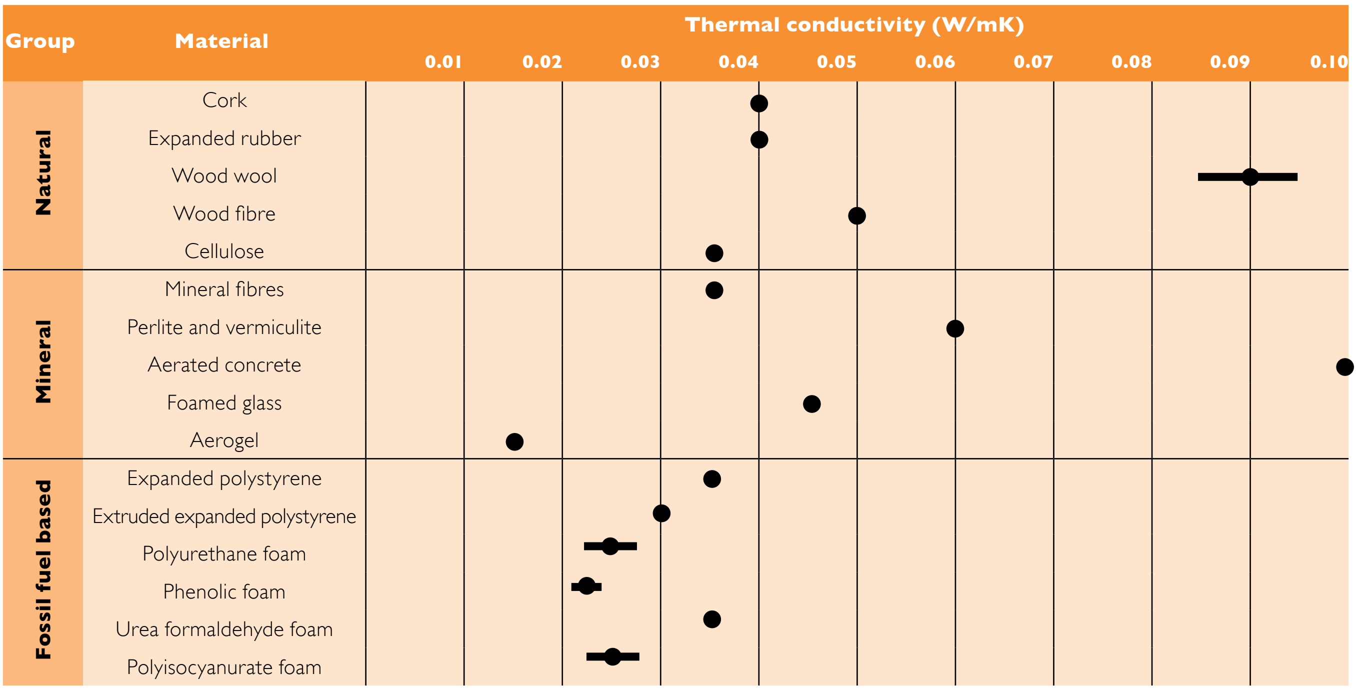


Table 2.1 Thermal conductivities of common insulating materials

Construction	U value (W/m²K)
Walls	
Solid brickwork (225 mm uninsulated)	2.30
Cavity (brick + dense block, unfilled)	1.60
Cavity (brick + lightweight block unfilled)	1.00
Cavity (brick + dense block filled)	0.52
Cavity (brick + lightweight block filled)	0.30
Modern timber frame or masonry wall	0.25
Superinsulated wall	0.15
Roofs	
No insulation	2.30
100 mm loft insulation	0.40
150 mm loft insulation	0.29
200 mm loft insulation	0.20
250 mm loft insulation	0.16
Floors	
Solid ground floor (uninsulated)	1.00
Suspended timber ground floor (uninsulated)	1.30
Modern insulated ground floor	0.18

Table 2.2 Approximate U values for typical domestic construction

Opening type	U value (W/m²K)	g value
Single glazed window	4.8	0.85
Single glazed window with secondary glazing	2.4	0.76
Double glazed window	2.7-3.1	0.76
Double glazed window with low-E coating	2.1-2.7	0.63-0.72
Double glazed window with low-E and argon fill	2.0-2.5	0.63-0.72
Triple glazed window with low-E and argon fill	1.5-1.9	0.68
Modern high performance window	0.7	0.55
Solid timber external door	3.0	-
Modern insulated external door	1.0	-

Table 2.3 Approximate U values and g values for timber framed windows and doors from SAP 2009 Table 6

U values

When it is incorporated in a building, an insulating material inhibits the thermal transmittance, or 'U value', of the building element (a floor, wall or roof). U values are measured in W/m²K, that is, the rate of heat transfer through one square metre of the element per K (or degree C) temperature difference across it. Again, the lower the U value, the better. Table 2.2 presents the approximate U values of some common domestic constructions for walls, roofs and floors, in dwellings of various ages.

For windows and doors, U values are usually quoted for the complete unit – glazing and frame. Table 2.3 presents the approximate U values of some common timber-framed window and door types. Also presented in Table 2.3 are approximate solar energy transmittances, or g values; note that the transmission of solar energy is reduced as more panes or low emissivity coatings are added.

When all the heat losses through the various building elements are added together, the overall heat loss will typically be between 2 kW for a modern, well-insulated house and 20 kW for a large, uninsulated house. The average semi-detached house shown in Figure 2.1 has an overall heat loss of approximately 7.5 kW.

Vapour permeability

The fabric of many older buildings (particularly those built before 1920) is 'vapour permeable'. This means that moisture (in the form of water vapour) in the internal air can migrate through the building fabric all the way to the exterior, reducing the risk of condensation on cold surfaces or in the interstices of the construction (which can lead to mould growth and rot). Increasing the level of thermal insulation of vapour permeable (or 'vapour balanced') construction will change the dynamic performance of the building. This may cause an unacceptable risk of harmful interstitial condensation if measures are not taken to minimise the movement of water vapour into the structure or to ensure that it migrates to the exterior.

By contrast, most modern construction is 'vapour sealed', i.e. moisture in the internal air is excluded from the building fabric by inner layers of impermeable material, and is removed from the building by ventilation. Modern, sealed buildings rely on the vapour seals and ventilation systems to reduce the risk of condensation.

It is very important that existing vapour permeable construction is not sealed up by the addition of vapour sealed insulation or finishing layers. Sealing the construction may be detrimental to the building fabric and threaten its architectural or structural integrity, as well as the health of the occupants. Older buildings must therefore be carefully assessed by specialists to establish whether they are of vapour permeable construction and to identify appropriate insulation and finishing materials for use in refurbishment. Appropriate ventilation and moisture management strategies must also be adopted. It may be that a combination of measures is required as part of a whole building approach. For example, where a vapour control layer is required to minimise the risk of interstitial condensation, additional ventilation may be required both of the interior spaces and of some layers of the

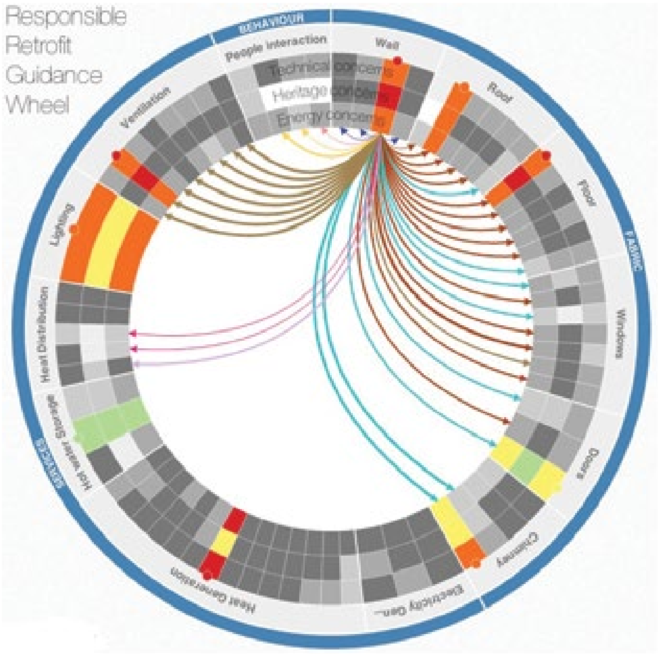


Figure 2.4 The STBA's Responsible Retrofit Guidance Wheel
Image courtesy of the STBA

Capital cost band	Symbol
Up to £100	£
£100 - £1,000	££
£1,000 - £5,000	£££
£5,000 - £10,000	££££
Over £10,000	£££££

Table 2.4 Capital cost bands used in this guide

building fabric on the cold side of the insulation. Some specialist conservation architects offer advice on this issue.

Most natural and mineral insulation materials are vapour permeable. Most fossil-fuel based plastic foam insulation is vapour sealed, as are foil-faced insulation boards. Plastic (i.e. polythene) membranes are also vapour sealed, but modern 'breather membranes' are vapour permeable.

Note that vapour permeability (or the lack of it) is not the same as air tightness. The former term relates to the migration of water vapour through the building fabric, the latter relates to the migration of air. Water molecules are smaller than air molecules, so vapour permeable construction can be air tight. Vapour sealed materials are usually air tight, but there may still be air leakage through both types of construction via cracks, joints, junctions and edges (see Chapter 8).

The Sustainable Traditional Buildings Alliance (STBA) has produced guidance on the improvement of traditionally constructed buildings, for the Department of Energy and Climate Change (forthcoming at the time of writing of this guide). See the STBA website at http://stbauk.org (and the government's 'planning portal', which is accessible via http://www.planningportal.gov.uk). The material includes an interactive 'guidance wheel' (see Figure 2.4) available at http://www.responsible-retrofit.org/wheel.

Improvement costs and 'carbon cost effectiveness'

The capital costs of improvement measures vary considerably, from almost nothing for a compact fluorescent lamp to several thousand pounds for solid wall insulation and up to £10,000 for a ground source heat pump. In this guide the approximate capital costs of improvement measures are shown by £ symbols, as shown in Table 2.4, and these figures apply to the average house shown in Figure 2.1. Actual improvement costs may be more or less than those shown, according to the house type.

Improvement measures also have different effects; some may reduce the carbon dioxide emissions associated with energy use in a dwelling only slightly, while others may deliver large reductions of many tonnes over their lifetimes. To complicate matters further, measures have different lifetimes – a low energy lamp may last five years, a new boiler may last fifteen years and insulation may last sixty years or more. It is helpful to know which measures represent the best investment, so when planning a refurbishment project we need to consider not only the capital costs of the improvement options but also by how much each measure is likely to reduce both fuel costs and carbon dioxide emissions over its life.

The 'carbon cost effectiveness' of an improvement measure is the capital cost of the measure minus the fuel cost savings that it will deliver, per tonne of carbon dioxide emission saved, during the lifetime of the measure. We have calculated the carbon cost effectiveness of improvement measures, using current average prices and fuel costs, for the typical semi-detached house shown in Figure 2.1.

Carbon cost effectiveness	Symbol
Pays for itself	☺☺☺☺☺
0 - 10 £/tonne CO_2	☺☺☺☺
10 - 100 £/tonne CO_2	☺☺☺
100 - 500 £/tonne CO_2	☺☺
> 500 £/tonne CO_2	☺

Table 2.5 Carbon cost effectiveness bands used in this guide

Some measures may be said to 'pay for themselves' – they reduce fuel costs over their lifetimes by more than their initial capital costs. Other measures involve substantial costs and deliver significant carbon dioxide emissions reduction. The least carbon cost effective measures may cost several thousand pounds per lifetime tonne of carbon dioxide saved. In this guide we have indicated the carbon cost effectiveness of various improvement measures in bands, indicated by ☺ symbols, as shown in Table 2.5.

How did we calculate carbon cost effectiveness?

These simplified carbon cost effectiveness calculations were developed for the Technology Strategy Board's 'Retrofit for the Future' competition.

Example A

Insulation Measure A costs £5,000 and has a lifetime of 60 years. It saves £50 in fuel bills and 400 kg (0.4 tonnes) of carbon dioxide each year.

Over the 60 year lifetime:

Fuel cost savings are: 60 years x £50	=		**£3,000**
The net cost of the measure is: £5,000 cost - £3,000 saving	=		**£2,000**
Carbon dioxide emissions are reduced by: 0.4 tonnes x 60 years	=		**24 tonnes**
The £s spent for every lifetime tonne of CO_2 is: £2,000 ÷ 24 tonnes	=	☺☺☺	**£83 per tonne**

Example B

Insulation Measure B costs £2,000 and has a lifetime of 60 years. It saves £50 in fuel bills and 400 kg (0.4 tonnes) of carbon dioxide each year.

Over the 60 year lifetime:

Fuel cost savings are: 60 years x £50	=		**£3,000**
The net cost of the measure is: £2,000 cost - £3,000 saving	=		**-£1,000**
Carbon dioxide emissions are reduced by: 0.4 tonnes x 60 years	=		**24 tonnes**
The £s spent for every lifetime tonne of CO_2 is: -£1,000 ÷ 24 tonnes	=	☺☺☺☺☺	**-£42 per tonne**

Example C

Heating Measure C costs £250 and has a lifetime of 10 years. It saves £10 in fuel bills and 100 kg (0.1 tonnes) of carbon dioxide each year.

To enable comparison with the insulation measures, we must compare them over similar periods of time. If we use the 60 year lifetime of the insulation measures, we will need to assume that Heating Measure C is replaced every 10 years. This means that the cost of the measure is £250 x 6 = £1,500.

Over the 60 year period:

Fuel cost savings are: 60 years x £10	=		**£600**
The net cost of the measure is: £1,500 cost - £600 saving	=		**£900**
Carbon dioxide emissions are reduced by: 0.1 tonnes x 60 years	=		**6 tonnes**
The £s spent for every lifetime tonne of CO_2 is: £900 ÷ 6 tonnes	=	☺☺	**£150 per tonne**

This simple analysis shows us that Measure B is the most cost effective as it saves more money over its life than it costs to install and the cost per tonne of carbon dioxide saved is negative. The next most cost effective is Measure A, which costs £83 per tonne of carbon dioxide saved, and then Measure C, which costs £150 per tonne of carbon dioxide saved.

Disruptiveness

Another attribute of improvement measures is that installing them may disrupt the life of the household. For simple measures such as low energy lamps, disruption is negligible, but more complicated measures such as the installation of internal wall insulation, ground floor insulation or whole-house ventilation are much more disruptive, often involving loss of use of some rooms or even having to move out of the house while the work is carried out. In Table 2.7 we have indicated the level of disruption likely to be experienced with each measure by 🛠 symbols, as shown in Table 2.6.

Disruption	Band	Examples	Description
Minimal	🛠	Low energy lamps, energy efficient appliances	You hardly notice it happening
Low	🛠🛠	Heating controls, cavity wall insulation, draught-stripping, loft insulation	It's noisy or intrusive for a short while, but you can live with it
Moderate	🛠🛠🛠	Replacement boiler, solar water heating	This takes a little longer, but you can still live with it – make tea
High	🛠🛠🛠🛠	Replacement windows, whole-house ventilation, external wall insulation	The installers will be everywhere – make lots of tea
Significant	🛠🛠🛠🛠🛠	Ground floor insulation, internal wall insulation, new heating system	You'll want to move out while this is happening

Table 2.6 Disruption bands used in this guide

An overview of improvement measures

Table 2.7 provides an overview of the most important domestic improvement measures that are dealt with in this guide. For each measure there is an indication of its capital cost, carbon cost effectiveness and level of disruption. The final column of the Table identifies the chapter of this guide in which more information can be found. The indicators in the Table have been worked out for the average house in Figure 2.1, so capital costs may be less for smaller properties and more for larger houses.

Measure	Capital cost	Carbon cost effectiveness	Disruption	Chapter
Floors				
Floor insulation	££	☺☺☺☺☺	🛠🛠🛠🛠🛠	4
Walls				5
Internal wall insulation	££££	☺☺☺☺☺	🛠🛠🛠🛠🛠	
Cavity wall insulation	££	☺☺☺☺☺	🛠🛠	
External wall insulation	££££/£	☺☺☺☺/☺	🛠🛠🛠	
Roofs				6
Loft insulation	££	☺☺☺☺☺	🛠🛠	
Rafter insulation (only when re-roofing)	£££	☺☺	🛠🛠🛠	
Windows and doors				7
Replacement windows and doors (U value 1.8)	£££	☺☺	🛠🛠🛠	
Replacement windows and doors (U value 0.8)	£££££	☺☺	🛠🛠🛠	
air tightness and ventilation				
Draught-stripping	£	☺☺☺☺☺	🛠🛠🛠	8
Major air tightness measures	££	☺☺☺☺☺	🛠🛠🛠	8
Air tightness measures with MVHR	£££	☺☺	🛠🛠🛠🛠	9
Lighting and appliances				12
Low energy lights	£	☺☺☺☺☺	🛠	
Low energy appliances (marginal cost of replacement)	£££	☺☺	🛠	
Heating				10
Replacement gas boiler	£££	☺☺	🛠🛠🛠	
Upgrading heating controls	££	☺☺☺	🛠🛠	
Micro CHP	££££	☺	🛠🛠🛠	
Ground source heat pump	£££££	☺	🛠🛠🛠🛠🛠	
Air source heat pump	££££	☺	🛠🛠🛠🛠	
Wood pellet boiler	££££	☺☺	🛠🛠🛠🛠	
Renewable energy systems				
Solar hot water heating	£££	☺	🛠🛠	11
1 kW solar photovoltaic panels	££££	☺	🛠🛠	12
Micro wind turbine	£££	☺	🛠🛠	12

Table 2.7 An overview of improvement measures for the average house shown in Figure 2.1

Note: costs are approximate and will vary depending on many factors, including detailed specification, actual home being upgraded and local conditions. Lower cost will improve carbon cost efficiencies

3. Before you start

There are several issues to consider before you start refurbishing a house. There may be statutory approvals (Planning and Building Regulations) to obtain, funding to seek and put in place, and professional advisors to consult. See the government's Planning Portal at www.planningportal.gov.uk. It is also important to establish a plan for the refurbishment – for a programme of work that may extend, intermittently, over many years.

Statutory approvals

The planning system seeks to guide the way our towns, cities and countryside develop. One part of the system is 'development control', or the need to obtain approval from the local planning authority (usually the local council) before some types of building work can commence. If the improvements you propose involve an extension to the house, a 'change of use' of any part of the house (e.g. the addition of a granny flat) or a change to the external character or appearance of the building, then planning permission may be required. You should seek guidance from a planning officer at your local planning authority. Applications for planning permission must be submitted to the local planning authority and usually take approximately eight weeks to be determined; the process can take much longer if the proposals are considered contentious or a neighbour objects. Applications can be approved (usually with conditions) or refused (in which case reasonable grounds for refusal must be given). There is a right of appeal to the Secretary of State against refusal; appeals must be submitted within twelve months and are determined on the advice of a planning inspector appointed by the Secretary of State.

The installation of some improvement measures is classed as 'permitted development' and has been exempted from the requirement for planning permission but there are strict conditions, so the local planning authority should always be consulted. The measures that are permitted development are roof-mounted solar photovoltaic (PV) panels and solar thermal collectors (provided that they do not stand more than 200 mm proud of the roof plane) and external wall insulation (provided that it does not change the character or appearance of the building).

If the house is 'listed' as of special architectural or historic interest, then listed building consent will usually be required for any work within the curtilage, except the most minor repairs. You should seek guidance from the local historic buildings officer before submitting an application for listed building consent to your local planning authority. Applications for listed building consent usually take approximately eight weeks to be determined, but can take much longer if the house is of exceptional architectural merit or the proposals are contentious. Some applications are referred to English Heritage, prior to determination. Similar constraints and procedures apply if the house is located in a conservation area or an Area of Outstanding Natural Beauty, or in or near a World Heritage Site, and permitted development does not apply in these areas.

Building Regulations set standards for the design and construction of buildings to ensure the health and safety of people in or near them. They include requirements to ensure that fuel and power are conserved and to limit the carbon dioxide emissions associated with energy use in buildings. Most work to existing buildings is controlled, other than minor repairs. Applications for approval under the Building Regulations may be submitted to any Building Control body and they are usually determined within eight weeks. Applications may be approved (usually with conditions) or refused (in which case the details of non-compliance must be identified). Work can be started without approval under the Building Regulations, provided that a Building Notice is submitted to the local Building Control body, who may then require information to demonstrate compliance.

Each local authority in England and Wales (Unitary, District and London Boroughs in England; County and County Borough Councils in Wales) has a Building Control section, which is the local Building Control body. It is their duty to ensure that building work complies with the Building Regulations except where it is formally under the control of an Approved Inspector (a private sector Building Control body). Individual local authorities coordinate their Building Control services regionally and nationally via Local Authority Building Control (LABC – see www.labc.uk.com). LABC has developed an online service for creating and submitting applications for approval under the Building Regulations; homeowners can use this service via www.submit-a-plan.com.

Part L of the Building Regulations deals with the conservation of fuel and power. Building Regulations Approved Document L1B and the Domestic Building Services Compliance Guide provide guidance on how work to existing dwellings may comply. The guidance covers 'thermal elements' (i.e. heat loss from floors, walls and roofs), 'controlled fittings' (i.e. windows, roof windows and external doors) and 'controlled services' (i.e. heating, hot water, ventilation and fixed internal and external lighting). Minimum insulation standards (i.e. maximum U values) apply if any thermal element is provided new (e.g. in an extension), replaced, retained through a change of use, or renovated. A thermal element is 'renovated' if any layer of its construction is added or replaced and the scope of the work includes more than 50% of the area of the element, although there is an overall limit of 25% of the area of total building envelope. Maximum U values apply to new and replacement controlled fittings (windows and external doors). Minimum efficiency and control standards apply if any controlled service (e.g. a heating system) is provided new or is wholly or partially replaced. In most cases approval for controlled work should be obtained via an application to a Building Control body (see above), but the compliance of new or replacement windows can be self-certified by installers who are registered with FENSA[8]. Similarly, the compliance of work to heating systems can be self-certified by a 'competent person', e.g. a registered Gas Safe, HETAS (Heating Equipment Testing and Approval Scheme) or OFTEC (Oil Firing Technical Association) fitter.

8 FENSA is the Fenestration Self-Assessment scheme operated by the Glass & Glazing Federation.

Funding

There are many sources of funding for domestic improvement measures that reduce fuel costs and/or carbon dioxide emissions. The Energy Saving Trust's online funding database[9] is a good starting point for identifying and accessing national and local funding schemes. Potential sources of funding include:

- The Energy Company Obligation (ECO), under which large energy retailers are required to spend approximately £650 million (collectively) per year (for at least four years from 2013) on measures to reduce the carbon dioxide emissions associated with energy use in buildings. Grants are available for 'hard to treat' dwellings (e.g. those with solid external walls, or that are not connected to the mains gas network), and for households deemed to be in fuel poverty. A Green Deal assessment (see below) is required to determine the eligibility of a dwelling for ECO funding and to estimate the likely emissions savings (in accordance with rules set by Ofgem). Grants are also available for community-scale refurbishment projects

- The Green Deal, which provides for loans to be made available to householders or landlords by Green Deal Providers (GDPs) to fund low carbon refurbishment. The loans are then repaid via electricity supply companies, over periods of up to twenty years, by means of charges attached to the electricity meters of the improved homes. The Green Deal 'Golden Rule' stipulates that the annual repayment charge must not exceed the predicted annual fuel cost saving. If the occupant of the dwelling changes during the loan period, the charge remains attached to the electricity meter (not to the occupant), so the new occupant becomes liable for the charge. Thus occupants only contribute to repaying the capital cost of improvements when they are enjoying the benefits of the refurbishment. Note, however, that, during a period of rising fuel prices, households whose refurbishment work is funded via the Green Deal may not be better off because the repayment charge offsets the fuel cost saving. They will however be more comfortable in their refurbished home, and less badly off than they would have been had they not refurbished. In order to obtain a Green Deal the dwelling must be assessed by a qualified Green Deal Advisor. The assessment predicts the fuel cost saving associated with improvement options, from which preferred options are incorporated in a Green Deal Plan. The Plan is agreed between the householder or landlord and a GDP, who will arrange the finance and the installation of the improvement measures, and for the Green Deal charge to be attached to the electricity meter

- The Feed in Tariff, which provides a payment for electricity generated from renewable sources (e.g. micro CHP, or solar Photovoltaics (PV) – see Chapters 10 and 12) and an additional payment for selling surplus electricity (i.e. electricity that is not used in the home) to the electricity grid. The surplus is currently deemed to be 50% of the total amount generated. The tariff paid is fixed at the time of each installation, lasts for twenty years, and is index linked. The tariffs available are degressed (i.e. reduced) at regular intervals to match reductions in the capital costs of the systems and maintain consistent rates of return. The Feed in Tariff for PV is likely to be phased out by 2020,

9 See www.energysavingtrust.org/funding/search; the EST's online funding guide is continuously updated.

when the cost of electricity it generates is expected to match that of grid electricity. For PV installations there are three Feed in Tariffs. The highest rate applies to dwellings with Energy Performance Certificates (EPCs) that confirm that they achieve at least EPC band D (provided that there are twenty–five or fewer dwellings involved). The middle rate applies to multiple installations (more than twenty–five) in which all the dwellings achieve at least EPC band D. The lowest rate applies to dwellings that do not achieve EPC band D or do not have EPCs

- The Renewable Heat Incentive, which provides a subsidy for generating heat locally (via solar water heating, biomass boilers or ground source heat pumps), in the form of regular payment related to the amount of heat generated (see Chapter 10). A Green Deal assessment is required before a dwelling becomes eligible for the Renewable Heat Incentive; any wall or loft insulation measures recommended in the assessment report must be implemented and the EPC must be updated

These programmes include elaborate provisions for consumer protection. The Green Deal is supervised by an Oversight and Registration Body (ORB – see http://gdorb.decc.gov.uk). For the Green Deal and ECO, the work of Green Deal Advisors, Providers and installers must be in accordance with the Green Deal Code of Practice (see http://gdorb.decc.gov.uk/code-of-practice). Installers must be certified and work to the standards specified in Publicly Available Specification 2030 (PAS 2030 – see www.bsigroup.com). Renewable energy systems funded by the Green Deal, the Feed in Tariff or the Renewable Heat Incentive must comply with the Microgeneration Certification Scheme (MCS – see www.microgenerationcertification.org).

Establishing an overall improvement plan

Most households do not have the opportunity to carry out a whole-house refurbishment of their home as a single project. More commonly, opportunities arise at intervals according to family circumstances, funding and the need to replace worn out building elements or services. Therefore it is a good idea to consider all aspects of the house at an early stage and to make an improvement plan, even though it may only be implemented in stages, over several years or even decades. Such a plan may assist with programming and funding of the work. The plan should also identify improvement opportunities that are likely to arise, and improvement options that should be preserved for implementation in the future. A starting point for an improvement plan might be the recommendations which form part of the Energy Performance Certificate for the house, if you have one. The T-Zero website (www.tzero.org.uk) provides a tool for identifying and comparing the options for your house and a 'marketplace' of green home improvement products and services[10].

Opportunities for improving our homes arise for many different reasons. We may need to extend to accommodate a growing family or an ageing relative, or we may need to replace something

10 T-Zero is a partnership of leading UK organisations in the fields of housing and energy efficiency, including the Construction Products Association.

(e.g. worn-out window frames or boiler), or we may just decide to invest some spare money in reducing our 'carbon footprint'. When improvement opportunities arise, there are two ways in which we may respond: we can exploit them by carrying out the work, or we can preserve them for later. Preserving opportunities is often a good policy in the context of a long-term plan to improve a home.

Figure 3.1 Extended roof verge to accommodate future external wall insulation. Picture courtesy of Gil Schalom

Examples of exploiting opportunities include:

- Adding internal wall insulation when re-plastering
- Adding roof insulation when re-roofing
- Installing high performance windows when replacing worn-out windows
- Installing high performance windows when installing external wall insulation
- Installing a very efficient gas boiler when replacing a worn-out boiler

Examples of preserving opportunities include:

- Extending the eaves while re-roofing to allow for external wall insulation to be added later (see Figure 3.1)
- Installing a dual-coil hot water cylinder when upgrading a heating system, to allow for solar water heating to be added later
- Postponing window replacement until wall insulation can also be afforded, for installation at the same time

Figure 3.2 Door replaced by a window to accommodate future flat roof insulation. Pictures: John Willoughby

These examples show that making an improvement plan can be a sophisticated process, which involves more than identifying the obvious improvements. Some improvements are difficult unless prior enabling work is carried out. An architect, surveyor, energy consultant or retrofit coordinator should be able to assist you in making an improvement plan. This plan should differentiate between 'quick fixes' and 'major projects', as well as identifying improvement opportunities that are to be exploited or preserved for the future.

A whole-house low carbon improvement plan has wider scope than the Green Deal Plan mentioned above. The whole-house plan should assess the energy performance of the existing dwelling, identify improvement options and evaluate their carbon cost effectiveness, assess improvement constraints (statutory, physical and financial) and establish an improvement process that exploits and preserves improvement opportunities in a coherent way. The plan should be retained as a form of 'logbook' for the dwelling, and updated regularly as the improvements are implemented.

Using specialists and professional consultants

Simple refurbishment works such as loft insulation can be carried out by local installers or builders and there should be no need to engage specialists or professional consultants. Cavity wall insulation is best carried out by a specialist installer, who should be a member of the Cavity Insulation Guarantee Agency (CIGA).

There are approximately 160 specialist cavity wall insulation installers who will assess the property before starting work to ensure that the walls are suitable for filling and will provide an independent 25-year CIGA guarantee.

Because of its complexity, external solid wall insulation should either be purpose-designed by an architect or installed by a specialist contractor who complies with a professional code of practice such as that operated by the National Insulation Association (NIA). The NIA can provide advice and details of local contractors (see www.nia-uk.org). It is important that work is carried out in accordance with the relevant technical approvals and guidance and is covered by a Solid Wall Insulation Guarantee Agency (SWIGA – see www.swiga.co.uk) or equivalent. SWIGA also accredits contractors and provides an arbitration service to consumers in the event of any dispute.

Replacement windows should be supplied and installed by a company registered with Fenestration Self-Assessment (FENSA– see www.fensa.org.uk), who will be able to self-certify the compliance of their products with the guidance in Building Regulations Approved Document L1B. Boiler replacement and heating control upgrades should be carried out by qualified heating installation specialists who are registered under the Gas Safe scheme; they should certify and guarantee their work and uphold the manufacturers' guarantees of the products that they supply and install.

For most properties, a detailed energy survey carried out by an experienced energy consultant will provide an invaluable insight into current energy use and help to identify the most appropriate improvement options. Surveys should embrace the building fabric and the building services and should include a performance assessment using energy rating software. The survey report should identify appropriate improvement options from among those dealt with in this guide. Energy consultants should be accredited through one of the domestic energy rating schemes. You can find an energy consultant via the Landmark database of accredited energy assessors at www.epcregister.com.

Where the refurbishment work is complex, perhaps involving several improvement measures that must be coordinated (e.g. external wall insulation combined with re-roofing and/or window replacement), it is advisable to engage an architect or surveyor who will be able to assist by providing some or all of the following services:

- Advising on the feasibility and approximate cost of your proposals and identifying related opportunities for future improvements
- Consulting the local planning authority about the need for planning approval and/or listed building consent, preparing and submitting application(s) on your behalf and negotiating with the planning authority
- Preparing drawings, schedules of works and specifications for a builder to price and work from and to support an application for approval under the Building Regulations
- Preparing and submitting an application for approval under the

Building Regulations on your behalf and negotiating with the Building Control body

- Inviting quotations or tenders from an agreed list of suitable builders or installers, advising on the tenders submitted and arranging a contract with a builder chosen to carry out the work
- Administering the terms of the building contract, visiting regularly to inspect progress and quality of the work, advising on any problems that arise during the course of the work and issuing instructions, payment certificates etc. required by the contract, on your behalf
- Inspecting the work at the end of a 'defects liability period' (usually six months) and arranging for the builder to repair any defects that have arisen

You can find an architect via the Royal Institute of British Architects at www.architecture.com/UseAnArchitect/Home.aspx. Some architects and surveyors specialise in low carbon refurbishment, and may hold additional qualifications as Domestic Energy Assessors (DEAs) or as Retrofit Coordinators (a new qualification for refurbishment specialists), or the CoRE Diploma in Retrofit offered by the Centre of Refurbishment Excellence (CoRE)[11]. These specialists have the skills and experience to help householders and landlords assess dwellings and to prepare and implement the comprehensive whole-house low carbon refurbishment plans described earlier.

Watch points

- Assess the need for professional advice – from an architect, surveyor, energy consultant or Retrofit Coordinator; ensure that your consultants have appropriate qualifications and experience, and that they carry professional indemnity insurance
- If the building is old (i.e. built before 1920) or is of a traditional or historic type of construction, engage a specialist to check whether the construction is vapour permeable, and to advise on the types of materials that should and should not be used in refurbishment
- Establish an overall improvement plan – even if you cannot implement all the proposed improvements at once; ensure that your plan preserves improvement opportunities for the future
- Check whether the improvement work proposed requires planning permission, listed building consent or approval under the Building Regulations, and arrange for the necessary approvals to be obtained before you proceed with any work
- If you intend to fund improvement work via the Green Deal, the Energy Company Obligation (ECO), the Feed in Tariff or the Renewable Heat Incentive, arrange for an energy assessment to be carried out by a Domestic Energy Assessor or Green Deal Advisor, as appropriate
- Check the rules of any funding schemes that you propose to access, to ensure that your proposals comply

11 See www.core-skills.com

Most houses built before the 1950s will have suspended timber floors. Those built after that date are more likely to have concrete floors, either slab on ground or suspended. Suspended timber floors are often leaky and cold but, unlike concrete floors, are relatively easy to upgrade.

Quick fixes

A cheap and relatively easy measure for suspended timber floors is to eliminate draughts (see below).

If suspended timber floors are over a cellar, an effective first fix is to insulate and draught-proof from below.

Opportunities

Rotten floor boards or damp penetration sometimes mean that floors need to be lifted. This gives an ideal opportunity to add insulation to the new work.

Major projects

When major works are being carried out, floor insulation should be added and the floor made draught-proof.

Building Regulations 2013	Good Practice	Advanced
Below 0.25	Below 0.25	Below 0.15

Table 4.1 U values for exposed floors (W/m²K)

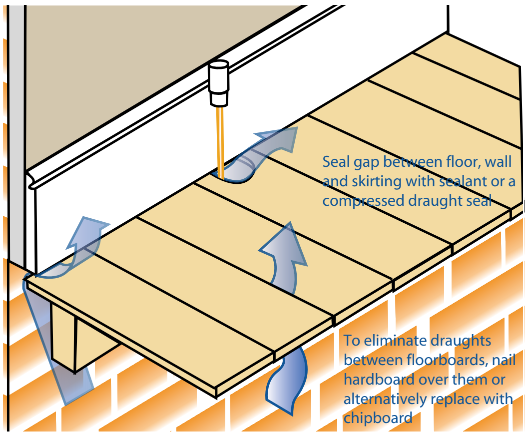


Figure 4.1 Air infiltration through a suspended timber floor[12]

Floor U values

Table 4.1 presents recommended maximum U values for exposed floors according to various standards.

Timber floors

Draught-proofing floors

Suspended timber floors are notoriously leaky. With old square edged floorboards, laying hardboard over the whole floor will eliminate draughts from between the boards. The hardboard should be taped at the joints and sealed at the edges. Alternatively the gaps can be sealed with a sealant, combined if necessary with timber beads. Gaps and holes in the floor where pipes or cables rise from below should be sealed with tightly-packed mineral fibre or expanding foam. It is important to maintain the ventilation under the floor void.

Figure 4.2a Membrane gives air tightness and supports insulation
Picture: John Willoughby

Figure 4.2b Insulating below the joists keeps timbers and pipes warm
Picture: John Willoughby

12 Figure 4.1 redrawn from 'Practical refurbishment of solid-walled houses', Energy Saving Trust (CE184).

Figure 4.3 Insulating a suspended floor from beneath, at the Nottingham EcoHome. Picture courtesy of Gil Schalom

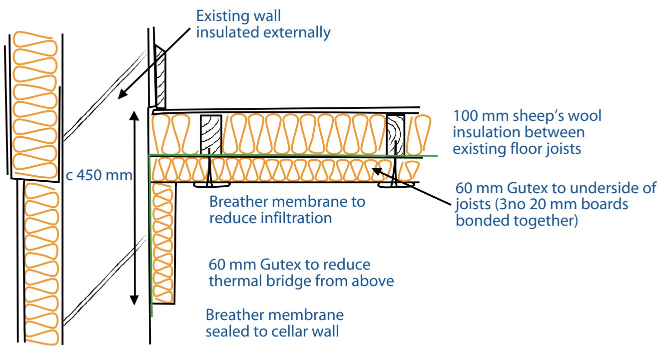


Figure 4.4 Cellar insulation at the Nottingham EcoHome

Figure 4.5 The floor seen from the cellar, before and after the installation of spray-applied polyurethane insulation. Pictures: Isothane

Insulating timber floors

Timber floorboards can be lifted and insulation fitted between the joists. A Building Control Officer should be consulted to ensure the correct fire performance is achieved. The most common technique is to use mineral fibre supported on plastic netting; rigid insulation can also be wedged or cut to fit tightly between the joists (although this is less reliable) or supported on timber battens fixed to the joists. It is important to fill the space between the netting and the floorboards. Air tightness measures should be applied. A membrane under the boards, sealed to the wall or skirtings, is recommended. To reduce the risk of condensation in the floor void, it is important to maintain under-floor ventilation.

Advanced insulation

At the Nottingham EcoHome, insulation was added to the suspended timber floor in two layers from the cellar below. First sheep's wool insulation was fitted between the joists. Then a vapour permeable air barrier was installed to make the floor airtight. Finally a rigid insulation board was fixed to the joists. These boards were also returned down the cellar wall to reduce the thermal bridge. The resulting U value was around 0.16 W/m²K.

Although niche products were used in this instance, mainstream products such as mineral fibre and rigid insulation boards are equally applicable.

At a traditional back-to-back house in Todmorden, the kitchen floor was insulated and draught-proofed from the cellar below in a single operation using proprietary spray-applied polyurethane (PUR) insulation. The insulation was applied between the floor joists and all gaps, cracks and voids were sealed during the two-minute curing process. The application took less than three hours to complete and a thickness of 195 mm insulation achieved a U value of 0.15 W/m²K.

Concrete floors

If solid floors are to be taken up and re-laid then there is an opportunity to add insulation to the new concrete floor slab. The construction is the same as a new-build floor. Insulation can be added above or below the slab.

If solid floors are not taken up then the only way to add insulation is to lay it on top of the existing floor. This can cause problems with room heights, door thresholds and at the bottom of the stairs. In some cases thin layers of insulation (e.g. 50 mm) can be added with an uninsulated well formed at the foot of the stairs as shown in Figure 4.7.

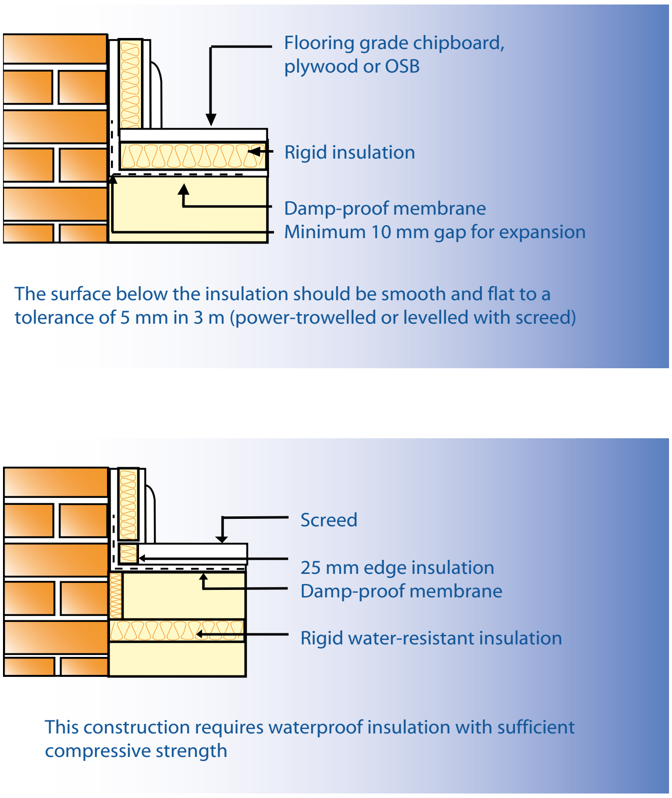


Figure 4.6 Insulating above and below concrete floors[13]

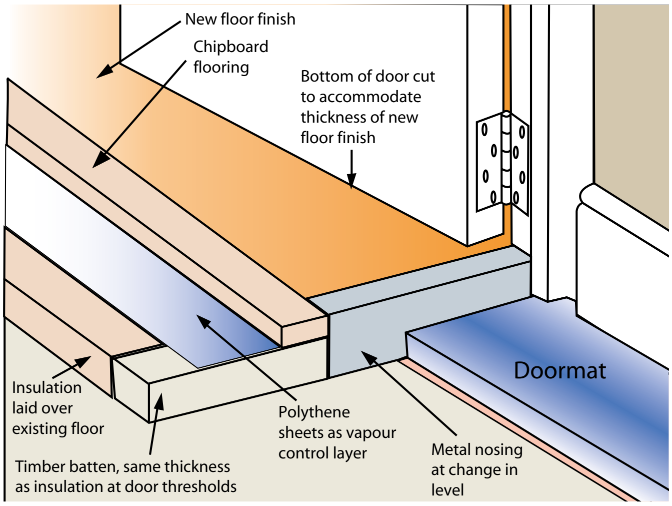


Figure 4.7 Incorporating a well in insulation above a concrete floor[14]

13 Figure 4.6 redrawn from 'Energy efficient refurbishment of existing housing', Energy Saving Trust (CE83).

14 Figure 4.7 redrawn from 'Refurbishment site guidance for solid-walled houses – ground floors', Energy Saving Trust (GPG 294).

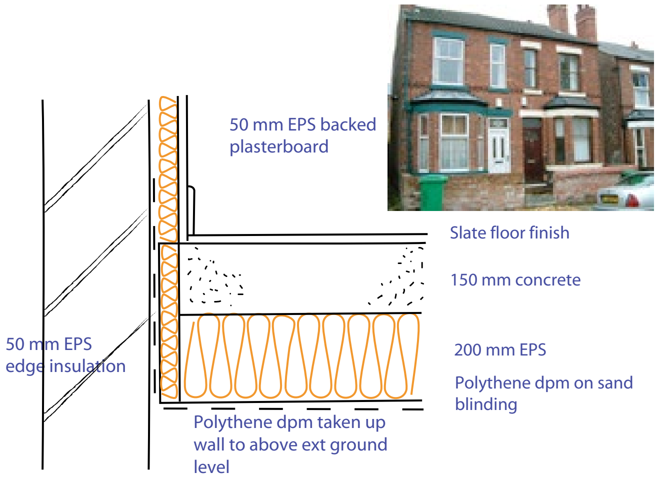


Figure 4.8 200 mm of insulation added under new concrete floor

Figure 4.9 A landing built at the bottom of stairs to even out the risers. Pictures: Tony Clelford

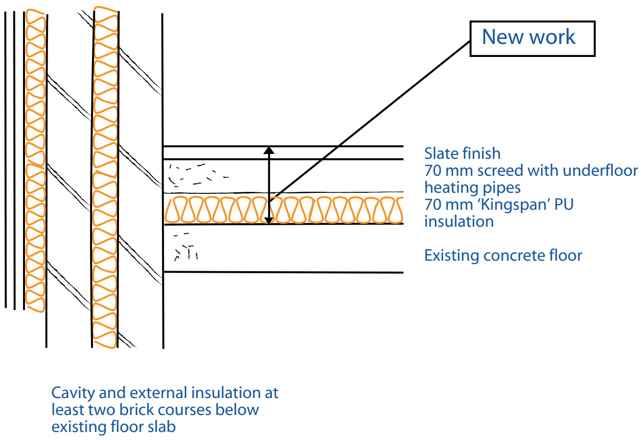


Figure 4.10 Additional insulation laid over an existing concrete floor

Advanced insulation

At another house in Nottingham, a new concrete floor was laid on 200 mm of expanded polystyrene (EPS) insulation to give a U value of approximately 0.14 W/m²K.

In a refurbishment of an old police house in Kent, the existing solid floors were overlaid with 70 mm of Polyurethane (PU) insulation and a new screed and floor finish, giving a U value of about 0.21 W/m²K. Lintels over internal ground floor doors were lifted and a landing built at the bottom of the stairs to even out the risers.

Watch points

- When insulating a suspended timber floor, ensure that the insulating material has the correct fire resistance; the insulation should fit tightly between the floor joists; incorporate an air-tight membrane beneath the floorboards and seal it to the walls at the edges of the floor; ensure that the void beneath the floor is ventilated
- When insulating above a floor, ensure that all stair risers are of equal height (as required by the Building Regulations); this may involve adjusting the floor levels near the foot of the stairway
- Ensure that wall insulation connects to or overlaps with the floor insulation to minimise thermal bridging at the floor-wall junction

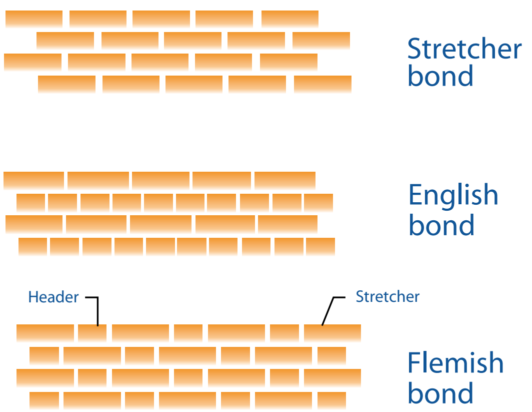


Figure 5.1 Brick bonds: the lower two examples are likely to be solid walls

In detached and semi-detached houses, heat lost through walls is often the largest contribution to fabric heat losses. Cavity walls are easy to insulate but solid walls are more difficult and expensive to treat.

Most houses built before the 1930s will have solid walls. Those built after that date are more likely to have cavity walls. Solid brick walls can usually be identified by the brick pattern: bricks laid across the wall show up as 'headers'. Cavity walls are built with 'stretcher' bond (see Figure 5.1). Note that modern timber frame houses are often also finished with brickwork in stretcher bond, and people sometimes mistake these walls for masonry cavity walls.

Quick fixes

If the walls are of cavity construction, cavity insulation is one of the most cost effective measures. Note however that cavity wall insulation alone will not improve the thermal performance of the wall to the Good Practice Standard – additional internal or external wall insulation will also be needed.

Opportunities

If internal plastering work has to be carried out, this presents an ideal opportunity to add internal wall insulation. Similarly if external render has to be replaced or extensive pointing of brickwork is needed, there is an opportunity to insulate externally.

Major projects

Because heat losses through walls are often large, internal or external insulation can have a dramatic effect on fuel use and carbon dioxide emissions as well as improving comfort conditions in the house. Adding at least 100 mm of wall insulation should always be considered during a major refurbishment.

Building Regulations 2013	Good Practice	Advanced
Cavity walls below 0.55 Solid walls below 0.30	Below 0.25	Below 0.15

Table 5.1 U values for exposed walls (W/m²K)

Wall U values

Table 5.1 presents recommended maximum U values for exposed walls according to various standards.

Cavity walls

Cavity wall insulation (CWI) is one of the most cost effective energy saving measures. A typical installation costs around £500 with the investment being paid back in two to three years. Not only will CWI save energy and reduce carbon dioxide emissions, but it will make the house more comfortable. An unfilled cavity will have cold air circulating in it. This cold air will enter the house via cracks and services penetrations and will cause draughts and heat losses. Cavity insulation will inhibit this air movement, reducing draughts and heat losses. Another benefit of CWI is that the internal surface temperature of the walls will be higher; the rooms will feel more comfortable as a result.

People are sometimes reluctant to fill cavity walls as they fear it will lead to damp penetration. But a survey carried out by the Building Research Establishment in the early 1990s showed that there was no evidence that filling the cavities resulted in any greater incidence of damp problems than in walls with empty


CAVITY INSULATION GUARANTEE AGENCY

25 Years Guarantee Certificate

The Guarantee

Period of Guarantee - 25 years from date of installation

Your Route to Total Satisfaction

Conditions

CIGA

Figure 5.2 CIGA guarantee certificate

Figure 5.3 A high-rise block in Edinburgh insulated with proprietary polyurethane cavity wall insulation. Picture: Isothane

Figure 5.4 Two layers of insulation allow timber battens to support the extended roof verge. Picture: John Willoughby

cavities. The study showed that the structural condition of the cavity wall is the critical factor in avoiding damp penetration. Typically there are 600,000 cavity wall installations each year.

Cavity wall insulation is a specialist job that should be carried out by an approved contractor who complies with an appropriate code of professional practice such as that operated by the National Insulation Association and can offer a Cavity Insulation Guarantee Agency (CIGA, www.ciga.co.uk) guarantee. The first job the contractor will do is to check that the wall is suitable for filling. Having carried out the inspection, the contractor will submit on your behalf a Building Control Notice to the local Building Control body. The wall will then be drilled in a defined pattern and the insulation pumped in under pressure. The holes will be made good and checks and tests completed.

The most common materials used for CWI are mineral wool or polystyrene beads. All CWI systems are tested and approved by independent bodies. When the work is complete the contractor will ask the Cavity Insulation Guarantee Agency (CIGA) to issue an independent 25-year guarantee covering defects in materials and workmanship.

There are many properties with cavity widths less than 50 mm, which cannot be insulated using the method described above. High-rise tower blocks in Edinburgh, where cavity widths varied between 28 mm and 120 mm, were insulated with proprietary polyurethane (PUR) cavity wall insulation. Carbon dioxide emissions were reduced by 590 kg/year per flat and heating bills were reduced by 77%. The installation was completed in four weeks with no tenant disruption. At present this insulation technique is not guaranteed by CIGA and reference should be made to the manufacturer and installer about suitability and warranties on a case-by-case basis.

Advanced insulation

To achieve radical reductions in emissions, it is likely that cavity wall insulation will need to be augmented with an extra layer of internal or external insulation. In Gloucestershire, problems with external render prompted one filled cavity wall to be insulated externally with 110 mm of phenolic foam. The DIY system used horizontal battens fixed to the wall for the first 55 mm layer, followed by vertical battens containing another layer of insulation. This was then covered with vapour permeable sarking felt and two coats of cement render on stainless steel expanded metal. The U value of the wall was improved from 0.65 to 0.21 W/m^{2}K.

In Kent, a 1950s house with cavity walls had its cavities filled and was covered with 60 mm of polyurethane insulation and weatherboarding to give a U value of 0.26 W/m^{2}K.

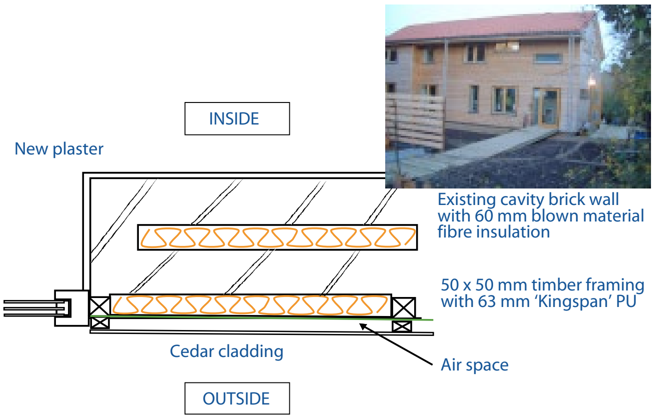


Figure 5.5 Insulated timber cladding to a cavity wall house. Picture: Tony Clelford

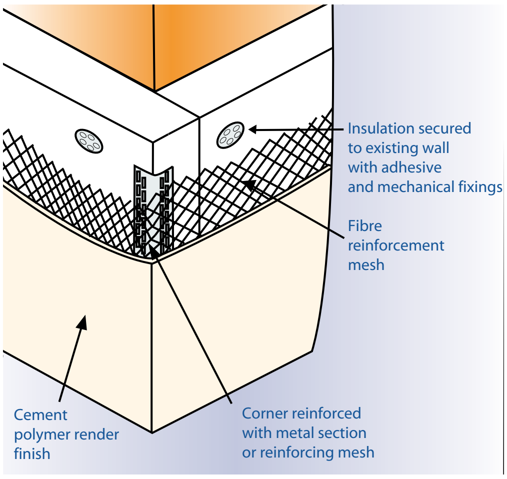


Figure 5.6 Typical external wall insulation system[15]

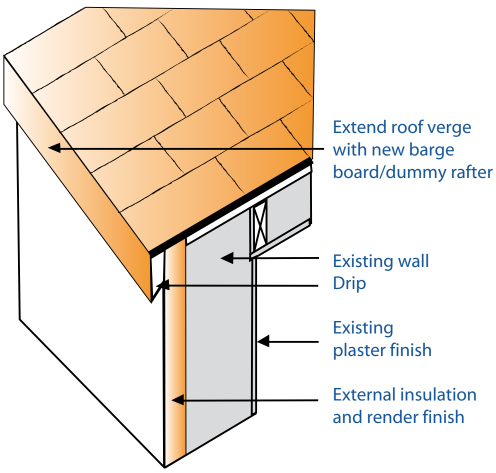


Figure 5.7 Refurbishment verge detail[16]

External wall insulation

External wall insulation (EWI) can be installed as a one-off job using local builders, but is more often installed using a proprietary external wall insulation system. External insulation has many advantages. The insulation layer is more complete than with internal wall insulation, which is interrupted at every internal partition. There is no loss of floor space. It causes less disruption to occupants and in many cases can enhance the external appearance of the home.

There are three generic types of EWI

- Wet render systems
- Dry cladding systems
- Bespoke systems

The most common systems use wet render. This can be a traditional thick cement-sand render but is more often a thin polymeric coating. These polymeric render coats give exceptional strength with a very thin coat, typically just 10 to 15 mm thick.

A typical system is shown in Figure 5.6. Usually, board insulation (mineral fibre or foamed plastic) is glued and mechanically fixed to the existing wall. The insulation is covered with a reinforcing mesh before the render is applied in two coats.

Insulation thicknesses vary typically between 50 and 140 mm, although systems using 250 mm thick insulation have recently become available (see Figure 5.8). Applied to a solid brick wall, 50 to 140 mm gives U values in the range 0.5 to 0.17 W/m^{2}K, depending on the material used.

The main problem with EWI systems is the detailing, particularly at the wall-roof junction. If the eaves are flush with the existing wall, it may make sense to install the wall insulation when re-roofing is being carried out. Although there are cappings available to cover the top of the insulation, their use means that a large thermal bridge at the eaves is inevitable. The verge detail is usually easier to deal with. A ladder system or a dummy barge board fixed through the insulation can be used (see Figure 5.7). Detailing at the base of the wall and around windows also requires careful attention. It is important that the wall insulation overlaps with any ground floor insulation to reduce the thermal bridge at the floor-wall junction. This may involve the wall insulation 'bridging' the damp-proof course (dpc) in the wall, so careful detailing is required to protect against rising damp.

15 Figure 5.6 redrawn from 'Practical refurbishment of solid-walled houses', Energy Saving Trust (CE 184).

16 Figure 5.7 redrawn from 'External insulation systems for walls of dwellings', Energy Saving Trust (CE 118 / GPG 293).

Figure 5.8 The gap between 250 mm thick grey polystyrene insulation and a window frame being sealed with expanding foam prior to rendering at Grove Cottage, Hereford. Pictures: Simmonds Mills Architects

Another issue with EWI is that of external fittings. Rainwater down pipes need to be moved and re-fixed; external lights and satellite dishes all need to be moved. These issues, and the need for scaffolding, make EWI the most expensive solution for wall insulation.

Advanced insulation

A refurbishment to near Passive House standards in Hereford uses 250 mm thick grey polystyrene to achieve a wall U value of 0.12 W/m^{2}K. The system is carefully tied into the new roof insulation to provide a continuous layer of insulation over the outside of the building. New windows are sealed to the wall before the insulation is installed. There are other insulation materials that are equally applicable.

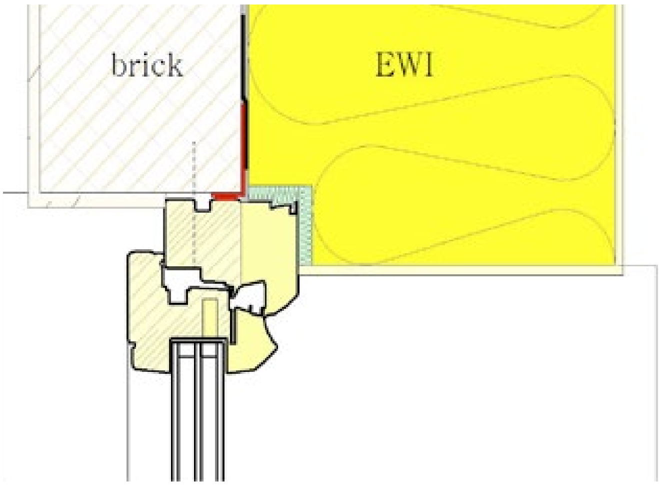


Figure 5.9 Window detail at Grove Cottage, Hereford. Image courtesy of Simmonds Mills Architects

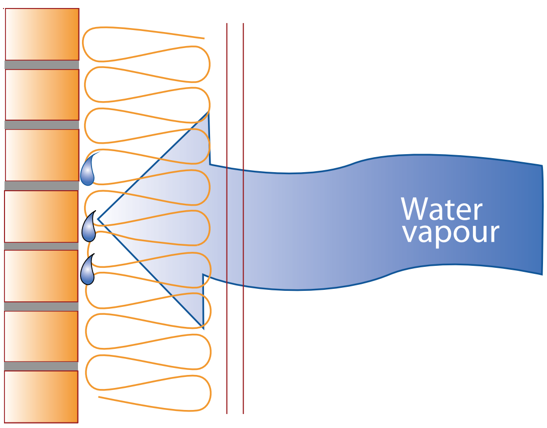


Figure 5.10 If water vapour passes through the insulation it can condense on the cold wall

Internal wall insulation

In many cases it is not possible to insulate a property externally; it may have beautiful external features, there may be other planning issues, or the detailing may be prohibitive. In these cases internal wall insulation (IWI) is the next best thing. IWI does have some disadvantages: there is a loss of floor space, there are thermal bridge problems at internal wall junctions and intermediate floors, and there is a danger of interstitial condensation on the existing wall if water vapour penetrates (see Figure 5.10).

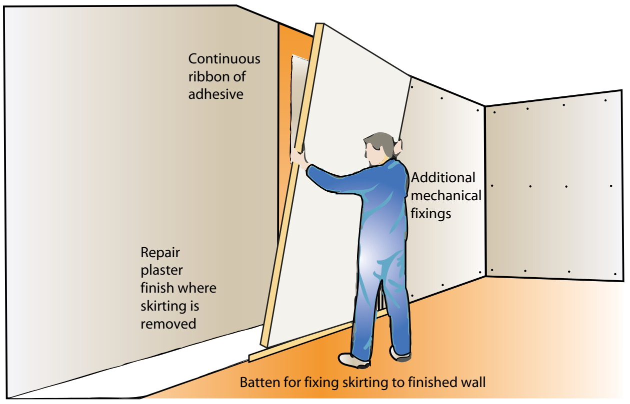


Figure 5.11 Insulated plasterboard[17]

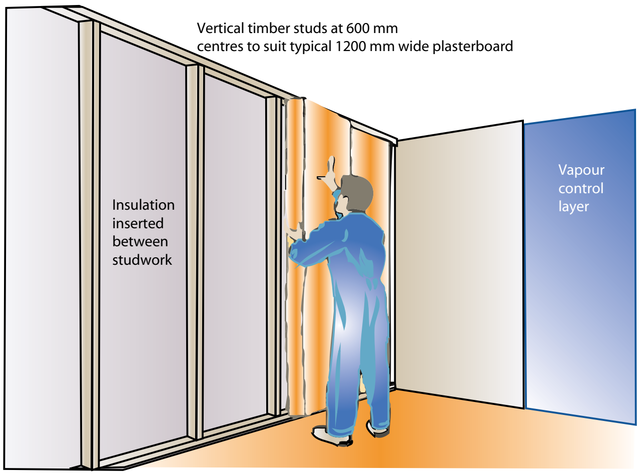


Figure 5.12 Insulation in a timber frame. The thermal bridge from the timber studs can be reduced by using insulated plasterboard[17]

Interstitial condensation

When a solid wall is internally insulated, the internal surface will be cold. If water vapour comes in contact with this surface it will condense. The condensation can become problematic, wetting the insulation and causing mould growth, rust and timber decay.

It is important to understand that water vapour can pass through to the wall in two ways: by diffusion through the insulation layer and (more significantly) by the movement of warm, moist air through any cracks or gaps. Vapour diffusion can be controlled by the use of a vapour barrier on the warm side of the insulation. Controlling air movement is much more difficult and necessitates that great care is taken with the installation to ensure that the vapour barrier is continuous.

Joist ends

If the ends of existing timber joists are built into the wall that is insulated, there is a risk that they will rot. Prior to installation of the insulation, the joists are kept warm and dry by heat passing through the wall, and they dry out quickly, even if the wall is intermittently saturated by driving rain. After IWI has been installed, the wall is no longer kept warm, and dries out much more slowly, so the moisture content of the joist ends may remain high, potentially leading to rot and structural failure. As yet, there is no simple solution to this problem, but to reduce the risk of rot it is advisable not to insulate between the floor joists (within the floor void), and to limit the thickness of insulation on walls that are very exposed to driving rain.

Internal wall insulation options

Insulated plasterboard (Figure 5.11) is a very common and useful material for IWI. The alternative is to build up insulation within a framing system (Figure 5.12). To meet the best practice standard U value of 0.3 W/m^{2}K requires an insulation thickness of between 80 and 120 mm, depending on the conductivity of the insulation.
The effectiveness of the insulation depends on both the thickness and the area of wall covered, so it is important to remember to insulate in the intermediate floor voids and other hard-to-reach areas.

Insulated plasterboard can be fixed on to existing plastered walls using drywall adhesive or plasterboard sealant. Framing systems can consist of timber or metal studs, or 'polystuds', made of insulating material bonded to timber or oriented stand board. If metal studs are used, they introduce a significant thermal bridge; this can be reduced by covering the studs with another layer of insulation.

17 Figures 5.11, 5.12 and 5.13 have been redrawn from 'Practical refurbishment of solid-walled houses', Energy Saving Trust (CE184).

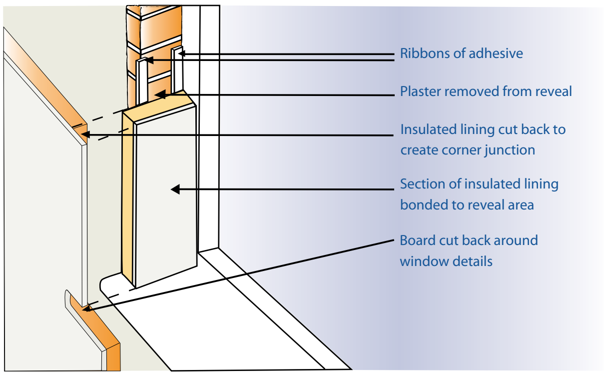


Figure 5.13 To avoid condensation on the cold window reveals, they should be insulated as well[17]

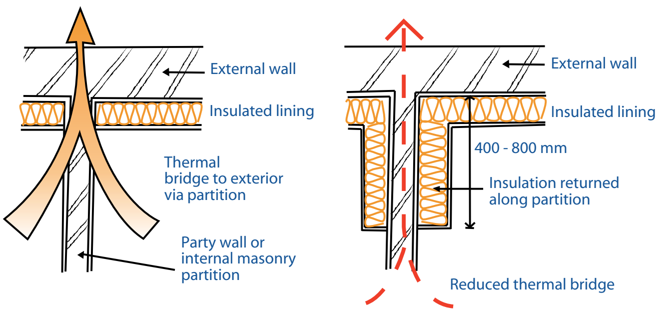


Figure 5.14 Internal partitions cause a thermal bridge (left). Returning the insulation along the partition reduces the problem (right)

Thermal bridges and air tightness

Thermal bridges can occur at the reveals, cills and heads of windows and external doors. The insulated lining should be run into the window and door surrounds as shown in Figure 5.13, and under the cill boards. If the window frames are not thick enough to accommodate the thickness of the insulation, thinner pieces of insulation with lower conductivity can be used; in some cases it may be necessary to replace the windows.

Thermal bridges also occur where internal or party walls meet external walls. There is a concentration of heat flux at this point as heat is conducted through the internal wall as well as the external wall. When the external wall is insulated, this thermal bridge is exaggerated; temperatures on the party wall can fall, resulting in excessive heat loss and condensation. To reduce this problem it is worth returning the insulation along the internal wall, as shown in Figure 5.14. The thermal bridge can never be eradicated but if the insulation is returned between 400 and 600 mm along the internal wall, the bridge will be much reduced. Electrical services such as switches and power sockets, and pipework and mechanical fixings for radiators, can compromise the air tightness of the insulated lining. It is a good idea to relocate these services on to internal walls, away from the insulated lining, if possible.

Figure 5.15 Internal insulation at the Nottingham EcoHome.
Pictures: Gil Schalom

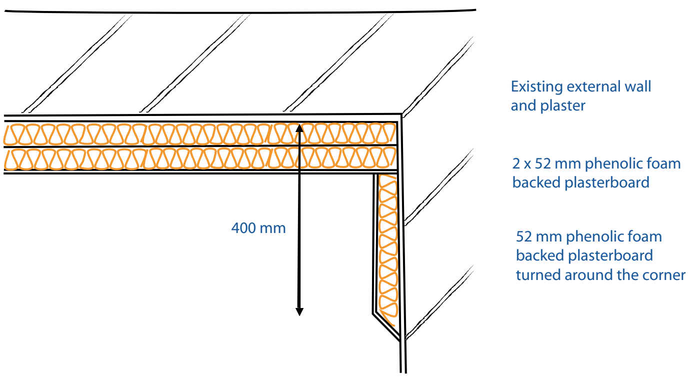


Figure 5.16 Internal insulation at the Nottingham EcoHome

Figure 5.17 Internal insulation at the Nottingham EcoHome – note the reinstated coving and the insulation returned along the party wall.
Picture: Gil Schalom

Advanced insulation

At the Nottingham EcoHome, internal wall insulation was used on the front wall. At the time of refurbishment the maximum available thickness of insulated plasterboard was 52.5 mm, so two layers of phenolic foam backed plasterboard were used to achieve a U value of 0.23 W/m^{2}K. Today, this U value could be achieved with a single, thicker layer of insulated plasterboard. The insulation was taken into the first floor void and returned at the internal partition.

Watch points

- When insulating cavity walls, use a specialist contractor who offers a CIGA guarantee; ensure that the contractor confirms that the cavity is suitable for filling before proceeding, and that a notice of the work is sent to the local Building Control body; do not fill wall cavities in locations that are very exposed to driving rain (e.g. at high altitudes or on the coast); consider augmenting cavity wall insulation with internal or external insulation to achieve appropriate thermal performance
- When insulating solid walls, choose external wall insulation rather than internal wall insulation whenever possible, because this is a more robust and less disruptive technique (but note that in some cases planning permission or listed building consent may be required)
- When insulating externally, use a proprietary system whenever possible, ensure that the installer is trained and approved by the supplier of the system, and obtain a SWIGA guarantee
- Ensure that external insulation is correctly detailed at corners, junctions and edges, and especially around window and door openings, to ensure the continuity of the insulated envelope; ensure that the wall insulation connects to or overlaps with the floor and roof insulation to minimise thermal bridging at the floor-wall junction and at the eaves; do not use metal edge fittings (because they are highly conductive and introduce thermal bridges into the construction)
- When insulating internally, either use a vapour balanced insulation system to control the migration of moisture through the wall, or include a vapour barrier on the warm side of the insulation, to reduce the risk of interstitial condensation; ensure that the vapour barrier is overlapped and sealed at all edges, corners and junctions, around window and door openings and at service penetrations

- When insulating internally, ensure that the wall insulation connects to or overlaps with the floor and roof insulation to minimise thermal bridging at the floor-wall junction and at the eaves, verges and gable ends; also insulate party walls and internal masonry partitions for approximately 600 mm back from the external walls to reduce thermal bridging and the risk of condensation and mould growth
- When insulating walls, consider replacing the windows at the same time; ensure that replacement windows are located in the plane of the insulation, if possible, to minimise thermal bridging, that any exposed reveals, cills and soffits of openings are insulated, and that the windows and doors are sealed into the insulated walls

Building Regulations 2013	Good Practice	Advanced
Loft insulation: below 0.16 Pitched insulation: below 0.18 2010: 0.16-0.18 Flat roof insulation: below 0.18	Below 0.16	Below 0.12

Table 6.1 U values for roofs (W/m²K)

Roof insulation is of two main types: loft insulation at ceiling joist level (typically mineral wool quilt or rigid insulation boards); or pitched roof insulation placed over, under or between the rafters that support the external roof covering.

Loft insulation is the most common thermal improvement to the fabric of British homes. But this seemingly simple measure is not without its challenges. If re-roofing work is being carried out then it may make more sense to insulate at rafter level. Insulating at rafter level creates a warm roof space and makes it easier to connect the roof insulation to external wall insulation.

Flat roofs are often poorly insulated and often difficult to upgrade. When the waterproof covering has failed, it is an ideal time to take radical steps to improve the insulation.

Quick fixes

Loft insulation is an improvement that can be made at almost any time. It is cheap and cost effective to top up loft insulation to between 250 and 300 mm thickness.

Opportunities

When re-roofing, the opportunity to improve insulation levels should be taken.

If modifications are being made to the heating system, it is a good idea to remove all wet services from the loft space, which can then be insulated more thoroughly without the fear of freezing pipes.

Major projects

Insulating the roof at rafter level and connecting that insulation to external wall insulation is a strategy well worth considering during a major refurbishment.

Roof U values

Table 6.1 presents recommended maximum U values for roofs according to various standards.

Loft insulation

In an insulated loft space, condensation will almost always form on the underside of the roof covering. This is usually impervious bituminised sarking felt and it is important to provide the loft space with sufficient ventilation to remove the condensation when the weather gets warmer. The ventilation is often introduced at the eaves, which makes it difficult to insulate the loft successfully. Figure 6.1 shows an insulated loft space looking towards the eaves. The thermograph in Figure 6.2 shows a window and the ceiling below the eaves. Cold air from the eaves vent passes under the insulation, nullifying its effect. There is little between the inside and outside air except for a sheet of plasterboard.

Figure 6.1 Mineral wool quilt insulation in a loft

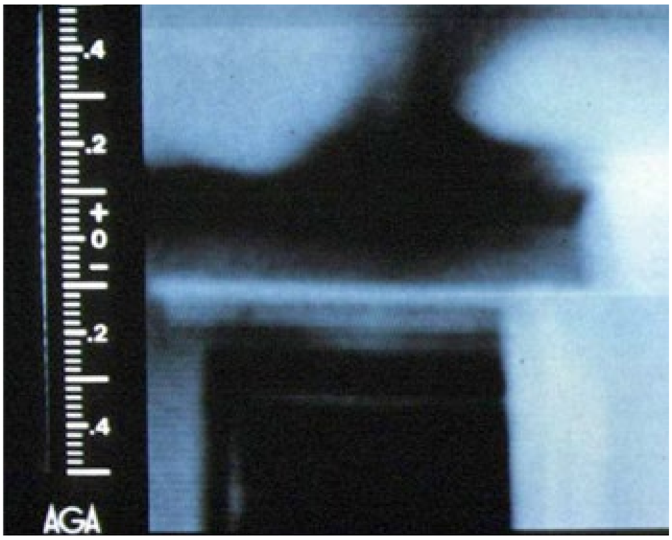


Figure 6.2 Thermograph showing how loft quilt lying on top of an electric cable allows air to get underneath creating a cold area in the room below

Eaves vents are a problem. If they are blocked up then the loft will suffer from condensation. If they are left open ventilation air may find its way beneath the insulation. Getting round this problem takes quite a bit of care. First a sealed void should be created to channel the ventilation air into the loft above the insulation. This channel can be formed with a board. It should be cut around and sealed to the ceiling joists. The loft insulation can then be pushed into the eaves and as far as possible connected to the wall insulation. There are also some compressible board systems on the market.

Mineral fibre quilt is the most common loft insulation material. However, using blown insulation can help to force the insulation into corners and areas which are difficult to reach with quilt. Blown insulation is also a useful technique for insulating lofts where there are trussed rafters; it is virtually impossible to insulate properly between and over trussed rafters using quilt because there will always be air gaps between the timber and the quilt, leading to thermal bypass (i.e. cold air getting beneath the insulation).

Services in loft spaces

It is difficult to insulate a loft thoroughly if there are tanks and pipes above the insulation. The strategy should be to remove the services from the roof space. Unless this is done, insulation will have to be left out under the tanks to stop them freezing. Not only will insulation be missing but there will be inevitable air leakage around the pipes, which pass through the ceiling. Using combi boilers, heat stores or unvented cylinders allows tanks and pipes to be removed from the cold loft space.

Electric cables should be kept on the cold side of the insulation. Burying cables under the insulation can cause overheating. This is most likely to be a problem with cables supplying large loads like electric showers, cookers or storage heaters. Cabling may need to be upgraded.

Recessed down-lighters cause another problem with loft insulation. Insulation must be removed around light fittings (or they must be boxed) to stop them overheating. This results in thermal bridges, and the hot light fittings promote air leakage. If recessed light fittings must be used, then they should be fitted in a false ceiling so that the integrity of the insulation and air tightness barrier can be maintained.

Rafter insulation

In dwellings without loft spaces, where the ceiling follows the line of the roof, insulation needs to be applied at rafter level. Insulating in the depth of the rafter (typically 100 mm) is insufficient to meet best practice standards. Generally there needs to be an additional layer of insulation across the rafters. This can be added on the inside or outside of the roof.

Figure 6.3 400 mm deep engineered timber 'I beams' with the first layer of roof insulation over the existing roof structure.
Picture: Simmonds Mills Architects

External rafter insulation

If the roof finish is being replaced then there is sometimes the opportunity to insulate between and over the rafters. Board material is laid over the rafters and covered with 'breathable' sarking felt; counterbattens can be fixed through the insulation to form a ventilated air space. The roof finish is then fixed on battens.

Advanced external rafter insulation

A refurbishment to near Passive House standards at Grove Cottage in Hereford uses 400 mm of insulation between engineered timber 'I beams' in a new roof structure to achieve a roof U value of 0.09 W/m^{2}K. The detail connects the roof insulation to 250 mm thick external wall insulation at the eaves, as shown in Figures 6.4 and 6.5.

Figure 6.4 The 250 mm thick external wall insulation, with a block shaped to fit at the eaves. Picture: Simmonds Mills Architects

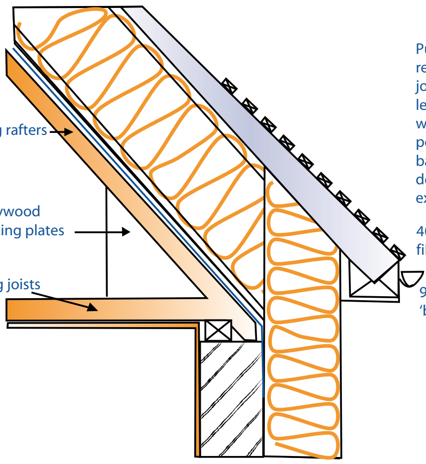


Figure 6.5 At Grove Cottage, the 400 mm thick roof insulation connects at the eaves to 250 mm thick external wall insulation

Figure 6.6 Z rafters were set out using a jig to ensure the spacings matched the rigid insulation board. Picture: Ray Exton

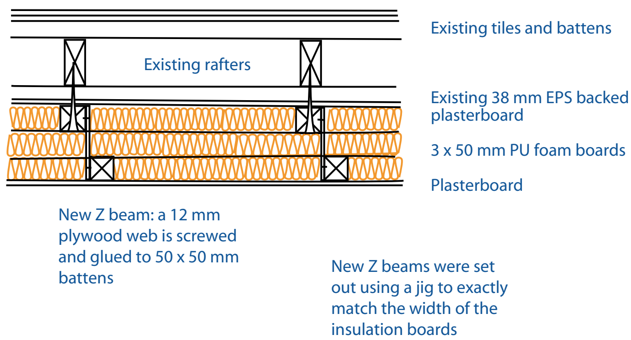


Figure 6.7 Z rafters fixed beneath the existing roof to support the insulation

Figure 6.8 Recess for rooflight in 300 mm deep extension rafters with air/ vapour barrier and plasterboard. Picture: Gil Schalom

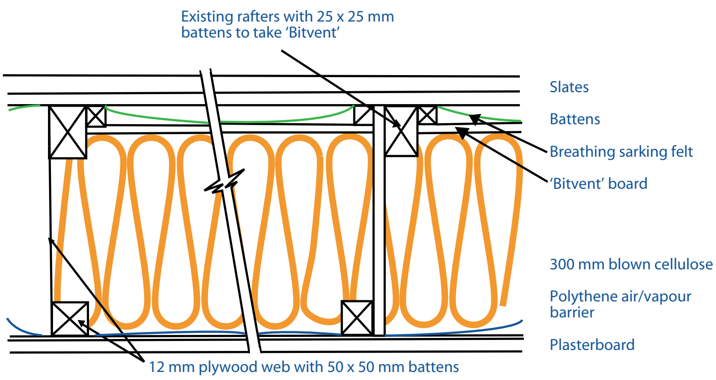


Figure 6.9 Plan section through the roof showing the new L beams added to existing roof structure

Internal rafter insulation

Where the roof finish is not being replaced or cannot be extended outwards (e.g. in semi-detached properties), insulation must be added internally. If the rafters are exposed, insulation can be added between and under the rafters. If an impervious sarking felt is to be left in place, then it is important to create a ventilated air space below it. The difficulty is in stopping this cold ventilation air from leaking around the insulation. A board material glued or foamed in place is probably the best way to solve this difficult detail. Sealing along the rafter is fairly easy but sealing at the eaves is more difficult.

Where the ceiling is to remain in place, space considerations usually determine the thickness of additional insulation. Insulated plasterboard applied to the underside of a sloping ceiling can be quite effective but the resulting U value is unlikely to be as good as the best practice standard of 0.15 W/m^{2}K. A good technique for adding thicker levels of insulation is to use spaced 'C' or 'Z' section extension rafters.

This technique was used on a house in Gloucestershire where a Z beam was made up and insulated with three 50 mm thick layers of PU insulation. The existing roof had a 38 mm insulated plasterboard ceiling with a U value of around 1.0 W/m^{2}K. Adding the Z beams reduced the U value to 0.16 W/m^{2}K.

Advanced internal rafter insulation

The Nottingham EcoHome is a semi-detached house so it was not possible to extend the roof outwards when re-roofing. 300 mm deep extension rafters were added before the roof was stripped. Bitumen impregnated fibreboard was used to create a void below the new roof slates. A polythene vapour barrier was installed behind the plasterboard on the warm side of the insulation. The void was pumped full with cellulose fibre. The resulting U value was 0.12 W/m^{2}K.

Loft conversions

Loft conversions provide an excellent opportunity to incorporate high levels of insulation and air tightness. Many of the techniques mentioned above can be used when new rooms are added to a loft space. Loft conversions are dealt with in another Construction Products Association publication: Loft Conversion Project Guide, CPA/RIBA Publishing, 2010, ISBN 978 1 85946 357 4, downloadable from www.constructionproducts.org.uk/publications/technical/display/view/loft-conversion-project-guide/.

Flat roof insulation

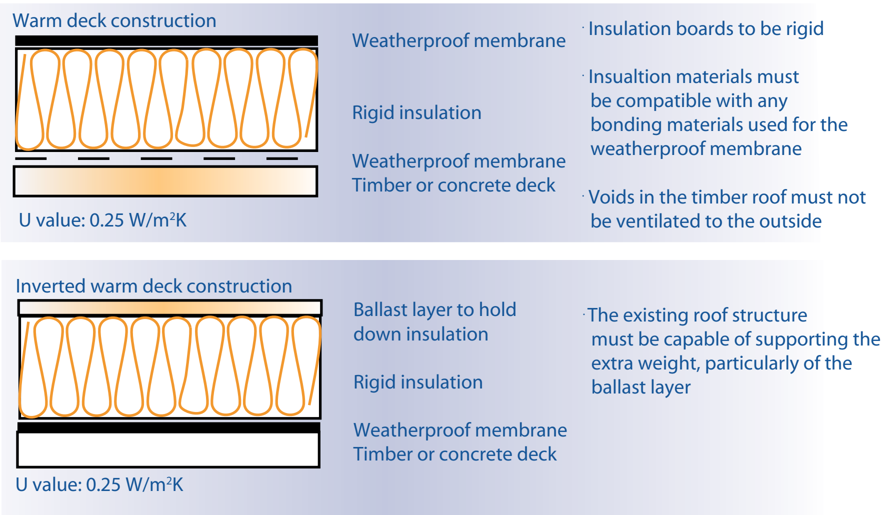


Figure 6.10 Warm deck constructions for upgrading flat roofs

Flat roofs are often poorly insulated. They can be upgraded internally using the techniques described above, but very often there is insufficient space to add very much insulation. External insulation is the preferred upgrade option. It can be added on top of the existing roof finish and there are two common systems: warm deck and inverted warm deck. In the warm deck, the insulation is placed on top of the existing roof finish and another waterproof layer is added. The inverted warm deck uses the existing membrane as the waterproof layer and adds loose-fitting waterproof insulation above it. Extruded expanded polystyrene is often used and held down with ballast or paving slabs. The disadvantages of the inverted warm roof are that the roof loading is increased and the cold rain can get on the warm side of the insulation.

Watch points

- Always consider insulating roofs on the pitch plane rather than horizontally at ceiling level in order to create a warm loft that can provide additional accommodation or a location for services; remember that if the insulation is moved to the pitch plane any exposed gable walls must also be insulated
- When insulating a loft at ceiling level, ensure that the insulation does not block ventilation at the eaves (ventilation is essential to reduce the risk of condensation and rot); install insulation in two layers, between and across the ceiling joists in order to obtain adequate thermal performance and reduce thermal bridging by the joists
- If the roof is of trussed rafter construction, do not attempt to insulate the loft with quilt; use a blown insulation material instead to ensure that the insulation is continuous and that cold air cannot penetrate beneath it
- When insulating a loft, ensure that electric cables run on the cold side of the insulation to avoid overheating and to eliminate routes for cold air to penetrate beneath the insulation; if possible, remove all services from the loft space in order to eliminate penetration of the insulation by pipes and wires, and to remove the risk of pipework freezing

- When insulating a roof on the pitch plane, place a layer of insulation above or below the rafters, as well as insulating between them, in order to reduce thermal bridging by the rafters; if the roof finish is being replaced, consider insulating between and over the rafters
- When insulating a roof on the pitch plane, either use a vapour balanced insulation system to control the migration of moisture through the construction or include a vapour barrier on the warm side of the insulation and maintain a minimum 50 mm wide ventilation gap above the insulation (between the rafters and below the roofing felt); ensure that the vapour barrier is lapped and sealed at all junctions, corners and edges, and at any services penetrations
- When insulating a flat roof, choose external insulation (on top of the roof) whenever possible in order to create a 'warm roof' construction and reduce the risk of interstitial condensation and rot; check that the roof structure can carry the additional load, and ensure that cold rain cannot penetrate below the insulation layer
- Ensure that roof insulation connects to or overlaps with the wall insulation at eaves, gable walls and verges in order to reduce thermal bridging

7. Windows and external doors

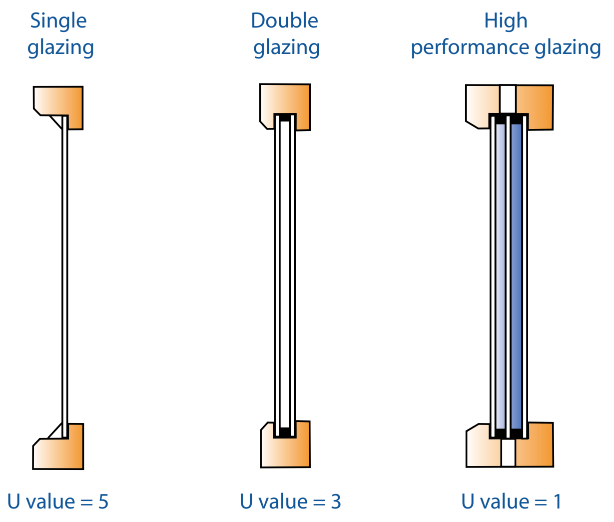


Figure 7.1 Improvements in U value of windows

Around two million windows are installed in the UK every year. The majority of these are replacement windows in existing homes. Many of these replacement windows replace old single glazed windows with double glazed ones. Such has the advance in glazing technology over the past few years that now it is possible to upgrade double glazing with a modern high performance window and get an improvement in performance similar to going from single to double glazing. Figure 7.1 indicates this improvement in performance – thermal transmittance is reduced by about 2 $W/m^2/K$ at each step.

A number of innovations have led to this improved performance.

- Low emissivity coatings reduce radiative heat loss across the glazing cavity. These soft coatings now have very low emissivities below 0.05, compared to 0.15 for hard coatings. At the same time as improving insulation levels, low-E coatings have been made more transparent
- Gas filling reduces the convective heat transfer across the glazing cavity. Argon gas is most common but krypton gas will give the same performance for a narrower cavity and this is often useful in refurbishment (see Figure 7.3)
- Insulated spacers reduce the thermal bridge due to the high conductivity of the aluminium or steel usually used for edge spacers. These insulated spacers are often referred to as 'warm edge'
- These improvements in glazing technology have resulted in the glazing performing better than the frame. So insulated frames are now available (see Figure 7.4) which result in U values for whole windows as low as 0.6 W/m^2K

Quick fixes

If windows are not being replaced, a simple DIY job can be used to improve performance. This involves sticking a thin transparent film over the window which is then stretched using a hair dryer (see Figure 7.2).

Properly fitting curtains with 'thermal' (low emissivity) linings can make a significant improvement to the performance of single or double glazed windows.

Opportunities

When windows, rooflights or doors are being replaced, high performance replacements should be considered. Good quality windows will last for fifty years so it makes sense to choose the best that can be afforded.

Major projects

When windows are being replaced as part of a major refurbishment, they can be tied in with wall insulation and air tightness measures.

Figure 7.2 Windows are rated on an A to G scale.
Picture: Gavin Hodgson, Oxford Brookes University

Building Regulations 2013	Good Practice	Advanced
WER band C or better	WER band A or better or U value below 1.4	WER band A+ or U value below 0.85

Table 7.1 Window energy ratings (WERs) and U values (W/m^{2}K) for windows and roof windows

Windows and doors are defined as 'controlled fittings' under Part L of the Building Regulations. This means that a Building Regulations application must be made when windows are replaced. In England and Wales, if a FENSA (Fenestration Self-Assessment scheme) registered installer is used, the work will be self-certified by the installer and no application is required.

The performance of a window depends on many factors: heat losses through the glass, spacers and frame; heat gains through the glazing; and infiltration through any cracks or gaps. To assess the effect of these factors, a European Window Energy Rating (WER) has been developed. In the UK the WER is administered by the British Fenestration Rating Council (BFRC). Windows are modelled or hot-box tested and a rating (A to G) is awarded depending on the U value, solar transmission (g value) and the effective air leakage (see Figure 7.2).

U values for windows and doors

Table 7.1 presents recommended maximum U values or minimum energy ratings for windows and rooflights, according to various standards.

Note that WER band A windows can have U values as high as 1.6 W/m^{2}K, so for advanced applications it is important to check the U value. Glass with low emissivity tends to have a lower g value; this may be significant if solar gains through southerly oriented windows are important to the refurbishment energy strategy.

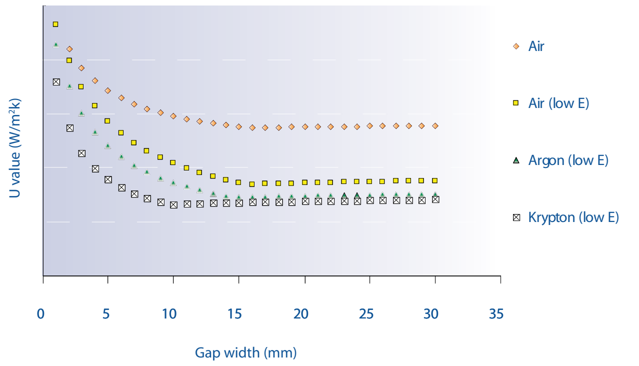


Figure 7.3 The graph shows that the most significant improvement in U value comes from low-E coatings. Note that the U value given by krypton gas filling with a gap of around 10 mm is similar to argon filling with a 16 mm gap

Figure 7.4 Triple glazed low emissivity gas filled glazing with insulated spacers in insulated timber frame, giving a whole window U value of 0.68 W/m^{2}K (Green Building Store)

Figure 7.5 Using 4/6/4 mm low emissivity krypton filled glazing gives a high performance for this handmade secondary window. The overall U value is about 1.2 W/m^{2}K. Picture: John Willoughby

Window installation

When high performance windows are installed in existing dwellings, there is a danger of excessive heat loss around the edge of the window. This can be due to infiltration and to thermal bridging at the head, cill and reveals. Infiltration can be dealt with by using expanding foam and special sealing tapes. The thermal bridge is often caused by a lack of insulation around the window. Steel lintels and masonry returns often result in excessive thermal bridging. If internal or external wall insulation is being used, a thin layer can be returned into the window reveal. More information may be found in BS8213-4, which is the Code of Practice for window installation.

Replacing windows usually necessitates some repairs to plaster window reveals. Even if wall insulation is not being carried out at the same time, using insulated plasterboard in the reveals helps to reduce the thermal bridges.

Secondary windows

If glazing is to be replaced within existing frames (e.g. in a Conservation Area) then vacuum insulated glazing provides high performance with minimum thickness. However, in most situations where windows are not being replaced, secondary windows will be a good alternative. The secondary glazing can often be tied into internal wall insulation. Using krypton filled low emissivity double glazing with a 6 to 8 mm gap can result in a slim window frame with a good thermal performance (see Figure 7.5).

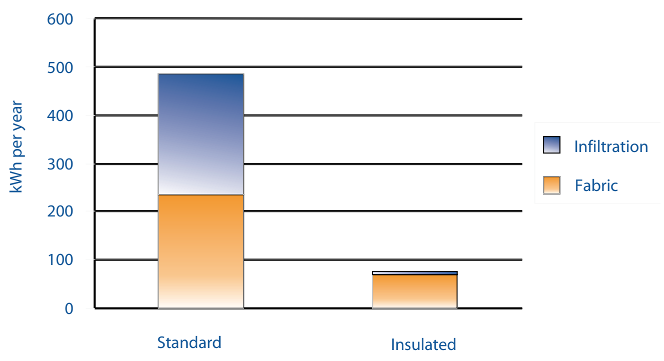


Figure 7.6 The greater savings from using an insulated door are from reductions in air leakage rather than in fabric heat losses. Graph courtesy of Peter Warm

Building Regulations 2013	Good Practice	Advanced
DER band E or better, or U value below 1.8	DER band B or better, or U value below 1.1	DER band A, or U value below 0.80

Table 7.2 Door energy ratings (DERs) and U values (W/m^{2}K) for external doors

External doors

Insulated doors reduce fabric heat losses but the main energy saving feature, when compared to the usual UK door, is in the reduction of air leakage. This is often achieved by the use of multi-point locks to ensure that the door seals are properly compressed. The graph in Figure 7.6 shows how reductions in air leakage dominate the energy savings.

The British Fenestration Rating Council (BFRC) has developed a Door Energy Rating (DER) scheme similar to the WER scheme for windows. See www.bfrc.org/doors/home.htm.

Air tightness and ventilation

It is important to ensure that replacement windows and doors are well sealed at the wall joint and are well draught-proofed. This work needs to be part of an overall strategy for air tightness and ventilation. Windows may well need to be specified with trickle vents if an adjustable air supply is required in the room. When existing windows that have trickle ventilators are replaced, the new windows must have trickle vents sized in accordance with the guidance in the Approved Document to Part F of the Building Regulations. Air tightness and ventilation issues are dealt with in the next two chapters of this guide.

Table 7.2 shows recommended U values or minimum energy ratings according to various standards.

Watch points

- Windows are 'controlled fittings' under the Building Regulations, so if they are replaced an application for approval under the Building Regulations should be made; alternatively, FENSA registered installers may self-certify the compliance of replacement windows with the regulations
- Window replacement is very compatible with wall insulation and best carried out at the same time; ensure that replacement windows are located in the plane of the insulation, if possible, to minimise thermal bridging, and that any exposed reveals, cills and soffits of openings are insulated
- Ensure that replacement windows and doors are well sealed into the walls, and that opening lights and doors are well draught-proofed
- Replacement external doors should have multi-point locking to ensure that the draught seals are compressed all around the door, not just at a single point
- Where background ventilation is required, or there is an extract ventilation system (i.e. intermittent fans, passive stack ventilation or mechanical extract ventilation) windows should incorporate trickle ventilators to admit a balancing supply of fresh air. Where there is mechanical supply and extract ventilation (i.e. MVHR) the windows should not include trickle ventilators, because fresh air is supplied by the ventilation system

8. Air tightness

British homes are notoriously leaky. In a typical house, the infiltration of external air causes the air in the dwelling to be changed about once every hour. This rate of air change is far more than is needed for ventilation and results in excessive heat losses as well as discomfort.

Air infiltration is caused by the wind and by the 'stack effect'. Wind causes positive and negative pressures on the building which forces cold air in and warm air out, through cracks and gaps in the structure. The stack effect causes warm air to rise and leak out through gaps in ceilings.

Generally UK homes rely on this infiltration to provide ventilation air. Ventilation is needed to maintain a good air quality and to remove pollutants, particularly water vapour. The problem is that the infiltration is more than is required for ventilation, and infiltration occurs all the time, even when the house is unoccupied. What is needed is a controllable supply of ventilation air in the right place at the right time. The maxim is 'build tight and ventilate right'.

Quick fixes

Draught-proofing is a simple measure that can be carried out at any time. Windows, doors and loft hatches can be draughtstripped and letterbox covers can be fitted. Suspended floors can be sealed as described in Chapter 4. Gaps around services pipes can be sealed with mastic or expanding foam.

Opportunities

When practically any improvements are being made, there is an opportunity to improve air tightness. Caulking can be carried out when decorating; and air tightness measures should accompany an insulation work. If plumbing work is being done, sealing should be carried out around services penetrations.

Major projects

Simple draught-proofing will not result in very low levels of infiltration because of all the unseen leaks, in floor voids for instance. So when a major refurbishment is being carried out, it is important to take a strategic approach to air tightness and use pressure testing to check performance.

Building Regulations 2013	Good Practice	Advanced
Reduce unwanted air leakage; 5 m^3/m^2h for MVHR	3 m^3/m^2h @ 50 Pa	1 m^3/m^2h @ 50 Pa

Table 8.1 Maximum recommended air permeabilities for existing dwellings

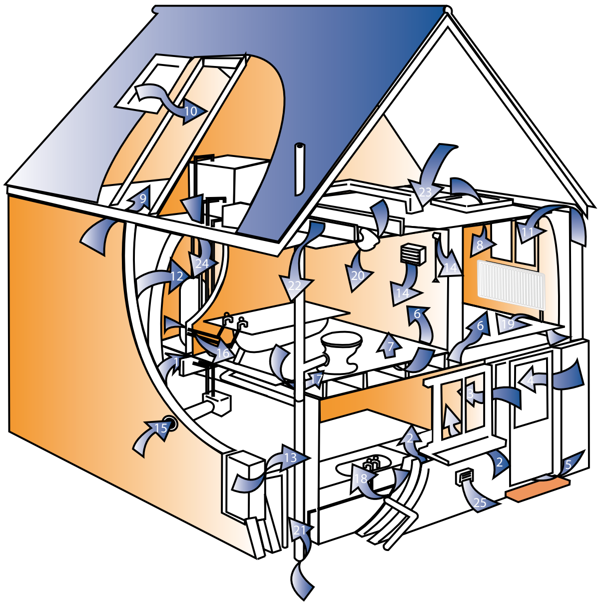


Figure 8.1 Common air leakage paths, see key below.
Diagram courtesy of Paul Jennings

Air permeability

Table 8.1 presents maximum recommended air permeabilities of dwellings, according to various standards. Air permeability is a measure of the air tightness of a dwelling, as discussed in the section about pressure testing.

Air leakage routes

Obvious air leakage paths, such as windows, doors and letter boxes, can be dealt with fairly easily. But these only account for a small part of the infiltration in a typical dwelling. Figure 8.1 identifies some air leakage paths that need to be considered.

Key to air leakage paths in Figure 8.1	
1	Around the ends of floor joists or joist hangers; through poor quality masonry between joists
2	Beneath inner window cills and around window frames
3	Through windows and/or hollow window frames
4	Through and around doors – particularly double doors
5	Beneath doors and doorframes
6	Along the top and bottom edges of skirting boards
7	Between and around sections of suspended floors, usually timber floorboards
8	Around loft hatches
9	Through the eaves
10	Around rooflights
11	Through gaps behind plasterboard on dabs or hollow studwork walls
12	Cracks or holes through a masonry inner leaf
13	Around supplies from external meter boxes
14	Around wall mounted fan or radiant heaters; around and through fused spurs and pull switches
15	Around boiler flues
16	Around water and heating pipes that penetrate into hollow floor voids and partition walls
17	Around waste pipes passing into floor voids or boxed in soil stacks
18	Around waste pipes passing through walls
19	Gaps around heating pipes
20	Around and through recessed spotlights
21	Around waste pipes, gas and water supplies, cables, which penetrate the lower floor
22	Hole around the top of a soil stack
23	Through MVHR or warm air heating systems; around terminals
24	Gaps around pipes to cold water and/or heating header tanks
25	Around and through wall-mounted extract fans, cooker hood vents and tumble dryer vents

Not on the diagram, but also:	
26	Around and through ceiling roses
27	Through room thermostats and heating controllers
28	Behind polystyrene coving along wall to roof joints
29	Through keyholes and where locks and bolts prevent effective draught-proofing
30	Around internal timber joists that penetrate plaster walls
31	Through subfloor air supplies to solid fuel heaters
32	Through gaps in the casings of MVHR units
33	Up chimneys, particularly where flue dampers are not fitted
34	Through airbricks and partially closable hit-and-miss vents
35	Through window spinner vents
36	Around and through closed trickle vents


Figure 8.2 Pressure testing equipment. Picture: Rickaby Thompson Associates

Strategic planning

A strategy for reducing air leakage needs to be part of any major refurbishment work. The most important part of this strategy is to identify how air tightness is to be achieved in each element (walls, floors, roofs) and how the elements are sealed to one another. For instance new wall insulation may incorporate an air/vapour barrier which should be sealed to air/vapour barriers in the roof and floor; services are then kept inside the air/vapour barrier envelope (see Advanced air tightness). As a general rule of thumb, it is quite difficult to reduce the air permeability (see below) of an existing dwelling by much more than half of the original pre-improvement value.

Pressure testing

Pressure testing involves fitting a fan in an external door opening (see Figure 8.2), raising the pressure in the house and measuring the airflow. This is a very useful technique to identify air leaks, which can be seen with a smoke pencil (Figure 8.3), and to check on the standard of air tightness.

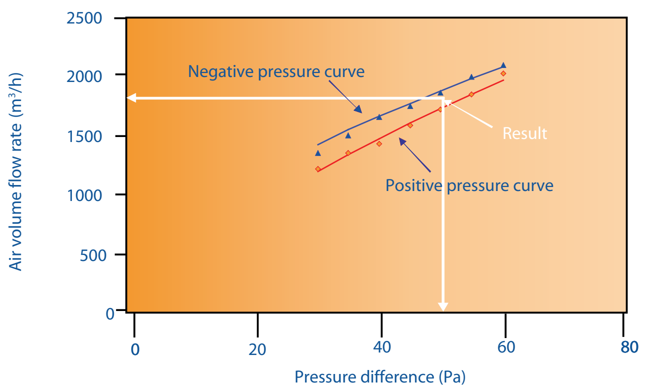


Figure 8.3 A results chart from a pressure test. Chart courtesy of Rickaby Thompson Associates

Figure 8.4 Exceptional levels of air tightness have been achieved at this refurbishment project in Hackney. New draught-proof windows have been carefully sealed to new internal wall insulation. Pictures: John Willoughby

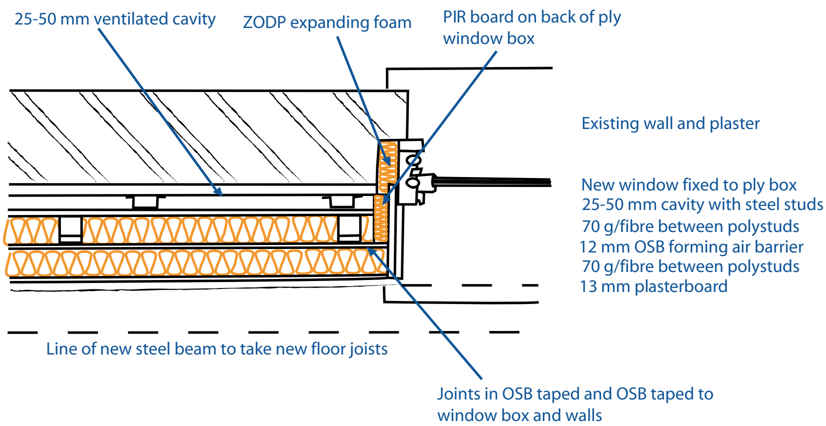


Figure 8.5 The second layer of OSB formed the air tightness layer. This was taped to window boxes and the other walls. Image courtesy of Prewett Bizley Architects

The volume of air passing through the door fan is recorded at various pressure differences. The results are used to assess the volume (m^3/h) at a standard pressure difference of 50 Pa. Dividing this volume by the internal surface area gives the 'air permeability', which has the units $m^3/h/m^2$ or m/h. Average air permeabilities in UK houses are around 18 $m^3/h/m^2$ @ 50 Pa; this can be compared with a new-build maximum allowable air permeability of 10, the best practice refurbishment standard of 3 and the Advanced standard of less than 1.

Registered pressure testers can be found at: www.attma.org/members.

Advanced air tightness

Two recent refurbishment schemes have attained air permeability standards of near to 1.0 $m^3/h/m^2$ @ 50 Pa. In Hackney, London, a Victorian terrace house has been refurbished. The main air tightness feature is orientated strand board (OSB) included in the internally insulated front walls. The OSB was carefully taped at the board joints and to the window boxes. Four different types of proprietary tapes were used to seal the OSB to the OSB in the insulated party walls, which in turn were taped to new masonry rear walls. Other tapes were used for the wall to roof and floor. See Figures 8.4 and 8.5.

Figure 8.6 Windows taped to walls before they were rendered and covered with 250 mm of insulation. Pictures: Simmonds Mills Architects

In Hereford, air tightness was achieved by a render coat applied to the brickwork before the EWI was applied. New windows were sealed to the wall to eliminate infiltration (see Figure 8.7).

In both the Hackney and Hereford projects, ventilation air is supplied via an advanced MVHR system.

Watch points

- Build tight, ventilate right – but don't be over-optimistic: it is often difficult to reduce the air permeability of an existing dwelling to much less than half of its original value
- Plans for major refurbishment projects should always include strategies for improving air tightness. Strategies should identify how air tightness is to be achieved in each element (floors, walls, roofs, windows and external doors) and how the elements will be sealed to each other
- Removing services from the roofspace (or creating a warm loft, with insulation on the pitch plane), and removing electrical services from external walls that are to be insulated internally both make it easier to improve air tightness
- In major refurbishment projects, pressure testing should be used to establish the air tightness of the existing building, identify the locations of air leakage, and demonstrate compliance with any adopted air tightness standard
- Whole-house supply and extract ventilation (MVHR) will not work properly unless the air permeability of the building envelope is less than 3 m^3/m^2h @ 50 Pa, so such systems should not be specified unless this standard can be achieved

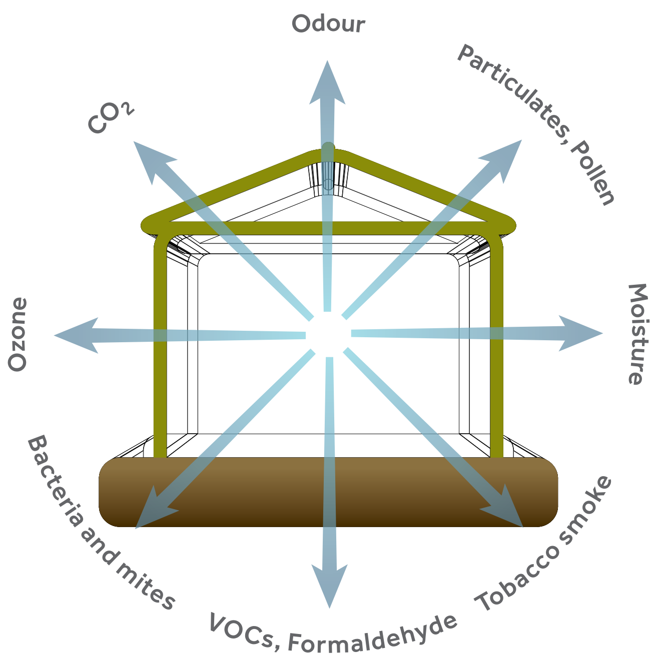


Figure 9.1 Sources of pollution in the home.
Image courtesy of Institute for Sustainability

We spend a great deal of time indoors in the company of many indoor pollutants (see Figure 9.1). Ventilation has a key role to play in diluting and removing these pollutants. If a house is made airtight without an adequate ventilation system, it can be an unhealthy place to live. Conversely, installing ventilation systems in leaky houses can add to heat losses and carbon emissions. It is important to build tight and ventilate right.

Quick fixes

Ensure that extract ventilation fans and trickle ventilators are clean and clear.

Opportunities

When extract fans need replacing, there is an opportunity to use low wattage replacements. In some cases it may be appropriate to change the extract fan for a heat recovery room ventilator.

Major projects

Major refurbishment work will allow a fresh look to be taken at the ventilation provision. If exceptional levels of air tightness can be achieved, whole-house heat recovery ventilation may be worth considering.

Building Regulations 2013	Good Practice	Advanced
Existing ventilation systems may be retained, replaced or improved	Whole-house mechanical extract ventilation (MEV)	Whole-house mechanical extract ventilation (MEV) or mechanical ventilation with heat recovery (MVHR), with demand control in either case

Table 9.1 Ventilation standards

Ventilation standards

Table 9.1 presents various ventilation standards.

Ventilation heat losses

The graph in Figure 9.2 shows the proportions of heat loss via the fabric (floors, walls, roofs and openings) and via infiltration and ventilation. In the unimproved three bedroom semi-detached house discussed in Chapter 2, nearly 80% of heat loss is through the building fabric. Infiltration and ventilation is a minor issue. However, if the building fabric is insulated to best practice standards, then infiltration and ventilation losses become much more significant. With further improvements in fabric performance, infiltration and ventilation losses can dominate, at nearly 60% of the total. At the advanced insulation standard, with air permeability down to 1.0 $m^3/h/m^2$ @ 50 Pa and a whole-house extract ventilation system, ventilation losses are still a significant part of the total. At this point using an advanced heat recovery ventilation system can reduce ventilation losses to a minor fraction of the total.

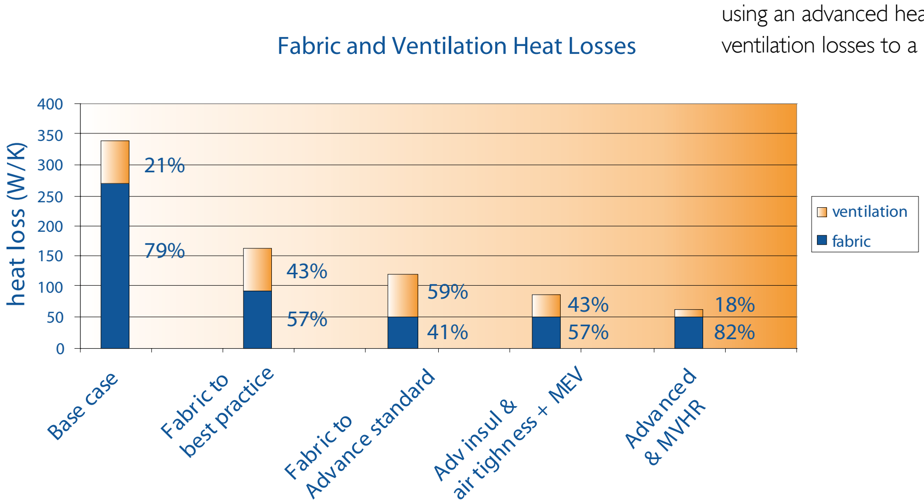


Figure 9.2 If building fabric improvements are made without attention to infiltration and ventilation, ventilation heat losses can dominate

It is clear that to make significant reductions in heat losses requires attention to the fabric insulation, infiltration heat losses and the ventilation system.

Ventilation options

Most UK homes rely on uncontrolled infiltration for background ventilation. Windows are opened or extract fans are used for intermittent purge ventilation. When air tightness issues have been addressed, a more controllable ventilation system should be considered. Options include intermittent or continuous extract fans with trickle vents, whole-house extract (also with trickle vents), passive stack ventilation, heat recovery room ventilators and whole-house heat recovery ventilation systems. Demand controlled ventilation can be used in conjunction with some of these systems to provide the correct level of ventilation in each room of the house.

Extract fans and trickle vents

Intermittent extract fans in bathrooms and kitchens are good for purge ventilation to remove odours and water vapour. Energy savings can be made by selecting low wattage fans. DC motors and improved fan design can reduce electricity use by as much as 80%. However in airtight houses, with air permeability of 3 $m^3/h/m^2$ or less, there is a danger that air quality will be poor. One way of improving air quality is to use continuous extract ventilation – the fans run continuously (and quietly) to provide background ventilation, and go into 'boost' mode when kitchens or bathrooms are used, or when internal humidity levels are high. With either option, trickle ventilators must be provided to balance the extraction of stale air by admitting fresh air.

Figure 9.3 Mechanical extract ventilation.
Image courtesy of Institute for Sustainability

Mechanical extract ventilation (MEV)

In airtight houses, air quality can be improved by using a continuous extract system. Air is taken from the wet rooms and trickle vents are used to admit fresh air into living rooms and bedrooms (see Figure 9.3). Extract rates can be boosted with switches or presence detectors. Further improvements can be made by using low watt fans and humidity-controlled trickle vents. The preferred option is a single central extract fan unit with ducts from the wet rooms.

If the air tightness of the house is being improved, it is important to provide sufficient trickle ventilators for fresh air supply – one in each window head may not be enough – and it may be necessary to fit some ventilators in walls. Good quality humidity-controlled trickle ventilators should be used; poor quality ones often leak air even when they are closed.

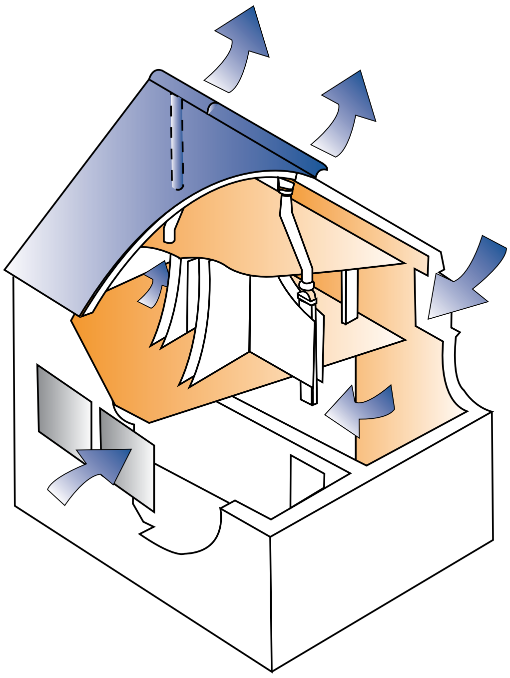


Figure 9.4 Passive stack ventilation. Diagram courtesy of Passivent

Passive stack ventilation (PSV)

Passive stack ventilation has the ability to ventilate the house without the use of electric fans. Ducts link the bathrooms and kitchens to terminals on the ridge of the roof. Humidity-controlled outlet vents in these wet rooms control the extract rate, while humidity-controlled trickle vents in living rooms and bedrooms control the fresh air supply (see Figure 9.4). In refurbishment schemes, using PSV will require a considerable amount of careful planning to accommodate the passive stacks.

All the above ventilation systems throw away expensive warm air. Heat recovery systems help to address this issue by recovering some of the heat in the exhaust air. This can be done on a room-by-room basis or with a whole-house system.

Heat recovery room ventilators (HRRVs)

These systems combine supply and extract ventilation with heat recovery in compact through-the-wall units (see Figure 9.5). Heat recovery efficiency can be as high as 80% with fan power as low as 2 W.

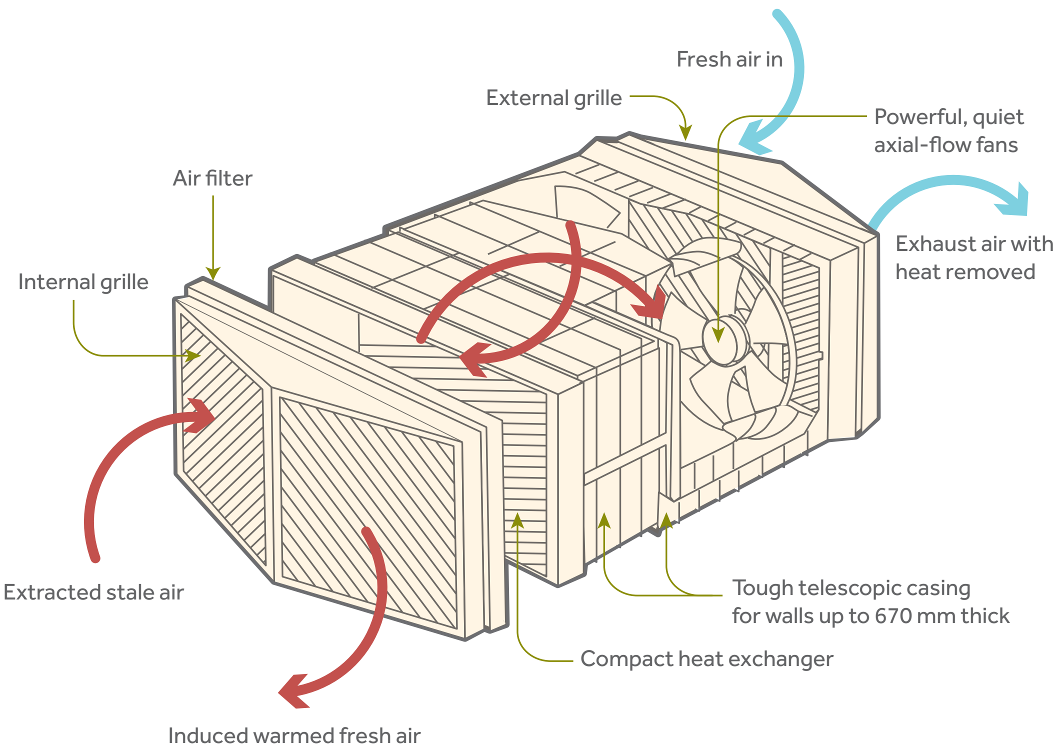


Figure 9.5 Room ventilator with heat recovery.
Image courtesy of Institute for Sustainability

Figure 9.6 Whole-house heat recovery ventilation. Image courtesy of Institute for Sustainability

Mechanical ventilation with heat recovery (MVHR)

Whole-house MVHR systems extract moist, stale air from wet rooms and supply fresh air to other rooms (see Figure 9.6). Typically, half an air change per hour is supplied, which is sufficient to give good air quality. Carefully designed heat exchangers can recover up to 90% of the heat in the extract air. It is important to select systems with high efficiencies because some systems only recover 60% of the heat. The other essential consideration in the selection of an MVHR unit is the fan power. If high wattage fans are used, the fuel costs and emissions associated with running them can continuously outweigh the heat recovery savings. The fan power is expressed in terms of the total wattage per litre per second of extract air (W/(l/s)). Some systems use as much as 1.5 W/(l/s), others as low as 0.5 W/(l/s).

Fan power and heat exchange efficiency are not the only issues needing careful specification. With low fan powers, it is essential that ducts are large in diameter (at least150 mm), smooth bore and rigid, with very few bends and as short as possible. Flexible ducts should only be used for the final terminations to air diffusers.

Using MVHR in refurbishment requires a lot of careful planning. The air permeability of the building envelope must not exceed 3 m^3/m^2hr, and if this is not achieved the MVHR system will not work efficiently. The fan unit and all the ductwork must be within the insulated airtight envelope, and filters must be easily accessible for regular cleaning or replacement. This is where insulating the roof at rafter level can come into its own – a warm loft space can accommodate the MVHR unit and the ductwork.

All MVHR systems should incorporate a summer bypass facility to disable heat recovery during warm weather in order to reduce the risk of overheating.

Figure 9.7 Heat recovery ventilation in a refurbishment project in Hackney (note the conglomeration of ducts and also the extensive use of sealing tape). Picture: John Willoughby

Demand controlled ventilation

'Demand control' can be combined with MEV or MVHR systems to ensure that the correct level of ventilation (extract and/or supply) is provided to every room. Sensors detect levels of humidity and/or carbon dioxide in individual rooms and continuously adjust the rates of stale air extraction or fresh air supply accordingly. It has been claimed that this level of control applied to an MEV system (without heat recovery) can be more energy efficient than a conventional MVHR system with intermittent whole-house boost.

Advanced ventilation

At Hackney, an MVHR unit has been accommodated in cupboards on the top floor of the house. A services distribution zone has been created in the middle of the house adjacent to the insulated party wall (see Figure 9.7).

Watch points

- Ventilation is essential for removing pollutants (including carbon dioxide and water vapour) and thus ensuring good internal air quality and reducing the risk of condensation and mould growth. Ventilation also helps to reduce overheating in warm summer weather
- A side effect of insulating a dwelling is improvement of its air tightness, and thus restriction of 'adventitious' or uncontrolled background ventilation, so insulation should always be accompanied by improved ventilation
- Build tight, ventilate right – and match the ventilation strategy to the air tightness of the building envelope
- Extract ventilation systems (i.e. intermittent or continuous extract fans, PSV and MEV) must always be accompanied by trickle ventilators (usually mounted in the heads of window frames) to admit a balancing supply of fresh air
- If supply and extract ventilation (MVHR or HRRVs) is installed then trickle ventilators should not be fitted because the fresh air is supplied by the ventilation system
- The efficiency of most ventilation systems can be improved by incorporating low energy (DC) fans and/or humidity controlled trickle ventilators, as appropriate
- Ventilation systems (MEV, MVHR) must be balanced and commissioned properly if they are to work effectively; this work should be carried out by a specialist
- Whole-house supply and extract ventilation (MVHR) will not work properly unless the air permeability of the building envelope is less than 3 m^3/m^2h @ 50 Pa, so such systems should not be specified unless this standard can be achieved
- MVHR systems are difficult to install in existing dwellings; the heat exchangers and all ductwork should be located within the insulated envelope (not in a cold loft); air ducts should be as short and straight as possible, with no sharp bends; ductwork should be circular in section, of at least 150 mm diameter, and smooth internally (not spiral wound); joints should be sealed and cold air ducts should be insulated

91% of British homes have central heating; 87% have gas central heating. This is in marked contrast to 1970, when only 31% of homes had central heating. Another interesting statistic is that around 40% of boilers are now combination types, or 'combis', providing heating and 'instant' hot water from the same boiler (without a hot water storage cylinder). This chapter concentrates on wet central heating systems but also mentions alternative solutions, which may prove to be viable low carbon solutions in the future.

Heating systems are defined as a 'controlled service' under Part L1B of the Building Regulations. Work on heating systems should comply with the Domestic Building Services Compliance Guide and a Building Control body should be notified of the work. This can be done by an application for approval under the Building Regulations before work starts or by a Building Notice. Alternatively the work can be self-certified by a 'competent person' (i.e. a registered Gas Safe, OFTEC or HETAS fitter).

Quick fixes

Regular servicing of heating equipment will ensure that high efficiencies are maintained. All central heating systems should be controlled with a time switch or programmer, thermostatic radiator valves (TRVs) and a room thermostat that switches the boiler off when the house is up to temperature. Upgrading controls is a fairly cheap and cost effective measure.

Opportunities

When a boiler breaks down, is more than ten to fifteen years old, or when the heating system is being modified, the opportunity to install an efficient A-rated boiler and advanced controls should be taken. The hot water system should be upgraded at the same time (see Chapter 11).

Major projects

Major refurbishment work should include a review of heating options, with the possibility of installing low carbon systems in combination with improved time and temperature zoning and controls.

Heating standards

Table 10.1 presents various standards for heating systems.

Building Regulations 2013	Good Practice	Advanced
Improvements should comply with the Domestic Building Services Compliance Guide	Gas- or oil-fired condensing boiler supplying radiators, controlled by a programmer, room thermostat(s), TRVs and compensator; or electric heat pump supplying an under-floor distribution system or low temperature radiators and controlled by a programmer and room thermostats	Internal heat gains recovered by a whole-house MVHR system supplemented by low carbon room heaters

Table 10.1 Standards for heating systems

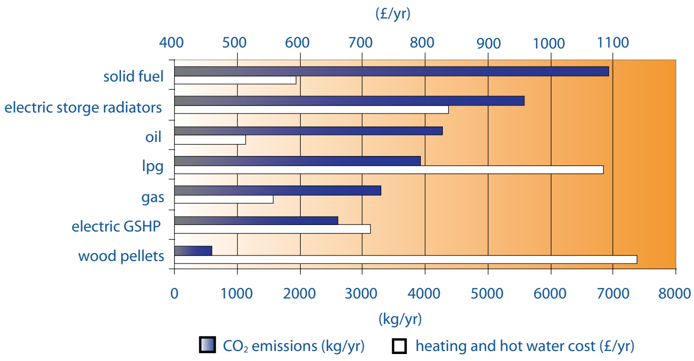


Figure 10.1 Carbon dioxide emissions and annual fuel costs for typical three bedroom semi-detached house

Fuel choice

The choice of fuel affects running costs and carbon dioxide emissions. Figure 10.1 shows running costs and carbon dioxide emissions for the typical three bedroom house discussed in Chapter 2, with various heating fuels.

The chart is arranged in order of carbon dioxide emissions. Solid fuel (anthracite) is the most polluting, while a wood pellet boiler is the least. In terms of fuel costs, oil, solid fuel and gas are cheapest, while wood pellets and LPG are the most expensive.

Gas-fired central heating

A gas-fired central heating system should have the following components:

- An A-rated boiler with an efficiency of over 90% sized to meet the heat load of the dwelling
- A programmer or time switch capable of controlling at least two heating periods during the day
- A room thermostat that switches the boiler off when the house has reached the desired temperature
- Thermostatic radiator valves (TRVs) to give temperature control in each room (the TRV should be omitted from the radiator in the space with the thermostat)

Wireless thermostats are particularly useful for refurbishment projects because they can be fitted without damaging finishes or decorations. The system can be enhanced by using a more sophisticated programmer or programmable thermostat, which gives options for at least five different temperatures at different times of the day. But these controls also need a sophisticated user. In addition, it is often advantageous to split the dwelling into more than one control zone so that different areas can be heated to different temperatures at different times of the day.

It is always worth reassessing the heat loss of the refurbished dwelling before installing a replacement boiler. The existing boiler is likely to be oversized and very often energy efficiency measures will have reduced the load so that a smaller boiler will suffice.

Gas-fired heating systems have relatively low carbon dioxide emissions and are relatively cheap to run, but it may well be worth considering alternatives that have the potential to reduce emissions further.

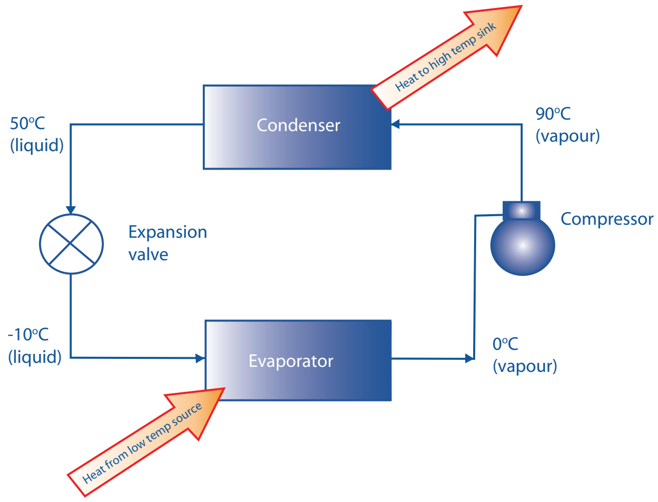


Figure 10.2 The basic components of a heat pump

Figure 10.3 Borehole drilling rig and ground loops, for ground source heat pumps. Pictures courtesy of DCH

Figure 10.4 An evaporator unit for an air source heat pump. Picture: John Willoughby

Alternatives to gas central heating

The Renewable Heat Incentive

The government's Renewable Heat Incentive (RHI) provides a financial incentive for the local generation of heat from renewable sources, in the form of regular payments based on the capacity of the installed system. Qualifying systems include solar water heating (see Chapter 11), biofuel boilers and ground source heat pumps (see below). A minimum level of energy efficiency (of the house) is required, and assessments are carried out before RHI funding is made available.

Heat pumps

Heat pumps use refrigeration technology to provide heat from a condensing unit. The evaporator side of the heat pump absorbs energy from outside the house. The evaporator typically uses outside air or the ground as the source of heat. Air source heat pumps (ASHPs) are cheaper and easier to install than ground source heat pumps (GSHPs) which use horizontal coils or vertical boreholes as the source. Figure 10.2 illustrates the basic components of a heat pump.

The efficiency of a heat pump is denoted by its 'coefficient of performance' (CoP). This is the ratio of the amount of energy extracted from the ground or air source (in the form of heat) to the amount of energy used by the heat pump itself (in the form of electricity). Typically, the CoP of a GSHP is approximately 3.0, and the CoP of an ASHP is approximately 2.5. Well designed and installed systems can achieve CoPs of 3.5 or more, but research has shown that many installations deliver significantly poorer performance than was claimed or predicted for them. Whether the heat produced has lower carbon dioxide emissions than other forms of heating depends on the emissions from electricity production. With the current mix of fuels for electricity production, heat pumps result in approximately the same fuel costs and levels of emissions as heating by gas-fired condensing boilers, so it is not appropriate to install heat pumps in dwellings that have mains gas supplies.

All heat pumps require specialist installation. In the case of ground source heat pumps, the evaporator can be carefully installed in a deep borehole, which must be drilled by a specialist. The depth of the borehole will depend on the ground conditions. If 'ground loops' (see Figure 10.3) are used instead of a borehole, the loops must not be too tightly coiled and the trenches in which they are placed must not be too close together. This avoids freezing the surrounding ground, which significantly reduces the CoP of the heat pump.

In the case of air source heat pumps, the external evaporator units (see Figure 10.4) must be adequately sized and sited away from obstacles that may obstruct air flow. If the evaporator is inadequately sized, or air flow is restricted, the unit may freeze, causing it to go into 'defrost' mode, reversing the heat pump and using electrical energy to melt the ice.

Figure 10.5 A domestic wood pellet boiler

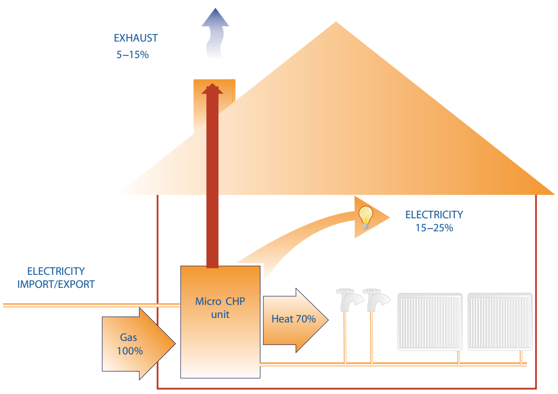


Figure 10.6 The micro CHP concept. Diagram courtesy of EA Technology

Figure 10.7 Domestic micro CHP unit.
Picture courtesy of Baxi Heating UK Ltd.

Biomass heating

In the domestic setting, biomass heating usually involves burning wood logs or pellets in stoves or boilers. Other biomass crops include woodchip, miscanthus grass or coppiced willow, which are usually burnt in larger heating appliances, perhaps serving several dwellings. 'Processed' fuels such as woodchip and wood pellets involve slightly more carbon dioxide emissions than logs, but they are often easier to manage and store.

Provided that the tree is replaced, using wood for heating can be seen as a low carbon solution. In burning, the tree releases the same amount of carbon dioxide as it absorbed during its growth, and as would be emitted when it eventually dies and decays. A small amount of carbon dioxide is emitted in felling and transporting the fuel, but overall burning wood involves only the emissions associated with the life cycle of the tree. Burning wood is therefore much less damaging than burning fossil fuels, which involves the release of carbon dioxide that has been 'locked up' for millions of years. Where supplies are plentiful, wood heating represents a viable low carbon solution. However, it can only be a niche market because there is not enough land available to grow sufficient wood to heat all UK homes.

A wide range of wood-burning domestic appliances is available, including log-burning, chip-burning and pellet-burning boilers and stoves. Some stoves are capable of supplying hot water to radiators in other rooms and of supplying domestic hot water. Figure 10.5 shows a domestic wood pellet boiler.

Micro CHP

A domestic combined heat and power (CHP) unit generates heat and electricity in one unit (see Figure 10.6). The heat can be used for heating the house and the electricity can be used in the house or exported to the grid. Micro CHP units are usually based on gas-fired Sterling engines and typically produce 6 to10 kW of heat and 1 kW of electricity. The electricity is a by-product of the heating so if micro CHP is to be effective in reducing costs and emissions, there needs to be a large heating load for long periods of the day and long periods of the year. Thus micro CHP units are best suited to large dwellings with high demand for hot water throughout the year. Small hotels or guesthouses are ideal situations to exploit this technology. The latest micro CHP systems such as the one shown in Figure 10.7 are of a similar size to a conventional domestic boiler. They can be installed in kitchens, as shown in the picture, but because micro CHP systems are slightly noisier than boilers some manufacturers suggest that utility rooms may be more suitable.

Thus micro CHP units are best suited to large dwellings with high demand for hot water throughout the year. Small hotels or guesthouses are ideal situations to exploit this technology.
The latest micro CHP systems such as the one shown in Figure 10.7 are of a similar size to a conventional domestic boiler.
The location of micro CHP units should always be checked with the manufacturers.

Watch points

- Heating systems are 'controlled services' under the Building Regulations, so if they are altered or replaced an application for approval should be made to a Building Control body; alternatively, work can be self-certified by a 'competent person' i.e. a registered Gas Safe, OFTEC (Oil Firing Technical Association) or HETAS (Heating Equipment Testing and Approval Scheme) fitter
- Insulating a dwelling reduces its heat loss, so existing heating systems, and heat emitters such as radiators, may become oversized. If the system output is matched to the heat loss of the dwelling, it will operate more efficiently
- Improving the heating controls in a dwelling, to make it more responsive, is one of the least expensive and most cost effective improvement measures, especially if the dwelling is also insulated, so this measure should always be considered, even if the heating system itself is not improved
- The fuel costs and carbon dioxide emissions associated with an electric heat pump are approximately the same as those associated with a gas-fired condensing boiler serving the same dwelling, but the heat pump is much more expensive; therefore it makes no sense to install a heat pump to heat a house that has a mains gas supply
- The performance of an electric heat pump depends on the quality of the installation, so these systems should always be designed and installed by experienced specialists who have been trained and approved by the suppliers
- A domestic combined heat and power (micro CHP) system generates heat and electricity in one unit. The electricity is a by-product of the heating so if micro CHP is to be effective in reducing costs and emissions, there must be a large and relatively constant heat load. Thus micro CHP is best suited to large dwellings with high demand for heat or hot water throughout the year
- Domestic biomass-only boilers and wood pellet stoves with back boilers are eligible for financial support via the Renewable Heat Incentive

11. Hot and cold water

Domestic water use in the UK is around 150 litres per person per day. Taking water from the environment, treating it, distributing it to households, using it in the home, collecting it when it has become sewage and then treating it before discharging it back into the environment are all processes that require energy and therefore result in carbon dioxide emissions. There is a national target to reduce water use to 130 litres per person per day by 2030. For new dwellings, the Building Regulations and the Code for Sustainable Homes set lower standards of water use, which are to be met by means of water conservation measures.

Simple measures

Regular servicing of heating equipment will ensure that high efficiencies are maintained. If the hot water system is gravity fed, then it may be possible to convert to a fully pumped system with the advantage of independent time and temperature control of hot water.

Opportunities

When a cylinder needs replacing, or is more than ten to fifteen years old, or when the heating system is being modified, the opportunity to install an efficient hot water system with good controls should be taken. The new 'high performance' hot water cylinder should be 'solar ready', i.e. have twin heat exchanger coils.

When modifications are being made to the heating system or work is being carried out on the roof, it may be a good opportunity to install solar water heating.

When taps or showers are being replaced, there is an opportunity to fit low flow alternatives.

Major projects

Major refurbishment work should include a review of heating and hot water systems with the possibility of installing low carbon alternatives.

Hot water standards

Table 11.1 presents various standards for domestic hot water.

Building Regulations 2013	Best Practice	Advanced
Improvements should comply with the Domestic Building Services Compliance Guide	Gas-fired condensing combination boiler; or gas- or oil-fired condensing boiler supplying an indirect cylinder and controlled by a programmer and thermostat; or electric heat pump supplying an indirect cylinder and supplemented by an electric immersion heater; all options supplemented by solar water heating	Solar water heating supplemented by heat from a low carbon source

Table 11.1 Standards for domestic hot water

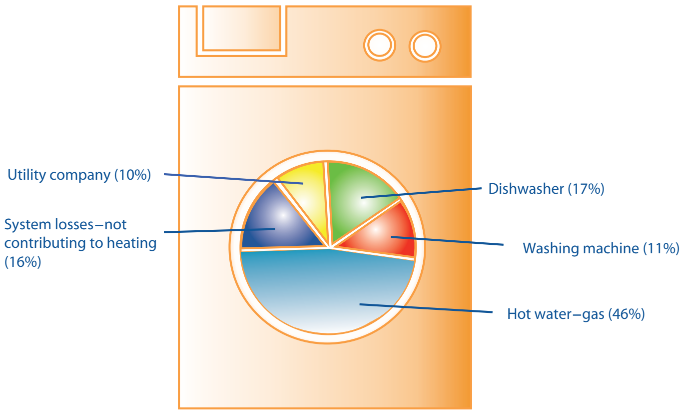


Figure 11.1 Water related carbon dioxide emissions[18]

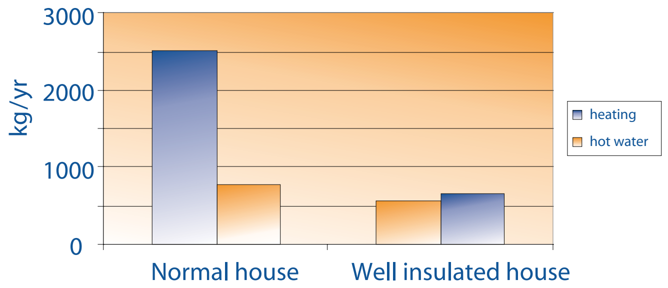


Figure 11.2 Carbon dioxide emissions from heating and hot water, for a typical three bedroom semi-detached house

Reducing demand

Figure 11.1 shows that the largest proportion of the carbon dioxide emissions relating to water use in the home is for heating hot water for use in the kitchen sink and bathrooms. The emissions associated with the washing machine and dishwasher are large because water in these appliances is often heated with electricity. 'Hot fill' washing machines (which use hot water from the domestic supply) are becoming increasingly difficult to obtain. 10% of the emissions are in treating, supplying mains water and disposing of waste water by the utility company.

Reducing water use in the home can be achieved by:

- Good housekeeping, including: taking showers instead of baths; taking short showers (using a shower timer); washing up with a bowl rather than under a running tap; mending leaking taps; not leaving taps running unnecessarily
- Installing low volume dual flush WC cisterns
- Fitting spray taps or aerators to taps on wash basins
- Fitting low flow showers with a maximum flow rate of six litres per minute
- Installing baths with volumes as small as possible for the intended use

These simple measures can reduce water use by as much as a half.

Reducing fuel used for hot water

The main use for gas in UK houses is to provide heating and hot water. In our typical three bedroom semi-detached house (see Chapter 2), carbon dioxide emissions from heating are much greater than those from hot water: emissions from hot water production are only 30% of the total from gas use. However, as shown in Figure 11.2, if the house is insulated to best practice standards, the emissions from hot water supply become dominant.

The importance of installing an efficient hot water system is clear; even if it is a minor heat source at present, it may become the dominant thermal load in the future. The amount of hot water used can first be dramatically reduced by installing efficient appliances; then the hot water must be produced in the most efficient way possible.

Hot water is most commonly produced by either a combination boiler (supplying 'instant' hot water directly to the taps) or a regular boiler supplying a hot water storage cylinder. When using a combi boiler there is much that can be done to reduce fuel use.

- Ensure that the boiler is of a type that condenses in hot water mode; the efficiency of many combi boilers is low when producing hot water only
- Make sure the combi is positioned near to the water using appliances, particularly the shower and the kitchen sink

18 Diagram taken from 'Quantifying the energy and carbon effects of water saving', Environment Agency / Energy Saving Trust, 2009.

- Micro bore pipework serving each appliance separately can be used to reduce the 'dead leg' between the boiler and the appliance
- Keep-hot facilities on combi boilers keep the hot water heat exchanger hot so that hot water is supplied quickly when a tap is turned on. Make sure that the combi either does not have a keep-hot facility or, if it does, make sure that it can be switched off. A keep-hot facility can significantly reduce the efficiency of the boiler

When using a regular boiler and cylinder, fuel use can be reduced as follows:

- Make sure that the cylinder is well insulated. More insulation can be added to existing cylinders and new cylinders can be supplied with high performance foam insulation. It is important also to make sure that the pipework connecting the cylinder to the taps is insulated. Primary pipework between the boiler and cylinder should also be insulated
- Use a 'high performance' cylinder that contains a heat exchanger with a larger surface than normal. This reduces the time taken to heat the water and may reduce boiler cycling. It gives a valuable reduction in recovery time between large draw-offs (such as baths) and helps to increase system efficiency (especially with older boilers). High performance cylinders often have improved factory-applied insulation as well
- Avoid the use of secondary hot water circulation around the building. This is sometimes included to avoid long dead legs but, because it runs continuously, it carries a large energy penalty. It is better to use cylinders local to appliances and, if there is sufficient water pressure, use micro bore pipework to each appliance

Solar water heating

Solar hot water systems can make a significant contribution to reducing carbon dioxide emissions. In summer, most of the hot water can be supplied and over the year a well designed system should reduce the emissions associated with water heating by approximately half. Solar water heating qualifies for financial support from the government's Renewable Heat Incentive (RHI).

Flat plate panels or evacuated tube arrays can be connected to a dedicated solar cylinder or to the lower coil of a dual coil 'combined' cylinder. Figure 11.3 shows a typical open vented system with a large combined cylinder containing an additional solar heat exchanger, usually referred to as twin-coil. Sealed solar primary systems (i.e. to collectors) are commonly used and unvented twin-coil cylinders are also available. When the solar panel is hotter than the cylinder, the pump is used to deliver solar heated water. The system is thermostatically controlled, so the boiler only fires to produce hot water when the solar system has not raised the cylinder temperature to the required temperature; this will happen only rarely in summer, but more often in winter.

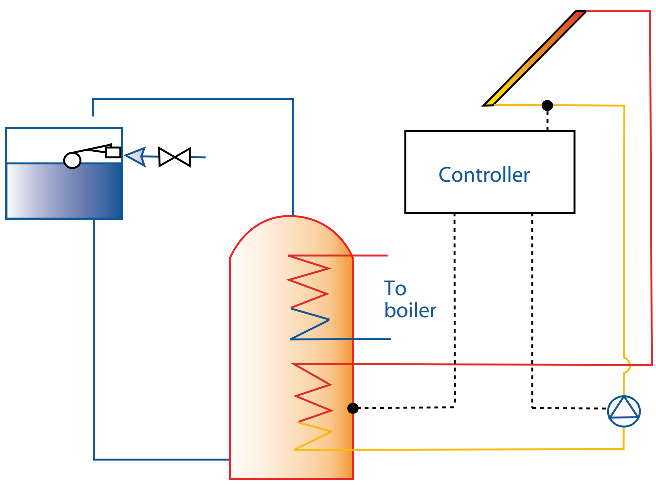


Figure 11.3 A typical solar water heating system[19]

19 Figure 11.3 redrawn from 'Domestic heating by gas: boiler systems', Energy Saving Trust (CE30).

A good rule of thumb for solar water heating systems is to allow one square metre of solar collector per occupant of the house, and forty litres of dedicated solar storage per occupant (seventy litres if evacuated tube collectors are used). Collectors work best if they are oriented to the south, but they work quite well when oriented between south-east and south-west; poor orientation may involve using a larger collector.

Watch points

- Although water heating may represent only a small part of the heat load of an existing house, it may become the dominant heat load when the house is insulated and the demand for space heating is reduced
- Water heating systems are 'controlled services' under the Building Regulations, so if they are altered or replaced an application for approval should be made to a Building Control body; alternatively, work can be self-certified by a 'competent person' (i.e. a registered Gas Safe, OFTEC or HETAS fitter)
- The amount of energy used for water heating can be reduced by installing appliances (washing machines, showers) with low water demand, as well as by heating the water efficiently
- The Building Regulations require hot water systems to be controlled independently of heating systems, i.e. it must be possible to programme water heating at different times from space heating
- If a gas-fired combination boiler is used for water heating, ensure that the boiler is of a type that condenses in hot water mode (which will be the main mode of operation in summer); ensure that the boiler is located close to the main water-using appliances (e.g. the washing machine); and avoid boilers with keep-hot facilities (which are less efficient than those without)
- If a regular gas-fired boiler is used to supply hot water via an indirect cylinder, ensure that the cylinder is of the 'high performance' type, is well insulated and has a thermostat to control the heat supply; the hot primary pipework between the boiler and the cylinder should be insulated
- In larger homes, use local hot water storage cylinders rather than circulating hot water continuously around the building
- A well designed solar water heating system should reduce the fuel costs and emissions associated with water heating by approximately half. A good rule of thumb for solar water heating systems is to allow one square metre of solar collector per occupant of the house, and forty litres of dedicated solar storage per occupant
- Domestic solar water heating systems are eligible for financial support via the Renewable Heat Incentive

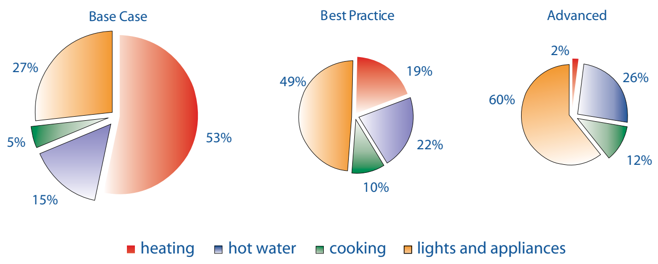


Figure 12.1 Carbon dioxide emissions by end use, for different standards of thermal performance

Using a unit of electricity in the home produces more than twice as much carbon dioxide emissions as using a unit of gas (see Table 1.1). A unit of electricity is also about four times more expensive than a unit of gas. Therefore energy saving electrical appliances and good housekeeping can make a significant impact on household fuel costs and emissions. Figure 12.1 shows that as more is done to reduce fuel used for heating, the more significant are emissions from electricity use.

Simple measures

Low energy lamps can be installed at any time. They are extremely cost effective. Good housekeeping can substantially reduce electricity use.

Opportunities

When appliances are being replaced, choosing the most efficient can halve electricity use.

Major projects

Major refurbishment work should include a review of lighting and electrical appliances. Low energy lamps should be installed throughout. The position and switching of lamps should be carefully considered in relation to tasks and daylighting. It is an ideal opportunity to invest in the best possible electrical appliances.

Building Regulations 2013	Best Practice	Advanced
Improvements should comply with the Domestic Building Services Compliance Guide	All fixed lamps CFLs and all appliances A-rated or better	LED lamps and A++ rated appliances throughout, and supply supplemented by solar photovoltaic (PV) system

Table 12.1 Standards for energy efficient lighting and appliances

Lights and appliances standards

Table 12.1 presents various standards for energy efficient lighting and appliances. EU Product Policy is to improve the efficiency of lighting installations across Europe by phasing out incandescent lamps completely, and replacing them with more efficient lamps – first with compact fluorescent lamps (CFLs) and then with light emitting diode (LED) lamps. Consequently most sizes of conventional tungsten lamps are now unavailable, and we can expect to see a progressive change of lighting in existing homes to CFLs and then to LED lamps. The range of available light fittings is expanding to accommodate both CFLs and LED lamps.

Figure 12.2 Even at a cost of £10 the compact fluorescent lamp saves seven times its cost over its life

Low energy lamps

Low energy lamps are a very cost effective investment. The extra cost of the lamp is paid for many times over during its life (see Figure 12.2). The latest LED lamps are even more efficient and longer-lived than the CFLs shown in Figure 12.2 and 12.3, although they are more costly to purchase.

CFLs are available for installation in existing fittings, but LED lamps (which use DC electricity) require completely new and different fittings incorporating transformers. Therefore CFLs are good 'quick fixes' while converting to LED lighting should always be considered as part of any major refurbishment project.

Figure 12.3 CFLs are available in many different shapes and sizes. Copyright Osram Sylvania and P.I.C. Corp

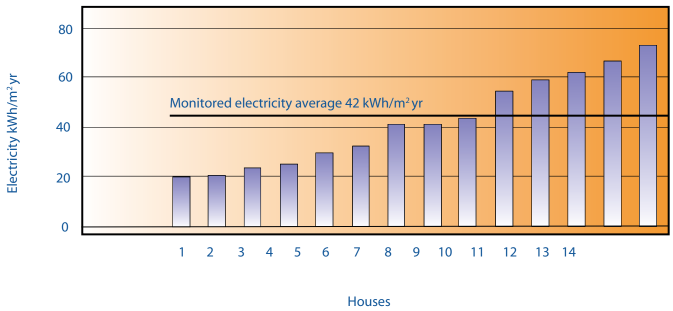


Figure 12.4 Monitored electricity use per square metre of floorspace, in similar houses

Luminous efficacy and colour temperature

The light output of a lamp, measured in lumens, can be compared with the power (Watts) used to run it in a measure called the 'luminous efficacy' (lumens/watt). Tungsten lamps have a poor luminous efficacy of around 12 lm/W. CFLs are much better at around 46 to 72 lm/W; fluorescent tubes are better again at 70 to 100 lm/W; light emitting diodes (LEDs) have an efficacy of 70 to 90 lm/W with recent claims of over 100 lm/W.

Colour temperature is important in a domestic setting: some lamps produce a very white light which is too harsh. CFLs with the Energy Efficiency Recommended label have minimum efficacies and specific colour temperatures.

Domestic appliances

Energy labelling of electrical appliances has been a major success in promoting energy efficiency over the past two decades. Awareness among consumers has increased but the main success has resulted from manufacturers vying for pole position in the market for efficient appliances. Such has been the success that many electrical goods are now on an A++ to G scale. Consumers now need to be aware that buying an A-rated appliance doesn't necessarily mean that it is the best available.

Electricity use in similar houses with different occupants can vary enormously. Figure 12.4 shows a range of over 3:1 in electricity use in similar houses. This suggests that there is a large potential for cutting electricity use by lifestyle changes.

Generating electricity

Electricity can be generated by photovoltaic panels (PV), CHP systems (see Chapter 10) and wind turbines.

Photovoltaics

PV panels use silicon cells (or other materials) to generate electricity from sunlight. The DC electricity produced by the PV array is converted to AC by an inverter and can then be used in the house or exported to the electricity grid. Electricity generated by domestic PV installations and exported to the grid qualifies for the Feed in Tariff (FIT), i.e. for payments significantly greater than the tariff the householder pays for electricity purchased from the grid.

As a general rule of thumb, a PV installation of 1 kW peak power will require a 7 m^2 array and generate approximately 750 kWh/year. PV cells are very sensitive to shading and orientation, so it is often difficult to identify sufficient well-oriented, unshaded roof (or another site adjacent to the house). To offset the electricity use in our three bedroom semi-detached house would require a PV array with an area of about 21 m^2 costing around £7,500. However, upgrading the house to energy efficient lighting and appliances throughout would halve the electricity use and thus halve the size and cost of the required PV installation, making this a more attractive and practical improvement measure.

Wind turbines

Small wind turbines attached to individual dwellings have been heavily promoted in recent years. However, the important thing to understand about wind power is that the power output from a wind turbine is proportional to the cube of the wind speed. So a halving of wind speed will result in a reduction of output by a factor of eight. A typical 'micro' wind turbine might be rated at 1,600 kWh/yr at an average wind speed of 12 m/s; however, the average wind speed in most of England is nearer 4 m/s, and in urban areas it is often less than 3 m/s. Halving the average wind speed to 6 m/s reduces the output of the turbine to 200 kWh/yr; halving it again to 3 m/s reduces the output to 25 kWh/yr (worth about £12). This illustrates why small, building-mounted wind turbines are not a cost effective improvement measure and are very unlikely to significantly offset the electricity demand of our homes.

However, large wind turbines on windy sites are an extremely cost effective way of producing low carbon electricity. Linking the house to a community wind turbine or to an off-site wind farm might be a very good way to reduce carbon emissions.

Green tariffs

Green tariffs offer the householder a convenient way of supporting suppliers of green electricity. However, not all green tariffs are the same. Some suppliers use only electricity from wind turbines and other zero carbon sources, while other green tariffs use the premium to augment development funds for green technologies. Care should be taken when selecting a green tariff, to ensure that the electricity to be purchased really will come from a low or zero carbon source. The energy regulator, Ofgem, operates an independent certification scheme to make green tariffs more transparent and to provide consumers with confidence that their green tariff is delivering positive environmental outcomes (see www.greenenergyscheme.org).

Watch points

- A unit of electricity costs approximately four times as much as a unit of mains gas, and involves more than twice as much carbon dioxide emission
- Modern LED lighting systems are many times more efficient than the now obsolete tungsten lamps that are installed in many existing homes, so replacement lighting is a very cost effective improvement measure
- Installing an electrical appliance with an A energy rating does not indicate that it is as efficient as possible – the rating band now goes up to A++
- Domestic solar photovoltaic (PV) systems are eligible for financial support from the Feed in Tariff
- Small domestic wind turbines are rarely cost effective, because average wind speeds are too low, especially in urban areas. Large-scale community wind turbines on windy sites are much more efficient and cost effective

If you make and implement a low carbon improvement plan for your home, there are some related issues that deserve consideration. These include the way the improved house is used and other aspects of the lifestyles of the occupants.

Using a low carbon home efficiently

There is little point in investing in expensive low carbon improvement measures if the house is not used in an efficient way. The intended carbon dioxide emissions savings will not be realised. Living in a low carbon home includes good housekeeping as well as using heating and hot water systems and domestic appliances efficiently. For example:

- Turning off lights in rooms that are unoccupied or where there is enough daylight
- Not leaving appliances such as televisions, computers and printers switched on, even in 'stand by' mode
- Not leaving chargers for mobile and cordless telephones, games consoles, etc., plugged in when they are not in use
- Ensuring that appliances such as washing machines have 'hot fill' connections and are not run part-loaded
- Reducing the duration of showers (perhaps by using a shower timer)
- Avoiding leaving taps running when washing up, shaving or cleaning teeth
- Setting the heating programmer to ensure that the heating is on only when it is needed
- Lowering the heating thermostat setting by one or two degrees and wearing warmer clothes

Modifying behaviour in this way may involve a culture change for some members of the household – particularly older persons who have become set in their ways and young people whose enthusiasms may lie elsewhere.

Display energy meters

It may be helpful to have a 'display energy meter' installed, to inform members of the household how much energy they are using. This is a device that is connected wirelessly to the incoming electricity supply and displays the amount of electricity that is being used in real time, as well as the amount and cost of electricity used to date. There are also display energy meters that monitor gas use, and some also display carbon dioxide emissions.

Beyond the home

UK carbon dioxide emissions amount to approximately ten tonnes per person per year, approximately one quarter of which is associated with energy use in the home. To set these emissions in context, Table 13.1 sets out typical levels of carbon dioxide emissions for an average family of four (two adults and two children).

Activity	Carbon Dioxide Emissions (tonnes/yr)
Home energy use	**6**
Family car (average size and mileage)	**4**
Second car (smaller, lower mileage)	**2**
Mediterranean holiday (by air)	**4**
Food (cultivation, harvesting, processing and distribution)	**7**

Table 13.1 Annual carbon dioxide emissions for a typical household

These figures suggest that other aspects of our lives can become 'low carbon' to complement our low carbon homes (and indeed that having a low carbon home would be a little pointless without them).

For example:

- Using a car that is as energy efficient as possible and driving it in an economical manner
- Reducing car mileage by walking, cycling or taking public transport instead and by making multi-purpose trips
- Reducing or eliminating flying and taking holidays in places that are accessible without the need to fly
- Growing some of our own food, obtaining other food from local sources and avoiding foods that have been imported from distant places
- Eating seasonal foods (fruits, vegetables and salad) as far as possible and avoiding foods that have been highly processed, chilled or frozen for long periods, or excessively packaged
- Reducing waste, reusing it wherever possible, then recycling as much as possible, to provide fuel (in some areas) and to minimise the carbon dioxide emissions associated with manufacturing new products

These changes in behaviour are likely to become much more commonplace in the coming years, alongside our low carbon homes, as our communities begin to meet the twin challenges of fossil fuel depletion and climate change.

Appendices

Case Study 1:

Knauf Insulation and
St Vincent's Housing Association
Cosy Home

Case Study 2:

Baxi Group
Baxi Bioflo Installation for Dumfries and Galloway Housing Partnership

Case Study 3:

Kingspan
Low Energy Solid Wall Refurbishment, Burnley

Case Study 4:

Ecospheric
Chorlton EcoHome

Case Study 5:

Rockwool
Dee Cottages, Flintshire

Case Study 6:

Retrofit for the Future
Hanley, Stoke-On-Trent

Case Study 7:

Saint-Gobain Isover
Optima Internal Wall Insulation System Installation in Bolton

Case Study 8:

Elmwood Avenue SuperHome
Chester

MEASURES:

Internal wall insulation, boiler replacement, passive flue gas heat recovery system, air-source heat pump, heat recovery ventilation unit, solar PV

WHAT WAS ACHIEVED:

- SAP rating increased from 64 (D) to 87 (B)
- Reduction in fuel use from 320 to 59 $kWh/m^2/yr$
- Reduction in fuel costs from £883 to £232 per yr
- Reduction in CO_2 from 5,200 to 1,900 kg/yr

Actual data

CAPITAL COST	DISRUPTION
£ £ £ £ £	⚒ ⚒ ⚒ ⚒ ⚒

St Vincent's Cosy Home

CASE STUDY 1:

Knauf Insulation and St Vincent's Housing Association

Cosy Home

The Cosy Home project saw the retrofit of a pre-1919 hard-to-treat terrace property using a fabric first approach to bring it up to 21st century standards, with affordable heating, hot water and lighting. The Cosy Home acts as a learning centre for the community, helping people to identify ways they can save energy and money in their own homes. The project was completed over a six-week period.

The following measures were installed:

Building fabric

Knauf Insulation's ThermoShell® Internal Wall Insulation (IWI) system was installed in the Cosy Home, enabling St Vincent's to fulfil their aim of keeping the façade of the house the same as surrounding properties.

The ThermoShell® system has been developed specifically as an effective solution to whole-house low energy refurbishments, delivering exceptional thermal performance and comfort through a straightforward and easy installation process. For this project, St Vincent's chose to double the thickness of the internal wall insulation to give an external wall U value of 0.20 Wm^2K.

The ThermoShell® system incorporates Earthwool EcoBatts – high performance, water repellent glass mineral wool slabs that are friction fitted between EcoStuds to completely fill the available space. This delivers a range of benefits over systems that have to be more accurately cut and installed to avoid the potential to cause air leakage. At the Cosy Home, air tightness was improved from 11.59 $m^3/hr/m^2$ @ 50 Pa to 5.86 $m^3/hr/m^2$ @ 50 Pa.

Overall, the ThermoShell® IWI system is almost 13% more thermally efficient than a timber stud system of the same thickness. The use of the thermally engineered insulated studs eliminates the thermal bridging issue associated with traditional systems incorporating timber and metal studs.

Ventilation

The Villavent VR 300 ECV/B heat recovery system replaces stale damp air with fresh, warmed air, recovering 60-70% of the heat normally lost through trickle vents and other breakout points in the building structure.

Heating and hot water

The inefficient gas boiler was replaced with a condensing combination boiler with passive flue gas heat recovery.

To test and showcase the technology, a Daikin Altherma Monobloc air-source heat pump was also installed at the Cosy Home, though this would not usually be required alongside an efficient gas boiler.

How disruptive was the work?

Installing internal wall insulation can be perceived as being fairly disruptive. However, if it is planned well, disturbances can be kept to a minimum. Many IWI installations are carried out in occupied properties, although in this case the property was vacant during the retrofit works. The ThermoShell® insulation system can be installed on a room-by-room basis, which means it can be installed with residents remaining in the home.

A key trigger point for installing insulation is when new bathrooms or kitchens are fitted. Usually these projects require the rooms to be stripped back to the masonry shell, which presents an ideal opportunity to thermally upgrade the walls. Boiler replacements, cosmetic décor upgrades and property vacancies are also good opportunities.

Costs and funding

Total cost for all measures was just over £24,000.

St Vincent's received funding from LEAF (Local Energy Assessment Fund) and a grant of £6,500 to carry out the project.

For more information contact:

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The ThermoShell® IWI system, showing the Earthwool EcoBatts and EcoStuds

MEASURES:	
Baxi Bioflo boilers, solar hot water systems, fabric and loft insulation measures	
WHAT WAS ACHIEVED:	
• EPC rating improved from band E to band C • Between £20 and £160 monthly household energy savings *Actual data*	
CAPITAL COST	**DISRUPTION**
£ £ £ £	🛠 🛠 🛠

Properties after works

CASE STUDY 2:

Baxi Group

Baxi Bioflo Installation for Dumfries and Galloway Housing Partnership

Prior to improvement works these seventeen properties managed by Dumfries and Galloway Housing Partnership were heated inefficiently and expensively using electric storage heaters and solid-fuel fires. High energy costs coupled with high rural living and travel costs were driving some tenants into fuel poverty.
The properties are a mix of one, two and three bedroom terraced and semi-detached homes in a semi-rural location.

The project team worked with individual tenants to help them choose an appropriate, efficient and affordable renewable heating system for their home, which would suit their lifestyle and their heating and hot water needs.

The following measures were installed:

Heating

Five households chose to have a Baxi Bioflo biomass boiler installed. The Bioflo is a freestanding 12 kW system boiler that provides clean, sustainable 'carbon neutral' heating and hot water, all year round.

Fully modulated for maximum efficiency, the manual feed pellet burner is compact and stylish and ideal for smaller properties.

Hot water

To supplement the hot water provision, solar hot water systems were fitted alongside the Bioflo boilers. In the summer, solar thermal systems can supply most of a home's hot water. Over the year, a well-designed solar package provides approximately 50% of the annual domestic hot water demand.

Building fabric

Fabric and loft insulation was installed to make the homes more energy efficient before the new heating systems were fitted.

Project successes

The renewable solutions installed have helped improve the energy efficiency ratings of the five properties, taking them from EPC band E to band C. More importantly from the tenants' perspective, the boilers save them between £20 and £160 per month on their energy costs, depending on the installation and other efficiency measures installed.

As biomass is considered a 'carbon neutral' energy source, the Baxi Bioflo boilers provide significant carbon dioxide emission reductions compared to the previous high carbon heating systems, whilst delivering improvements in energy efficiency and occupant comfort.

Baxi Bioflo boiler installed

Lessons learned

Rather than forcing new technology on them, tenants were encouraged to select a suitable renewable solution for themselves based on their home and lifestyle. This approach ensured that tenants who might otherwise be reluctant to embrace renewable technologies felt empowered and bought in to the solution, which helped ensure their commitment to its successful operation.

Potential for replication

There is huge potential to replicate this type of project elsewhere, particularly in rural areas that are not connected to the mains gas, where fuel poverty is often an issue.

Costs and funding

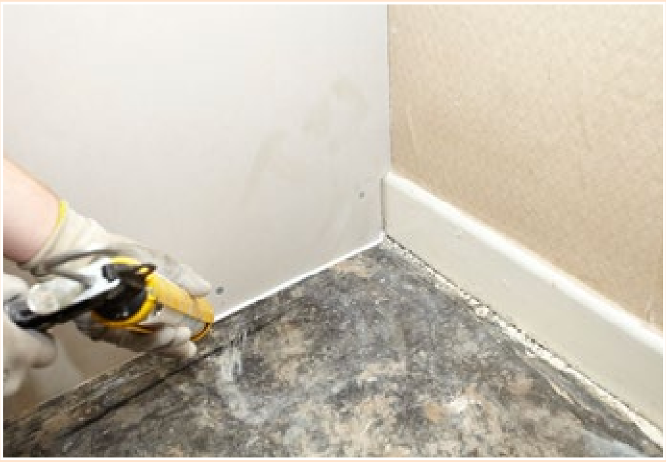
Costs for the Bioflo boiler start from around £7,600 plus VAT and installation.

Dumfries and Galloway Housing Partnership secured £175,000 in funding from the government's Renewable Heat Premium Payment scheme to support this project, which helped to bring down the cost and the initial outlay required by the housing association.

For more information contact:

baxi@bright-consultancy.co.uk

MEASURES:	
Kingspan Kooltherm K18 Insulated Dry-Lining System	
WHAT WAS ACHIEVED:	
• SAP rating increased from 50 (E) to 66 (D) • Reduction in fuel use from 149 to 82 $kWh/m^2/yr$ • Reduction in fuel cost from £951 to £527 per yr • Reduction in CO_2 emissions from 3,793 to 2,099 kg/yr *Actual data*	
CAPITAL COST	**DISRUPTION**
£ £ £ £	🛠 🛠 🛠 🛠 🛠



Installation of Kooltherm IWI

Property after retrofit works

CASE STUDY 3:

Kingspan

Low Energy Solid Wall Refurbishment, Burnley

The Kingspan Kooltherm K18 Insulated Dry-Lining System was installed in a pre-1900s, stone-built, mid-terrace dwelling in Burnley, Lancashire, as part of a larger study to quantify the energy efficiency benefits that result from solid wall insulation.

The primary objectives behind Kingspan's involvement in the study were to determine the real impact of the Kingspan Kooltherm Internal Wall Insulation System on the following issues: wall U values; primary space heating energy use and associated carbon dioxide emissions and costs; air-permeability; heating patterns; and indoor environmental quality.

Kingspan Kooltherm K18 Insulated Plasterboard was mechanically fixed to 25 x 50 mm pre-treated timber battens lined with 100 mm damp-proof course strips on the 500 mm thick internal stone walls exposed to the outdoors. A 92.5 mm product thickness was selected based upon the owners' space requirements.

To enable the system to perform as intended, the ancillary fixing components were chosen to satisfy stringent performance specification requirements defined by Kingspan Insulation. The works were carried out by operatives experienced in installing insulated dry-lining to ensure that required standards of workmanship were achieved.

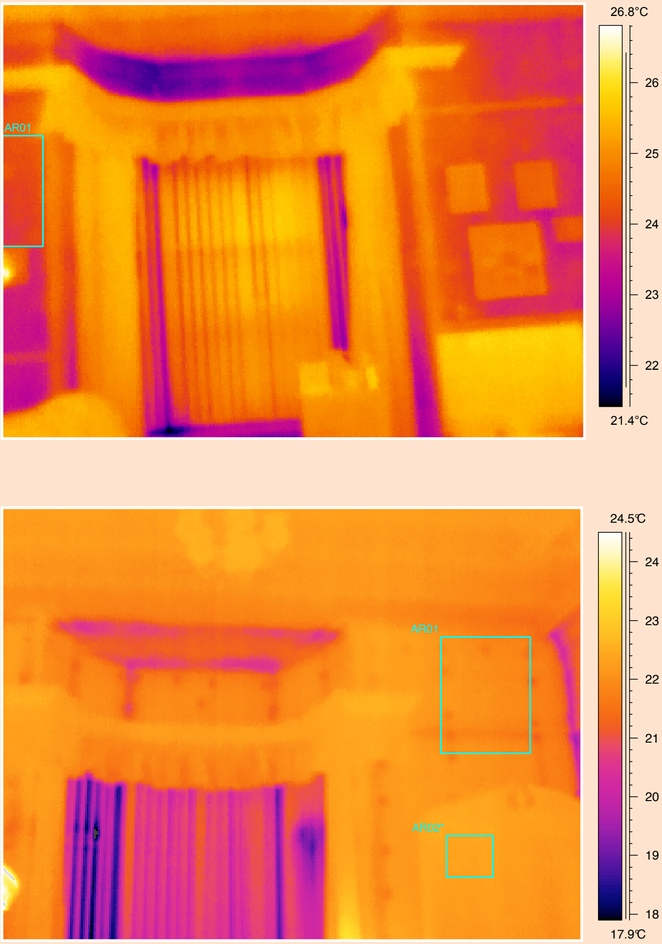
How disruptive was the work?

As with any retrofit works, the homeowners, a retired couple in their mid-sixties, experienced a degree of disruption, particularly as they preferred to remain in the property for the two week duration of the project. Precautionary measures were taken to minimise the impact of any disturbances, including the use of sheeting to protect soft furnishings, and execution of the works on a room-by-room basis. To enable living arrangements to continue as normally as possible, materials were temporarily stored outdoors, clear of the ground and protected from the weather.

Project successes

Empirical data derived from the monitoring and measuring of the property's performance revealed an 89% improvement in wall U value and a 45% decrease in normalised annual gas consumption for primary space heating (and correspondingly, carbon dioxide emissions and heating bills). Pre- and post-works pressure tests revealed a 57% improvement in air tightness.

Thermal images comparing different parts of the property before and after being insulated illustrate the positive effect of the internal wall insulation and proper installation practice at junction locations. The cold regions appear to have been largely eliminated and the overall warmth of the different indoor areas appears to have improved significantly.



Thermal image of bay window pre and post insulation

A change in heating pattern indicates that the increased thermal efficiency of the building envelope has enhanced the ability of the property to retain heat, enabling a reduction in both the intensity and duration of heating events to achieve the desired temperature, particularly in the evening.

Lessons learned

The internal wall insulation works could have been coordinated as part of a larger programme of renovation, maintenance and improvement. For instance, had the roofs, ceilings (including that over the bay window) and floors also been insulated in conjunction with the walls, a greater improvement in air tightness and thermal bridging may have been realised.

Addressing issues such as the ingress of cold air around the front door area may have also made a noticeable difference to the building's energy performance.

Costs and funding

Supply and installation of the system, as well as the additional labour for the removal and reinstatement of the furniture, fixtures and fittings in the kitchen and the cornicing in the lounge, cost approximately £7,640.

It must be noted, however, that these works were part of a larger research programme and the material and labour element is extracted from the overall project cost comprising: the monitoring, measuring and recording of the property's energy performance; and the analysis of the resultant data.

For more information contact:

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MEASURES:

Condensing boiler, draught-proofing, external wall insulation, floor insulation, low energy appliances, low energy lighting, MVHR, roof insulation, solar PV, solar water heating, triple glazing, water saving devices, two wood burning stoves

WHAT WAS ACHIEVED:

- Current energy bills for the property are around £250 a year (excluding income from the Feed in Tariff and projected income from the Renewable Heat Incentive)
- Based on actual usage per square metre the energy rating is equivalent to SAP 88

CAPITAL COST	DISRUPTION
£ £ £ £ £	🛠 🛠 🛠 🛠 🛠

The Chorlton EcoHome

CASE STUDY 4:

Ecospheric

Chorlton EcoHome

This 1909 semi-detached solid wall home, situated in a conservation area in South Manchester, showcases over 100 energy saving features. Designed as a show home for domestic retrofit consultancy Ecospheric, the Chorlton EcoHome incorporates a number of pioneering technologies and systems.

Initial renovation work took place over fourteen months from 2009. Since then, additional measures have been installed and systems further developed as opportunities have arisen.

Building fabric

Hybrid Spacetherm, Kooltherm K5 EWB phenolic foam external insulation provides a U value of 0.263 with just 50 mm of insulation. This innovative hybrid system allows render to be directly applied to external walls. 300 mm organically bound glass fibre is installed in the roof (U value 0.123) and 260 mm glass wool insulation in the floor (U value 0.128). The large open plan space at the rear of the property incorporates passive solar design techniques to capture solar energy, store it and distribute it throughout the home, throughout the day.

Ventilation

The Passivent hybrid ventilation system combines natural passive stack ventilation with mechanical heat recovery available as necessary to reduce annual running costs.

The system predominantly uses natural passive stack ventilation, which does not require any active components but relies on the stack effect of warm air rising to ventilate stale air out of the property. Humidity sensitive extracts in each room sense when additional ventilation is required and activate the MVHR. When the external temperature falls below 9°C, the system switches to heat recovery mode, switching air transfer via the heat exchanger, transmitting warmth from the exhaust air to the cooler incoming air.

Hot water and electric power

The property also features a hybrid Photovoltaic Thermal (PVT) system with battery storage, commissioned through a partnership between Ecospheric and Newform Energy. Normal photovoltaics generally decrease in efficiency as the panels heat up during the day; the hybrid system pumps cool water through the panels, which not only cools them to increase their efficiency, but also creates hot water as a by-product. Battery storage means that less energy is sent back to the grid, which is particularly important as, typically, most energy is generated during the day but utilised in the evening.

With the electrical storage and energy management system in place, the system utilises over 80% of the electricity generated on site (compared to a typical 15%).

Ventilation ducting in loft

Solar system and passive ventilation chimney stack

Heating

The home is heated by two highly efficient wood burning stoves with direct air-feeds (a Xeoos Twinfire and a Burley Debdale).

Lessons learned

In developing a number of innovative systems and incorporating technologies for testing and demonstration purposes, there has been considerable learning involved in the retrofit of this property.

If specifying the ventilation system again, Ecospheric would take a different approach to commissioning, they would use a device with a lower specific fan power, and would design the layout of the pipe network differently.

Although hybrid solar systems are now fairly well established, integrating the system with the energy management system added another layer of complexity, particularly around compatibility of the power optimisers.

Costs and funding

Ecospheric estimates that whole-house renovation and construction of the new extension to this standard would normally cost around £125,000. Actual costs, including some systems incorporated for demonstration purposes only and development of some 'world first' hybrid systems, were closer to £175,000.

The ventilation system would normally cost £5,500, including design, supply and installation.

The integrated solar system, not including the energy management system, cost around £10,000.

For more information contact:

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Ecospheric
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MEASURES:	
Brickshield 110 mm exterior wall insulation	
WHAT WAS ACHIEVED:	
• U value reduced from 2.1 to 0.3	
CAPITAL COST	**DISRUPTION**
£ £ £ £	⚒ ⚒ ⚒

Work in progress

CASE STUDY 5:

Rockwool

Dee Cottages, Flintshire

These forty-two cottages in Flintshire, providing supported housing for vulnerable and elderly residents, were refurbished to improve energy efficiency whilst providing an exterior finish that matched the distinctive brickwork in the area, an important aspect of the local heritage.

The following measures were installed:

Rockwool Brickshield was chosen as the external wall insulation system to meet both the thermal and the aesthetic requirements of the project.

Rockwool Brickshield is the first BBA-approved insulated external wall cladding system with a genuine brick finish. Once the property had been 'wrapped' in a thermal layer of stone mineral wool, a layer of 'brick slips' – 20 mm deep bricks – was applied to the outer surface to create the brick wall finish. For this project, the brick slips were chosen and applied to match the distinctive pattern of black crosses on the original buildings, ensuring the newly insulated properties blended perfectly with the area.

Design and detailing support was provided by Rockwool's in-house architectural design consultants to minimise thermal bridging. New window cills were specifically made to match the existing detailing of the cottages and the brick slip pistols over the window and door heads were installed in soldier course to recreate brick lintel detailing. Treated timber Pattress blocks were installed at a number of properties to allow hanging baskets and washing lines to be fixed in the same position without disturbing the insulation.

Project successes

Rockwool worked in collaboration with a locally based contractor to develop a bespoke logistics solution to overcome site access difficulties.

As well as improving energy efficiency, the acoustic properties of the stone wool have helped to reduce the effects of external noise.

Lessons learned

Renovating forty-two properties required a substantial amount of materials on site. To minimise disruption along the narrow lane access, the Rhyl based contractor managed the loads at their site and decanted deliveries into smaller vehicles as required.

Potential for replication

Bespoke finishes for external wall insulation systems can help to improve the energy efficiency of houses while maintaining local heritage, meaning there is great potential for this type of solution for solid wall properties across the UK.

Dee Cottages post works

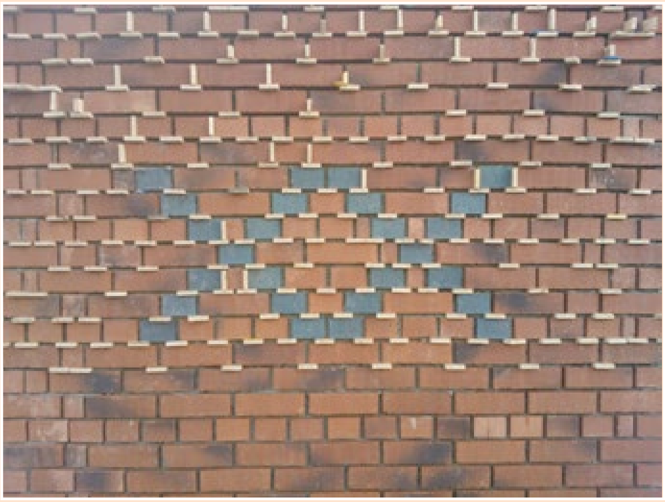
How disruptive was the work?

Although external wall insulation involves a degree of disruption, the project was carried out without scaffolding to ensure this was minimised. Richard Evans, project manager, said: "As we were working with elderly people, we needed to make sure access to the houses was kept completely clear. To keep disruption to an absolute minimum, we decided not to use any scaffolding during the installations and used cherry pickers instead."

Since the work was carried out on the outside of the property, the residents did not have to be decanted for the work to take place.

Costs and funding

The total project cost was £2.5 million, and the insulation costs were just over £150,000. The project was 100% funded through the Community Energy Savings Programme (CESP).



Brick slip installation with spacers

For more information contact:

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MEASURES:	
Sheep's wool insulation with wood fibre board to internal walls, sheep's wool roof insulation, wood fibre board external wall insulation, MVHR, Rotex gas boiler with integrated solar thermal system	
WHAT WAS ACHIEVED:	
• SAP rating improved from 47 (E) to 90 (B) • Fuel use reduced from 765 to 266 kWh/m^2/yr • CO_2 emissions reduced from 140 to 57 kg/m^2/yr *Actual data*	
CAPITAL COST	**DISRUPTION**
£ £ £ £ £	🛠 🛠 🛠 🛠 🛠

Property before works

CASE STUDY 6:

Retrofit for the Future

Hanley, Stoke-On-Trent

The whole-house retrofit of this 19th century terraced house was achieved through detailed application of passivhaus principles, focussing on fabric insulation, excellent air tightness, whole-house heat recovery ventilation and minimal space heating requirement.

Renovated as part of the Retrofit for the Future competition, the aim for this project was to achieve an 80% reduction in carbon dioxide emissions over average performance for a house of this type.

The existing building was carefully surveyed, and proposed fabric measures and services analysed using the Passive House Planning Package (PHPP), which allows designers to thoroughly test assumptions. This is a small terrace house, (area 64 m^2) with a poor orientation for passive solar gain, so insulation was the main focus.

The following measures were installed:

Building fabric

Sheep's wool insulation with wood fibre board and lime plaster was used to internally insulate walls (U value 0.2 Wm^2/K). Sheep's wool was also used in the roof of the main property at ceiling level (U value 0.1 Wm^2/K). The new rear extension of thin-joint clay blockwork was externally insulated with wood fibre board (U value 0.15 Wm^2/K).

Sheep's wool and wood fibre insulation were specified for their low embodied energy and hygroscopic qualities (allowing them to absorb, store and release moisture, naturally controlling condensation levels). Natural materials were specified where appropriate to retain a moisture permeable construction and to protect the existing fabric.

Thermal bridge detailing included insulation being taken down well below ground level and rebated insulation to windows and external doors.

Extensive work was undertaken to improve air tightness. All new work was carefully detailed, existing walls were parge coated before insulation was fitted, joists were taped and plaster taken between the joists at first floor level, grommets were used for all cabling penetrations, and intelligent airtight membranes that can alter vapour permeability depending on conditions to reduce the risk of condensation were incorporated into ceilings and external walls. Unfortunately, the air tightness target of 1 ach was not achieved, seemingly a result of problems at the party wall, which is only half a brick thick. The final air tightness test result was 4.27 m^3/m^2/hr, with the main losses to the next door property.

Ventilation

A Maico mechanical ventilation heat recovery unit was carefully designed and installed to achieve a quiet and reliable performance. An initial problem with noise on the maximum setting was resolved. Controls, installed in the kitchen, are simple to understand and the residents have found that the system works well.

Rear of property after completion

Heating and hot water

A Rotex gas boiler with integrated solar thermal system and a small wet radiator system meet all of the homes heating and hot water needs.

Project successes

The design and construction team worked well together, taking care to understand the design approach and targets. Learning from this project was substantial for many involved.

Outcomes have been good, carbon dioxide emissions have been reduced, a high level of comfort, and a stable internal environment and temperature have been achieved.

Lessons learned

Specification of services needs to take into account availability and complexity of maintenance. Maintenance of the Rotex gas boiler has been problematic in this case as the housing association's maintenance contractor was not familiar with the product. Some of the products used in the project were imported, which increased costs and meant it was difficult to source the high standard of installation required.

How disruptive was the work?

The existing house was in a poor state of repair. Work included rebuilding the rear extension, installing a new floor and completely replastering, rewiring and replumbing, so the building was not occupied during the works.

Costs and funding

The project was funded by the Retrofit for the Future competition. Funding of up to £150,000 including fees and VAT was awarded by the Technology Strategy Board to eighty-six retrofit projects to encourage innovation and explore what level of carbon dioxide reduction could be achieved in the existing housing stock using current technologies and practices.

Project team

Owner: Sanctuary Group; Architects: Anne Thorne Architects LLP; Engineers: King Shaw; Energy Consultants: Eight Associates; Contractors: Seddons; Quantity Surveyor: McBains Cooper; Monitoring: RSK

For more information contact:

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MEASURES:	
Isover Optima Internal Wall Insulation	
WHAT WAS ACHIEVED:	
• A reduction in fuel use from 16,946 to 13,341 kWh/yr • A reduction in fuel costs from £786 to £619 per year • A reduction in CO_2 emissions from 3,315 to 2,468 kg/yr	
CAPITAL COST	**DISRUPTION**
£ £ £ £	🛠 🛠 🛠 🛠 🛠

The Optima IWI metal framework

CASE STUDY 7:

Saint-Gobain Isover

Optima Internal Wall Insulation System Installation in Bolton

Saint-Gobain Isover installed its Optima Internal Wall Insulation (IWI) system into a natural stone construction, three bedroom family home in Bolton, Greater Manchester.

The work was undertaken as part of a trial to measure the effectiveness of solid wall insulation systems alone, so no other fabric or energy saving measures were installed. Double glazing is installed throughout and a single storey extension had recently been constructed at the rear of the house.

The external walls of the property were fitted with the Isover Optima IWI system in order to enhance the thermal performance of the wall structure. This saw an average reduction in wall U value from 1.13 W/m^{2}K pre-installation to 0.18 post installation, leading to an approximate annual reduction in heating fuel demand of 26% and a consequent reduction in carbon dioxide emissions.

Although no other draught-—proofing or air tightness measures were installed, an increase in air tightness was observed post installation of approximately 1 m^3/m^2/hr.

The Isover Optima IWI system utilises a metal framework that is independent of the existing wall structure. This framework forms a cavity that is insulated with a consistent layer of factory manufactured Isover glass wool insulation. The only connection between the metal framework and existing wall (bridging the insulation layer) is a fibre reinforced polyamide bracket, which has a very low thermal conductivity, effectively removing any repeatable thermal bridge whilst retaining impact requirements. All other potential thermal bridging aspects such as window/ door reveals, element junctions and support requirements were installed in line with Isover's installer instruction, that reduces the effect of thermal bridging as far as practically possible.

Project successes

This trial was the first full-dwelling installation of the Isover Optima IWI system in the UK by UK based trades. It proved to be a successful system that had the adaptability to deal with all the application issues, irregularities and problems associated with retrofitting old properties. Feedback from the contractors was extremely positive.

Challenges

The property had a large number of relatively small rooms spread over three floors which meant that there was a lot of detailing required between the lining system and associated elements such as internal partition walls, separating walls, partition floors, ground floors, etc.

Access at the property was also limited, which could have been problematic for systems made up of large components.

Installation of the Optima system

Lessons learned

Good installer training is extremely important. Ensuring training results in an understanding of specific system requirements, as well as general knowledge pertaining to thermal lining and issues such as thermal bridging and moisture, is key. This allows the installer to make the right decision when faced with non-typical applications.

Potential for replication

The total system has been designed to be as user friendly and adaptable as possible, allowing it to be applied on a large scale across the wider housing stock. The system is already used extensively throughout Europe.

How disruptive was the work?

The nature of the system allows for room-by-room installation, enabling households to apply lining systems in stages and in line with allowable funds.

Installation involved trades working internally in all areas of the dwelling, which meant that all furniture had to be moved from the working area (approximately 1.5 m from the external walls), as walls were lined, skimmed and redecorated. Although this sounds very disruptive, the occupants remained in the dwelling whilst the installation was carried out. The contractors were experienced with this kind of work and carried out all work behind a temporary curtain to control mess.

Costs and funding

The total cost of the complete system application (including finished plaster skim coat, external application of Isover Protect, complete lining to all suitable walls, window reveal application, existing element detailing and all labour and fees), was approximately £7,500.

For more information contact:

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Project Manager
Saint-Gobain Isover UK
0115 969 8009
tom.cox@saint-gobain.com

MEASURES:	
Cavity wall insulation, internal wall insulation, loft insulation, gas condensing boiler, solar thermal, solar PV, wood burner	
WHAT WAS ACHIEVED:	
Actual energy usage: • Electricity: 20 kWh/m²/yr • Gas : 57 kWh/m²/yr A full energy survey has not been carried out *Actual data (2013)*	
CAPITAL COST	**DISRUPTION**
£ £ £ £ £	🛠 🛠 🛠 🛠 🛠

Elmwood Avenue SuperHome

CASE STUDY 8:

Elmwood Avenue SuperHome

Chester

When the owners purchased this two storey, semi-detached 1930s property, they intended to extend the existing building incorporating energy saving measures to create a light and warm home for their growing family. Since carrying out their initial improvement work over a decade ago, they have taken advantage of various opportunities to further reduce their energy use.

The following measures have been installed:

Heating and hot water

Space heating is provided by a high efficiency, gas condensing boiler with portable wireless room thermostat. 95% of the radiators are fitted with TRVs.

Two Solartwin solar thermal panels are installed on the south facing roof, providing virtually all the family's hot water needs in the summer. Unlike most solar thermal systems that use a heat exchanger, with the Solartwin system the water that passes through the panels is the water that comes out of the taps. The technology also incorporates a small solar PV unit in the panel to drive the pump.

The homeowners have recently installed a 5 kW Town & Country 'Little Thurlow' wood burner. Using locally sourced wood, they can now heat the kitchen area without needing to heat the rest of the house.

Building fabric

All cavity walls are filled with either polystyrene bead or mineral wool insulation. Walls between the house and the unheated garage were insulated internally with 50 mm polystyrene board. 75 mm polystyrene board was also incorporated under the new solid floor in the conservatory and extension.

The loft has been insulated with 250 mm of Warmcell 100 loose-fill cellulose between the extended joists and 50 mm Knauf Space Board, an extruded polystyrene insulation board, fitted above the joists. The Space Board, combined with chipboard decking, provides a solid storage deck covering around two thirds of the loft area.

Electric power

High capital costs prevented the homeowners incorporating solar PV when they first renovated the property. However, in 2009, grant funding and the imminent introduction of the Feed in Tariff meant that the system became much more affordable and they were able to install a 1.25 kW peak system made up of seven 175 W panels.

Project successes

After the first year, the family found that their total energy bill was slightly less than at their previous home, despite their new home being almost twice the size. The solar thermal system has led to substantial savings as gas usage during summer is extremely low.

Lessons learned

Many of the energy saving measures installed have required the occupants to adapt their behaviour slightly, for example, using electrical appliances during the day when the solar PV is generating power, using hot water in the evening after it's been heated by the sun during the day, and ensuring that the back-up hot water boiler only comes on after sunset to gain maximum benefit from the solar system.

When the initial solar thermal panels were installed they were positioned in the centre of the roof which meant that the size of the later solar PV installation was limited to the remaining available roof area. The impact on future opportunities for improvement should always be considered when installing measures, even in a case like this where it was over ten years between installations.

Potential for replication

Implementing a whole-house package of energy saving measures when undertaking large scale renovations and adding further improvements as opportunities arise, is an approach that makes sense for many homeowners. Installing fabric measures and new heating systems is less disruptive when major works are already underway and it is usually much cheaper as it means that enabling works and redecoration are only required once.

Costs and funding

The major works, including the extension, solar thermal, heating system, and most of the double glazing, cost around £70,000 (1999/2000).

The solar PV cost £7,365, part grant-funded through the Low Carbon Buildings Fund (2009).

The wood burner, including supply, fitting of the chimney liner and knocking out space to house the stove, cost around £2,000 (2012).

For more information contact:

The property is part of the SuperHomes network and is open to the public in September. For more information, and to get in touch with the homeowners, see www.superhomes.org.uk.

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