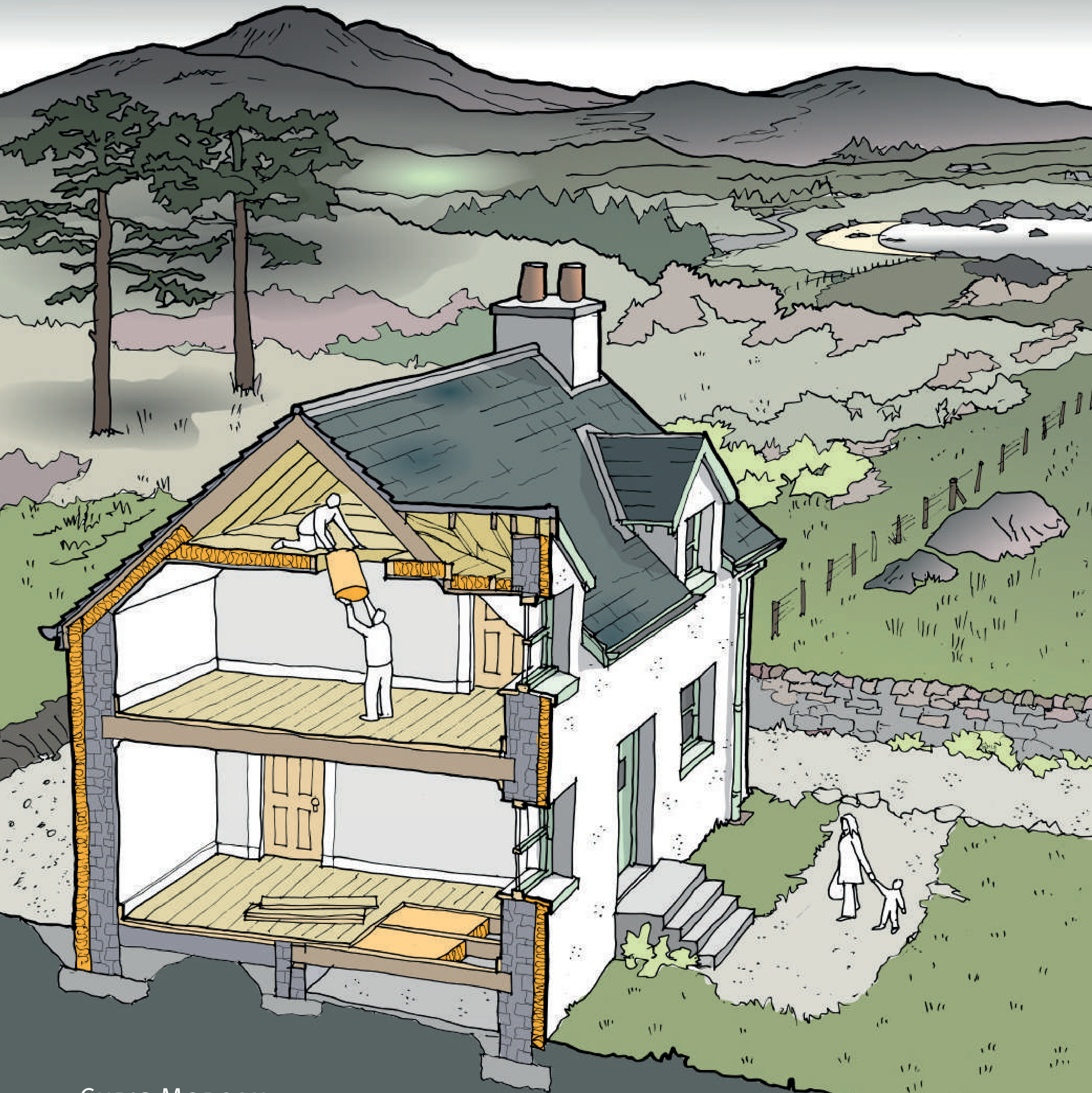
SUSTAINABLE RENOVATION

IMPROVING HOMES FOR ENERGY, HEALTH AND ENVIRONMENT



CHRIS MORGAN

A SEDA GUIDE TO BEST PRACTICE, FUNDED BY THE PEBBLE TRUST

The Pebble Trust

John Gilbert ARCHITECTS

SEDA Scottish Ecological Design Association

HISTORIC ENVIRONMENT SCOTLAND

HAB-LAB

While we have made every effort to ensure that the information contained within this guide is correct, John Gilbert Architects cannot take responsibility for errors or omissions contained within it. You should take professional advice specifically for your project

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This publication was initiated and largely funded by The Pebble Trust, a Scottish charity based in the Highlands. It has a vision of a more sustainable, fair, and low-carbon society, where constraints on fossil fuels lead to a more localised economy with stronger, more resilient communities, and where human activities take account of climate change and the wider environment. The Trust supports projects in the Highlands and Islands of Scotland while also considering exceptional projects that have an impact across the whole of Scotland. The website address is www.thepebbletrust.org

Aware of the need to increase the impact of this work, The Pebble Trust agreed to co-host the publication with Scottish Ecological Design Association (SEDA) which has an existing portfolio of guidance on sustainable design. SEDA provided some funding for the project, and this guide can be found among others at their website: www.seda.uk.net

The guide was largely conceived and written by Chris Morgan, Director at John Gilbert Architects in Glasgow. Chris is a registered and chartered architect, a certified Passivhaus designer, and additionally certified in Building Biology (Buildings and Health) and Permaculture. He was chair of SEDA and is one of three architects in Scotland accredited to 'Advanced' level in Sustainable Design. Chris is a design review panellist for Architecture + Design Scotland.

A small group of experts was asked to act as an advisory board and has given a good deal of their time to help advise on, and shape the guidance. These are:

Pebble Trust Steering Group: Penny Edwards, Martin Sherring

Existing Homes Alliance: Elizabeth Leighton (who also wrote the chapter on recent legislation)

SEDA: Richard Atkins

Historic Environment Scotland: Roger Curtis

Sustainable Traditional Buildings Alliance: Neil May

Energy Agency: Liz Marquis

We are very grateful to the Estate of Norman Thelwell for permission to reproduce a few of his cartoons.

Brigit Luffingham and Gillies MacPhail of John Gilbert Architects coordinated the layout and produced the detail drawings, respectively. Lina Khairy co-ordinated the layout for the second edition.

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Foreword to the Second Edition

The Pebble Trust is delighted, with this book, to have played a small part in improving the quality of home renovation in the UK, and in particular in Scotland. The need to improve the energy-efficiency of the UK's housing stock has been recognised for many years, and there has been some progress in the cheap and easy ways to add insulation—mainly focused on roofs and cavity walls—but efforts to do more have failed to live up to expectations.

At the same time, with home heating accounting for around 14% of the UK's greenhouse gas emissions, it is increasingly clear that we need to wean ourselves off our use of fossil fuels to heat our homes, and that this will mostly mean switching to electricity from renewables and nuclear power. But that also brings its own problems as we can see from the controversies surrounding on-shore wind farms, hydro schemes and new nuclear reactors, and from the higher cost of electricity compared with gas. There are other options involving international energy trading but recent events in Ukraine show the dangers of relying on foreign powers for essential supplies. So, given the problems of producing green electricity, it's essential that we find ways to use less of it, and that is the reason for a renewed political focus on domestic retrofit. There are, however, wider potential benefits from insulating our homes—in reducing fuel poverty, improving respiratory health and making it easier for people to keep warm and comfortable—and we need to keep all these in mind.

Whilst we wholeheartedly welcome the drive to improve the fabric of our homes, we see a serious danger that changes will be driven purely by cost and modelled heat savings. We are already seeing examples of how that can lead to poor internal air quality, damage to the structures we are trying to improve, and actual heat savings which are much more modest than suggested by the models. The aim of this book is to encourage a more holistic approach—looking beyond the immediate cost of retrofit to the longer-term value for money, and beyond energy efficiency to a wider range of benefits.

We have been encouraged to update the book by its popularity with professionals, homeowners and students, both as a hard copy and as a digital version. This second edition reflects changes in the regulatory environment in the five years since the first edition was written in 2018 and updates the indicative costs of energy—although costs are changing on a monthly basis at present, so readers will need to exercise some caution in interpreting those parts of the book. We have also added a section about climate adaptation, extended the section on timber-framed walls, added a short section on making homes "heat pump ready", and included some comments on scaling retrofit in the future, along with other minor tweaks.

The fundamental message remains unchanged—quality renovation, taking a holistic approach, can make our homes better both for the planet and for the wellbeing and health of their occupants.

The Pebble Trust trustees: Jo Cumming, Penny Edwards, Nicholas Gubbins, Arabella Kennard, Catriona Mallows, Sarah Nicholas, Martin Sherring, Neil Sutherland and Emma Whitham.

March 2023

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1. INTRODUCTION

1.1 Aim of This Guide

The aim of this guide is to help everyone involved in the renovation of homes and housing and to improve the work undertaken. By improve, we mean to increase the efficacy of efforts to reduce energy consumption but also to reduce the problems that this work sometimes causes

The timing is important because the Scottish Government is investing heavily in retrofit and envisages a Scotland where we are all living in nearly zero carbon homes by 2045. Regulation has been changed to ensure all properties will be included in this vision, but there are real challenges ahead, particularly in relation to historic properties. A huge amount of effort and money will be spent on renovating homes across Scotland in the next few years. The potential to improve energy efficiency and reduce fuel poverty is significant, but this guide sets out a number of aspects we believe need to be improved in order to fulfil the potential of this investment and to avoid wider problems, and costs, in the long term.

There are 2.5 million households in Scotland, of which 600,000 are classified as 'social housing'. In the past most efforts to improve energy efficiency have been directed at these, but recently, regulation has changed to include all homes across Scotland.

There is no doubt that current efforts to save energy are making a huge (and positive) difference while improving comfort for thousands, but the impulse for writing the guide was the realisation that many renovation projects are not as effective as they could be. In fact, they can create a number of unintended consequences that have negative effects on the comfort and health of occupants, the condition and durability of the buildings, and in some cases the conservation value of the buildings. There are many reasons for this, and in this guide we aim to show how conservation of older buildings, energy efficiency, health, and comfort can all be achieved through a more careful and balanced approach.

The techniques routinely applied to upgrade buildings are not always appropriate for historic buildings

We have focused herein on domestic projects, that is, individual homes and larger scale housing projects. Many of the principles discussed can be applied to other buildings, but the range of specific issues multiplies with more specialist building types, making it difficult to address them adequately.

Some of the principles and details discussed may also be useful in new buildings, but the intention is to concentrate on existing buildings. Many of the examples shown are 'traditional' (i.e. pre-1919) solid-walled buildings, but the guide also addresses more recent types of building. The most important difference between building types is usually the choice of wall construction. We discuss both external and internal insulation to solid walls, cavity walls, and the more recent timber frame construction. Roof construction has changed very little for the vast majority of domestic buildings, but there are two quite different places to put insulation when renovating. Finally, there are really only two types of floor construction: solid or suspended, and these are both discussed in the section on floors.

This guide can be used for all existing buildings, including more modern homes such as this timber framed house from the 1980s

There are a number of terms used to describe the upgrading of existing buildings. In smaller scale domestic projects, the word 'renovation' tends to be used. Larger scale works by councils and housing associations are normally referred to as 'retrofit', a term used in government and policy circles as well. In this guide, we have used the terms interchangeably.

1.2 A Different Approach

> **Target Audience**
>
> We want this guide to be useful to as many people as possible. We have deliberately written it in a straightforward and non-technical way so that it is easily understood by the householder wanting to upgrade his or her own home. However, we also want it to be relevant to architects and builders, as well as larger organisations like council housing departments, housing associations, landlords and developers who want to renovate their building stock in a way which balances energy efficiency, heritage value, comfort and the long-term health of occupants and building fabric.

This guide is not like other guides to renovation. In Chapter 3, the reasons for this are discussed in detail but it is worth emphasising the point here because of the potential to cause confusion. There are four primary differences but these can be broken down into ten separate aspects as described below.

Most guidance on renovation is exclusively or almost exclusively focussed on energy efficiency. We have seen too many examples of how this focus can cause problems elsewhere. The first important difference between this guide and others therefore is that we aim for a *balance* between energy efficiency, the comfort and health of occupants, and the durability and condition of the building fabric. This is covered by points 1-3 listed below.

Broadening the focus beyond energy efficiency does not mean we do not value energy efficiency. The opposite is true. The difference is that while most conventional guidance is based on the modelling tools used to calculate energy consumption in buildings, our guidance is based on observations and investigations of 'real' energy consumption, measured and monitored in real buildings once completed and inhabited. We are interested in what *actually* improves energy consumption, rather than what *purports* to improve energy consumption on a spreadsheet. This interest in *reality* is covered by points 4-6 listed below.

Almost all studies into how buildings perform in reality acknowledge that the way people behave in buildings makes as much, if not more difference than the technical aspects of the buildings. Thus in this document we place considerable importance on engaging with *people*. This is covered by point 7 listed below. Lastly, in this guide we acknowledge the value that the conservation or *heritage* sector has brought to the understanding of how to work with existing buildings. There is a great deal written about this, but it is usually confined to publications aimed at those who own or work with listed buildings, whereas the advice is relevant to most existing buildings. This is covered by points 8-10 listed below.

In summary, there are ten ways in which this guidance differs from the majority of advice currently available. Our guidance:

1. seeks a more effective approach to *energy efficiency*
2. takes account of the *comfort and health of people* who live in buildings
3. avoids problems which could lead to *building fabric decay* and deterioration
4. favours details based on *real, measured performance*, rather than modelled predictions
5. highlights the need for more co-ordination and inspection, and for more *careful workmanship*
6. integrates considerations of *moisture* in buildings
7. proposes a much closer level of *engagement with people*, particularly occupants
8. acknowledges the *different construction principles and materials* found in older buildings
9. places value on *maintenance* and the need to re-integrate this into design and building management
10. suggests that the principle of respecting the '*significance*' of individual buildings which comes from the conservation sector should be integrated into routine retrofit assessment.

We highlight the differences between our guidance and conventional guidance and we explain the reasons for this so that the reader can understand the breadth of opinion on the subject and can form his or her own view as to how best to proceed.

Since the first edition of this guide was launched, the Publicly Available Specification (PAS) 2035 has been published and updated. The PAS is similar in spirit to this guide and arose from a similar impulse to radically improve common retrofit practice. Increasingly used in public procurement, but available to any project, it is discussed more fully in the boxout to the right.

1.3 How to Use This Guide

The guide is divided into four chapters. The first three present the broader context and reasons for a different approach to retrofit, while Chapter 4 looks in more detail at how these changes can be put into practice.

After this introduction, Chapter 2 lays out some important context for retrofit in Scotland, while Chapter 3 discusses the four principles (which form each section) and within those the ten aspects summarised above.

Chapter 4 looks at a range of building elements and, where relevant, explains how the differences link back to the points raised in the first section. Those interested in one area only (e.g. windows) can skip straight to that section without reading all of the supporting and background information.

Chapter 4 is followed by a references section that includes a bibliography and glossary including a list of acronyms.

1.4 Caveats

Every building is unique, and the variety of spaces, arrangements and details to be found means we cannot possibly attempt to describe or illustrate all circumstances. We have described what we hope is a reasonably representative sample of situations in the hope that the principles discussed will help the reader in their own home or project.

We cannot take responsibility for design and installation decisions taken as a result of following the ideas described in this guide. We would always recommend that you use a suitably qualified designer and/or contractor but we hope that using this guide gives you a better understanding of the issues and the sorts of questions to ask.

We have provided a list of further sources of information along with a little description in some cases to help direct readers to the most appropriate resource.

Although the bulk of this guide focusses on the details of individual projects, it wlll need to fit into a larger picture of retrofit and there are three aspects of the process of future retrofit which will be crucial if we are to avert the worst effects of climate change and maximise the benefits of the effort.

The first and most important is that any realistic effort must be undertaken at scale. This is for two main reasons. The first is that the numbers demand it – the scale of operation simply cannot be achieved on a house-by-house basis. The other reason is that this is the only way

PAS 2035 is the description of a process by which retrofit should take place to optimise performance and minimise unintended consequences. It does not require any particular targets for energy efficiency, air quality or durability but does set out a variety of tasks that need to be undertaken and a number of personnel roles which should carry out these tasks.

PAS 2035 arose from the 27 recommendations made in the 2015 UK Government report 'Each Home Counts' which investigated problems with the retrofit industry. The PAS is linked to the updated PAS 2030 which sets out how retrofit measures specified in PAS 2035 are installed, commissioned and handed over to occupants. There is also a PAS 2038 for non-domestic buildings. It is also linked to what is now called the 'Trustmark' Government endorsed quality scheme and all projects associated with the PAS need to have their details lodged with the Trustmark database.

At the heart of the PAS 2035 is the establishment of a risk assessment process. Three classes of risk are noted with low risk projects requiring relatively little oversight. For the higher risk projects however, the amount of work required to evaluate options, optimise performance and avoid problems is much increased over most previous mainstream practice.

The PAS has introduced a whole new vocabulary of personnel roles including Retrofit Assessors, Retrofit Advisors, Retrofit Designers and Retrofit Co-ordinators. Within the PAS contractors are referred to as Retrofit installers and importantly a Retrofit Evaluator is introduced to carry out building performance evaluation and/or monitoring where possible, or as a minimum a follow up check that all measures are working as intended as required within this contract.

Archetypes

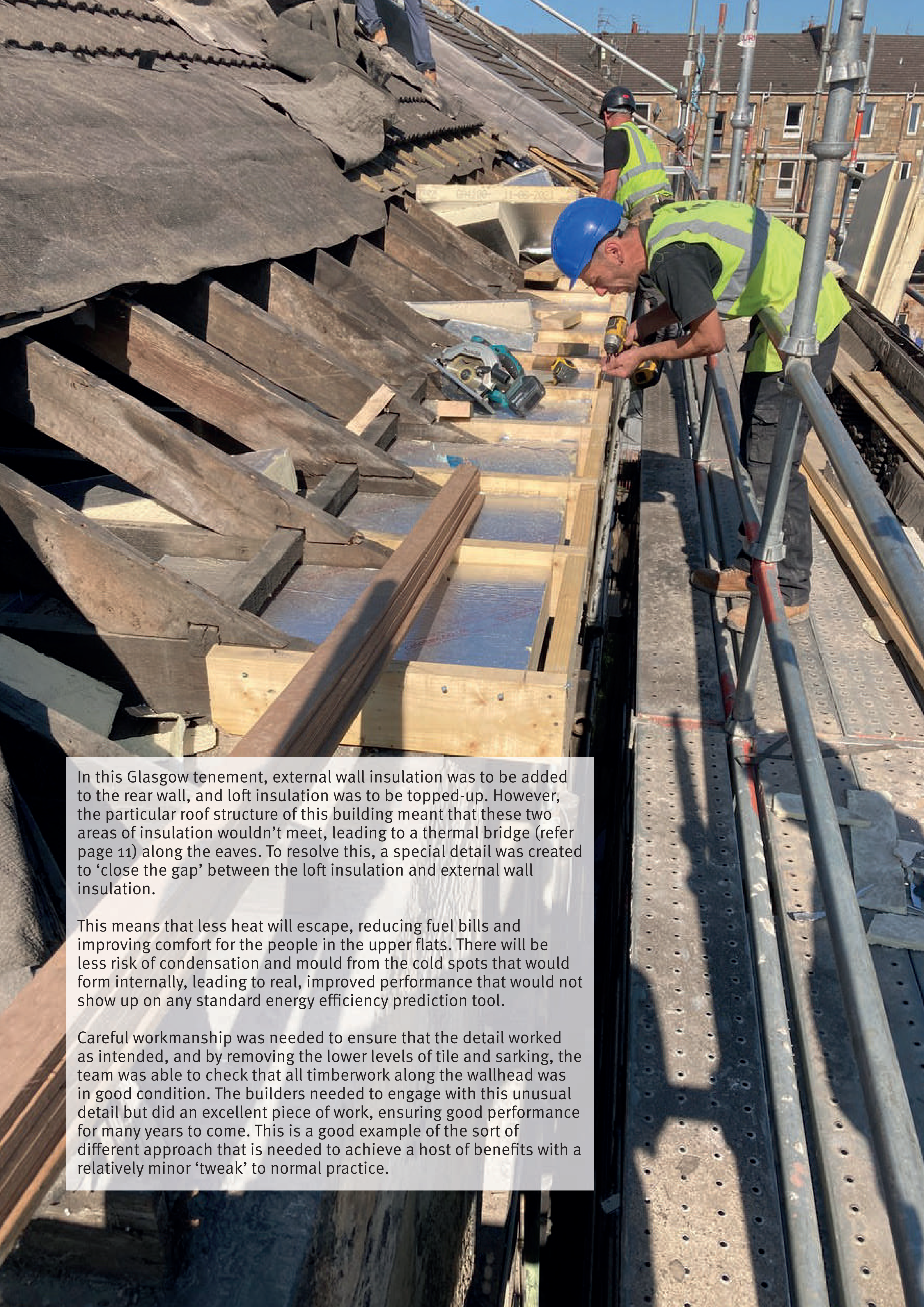
Although we need a far more careful assessment of buildings before we refurbish them, we almost certainly won't have the resources to undertake an individual study on every single property. Luckily, many homes are essentially the same, and so we can 'group' our approach. Many council-built properties, some 'system built' homes and many others are identical in basic construction and layout, albeit usually with a few non-critical alterations made over the years. It makes sense therefore to treat these buildings the same, as long as any obvious deviations are identified.

Similar properties are normally referred to as belonging to one 'archetype'. There are several different ways of creating an archetype. The most common include grouping by construction (same roof, wall and floor construction) and by form or layout (eg 'Four-in-a-block'). It can be also useful to group or sub-divide properties in relation to any energy efficiency measures they already have installed, by legal, regulatory, structural or funding constraints (for example listed buildings cannot necessarily be retrofitted like other buildings), by existing services or by EPC rating. A useful sub-division not always recognised is that of scale, whereby solutions which may be suitable on an individual house, may not work so well if a whole street was to improved, or vice versa.

to make the operation cost effective. Because of the numbers involved, an archetype approach (see boxout) will be needed, where properties with similar characteristics can be upgraded in a similar manner. The effort is costly, but an archetype approach and the economies of scale will make a significant difference.

The second is that a suitable funding mechanism must be found. Many options exist across the world and these can be either privately or publicly sector funded, or a mix of both. Payback may be envisaged directly through reduced fuel bills, or in a more diffuse way through reduced future maintenance costs, lower national health burden, greater tax recovery and so on. The key, particularly for public sector financing, is that the costs should be met through by more than one sector, with the acknowledgement that the benefits accrue across many sectors.

The third is that the works themselves will need to be accompanied by a concomitant effort in training and awareness. Commonly the focus is on discussing the need to train a large number of builders and other operatives who will be needed. However, we believe that this training and awareness will also needs to extend to commissioning clients and policy makers, designers, those responsible for planning and technical standards, as well as a broad drive to educate and engage the general population. Implicit in this training and awareness is the need to work across sectors to be able to address issues holistically as described in this guide.



In this Glasgow tenement, external wall insulation was to be added to the rear wall, and loft insulation was to be topped-up. However, the particular roof structure of this building meant that these two areas of insulation wouldn't meet, leading to a thermal bridge (refer page 11) along the eaves. To resolve this, a special detail was created to 'close the gap' between the loft insulation and external wall insulation.

This means that less heat will escape, reducing fuel bills and improving comfort for the people in the upper flats. There will be less risk of condensation and mould from the cold spots that would form internally, leading to real, improved performance that would not show up on any standard energy efficiency prediction tool.

Careful workmanship was needed to ensure that the detail worked as intended, and by removing the lower levels of tile and sarking, the team was able to check that all timberwork along the wallhead was in good condition. The builders needed to engage with this unusual detail but did an excellent piece of work, ensuring good performance for many years to come. This is a good example of the sort of different approach that is needed to achieve a host of benefits with a relatively minor 'tweak' to normal practice.

2. CONTEXT

This chapter looks at four aspects of the wider picture of retrofit:

- the government policy context which is driving the retrofit and decarbonisation of heat in Scotland's homes and buildings
- the science behind both the reasoning and detail of the proposals contained in this guide
- the need to take a step back at times, and develop a more nuanced view in order to achieve truly best practice
- a broader look at climate change adaptation and how it affects buildings and retrofit

2.1 Scottish Policy Context

This guidance comes at a particularly useful time with concerns about rising fuel poverty rates, the energy crisis and the climate emergency more urgent than ever before. Energy efficient homes will not only alleviate fuel poverty and cut greenhouse gas emissions, they will make us more resilient to the effects of volatile fossil fuel markets.

While energy policy is reserved to the UK, the Scottish Government has devolved powers for energy efficiency and emissions. It has significant programmes to reduce fuel poverty through energy efficiency, and also offers financial support to all Scots for insulation, draught-proofing and renewable heat. Improving the energy efficiency of the building fabric is key to saving on energy bills, but it also means, as less heating is required, the costs of installing and running a renewable heat system are lower.

There are wider benefits to society too—energy efficient homes mean we reduce demand on the national grid, with less need for costly new generation, and improvements to householders' health and well-being. There is also increasing awareness that renovation should aim to make buildings resilient to climate impacts such as warmer summers and more intense storm events.

The Scottish Government has very ambitious statutory climate targets to reduce emissions by 75% by 2030 and reach net zero by 2045. The government also has a statutory target to reduce the fuel poverty rate to no more than 5% by 2040. These are challenging targets, and the Heat in Buildings Strategy[1] has several strands of work to achieve these, most notably the ambition for all homes to be highly energy efficient by 2033 and over 1 million homes to switch to zero emissions heating by 2030, with all homes net zero by 2045. The strategy focuses on the following 'no and low regrets' areas: energy efficiency, heat pumps, and heat networks.

The government has stated that extra support will be provided so no one will be left behind or disadvantaged by the heat transition. Overall, the government estimates the transition to net-zero buildings will cost £33bn of public and private funding, with £1.8bn pledged for the parliamentary term 2021–2026.

Significantly, the Scottish Government is committed to introducing a Heat in Buildings Bill in 2024, which would include proposals for mandatory standards for both energy efficiency and the transition to zero emissions heat so homeowners, landlords and installers know what changes need to happen by when. The timing and approach

1 https://www.gov.scot/publications/heat-buildings-strategy-achieving-net-zero-emissions-scotlands-buildings/

will vary by tenure and house type; for example. flats and tenements will work to a slower timescale to allow for 'whole building' solutions such as Scandinavian style piped heating from a single energy source (eg heat network) and solid wall insulation where appropriate. There is an ambition to achieve an 'all tenure' housing standard by 2040. Local authorities are tasked with developing and implementing Local Heat and Energy Efficiency Strategies which will coordinate this heat transition in their communities. There are also plans to reform the Energy Performance Certificate to include a heat demand metric although the precise nature of this is not yet agreed.

A new Heat and Energy Efficient Scotland 'virtual' Agency is leading the communication and engagement on the transition, supporting individuals and businesses to comply with future standards. The agency will lead and oversee the delivery of government programmes on energy efficiency and the heat transition, including fuel poverty programmes, independent energy advice, finance for retrofit and renewable heat such as grants and loans, and support for the development of heat networks.

The Heat in Buildings programme[2] also covers consumer protection, building skills and capacity in the supply chain, additional support for traditional buildings, and monitoring the outcomes of these programmes.

Home Energy Scotland is a government funded, independent energy advice service which can provide information and advice on energy efficiency, renewables and support programmes[3].

This section will be updated in the online version of this book when the Heat and Buildings Bill completes its parliamentary process and Scottish Government policy is developed regarding mandatory standards, consumer protection, supply chain support and finance.

2 *https://www.gov.scot/policies/energy-efficiency/the-heat-in-buildings-programme/*
3 *https://www.homeenergyscotland.org/ 0808 808 2282*

2.2 Retrofit Building Science

Every building is unique, because of its location, microclimate, the materials with which it was built, the systems installed to keep it warm, the changes made over the years and the way that people live and work in it. In addition, buildings are genuinely complex; changing one element can alter many other aspects, some of which might not be obvious.

Buildings are being retrofitted without sufficient understanding of this complexity. Government policies understandably focus on large scale goals (carbon emissions and fuel poverty reduction), but those tasked with enacting these policies are rarely expert in building science and people living and working in buildings tend to be sensitive to some, but not all of the risks involved.

There are only three main agents at work in all of this, technically speaking; heat, air and moisture, but it is their interrelationships—and their interactions with buildings and occupants—which create the complexity. For this reason it is critical to understand a little of how they operate, and how they affect each other, buildings and people.

Heat

Heat is energy which is constantly seeking to dissipate, that is, spread out until everything is the same temperature. Thus it is always flowing from warm (more energy) to cold (less energy). In temperate countries like ours, we need our houses to be warmer than outside most of the time and so we artificially heat them, and then have to find ways of slowing down the flow of heat to the outside world.

Conduction, Convection & Radiation

Heat moves in three ways: conduction, convection and radiation. Conduction is the flow of heat through a solid material, from molecule to molecule. Generally, the closer these molecules are packed (the denser the material) the more effectively heat can pass between them. Conversely, the more they are spaced out the harder it is for the heat to flow. This is the fundamental principle of insulation which seeks to 'trap air' or in other words spread out the molecules of the solid material as far from each other as possible, separated by pockets of still air.

Different materials allow heat through to different degrees and this is known as their thermal conductivity, or lambda value. Better insulating materials have lower lambda values. To the right is a table of common materials and indicative lambda values for comparison.

The temptation when looking at tables like this and considering insulation choice is to opt for the lowest number, but there are so many other variables at play that it is important to resist! Quite apart from cost (not surprisingly some of the much lower lambda materials are correspondingly expensive) there are issues such as fire resistance, performance with moisture, ease of use, durability, availability and environmental impact to consider and these are briefly discussed in the box overleaf.

The second way in which heat flows is convection. This is the flow of heat through liquids and gases (rather than solids). Because molecules in liquids and gases are free to move, convection can be very effective.

A scene that is familiar to thousands of households. The mould is due to a combination of excess moisture, cold surfaces and inadequate ventilation. It will impact on the health of the people using that room, and, over time, the condition of the building fabric.

Material	Lambda (W/mK)
Aluminium	200
Steel	60
Concrete	1.4
Brick	0.8
wood	0.13
Wood fibre	0.045
Expanded Polystyrene	0.036
Mineral wool	0.035
Phenolic foam	0.022
Aerogel board	0.013

INSULATION CONSIDERATIONS

- Lambda value indicates how well the material resists heat loss and is important, but not the only consideration.
- Even tiny gaps within or around insulation will allow heat to bypass, so it has to be fitted without any gaps at all. This is not easy in practice, and so the practical difficulties of ensuring a snug fit between other components like a timber frame—using materials which have a little 'give'—is often as important as lambda value.
- Because it is hard in practice to avoid gaps, it's worth trying to add air barriers (but not moisture barriers) either side of—and tight up against—the insulation. These prevent air entering and so gaps within the insulation are less of a problem. With rigid boards, taping all joints will have a similar benefit.
- When using fibrous insulation like mineral wools or sheepswool, cold air can flow across and through the outside face. Although not penetrating to the inside, this 'wind-washing' can wick heat away and where possible should be prevented through the use of a membrane.
- There are a number of health concerns about some synthetic insulation materials. These are controversial, but SEDA has always sought to use the precautionary principle in such matters and where possible, we suggest using natural materials.
- Natural insulation materials (sheepswool, woodfibre, flax, hemp, sisal, cork etc.) tend to be 'hygroscopic' which means they can absorb, safely store and desorb moisture. This has several advantages, including the ability to protect adjacent (usually timber) structural elements from excess moisture. They are also 'breathable' meaning moisture can pass through safely and dissipate where designed as part of a 'breathable' system.
- On the whole, synthetic insulation materials (mineral wools and plastic foamed products) tend to have high embodied energy (which is worse) relative to the natural insulation options.
- There are some recycling arrangements in place for some synthetic insulation materials, but it is not always economic to undertake. Natural insulations are usually biodegradable or compostable and so represent a zero waste option.
- Insulation needs to be installed in a wide variety of situations, and some of these have quite specific requirements, for example related to fire (high rise buildings), high compression resistance (under the ground floor slab), acoustics (between properties) or vapour resistance (around water pipes). Clearly, these requirements might outweigh any of the considerations above.
- There are many commonly used insulation products such as boards, rolls and batts, and the bulk of our guidance relates to these. However there are also some less common ones, such as insulating plaster, loose fill granules, fibres or beads and sprayed-on foams, and although not necessarily mentioned, these may be appropriate in some situations. The important thing to consider is the long-term performance as well as any more obvious or immediate advantages.

Molecules move according to pressure differences which can be natural, such as wind or differences in density or temperature, or mechanically induced by fans.

Heat loss by convection is more important than many people realise because it is linked to airtightness, to thermal bypass (see below) and build quality (gaps) which are all under-represented using conventional models. One of the differences between this guide and others is that we are far more concerned to reduce heat loss by convection than is normally the case.

The third way in which heat flows is radiation. Technically, heat radiation is mainly infrared electromagnetic radiation which is short-wave radiation adjacent to the visible spectrum (light). Any object warmer than its surroundings radiates (including people) but we tend to associate it with hot objects like the sun and fire.

Because humans have evolved entirely with the sun, and for many hundreds of generations with fire, there is no doubt that the human body has adapted to respond well to radiant warmth. For this reason we place greater value on this form of heating whereas conventional guidance pays it little attention. This is discussed more in the section on heating.

Heat Loss through Buildings

Buildings lose heat in relation to their location and surrounding microclimate, but for a guide on renovation, our main concerns are the basic mechanisms of heat loss due to the characteristics of the building itself.

a. Thermal Transmittance

While thermal conductivity (lambda) measures the ability of individual materials to resist heat, walls, roofs and even single components like windows are made of more than one material so it gets more complicated. Thermal transmittance is how a collection of different materials in combination resist heat together, so it is possible to get a single number (U-value) for any combination of materials forming a wall, roof, window, floor etc. This number is what the building regulations need to know to ensure that each element of the building is adequately insulated.

The total heat loss of the building is then worked out by multiplying the area of the various elements (roof, wall etc) by the U value of each. For compliance, certain temperature differences between inside and outside are assumed so that all assessments are comparable. It is worth noting that it's not just the thermal transmittance of the building element that is important. Two buildings with the same internal area might have very different layouts and one might have more external surface area, leading to greater heat loss. For this reason, it makes sense to keep buildings compact to minimise heat loss.

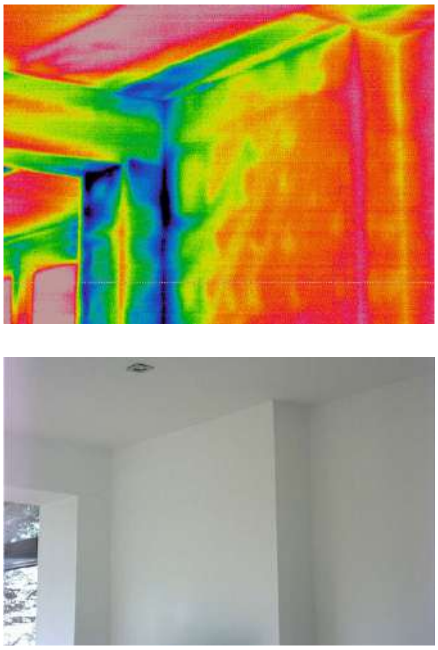
b. Thermal Bridging

Thermal bridging occurs where one part of the construction is more conductive to heat than another part. The overall U value might say one thing, but in these areas the actual heat loss is worse. An example might be in a timber frame wall where for structural reasons there are several timber studs together (and therefore no insulation), or in a retrofit where internal wall insulation is omitted from some areas because they are difficult to access. Thermal bridges have their own value (psi, measured in W/mK) which needs to be added into any overall heat loss equation to give an accurate picture of the whole building.

In the past, these anomalies were generally ignored, or at best treated with generic 'get-arounds'. Nowadays more people are aware of the issue and it is beginning to be taken more seriously. There are two types: repeating and non-repeating. Repeating thermal bridges, as their name suggests, form at repeating, generally regular and known points, such as where fixings penetrate the insulation in external wall insulation. These fixings transmit more heat than the insulation around them, so a psi value has to be established, multiplied by the number of fixings and the total added to the overall heat loss of that section of wall.

Non-repeating thermal bridges are also called linear thermal bridges and tend to occur where elements of construction meet, such as at the junction of floor and wall, wall and roof and around openings. The problem often occurs because certain elements are needed for structural reasons and it is then difficult to fit enough insulation around them. A significant amount of what constitutes good practice involves identifying and resolving these thermal bridges. This is because they allow more heat out of the building, but more importantly, they create relatively cold internal surfaces. These can lead to condensation, stains and mould, with unwelcome implications for human health and the durability of the building fabric.

Corners form their own sort of thermal bridge and are often colder than adjacent wall areas. The mould here is also probably related to being normally behind a sofa with little air movement. The image in the top corner is a thermal or thermographic image (infrared) which shows the surface temperatures of the surroundings. There are several examples of thermal images in this document.



A clear example of thermal bypass. Cold air from the junction with a new conservatory is getting behind the plasterboard in the kitchen area and cooling the wall.

c. Thermal Bypass

Thermal bypass is the lesser known cousin of air leakage, discussed below. With thermal bypass, air gets in or out of the building fabric but only part of the way. Because buildings tend to have lots of cavities, this air can cause havoc once it's inside the building fabric, cooling the building fabric from within or depositing warm, moist air in places that can't be seen or reached.

The significance of thermal bypass has only recently come to light due to the efforts of building performance practitioners. In one study, ventilated party walls between terraced homes and flats meant measured heat loss from the homes was far higher than anticipated. Other examples include 'wind-washing' where fibrous insulation materials do not perform as well as expected due to air movement on their outer edge drawing warmth from them. This has led to the proposed use of a 'wind-barrier' to the outer face of insulation, as shown in the loft insulation described in Section 4.4.

Because thermal bypass, like air leakage, exploits gaps in construction as much as cavities, it is also relevant to issues of quality and workmanship on site. Many construction anomalies picked up by thermographic cameras are assumed to show thermal bridging whereas they often show cold air movement indicating a gap somewhere there shouldn't be i.e. thermal bypass.

d. Thermal Mass

Thermal mass is the capacity that all materials have to absorb heat energy and store it, releasing it again when the surroundings are cooler. It can be put to very good use but while simple in principle, can be quite complex in practice. The practical implications of working with thermal mass are discussed more fully in the section on heating.

Air

Like heat energy, air is moving all of the time across the globe, driven by both horizontal and vertical pressure differences. At the small scale of buildings these two pressure differences are known as 'wind-driven' and 'stack effect'.

'Wind driven' pressure is where the wind is blowing in one direction across the building, creating positive pressure on one side and negative pressure (suction) on the other (leeward) side. This differential can be exploited naturally by opening windows on both sides of the building, allowing air to move through the house. This is called 'cross-ventilation' and is very effective at providing fresh air where used.

The 'stack effect' links air movement to temperature. Warmer air is less dense and tends to rise, and where this occurs, cooler air comes in below to fill the vacuum. Again, this phenomenon can be harnessed to form a very effective ventilation system. In warmer weather, windows (or roof lights) opened at high level will allow warm air to rise up and away, drawing in cooler air from low level windows (ideally to the north) and keeping the building and the occupants cool.

Ventilation is the term used to describe air movement which is designed, intentional and controllable. Every building must have this in order to ensure an adequate supply of fresh air and an adequate way of removing stale / moist air. In older buildings the main mechanisms employed were openable windows and chimneys, fires and stoves which worked in concert with cross and stack ventilation as noted above. These two mechanisms remain in many older buildings although chimneys are often blocked, while in most modern buildings, ventilation is also managed through the use of mechanical extract fans with trickle vents in windows providing the replacement air. This is a regulatory requirement in all new buildings.

Whether natural or mechanical, the purpose of ventilation is fourfold:
- to remove excess moisture
- to remove unwanted pollutants from internal activities (including carbon dioxide)
- to provide 'fresh' air / oxygen
- in warm weather, to cool occupants.

There is some debate about how much ventilation is required: it can be derived by considering how much (stale / moist) air needs to be removed from a space, or by considering how much (fresh) needs to be provided—in other words by considering the extraction or supply rate.

The problem, however, is that not all air movement in buildings is designed. Much of it is not designed, not anticipated and not particularly welcome! Infiltration is the term to describe air getting in and out of the building which wasn't designed, not intended, nor controllable. It is due to gaps and cracks in the building and around things like services penetrations and so is affected by the quality of construction. It is driven by wind pressure and temperature differences just the same as ventilation but, unlike ventilation, can't be controlled and leads to a number of problems, like heat loss. Infiltration is also known as air leakage or more commonly as draughts, while the solutions are known as addressing airtightness, reducing air leakage / permeability, or simply as draughtproofing.

When air moves it cools the human body, even if the air is warm, which is why draughts are not just an energy problem, they're also a comfort problem. Downdraughts from cold surfaces, like large glazed areas, can cause discomfort, but in this Passivhaus, the large windows are draught sealed and triple-glazed, meaning there is no downdraught and it is possible to sit close to the window and appreciate the garden in complete comfort.

The term most commonly used within the UK industry is 'air permeability' and the air permeability of a building is measured in m3/hr/m2 at a standard pressure difference of 50 pascals. That is, the volume of air (m3) escaping per hour for each m2 of external surface area. In recognition of the problems it can cause, new buildings now need to be tested to ensure a suitable level of air permeability. The importance of airtightness is discussed in more detail in Section 4.2 which also addresses some of the controversies surrounding the subject and looks at what can be done to reduce infiltration.

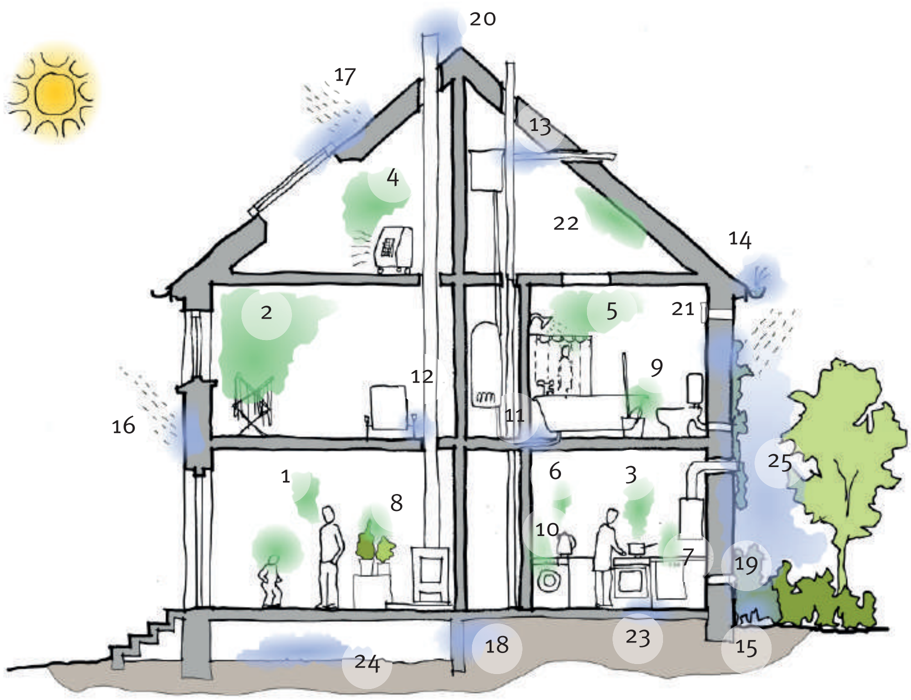
Moisture

Like heat energy and air, moisture, in its various forms, is constantly on the move. It flows through the environment at large, interacting with buildings in different ways depending on its state. Unlike heat and air movement however, most people tend not to be particularly sensitive to changes in moisture levels and so the issue remains unnoticed until its effects - often damp and mould - bring it into focus. Understanding moisture in buildings however is critical in order to ensure not only an energy efficient project, but a healthy indoor environment, and a robust building envelope. Moisture appears in three different states depending on its temperature: gas, liquid or solid.

Water Vapour

Water vapour is water in its gaseous form and is almost always present in air, both inside and outside. The amount of vapour in air at any point is known as the absolute humidity level and is measured in grams per cubic metre (g/m^3). When air is carrying as much water as it can, it is

1. breathing & perspiration
2. clothes drying
3. cooking
4. portable gas heating
5. bathing
6. kettles
7. dishwashing
8. plants (& soil)
9. floor/surface washing
10. washing machine/tumble dryer (depending on venting arrangement)
11. leaks in waste drainage (eg bath connection or toilet cistern) or overflowing bath/basin
12. plumbing leaks - water supplies or central heating
13. burst (frozen) pipes in uninsulated areas
14. gutters leaking/blocked/ overflowing or downpipes leaking/blocked e.g., at fixings
15. gullies blocked/ground nearby saturated
16. rain direct onto walls, in via gaps/cracks in pointing or render
17. rain direct through roof, via missing slates/leaking flashings etc.
18. groundwater via inadequately waterproofed low level walls or floors
19. ‘rising damp’ driven up walls
20. rain via uncapped chimneys/ flues/flashings etc.
21. condensation in wet rooms/cold surfaces/poor ventilation
22. condensation in colder areas/ cold surfaces/poor ventilation
23. ‘built-in’ moisture from construction
24. flooding/high water tables
25. high moisture levels to shaded/ unventilated areas (overgrown/ to north)



Common moisture sources in a building. Water vapour sources shown in green, liquid water sources shown in blue.

said to be saturated and beyond this level the vapour will condense out of the air, ie change to its liquid state.

However, the amount of vapour that air can contain increases with temperature and so in practice it tends to be relative humidity (RH), described as a percentage of the total capacity at that temperature, rather than absolute humidity which is generally used when describing water vapour in the air. The difference in carrying capacity of vapour is quite dramatic; air at 25°C can hold ten times more vapour than air at -10°C.

Liquid & Solid Water

Water in liquid form mostly affects us as rain, but also when water pipes leak, groundwater seeps upwards into walls and floors and importantly, as condensate. Solid water takes the form of snow and ice. Snow tends to be handled in the same way as rain although it can settle and so adds to the weight loads on roofs, and ice can cause spalling when it forms near the outside face of masonry.

An important part of building design is given over to keeping rain safely away from the vulnerable parts of the construction. Thus roof finishes, flashings, rainwater goods, renders and damp proof courses and membranes are all routinely installed to keep buildings dry. However, every one of these is subject to deterioration, movement and weathering and so maintenance becomes a critical part of managing moisture in buildings. The diagram above shows the range of potential sources of moisture inside a building.

Water and Vapour Flow

There are two sets of moisture movement in any home as indicated in the drawing above. The first relates to rain and snow and the techniques to keep this water out have not changed much over the years. Modern methods and materials are as effective as traditional methods but tend to rely less on regular maintenance, which is where the problem can sometimes arise as retrofit projects often involve older buildings which tend to need regular maintenance more than some modern designs.

The second relates to water vapour and mainly affects the inside of the home. This is being heated to a higher temperature than outdoors (so the air within can contain more moisture) and a fair bit of moisture is being generated (from the various sources noted above), creating a situation where warm, moist air is exerting a higher vapour pressure which is then 'pushing' outwards against the building fabric.

There are two sets of risks associated with this outward expansion of warm, moist air. The first is to the internal contents and finishes of the home, and the second is to the fabric of the building itself. An example of the first type of risk is where air at 25° and 100% RH inside a house encounters a surface sufficiently cold to cool the adjacent air. In a typically heated home, surface temperatures of around 12° or below will present this risk. Common places include a window frame, areas behind large furniture where air circulation is poor, or somewhere with a thermal anomaly—missing insulation, a thermal bridge or air gap where cold air is getting in and cooling the internal surfaces. This colder surface cools the adjacent air which is already at 100% RH so has no more capacity to contain the water and it condenses out, going on over time to form stains and potentially mould.

The second risk is known as interstitial condensation and is essentially the same process of warm, moist air cooling in contact with cold surfaces, but in this case it happens within the building fabric. Warm, moist air from inside escapes through cracks in the internal surfaces, or by diffusion through materials, and works its way outwards until it reaches materials and surfaces near the outer face of the wall which are colder. At this point the excess moisture condenses. If this happens on or near timber, there is a risk of decay, near metal there is a risk of corrosion, and if in masonry, then it can freeze, causing spalling on the outer faces.

Until perhaps a generation or two ago, this outward pressure of vapour pressure was not as strong (fewer sources of moisture and lower temperatures) and the general draughtiness of buildings, as well as the fact that the fabric of the building was capable of both absorbing and diffusing moisture, meant that this phenomenon was less of an issue. In buildings built or upgraded within the last 40 years or so, and with today's lifestyles, it is much more of a problem. In general, we keep homes warmer, we generate more moisture and the materials and construction of modern homes are much more vulnerable. This moisture can push its way out through the building fabric, cooling and condensing against impervious materials throughout the construction, causing all manner of problems, most importantly the decay of any organic materials therein, such as structural timber frame.

To prevent this, most modern homes employ two techniques to keep buildings safe from internally generated moisture damage. The first is to ensure that wet rooms (kitchen, bathroom, utility rooms etc) are fitted with fans which extract any moist air out 'at source'. The second technique is to ensure that the whole inside of the house is covered with a vapour barrier (VB) or vapour control layer (VCL) which prevents moisture getting into the building fabric. By and large these techniques work, but they are not without their weaknesses. Fans will only remove moisture if they are operational, and building performance investigators have often found fans to be broken, not extracting effectively or switched off by irritated occupants who dislike the level of noise

Cables protruding through plasterboard where no service void has been provided meaning the vapour barrier here has been breached

A timber framed 'breathing wall' under construction with hygroscopic recycled cellulose insulation being pumped into ceiling voids and already installed into the walls.

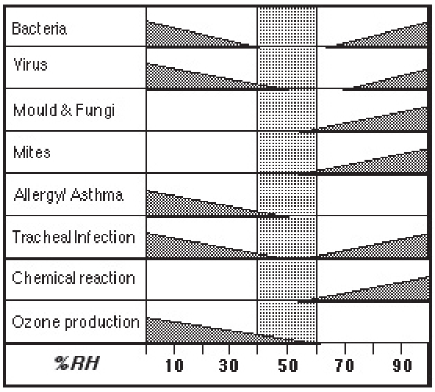


Diagram showing the health risks associated with high and low relative humidity extremes
Based on the 'Sterling Bar Chart' introduced in "Indirect Health Effects of Relative Humidity in Indoor Environments" by Anthony V. Arundel, Elia M. Sterling, Judith H. Biggin and Theodor D. Sterling. Environmental Health Perspectives, Vol. 65, (Mar., 1986), pp. 351-361.

produced. Equally, vapour barriers only work if they are continuous, and there are countless examples of this not being the case, particularly where the barrier is broken by electrical back boxes and other service penetrations.

A simple way to resolve this is to introduce a service void in which the barrier is left undisturbed behind a void containing the services. Another is to use 'breathing walls'. 'Breathing walls' are a relatively recent technique which take as their starting point the idea that—like traditional construction—if the construction is intrinsically safe from decay, then there is less risk overall, and the techniques designed to protect the construction from moisture (extract ventilation and vapour barriers) become less critical. Breathing walls make construction safer by taking advantage of two material characteristics; *hygroscopicity* and *vapour diffusivity*.

Hygroscopicity is the characteristic some materials have to safely absorb and then desorb (let out) moisture. Natural material insulations like those made from woodfibre, sheepswool, hemp etc. are highly hygroscopic and can absorb and store moisture safely, letting it out again and allowing it to pass through, whereas this is not the case with more highly processed insulation materials. Equally, earth and lime mortars and plasters can 'manage' moisture whereas more conventional gypsum and cement mixes cannot, or at least not to the same extent.

Vapour diffusivity is the characteristic some materials have to allow moisture to pass safely through them although it is normally measured inversely, i.e. as the *resistivity* of the material to diffusion. Vapour resistivity has units of Ns/gm (Newton seconds/gram metre). The larger the number the greater the resistance to vapour flow.

The *resistivity* is the intrinsic level for each material but this is multiplied by the thickness of a material or component (in metres) to give the vapour resistance, which has units of Ns/g, or MNs/g (Mega-Newton seconds per gram) and this is the unit most commonly used to describe vapour flow through materials. Breathing walls, roofs and floors use materials with quite specific vapour resistance which decreases from inside to out. This means that any moisture finding its way into the building fabric, will find it increasingly easy to escape outwards.

There is another aspect of moisture in the air which is worth mentioning. The diagram left shows that a range of common risks to human health are increased at both extremes of relative humidity (RH). In larger commercial buildings, RH is managed through complex air handling and conditioning equipment but this is rarely an option for houses. Apart from simply ensuring that there is adequate ventilation at all times (which will tend to ensure that higher levels of RH are avoided), it is also possible to passively buffer the humidity using the sort of natural, hygroscopic materials discussed above. These will absorb water vapour when RH levels are high and desorb it again when the air is drier, helping to balance the RH and reduce risks to the health of those in the house.

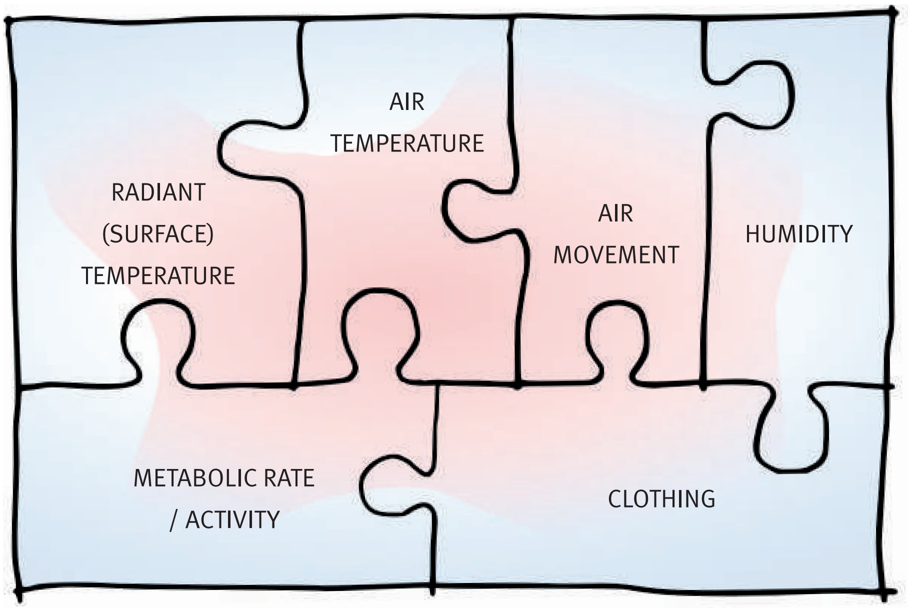
This technique is usually termed 'humidity buffering' and has been used successfully by a number of practitioners, particularly in museums containing delicate artefacts such as parchment or other humidity-sensitive materials.

Comfort

It should be clear from the previous section that temperature and heat loss, air flow and moisture are all interrelated; change one and you alter the other two, with knock-on effects on the building and the people in it. Until about ten years ago, most discourse on retrofit was restricted to heat loss and insulation. In the last ten years most people in the industry have become more aware of the need to look at air movement, but in the future we need to broaden our area of focus again to include moisture, and ventilation which connects to all three.

It is important to discuss comfort because with the focus so heavily on the sorts of technical and physical changes that need to be made to buildings, it is easy to forget that it is not really buildings we are trying to keep warm—it is people.

In fact comfort is a major topic of debate, albeit mainly within the building services sector. There is an International Standard (ISO 7730) which describes the general conditions which need to be met in buildings in order to optimise comfort levels for most people. There are broadly six components of what constitutes comfort and these are shown in the diagram below.



The six parameters of thermal comfort of which four are environmental and two relate to people

Most people in Scotland, having lived for many years with central heating, would consider air temperature to be the most important, if not the only parameter of comfort. After all, it is usually the only thing we get to control on our thermostats. However in fact the radiant surface temperatures surrounding us are the most important. See the section on heating for more on this but the problem is that we do not have a way of controlling this in most heating systems. It is also worth noting that human beings tend to feel more comfortable with warm feet and cool heads, so any system of creating comfort should strive to provide those conditions.

In the last 15 years, another approach has developed which recognises more fully that everyone has different ideas of comfort. It is called the 'adaptive comfort' approach. Whilst adaptive comfort recognises that there are some basic parameters of comfort, it acknowledges that some people can operate quite happily outside the 'normal' confines described in the more prescriptive standard. An adaptive comfort approach recognises that older, infirm and sedentary people and those from warmer countries tend to need higher temperatures. Younger, more active people will be more likely to tolerate lower temperatures and this tends also to be true for people from colder climates or who are otherwise used to being in cooler conditions. Adaptive comfort also acknowledges that even for the same person, boundaries of what is comfortable alter across seasons—we are more tolerant of higher temperatures indoors when it is warmer outside and vice versa.

The critical outcome of adaptive comfort is the need to design for personal control. People who can exert control over their immediate surroundings (opening windows, operating fans, adjusting local heating) will tolerate much more variety in their surroundings than those who have no such control and are obliged to 'put-up with' standardised, often remotely controlled conditions. This is known as the 'forgiveness factor' and takes the normally technologically driven world of building services deep into the territory of psychology and behavioural studies. In terms of designing buildings, the adaptive comfort model suggests basic parameters, then concentrates on creating opportunities for individuals to control their own environment. It is for this reason that the subject of controls is an important aspect of this guidance.

2.3 People and Perspective

How much should you spend on a retrofit project? Will the up-front costs be balanced by savings in the long run? Is your motivation to save money, or to reduce carbon emissions, or both? How do you balance keeping warm versus keeping the mould at bay? These are not simple questions to answer but it helps to have a little perspective on what is 'normal' or average. The short section below will enable you to assess where your household sits, and how much it is worth spending on renovation works.

In this document we have unashamedly striven to show the 'best' solutions to each element of building retrofit and explained our reasoning. However, we understand that circumstances do not always lend themselves to what might be 'best' technically. Indeed, the 'best' solutions in reality are those where global aspirations (carbon emission reductions, healthy indoor air quality, exemplary levels of maintenance) meet and match more local aspirations, including the specific requirements of those who live in each building and the particular circumstances of each location. Ultimately, it is only when we value these issues equally, that we can really say we have produced the 'best' solution.

Perspective

There are roughly 5.5 million people in Scotland and 2.6 million households. The general trend is for more houses and fewer people per household. In 2020 the average household had just over two people in it (2.14 to be precise). In 2019 the most common household had one person only (900,000), closely followed by two people (881,000), with just over 700,000 households with three people or more.

The average home in Scotland is 96 sq.m (1,033 sq.feet) which is a little bigger than England and Wales where the average is 90 sq.m. The average house is about twice the size of an average flat and we sit somewhere in the middle of the table of average house size across the EU but far smaller than the USA.

Very roughly, and based on December 2022 prices, the average annual Scottish heating bill (gas) was approximately £1,300 and the average electricity bill was around £1,200, making about £2,500 per year or just over £200 per month. See boxout for more details however as these figures vary enormously and will increase in the future. In most cases, the heating component is made up of around 3/4 space heating and 1/4 water heating. See the boxout on page 20 for more details.

So, the average household in Scotland is about 96 sq.m, has two people in it and spends about £1,300 (December 2022) per year on heating the house and hot water.

The average house in Scotland is not very energy efficient, so there is almost always room for improvement, but the above allows you to gauge where you sit in relation to others across the country. If your bills are higher than average, but you have a larger house and four occupants, then perhaps that's about right. If your bills are much higher, and you have a small house and live alone, then there's clearly more reason to spend money up front, because the savings will be greater.

AVERAGE HOME SIZES (SQ.M)

USA	245
Cyprus	141
Luxemburg	131
Portugal	106
Spain	99
SCOTLAND	**96**
Italy	94
France	94
Germany	94
England/Wales	90
Greece	89
Ireland	81
Latvia	63
Romania	45

Based on data from the Office of National Statistics

Energy costs vary hugely and as such offering average figures can be misleading.

Energy prices broadly doubled in the year or so leading up to October 2022. The original version of this document noted an average Scottish annual heating bill of £700, whereas this version notes it as £1,300, and there is little doubt that this will increase again in the future. Stating energy costs in relation to time, with such volatile global fuel prices is potentially unhelpful, but this is not the only variable.

The biggest of these is which fuel is being used to heat the property. Mains gas supplies around 83% of homes in Scotland and is far cheaper than all of the alternatives, thus around 17% of homes are paying much more for their heat than this. Many households have pre-payment or pay-as-you-go systems which invariably cost more again, and there are a variety of tariffs from a range of suppliers which differ as well.

Scottish Government publishes average figures based on keeping homes at the recommended temperatures (21oC in living areas and 18oC elsewhere, with higher temperatures for older or otherwise vulnerable people) but many households cannot afford to keep their homes consistently at these temperatures, so 'real' costs are often lower than predicted.

Rural properties suffer in many ways compared to those in urban areas. They are often larger, older, poorly insulated, more exposed to the weather and more often off the gas grid. With most other costs (transportation and food in particular) also higher, and with a marginally older demographic, more in need of warmth and comfort, rural households tend to face even greater pressures with fuel costs often double or triple those quoted above.

The number of variables that come into play can be bewildering. The section below addresses the 'real-life' judgements that come into play and if Scotland is to lead the way in addressing retrofit as part of a wider sustainability push—as many say we should—and if we are to move beyond generic EPC ratings and routine solutions, then these are the sorts of decisions in which the industry will need to become more skilled.

People and Circumstances

Consider an older lady living in a rural cottage in the outer Hebrides. Her annual heating bills are £2,000 with about £500 for electricity. Her total bills are the same as the Scottish average, but made up quite differently. Occupancy is lower than average, she doesn't use much hot water, nor much electricity (hence small electricity bills). The cottage, albeit not exactly large is about 140 sq.m but she doesn't use the second or third bedroom and keeps the heating off unless the grandchildren stay. She tends to keep the kitchen and living room warm but no other rooms. All of the above except the slightly larger house size would suggest that heating bills should be lower than average. She doesn't have mains gas, so there is an oil tank in the garden which is filled by tanker. Radiators are fed by an old oil boiler. These three last facts would suggest higher fuel bills than average.

The cottage is entirely uninsulated with draughty single glazed windows, it is often windy and the cottage is fairly exposed. Technically, it is clear that the major proportion of her bills is going on space heating—even the small proportion of the house she does heat—and that there is ample reason to insulate the house and save her a significant proportion of her heating bills. With an uninsulated house and expensive fuel, it's a straightforward case, and the 'best' solution is obvious.

However, while her children worry about the cold affecting her as she ages, this particular lady doesn't really mind the cold, having lived with it all her life. She likes to keep the windows open. The house value in this remote area is very low and she fears that any money spent on upgrading would be wasted. She doesn't feel the need to spend the money on herself and acknowledges that the children and grandchildren would sell the house after her death rather than move back to the island, and so any improvement work is of little value to them. She likes the house the way it is and keeps it in good condition generally. Most important of all, neither she, nor her children have a great deal of money to spare.

There is no doubt that *technically* the house would benefit from a significant overhaul including perhaps external wall insulation, new windows and a host of other measures, but there isn't the money for this. She is already operating the house in a efficient way (keeping unused rooms unheated, for example and not using much hot water) so the following suggestions might suffice:

- Insulate the loft - a grant available so no cost, and keeps the bedroom warmer
- Install secondary glazing - reduce heat loss and draughts, cheap, can be removed in summer
- A new boiler / insulate all hot water pipes - again not too expensive but big gains in efficiency.

Consider next a family of two parents and three teenage children who live in a fairly small terraced house (95 sq.m) in the central belt. Money is tight and the loft has already been well insulated when it was converted into a bedroom for the oldest child, but bills remain high—about £2,000 for heating (mains gas) and £1,400 for electricity. In addition, there is mould in a number of areas, particularly window frames, and two of the children suffer from asthmatic symptoms.

The high electricity bills can be explained by the relatively high occupancy, clothes washing and the large number of gadgets using electricity and needing charged overnight etc. The lights could be changed to LEDs and some appliances could be upgraded and it would be worth getting a smart meter and seeing if there are any excessively large loads, but without further significant lifestyle change it will be hard to reduce that figure by much.

Secondary glazing can be a cost effective alternative to double glazing, and some systems can be fixed using magnetic strips, meaning they are easily removable for maintenance or during the summer, for example

The heating bills on the other hand seem high for a house in which the majority of the walls adjoin neighbouring homes and there is an insulated roof. The existing double glazing is quite old and could be replaced, which is what the family think they need to do, but they are worried about the high cost of replacement windows.

Replacing windows might help a little but it is expensive and the key issue here is that all five occupants are very active and there are almost five baths or showers needed every day along with the clothes washing. If heat meters were placed around the central heating pipes, it would become clear that relatively little heat is used the keep the building warm—the majority is used to heat hot water. Some of this is electricity for the washing machine, but for the baths and showers, either solar water panels (which use the sun to heat water and could provide about 40% of the warmth over a year) or a waste water heat recovery system (which provides about the same amount of heat by recovering warmth from the outgoing waste water) could be usefully installed to reduce the hot water bills, taking the overall level back to around average and saving perhaps £700 per year.

The high level of hot water use is also behind the mould issues. Because of the high bills, the family tend to keep all windows closed and the fan in the bathroom doesn't work well. There is a lot of cooking on gas and no extract fan in the kitchen, and the high cost of the tumble drier and rainy weather combined means clothes tend to be dried on radiators around the house. Doors are left open and the moisture in the air finds its way to the coldest spots around the house, forming condensation and then mould, particularly around the windows.

A 'lean-to' shelter like this means washing can be dried even in rainy weather, reducing possible moisture generation in the home.

In the first instance, the following should help, saving higher cost items for later:

- Install either a solar thermal system or waste water heat recovery system to deal with the high hot water loads
- install new, quiet, heat recovery fans in kitchen and bathroom - inexpensive and will reduce moisture at source
- build a simple 'lean-to' in the garden to dry wet clothes / towels in any weather.

2.4 Climate Adaptation

There is now no doubt that climate change is baked into our future, and the issue is that the slower we are and the less we do to mitigate against it, the worse it will become. There is a great deal of uncertainty around the details, but there is consensus about the overall trends that will affect Scotland and the UK: it is going to get warmer, wetter, and wilder.

The overall trend is one of gradual warming, but this will be most keenly felt in the summers when we will see more very hot periods and, consequently, overheating in buildings. Rainfall will increase, particularly in the winter, but amongst these general trends will be more extreme weather which will sometimes reinforce, and at other times buck the trend. Thus, we will see periods of stronger winds and storm damage, extreme rainfall, and flooding, whilst also experiencing hot summers and sometimes droughts. These will be played out against a context of global disruption, which will have vast ramifications for people and societies, with some areas becoming uninhabitable and thereby increasing migration.

For those interested in the subject, the UK Climate Change Committee and Adaptation Scotland are useful resources, but the focus of this guide is around the immediate consequences for buildings.

Warmer

Overheating

To those who feel the cold, the thought of overheating may seem like a rather welcome change, but the reality is much more problematic. Overheating in buildings in the UK is generally considered a temperature of 25°C or more, and while this is no more than an inconvenience for some, it can become a serious issue for others, particularly infants, the elderly, the obese, the socially isolated, and those suffering chronic illnesses. It will also affect those in urban areas more.

Mild heat-related health effects include dehydration, prickly heat, heat cramps, heat oedema (swelling), fainting, and heat rash. More severe effects include mental health aspects and heat exhaustion which can lead to heat stroke if not managed. Heat stroke can be fatal and appears to be under-reported due to its similarity to strokes and heart attacks. Overheating risks are increased by higher night-time temperatures in bedrooms due to the inability to recover from heat stress during the day.

The biggest problem is that because overheating has never been much of an issue in the UK, our buildings have little built-in resilience, and this is particularly the case with most modern homes. Another problem is that there tends to be a mismatch between modelled results and monitored results in real buildings. Several academic scenarios have been modelled which show considerable risks of overheating in the South of the UK in the short term, but far less overheating in Scotland, except perhaps in the longer term. However, monitoring of real, usually low energy buildings in Scotland and other 'cold' countries suggests that overheating is already a problem. This is because the risk of overheating is usually predicated more on occupant behaviour, then on the specific design of a building and least of all on its location.

Managing Overheating in Existing Homes

There are two particularly effective techniques to avoid or reduce overheating. The first is high level openings, ideally roof lights and ideally combined with low level openings that can create an effective 'chimney' effect in warm weather. The second is external shading which prevents sunlight entering the home in the first place. Horizontal shading that blocks out the sun at its highest is most effective but West-facing shading is also useful to reduce solar gain on longer, summer evenings when the house is already warm.

Some aspects that increase overheating are unavoidable such as location (urban, low altitude and Southern locations tend to be at more risk) and some aspects are hard to alter such as small room volumes, low ceiling heights and window sizes, but for existing homes the greatest remaining potential lies in optimising ventilation options, making sure hot water pipes are insulated and controls are not inadvertently exacerbating the problem.

Typically, the two most practical ways to mitigate against overheating in buildings are external shading—fixed or moving, to prevent the heat getting in in the first place—and openable windows at both low and high level, which can effectively exhaust warm air on still, warm days.

Thermal Stress

Thermal stress in buildings occurs when parts of the building heat up and want to expand as a result. When they are constrained, they can break. Relatively common examples are of South-facing glass cracking and black bitumen based flat roofs becoming soft or breaking up.

Having broken components means, of course, higher maintenance costs, but these breakages will also lead to consequential damage like water ingress through a failed flat roof covering.

Increasing temperatures will inevitably lead to more of these sorts of problems. The key is to anticipate these issues and design them out or to alter particularly vulnerable components. Surfaces that face south and are closer to horizontal than vertical will take the bulk of the increased heat load; unshaded surfaces, and darker colours will also be more at risk.

Solutions include providing more shade and/or changing the colour of more vulnerable surfaces to pale alternatives (known as the 'albedo effect'). Providing tolerance in systems with rigid components—so that thermal movement is allowed for without failure—will also help in some places, along with more regular maintenance generally.

Freeze/Thaw

In the past, colder temperatures have often lingered for long periods, whereas it is likely that with warmer winters, these prolonged cold periods will reduce in both frequency and length, meaning that the +/- zero threshold will be passed more regularly. This is likely to increase the incidence of cycles of freeze and thaw which tend to damage vulnerable materials.

Practically, the material most at risk is likely to be masonry in external walls. Spalling of masonry will occur more often, and whilst some superficial damage is not of itself serious, clearly it can lead to more serious problems when high level masonry begins to fail.

The key, as ever, will be better maintenance and in particular the use of sacrificial coatings and renders. This will present a challenge to the long-held preference for 'bare' masonry, which will be at much greater risk, bearing in mind the higher amount of rainfall also likely.

Another issue will be the ability of buildings to discharge water effectively from roofs and walls, such that water is shed before it gets an opportunity to be absorbed. Blocked gutters leading to saturated wallheads, inadequate projections and drips, flat masonry coping stones, moss that soaks up and stores moisture, and poor weatherproof detailing in general will all increase the problem.

Trees and other planting bring a little nature and biodiversity into urban spaces and can provide significant shading benefits. This can lead to reduced overheating and thermal stress of the buildings as well as working generally towards a reduced urban heat island effect

Urban Heat Islands and Wildfires

Urban Heat Islands is a well-known phenomenon whereby urban areas can be several degrees warmer than adjacent rural areas. This is largely due to the high thermal mass of acres of concrete, tarmac, and other masonry surfaces, which heat up and then exacerbate already warm conditions, combined with limited natural shade.

The same principles that apply to individual homes also apply to urban areas; making darker colours light, breaking up the mass of concrete and tarmac, adding bodies of water that can evaporate and reduce warmth locally, providing shading, particularly trees, and adding planting, for example to rooftops, will all help to reduce the exacerbating effect of urban areas.

Meanwhile, in rural areas, the risk of wildfires will increase. This has already been seen in some parts of the world, but the same will be true of the UK when woodlands or moors, with high air temperatures, little moisture in the ground, and a lot of dead material will become increasingly vulnerable to natural or manmade fires. We will need to learn quickly techniques from areas already prone to wildfires to build the necessary resilience.

Wetter

Biological Growth

Lack of maintenance can lead to algal 'greening' like this and plant growth. This problem will unfortunately only get worse with climate change and will increase the need for maintenance.

Warmer, wetter weather generally will encourage all biological growth, including those things we don't particularly want in our buildings, like algae on masonry, bacteria, mould, mosses on roofs and plants in gutters, cracks in walls, and so on.

Plant growth in buildings is already something of a bugbear for those responsible for maintenance, and the reality is that this will just become more of an issue. Maintenance is the key, ensuring effective run-off of rain from roofs, rainwater goods and walls, as well as limiting opportunities for growth to take a hold, for example via good perimeter drainage and more regular clearance of gutters etc.

Internally, warmer, more humid conditions will increase the risk of mould and timber decay, either fungal or from insects. Rather than relying on more chemical treatments, the key will be ensuring adequate ventilation so that the necessary humidity does not build.

Rain Penetration

More rainfall, combined with higher winds, means that more water will penetrate buildings through poorly maintained areas, cracks in render, or in areas of splash back. Buildings that are more exposed to the weather will suffer more than those which are relatively sheltered.

As ever, maintenance is the main issue, but we can also alter how we detail both new buildings and refurbishment to help deal with the increased pressure they will be under.

Renders and cavities will help, but the best protection will be rainscreen solutions that are disconnected from the wall beneath. Improved details to shed water effectively, better overhangs, larger and more robust rainwater goods, and flashings and better access for maintenance are all techniques that can be employed to protect our buildings effectively.

Another aspect will be to increase the use of vapour open materials that will tend to allow moisture to escape freely, rather than trapping it.

Wetting/Drying Cycles

Increases in moisture levels generally, combined with higher winds will lead to an increase in the wetting and drying of exposed materials. Where this is already an issue, such as where salts are slowly leaching from masonry, it is likely to become more of an issue.

Potential solutions are the same as for some of the other aspects and all involve greater protection to exposed surfaces. This may be rendered finishes in preference to bare masonry, rainscreen cladding options, and improved details to shed water more generally.

Flooding

More rainfall will lead, inevitably, to flooding in some areas. This will be linked to a range of other issues such as rising sea levels and higher groundwater in some areas at times.

Unfortunately, much of what we now routinely do will add to this problem. Impermeable surfaces like roads, car parks, pavements, and hard surfaces generally will significantly add to the problem, as will poorly maintained drains. In many cases, location makes it difficult to escape the risks; being 'downstream' will always be a greater risk than being 'upstream' and there will probably come a time when certain areas or properties become uninsurable or essentially untenable as properties. A number of more recent housing developments have taken place on what has traditionally been seen as flood risk areas, and it is quite possible that these areas will become too great a financial or practical burden to retain as habitable places in the longer term.

Areas especially vulnerable to flooding include any locally low-lying areas, coastal areas, and areas close to rivers, especially when the rivers themselves are relatively level and the land is flatter.

There is, however, a huge amount of work that can be done to mitigate against flooding. The most important of these need to take place at the largest scale. Land management can be adjusted to significantly reduce the risk of flooding with tree planting, wetland creation, field planting schedules that avoid bare earth (which is easily washed away), larger scale swales, ponds and other retention devices, and many other techniques that will anticipate and control high rainfall events.

At a building or street level, the key is to create as much natural water storage as possible by avoiding impermeable surfaces wherever possible and creating retention areas, with the ground itself being the main one, supplemented where necessary by manmade storage. Greater absorption and slower release of water can also be improved by tree planting and other greenery—in some cases, a tree will reduce the amount of rain reaching the ground by 75% and slow down the rate of release of that water, so trees and other plants have a vital role to play.

To protect buildings on an individual basis, it is important to ensure the rainwater goods and nearby drains are clear and well maintained because blockages could cause local flooding, while hard surfaces can exacerbate surface water issues. Sewage and surface water drains should be separated wherever possible. If the building is liable to flooding, suitable finishes that can dry more readily and electrical infrastructure that drops down from a high level (rather than coming up from the ground) will be safer.

This new-build development incorporates several features to reduce flood risk. All road services are permeable (but adequate for emergency vehicles) while the rainwater that falls on the houses is taken to underground rainwater tanks to be used for WC flushing and garden use. All owners incorporated ponds into their gardens also for biodiversity reasons and car port roofs (built later) are planted to further reduce run-off.

Ground Movement

More rain means more moisture in the ground, which increases its fluidity in some places, particularly on slopes and where combined with increased expansion and contraction of clays. This can lead to slumps or landslides and instability more generally.

Buildings situated on affected slopes may be at risk, but effective land drainage can help, along with more disruptive 'engineered' solutions.

Wilder

Droughts

Although the general trend, in the UK at least, is for warmer and wetter conditions, the broader destabilisation of global climate patterns means that at times, we will see increasing droughts, even in Scotland.

Agriculture and industry use a great deal of water, but in buildings, it is possible to reduce our water demands though water conservation products such as low flush toilets and aerated shower heads and taps. Composting toilets offer a water-free solution in some cases. Rainwater harvesting systems collect rainwater from a building, store it, and use it typically for flushing toilets and watering gardens among other things. This can reduce water consumption in a household by around half.

At a larger scale, providing shade will reduce evaporative losses while the same techniques used to prevent flooding—in particular, avoiding impermeable surfaces—can improve and increase the capacity of the ground to store water, which can help.

Storm Damage

Increased frequency and ferocity of winds will bring increasing disruption and damage. This will take two forms: direct (e.g., roof tiles blown off) and indirect (e.g., trees or power cables knocked over onto houses).

Once again, regular maintenance is the key issue here, along with the addition of a regular safety or risk review process. Adjacent trees, boundary walls, and overhead and underground services should all be included in such a review. Rainwater goods should also be checked and if possible 'oversized' to ensure they can discharge rainwater effectively even in a storm. Roof edges, if vulnerable, should be reinforced or otherwise somehow protected.

Common Solutions

Although some of the risks, and their potential solutions, are quite specific, there are also a number of solutions that will help resolve or reduce a range of possible future threats. The following is a checklist of potential solutions for both new-build and retrofit projects:

- Consider overheating risk and undertake modelling to stress test the building (The Good Homes Alliance have a tool to assist).
- Two simple solutions which will usually work are external shading (against high level summer sun) and ventilation at both low and high level (stack ventilation).
- Make sure that roofs, roof edges (particularly verges) and high-level masonry are robust and well-maintained.
- Use generally robust materials that are well detailed against weather and repairable.

- Where possible consider (sacrificial and lime based) renders in preference to exposed masonry.
- The best solution for walls is a rainscreen externally, where feasible.
- Corners, horizontal surfaces, and cills beneath windows are all particularly vulnerable.
- Consider greater use of vapour-open materials to reduce the risk of moisture build-up in the building fabric.
- Use lighter colours for roofs, albeit planted roofs are preferable.
- Ensure details include for some tolerance, flexibility or shading to deal with thermal stress in components, especially those that face south.
- Makes sure there is a robust ventilation strategy for all internal spaces.
- Ensure all drainage and land drainage are well maintained and clear; regular checks are advised.
- Rainwater goods should ideally be oversized, robust (metal in preference to plastic) and with good, low-level access for rodding and debris removal.
- Where possible, stay clear of likely areas of flood risk, and if unavoidable, consider the mitigating solutions mentioned above.
- Check on items that could cause problems in a storm. While trees can represent a risk, they also provide shade, soil stabilisation, flood risk reduction, and a host of other ecological benefits so should not be removed unless clearly unsafe.

Taking a step back, it becomes clear that overall, the three main risks are exposure, fluctuation (of temperatures, air movemeent, and moisture), and lack of capacity. The solutions therefore will tend to comprise a combination of protection, buffering, and storage.

3. A DIFFERENT APPROACH

This section describes the context within which we have developed this guide, and sets out the reasons for the different approach we have taken.

3.1 Beyond Energy Efficiency to a Balanced Approach

Climate Change is Not the Only Issue We Face

There is little doubt that climate change is the most significant threat facing humanity and it is right that huge efforts are made to address this problem globally. As domestic energy use represents 30% of total national energy use the sector clearly has an important role to play in helping to achieve the targeted reductions, and as discussed in Section 2.1, the joint concerns of climate change and fuel poverty are driving the retrofit agenda in Scotland.

Balance

Focussing on energy issues only can cause unintended consequences, particularly in relation to comfort, health and the condition of the building fabric. We need to approach retrofit in a more balanced way which gives equal weight to all three of these aspects.

Climate change and fuel poverty are not, however, the only threats facing us and our planet. Global population growth, the increase in urbanisation and loss of soil and useful agricultural land form a worrying combination, while losses in biodiversity, continued species extinction and many of the outcomes of climate change such as flooding, rising sea levels, increasing extreme weather and storm damage all combine to create vast challenges. On a human level, both absolute and relative poverty continue to cause untold suffering and frustrate efforts to improve life for billions.

Beyond 'compassion fatigue' the sheer range of problems facing us presents us with a more practical issue: it is difficult to grasp the interrelationships between these problems, and therefore to address them in a co-ordinated or effective manner. It is much easier to pick one area of concern or interest and focus on dealing with that. Concentrating on solving one problem for any length of time however almost always leads to the conclusion that the problem at hand cannot be solved in isolation.

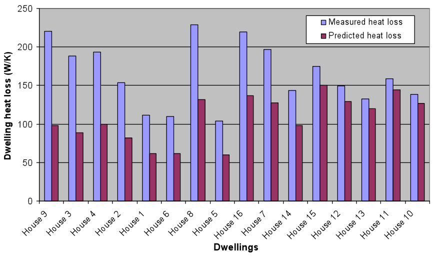
Although it is difficult to appreciate these interrelationships initially, there is no doubt that they are all interrelated and it is our task to attempt to identify and understand these relationships as far as we possibly can. This is because, as most of us appreciate at some level, if we only solve one problem, in isolation, there is a risk that we will only create other problems which will need to be solved in the future, often at higher cost.

This is exactly what is currently happening in the world of building retrofit. Current practice is helping to reduce carbon emissions and fuel bills, but not as effectively as it could, and is at times increasing risks to the health of occupants and the longevity of Scotland's built heritage. This guide is an attempt to broaden out our area of focus in retrofit using a balanced approach which will more effectively reduce energy consumption, safeguard the health of people living in renovated homes, and ensure that the long-term costs of maintaining buildings and caring for our heritage are minimised.

The Performance Gap and Building Performance Evaluation

If the previous section described the need for a balanced approach from a more philosophical angle, this section describes how the same conclusion is reached from a purely technological angle.

The Performance Gap



Graph showing the measured vs predicted whole house heat loss for 16 dwellings
as described in Zero Carbon Hub / NHBC Foundation: Carbon Compliance for Tomorrow's New Homes, Top4 Report, 2010

There is a small but growing area of investigation around what is termed the 'performance gap'. That is, the gap between predicted energy efficiency and the results of in situ tests which accurately measure the real life performance of the buildings once completed, and, in most cases, inhabited. The UK government funded a number of studies on the subject because it is becoming clear that one of the most significant threats to achieving our carbon emissions targets (like the ones described in Section 2.1) is this performance gap.

The graph illustrates the scale of the problem. The mauve columns indicate the predicted heat loss of the buildings while the adjacent blue columns show the actual heat loss, as measured on the completed building. The graph covers only 16 case studies but a pattern is immediately clear: the actual heat loss is consistently higher than predicted, and in one case, the discrepancy was 120% more than the predicted amount. Worryingly, the case studies all had a focus on improved energy performance, where particular attention was being paid to ensuring the buildings behaved as intended. In other studies, energy consumption has been shown to be over 300% the predicted levels.

Building Performance Evaluation (BPE)

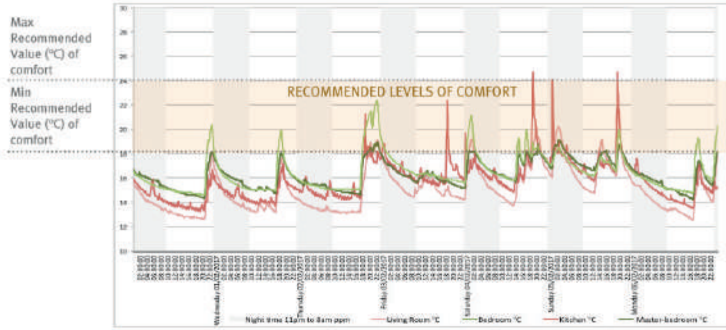
Although the initial impulse to study the performance gap grew from a concern about energy efficiency and the gap between predicted and real performance, it has broadened into an investigation about a number of other 'unintended consequences' which have been discovered along the way. This field of investigation is generally called Building Performance Evaluation (BPE).

Broadly speaking, the practice involves four types of investigation. The first is a range of physical tests carried out on the buildings themselves. These usually include in situ 'U' value testing, airtightness tests, thermography and testing of heating and ventilation systems. The second is the monitoring of energy consumption, be it electric, gas or other such as heat metering or quantification of biofuel use. In the case of electricity, the investigation can be broken down into individual sub-circuits, so that it is possible to isolate the energy used by individual components or spaces.

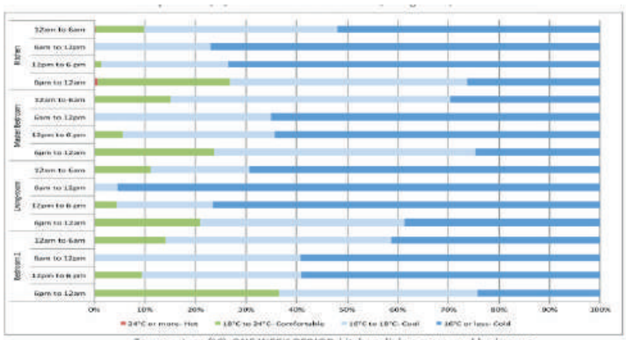
BPE: checking that high performance heat recovery ventilation systems are working as intended

The third type of investigation relates to the monitoring of internal conditions within a home such as temperature, relative humidity and CO2 levels but increasingly, investigators are also interested in VOCs (Volatile Organic Compounds) and other gases and particulates which might affect occupant health. The fourth type is made up of various techniques to engage people. This aspect started with a concern to help occupants of building understand and manage their buildings more effectively, but as it became clear that it wasn't just occupants who didn't understand how building worked, this effort has expanded to include anyone involved in funding, procuring, designing, regulating, building and living in buildings. While this 'soft' information might seem less scientific than the 'hard' data being gathered elsewhere, in fact this aspect has been shown many times to offer the greatest potential to improve energy efficiency and internal conditions through behaviour change.

These four aspects are then drawn together to form an overall view of the building and occupants; establishing any problems clearly, and what to do about them. Importantly, this information is evidence-based and can be shared with clients, occupants and others. Because the basic data tends to come in the form of thousands of individual data points, it is important to develop ways of presenting the data in ways which are easy to understand and which clearly show results and ways forward.



Temperature (°C)-ONE WEEK PERIOD-kitchen, living-room, and bedrooms


Temperature (°C)-ONE WEEK PERIOD-kitchen, living-room, and bedrooms

A key part of reporting on building performance is to make sense of the data in a way which is intuitive. The graph on the left shows temperatures in a house over the course of a week. The shaded area shows the recommended temperatures that should be reached and it should be clear that apart from a few peaks, most of the rooms are not managing it for most of the time. The graph on the right shows the same information differently. There are four rooms, and each room is divided into four time zones, represented by a coloured bar. The graph shows that each room reaches an acceptable temperature (green) for a short period in the evening (when the heating is on) but is too cold (shades of blue) for most of the time.

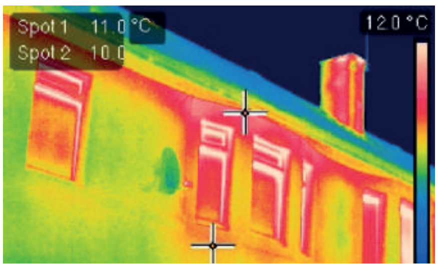
Unintended Consequences and the Need for a Balanced Approach

Although every investigation is different, the efforts of BPE practitioners are increasingly showing trends and patterns of problems encountered which help us understand why energy is not being saved as intended and what effects the focus on energy is having on other aspects. We have drawn heavily on these findings for this guidance because they are based on real results, rather than modelled predictions. Some of the most common problems encountered are discussed below and shown in the table at the end of this section.

Problems with Energy Efficiency

The most obvious finding from most BPE studies is that the savings that were anticipated have not materialised in reality. There are many reasons for this, and they differ across different projects. One of the most common reasons is that people do not behave as expected in buildings. When the discrepancy between predicted and monitored energy consumption has been identified in the past, it is the 'unexpected' behaviour of occupants which has been held up as the reason. There is plenty of truth in this, but it is far from the only reason and it is important that a responsible industry looks beyond this, towards some of the more inconvenient issues.

An important reason is the raft of limitations of the modelling tools used to predict energy consumption and this is discussed in some detail in the following section. Another is poor design, detailing and specification, and Chapter 4 of this guide is an attempt to address some of these shortcomings. Another is the poor installation of materials and components by contractors and this is discussed in the following section on quality and inspection. Inadequacies are routinely found in the design and installation of the building services and one of the most important aspects of this is the various control interfaces which are often poorly conceived and poorly understood by the occupants of the building who then don't use them effectively.



BPE: Thermographic image showing excessive heat loss at the wallhead and around windows. Extra care should be taken to investigate these areas before making retrofit recommendations.

Lack of maintenance can directly affect the energy efficiency of a building, mainly because building fabric which is damp will conduct heat more readily than when dry. In larger organisations like housing associations and council housing departments, maintenance budgets and responsibilities are usually separate from energy efficiency ones, but an important aspect of this guidance is that the two issues are closely related and should be seen as complementary wherever possible.

Energy efficiency is not always delivered as intended, and this also affects fuel poverty aspirations, leading to dissatisfaction from vulnerable occupants and frustration for organisations who carry responsibility for caring for their tenants.

Renovated buildings which use more energy than expected will have a greater carbon footprint, but operational energy—the energy used day to day to keep warm and run electrical goods—is not the only energy impact buildings have on the planet. 'Embodied energy' is the term used to describe the energy associated with manufacturing (and disposing of) a material or component. Many of the materials used in retrofit have very high levels of embodied energy. This is often justified by the fact that such materials save far more energy, once installed, than is used to create them, but products usually exist with much lower embodied energy which can fulfil the same task. In new-build projects, embodied energy often represents around half of all carbon emissions during the lifetime of that building. In retrofit the proportion is normally smaller due to the smaller volume of new materials being introduced, but taking a broader view of energy efficiency means that all savings in energy consumption, and carbon emissions, are to be welcomed.

Taking a further step back, it is possible to identify a phenomenon known as the 'rebound effect'. The most common example of this is that where houses have been insulated, monitored energy consumption does not reduce as much as anticipated because homes and rooms which were previously too cold, are now kept warm. Insofar as this now means people are comfortable when they were not before, this is wholly a good result, but this and externalised activities (like spending the money saved on cheap flight holidays) means that overall, carbon emissions are not always reduced as anticipated.

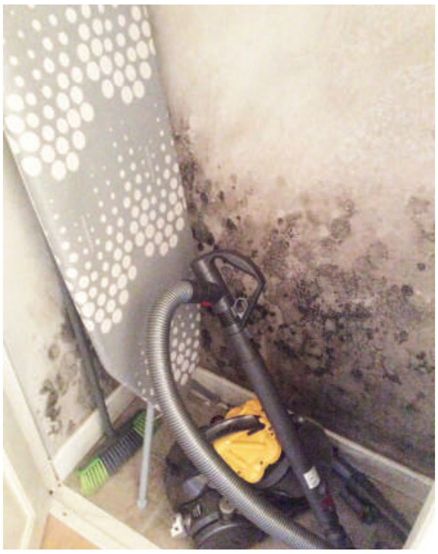
Comfort and Health Issues

The most important outcome of most retrofit works is that homes are warmer for the people who live there. Despite the potential rebound effect mentioned above, any result which allows people to live in comfort is welcome. However, as internal temperatures rise there comes a point at which the home becomes too warm. Such a point is difficult to define because people vary in their comfort thresholds, but there is no doubt that a house that is 'too warm' for whatever reason is not good for health and can become seriously so in extreme cases. Overheating is now a recognised problem in the South of England where well insulated and airtight new homes, and recently retrofitted homes, have overheated significantly, causing discomfort, risks to health and even death in some cases. Monitoring of some low energy buildings in Scotland has shown that despite our higher latitudes, highly insulated and airtight homes that do not take account of the risks are already overheating, creating comfort and health concerns.

Another common consequence of retrofitting buildings is that a combination of improved insulation and airtightness, coupled with *unimproved* ventilation results in warmer, more humid and stuffier air. This has two important implications.

The first is that warmer air carries more moisture and so the total level of moisture in the home increases. This warm, moist air can condense on cold surfaces as described in Section 2.2. BPE investigators routinely find areas of mould on walls, furniture or stored clothing and other areas with reduced air movement. Mould is implicated in a number of respiratory health problems and is clearly an undesirable consequence of improvement works.

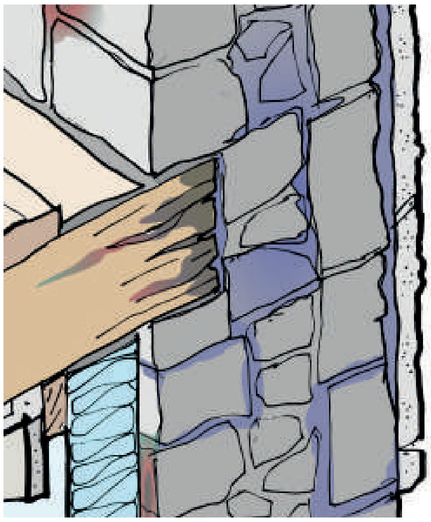
The other implication is that the pollutants that are commonly introduced into internal air from modern lifestyles, furniture and buildings are not ventilated away and can build up. At low levels this 'stuffiness' is not particularly serious, but at higher levels, over prolonged periods, and for some more vulnerable people, it can become a serious health problem. The dual risks of increased humidity and internal pollutants is discussed more fully in Section 4.9 on ventilation.



This cupboard developed mould after this flat was retrofitted with external wall insulation. The insulation didn't extend to the close wall (the cupboard backs onto the close) making this the coldest surface. This unintended consequence creates health risks for occupants and requires additional costs to resolve.

Risks to Building Fabric and Heritage

The same moisture that is causing problems for human health can also cause problems for the building fabric. Condensation left unattended can seep into adjacent porous materials such as insulation or timber and the same is true of water which has got into the fabric from outside due to lack of maintenance. This moisture can saturate materials leading to decay of timber, rusting of ferrous metal components and spalling of masonry components near the outer face of the building. Many millions of pounds are spent each year dealing with the repair and replacement of moisture-damaged components in buildings. Much of this cost could be avoided with a better appreciation of the way moisture moves in buildings, and the need for good ventilation and maintenance.



Moisture which gets into the building fabric from either inside or outside can cause damage to organic materials like timber embedded in the walls, as well as rust in some metal components and spalling in external masonry from the freeze / thaw cycle

The importance of ventilation in helping resolve the problems of moisture and building fabric decay, as well as moisture and human health cannot be overstated. While ventilation doesn't tackle the sources of the moisture, nor of pollutants, it can be effective in dissipating both and should always be considered an integral part of any renovation project.

Beyond the physical condition of the building, inappropriate measures to save energy can have a detrimental effect on the heritage value of a building and this is discussed in greater detail in Section 3.4.

Common Findings in Building Performance Evaluation

Problems with Energy Efficiency	
Energy efficiency not as good as expected	Due to Inaccurate modelling / prediction, inadequate design / specification and installation generally (eg of insulation / airtightness measures), inadequate installation and performance of products, misunderstanding / lack of interest in controls / systems, inadequate maintenance.
Environmental impact increased	Due to above, also high embodied energy of components, or use of rare materials / from vulnerable habitats. Rebound effect.
Fuel Poverty not reduced as far as anticipated	Due to above, lack of comfort + higher costs for energy for vulnerable households, frustrations for occupants and social landlords.
Rebound effect	Increased comfort (higher temperatures) absorb potential savings, unappreciated under-heating of property before retrofit works, savings spent on carbon-heavy items (eg cheap flight holidays).

Problems with Comfort and Human Health	
Surface condensation and mould growth	Due to combinations of low surface temperatures (thermal bridging / bypass), inadequate ventilation (including reduced air leakage) and high internal humidity linked to lifestyle.
Poor Indoor Air Quality (IAQ)	Reduced ventilation / increased airtightness, higher levels of humidity, toxins / pollutants from variety of external and internal sources.
Overheating / temperature fluctuation	Reduced thermal mass from internal wall insulation (IWI) or floor overlay, sometimes combined with heating controls, increased insulation generally, reduced ventilation / air leakage, higher levels of glazing, lack of measures to avoid overheating.

Problems with Building Fabric and Heritage	
Building fabric decay (timber rot / infestation, rust / masonry spalling etc)	Linked to surface temperatures and mould above, build-up of moisture due to impermeable materials used, ingress of rain / leaks (inadequate maintenance / external works), air leakage from inside, inadequate ventilation internally or to cavities.
Changes to external appearance / loss of historic fabric	External wall insulation (EWI) insensitively applied, inappropriate replacement windows, or renewables installations, incongruous alterations especially in relation to street.
Changes in internal appearance / loss of historic fabric	Loss of original features due to removal / IWI, loss of windows, finishes generally, inappropriate services intrusions.

3.2 Reality and the Design and Build Process

The previous section describes how BPE has underscored the need to adopt a more balanced approach to retrofit which values health and comfort issues, and the building fabric as well as energy efficiency. If this more balanced approach could be described as a change in the fundamental direction of retrofit, this section describes three more BPE findings which could be described as weaknesses in the working processes of retrofit as commonly practised.

Modelling vs Reality

There are many reasons for the performance gap described in Section 3.1, but one of the most important is the limitations of the tools commonly used to predict energy consumption. In the UK, for domestic projects, the tool that must be used to show compliance with the building regulations is Standard Assessment Procedure (SAP). Its much simplified brother Reduced data SAP (RdSAP) is used in most retrofit scenarios. Both are described in the adjacent box.

SAP calculations have been a hugely important part of the overall drive to make building construction more energy efficient over the last 30 years or so. By providing a quantifiable method they have enabled the industry to develop far more effective ways of creating energy efficient buildings. Nowadays however, the SAP calculation is above all a *compliance* tool and does not necessarily represent the 'real' energy consumption of a dwelling.

However, the (very significant) trouble with this is that both SAP and RdSAP are almost universally treated as being representative of actual energy consumption. They are used by policy advisors and government officials to provide evidence of both existing and projected energy consumption scenarios and funding regimes (as described in Section 2.1), while at the other end they are used by occupants of homes to understand their own energy bills and potential improvements.

Some of the reasons SAP and RdSAP do not necessarily represent reality are limitations on any prediction tool, others are peculiar to them only. A list of some of the more important reasons is given in the box on the next page.

While SAP and RdSAP have been an invaluable aid in driving forward the energy efficiency agenda, there is a risk that they are also acting as a straightjacket that has the potential to cause problems beyond their own narrow remit, and particularly for older buildings. This is one of the principal lessons to emerge from studying the performance gap but it remains problematic for the industry because SAP remains such a significant determinant of regulation, policy, funding, design and installation criteria.

Both tools are constantly under development. Looking forward, if they continue to be treated as representative of reality by policymakers and the industry, they should be calibrated against 'real' monitored results which would give greater confidence that we are basing our regulation and policies on sound data.

Reality

It is the real carbon dioxide emissions which cause climate change, not the predicted ones, the real energy bills which create fuel poverty, and it is what happens on building sites that determines the real performance of a building, which is why we need to focus on what happens in reality, not on spreadsheets

SAP AND RDSAP

The Standard Assessment Procedure for the Energy Rating of Dwellings (SAP) was developed by the Building Research Establishment (BRE). It first appeared in the early 1990s and was first cited in the UK building regulations in 1994. Since then it has been the default methodology used by the UK (and Scottish) Government for calculating the energy performance of dwellings, and this role provides the compliance route for all domestic projects submitted to the building warrant process. SAP is a detailed calculation looking at floor areas, window layouts, construction elements and all services installations. As such it is arguably too onerous when applied to the large numbers of existing dwellings which need to be retrofitted across the country. Thus RdSAP (Reduced data SAP) was developed to simplify the process for surveyors establishing the most suitable improvements for existing homes under government-backed retrofit initiatives.

Quality, Coordination and Inspection in Construction

Many buildings are designed by architects and checked by building control, both of whom have an overview of the project. Both are then engaged in maintaining that overview during construction and have a role that is independent of the client and the builder. In many cases, a clerk of works is also employed by the client to keep an eye on things on site on a day-to-day basis. No system is perfect but the key thing is that there are often three qualified people who are responsible for a coordinated overview of the construction, as well as a responsibility to inspect and review quality on site.

In many contemporary retrofit projects, none of those three roles are now involved. Architects tend not to be employed for the large-scale energy efficiency upgrades which affect the homes of many thousands of people in Scotland. Levels of regulatory involvement by building control vary across the country, but on the larger scale energy efficiency upgrade projects, they tend to restrict themselves to a limited series of paperwork compliance issues to be provided in advance of the works. In many cases, housing associations and council housing departments do not even employ a clerk of works who is independent of the builder.

In this way, for many projects—and in particular projects expected to deliver the carbon emissions and fuel poverty reductions demanded by the Scottish Government—there is often no-one with a overview of the building in its entirety, nor someone with an independent role to inspect quality on site. In every case, contractors will provide their own coordination and inspection services, but it is naive to imagine that standards on site will always remain high when there is no independent check.

As regulatory standards of energy efficiency increase, demands made of contractors are increasing. These demands include a higher standard of workmanship than previously required, but also the inclusion of relatively new procedures, such as the additional demands of airtightness and renewable energy systems. Complexity is increasing, design and specification information is not always up to scratch and being generic, is not always appropriate for all building types. All of this is also set against an economic context in which clients are under pressure to reduce costs, so profit margins and tolerances in the system are being worn down.

Under their own pressures, contractors, their designers and suppliers undertaking energy efficiency retrofit projects tend to 'design to SAP' meaning that works are specified simply to tick the relevant boxes in the SAP or RdSAP calculation. This is reasonable because it is the only major regulatory hurdle to be cleared in the process, but as discussed above, these calculations are 'defect-blind' and cannot provide guidance on site quality issues.

There are some checks in place on retrofit projects. Manufacturers usually provide guidance on how to use their products and many offer warranties on the use of their products provided they are installed as required. Most warranties only apply to that product or system however, and can say little about their interaction with other components or areas which have been missed on site. There are also a number of training and certification programmes on offer for builders and all related trades. Some of these operate at a very high level, but a great deal of workmanship is well below acceptable standards.

Some Issues with SAP

SAP makes assumptions about how people will act in a building in order to compare buildings fairly. However, people actually maintain their homes at considerably different temperatures so it is impossible to accurately overlay the assumption made by SAP onto actual energy consumption and fuel bills.

SAP cannot predict the actual quality of the construction, despite a number of input points that allow it to go some way towards this. When buildings are built or retrofitted poorly the actual energy consumption increases relative to the assumptions made by the calculation.

While SAP shares much of its basic structure with other energy prediction tools, there are variations in the assumptions and weightings it gives specific items. For example, SAP is very responsive to changes in boiler choice, but relatively unresponsive to changes in airtightness and window configuration.

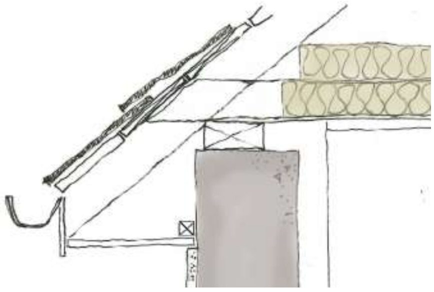
Unlike some calculation methodologies, many of the assumptions and algorithms that lie beneath the surface of SAP are hidden and not accessible, so it is not possible to adjust to suit different circumstances, nor to understand why certain default figures are chosen.

In parts of the calculation, SAP assumes that all buildings are located in the centre of the UK, near Derby to be precise! This meant that increasing latitudes South and North of this location would lead to increasingly misrepresentative results, with buildings in Scotland almost certainly performing worse than predicted.

The main EPC rating is not based on energy efficiency but on energy cost. This is helpful in assessing affordability but creates unintended consequences, with cheaper fossil fuels being encouraged in some cases. Stated carbon emissions are based on 'carbon factors' which are often quickly out of date, again skewing the value of the results.

The main output of SAP is a relative improvement over a notional building of the same form. This means that absolute performance isn't measured, preventing any real assessment of impact or progress. This approach also makes it easier to pass with inefficient forms, thus disincentivising some of the simplest and most cost effective ways to reduce energy consumption.

BPE has highlighted a number of issues in relation to quality on sites but two stand out as important. The first is the need for a sufficiently skilled person to have an *independent overview* of the whole building, ideally with responsibility that extends beyond funded energy efficiency measures to issues like maintenance, building condition generally and indoor air quality. The second is to have a skilled person (potentially the same) who has a role independent of the builder to inspect quality of construction. The goal is to have buildings which perform in reality, as well as predicted. Under PAS 2035, this person is the Retrofit Co-ordinator but even if PAS 2035 is not being used, there should be somebody undertaking this role.



A solid concrete walled housing block required EWI which was to extend to the underside of the soffit board. The soffit board was to be retained as it was asbestos and too costly to remove, also it was not part of the energy efficiency works.

Moisture

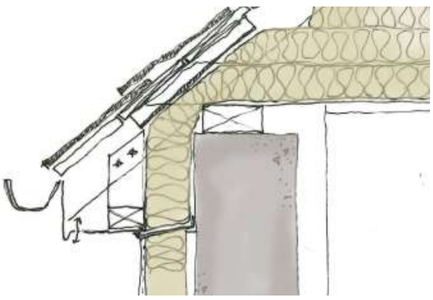
The issue of moisture is implicit in several of the subjects discussed so far, but its importance makes it worth separate mention. At a basic level we all know moisture is important: roofs and walls keep the rain out and most people know to open a window after a shower. However, our sensitivity to changes in moisture around us is not well developed as noted in Section 2.2 which means we are not well equipped to know when the relative humidity in the air in our homes might lead to problems, until it is too late.

In addition, it was found that the existing loft insulation did not extend over the wall-head, but this was not considered part of the contractors package of works

The building regulations deal extensively with moisture; ensuring that water from outside cannot penetrate from the sky or the ground, and also ensuring that moisture generated inside our homes cannot enter the building fabric, and is safely vented away. Interstitial condensation calculations are usually required for new build projects. However building control compliance is rarely required in retrofit projects and so these checks are not made.

The principal regulatory issue for most retrofit projects is the need to comply with the requirements of RdSAP. Beyond cursory assessments of exposure to the weather neither SAP nor RdSAP recognise the importance of moisture and the difference it can make *in reality*.

It is possible to model moisture movement in buildings, both in the air and in the building fabric itself using 'hygrothermal' modelling software such as 'WUFI' and 'DELPHIN' as well as detailed analyses such as 'ESP-r' but all of these models are complex and therefore both time-consuming and expensive to undertake. A small number of specialists provide such calculations in association with their products but on the whole this is not undertaken in most retrofit projects.



If the works had gone ahead as planned there would have been a large gap between the EWI and the existing loft insulation, creating a significant thermal bridge. However an independent consultant was brought in to provide an overview and it was agreed to extend to the EWI contract to include removal of the soffit boards, bring the loft insulation over the wall-head and extend downwards to meet the EWI, thereby closing the gap, closing the performance gap in heat loss and reducing the risks of condensation and mould internally.

Thus, we are left in the situation that in many retrofit projects, the issue of moisture is not addressed in any formal sense, despite the fact that it is critical to the performance of the energy efficiency upgrade, the health of the occupants and the longevity of the building.

The problem is compounded by the fact that modern, impervious materials are often used, which then direct moisture in unexpected ways, and further worsened by the fact that ventilation—which can reduce the worst effects of excess moisture inside buildings—is not included in the upgrade works because it is not considered an energy efficiency measure.

3.3 Occupant Engagement

Although we design and build buildings, it is people we are trying to keep warm and healthy, so it is people—and the way they interact with buildings—that we need to understand.

The largest variable in energy efficiency in practice is often nothing technical to do with insulation or airtightness, but the variability between the ways in which different people use the buildings they inhabit.

Although this is widely understood, the subject remains outside the remit of almost everyone involved in the construction industry. If people want to leave their heating on full and their windows wide open there really is nothing we can do about it. Although this is true, and the urge to 'make people do the right thing' is moving into ethically ambiguous territory, the scale of the issue and the benefits that could accrue from some form of 'occupant behaviour engagement' make this a subject with which everyone within the industry will have to become increasingly involved.

The lessons to be learnt are equally valuable to homeowners contemplating their own retrofit as to large-scale landlords such as councils or housing associations, but while it is easy for the homeowner to act directly as they see fit on the basis of this guidance, it is not so simple for the landlord and some sensitivity is required.

Engagement, Understanding and Controls

The act of engagement involves three related tasks. The first is to educate occupants as to the background issues and reasons for greater engagement. Grasping the benefits of greater energy savings, better comfort levels and indoor air quality, and avoiding condensation and mould in their own homes is easy to do without the need for complex instructions and reasoning. It is easier still when specific problems have already arisen, for example where children have developed respiratory problems or where it is proving difficult to keep some areas of the home adequately warm. Meaningful engagement which encourages 'good behaviour' can also help reduce the 'rebound effect' noted in Section 3.1.

The second and closely linked aspect is to encourage engagement with the controls and mechanisms of the home. It is sometimes surprising how little people understand of the way their home is controlled, especially given the costs involved. The best time for this engagement tends to be when specific works are undertaken. Thus in retrofit projects, it is imperative that the commissioning and handover section is carried out carefully and thoroughly. The onus is often on the contractor here at a time when they are near, or at, completion, with competing pressures, and difficulties in co-ordinating times when the occupants are at home, so systems often aren't properly explained.

A digital control panel for heat recovery mechanical ventilation system. It's relatively clear for most people to use, but the complexity puts some off, and others don't like a touch-screen interface, preferring an 'old-fashioned' dial or buttons

The third aspect of engagement is to ensure that controls (such as thermostats) are *designed* to be clear and easy to manage. This aspect is worth mentioning because it is often overlooked and BPE practitioners often come across controls interfaces which make little sense. The problem is that the design and specification of controls tends to fall to sub-contractors (usually electricians) who install whatever is simplest and most easily available. Controls are often not intuitive, do not say what they control, or offer a range of options which do not make sense. The onus here is on the designers and specifiers of the heating and ventilation systems to engage meaningfully with those who will use their products.

Recommendations

The following suggestions will enable occupants to better engage with their homes and provide greater understanding and control over their bills, comfort and air quality.

At Design / Procurement Stage:

- Consider the sections on heating and electrical equipment, both of which contain guidance on how to reduce costs, but also to increase control over the various systems in the property.
- Ensure suitable 'smart' meters for both heat and electricity are installed with interfaces in prominent / commonly used locations to allow for immediate and intuitive feedback on energy consumption, with current figures and memory data allowing comparisons of current use, for example with previous year / month / week etc.
- In addition to fire and safety alarms, consider hardwired indoor air quality sensors with visual interfaces to main rooms, offering instant feedback about temperature, relative humidity, CO and CO_2 levels as a minimum. (CO_2 monitors are now required in new build homes for bedrooms).
- Agree a strategy to ensure all controls are considered as part of the design. All controls for heating / cooling and electrical items should be agreed with the client either as a particular specification, or a performance specification. Issues might include engraving of switches, neon indicators to show when items are 'on', consideration of type of switch (eg. on/off switch or dial, 'rocker', dimmable, LED display etc.) A useful guide is provided by the BCIA (Building Controls Industry Association) entitled 'Controls for End Users'.

At Commissioning & Handover:

- Ensure commissioning process is rigorously carried out, ideally with individual sign-off sheets for all major systems.
- Ensure all handover procedures are carried out carefully. The NHBC Foundation has published a guide on best practice and there is a good deal of other guidance around. Timing is critical so people are sufficiently familiar with controls and not trying to take on the information as they physically move in.
- For larger housing organisations, it may be worth creating a role to specifically help tenants with their systems and controls. This can be carried out at handover, but can also be an ongoing service for all tenants. Renfrewshire Council employed a suitably trained person specifically to speak to all tenants and ensure they understood their own systems and could set them to achieve the optimum levels of comfort and cost savings in relation to their individual lifestyle.
- Quick start guides are now required for all new homes in Scotland and a similar approach could be taken with significantly renovated properties, especially where services such as heating or ventilation have been changed. Quick start guides should provide a clear and succinct account of how to use all of the main equipment in a home, but also the benefits of doing so.

An example of a quick start guide, which briefly, clearly and graphically explains the principles and systems of a new home

3.4 Retrofit and Conservation

Heritage

Some of the good practice in the conservation sector would significantly improve the effectiveness of the retrofit sector, so we have picked out three particular aspects we believe would add value.

Until quite recently, efforts to improve sustainability and energy efficiency in the built environment were focussed on the new build sector, largely through incremental improvements to the building regulations. However, it has become more widely appreciated that to address climate change and fuel poverty, it is critical to begin to address the existing building stock in a systematic way. The majority of energy efficient upgrade work funded by Scottish Government is undertaken by the retrofit sector as described in the box on the right. The goal is to reduce energy consumption in buildings, and although this is being achieved, it is the sector where the concerns noted in this document are greatest and where the greatest potential lies for improvement.

Meanwhile, the conservation sector has been busy refining its own approach to sustainability and the preservation of that small but important number of buildings for which it has responsibility. Having developed from the perspective of protecting important historical buildings, monuments and landscapes from insensitive development or demolition, the attitude of most conservation bodies has traditionally been one of resisting change as far as possible, whilst acknowledging in principle that some change is inevitable. Within parts of the conservation movement however, there is now a more open approach and greater willingness for compromise and dialogue on integrating the traditional conservation approach with energy efficiency and wider sustainability aspects.

This is encouraging, but lessons can also be learnt the other way around. The conservation movement has developed over many years a sophisticated and practical understanding of older buildings and how they need to be treated. That knowledge is not moving in the direction of the wider retrofit sector fast enough and is an important aspect of this guide.

In essence the issue is one of quantity and quality. The goal of the retrofit sector is to reduce carbon emissions and reduce fuel poverty and so the more buildings that can be upgraded the better. As discussed, the existing mechanisms used are relatively blind to quality and tend to over- emphasise quantity. The goal of the conservation sector by contrast is to faithfully preserve and manage the legacies of our built heritage and the emphasis has always been very much on quality, both of materials and processes.

Both approaches have been partly successful on their own terms. Completed publicly funded conservation projects are exemplary in their approach but there simply isn't the money available to lavish that degree of care and attention on the many scores of thousands of older buildings that form the core of our cities, towns and villages. The publicly funded retrofit sector by contrast has upgraded many thousands of properties, but as discussed, has not achieved the savings anticipated in many cases, creates a range of unintended consequences, and is at times complicit in the loss of architectural and cultural character of places.

There is no doubt of the overarching imperative of climate change but an important part of this guidance is to take some of the lessons learnt from the conservation sector and apply this to the retrofit sector. Not only will this lead to improved energy savings, it will provide benefits on a wide range of other fronts.

The Retrofit Sector

This sector has sprung from the acknowledgement that to meet emissions targets worldwide, governments must extend efforts to make the existing built stock more energy efficient. In Scotland, the primary agent is the Scottish Government, with links back to UK and European legislation.

Other important agents have been the larger manufacturers and contracting companies who provide the bulk of the materials and labour between them. Recent initiatives have involved the large energy and utilities companies who have delivered much of the most recent retrofit works in Scotland through extensive outsourcing.

The Conservation Sector

The first conservation organisation was the Society for the Protection of Ancient Buildings initiated by William Morris and others in 1877. The National Trust was formed soon after in 1895 and the sector now comprises a great many organisations in the UK and worldwide that share concern for the protection and sensitive maintenance and refurbishment of historic buildings, monuments and landscapes. There is a great deal of overlap between those organisations primarily interested in buildings, and those concerned with the greater conservation of natural environments.

Some of the work of the sector has been absorbed into government and become part of statutory processes such as the listing of important buildings. In Scotland the principal agent is Historic Environment Scotland (HES) while conservation officers form part of the planning departments of most local councils.

Different Construction Principles and Materials

The first lesson is an understanding that older buildings, especially those built before 1919, were constructed quite differently from contemporary buildings in some important ways. Some of these differences can be partly attributed to the fact that people behaved differently and had different expectations, thus traditional buildings were not required to achieve some of the things we ask of them nowadays (insulation and airtightness in particular) but even allowing for this the following describe some significant differences:

- As discussed above, older buildings manage moisture quite differently, and rather than apply modern approaches to moisture management, approaches which more closely match the original principles and construction will result in better performance in the long term. The need to provide greater airtightness complicates this aspiration but the use of ‘breathable’ (vapour permeable) and hygroscopic materials allows for a closer correspondence with original intentions while also reducing heat loss.
- Until the arrival of concrete and cement, most older buildings were built to be flexible, tolerating the various small and slow movements characteristic of buildings. This is in contrast to much modern construction which is often rigid and brittle, meaning that the inevitable movement of buildings can lead to cracks and other problems. Using inherently flexible and slightly more ‘forgiving’ materials will lead to better performance and fewer problems in the long term.
- Older buildings tended to use fewer elements, many of which performed a number of roles in the building, in contrast to modern construction which tends to use many more components, each of which have a single and targeted role to play. Retrofit solutions using fewer elements to achieve a number of goals are likely to ‘fit in’ better than more complex alternatives.
- Traditional buildings used a limited palette of mainly natural materials which gave them and the local area a character which is now highly valued. Modern designers and contractors have a huge range of materials to choose from but some sensitivity to the local and natural options can only help solutions to look and perform better in context.
- Maintenance of internal and external finishes was assumed in traditional buildings. This is generally seen as unwelcome nowadays, but there are long term benefits from this approach as discussed below.

This solid stone wall has been re-pointed with a cement mortar instead of a lime based mortar. As the masonry has moved over time, this has caused cracking in the mortar—the patching of which is clearly visible. There are other cracks too small to see at this scale, but these allow rainwater into the stonework which is saturated. Evidence of this is the salt staining which can be seen leaking out at low level in particular.

Maintenance

Nowadays, the concept of maintenance is much maligned and manufacturers go to considerable lengths to promote 'maintenance-free' products and systems. This fits well with our social and cultural norms of 'time-saving' devices and with many leading busy lives, there is undeniable value in this. By contrast, the conservation approach—and the approach of this guide—is to consider potentially higher quality items at the outset which need to be, or at least benefit from being, maintained regularly.

There are three benefits which accrue from this approach. The first is that by reflecting the original intentions of the design, solutions achieve a degree of philosophical and practical correspondence which 'fit-and-forget' solutions could never achieve. The second and third benefits relate to the fact that despite the initial cost, well-designed and installed higher quality components which are maintained will outlast a series of cheaper solutions which are inevitably replaced. This leads both to cost savings in the long term and to reduced resource consumption—less disruption and waste.

Examples of this approach include the use of traditional Scottish slate detailing which by using a single nail instead of two allows for much simpler replacement, the choice of wooden windows which, when maintained can last for hundreds of years, and the use of lime mortar which has a number of long term benefits over cement. It is worth saying however, that this approach requires a commitment that maintenance will take place from those responsible, and the careful choice of components and materials to allow this to be a simple and cost-effective process.

Significance and a Good Survey

The house surveys undertaken to generate the RdSAP calculation are cursory and work with a large number of default settings which speed up the process, but do not allow for more than a passing understanding of the property, and indeed are often quite wrong.

By contrast, the conservation sector takes the issue of a survey very seriously, and in most cases this would include an in-depth survey and investigation of the building leading to a broad understanding both of the construction and condition of the building, but also an understanding of its history, in order to better understand its significance. If there are idiosyncrasies in the building, these are to be respected. This significance can be quite obvious physically, for example, an ornate stone façade, or it can be quite hidden, related to a unique view, being part of a greater whole, or the fact that someone famous lived there. The point is that this significance, however it is derived, is allowed to determine the appropriateness of subsequent measures.

There is no way the resources used in typical conservation projects could be applied universally, nor would this be necessary in many cases, but there is no doubt the current level of understanding needs to be raised in the retrofit sector. A better knowledge of the property in advance, coupled with the sort of awareness of the differences in construction described above, could lead to much more effective and appropriate solutions.

Equally, it is important that the unique or noteworthy characteristics of Scotland's buildings are respected and retained, not lost beneath a well-meaning blanket of insulation. To achieve this, the initial survey needs to be more detailed and nuanced. It is also important that some level of judgement and flexibility is included in all retrofit works in order to preserve the unique features of our buildings and the places they characterise.

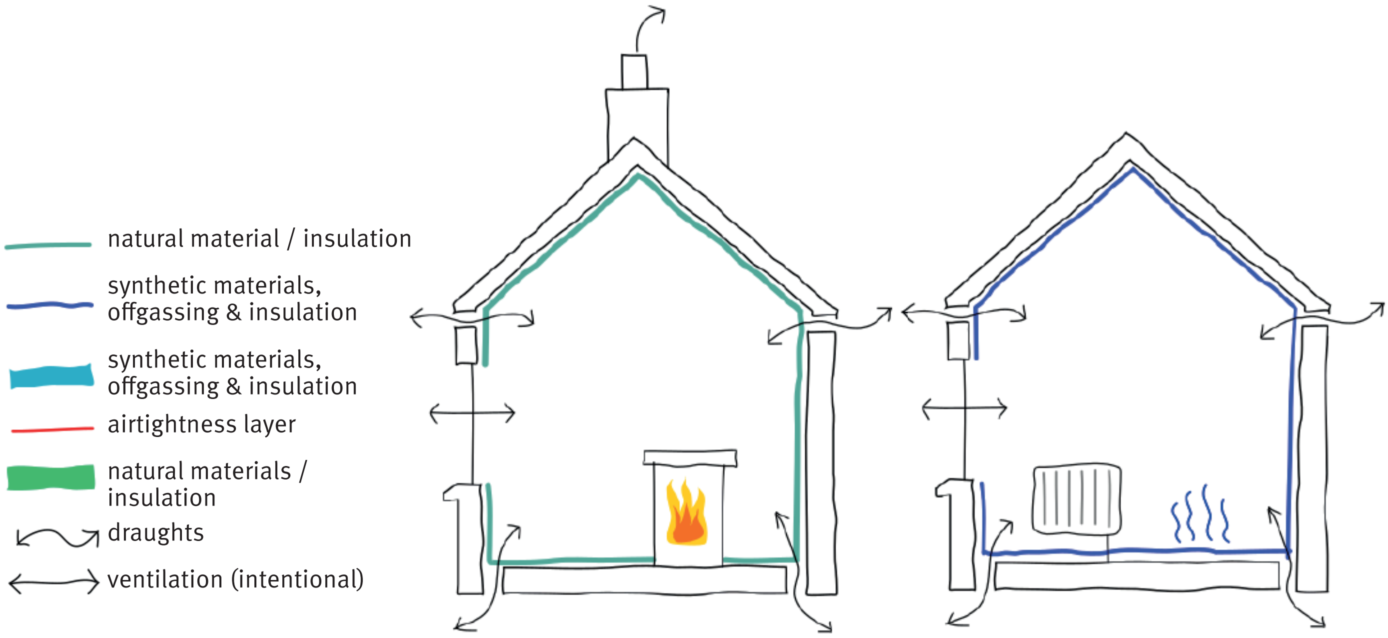
3.5 A Different Approach

Over the course of the last four sections we have discussed the four primary objectives of this guidance; to achieve a greater balance, to focus more on *reality*, to better engage people, and to take on board some of the lessons of the *heritage* or conservation sector. Within these four, we have highlighted ten issues which, if adopted conscientiously, would achieve these objectives and significantly improve retrofit practice in Scotland.

In this section, we provide an overview of this approach to give some context for the more detailed suggestions made in the following chapter.

The diagram below looks at how we have been approaching buildings in the last 100 years or so. The diagram is not meant to be perfectly accurate and of course is a huge generalisation, but it helps to provide some context and history to the way we are approaching renovation in this document and how this differs from other guidance. What it does not show is how we value the heritage of a building but the six 'streams' below indicate different outcomes to the general approach adopted in each period shown.

Up until perhaps the Second World War, buildings were largely draughty and uninsulated, making them expensive (in cost or effort) to keep warm, so people often kept only some of the rooms comfortable. Materials were largely natural and non-toxic (although there was lead



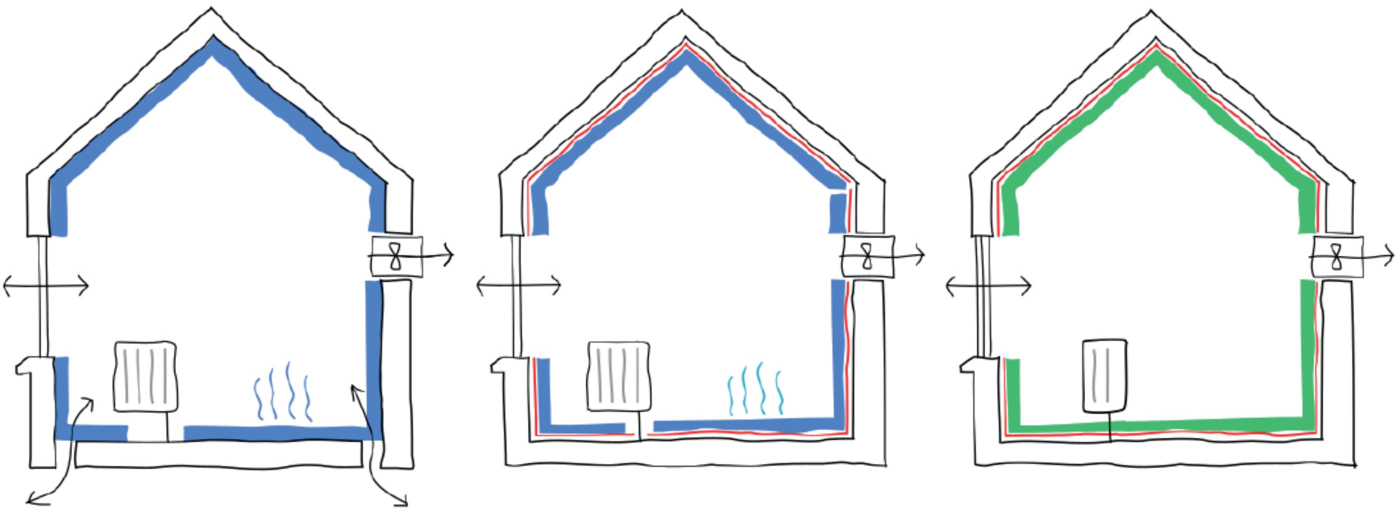
	› 1945	› 1970s + synthetics
TEMPERATURE	Cold	Cold
AIR MOVEMENT	Draughty	Draughty
AIR QUALITY	Good IAQ	Poor IAQ
COST TO HEAT	£££	£££
MATERIALS / FINISHES	Natural	Synthetic
DURABILTY	Robust	Less robust

in paint) and so on the whole, due also to the draughtiness, air quality was good. The draughts which made the houses cold also kept them dry and because maintenance was often more accepted as part and parcel of life, the houses could last well and were relatively robust.

In the 1970s, the biggest change was the sudden expansion of synthetic materials, particularly surface finishes which were often wipeable or stain-resistant or had some other practical advantage. What was less well appreciated is that these 'modern materials' introduced some fairly unwelcome vapours into homes, as well as other sorts of hazardous items such as asbestos, which are better known.

After the early 1970 oil crisis, the 1980s saw the building industry slowly start to introduce insulation in recognition of the need to conserve energy. Levels of insulation required have risen steadily ever since, making homes cheaper to keep warm for most. However, the overall quality of workmanship and materials being used was deteriorating, the complexity was expanding and overall, houses were becoming less robust.

In the first few years of this century, we began to get more serious about airtightness. This has improved energy efficiency once more, and combined with improved insulation levels has genuinely made homes easier to keep warm and more comfortable for most. However, the reduction in draughts has not been balanced with an improvement in ventilation. In addition people now use homes very differently from how they used them 50 years ago. We produce much more moisture in our buildings, and the plethora of synthetic materials and electronic



1980s–2000s + insulation	2000–2020 + airtightness	2020 › + ventilation – toxicity
Warmer	Warm	Warm
Still draughty	Airtight	Airtight
Poor IAQ	Poor IAQ	Good IAQ
££	£	£
Synthetic	Synthetic	Natural
Less robust	Not Robust	Robust

equipment common in most homes now combine to create sometimes serious issues with indoor air quality about which most people are largely ignorant. Without draughts or properly designed ventilation systems to disperse this pollution, we are creating homes which pose clear risks to our health, and to the long term durability of the buildings themselves.

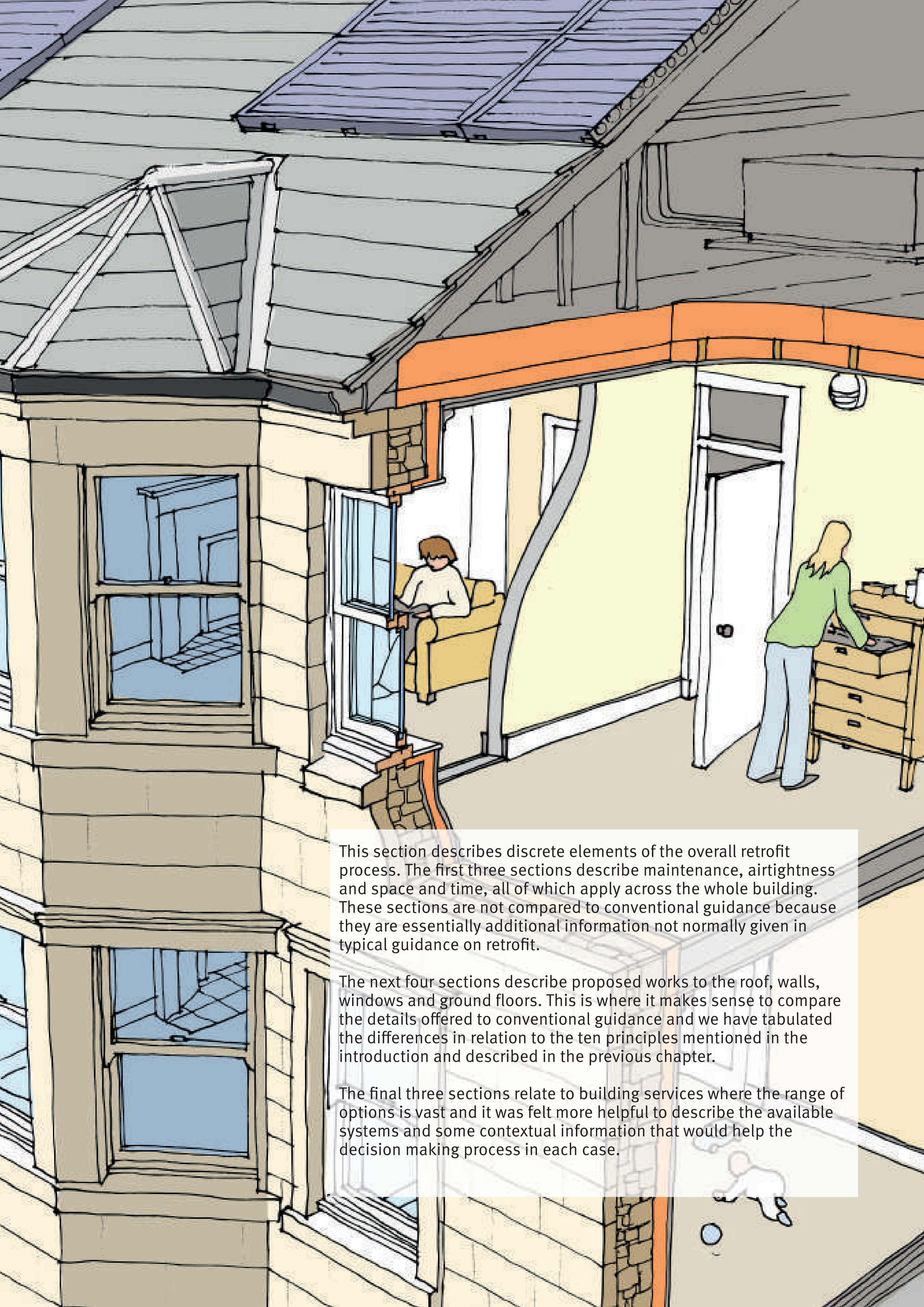
This document therefore sets out to achieve the final diagram. In this, buildings are carefully insulated and airtight (usually) making them easy to keep warm. However, they are completed using largely natural materials, or at least materials which do not pose a risk to health, and they are carefully ventilated, meaning that neither moisture nor air quality remain a concern. In this way we resolve the energy efficiency problem, but we also resolve the problems associated with air quality, moisture and long term durability of our buildings.

Another way to show this approach is to provide a case study. The table on the next page summarises the sorts of decisions that might be made for a pre-1919 terraced home in a conservation area, where a balance has to be struck between a range of competing elements, not least cost. The case study is based on a similar example provided by the Sustainable Traditional Buildings Alliance (STBA).

Hopefully it is clear from the brief description that the measures taken effectively reduce energy consumption, but also improve the health of occupants by reducing excess moisture and improving internal air quality (IAQ). At the same time the building fabric is protected from the effects of excess moisture and cold, while the heritage value of the property is preserved and indeed enhanced, at least from the street. Importantly, the residents have been involved in the decision making, now understand the systems installed and are committed to an ongoing monitoring regime to ensure conditions remain good.

Case Study – Georgian terraced town house in poor condition
Some options for a balanced renovation approach undertaken for a young family

CONTEXT		
Location / orientation	Subject to driven rain at front but rear elevation (to north) stays wet due to lack of wind and sun.	
Form and condition	Bad pointing, leaky gutters, high ground levels. Chimney stack in poor condition, some dampness in walls and floor joists.	
Heritage / community	Conservation area. Local stonework front & back with brick & cement render extension to rear. Fine window details. Internal cornices. Original timber floors.	
FABRIC: *BEFORE*	**FABRIC: *AFTER***	
Uninsulated 500m stone with lath and plaster finish, slate roof OK condition	Vapour open EWI to the rear & extension. Insulated lime plaster internally at front, lime repointing & stone repair to front elevation. Repairs to chimney & gutters, flashings replaced, slate work patched.	
Single glazed sash windows. Old shutters previously removed	Shutters reinstated & working, reveals insulated, double glazed unit in existing sashes, draughtstripped and redecorated, thermal roller blinds / insulated curtains.	
Partially insulated roof space	Existing insulation re-laid neatly and overlaid with new to 300mm, no gaps, including hatch. Airtightness improved. Roof ventilation maintained.	
Uninsulated timber floors to front rooms	Timber floors lifted, draught proofed and insulated, lowered ground levels externally, ventilation checked to solum beneath and enhanced.	
SERVICES: *BEFORE*	**SERVICES: *AFTER***	
1980's era gas central heating	New condensing boiler; TRVs in all rooms; set back heating controls. Radiant heating panels in bathroom and kitchen.	
No ventilation; windows and flues blocked shut	All windows brought back into use. Whole house MEV ventilation, with humidity-sensitive demand control. (airtightness improved due to other improvements, minimal disruption)	
No renewables or low carbon technologies	Photovoltaic panels to contribute towards electricity demand. Waste water heat recovery for upstairs shower (high disruption but 45% reduction in hot water costs).	
PEOPLE: *BEFORE*	**PEOPLE: *AFTER***	
Young family. Children have asthma. No interest / understanding of building health or energy	Designer and contractor work with owners to increase understanding of occupant role in building health, energy use and importance of maintenance. DIY loft insulation, regular use of shutters / curtains at night, ongoing monitoring of key spaces for energy and air quality. More engaged.	
WHAT MATTERS	**BEFORE**	**AFTER**
Energy / Environment	Above average energy bills. Above average CO_2 emissions.	60% or more reduction in energy (gas and electric) bills and CO_2 emissions, now considerably lower than UK average. Ongoing monitoring.
Comfort / Health	Cold / expensive to keep warm. High RH in bathroom leading to mould here and elsewhere. High VOCs in kitchen. Children asthmatic. Low levels of comfort and health.	Rooms are now drier, no mould on window reveals. RH and VOCs now safe for health/fabric and monitored. Health improvements for all the family.
Building Fabric / Heritage	Conservation area. Original sash windows. Original cornices in front rooms. Decay in roof timbers. Dampness in walls.	Front elevation retained / improved by re-pointing etc. Sashes preserved/ maintained. Part of cornice covered. Timber decay arrested by drier conditions. Walls dried out.



This section describes discrete elements of the overall retrofit process. The first three sections describe maintenance, airtightness and space and time, all of which apply across the whole building. These sections are not compared to conventional guidance because they are essentially additional information not normally given in typical guidance on retrofit.

The next four sections describe proposed works to the roof, walls, windows and ground floors. This is where it makes sense to compare the details offered to conventional guidance and we have tabulated the differences in relation to the ten principles mentioned in the introduction and described in the previous chapter.

The final three sections relate to building services where the range of options is vast and it was felt more helpful to describe the available systems and some contextual information that would help the decision making process in each case.

4. WORKS

4.1 Maintenance

The Importance of Maintenance

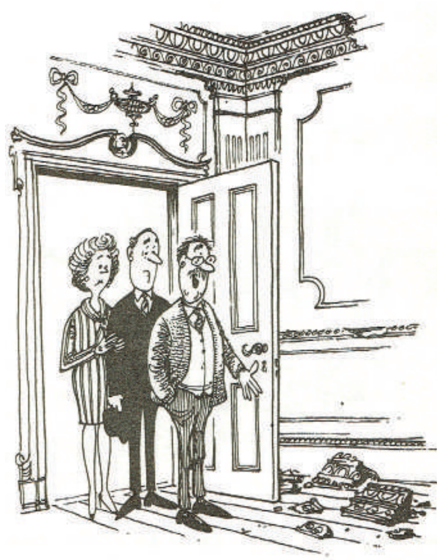
In this document, we assert the importance of maintenance as a prerequisite of any works to improve buildings. There are many reasons given to undertake regular and comprehensive maintenance on your property:

- property in good repair will tend to be worth more and will sell faster if on the market
- minor repairs which cost relatively little, left for longer periods, can cause extensive damage and end up costing far more in the long term
- in general the cost of repairs is increasing faster than the cost of inflation
- poorly maintained buildings can lower the value of property in the surrounding area
- as climate change begins to bite, we will see more extreme weather. In Scotland it will become wetter and windier, putting a greater strain on the external fabric of buildings
- owners of buildings have a duty of care to ensure the safety of the general public. Unmaintained elements of the building can fall and injure people below, sometimes fatally
- our older buildings are a valuable and often irreplaceable resource and from the perspectives of both sustainability (resources and embodied energy) and cultural heritage, we have an obligation to care for these so that subsequent generations can enjoy them as we have
- caring for and maintaining historic buildings means supporting a wide range of traditional skills and techniques which, like the buildings themselves, are important to retain

A further reason, less commonly discussed, is that good maintenance is a necessary prerequisite of energy efficiency. Leaks, blockages and cracks in roofs and walls can all allow moisture into the fabric of a building causing all manner of problems. Damp patches, mould and rotten joist ends are all commonly acknowledged as issues arising from poor maintenance but another, unseen consequence is that saturated materials conduct heat more effectively, 'wicking' warmth from a building, while gaps in buildings can allow cold air in, and warm air out.

On many retrofit projects, delays and additional costs are incurred due to uncovering things like rotten rafter or joist ends, damp patches in stonework or rusting metalwork which then need to be repaired. In short, regular maintenance would result in many expensive retrofit projects not being required at all, and saving a good deal of money in those that are undertaken. While regular maintenance work costs money, it is rarely as much, in the long term, as the alternative.

Much of the basic investigation work can be done by anyone, but it pays to have a professional undertake a more detailed investigation, particularly where access isn't safe or straightforward, or where cause and effect are not obvious.



"They don't make ceilings like that anymore."

Poorly maintained buildings can lower the value of your property.

© The Estate of Norman Thelwell

The Myth of Maintenance Free

Traditional buildings on the whole were built to wear and weather relatively well as long as they were maintained. We know this works well because we can see the results of buildings built many hundreds of years ago. Products marketed as 'maintenance-free' purport to have escaped from the natural processes of weathering and wear and tear which is impossible in reality, and while in practice they may extend the period between maintenance, this is usually at the cost of being 'non-maintainable' meaning that the whole component needs to be replaced at the (inevitable) end of its service life. Not being maintainable, another problem can be when sub-components (like window handles) break, requiring the replacement of the whole unit.

Roofs

One of the most common problems is of blocked gutters and downpipes

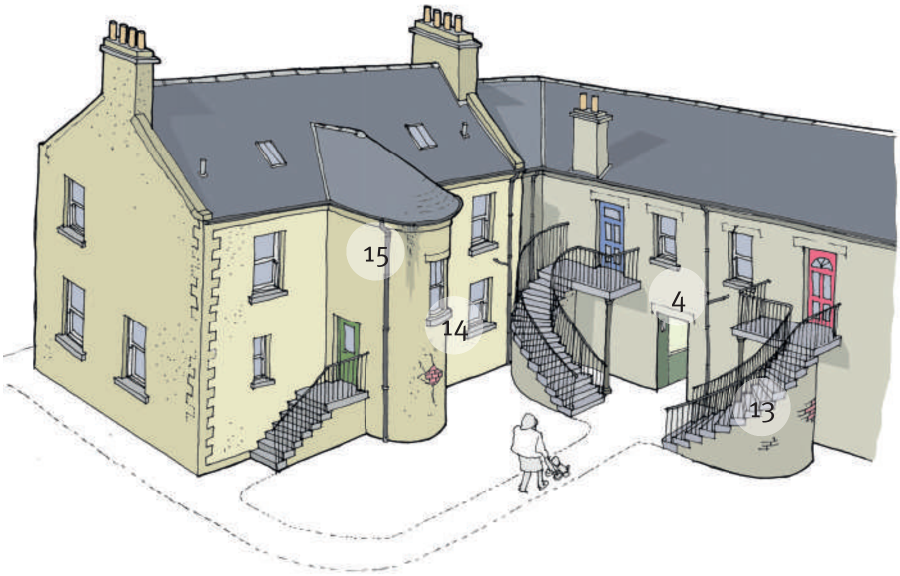
The roofscape takes the brunt of the weather, so it is the area where maintenance is most important. Being at the top of the building and factoring in gravity, problems with a roof can lead to problems through the whole building. As climate change brings more extreme weather, the importance of maintaining a weatherproof roof will only increase. At roof level, (ideally using binoculars) check:

1. slates or tiles which may have slipped or been damaged, sometimes slates are lying in the gutter below making it easy to see the problem
2. various flashings including the ridge flashing, valleys, parapets and abutments. In some cases these are formed by cement, which tends not to last as well as traditional lead or other metal flashings
3. dislodged, leaking or overflowing rhones (gutters) and downpipes. Problems are more obvious when it's raining, while at other times the giveaway sign is staining on the wall behind. It is also important to check that fixings for gutters and downpipes are adequate
4. occasionally waste pipes will have problems, especially in cold weather where smaller amounts of water within freeze and create blockages
5. chimneys and chimney pots
6. loose or damaged stonework, on chimneys or wall copes which could potentially dislodge and fall
7. plant growth anywhere on a roof is a bad sign. Plants tend to hold onto moisture, increasing the risk of other moisture related problems while roots grow and eventually cause problems as they expand.

Common areas requiring regular review and sometimes maintenance

Internally, check for damp patches which could indicate an external problem that isn't otherwise noticeable. It is also important to look in the loft if that is possible. It is possible that water getting in can run from the source of the problem to a low point somewhere else making problems harder to identify. Where insulation has become soaked or timbers moist, it is important to remove anything wet immediately and set about trying to ventilate the area.

Access to the roof is an issue. If the work is extensive, it is almost certainly best to arrange for scaffolding to allow safe and simple access to the whole area, but of course there are times when this isn't possible, or only possible to some areas. Tower access is sometimes a possibility if the work is limited in area, and small areas can be accessed by a 'cherry picker' which is a small guarded platform on a crane which is lifted into place. In each case, there may be issues with access. Another solution, usually best if the work is not extensive or difficult, is to access the roof using steeplejacks and other trained climbers. Professional guidance is required, but contractors can also advise on the best way forward.



Access for maintenance at the rear of properties can be more difficult

Walls

For external walls, scan carefully across in sections and check:

8. areas of decayed or spalling stonework
9. gaps in the mortar, and if the stonework has had modern cement pointing
10. visible cracks, particularly associated with lintols and windows, and any snaking down the building
11. lintols or courses of stonework not level
12. cracked or loose render
13. previous patch repairs or obvious alterations / improvements should be carefully checked as these often hold clues to problems below
14. items fixed to the wall which can come loose or damage the masonry, like TV aerials, washing line fixings etc.
15. staining of walls from gutters and downpipes, leaking waste pipes, inadequate drips beneath cills etc.

Render fallen from a brick wall. It is likely that adjacent render is 'boss' (loose) and repair is urgently needed

Occasionally walls suffer from structural failure and very occasionally there will be something inherently wrong, but on the whole walls themselves, if left as built, tend to be pretty robust. Problems tend to occur with leaks, for example from gutters and downpipes etc, but also inappropriate finishes often applied later. The problems with these tend to be due to two things: movement and moisture.

Traditionally most stone buildings in Scotland would have been rendered ('harled') with a lime render with coats of limewash applied regularly for looks and protection. The lime render and limewash are flexible, meaning they were able to absorb the sorts of movements associated with masonry buildings, and also 'breathable' so moisture within the walls was able to safely escape. By contrast most cement or cement-rich renders are inflexible and impervious to moisture. This creates a number of problems. First, when the underlying masonry moves, the cement render cannot accommodate it and cracks. This crack then allows rainwater to enter the wall. Once inside, the impervious nature of the cement means that the water cannot escape and will tend to saturate the wall creating all sorts of mischief, leaching salts and creating spalling when the saturated stonework freezes and expands. Timbers like floor joists and lintels within the wall can decay due to the surrounding moisture and in addition, the saturated wall transfers heat much more readily, making homes harder to keep warm.

Cement pointing (still visible to the left) has been removed from the face of this chimney stack and replaced with a lime mix. In addition, a damaged stone has been replaced with a matching natural stone indent. In common with good conservation practice, the new stone matches the colour of the original, but the older stones have been heavily discoloured over time.

In late Georgian and Victorian times, a fashion for uncovered stonework emerged so many buildings of that era have a finished stone exterior. We are used to these nowadays and almost universally want to retain them. These facades are not subject to the same problems of cement render, but where they have been cement pointed, the cement mortar causes the same problems, allowing moisture in when cracked, but not letting it out again, leading to the sorts of 'stone decay' noted above.

For these reasons, it is usually best that cement renders and pointing are removed from those buildings originally rendered and re-pointed with lime. This is neither easy nor cheap, but not doing so means that any work carried out to improve the energy efficiency of the wall is at risk, along with the wall itself and anything structurally linked to the wall. Buildings built more recently which were designed with cement mortar and renders tend to have designed movement joints and will not suffer in the same way, although the principles above still apply and care should be taken to ensure that the building's longevity is assured.

Windows

Windows can be inspected from outside and inside if access is available. Keeping careful note / schedule of each window, check:

- the condition of adjacent stonework, especially cills beneath
- the mastic surround to the window frame
- paintwork generally
- the condition of the timber (or other material), particularly at the lower levels.

If it is possible to access the windows from inside it may be worth assessing the following as well:

- the condition of the original timber 'safe' lintels
- the mechanisms allowing the window sashes to open and close smoothly, and to be effectively locked
- if the windows are draughty and whether draughtstripping would be beneficial
- the condition of any adjacent shutters and linings.

Many thousands of windows have been removed and thrown into landfill when they could have been repaired and maintained for a fraction of the cost. This waste is due most importantly to a lack of awareness of how simple repair can be, a preference for 'one-size-fits-all' solutions (even when far more expensive) and a sometimes misguided drive to improve energy performance when many options to do so are available.

If a painted timber window is not maintained, then a combination of water running off the glass onto the lower portions, ultra-violet (UV) degradation of paint and thermal movement (warming up in the sun and contracting in the cold / at night) will eventually lead to failure of the paint coating. At this point water will get in through cracks or flaking areas and saturate the timber. Because, initially, most of the paint remains attached and is impervious to moisture, this water cannot escape naturally and the timber starts the process of decay. There are timber paints available which do not form a 'skin' as most do, so cannot crack or flake, and in addition allow vapour to pass through. In this way they provide much greater protection against decay.

Minimal maintenance, every five years or thereabouts, will avoid this and enable the windows to last many decades, if not hundreds of years. The maintenance involved can often be nothing more than a rub-down and re-coating of just the lower portions of the window. It is worth noting that it is usually only the lower portions of the window that are subject to this degradation. For this reason, regular maintenance can be both minimal and inexpensive unless there are complex access issues (such as the need for scaffolding). Equally, if there has been advanced decay, then it is almost always only these two lower sections, which are relatively easy to repair. Thus timber windows are not inherently high-maintenance as often stated, but with a little effort can be maintained for the entire service life of the building.

The rotten cill of this window has been removed and replaced with new, primed timber, while the lower rail and lower parts of the adjoining stiles of the window are due to be replaced. The paintwork will then need rubbed down and recoated, and a new sand mastic seal installed between the window and stonework.

There are many issues to consider in relation to window coatings, but it is worth noting that white, opaque (paint) coatings will protect the wood better from UV degradation and thermal movement more than dark, translucent (stain) coatings

Common Stairs

If there is a common stair in the property, check:

- loose or missing balusters which children could fall through, damaged or incomplete handrails
- uneven steps or problems with stair or floor surfaces that could be unsafe
- emergency lighting and any alarm system.

Common Repairs and Responsibilities

The illustrations overleaf show the typical arrangement but it depends on the exact wording of any title deeds (and that of others) so it is important to fully understand these before assuming anything.

Problems in closes are more difficult to restore because there is shared responsibility between all properties on the stair

Common Responsibility

- external walls from the halfway point within the individual flat or close
- foundations and damp-proof course
- roof structure, slating, flashings, gutters and downpipes
- services—as far as the branch into an individual flat.

Individual Responsibility

- anything serving only one property
- windows (but individuals have a duty to maintain their windows on behalf of other owners)

- doors to individual properties (usually flats)
- chimney pots and cowls related to individual flues
- front shop facades
- plumbing connection from fittings to waste pipe

Mutual Responsibility

- Anything owned by two or more owners should be paid equally by all who use the part, unless the title deeds say otherwise
- Chimneys, paid for by all those that have a use of the chimney
- gable walls shared with an adjacent property (although hard to enforce)
- Close windows
- Close, close stair, pend and all owners who have use of access
- the floor between two flats is usually shared between the two flats.
- Each owner in a shared building is responsible for fully insuring and maintaining any part of that building that provides support and shelter, and paying their share of any common maintenance where proper procedures have been followed. Each owner is also responsible for paying their fair share of any repair works, even if the property has been sold, if the works date to a time when they were living there.

Each owner has a right to ask other owners for proof of insurance, to arrange essential repairs, to access a neighbour's property to carry out the repairs and to recover the costs from others. Equally, each owner has the right to refuse to pay for repairs if these are non-essential, or they were not informed of the works. Further, they have the right to appeal decisions that they did not agree with at the Sheriff Court within 28 days.

Owners normally decide by majority vote on what needs to be done, organising surveys, appointing contractors to carry out works and the appointment of property managers. They can also decide on organising common insurance and running a maintenance account.

It's really important when undertaking common works to ensure that there is agreement as far as possible. Much more information is available from The Tenement Handbook and 'Under One Roof' website which also advises on a range of issues including the creation of a regular maintenance schedule. It is important to be as fully briefed as possible with professional, and possibly legal guidance.

Common repairs and responsibilities: common (shown in green), individual (shown in brown) and mutual (shown in purple)

4.2 Airtightness (Draughtproofing)

Like maintenance and the next chapter on the use of space and time, airtightness is an issue in every part of the building. Where it occurs in roofs, floors, walls and windows, this guide makes recommendations in the relevant section, but as a subject it needs to be introduced separately.

Airtightness is inextricably bound up with the issue of ventilation and although they are dealt with separately in this guide, it is important to emphasise from the outset that they need to be considered together. As the saying goes: "Build tight, ventilate right."

The Importance of Airtightness

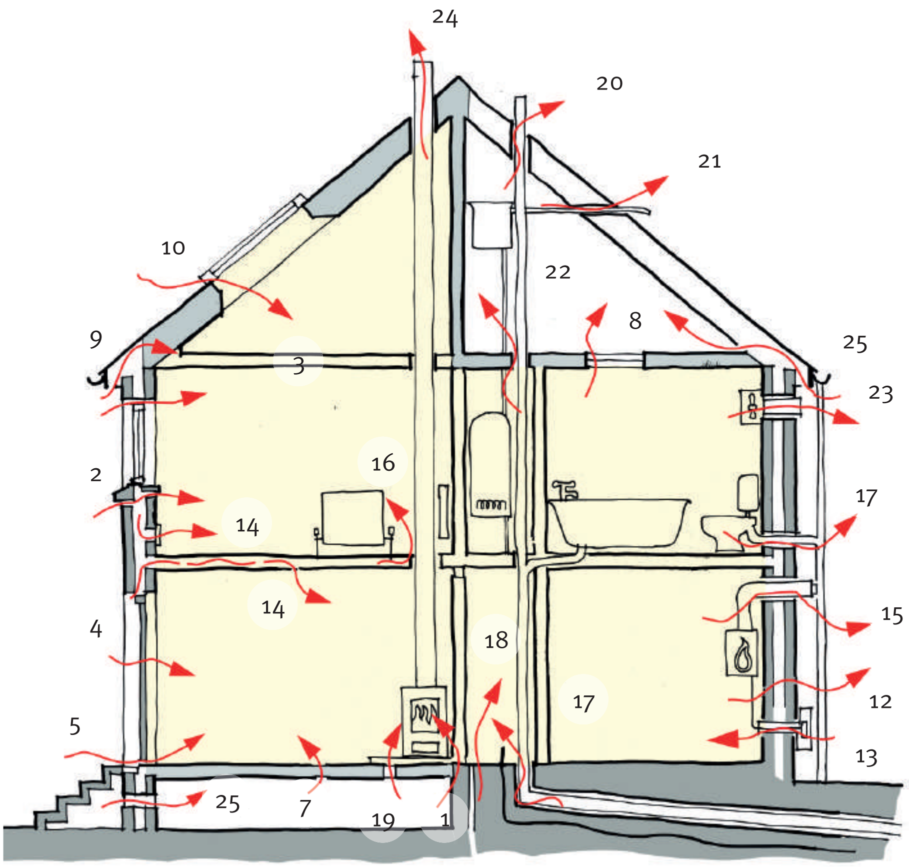
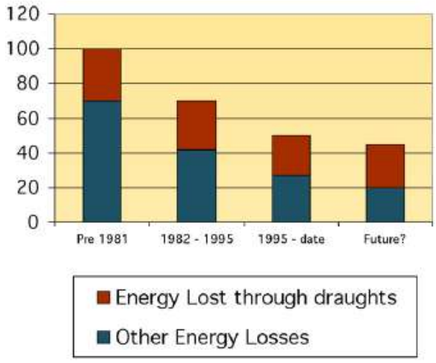


Diagram indicating the many ways in which air can infiltrate a building with a cavity wall (key to the right).

As an issue, airtightness has come to the fore in the last ten or so years in Scotland, creeping first into large scale non-domestic regulation and now into domestic new-build regulation. It is a welcome development because of the scale of heat loss associated with draughts. As levels of insulation have increased since the 1980s, the proportion of heat lost due to draughts has increased to the point where it made no sense to increase the levels of insulation required without also addressing airtightness. It doesn't matter how much insulation you put in a building if the heat can simply bypass it through gaps and holes around the edges.

The scale of heat loss (and other problems) associated with draughts is huge. Although common estimates put air leakage at around 10% of total building heat loss, this is usually because air leakage associated

1. gaps between floor joists and inner leaf of external wall can connect with gaps throughout the building
2. gaps and poorly sealed membranes around, but especially beneath windows and window cills, leak to the outside or into the cavity
3. leakage through window openings due to ineffective or missing draughtproofing or through hollow (plastic or metal) frames themselves
4. leakage through doors, especially the meeting stiles of double doors
5. gaps beneath and around doors
6. cracks around skirting boards linked to gaps around the edges of suspended floors
7. leakage through suspended floors, typically bare timber floor boards
8. gaps around loft hatches
9. leakage from eaves into attics often via cavities and behind plasterboard, indirectly into rooms
10. gaps around rooflights, eg where the rooflight frame is not sealed to the adjacent rafters
11. cracks where dissimilar structural elements such as columns meet floor slabs
12. leakage through porous masonry leafs, eg perpends not filled, often linked to gaps behind drylining. In timber frame building eg where a vapour check is torn or not sealed.
13. gaps in the external wall at services entry
14. leaks around sockets, ceiling roses, recessed spotlights and switches between a warm room and roof space / intermediate floor / cavity
15. gaps around boiler flues (in walls and roofs)
16. small gaps where water / heating pipes enter rooms from floors, walls and boxed in spaces
17. gaps around waste pipe penetrations eg behind toilets, baths and kitchen sinks
18. service entry points, even in concrete slabs within a larger diameter pipe
19. airbrick / air entry to open-flued fires required by the regulations admit air at all times, not just when the fire is in use
20. large gaps where soil pipes / ventilation flues penetrate the roof
21. other roof penetrations eg overflow pipes
22. gaps between heated spaces and a cold loft where water pipes and cables pass between, often in airing cupboards
23. poorly sealed wall mounted extract fans, also ducted extract from cooker hoods, tumble driers etc allow air directly into and out of the room, but also into the cavity
24. chimneys and flues, if not sealed will allow leakage at all times
25. air movement into an attic and beneath a suspended floor is desirable but excessive draughts can exacerbate other problems



As insulation levels have improved, the relative importance of airtightness has increased
© Paul Jennings

with other components (roofs, windows, walls etc) is counted as part of that element. Taken as an isolated item, the proportion of heat loss in a typical building due to draughts is very roughly 40%. This means that for every £100 spent on heating bills, £40 is due to air leakage. Also, as buildings are responsible for around half of all UK carbon emissions, and as draughts are responsible for nearly half of that amount, then draughts are responsible for nearly a quarter of all UK carbon emissions, comparable to all carbon emissions associated with transport, that is, all car, bus and train journeys, every year. So while airtightness can feel like a rather mundane subject, it is also extremely important.

Beyond regulatory compliance, the advantages of making a building more airtight include:

- reduced heating bills and carbon emissions
- greater comfort levels
- reduced requirement for heating system, potential capital cost savings
- better control of conditions internally, more reliable, less affected by weather
- reduced risks of fabric deterioration.

This last point is often overlooked and bears further mention. Leaky buildings allow cold air in and warm air out, losing heat and causing discomfort. However the warm air going out is also often relatively moist. This moisture can reach colder, outer parts of the construction where it cools and condenses, leading to a build-up of moisture within the fabric. This moisture in turn can lead to a number of unwelcome outcomes including:

- decay of organic materials, usually timber frames, joists and rafters embedded in masonry
- saturation of insulating materials, reducing their ability to resist heat
- corrosion of metal components
- frost damage, such as spalling masonry on the cold side of the insulation.

Another reason airtightness is important is because it is usually the most *cost effective* way we have to reduce energy consumption. The difference between the construction costs of creating a leaky and an airtight building is perhaps no more than 1%, yet it could mean a 40% improvement in performance. For those looking for "quick wins" there simply isn't a more cost-effective solution.

Airtightness and 'Stuffiness'

The issue of airtightness is a little controversial and it is worth briefly reviewing this to enable readers to form their own views on what is an important subject. Many people intuitively sense that an airtight building would necessarily be 'stuffy' inside.

The thing to remember is that there are two forms of air movement in any building as discussed in Section 2.2: ventilation and infiltration (draughts). An airtight house with poor ventilation (windows fixed shut / fans not working) will indeed soon become stuffy. A draughty house with the same ventilation problems will also become stuffy, although it might take a little longer. Most of us have experienced stuffy spaces and it's likely that these experiences were in 'normal' (ie quite draughty) places.

The problem was probably an excess of people or inadequate ventilation, but it wasn't due to airtightness. An airtight home with good ventilation will be fine, just as a draughty house with good ventilation will be fine (if a little colder!). Stuffiness is related to poor ventilation—which can be resolved—not so much to airtightness.

However, the threat of 'stuffiness' in retrofitted homes is real, and this is not just an inconvenient thing; it can be very serious when it leads to increased risks of mould and to respiratory problems like asthma and Chronic Obstructive Pulmonary Disease (COPD).

The risk is real in retrofit projects because ventilation is not normally considered as part of the retrofit process, geared as it is towards energy efficiency only. Because ventilation is not generally considered to be part of making buildings more energy efficient, retrofitted buildings can be made much more airtight but without a concomitant ventilation strategy. In other words they are building tight, but not ventilating right, and this often results in poor air quality, damp and mould. The finger of blame is pointed at the airtightness but it is really a lack of adequate ventilation. Until the two are considered together at all times, the risk of airtightness getting a bad name remains.

Example of mould / damage due to cold air behind plaster board or window reveal

Suitable Airtightness Targets

In Scotland, new homes are encouraged to achieve an air permeability of no more than 7 m3/hr/m2 at 50 Pa. If the infiltration rates achieved are lower than 5 m3/hr/m2 at 50 Pa, the Technical Standards recommend continuous mechanical ventilation. Although these new-build regulations do not apply in renovation projects, it makes sense to attempt to replicate similar levels of performance.

The Passivhaus approach when renovating older buildings is known as the 'ENERPHIT Standard' and requires a n50 of 1.0 m3/hr/m3 at 50 Pa. Although n50 and q50 are not directly translatable, for most buildings the results for both are *fairly* similar. The two methods for measuring airtightness are discussed in the boxout. Whilst it is not always feasible or cost effective to renovate to that exacting standard, we would generally recommend figures of air permeability lower than 3 for renovation projects but with accompanying carefully designed ventilation and a concerted effort to engage occupants in the ongoing maintenance of good conditions.

There are several ways of measuring air leakage from a building. One of the early methods was to help visualise the overall size of hole by describing the result as an 'Equivalent Leakage Area' but the two methods that have taken over are often referred to as the 'n50' and the 'q50' figures.

Both are tested using an air pressure test and both calculate the volume of air that passes through the building envelope at a pressure difference of 50 pascals. However, while the n50 divides that volume of air by the volume of the building, the q50 divides that same volume of air by the total area of the building fabric.

In the UK, it has been decided that the method to be used is the 'q50' whereas the Passivhaus methodology uses the 'n50' approach which can cause some confusion.

Achieving Airtight Retrofit Buildings

Achieving airtight buildings is covered in detail in a previous SEDA Guide: Design for Airtightness, available on SEDA's website: www.seda.uk.net.

At the design stage, the following should be considered:

- creating a performance specification to establish targets, the methodology for achieving these and roles and responsibilities
- conceiving the building as a series of zones and ensuring that the air control layer is clearly shown on all drawings
- identifying all of the likely penetration points through the air control layer and where possible grouping them to concentrate the areas where airtightness works will be needed
- where possible ensuring that the details for achieving airtightness are visible, simple (buildable) and formed from 'positive' mechanical connections, rather than relying on adhesive.

The infiltration level of a property can be established accurately using a pressurisation test, which measures how 'leaky' a building is

On site, the following should be considered:

- allowing for sufficient inspection of the works and ensuring the contractor has a nominated 'champion' for the airtightness
- ensuring that at least two pressure tests are undertaken; the first when all airtightness layers have been installed, but before these are covered over by the final finishes, and the second towards the end of the process (but not so late that there is no time for remedial works!)
- it can be helpful to carry out thermography while the air pressure tests are being carried out to help everyone involved see if there are any other hidden issues. The first test should also include an air leakage audit which identifies the causes and locations of all leaks, rather than simply giving an overall air permeability figure.
- there are 'DIY' air pressurisation kits available which allow contractors to test their own projects whenever they want, forming an internal quality assurance process which provides training and ensures that there are no nasty surprises when the independent tester arrives at the end
- apart from self-tested results, the final test should ALWAYS be independently commissioned by the client or design team
- SEDA's 'Design and Detailing for Airtightness' includes a useful checklist of common places to inspect for air leakage points.

4.3 Space and Time

Renovation does not necessarily entail any changes to the layout of the building, but there are times when improvements in the elements of a building are part of a wider effort to extend or alter the building layout.

Building work of any sort can be expensive and few people are without financial pressures. Sometimes it can be argued that building work will add directly to the value of the property and the money spent can therefore be recouped in time, but this argument is usually harder to make with retrofit. In addition, building work inevitably involves the consumption of some parts of the earth's resources and the disposal of others. Thus, it always makes sense to pause to consider if there are other ways of achieving your goals—for the sake of the planet and your pocket alike.

Space

Space in buildings is expensive. We pay to form a secure and weather-proof construction around it, we pay to fill it with both practical and desirable things, we then pay to keep it warm and comfortable, and we also pay to maintain it and keep it clean. In some circumstances we also pay to repair, upgrade and replace parts of it and in some cases to demolish it. It pays therefore to think carefully about how we can use space as effectively as we can.

Interior of the NestHouse™ designed and built by Jonathan Avery

© TinyHouseScotland.co.uk

The table in Section 2.3 shows how UK and Scottish average house sizes compare to other, mostly developed nations. What the table does not show is the several billion people in less developed nations who live in far smaller dwellings. However, the physical size of the space is only a small part of the story. The nature and quality of the space and the way it is used is also of interest. A number of designers now specialise in small or micro-houses and contend that it is all to do with the quality of the design. Small spaces can feel every bit as spacious if well designed, and there are many examples of this, such as the Scottish example, alongside. Furthermore, the physical space and its nature do not consider occupancy. Even a very large house will feel cramped if it has three generations of a very large family living within.

For those in larger properties, a number of options are available to make best use of the resource, and potentially to help with finances. A room can be offered to lodgers or friends, the house, or some part of it can be shared with members of the family, perhaps elderly relatives who would otherwise be alone. The arrangement can be short or long-term, paid or not and can extend, for example, to offering bed and breakfast.

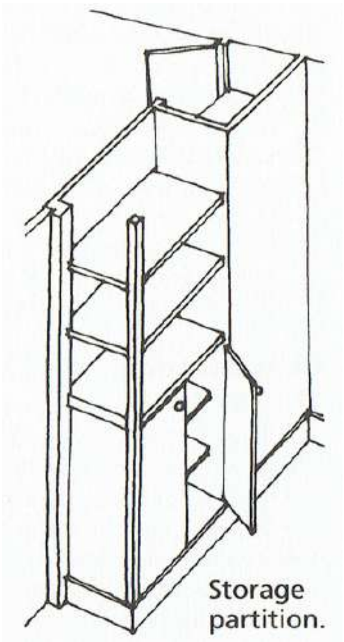
"All right, I admit it! You can't swing a cat."

Small spaces can feel every bit as spacious if well designed, but still have their limitations!

© The Estate of Norman Thelwell

Another issue that impacts on space, and the experience of it, is clutter. While it might seem odd to mention, many people feel overwhelmed by clutter and often assume that the best solution is to extend their property to resolve the problem. It rarely does, whereas investing time in 'de- cluttering' and better storage options is cheaper and often more effective.

Again, it is not necessarily the lack of space that is the problem, but the perception of that space. Storage then becomes a surprisingly important subject because well organised storage not only helps keep things in order, facilitating an easier life, but allows residual living spaces to be 'freed- up', with a potential corollary reduction in stress.



Storage partitions can be used to break up larger spaces and if designed well can add to the overall enjoyment of a room, while also adding useful storage space
© Duncan Roberts

In Scotland, many people have too much stuff. This is less an ethical observation than a practical one. While there are many good reasons for holding onto personal mementos and other important items, there is no doubt that those who have undertaken the process of de-cluttering find it extremely liberating and above all useful. In a guide aspiring to improve the sustainability of the housing stock, it is important to look squarely at the issue and consider the possibilities of living with less stuff, before we look at storage.

It is surprising how much can be gained from approaching the subject of storage with a more strategic approach. Characterise the type of items to be stored and consider where they could best go. Some items are used regularly and need to be close at hand, while others are only used once a year, some are easy to lift, some are heavy and need two hands, some need to be kept warm, some cold, and some items have no such constraints. Some can get wet, some must be kept dry. Some can be displayed, some are best out of sight.

Relating these requirements to available options then allows for a sensible strategy. Low level shelves above the kitchen worktop will help for items used every mealtime, some items could be removed from kitchen cupboards and placed elsewhere, or at high level. Some items could go in the loft, or garage, or garden shed if these are available. Large rooms can be partly sub-divided with storage subdivisions, unused nooks and crannies can be transformed with creative solutions. Nowadays, there are many sources of information and help on this subject.

In this housing block renovation, under-utilised balconies were upgraded into semi-indoor spaces creating much improved and more useable space for residents

For those with adjacent gardens a valuable addition can be part-indoor, part-outdoor spaces such as porches, car ports and conservatories Whilst this isn't normally an option for those living in tenements and flats, there are sometimes opportunities in retrofitting to provide such spaces. In many 1960s and 1970s blocks, balconies were provided which proved to be little used. In certain retrofit projects, these balconies have been enclosed to provide warmer, more comfortable and above all more useful spaces, adding greatly to the property.

This guide is predicated on the notion of improved sustainability in housing and retrofit so it would be remiss not to mention that overall sustainability is not just achieved through better energy efficient, healthy and comfortable homes. For those contemplating a retrofit, there are many ways in which sustainability, in its widest sense can also be achieved, which may affect the proposals:

- creating spaces to grow and store food (often in cold spaces, not necessarily fridges and freezers)
- spaces for making, repairing and maintaining items
- improved space and arrangements for recycling and reuse, including composting at home
- provision of habitats for flora and fauna, such as ponds, bat boxes, plants for birds, bees and butterflies etc.

Time

The majority of space we paid for is actually empty or under-used for much of the time. For people who go out to work, houses are usually empty for eight hours a day or so, while bedrooms tend to be used only for sleeping—eight out of 24 hours—and living spaces are used for perhaps four or five hours a day at best? Of course there are many occupancy patterns, and the Covid pandemic has meant that many more people work from home at least some of the time, but the point is that most of this expensive space we paid for and continue to pay to keep warm and clean is empty for long periods.

In commercial situations where companies wish to extract more value from their properties, it is possible to "sweat the asset" by simply finding uses for spaces when they might otherwise be empty. Flexible working hours policies help those with different home / work balance and mean the building can be used between, say 7am and 8pm, meaning much more value can be gained from a space that was going to be kept warm and clean anyway. In community buildings, extending the hours of use can make the difference between a financially viable operation or not, and some school buildings have been re-imagined as community 'hubs' providing a range of community facilities where there might not have been any previously. There are undeniable challenges with these arrangements, not least with security, but the point is that as a society we can make better use of limited resources.

Attractive and enticing spaces can be created, especially in childrens' rooms, by lifting the bed and creating a den or desk space beneath

© Duncan Roberts

In domestic situations, this thinking can save money and resources too. The strategy is to take nominally separate functions and simply overlap them where it is feasible to do so. Kitchens and dining rooms in certain social circles were always quite separate but now are often combined.

Building a guest room extension for parents who only come for two or three days over Christmas is expensive, whereas the existing study could be furnished with a fold-down double bed. It was only recently that people felt that children needed separate bedrooms. The contemporary penchant for ensuite bathrooms is lamentable from an ecological perspective, but the concept of 'Jack-and-Jill' bathrooms with two doors allows for bedrooms to have sole use of a space at times, while allowing the option of access from the rest of the house when needed.

The point in all of this, before proceeding with a 'business-as-usual' approach, is to check whether there are alternative solutions that might make better use of the available space either spatially or over time. With careful design, multi-purpose rooms can allow much more creative and engaging use of spaces than is often the case in current Scottish domestic architecture.

The costs of scaffolding are high, so if it is needed for one works package (e.g. window replacement) it makes sense to take the opportunity, as Renfrewshire Council did here, to also externally insulate and renew the roof finish

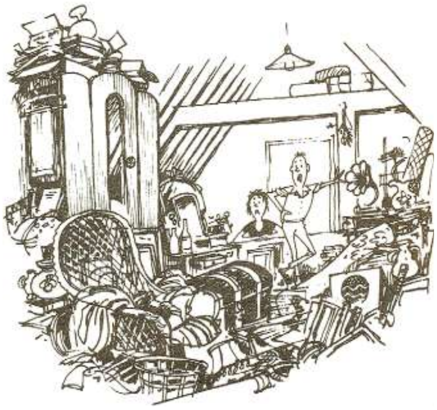
This approach can also be extended to furniture. There are now many examples of furniture which can 'double-up' to provide more than one function. The most obvious are sofa-beds but there are many others, and they offer the ability to unlock space in a home which might otherwise be unusable, to provide unexpected storage options or alter the way we use spaces. Beds can be raised and delightful spaces created beneath for children, fold-away chairs can be stored separately, extendable tables can be extended for large groups only when necessary, inflatable items like spare mattresses can be stored away when not required and wall-hung items like small tables, chairs, ironing boards and similar can be kept out of the way to create more space in constrained areas.

A final aspect related to time is that of opportunity. For example, if several properties on one street are looking to get the cavity walls filled, or roofs upgraded, it makes sense to take the opportunity to do likewise and potentially benefit from economies of scale. Similarly, if scaffold is going to be required to fix some slates or upgrade a roof, then it makes sense to take the opportunity to look at any works that could beneficially be done while the scaffold is up.

This can also be done pro-actively, rather than reactively and the image shows a comprehensive external tenement retrofit where a variety of separate 30-year maintenance cycles were brought together to share a single scaffold cost, with roofing upgraded, windows replaced and external wall insulation all carried out in one go.

4.4 Roofs and Ceilings

Unless already well insulated, the roof and ceiling are the most important place to concentrate on in retrofit because insulating them effectively will make the greatest difference to saving energy and increasing comfort. Retrofitting these areas carries very few risks to the long term performance of the property and the conservation value of historic buildings. In other words, you get the most benefits, with the fewest problems to overcome.



"I can't see any heat escaping through that lot."

Heat in the air rises so the ceiling is the priority for insulation but for many people removing the 'long-term stored items' can be a real obstacle.

Lofts: Insulation at Ceiling Level

Important to Know

- The roof takes the brunt of the weather and problems here can work their way down into the building, so the roof represents the number one priority for maintenance.
- Heat in the air rises and so the roof and ceiling also represent the number one priority for insulation and draughtproofing.
- Even if the loft has already been insulated, but not well, then it is still the most cost-effective place to focus.
- It is important that there is a free flow of air above the insulation to keep the roof timbers dry and avoid moisture build-up and decay.

Our Guidance vs Conventional Guidance

Our guidance is different because of the emphasis we place on the many little details. This is because we have seen how much difference they make in reality to the overall effectiveness of the insulation, in what is the most important area to get right. We also place more importance on maintenance, on preparing properly, and the specific type of insulation to be used.

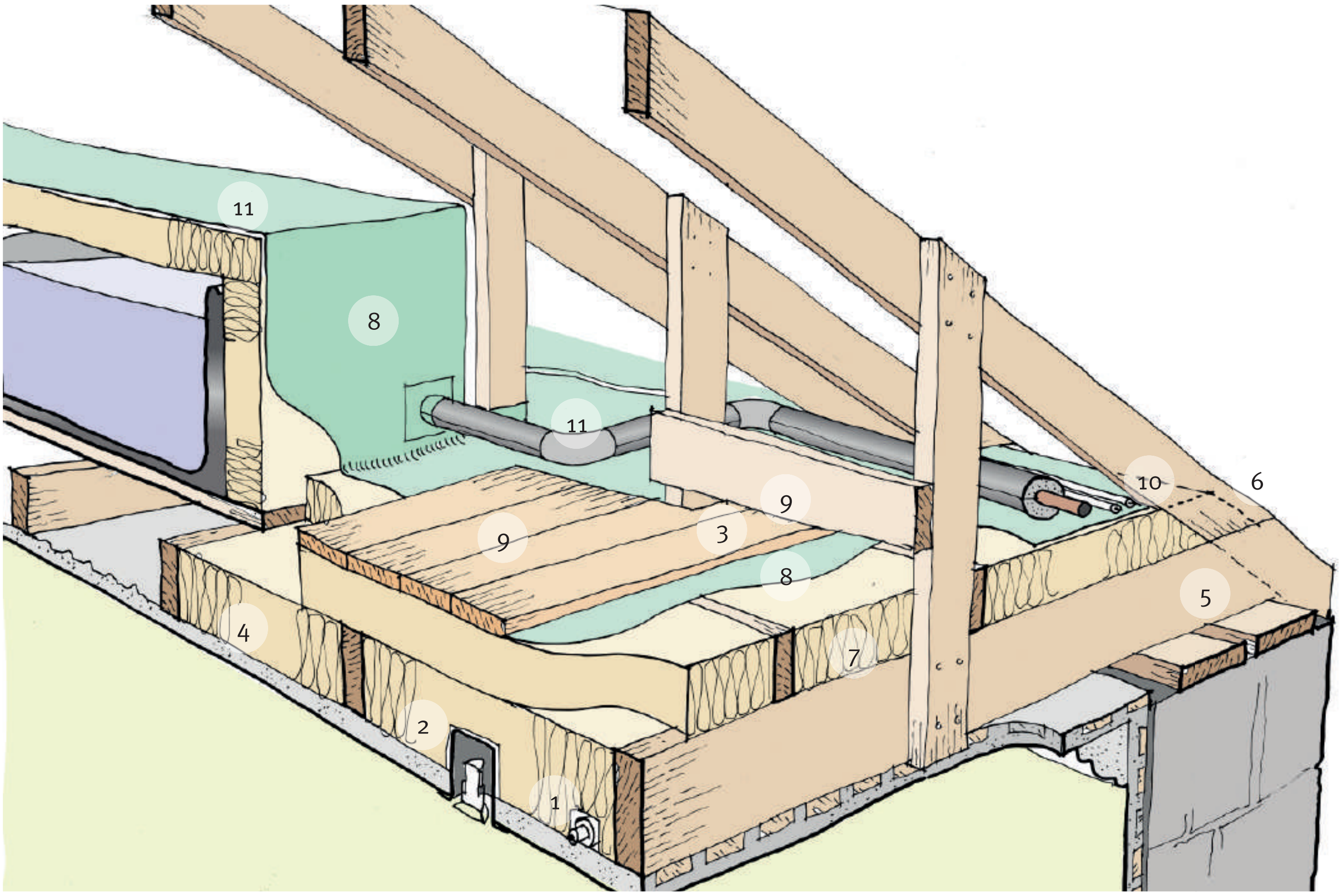
	Conventional Guidance	Our Guidance
Balance — *ENERGY*	300mm insulation. Lay cross-ways.	300mm insulation. No gaps. Lay cross-ways. Existing poorly laid insulation to be re-laid. Insulate over hoods at lights etc. Create access above to avoid later compaction of insulation. Use 'soft' rolls to fit snugly. Use a 'breather membrane' over. Natural insulation reduces embodied energy.
HEALTH	–	Effective insulation reduces mould risk internally & improves comfort. Use of natural insulation reduces respiratory health risk (mainly when installing)
FABRIC	Maintain air flow above, and at eaves.	Measures noted for Energy, Health, Maintenance and Moisture will all serve to protect building fabric from long-term problems.
Reality — *MODELLING*	–	As Energy above—emphasis on little details in practice.
QUALITY	–	As Energy above.

	Conventional Guidance	Our Guidance
MOISTURE	(Air flow above.)	Air flow above insulation removes moisture safely. Hygroscopic insulation helps protect timber. Insulation to water pipes to be vapour-proof avoids condensation problems.
People *PEOPLE*	–	Separate effort required to remove/replace items stored in lofts. Invest in upgrading services etc. before installing insulation (less cost and disruption later). Walkway created allows for use of the space for storage etc.
Heritage *CONSTRUCTION*	–	Soft insulation works better between timbers. Hygroscopic material helps protect timber from moisture problems.
MAINTENANCE	Electrics above insulation. Plumbing insulated	Ensure all external maintenance carried out first. Review existing services / condition before starting. Electrics above insulation (or in conduit). Plumbing insulated. Walkway provides safe access in the future.
SIGNIFICANCE	–	Unlikely to be relevant. Otherwise, as Fabric above.

Preparation

Sometimes, preparing the loft can be as much work as insulating it. In this large, but tidy loft, lots of items will have to be removed and the flooring all taken up, as there is no insulation beneath, before a replacement access floor can be re-built and all the stored items put back.

- Usually the loft has to be cleared. This one task often prevents any work taking place as it isn't normally taken on by insulation installers, and in some cases can't be done by householders. If more agile friends or family members cannot be persuaded to help, then this work can be done by paid odd-job tradespeople.
- It is worth reviewing the loft once cleared to ensure redundant cables and plumbing (such as old water tanks) are removed. Anything else that would interrupt the continuity of the insulation should also be removed, unless it is structural!
- This is the time to renew any services, upgrade electrics and telecoms cables if required.
- All cabling that is not going to be raised above the insulation should be laid in conduit or covered in such a way as to prevent it overheating beneath the insulation (ensuring some air movement around). (1—drawing on pg. 63)
- If there are recessed light fittings in the ceiling below, these often have insulation removed above by electricians to avoid overheating, but this leaves gaps for heat to escape. The correct solution is to fit hoods over these which prevent them from being smothered by insulation while also stopping heat escaping into the loft. (2)
- The size and location of loft hatches can be a problem and any necessary changes should be made before installation starts.
- If the loft is to be used for storage, or if safe access is needed in future to services, then it is easiest to form the structure of the walkway or platform before insulation is installed. (3)
- The best type of insulation to use is a soft roll or 'semi-rigid' type so that it is easy to fit snugly between timbers and against adjacent rolls and avoid any gaps. It is also better to use a natural, hygroscopic insulation type. Refer to 'Insulation Considerations' in Section 2.2.

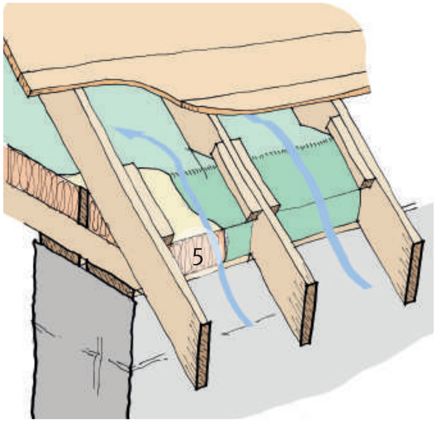


Sketch showing the recommended arrangement of insulation, services, and access in loft

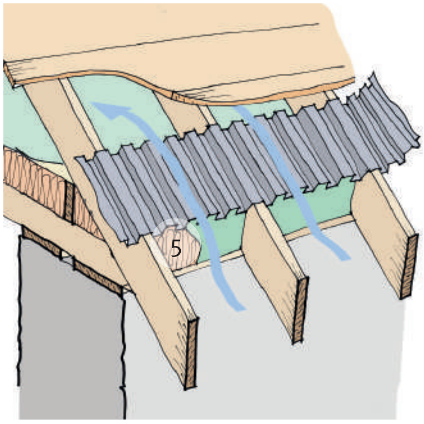
Installation

- If there is existing insulation, this can be left in-situ if it is neatly installed, or re-laid wherever required, taking care to identify existing cables. (4)
- The first layer of insulation should be laid carefully between joists making sure there are no gaps, and that where possible, insulation continues tight up to adjacent walls. (5)
- At eaves, achieving a continuous line of insulation means the insulation should be extended as far as possible over the wall-head, but leaving a small gap (25mm minimum) for air movement above if this is the path of airflow. (6) See diagrams overleaf for more detail.
- Subsequent layers of insulation should be laid perpendicular to avoid coincidence of gaps between rolls. Above the first layer of joists, there are sometimes truss pieces which get in the way and care needs to be taken to ensure that the insulation fits neatly around these without leaving gaps. (7)
- Once the insulation is installed, it is advisable to overlay a moisture- permeable ('breather') membrane which is also airtight. This prevents 'wind-washing' which draws the heat from the outer layers of the insulation, reducing its efficacy. It is very important however that the membrane is 'breathable' to avoid condensation forming on the underside. (8)
- If the loft is to be used for storage or access in future then a walkway needs to be built over the insulation and in such a way as to avoid crushing the insulation. It's best to use timber boards with gaps rather than large format panels such as plywood due to the risk of condensation forming on the underside. Edge strips are advisable to stop feet or stored items slipping onto the insulation and some simple form of barrier is helpful for safety and stability. (9)
- Electric cables not within conduit or protected beneath the

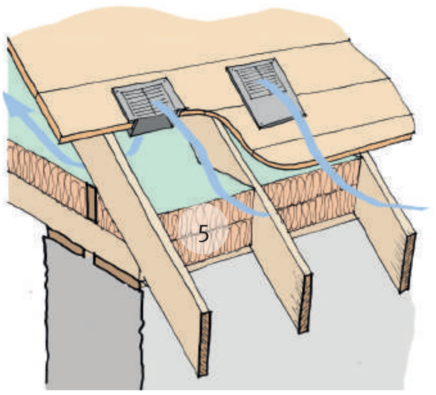
A common scene: an electrician has installed recessed lights and removed the insulation in the area to avoid overheating of the light fittings. This solves one problem but causes considerable heat loss. The correct solution is to fit a fireproof hood over the light and replace the insulation neatly.



Eaves ventilation space maintained using battens to restrain insulation



Sarking lifted and ventilation path formed using 'rafter roll' over rafters



Eaves filled with insulation, roof space ventilated by fitting 'slate vents' through sarking

insulation can be laid over the top of the insulation, but care needs to be taken where they penetrate the insulation to make sure there are no gaps where heat can escape. (10)

- Once insulated effectively, the loft can become as cold in winter as outside, so to prevent freezing, any live pipework containing water must be fully insulated, including at all junctions, valves etc. Tanks should have the insulation taken over the top of them, and without any beneath, so that they become, thermally speaking, part of the house below. Insulation used around pipes should be vapour-proof. This is to prevent the moisture in warm air condensing on cold pipework, potentially creating as many problems as a leak in the roof. Needless to say, it is preferable to avoid plumbing in the loft if possible. (11)
- The same is true of air ductwork from mechanical ventilation systems. In a cold loft, any ductwork should be carefully insulated using a vapour-proof insulant to save energy and prevent condensation forming.
- Ceiling hatches should be insulated to the same degree as the rest of the loft where possible. This is easier to say than to do in most cases. With simple, lift-off hatches, a more rigid board type can be used to a similar depth and rigid boards can also be cut around mechanisms for hatches with attached ladders. Also provide a form of air seal when the hatch is closed.

Alternatives

- When insulating a ceiling, it is possible to use loose-fill insulation instead of the rolls discussed above. The same principles apply. Care needs to be taken that the material does not fall through gaps in the ceiling (for example at downlighters) or into wall cavities, nor that it gets blown into piles of uneven depth.
- It is possible to install insulation beneath a ceiling and a number of proprietary materials are available to do this. This can be done in addition to insulating between joists above. The disadvantages are that it reduces ceiling height, and the components tend to be expensive, but one advantage is that a continuous layer of insulation applied like this reduces the thermal bridging effect of the timber joists.

Health & Safety

The most obvious risk is getting in and out of the loft, so ensure a safe and secure ladder is used with adequate space above and below, and handrails for stability. Works should be carried out on crawl boards to avoid stepping between the ceiling joists. Care should be taken where the roof above slopes down to form a confined space, especially in relation to nails protruding through the sarking boards. It is important to set up (if not already installed) both general and additional task lighting, and remember not to cover electric cables as noted above. Most synthetic fibrous insulations carry some risk to respiratory systems and can cause skin irritation, so good quality masks should be worn at all times and skin covered.

How Much is Enough?

Depending on the type of insulation, 300mm of insulation will provide a 'U' value of around 0.16 W/m^{2}K which is adequate for most properties and our guidance here is no different from conventional guidance. Beyond this level, the benefits of greater depths are likely to be compromised by the inevitable areas where that level of insulation is not feasible (eaves, loft hatch etc). Rather than aiming for more than

300mm, it is far more important to ensure all of the gaps are closed, the loft hatch is well insulated and draughtstripped and that there are no 'weak points' in the installation generally.

Insulation at Rafter Level

Important to Know

- The roof takes the brunt of the weather and problems here can work their way down into the building, so the roof represents the number one priority for maintenance.
- Heat in the air rises and so the roof is also the number one priority for insulation and draughtproofing.
- Within the rafters, it is important that there is a free flow of air above the insulation to dissipate moisture and avoid timber decay.

Our Guidance vs Conventional Guidance

The biggest problem with insulating at rafter level is that there isn't usually enough depth within the rafters to get the thickness of insulation recommended. In conventional retrofit, where energy efficiency is the only objective, it makes sense to seek the lowest lambda value for the insulation and so guidance tends to suggest the use of high performance rigid plastic insulants. There are three problems with this in practice; it is very difficult to cut and fit the boards perfectly, so there are always air gaps which compromise the high performance boards, the insulation is compromised anyway by the timbers, and using moisture-impermeable materials forces any moisture through the timbers, placing them at greater risk of moisture damage. Carried out carefully, our guidance will lead to a solution as effective in reality, but with greater benefits to the long term performance of the building. Our guidance is different because of the emphasis we place therefore on the many little details, including maintenance.

Preparation

	Conventional Guidance	*Our Guidance*
Balance *ENERGY*	Insulate between rafters. Supplement with internal insulation if needed.	Insulate between rafters. No gaps. Supplement with internal insulation if needed. Use 'semi-rigid' rolls to fit snugly. Natural insulation reduces embodied energy. Mid-way coombe opening of ceiling finish allows for a neater and more complete installation (refer to detail on pg. 69).
HEALTH		Effective insulation reduces mould risk internally & improves comfort. Use of natural insulation reduces respiratory health risk (mainly when installing)
FABRIC	Maintain air flow above, and at eaves.	Measures noted for Energy, Health, Maintenance and Moisture will all serve to protect building fabric from long-term problems.
Reality *MODELLING*		As Energy above - emphasis on little details in practice.

	Conventional Guidance	Our Guidance
QUALITY	–	As Energy above.
MOISTURE	(Air flow above)	Air flow above insulation removes moisture safely. Hygroscopic insulation helps protect timber.
PEOPLE	–	Invest in upgrading services etc. before installing insulation (less cost and disruption later). Mid-way coombe opening of ceiling finish allows for a neater and more complete installation (refer to detail on pg. 69).
CONSTRUCTION	–	Soft insulation works better between timbers. Hygroscopic material helps protect timber from moisture problems.
MAINTENANCE	–	Ensure all external maintenance carried out first. Review existing services / condition before starting. Electrics above insulation (or in conduit).
SIGNIFICANCE	–	Unlikely to be relevant, but removal of possibly original plasterwork may be an issue. Otherwise, as Fabric above.

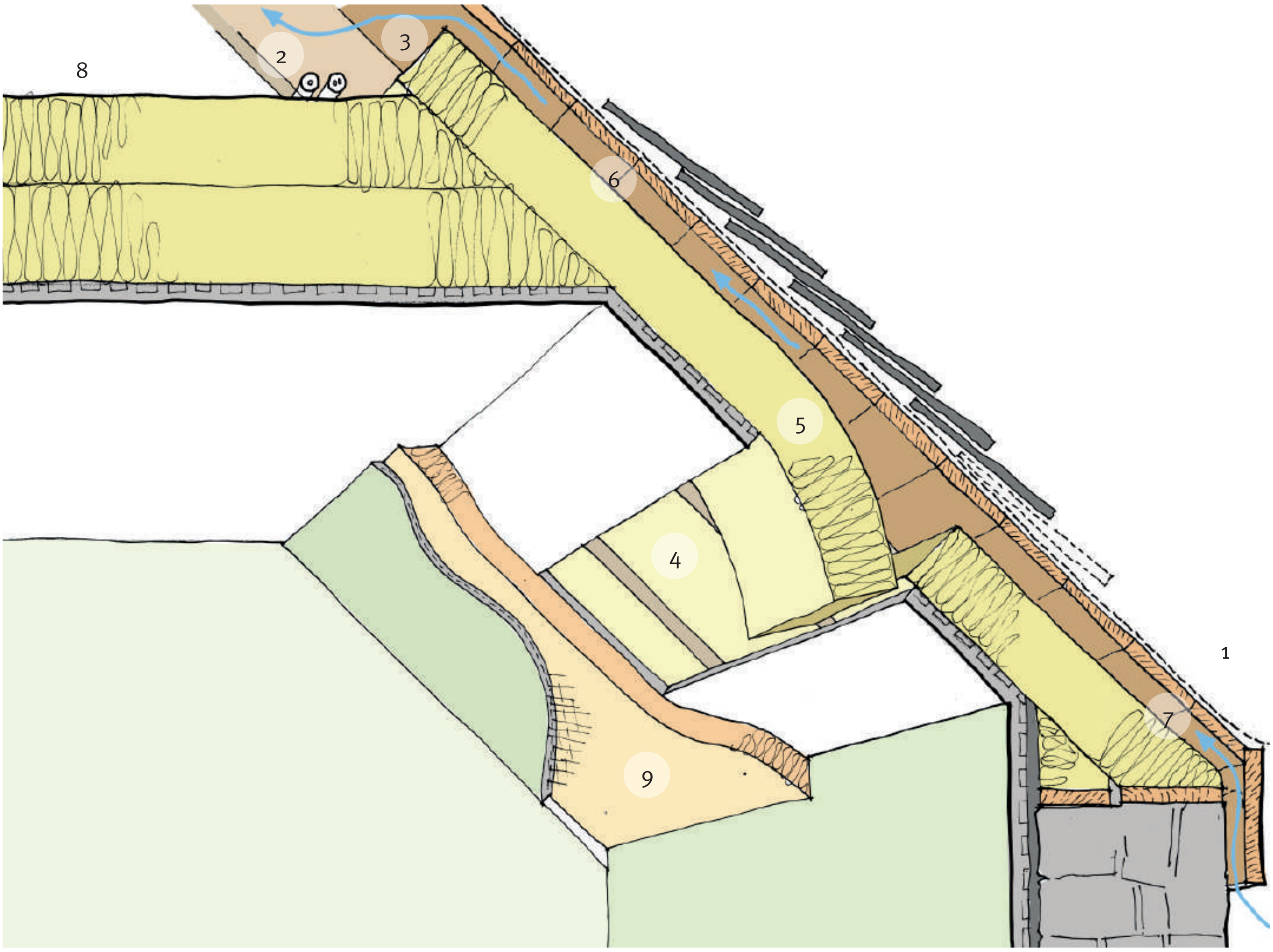
- In some cases, the external roof finish can be removed and insulation can be inserted between rafters from outside. If internal finishes are retained, this allows for simple installation leaving a 25mm gap along the outer edge of the rafters before replacing the roof finishes
- Even if the roof finish isn't to be replaced, it is often worth removing the first half-metre or so up from the eaves in order to inspect the condition of the rafter ends and the wall-head (1). Any repairs can be carried out and insulation can then be easily installed along the eaves, ensuring that ventilation is maintained above the insulation.
- Electric cables within the rafters should be re-located or placed within conduit to prevent overheating when covered by insulation. Ideally, they would be placed in a service void created on the inner side of the structure. Where the cables penetrate the inner faces of the ceiling, they should be sealed carefully to prevent moisture and warm air from inside escaping into the construction. (2)

In this attic room, timber linings to the coombe and wall have been removed, wood fibre insulation installed and linings replaced.

© Historic Environment Scotland

Installation

- If the ceiling finish is original lath & plaster and it is desirable to avoid damaging this, the question is how to get the insulation into all areas. It may be possible to push rigid boards in from a small attic space (3), or by using a long thin implement, pushing down a softer roll- type insulation. However in this scenario, it is hard to be sure that the insulation is filling all gaps well.
- Whilst still retaining most of the original finish, it is possible to cut a horizontal strip mid-way within the coombe to allow insulation to be more carefully installed, extending neatly to the eaves and fully filling the space available (4). A 600mm wide strip allows for manoeuvring and can be replaced by a matching lath & plaster or a modern equivalent with all joins made good and re-decorated.



Insulation at Rafter Level
Sketch detail showing how much insulation can be installed in coombes with limited damage and disruption

Sometimes ceilings have timber linings or similar boarded finishes, which make removal and replacement easier.

- It may be possible, or desirable to remove all of the ceiling linings. The advantages of this are that it makes installation of the insulation much simpler, and allows for the installation of a vapour control and airtightness membrane before replacing ceiling finishes. The disadvantage is an increase in cost, disruption, mess and waste of resources.
- More often, it is possible to form the horizontal strips mentioned above, retaining the majority of the internal finish while ensuring insulation is installed neatly.
- The best type of insulation to use is a semi-rigid type so that it is easy to fit snugly between timbers and against adjacent rolls without the need to be perfectly cut to size. In order to protect the roof timbers from the risk of moisture build-up, it is also better to use a hygroscopic material (5).
- However it is achieved, insulation should be inserted between each rafter, fitting tightly at all times, flush with the inner face and leaving about 25mm to the outer edge as free area for air movement (6).
- At the eaves, the insulation should be extended as far as possible over the wallhead, leaving a 25mm gap for air movement if this is the path of airflow. See diagrams for more explanation (7).
- Often in 'room in the roof' spaces, there is a small 'attic' section formed by the cross-piece of the roof truss, and in these situations the guidance for lofts can be used (8).
- In attic rooms, it is common to find dormer windows. With the rest of the roof insulated, these will represent a weak spot in terms

A consequence of warm, moist air entering the loft area but not being adequately ventilated away, hence the importance of ventilation at the eaves

of heat loss. Although it can be quite a fiddly job, they need to be insulated to a similar level as the adjacent roof. This involves three separate tasks: the window, the ceiling and the side walls (cheeks), all of which may require different treatments.
- Rooflights are extremely effective at bringing in light, ventilation and fire escape from certain spaces but they represent a 'gap' in the insulated envelope for heat loss. In conservation areas and on listed buildings there may be a requirement to use 'conservation' rooflights, but it is also important to use a rooflight with a good overall U-value and good airtightness. Quadruple glazed units and special insulated flashing packs are available which ensure a better insulated and airtight installation.

Alternatives

- It is also possible to install insulation across the inner face of the ceiling. A number of components are available for this including composite boards of plasterboard finish with rigid insulation bonded to the back. Installing these is quicker and simpler than the solution above and this technique avoids the thermal bridging associated with the rafters. However, the components generally used are relatively expensive, and as this work reduces ceiling heights, often in already constrained spaces, there are limits to its applicability. As a solution, it is unlikely to provide enough insulation on its own, but if there is headroom and budget, then it can be used to supplement the insulation within rafters described above. We have shown a natural, rigid board such as wood fibre fixed to the coombe with a plaster finish as an option. (9)
- An alternative to the composite panels described above is to install battens across the face of the ceiling and insulate between them. This solution can reduce thermal bridging by running battens perpendicular to the rafters and allows for the installation of a vapour control layer.
- The advice given here is equally applicable to flat roofs but because flat roofs have to have a continuous waterproof layer to keep water out, it is even more important to ensure a good route for ventilation above the insulation along with a robust vapour control layer beneath.

Health and Safety

There is usually a need to access ceiling areas above head height and in these cases, care should be taken to ensure safe access and a safe and secure working platform. Comments made above about the risks from fibrous insulation remain relevant and it is common to find nails protruding through the timber sarking boards which present an obvious risk.

How Much is Enough?

In theory, a level similar to that installed in a loft is required, ie about 300mm achieving a U-value of around 0.16 w/m^2K. However, it is unlikely that this level of insulation can be installed within existing rafters, and even adding additional insulation beneath the ceiling may not get close to this level. In reality, it is more important to achieve a continuous layer of insulation, across small loft spaces, around dormers and rooflights, and linking neatly with wall insulation as this will reduce heat loss more effectively in practice.

4.5 Walls

While roof and floor construction has changed little across Scotland over both region and time, wall construction varies considerably. Traditionally, wall construction depended on what was locally available while in the 20th century construction types began to diversify. Buildings are often described simply by their wall type because of this variation, as it is the principal relevant technical characteristic. This makes it more difficult to provide guidance that covers all wall types, but while we have restricted the number of wall types, most of the key principles discussed are widely applicable.

Of the 2.5 million dwellings in Scotland, just over 3/4 (over 1.8 million) have cavity walls, while around 1/4 (620,000) have solid walls or a range of other types like timber frame. Only a small percentage of the solid or 'other' walls have been insulated while around 3/4 of the cavity walls have already been insulated.

On some renovation projects, it is only the walls which are being renovated; the rest is really all new

Cavity Wall Insulation

Cavity walls were introduced well over 100 years ago to reduce water penetration through solid walls. The idea of filling this cavity therefore might appear perverse. Many new masonry buildings are built with partial cavity insulation, normally in the form of rigid batts attached to the inner leaf and slotted over wall ties. This is not something that can be done in a retrofit situation, so we concern ourselves here only with 'retrofilled' cavities—fully filled by injecting insulation into the cavity after the building has been completed.

Despite the obvious drawback of filling the cavity put there to avoid water penetration, the 'retrofill' industry has grown and since 1996 over 6 million UK houses have had their cavities filled in an effort to reduce energy consumption and make homes more comfortable. There is no doubt that in many cases, this has indeed been the result, and the technique avoids most of the obvious disadvantages of both external and internal wall insulation, so there are undoubtedly benefits to be had from cavity fill.

However the industry has been dogged by problems due largely to the fact that insulation can indeed draw moisture across the cavity, and being an unseen operation, it is difficult to check the work and be certain that it's been completed properly. These two intrinsic problems have been combined with poor practice by installers meaning that many installations suffer from problems.

Important to Know

- Cavity fill can be an excellent solution reducing energy consumption, carbon emissions and improving comfort, and at little relative cost.
- However, cavity fill can lead to problems and so it is important to carefully review the viability of this technique in each property and insist on the best practice installation and aftercare.

Our Guidance vs Conventional Guidance

The installation of cavity fill insulation is represented by the National Insulation Association (www.nia-uk.org) who also provide support for external and internal solid wall insulation works. They host the Cavity Insulation Guarantee Agency (CIGA) which guarantees works undertaken. Guidance to best practice is given along with guidance on handling complaints and wider guidance on how companies should operate.

We have not included a table of differences here because our guidance is only different in two quite specific ways. Conventional guidance as written is extensive and reasonable, but is not always followed carefully. Installers are usually the ones who undertake the review and it is obviously in their commercial interests to undertake the works, even if the property might not be suitable. In addition, the full extent of preparatory works sometimes required can make the operation far from cost effective so there is a clear economic incentive to avoid some of the most onerous tasks.

Our first recommendation therefore is that owners ensure that all guidance is strictly followed, and to support this, we further recommend that an independent specialist is engaged to undertake the suitability review, as well as a thorough check afterwards. The property should be assessed against the following criteria that inform suitability for installation.

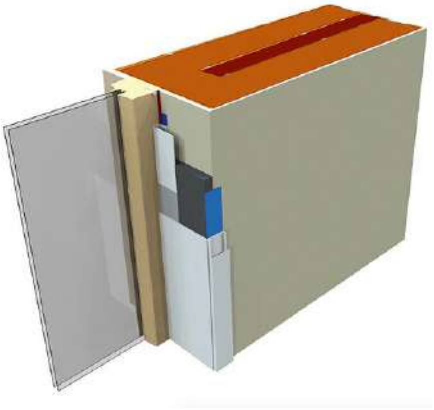
Preparation

- Exposure to wind driven rain: BRE (the Building Research Establishment) have produced a map of the UK which indicates four zones of exposure. The higher the exposure, the higher the risk of water being forced across the cavity under wind pressure. Clearly however, local geography and features will have an effect, and some judgement is required in interpretation. The risks increase at greater height from the ground so installations over 12m from the ground are subject to different guidance.
- Building characteristics: a number of individual features of a building might offer clues as to suitability. Existing signs of dampness and/or works to rectify dampness might indicate a higher than normal risk, structural problems like leaning, bulging or cracking might indicate problems that could exacerbate, or be exacerbated by installation of insulation. Buildings should be checked externally and internally noting also where changes might have been made (eg., old openings, now blocked up). External walls where the mortar beds are recessed create a greater risk of rainwater sitting and being blown in.
- In all cases cavities should be checked carefully. A borescope survey should be undertaken in several places in addition to extensive external and internal visual surveys. Cavities less than 50mm wide are at greater risk of water penetration across and there may be areas of the cavity which for one reason or other make installation difficult or impossible. Wall ties should be checked for adequacy and also to ensure they are not running downwards towards the inner leaf (which could lead to water running across). Sometimes, cavities are filled with lumps of mortar from untidy workmanship and these can block the cavity and help move moisture from one side to the other. Cavities are not always closed off, for example in an attic, or where they have been penetrated by services, so an important part of any survey is to ensure that they are closed off before insulation is pumped in. Check that there are weepholes at the base sufficient to drain any water in the cavity away safely.
- The most important aspect of the preparation is to establish whether the external wall is adequate to keep water out of the cavity. Any weaknesses in this wall may previously have been managed by the ability of water to run out within the cavity and

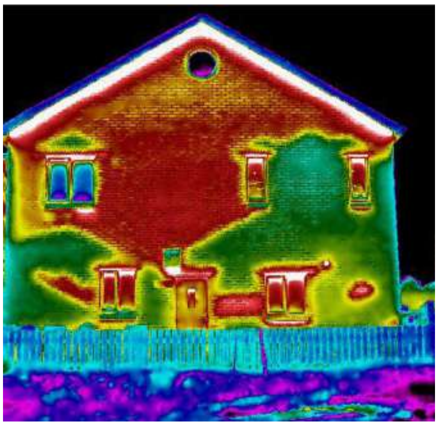
A borescope survey of a cavity wall showing the borescope inserted into the wall. The screen shows a tidy—and empty—cavity and a wall tie that is not straight.
© Stanger Testing Services

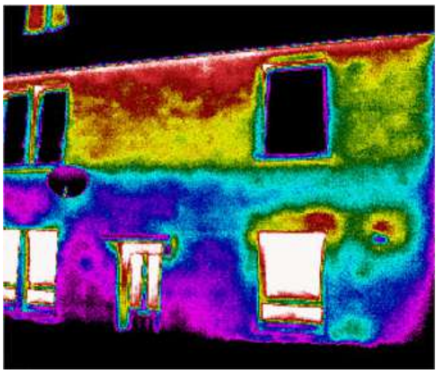
exit through weepholes at the base. When insulation is installed this ability will be compromised and so the first line of defence becomes more important. Any maintenance or improvement works required will need to be included in the works.

- Complications occur where a cavity extends beyond the boundary of the property, where it is part of a terrace or block of flats for example. Cavity barriers should be installed unless the whole block is to be insulated, but this increases costs of course. Where cavities extend below ground level, insulation should not be installed unless it is quite clear how water will escape to avoid problems with temporary flooding.
- Complications can also arise when the main external wall to be insulated is covered by a subsequent extension such as a conservatory. Bespoke arrangements need then to be agreed and documented in respect of that area.
- It is important to check any services which run through (or sometimes within) the cavity. Any cables with pvc sheathing (most) could be affected by polystyrene beads and should be either moved, replaced with non-pvc alternatives or placed within a conduit. At every penetration, there is a risk of the insulation emerging from the cavity under pressure, so all penetrations need to be carefully sealed.
- Some wall vents are formed by a continuous casing that extends through the cavity, but some vents (for example, to solums beneath the ground floor) are formed by an air brick in each masonry leaf. Cavity insulation would block the air path between them and so these will need to be made good such that the flow of air remains unimpeded.
- The location of chimneys is important where they exist (often blocked over so difficult to know) to ensure that insulation is not inadvertently pumped into the chimney itself.
- It is important that any defects in the building as pre-existing are carefully documented before any works take place. This protects both parties: installers are protected from spurious claims, while the most likely way that a guarantee won't be honoured is the argument that the defect existed before the works took place. We suggest that this process is carried out by an independent specialist either instead of, or in addition to the documentation provided by the installer.
- Once insulated, some homeowners find that draughts which emanated from the cavity will be reduced. This is largely a good thing, adding an airtightness benefit to the installation, but it also raises the risks associated with lack of ventilation. For this reason we suggest that all cavity fill installations are also accompanied by a review of, and where necessary, an upgrading of the ventilation arrangements in the property. For more information on this refer to the section on ventilation.
- Before undertaking the work the installer should agree a number of items with the occupant such as programme of works, access for vehicles, method of making good holes, any unusual areas or internal access required, extent of installation (some areas may not be accessible) and when the guarantee will be received.
- In Scotland a building warrant application is not required for cavity fill insulation, although the work should comply with the regulations.
- Grants may be available for the installation depending on the area, property type or occupants, so it is worth contacting the National Insulation Association (NIA), The Cavity Insulation Guarantee Agency (CIGA) or The Energy Saving Trust (EST), all of whom will be able to advise.



Once the cavity is insulated, reveals can represent a thermal bridge. Specialist solutions exist to insulate just these areas to reduce heat loss and the risk of condensation and mould.
© Enviroform Solutions





In the upper thermographic image, cavity wall insulation has been installed, caused problems and subsequently sucked out again. However, the image clearly shows that the removal process was only partially completed.
In the lower picture, the lower floor has been cavity filled (patchily), but the upper floor appears to have been missed!
© Irt Surveys Ltd.

Installation

- Cavity fill needs to be undertaken by suitably qualified tradespeople. The NIA and CIGA can provide contact details for local companies and you can request the BBA certificate which accompanies any registered installation. The CIGA guarantee is provided once the work is completed.
- There are three main types of insulation commonly used. The cheapest is a form of mineral wool fibre but this appears to be the type most commonly associated with failure and we believe should be avoided mainly due to its capacity to 'hold onto' moisture, should any get into the cavity. Various foam products are also used but being impervious to moisture they more fundamentally alter the nature of the wall making it more difficult for moisture to escape. The third, and generally most expensive involves small polystyrene (EPS) balls, installed with a weak adhesive mix to help them form a fairly robust material within the cavity which holds its shape and reduces the risk of them pouring out of the cavity at any unsealed openings. EPS balls appear to be less liable to slump than mineral wool, and do not 'hold onto' moisture in the same way. Unlike foam they are intrinsically vapour permeable and because they leave gaps between balls, there remains greater potential for both moisture and air movement, allowing the cavity to perform a little bit as it did before, albeit much reduced. In short, EPS beads appear to represent the lowest risk option in the long term.
- Usually, the insulation is injected from outside using the mortar beds between brick or stonework and at about 1.2m centres. The holes are then filled up afterwards using a matching material. In some cases more holes will be required around obstacles like windows. Where access isn't possible from outside, by agreement it might be necessary to inject some insulation from inside.
- A complication which is not easy to solve is that of thermal bridging, usually at openings in older buildings. Around doors and windows in older cavity walls, the inner masonry leaf 'returns' to form a solid wall around the opening for robustness. Structurally, this makes sense, but in terms of insulation, it creates a problem because heat is more readily transferred. When the cavity fill is installed, this area will become colder than the warmer areas around and may be subject to increased risk of condensation and mould formation. It may be advisable to provide additional insulation on the inside to avoid this. The diagram at the top left shows such an arrangement but clearly doing this around every window and door considerably increases costs, not just of the work itself, but for redecoration of all rooms.
- Once the installation has been checked and holes made good, that should be it. All combustion appliances are checked to ensure they have been unaffected. Associated works recommended such as ventilation should also be considered, but, in addition, we recommend undertaking a thermographic survey to see if the works have been completed fully. It is only fair to let the installer know that you intend to carry this out, and since thermography works best when there is a significant temperature difference between inside and outside, it can sometimes only be done in the colder months.

Alternatives

Where the property is found to be unsuitable for cavity fill due to likelihood of water penetration from outside, one possibility is to install the insulation as planned, but to also install some form of additional weatherproofing to the outside of the building. This could be in the form of a rain screen cladding (for example timber cladding, or large format boarding, or even matching render over a mesh substrate) or it could be external wall insulation. Clearly this is less cost effective but may be the only way to be confident of long term performance where the wall cannot be made sufficiently weatherproof due to location or exposure. Internal insulation may not be feasible for a variety of reasons and if cavity fill isn't safe, then the only option is external insulation. However, installing this external layer makes little energy efficiency sense when it exists 'outside' of the ventilated cavity. Carrying out both means that the building can be effectively insulated and robustly protected in the long term.

Health & Safety

Cavity wall insulation raises few health & safety issues. Health risks associated with mineral wool fibres can be avoided by making sure there are no escape routes from the cavity, and the drilling and installation works can cause noise and some vibration disruption. Access to higher areas would usually involve working from height in some form and any ancillary works (such as breaking out masonry to install cavity barriers) carries its own risks.

How Much is Enough?

Clearly the cavity sets its own constraints due to thickness. The thermal resistance of the insulation injected is far less important than ensuring that the cavity is fully filled, and keeping the cavity dry.

Solid Walls: Internal Wall Insulation (IWI) vs External Wall Insulation (EWI)

About a quarter of all buildings in Scotland are solid walled, usually stone but sometimes brick or concrete. Many remain uninsulated and a significant part of the Scottish Government's spend in the next few years will be on wall insulation so it is worth taking a moment to consider the 'best' option. SAP does not differentiate between internal and external insulation of solid walls and concentrates instead on the U-value required, which can be achieved using either method.

Typically, internal insulation is the preferred route for insulating solid walls due to the following advantages:

1. it is usually cheaper (this depends very greatly on circumstance)
2. no external alterations are required, so there are no issues with planning or with neighbours
3. no restrictions on when the work is carried out due to season or bad weather
4. no restrictions related to the building type or location (eg: high rise blocks)
5. usually no need for specialist installers. DIY is possible, which can also make it cheaper.

There are some well known disadvantages of internal insulation which can swing the decision the other way in some cases:

1. the need to decant occupants, or have empty properties.
2. the loss of internal space, which is more critical in smaller spaces.
3. in some cases, work can be complex, for example where there is cornicing, extensive servicing or historic internal linings and facings.

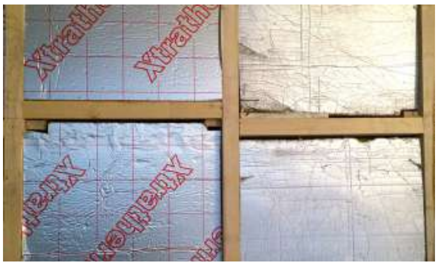
Installing an internal frame, infilled with insulation and a plasterboard finish is relatively simple and inexpensive. In this example, the frame is set apart from the wall to avoid moisture in the stonework affecting the new works.

4. in some cases there may be issues with fixing heavy loads to less robust internal finishes
5. thermal bridging (via internal structure) can lead to problems and reduces the efficacy of any measures installed. This is discussed in more detail in the boxout on the next page.

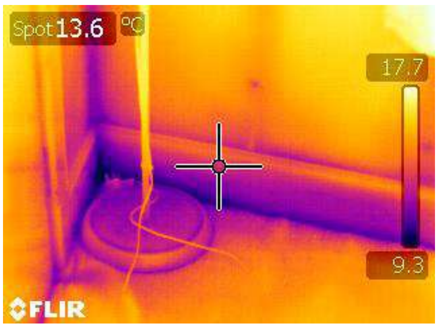
By and large all of these issues are understood within the construction industry with the possible exception of number 5. However, there are a further five disadvantages of internal insulation, which are more technical in nature and relatively little appreciated. These represent 'universal' risks associated with internal insulation of solid walls—none are associated with external insulation—and which need to be understood better:

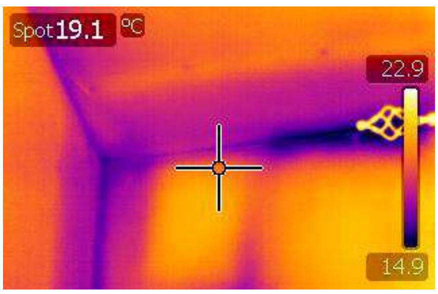
6. lack of protection from the weather. Unless the wall and all joins are very well maintained, there is a risk that water can still enter the wall, for example via cracks, leaks or just soft stone / joins. Climate change will exacerbate these concerns with windier and wetter weather meaning that internally insulated walls are more susceptible to damage and decay over time. Put another way, one of the biggest advantages of external insulation is that it can save you carrying out maintenance that would otherwise have been necessary, because you are providing a new external finish.
7. insulating on the inside means that the solid wall becomes isolated from the warmth of the internal rooms and becomes cold for longer periods. This creates an increased risk of interstitial condensation occurring within the wall, usually near the interface of insulation and existing solid wall where it is more difficult for it to escape. This is less of a problem with breathable internal insulation, but this is more rarely used.
8. most common insulants used are non-breathable. Using these internally means the wall cannot dry out towards the inside as it often did before. When linked to both points above, with interstitial condensation forming in the centre of the wall and rainwater potentially entering from the outside, the moisture load on the wall is raised considerably, creating a number of potential long-term problems.
9. insulating internally involves isolating the available thermal mass meaning the resultant space does not benefit from its capacity for thermal buffering. If this is coupled with a lack of hygroscopic (moisture) buffering and depending on the heating and ventilation regime, this can lead to increased fluctuation in temperatures and relative humidity which is associated with an increase in health risks.
10. the issues of thermal bridging and air leakage mean that internal insulation is inherently limited in terms of energy saving.

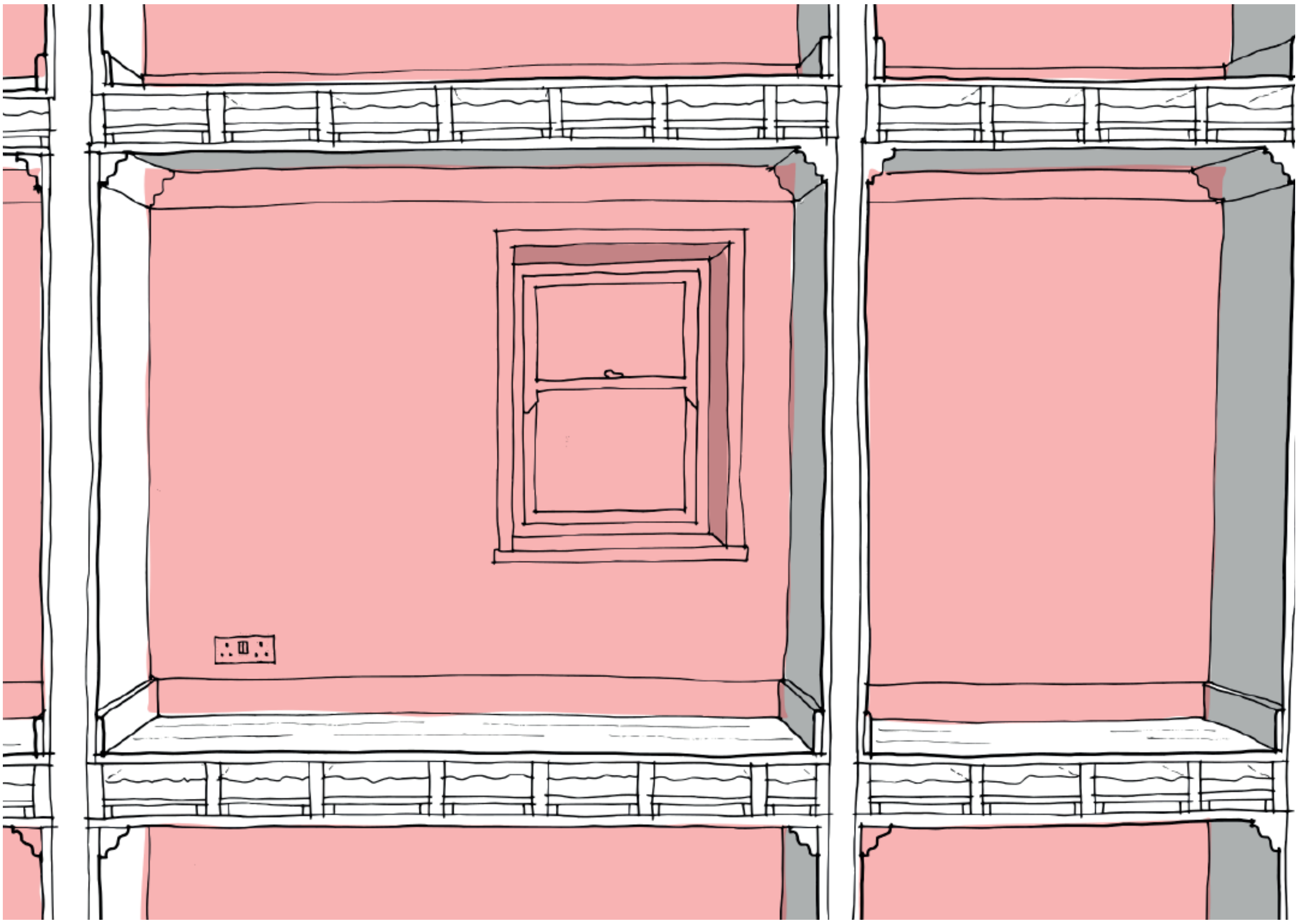
Although they are not well known, these five characteristics of internal insulation represent considerable risks to the basic health of both the occupants and the building fabric itself, as well as meaning that energy savings can be less than anticipated. For the reasons above, we recommend that in most cases, internal wall insulation should NOT be undertaken. If it is, then the following guidance will ensure that the anticipated savings are realised, and that the health of both occupants and the building are safeguarded.



Top image: rigid insulation board installed fairly neatly, but there are still gaps through which heat, air and moisture will flow.
Middle image: more of the same but note the unfilled gap between wall and ceiling.
Lower image: wood fibre used here which reduces some moisture-related risk, but the gaps remain.
© Historic Environment Scotland.
Below : The sorts of gaps shown above lead inevitably to cold spots, especially where these gaps are close to existing gaps in the outer walls or floors.







Insulated external walls (in red) coupled with cold, uninsulated walls and floors (in white) create thermal bridges, which can give rise to a host of issues such as interstitial condensation.

The Problem of Thermal Bridging

As noted in points 5 and 10 on page 76, internal insulation of most buildings is compromised by thermal bridging and a host of other problems which are not widely appreciated. Thermal bridges are discussed in detail in Section 2.2, and they become an important consideration with IWI.

The drawing above illustrates the problem in a notional tenement block, but the problems arise to an extent in any building with masonry partitions and more than one floor. In most tenemental properties however, individual owners will not own, nor have control over the properties above and below. In some cases, a Housing Association or Council, or even a private landlord may own adjacent properties, but this is relatively rare.

Without major structural intervention, it is impossible to insert insulation between the cross walls shown and the outer wall, so those thermal bridges are baked in. The thermal bridge can be reduced by extending the outer wall insulation ‘inwards’ along the adjoining walls for around a metre or so, but this does not address the space between the floors above and below, which represents further disruption and cost and is rarely carried out except in very high performance retrofits.

It is not just the thermal bridging though. Heat, air and moisture are all relatively free to travel from the warm rooms into the spaces within the floor joists and make their way unimpeded towards the uninsulated parts of the external wall or deeper into the building. The risk is that in winter, warm, moist air can readily make its way into the external wall fabric, cool and condense, adding to the moisture load in the wall and, more importantly, to the organic components (floor joists mainly) embedded with that wall. Depending on the condition of the outer wall, it is possible that cold air and moisture can also make their way into these interstitial spaces, especially if the insulation installed included a cavity between the insulation and the outer wall.

In short, it is almost never possible to provide complete continuity of internal insulation in reality. At the same time, any insulation install with gaps is inherently risky. Thus almost all IWI installations increase the risk associated with thermal bridging, air leakage and thermal bypass.

Internal Solid Wall Insulation (IWI)

Important to Know

In this trial IWI installation, there is no maintenance of the outer wall and water is finding its way in. There is no designed ventilation in the cavity so the risk is that this moisture will collect unseen and could lead to decay of the timber floor and wall frame over time.

- Internal wall insulation of any sort should only be carried out if you are sure that the condition of the outer roof, rainwater goods and wall are good. That is, the outer surface generally resists water ingress and also allows it to escape in drier weather
- Internal wall insulation is best undertaken only if you can be sure that the insulation will be fully continuous, avoiding all thermal bridging and air leakage
- Due to the risks associated with interstitial condensation which will occur with any internal form of insulation, it is best if the level of insulation is less than typically specified. In other words, aim for modest U-value upgrades, concentrating instead on the continuity of the insulation and airtightness measures installed. This will mean energy savings will be made in reality, even if this is not accurately represented in SAP.
- Because of the risks of solid walls becoming saturated, and unable to dry out to the inside, it is important that the insulation and internal finishes used are vapour permeable.
- To help counteract the likely internal temperature fluctuations caused by internal insulation, it is best to use an insulation material which has some density. Common synthetic insulations have little or no density—their whole modus operandi is to avoid this—but some insulations are actually quite dense which means that there is some thermal mass, and natural products, like hemp and woodfibre, have some moisture buffering capacity as well. In combination with a hygroscopic internal finish, this will beneficially moderate temperature and humidity swings internally, safeguarding the respiratory health of the occupants; refer to the diagram on page 16.

The issue of internal insulation is where this guide differs most from conventional guidance. Current approaches to internal wall insulation are much more problematic than most people realise, with potential to do widespread damage to our built heritage whilst not necessarily creating the savings expected.

There are various configurations of IWI:

1. The most common is where a cavity is created between the insulation and wall, usually using battens direct (over a dpc) against the masonry or a separate frame. Where an existing masonry wall may be damp, it makes sense instinctively to keep the timber frame separate. Where there is air movement in the cavity created, this may serve to remove any moisture from either part of the construction. There are two potentially significant disadvantages of this arrangement however. The first is that in many cases, the moving air is free to flow behind the insulation and usually finds its way into the building or cools the internal surfaces as thermal bypass. The second is the question of where the moving air deposits any moisture it may carry when it meets cold surfaces. In many cases there is a very real risk of unchecked air movement creating interstitial condensation which cannot be seen. Unless an additional service void is created on the internal face of the insulation, this arrangement may also suffer from the compromise of insulation, vapour and air control when installing services boxes.
2. A less common solution, but the one we propose is to install insulation directly onto the masonry wall, albeit in our proposal this is done over an initial levelling plaster. The obvious

Our Guidance vs Conventional Guidance

	Conventional Guidance	Our Guidance
Balance *ENERGY*	Various options, but high performance insulation reduces thickness required, less space loss & lower U-value preferred.	Lambda / U-value less important than continuity of insulation. No gaps - in insulation or air / moisture control layers (eg to window reveals, into floor depths above and below etc.) Maintained (dry) wall reduces heat loss. Natural insulation reduces embodied energy.
HEALTH	–	Effective insulation reduces cold spots and mould risk internally & improves comfort. Use of natural insulation reduces respiratory health risk. Use of dense insulation reduces fluctuations in temp / RH.
FABRIC	DPC or air gap between internal frame and solid wall.	Measures noted for Energy, Health, Maintenance and Moisture will all serve to protect building fabric from long-term problems.
Reality *MODELLING*	–	As Energy above—emphasis on little details in practice.
QUALITY	–	As Energy above.
MOISTURE	VCL internally, usually part of composite board.	Impervious internal finishes to be removed. Vapour permeable and hygroscopic insulation helps protect construction from saturation. Continuous VCL protects construction from internal vapour pressure, while emphasis on maintenance reduces risks from outside. Modest U-values mean reduced risk of interstitial condensation
People *PEOPLE*	–	Invest in upgrading services etc. before installing insulation (less cost and disruption later).
Heritage *CONSTRUCTION*	–	Proposals combine existing construction with new, working together, rather than separate internal 'shell'
MAINTENANCE	–	Emphasis on ensuring all external maintenance carried out first. Electrics in service void.
SIGNIFICANCE	Cornicing either removed or left in-situ.	Emphasis on continuity of insulation could lead to removal of cornicing etc. but where internal finish is significant, this should be retained, but could be replaced over insulated finish.

disadvantage of this technique is that there is no vented cavity to remove any potential moisture and another is that sometimes extra work can be required to get a level surface if the underlying masonry is not itself level or in good condition. However the big advantage is that this direct application stops any air ingress into the building fabric, while the issue of possible damp is managed through ensuring that the build-up is wholly made of vapour permeable - 'breathable'- materials which allow moisture within the wall to safely escape. Like the first solution, this arrangement is far more robust if a service void is created on the inside in which to locate service boxes etc.

3. A version of the second option, pioneered by Historic Environment Scotland, is to inject an insulation material (usually EPS beads but other options are available) into the gap between original lath and plaster and the masonry behind. This has the very significant advantage of creating almost no disruption to existing finishes which is particularly valuable in historic interiors, but its long term robustness to moisture is less easy to clarify. It may well be a good option where you can be confident that the outer faces of the walls are in good condition (well maintained) and not likely to become saturated. Note that EPS beads and some foams can damage electrical cables.
4. Another version of the direct applied option - and by far the simplest - is to apply an insulated plaster directly onto the masonry. Although not a well known technique, we believe this to be an eminently viable option in many places and can also be used externally.

Conventional guidance focuses on attaining good U-values, primarily through high performance insulation products, whereas BPE has shown that this does not necessarily lead to good performance overall - and therefore we concentrate more on the continuity of the insulation, and airtightness / vapour control membranes in order to close the gap between anticipated and actual improvement. High levels of internal insulation serve to increase the thermal separation of the original masonry wall which in turn increases the risk of moisture problems. Therefore, we recommend relatively modest levels of insulation and recommend that a 'breathable' material is used to reduce risks associated with trapped moisture.

Drawings representing typical (but poor) practice as well as our recommended approach are shown overleaf and opposite each other for direct comparison. We should stress that the purpose of these drawings is to illustrate the sorts of issues which need to be addressed and in the case of the typical / poor practice drawing indicate very much a 'worst case' scenario. Numbers on the drawings relate to the problems / solutions discussed alongside.

Preparation

- The first thing is to ensure that the exterior of the wall, including the roof work and guttering, and ground areas are all in good condition, keeping the wall dry [14]. Maintenance is always important of course, but adding internal insulation increases the risks associated with poor maintenance. Ideally cement renders and pointing will be removed in their entirety and replaced with lime-based alternatives. This is easy to write, but far harder and more expensive to carry out in reality and needs to be fully accounted for when weighing up the relative costs of internal and external insulation.

- In order to ensure that moisture cannot be trapped within the wall, it is important that there are no impermeable layers left on the wall before it is insulated. Old wallpapers and paint should be removed, unless of historic value, to get back to a suitable substrate. This is likely to be either the masonry itself, or a lime-based plaster finish.
- Any IWI solution should ideally be checked using WUFI or a similar hygrothermal model to establish long term moisture risks, particularly to the timbers embedded in the wall. Where a risk of decay is identified, it may be necessary to remove joist ends from the outer wall and reconnect them to a installed perimeter beam, which is costly and probably very difficult to arrange if only one side of the floor is owned.
- Depending on circumstances, it may be necessary to extend the insulation into the floors above and / or below which may mean removing ceiling or floor finishes adjacent to the external wall [2]. Again, this is easier to write than to do, and adds to the workload, cost and disruption of the works.
- Existing cables and other services should ideally be loosened, disconnected and moved / re-connected within a service void on the warm side of the insulation and airtightness layer. If not moved, they will need to be placed within conduit to be buried within the insulation although this will mean a reduction in the depth of insulation, the need to cut around it and an additional penetration through the airtightness layer.
- If windows and doors are to be replaced or repaired, it is best if this is undertaken before the insulation is installed so that the insulation can be carefully fitted to, and sealed against window frames.

Specialist tapes like this allow for a robust and airtight seal between the window frame and adjacent plaster, but need to be installed before insulation. See [4] in both diagrams overleaf.

Common Issues with Conventional Internal Wall Insulation

Energy Problems

1. heat loss via gaps in the insulation
2. heat loss: no insulation across floor joist junction with wall
3. heat loss around window: insulation is not taken into reveals
4. air leakage around window
5. increased heat loss due to saturation of wall in places
6. thermal bypass: cold air behind plasterboard cools internal surfaces increasing radiant heat loss
7. thermal bypass: cold air flowing behind plasterboard draws away heat within fabric to outside
8. high performance insulation with high embodied energy

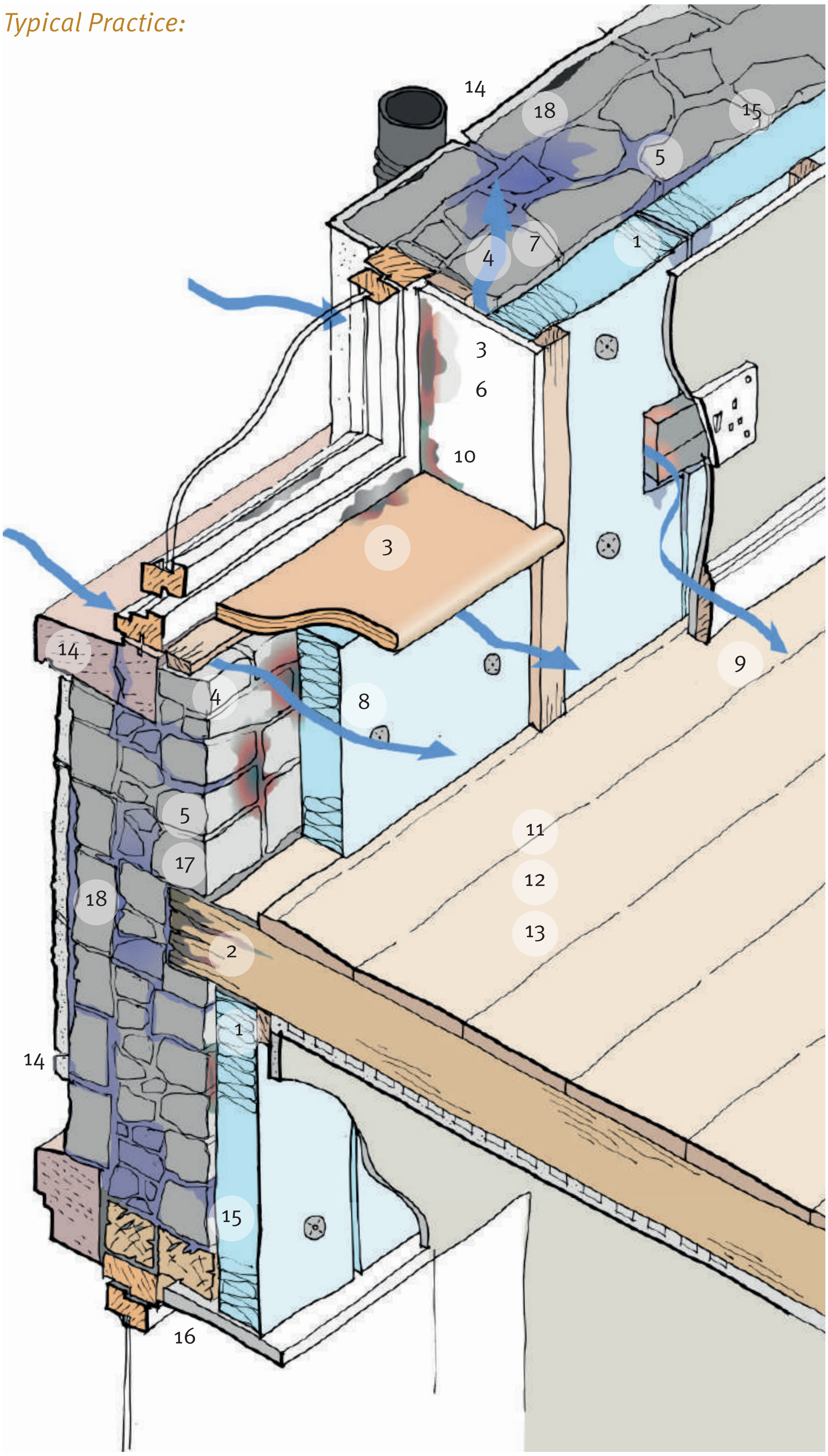
Comfort & Health Problems

9. discomfort due to draughts
10. condensation and mould forming on cold surfaces
11. internal insulation reduces access to thermally massive / hygroscopic surfaces, increasing fluctuation in temperature and humidity, with accompanying increased health risks
12. reduced IAQ: increased presence of mould spores, increased humidity, VOCs etc. from synthetic materials

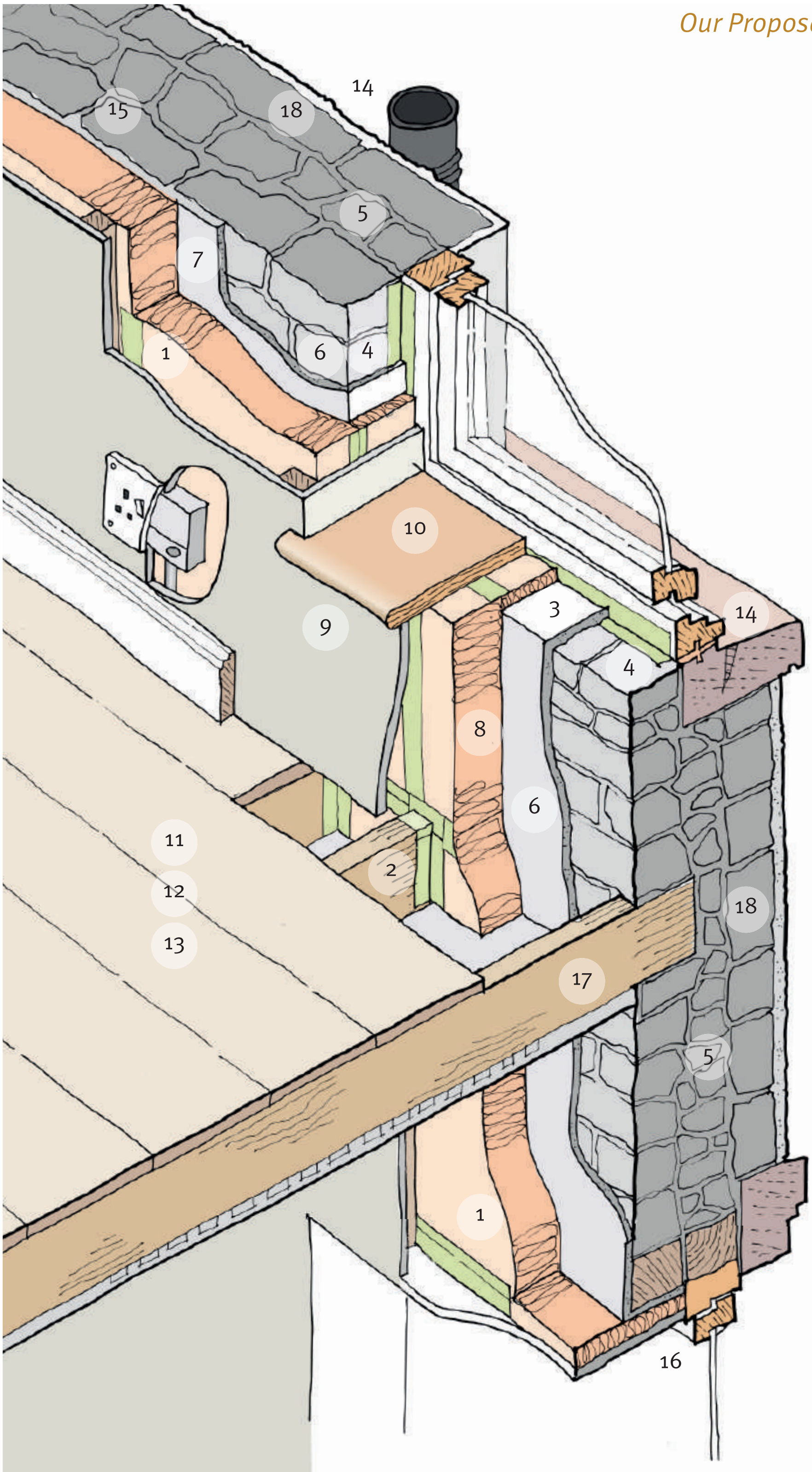
Building Fabric & Conservation Problems

13. loss of original cornicing/plaster / linings, both a conservation loss and a resource/waste issue, more to landfill
14. opportunities for maintenance and repair not taken, with conservation and practical implications (downpipe fixing loose, downpipes blocked/water flowing into hole created, crack in cill, cracks in render and missing/boss render). This also creates H&S issues if masonry falls
15. combination of interstitial condensation, gaps in insulation, rainwater penetration, lack of breathability and capillary action create moisture spread between insulation and wall - ideal conditions for rot
16. increased risk of rot/insect attack of timber safe lintols
17. increased risk of rot/insect attack of floor joist ends
18. saturation of wall leading to increased risk of leaching of salts, failure of mortar, spalling of masonry to outer faces

Typical Practice:



The drawing on the left shows a range of problems which can result from poorly conceived and installed internal wall insulation. The drawing on the right shows our recommendations for avoiding almost all of these problems and achieving in reality an energy efficient, healthy, and durable installation.



Our Proposal:

Recommended Internal Wall Insulation Solution

Energy Solutions

1. no gaps in insulation, all joints / corners taped
2. insulation taken across floor depth and taped against all joists
3. insulation taken into all reveals.
4. window fully taped / sealed to surrounding wall (no air leakage)
5. wall remains dry: better insulation
6. no thermal bypass: no cold air entering, insulation tight to wall: internal surfaces remain warm
7. no thermal bypass: no cold air behind plasterboard so no heat loss
8. natural, hygroscopic insulation with lower embodied energy

Comfort & Health Solutions

9. no draughts, greater comfort regardless of air temperature
10. all surfaces are relatively warm: less risk of condensation and mould
11. relatively dense and hygroscopic insulation offers both thermal and moisture balancing mass, so temperature and RH fluctuations from loss of access to masonry not as problematic
12. minimal reduction to IAQ through use of natural materials, non-toxic finishes, more balanced RH, less risk of mould

Building Fabric & Conservation Solutions

13. loss of original fabric still an issue, but refer to alternatives for an approach which avoids all removal of original finishes
14. external maintenance carried out first. downpipe cleared, fixing repaired, render repaired, all pointing and render in lime to allow wall to dry out, crack in cill repaired. no H&S issues with insecure masonry
15. vapour permeable insulation + equalising coat reduces risks of interstitial condensation; condensation that does occur is diffused within construction and can dissipate
16. reduced risk of rot/insect attack of timber safe lintols (dry wall, warm surfaces, moisture can dissipate internally)
17. reduced risk of rot/insect attack of floor joist ends, same reasons as above
18. wall remains relatively dry, thus reduced risk of leaching of salts, leaching of mortar, spalling of masonry to outer faces via freeze/ thaw action etc.

An example of an IWI system much like the one we propose. Note the 'equalising' layer between insulation and masonry. This option has a lime plaster direct over the insulation and no service void, but drylined options with service voids can also be achieved.

© Natural Building Technologies (Pavadendro system)

Installation

- Most systems require an 'equalising' plaster layer initially [6]. This may not be required if the substrate is smooth and level, but this layer usually fulfils several roles, including drawing moisture from the wall, filling out irregularities in the wall surface or simply providing an adhesive surface against which to temporarily affix the insulation boards. In some cases the masonry substrate is very irregular and it is not possible to just allow for a slight thickening of the plaster layer. Options then include a masonry re-build, or the use of a 'filler' layer, ideally in a cost effective, but similar mineral form such as an insulating plaster
- Window reveals should receive as much insulation as is feasible [3], assuming this will always be less than the wall itself and the wall between floor joists beneath should be insulated and made airtight first [2], so that floorboards can be replaced allowing for the safe insulation of the rest of the walls
- Masonry partition walls represent a thermal bridge and it is rarely appropriate, safe or cost-effective to remove these. Apart from simply accepting this and acknowledging the risks of cold spots here, conventional wisdom suggests that these walls should be insulated internally for at least 1m 'back' from the external wall. Where this is technically possible and acceptable, then it should be carried out. Not being subject to the complex moisture issues of external walls, it is possible in these situations to use thinner and/or non-breathable insulation which helps to minimise the 'step' in the wall surface that this creates.
- Insulation boards can be applied to the main areas of wall. There are various ways in which these can be affixed, sometimes a mix of both adhesive and mechanical fixings [8]. It is important that the boards all fit together neatly with no gaps anywhere, including at all corners.
- There is some debate about the value of an air barrier and vapour control membrane. In our view, as long as the ventilation system is providing a reliable under-pressure meaning that moisture is always being removed from the property then it is usually acceptable without a membrane. It is however important to seal all of the insulation joins so these should be carefully taped using a suitable tape recommended by the manufacturer [1]. The need for a vapour control membrane can be clarified via one of various hygrothermal modelling tools, such as 'WUFI', 'DELPHIN' or others. A number of manufacturers offer this as evidence of the efficacy of their products. If a membrane is used, it is important that it is an 'intelligent' type which allows vapour back into the property at low pressure. If a conventional membrane is used, there is a risk that moisture in the wall can become trapped.
- Once the insulation (and membrane if required) is installed, re-affix all services within a service void. In this way, none of the services need to penetrate the membranes or insulation meaning the performance of both are safeguarded.
- Any sort of conventional finish can then be affixed to the battens, including plasterboard, timber lining, or some form of mesh and lime or clay plaster finish and finished with decoration as necessary. Bear in mind that conventional paints tend to be impervious to moisture and so it is important to use vapour permeable paints, especially if used on a plaster finish applied directly to insulation.

Health & Safety

Removal of existing finishes can be of some concern. Beyond simple generation of dust, additional concerns surround animal hair which is sometimes found in traditional plaster and there are issues surrounding the removal of lead paint. If the furniture of occupants is left in the rooms, then it is important that it is protected from dust and rooms sealed while works are undertaken to stop the spread of dust to other spaces in the property. It is assumed that works can be carried out from inside and so there are no issues associated with working from height, nor confined spaces. In some cases, we recommend that the insulation extends into the depth of the floor beneath a room and in these situations, it will be necessary to exercise greater care around the gaps in working platform created.

How much is enough?

This depends greatly on the masonry wall itself. We would recommend a depth of insulation of between 40mm and 80mm. Using 60mm woodfibre with a lambda value of around 0.045W/mk on a typical 500mm stone wall should give a U-value of around 0.45W/m^2K or less. If this is continuous across all obstacles and penetrations then this is adequate. Depending on the circumstances of the retrofit this may need to be agreed with building control (who may require lower U-values) and bear in mind that most within the industry would consider this an inadequate return—on paper—for the effort and cost.

External Solid Wall Insulation (EWI)

Important to Know

- In order to achieve a continuous layer of insulation it may be necessary to undertake a lot of preparatory work, some of which may involve utilities companies which can be difficult to co-ordinate.
- It is critical that the insulation used is vapour permeable in order that moisture can safely escape from the construction to the outside.

Our Guidance vs Conventional Guidance

	Conventional Guidance	*Our Guidance*
Balance *ENERGY*	Various products and finishes to give an acceptable U-value	U-value less important than continuity of insulation. No gaps - resulting in removal / replacement of common items like downpipes / gas meters / wallhead etc. Protected dry wall reduces heat loss. Thermal mass of original wall available. Natural insulation reduces embodied energy.
HEALTH	–	Effective insulation reduces cold spots and mould risk internally & improves comfort.
FABRIC	–	Protecting wall from weather safeguards longevity. Measures noted for Energy, Health, Maintenance and Moisture will all serve to protect building fabric from long-term problems.

	Conventional Guidance	Our Guidance
MODELLING		As Energy above—emphasis on little details in practice.
QUALITY	–	As Energy above.
MOISTURE		Far less risk of interstitial condensation. Vapour permeable and hygroscopic insulation helps protect construction from saturation.
People *PEOPLE*	–	–
Heritage *CONSTRUCTION*	–	Using vapour permeable insulation and flexible, natural coatings should ensure greater consistency (movement/moisture) between substrate and new materials.
MAINTENANCE	(Installation of EWI reduces need for maintenance of original wall)	Emphasis on ensuring all making good and maintenance carried out first. EWI forms a new external surface so maintenance costs reduced in future.
SIGNIFICANCE	Not acceptable for listed buildings, Conservation Areas, some 'finer' properties where agreed.	As conventional guidance, but greater importance attached to existing external features: either avoid EWI or additional effort/cost to faithfully replicate details.

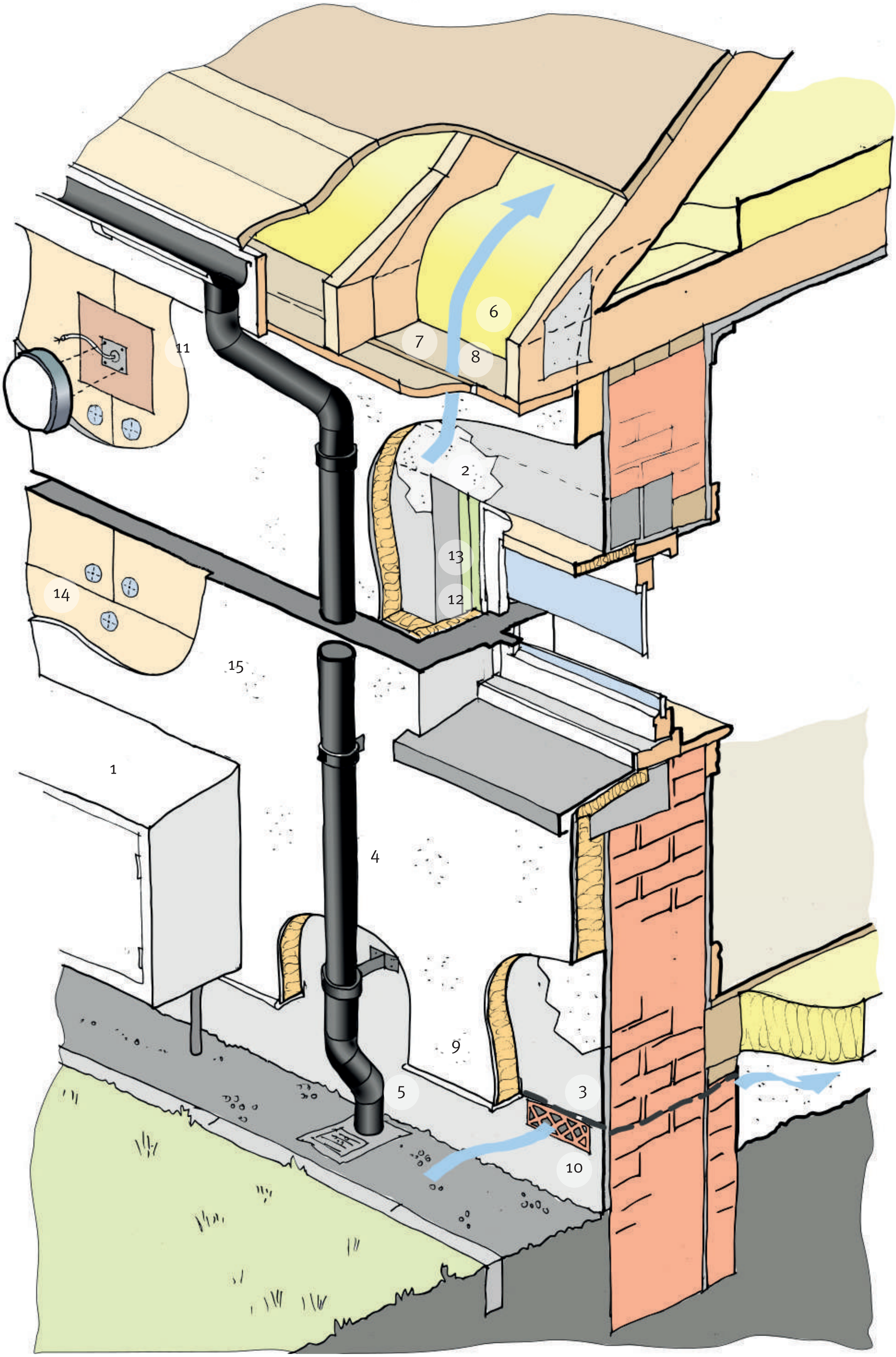
In this project, getting the gas company to move the gas meter boxes proved too difficult, and as a result, the insulation has been formed around them, leaving a significant thermal bridge with a risk of cold surfaces internally and mould.

In this project, underlying render failures were repaired, conduits installed for all external cables and rainwater and waste pipes re-fixed to allow the insulation to extend behind without breaks.

Our guidance is different from conventional guidance in that we suggest taking far more trouble to achieve a continuous layer of insulation, mainly related to the level of preparatory works noted below.

Preparation

- The first thing is to undertake a review of the utilities and services entering the building. In many cases, these will enter the building underground, rising in a services cupboard for example, which is fine. The issue arises where services enter through the wall, travel along the wall on the outside or, as is often the case with gas meters, enter via a meter and box which is affixed to the wall. Since the objective is to avoid any breaks in the insulation, any items which could penetrate the insulation should ideally be re-routed to enter from underground, or in the worst case, penetrate the insulation at a single point only. Where services must run across the surface of the building, it is best to install them within conduits to allow for future alterations. In the case of gas meters which usually have to remain accessible and on the external face of the building, it is important to agree with the gas company to move the meter and box in advance so that it stands proud of the wall a sufficient distance to allow the insulation to run behind it. [1]
- Another early item is to survey the condition of the existing face of the building. Existing structural defects will need to be rectified [2]. In some cases, it may be that the existing render or other surface is not sound. In every location where this is the case remedial work
- should be undertaken to the face of the wall so that fixings made into it are securely fastened into sound and homogenous material



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[3]. A structural engineer's report is sometimes required following 'pull-out tests' of the masonry to ensure that the wall can support the insulation and resist it being sucked away by adverse wind conditions.

- Downpipes [4] and waste pipes running across the facade need to be moved outward, to allow the insulation to run behind them. Extended fixings are available for every type of pipe. Adjustments also have to be made at the top and bottom of pipes where they connect to the gutter above and drains below. In some cases it is possible to 'swan- neck' the pipework back into the existing ground connections [5] but in others, it is necessary to move the existing drain connection or create a new connection.

It is important that the roof insulation above meets the EWI below.

- Existing eaves details vary significantly. The key for effective insulation is to make sure that the insulation in the roof or ceiling is continuous with the insulation on the walls. [6] Many buildings have overhanging eaves which enable the roof insulation to cover the wallhead and it is relatively straightforward to ensure that the two insulation layers meet. In cases like this, there is often a soffit board which will need to be removed to allow access to the wall-head. [7] In older properties, the roof can be 'tight' to the wall, meaning there is no opportunity to join the external wall insulation so if allowable and practical, the lower section of the roof needs to be extended to enable insulation to continue across the wall-head and join the external boards. The eaves board and gutter can be moved at the same time and the overall appearance remain the same. It is always important to ensure that there is a route for ventilation above the insulation whether this is in a loft or within the rafters [8].

This image shows a mineral wool strip between floors to resist fire between property boundaries. Note also conduit for telecom cables is notched into the back of the insulation boards.

- Typical practice for external insulation is to install the bottom or starting runner for the insulation approximately 50mm above the internal floor level. This means that heat leaks out of the base of the wall creating cold areas internally which attract condensation and mould. In contrast, we strongly advise that the insulation is extended downwards at least as far as the depth of the floor structure and ideally further to reduce the thermal bridge. [9] In solid floored properties, it makes sense to take the insulation down to ground level, and if possible, below ground level. The insulation used should be a closed cell type (impervious to moisture) and more robust to offer some resistance to knocks. This insulation should be installed up to and tight to the starter rail normally used to set the main insulation boards, sealed with a non-setting sealant and finished with a similar render.
- In suspended floors remember that ventilation to the spaces beneath the joists must be retained (and if missing, installed) [10].
- Most properties have some features externally which can complicate external wall insulation. External lights [11] and signs, satellite aerials and dishes, hanging flower baskets and other items should be removed, and replaced, secured using thermally broken fixings through a pattress of suitable (robust) insulation of the same depth.

This image shows insulation applied to the upper levels of the gable. This area is often ignored but a small section of the upper flat has been insulated here.

- If windows and doors are to be replaced or repaired, it is best if this is undertaken before the insulation in installed so that the insulation can be carefully fitted to and sealed against the frames. Windows should be installed close to or in line with the line of the insulation.
- The further back from the face of the wall, the more of a gap is created across the reveal which needs to be insulated. Ideally at least 20mm of insulation should be installed to all reveals (including the cill) although specially designed thin insulation can be used if there isn't enough room. [12] In all cases, it is worth installing airtightness tape over the join between windows and

masonry to avoid air leakage at this common weak spot. [13]

Installation

- In terms of the installation of the main insulation boards themselves, there is no difference between our guidance and conventional guidance. The main thing is to follow the guidance of the manufacturer, ensuring that there are no gaps, corners around openings do not coincide with joins in boards, and that the correct beads are used. [14] On some projects, the more difficult to access areas sometimes get left, and we would advise that an independent person inspects both the extent, and quality of the installation of boards (particularly regarding gaps) before the first coats of render are applied.
- It is important that the insulation material is vapour permeable in order to allow moisture within the wall to escape. Most 'natural' materials tend to be breathable as are most configurations of mineral wool and expanded polystyrene. Certain plastic insulants that are described as 'closed cell' are likely to be impervious to moisture and these should be avoided unless there is a clear alternative strategy to remove moisture within the wall.
- The Grenfell Tower tragedy has raised concerns about the behaviour of building materials in fire. In this regard, mineral wool products have a clear advantage over plastic and most natural insulation. However, when insulation is installed tight against a masonry wall, and covered in a non-combustible render—as described here—the risk of fire spread is minimised because fire cannot easily reach the insulation, nor once in, can it readily spread. The risk of fire spread in cases like Grenfell is linked to the insulation being adjacent to a continuous cavity.
- Render is thereafter applied to the insulation boards and tends to be built up in two or three coats, and with a variety of finishes [15]. As with the insulation, it is important that the render is both waterproof and vapour permeable. Different thicknesses and finishes are often applied to reveals of openings, to different areas of the building (for aesthetic reasons) and often to the base course if applied.
- Original features of the building where possible should be replaced/re-formed as far as is practical.
- Once render is completed, the items temporarily removed should be re-connected or replaced.

In this project, wood fibre EWI is being installed over a solid brick property
© Natural Building Technologies

Alternatives

- Another technique, once the wall is prepared, is to install an insulating render directly onto the wall. This technique has some significant advantages, mainly that it represents fewer operations and so is likely to be much cheaper, quicker and simpler to undertake. The modest U-value improvements are not a problem as discussed above, although they may be an issue for compliance.
- As discussed in Section 2.4, climate change will bring increasingly wet and windy weather at times. Some in the industry have concerns that the relatively thin renders used on most external wall systems are too vulnerable to damage, so thicker renders may become more common. An alternative is to introduce rainscreen finishes which offer far greater protection against driving rain but this will increase costs.

In this retrofit project, some of the decorative details of these houses have been lost through EWI. If we want to preserve the identity and enjoyment of places across Scotland then we will have to treat social housing like this with more of the care and attention typically spent on 'conservation' projects

Health & Safety

- The most common health & safety issues centre around access (working off scaffolding) and the issues raised during disconnection and reconnection of existing externally mounted services (such as gas meters).

How Much is Enough?

- Unless there is a particular U-value target to be reached, around 100mm of suitable insulation is usually sufficient. In Passivhaus-standard retrofits this will likely be thicker. What is much more important than the precise depth of the insulation is the continuity of the insulation, so, for example, it is more important to move all of the downpipes / waste pipes / gas meters / external lights than add an extra 20mm of insulation.

Timber Frame Retrofit

This timber frame house was built in the 80s but had a number of insulation gaps which needed to be resolved in order to reach the expected comfort levels

In Scotland most new homes are now built in timber frame. The majority of these homes feature a timber frame internally, filled with insulation, with a ventilated cavity outside that and a masonry wall beyond to make it look like a masonry home. The timber frame is the structural element however holding up the intermediate floors and the roof.

There is a lot to like about timber frame construction. Above all it is relatively fast and cheap to build compared to masonry. In a country with bad weather, this means you can get the roof on quickly and be working in the dry sooner. The masonry outer leaf can be put up any time thereafter and is largely outwith the ‘critical path’ of a build process. Timber framed homes are generally better insulated than older homes and timber is a relatively ‘green’ material compared to most masonry options, with less embodied energy.

However, there are a number of potential downsides to timber framed buildings. Timber burns of course and being organic it can also rot or become infested with insects if the conditions are right, and it can move if it’s not installed at the correct moisture content. Timber frame walls don’t have the sheer mass of masonry and so have to manage acoustic separation differently.

All of these downsides are managed through the building control system, design codes and through manufacturers’ recommendations. However, the increase in complexity required by the building regulations and a widespread de-skilling of the construction industry means that while timber framed homes built in the last 50 years or so are theoretically better performing than older buildings, this is not always the case in reality.

They can also be more complicated constructionally and less robust, making it harder to devise improvements which are effective in both cost and performance. For example, a common notion to improve the performance of timber framed buildings is to install insulation within the cavity between the timber frame and the outer masonry. Like masonry cavity wall insulation, this increases the risk of moisture passing across the cavity to cause damp internally. Unlike masonry cavity construction however the damp this could cause can also cause decay of the timber structure and complete failure of the building.

We have proposed two solutions to improve timber framed buildings. Both involve considerable disruption and likely cost, but represent long term strategies to improve the insulation in the walls whilst still ensuring a robust fabric that will last indefinitely. The first involves stripping out and insulating from the inside of the building. This creates considerable disruption internally but means the external finish remains unchanged. The second involves improving the insulation from the outside and so while the insides of the building are untouched, there would be extensive disruption externally.

Important to Know

- It is important to remember at all times that timber is organic, so it can decay under the right circumstances. This means material choices, air and vapour barriers, and ventilation all play a part in keeping the timber and insulation dry and performing well.

Our Guidance vs Conventional Guidance

		Conventional Guidance	Our Guidance
Balance	ENERGY	Improve U-values, fill frames if empty.	Improve U-values, fill frames if empty. As Construction below. Importance of airtightness. Potential to upgrade existing insulation in frame (often inadequate) Lambda / U-value less important than continuity of insulation (eg to reveals). Additional insulation resolves thermal bridging of studwork. Natural insulation reduces embodied energy.
	HEALTH	–	Effective insulation reduces cold spots and mould risk internally & improves comfort. Use of natural insulation reduces respiratory health risk. Use of dense insulation reduces fluctuations in temp / RH.
	FABRIC	–	Measures noted in other sections will all serve to protect building fabric from long-term problems.
Reality	MODELLING	–	As Energy and Construction.
	QUALITY	–	As Energy, Moisture and Construction.
	MOISTURE	–	Continuous installation of VCL and service void protects frame from internal moisture more effectively.
People	PEOPLE	–	Providing a service void protects the membrane but also offers less cost and disruption if services are to be upgraded in future - helping to ‘future-proof’ the house.
Heritage	CONSTRUCTION	–	Carry out pressure test first and audit to assess, adjust works accordingly. Allow for potential localised improvement, reflects ‘patchiness’ of some timber frame buildings.
	MAINTENANCE	–	Topping up insulation is a fairly extreme form of maintenance of the insulated fabric.
	SIGNIFICANCE	–	Unlikely to be problematic, unless there are internal finishes of significance.

There is actually very little guidance on retrofitting timber framed houses, and what there is is quite diverse, often coming from a commercial standpoint, and often assuming that there is no insulation within the frame at all. Our experience suggests that there is almost always some insulation, but that it is very poorly installed.

This shows the upstairs wall of the house shown on page 90. The polystyrene insulation has been removed to install pipes and nothing replaced, meaning that in effect, there is only plasterboard between the bedrooms and the outside air. In addition, the hot water pipes are uninsulated. Unfortunately, there's a lot of fiddly insulating and airtightness work to be done here.

As well as improving the U-value through additional insulation, our proposals allow us to 'top- up' any slumped, failed or missing insulation within the frame itself. In addition, the first option resolves a principal weakness in most timber frame walls by providing a continuous vapour control layer, no longer compromised by penetrating services.

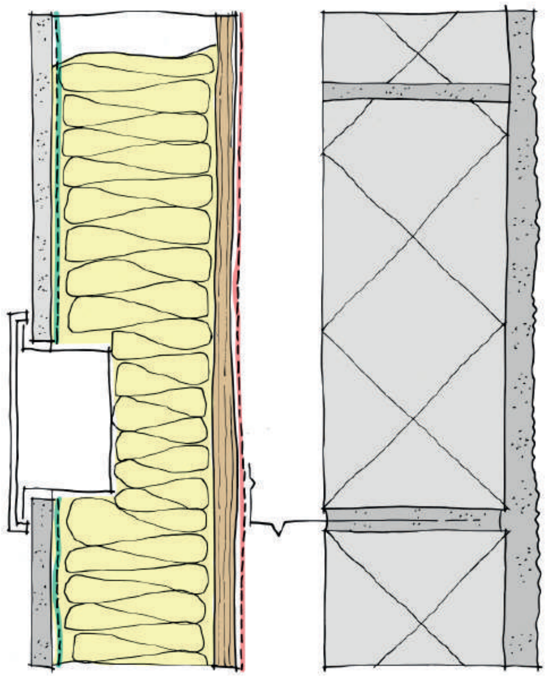
Preparation

- Compared to a solid walled house, timber framed buildings are quite complex constructionally, with lots of layers, all of which play a different role. This complexity means that it is worth spending a little time investigating before making a decision one way or another. The most helpful test is an air pressure test because this will determine how much of the heat loss can be linked to draughts. Results can differ widely and will affect how to proceed. While undertaking the pressure test, make sure it includes an audit (usually with a smoke pencil) and thermographic images are taken so that potential problems and the overall quality of the construction can be assessed.
- If the reporting above shows that the building suffers from excessive draughts, then it makes more sense to tackle these before spending time and money on disruptive insulation improvements. Common areas are discussed in the section on airtightness. Remember when undertaking these works to ensure that ventilation is also considered.
- If the reporting shows that the building is relatively airtight but that there are localised issues within the walls or other areas, then a targeted approach may be best. It is possible to inject insulation directly into timber frames, but this doesn't allow you to see what is happening and there are risks of materials used affecting electric cables. Therefore it is usually better to remove plasterboard, assess what is there and carefully re-insulate, repair the vapour control layer (if present), put back plasterboard and re-decorate. If this is only in one or two areas, then it is not too onerous.
- If the timber frame is uninsulated, then clearly this is the place to start. Insulating within the frame will make a huge difference but all of the following points remain useful to consider.

The insulation within timber frames is often far from adequate and so it is usually worth removing finishes to inspect before adding or adjusting insulation. This one shows not only that the insulation does not fill the cavity, but that inadequate vapour control has led to mould within the frame itself. If following the detail on the next page, this mineral wool should be removed, the frame dried out and new insulation installed with robust vapour control.

Installation Method 1: Insulating from Inside

- The first step is to remove and/or protect furniture and finishes in the room and then remove the plasterboard. Depending on what is to be done with services, it may be necessary to involve an electrician to disconnect cables etc. while the other works are undertaken.
- Once the plasterboard is removed, it will be possible to inspect the existing insulation (see image on the left) and services within the frame, and to upgrade, or top up any insulation which has slumped or is missing [1]. Comments on the best type of insulation and need for attention to



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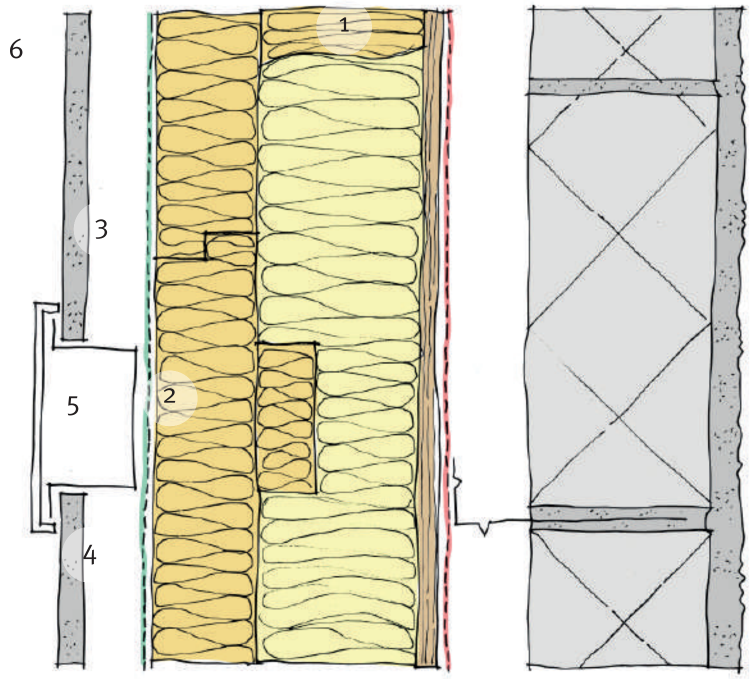


Proposed

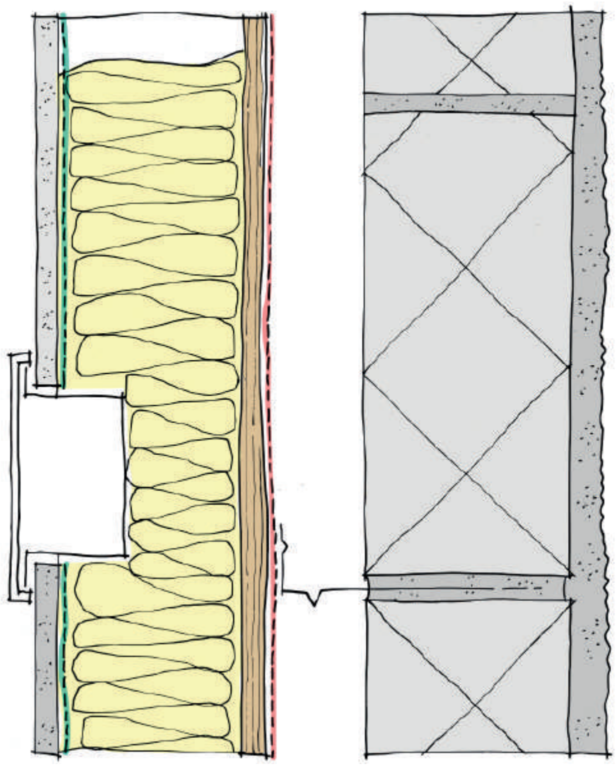
Insulating from inside: The drawings show the most common existing arrangement of timber frame (left) and a proposal (right) to improve energy efficiency without affecting the outward appearance of the building

detail (no gaps) discussed in the roof section apply here too.

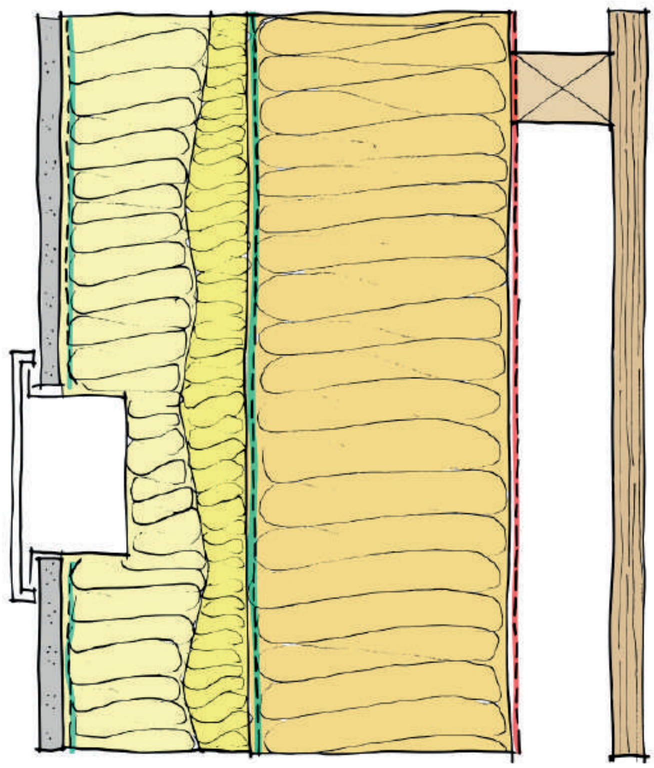
- A layer of ideally interlocking insulation boards can then be affixed over the inner face of the studs. This gives both more insulation, but also overcomes the thermal bridging effect of the studs [2]. These boards should be fairly rigid to avoid the need for additional woodwork and ideally hygroscopic and denser materials (such as woodfibre) in order to better manage any moisture in the wall. As with standard Internal Wall Insulation (IWI) it is important where possible to insulate the reveals of windows and to seal all gaps and service penetrations etc.
- The vapour control layer that is then shown inside the insulation [3] should be an 'intelligent' type which allows some vapour 'back into' the room under low pressure while maintaining an effective barrier to high levels of vapour pressure into the wall. This is because the external sheathing of the wall is likely to be plywood or OSB (Oriented Strand Board), neither of which is vapour permeable, so moisture that gets into the wall cannot escape, as it can in a 'breathing wall' (Refer to 'Building Science' section).
- Not only is it critical to have a vapour barrier to stop moisture getting into the wall, it is important not to then puncture this barrier and for this reason we have shown a service void formed of battens inside the membrane [4]. These allow for future changes of servicing and location of electric boxes etc. [5] without damaging either the insulation or the vapour barrier in the long term.
- The internal finish can then be completed with plasterboard as shown although another solution would be a clay board or any other dry lining. [6].

Installation Method 2: Insulating from Outside

- In almost all timber frame constructions, the timber frame itself takes all of the structural loads but it would be sensible in all cases to ensure a structural engineer has checked that this is the case before removal of the blockwork, along with a plan for removal of the external sheathing and any other issues which may arise.
- With this option, there will almost certainly need to be engagement with Planning and Building Control in advance and an agreement



Existing



Proposed

Insulating from outside: The drawings show the most common arrangement of timber frame (left) and a proposal (right) to improve energy efficiency without affecting the inside of the building.

in place for a new external finish. The removal of the outer blockwork will necessitate a plan for the eaves, window and door reveals as well as service penetrations and all the usual things that are attached to external walls like lights, signs and secondary structures. There will also need to be a plan for the removed blockwork.

- Once the blockwork is removed wall ties need to be removed and if possible the external sheathing to review and if necessary supplement the existing insulation. An alternative is to leave the existing sheathing in place which will make things easier but it does mean that there is no opportunity to check and supplement the existing insulation.
- It may be necessary to carry out the works in sections to ensure the bracing of the wall is retained. The bracing role of the external sheathing may be undertaken by the new external insulation, by replacing the original or a new sheathing board, by using diagonal metal braces or by some other method.
- Depending on the confidence in the existing vapour control layer it may be worth considering an additional vapour and air control layer on the outer face of the timber frame / outer sheathing.
- Thereafter, insulation can be installed to whatever depth is desired bearing in mind that fixings will almost certainly need to be taken back to the frame behind. The insulation should be a vapour open material if possible and ideally tongue-and-grooved.

Our proposals allow for a breather membrane over the insulation followed by battens forming a vented cavity and a rainscreen like timber cladding to finish. A rainscreen finish like this accords with the need to be certain that the insulated wall is kept dry as discussed in Section 2.4 on climate change adaptation, but the external finish could be anything including a rendered finish to match the original rendered blockwork.

It is worth noting that in theory a replacement blockwork wall could be constructed but this would probably mean extending the existing foundation to provide a footing for the new masonry. In any event, all external finishes / junctions and items like external lamps will need to reconnected.

Alternatives

We are aware of two alternative approaches to insulating timber framed homes which have been discussed within the industry. Both are far simpler and cheaper to undertake, but neither appear sensible.

- The first is the filling of the cavity discussed at the beginning of this section which raises very serious concerns about the longevity of the timber frame itself.
- Another is to install EWI on the outside of the outer masonry. Fundamentally this makes no sense because any potential benefits of the added insulation will be bypassed by the vented cavity. This has been modelled in detail to establish whether it could work and the conclusion was that it might offer some thermal benefits if the cavity itself was to be fully sealed. However, this means re-writing the logic of the detail as envisaged (which relies on a vented cavity to remove moisture), there is thus a heightened risk of moisture damage and it could only work if the cavity could be 100% sealed. Given that it would have been designed to be vented this may be impossible in practice so appears to be too deeply flawed to be considered further.

In this upgrade on a previously insulated stone building, the timber frame was exposed and insulation within tidied up before wood fibre boards were installed across the face before finishes were applied

© Sam Foster Architects

Health & Safety

- There are risks associated with the dust of demolition and potentially from breathing in the fibrous dust of the existing insulation. If working externally at height there are associated risks and there are issues related to disconnecting and re-connecting services.

How Much is Enough?

- Unless there is a particular U-value target to be reached, around 100mm of additional insulation is usually sufficient, assuming the frame already has around 150mm of insulation within. In Passivhaus-standard retrofits this might need to be thicker. What is much more important than the precise depth of the insulation is the continuity of the insulation.

4.6 Windows & Doors

The world of window replacement tends to split into two broad camps. The first and largest is the straightforward replacement of windows across council and housing association properties which are usually undertaken on a 30-year cycle. The work is considered an issue of maintenance, with sometimes a consideration of energy efficiency. Since windows nearing time for replacement tend to be wooden and have often been badly neglected, there is a common perception that timber windows perform badly and so PVCu windows are often considered for replacement.

The second camp is where the building has some historical merit or is in a conservation area. Although Historic Environment Scotland as a body has moved a long way forward in its appreciation of the issues of historical window upgrading, planning and conservation officers too often default to an inflexible view that these windows need to be kept as single-glazed, or replaced on a strictly like-for-like basis.

In this way, both camps miss out on the huge range of interest and potential that exists in this subject to improve every aspect of window design without necessarily losing any of the beauty or functionality of existing window arrangements. We have added a section in this chapter to introduce the range of issues, not always considered, which impact on our recommendation. We have divided our guidance into two possible solutions, responding to the very different routes that open up in the presence, or absence, of regulatory conservation concerns.

Important to Know

- Doors and windows usually lose heat at around 5x to 10x the rate of other areas of the house (per unit of area), and so it makes sense to look carefully at how we can improve what is often the 'weakest link' in the building envelope.
- However, heat loss is not the whole story with openings; south facing windows also bring warmth into the building during the day, east and west-facing windows to a lesser extent, and all windows lose heat at night. Heat loss is also related to draughts, not just U-values. Balancing energy flows is not straightforward.
- Moreover, warmth is not the only issue with windows and doors; they also admit light, provide views and a connection to nature and the outside, allow us ventilation at times and from the outside provide the 'eyes' of the property. In Scotland where the summer days are long and winter days are short, they significantly affect the mental health of a population which spends 90% of its time indoors, so again, getting the 'best' opening is not a simple exercise.
- A number of regulations may apply to windows in retrofit projects which must be adhered to. These may include constraints imposed by conservation officers, as well as building control aspects such as those related to fire escape and security.
- In this section we refer to openings to encompass both doors and windows

Additional Issues to Consider with Openings

a. Energy Efficiency
- U-values are often the only consideration when contemplating energy efficiency. In an older solid-walled house, uninsulated with single-glazed windows, the U-values of the walls might be perhaps

1.1 W/m²K and 4.5 W/m²K for the windows. Typically therefore the windows and doors lose heat at around four times the rate when considering U-values alone. In an insulated house with good quality double glazing, the U-values for walls and windows might be 0.2 W/m²K and 1.4 W/m²K respectively, meaning that even though the windows are approaching the efficiency of the older uninsulated walls, they are still losing heat at now seven times the rate.

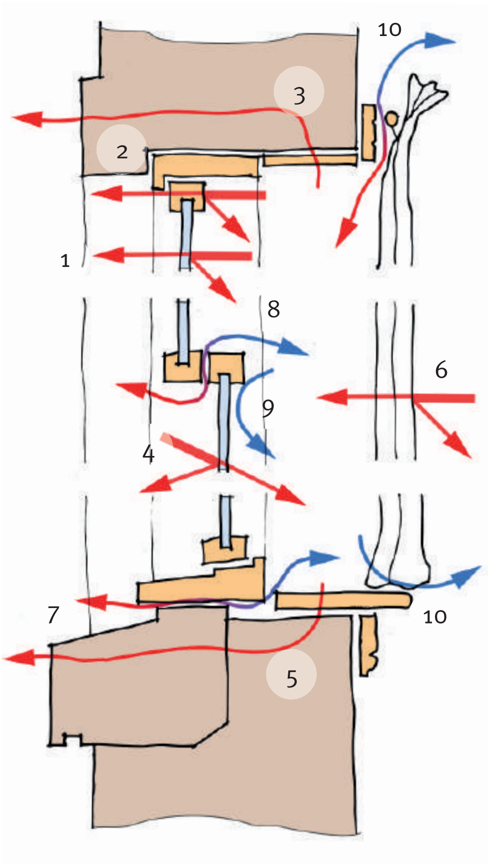


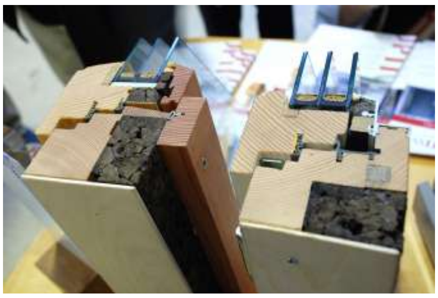
Diagram showing the 10 ways in which buildings can gain and lose heat through windows

1. mainly radiant losses through the glazing, better U-values will reflect more back into the room
2. conductive losses through the frame (timber frames better than PVCu and metal, but can be improved)
3. mainly conductive losses through the surrounding construction and materials used to fill the installation gap (if any)
4. mainly radiant gains from sunshine, better U-value glazing will reflect more, preventing heat gain
5. like 3, but water running off glazing can saturate the wall beneath a window if the cill is not effective and cause greater heat loss
6. curtains (but also blinds, shutters, secondary glazing) will reduce radiant losses from the room
7. convective losses from draughts between the window and the surrounding walls —a common problem
8. convective losses from inadequately airtight windows
9. downdraughts caused by cold glazing can lead to cold air running at low level into the room, causing discomfort
10. downdraughts caused by inadequate seal top and bottom to curtain, or whatever is placed in front of the window at night

- Doors and windows lose heat through the glass, but they also lose heat through their frame, and so the material and design of the frame itself is important. Beyond this however, windows and doors can also lose heat through the gaps around them, or between them and the wall itself. For this reason, the installation of any window or door is considered important in our guidance whereas it is usually ignored in conventional guidance.
- Because of the position and movement of the sun, windows gain and lose heat differently depending on their orientation. Very broadly, in Scotland, south-facing windows can gain as much heat as they lose over the course of the year, while west and east-facing windows lose more than they gain, and north-facing windows lose far more.
- In addition, openings gain and lose heat at different times of the day, so while south-facing windows will bring in warmth during the day, they will of course lose heat overnight. Traditional and common techniques of using shutters and heavy curtains therefore work well in combination with even quite poor quality windows

because they allow for gains during the day, while significantly reducing heat losses overnight. Similarly, using removable secondary glazing over the heating season, and removing it during the warmer months is a sensible option when considering energy balances across a whole year.
- What U-values don't tell us is that a great deal of heat loss through windows is due to draughts which can increase the heat loss associated with windows far more than normally appreciated.

2. Comfort & Wellbeing
- In Passivhaus design, there is a stipulation that windows must have an maximum installed U-value of 0.8 W/m²K. This almost always means high performance triple-glazing. This stipulation is only partly related to energy efficiency however, it is also related to the fact that at this level of performance, even the coldest temperatures externally will not create a 'downdraught' on the inside. Whilst only a fraction of retrofit projects will aspire to Passivhaus levels of energy efficiency and comfort, it is worth considering higher specifications where particularly large windows are being replaced, or where there is a likelihood that older or more vulnerable people will be spending a lot of time near the window, for example in care homes.
- For many people, the views from their home are the primary reason for purchase and the most treasured aspect of the property. In health care design it is now well understood that a view of the outside, and particularly of natural settings aids recuperation and healing. Studies have also shown higher levels of satisfaction and better performance from workers in commercial settings who have views to outside, and so it is important that this aspect is considered in any retrofit scenario. Whilst windows placed higher in the wall will throw light into the far reaches of the room, and offer views of the sky, windows which reach down to the ground, or low level offer a more immediate view of, and relationship with the external spaces adjacent, which is valued. In most retrofit projects, the location and position of windows is fixed, but in relevant cases, it is worth a pause to consider these aspects before simply accepting what is there.
- In the relatively high latitudes of Scotland, and especially in the north, the winter days are short and people spending most of their time indoors can suffer from Seasonally Affective Disorder (SAD). Providing higher levels of natural light, especially during the winter months is therefore worth consideration for the wellbeing of those using the building, especially those who don't get out as much.
- Unlikely (and welcome) as it may seem to some, overheating is a risk in Scotland where buildings are designed to higher levels of energy efficiency and airtightness. In warm, retrofitted buildings, large, unshaded south-facing windows and lack of ventilation can lead to uncomfortably hot conditions. Whilst this can be little more than a minor inconvenience in some cases it can become serious in others, leading to inability to sleep or more serious health issues. This is a risk not taken seriously now, but it will become a larger feature of our lives as the climate changes and needs to be accounted for when retrofitting buildings. Fixed or adjustable external shading mainly to the south, and ventilation are the key tactics to avoid problems in the future.



In these European examples, the timber frames have been supplemented with cork and sheepswool insulation to provide a highly insulating—and completely natural—window frames suitable for Passivhaus projects.

3. Materials & Resources
- There is no doubt that timber windows represent a 'greener' option for window frames due to the simple fact that timber is renewable, while PVCu and metal are not. Timber frames tend to be better performing thermally as well.

- On the other hand, timber windows are rarely fully reused because it is not economic for anyone to remove the glass which has been puttied into the timber frame and the timber itself has little value. Conversely, PVCu and metal windows can, and often are separated because the glass is 'dry-glazed' (no putty) so it is easy to remove, and then both glass and plastic / metal have some scrap or recycling value. The solution to this if seeking the 'greenest' option is to use timber, but to ensure that the glaze is 'dry-glazed' so that at the very least, the glass can be readily removed and recycled.

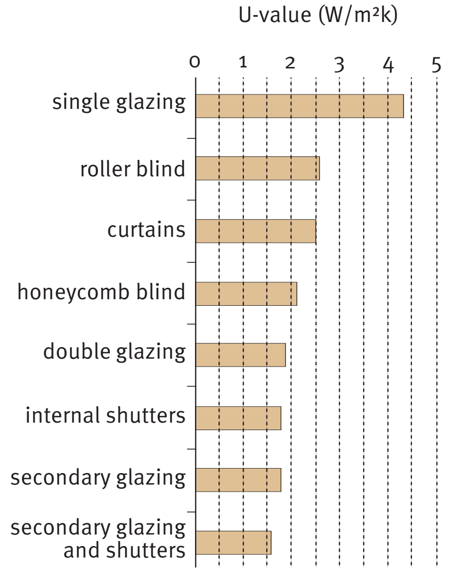
Openings in Historically Sensitive Buildings

Our Guidance vs Conventional Guidance

Where there is regulatory conservation control, then conventional guidance is essentially conservation guidance and ours is similar.

In this example, we presume that the existing sash and case window and frame is to be retained, repaired in places and draughtstripped, all of which is common conservation practice. Where it potentially deviates is in the use of slim replacement double-glazed panels installed into the existing panes. Further, we consider the use of secondary glazing, shutters and heavy curtains. All of these measures have been investigated carefully by Historic Environment Scotland (HES) and, if carried out well, will provide a U-value (with shutters/curtains etc. drawn) comparable to new double glazed windows. Acoustic performance and security is of course also improved.

At all times, it is assumed that the planning department and in particular the conservation officer will have an active interest and will need to agree all proposals. The following borrows heavily from the work that has been done on this subject by HES.



Graph showing different U-values for different window configurations. Current requirements for double glazing on new properties are a maximum U-value of 1.4 W/m²K, so it is easy to see that unchanged single glazed windows, with secondary glazing and shutters are comparable.

Preparation

- Because heat loss from doors and windows is due not just to the door or window itself, but to the gap between the component and the adjacent wall, it is well worth spending time to insulate and seal this area. The aim is to reduce air leakage and to fully fill the gaps with insulation. This insulation can also be extended into the internal reveals of the opening to counter the effects of the thinner walls in this area. Remove all of the existing linings, taking care if they are to be replaced to minimise damage. Ideally there should be some form of damp-proof course to prevent moisture in the masonry causing decay in the timber. If not present, it may be possible to add this, preferably against the masonry to prevent moisture affecting the insulation as well.
- A variety of methods can be used to effect an airtight and fully insulated space. It may be possible to apply high performance airtightness tapes across any gap, or to tightly stuff insulation or felt into any small gaps. Making sure that any insulation cannot get wet, pressing roll-type insulation fully into the gap can be done with hands or where the gap is small with a screwdriver or similar. For some reason installers often forget to insulate underneath windows, so take care to ensure all four sides are carefully sealed. Glass and mineral based wools are prone to becoming brittle and failing over time, so we recommend sheepswool which fares better in the long-term.
- The reveals around doors and windows vary widely, but in most cases, it may be possible to install additional insulation across the width of the reveal before replacing or adding finishes. Doing

In this example, the reveal has been insulated with a natural, vapour permeable insulating plaster to counteract the poor performance of the thinner walls, and to complement the new windows

© Sam Foster Architects

so is beneficial because it tackles the relatively poor thermal performance of the reveal itself.

Installation

- A number of companies specialise in this field and techniques will vary, but broadly, the first step will be to remove the casements, leaving the frame in place. Existing single-glazing is removed from the panes and the surrounding timber cleaned down and routed out if necessary to accept the slightly thicker double-glazed panels. The glazing may be puttied back in (the traditional method, but not ideal for reuse of materials) or held in place in some other way. Additional grooves may be routed to install draughtproofing strips, repairs to rotten areas made and the timberwork may be re-painted.
- The frame itself should then be reviewed and refurbished. This may mean repairs to cills or other areas, checking and replacement if necessary of weights or counter-balances and in some cases the addition of removable facings and hinges to facilitate internal cleaning of the lower sash. Once the casements are replaced, the whole window needs to be working smoothly with no draughts, restrictor stays if necessary and handles / locks and so on. Ideally the frame is redecorated as well and all mastic seals externally refurbished.
- Where feasible, the opportunity should be taken to ensure the window frame is well sealed to the adjacent wall to guard against air leakage and, if possible, insulation added to the reveal areas (as discussed on page 74).
- In this example we have included secondary glazing. Secondary glazing comes in many variants. Some involve glass panels, some perspex or polycarbonate options which tend to be cheaper, lighter and less of an issue in relation to breakage. They can be rigid or flexible and installed within a separate frame or onto adhesive or magnetic strips. In addition, they can be installed on the face of the existing window or, depending on the configuration of facings, within the frame. We would recommend a system which is easy to remove and store so that it can be removed for cleaning and to allow for seasonal deployment since it won’t be needed in summer. Where it is possible to also use shutters, it is worth using a system which sits within the original window frame in order to allow the shutters to work.
- One disadvantage of secondary glazing is that many systems prevent the original window being accessed for ventilation, but some systems provide sliding or hinged casements which allow for continued use of the openable window when required.
- Where possible, it is always beneficial to use, or bring back to use the original shutters. The significance is that shutters, prepared carefully, can significantly improve the performance of the window at night thereby making a substantial contribution to energy efficiency as well as bringing acoustic and security benefits.
- The benefits of shutters can be maximised by ensuring that they form a complete seal (against air leakage) when closed. This can mean creating rebates with small seals where they join and ensuring that they close tightly against a facing. In addition, the central timber panels can be replaced in some circumstances by highly insulating panels and finished to match the original.
- Finally, curtains can be adjusted to retain heat at night. This is done bearing in mind the two objectives which are to seal against air movement, and to reduce radiant heat loss. Adding thick or insulating layers (such as bubble wrap) between the curtain finish and lining reduces radiant heat loss, while ensuring that the

curtain physically touches the ground and sides of the opening creates a 'sealed cavity' where cold air cannot get in and warm air out. Small, linear weights can be used to ensure the curtain rests on the ground and Velcro can be used to ensure that hidden within the folds of the curtain, the sides are physically attached to the adjacent wall. It is usually difficult to seal the top area but if the space is well sealed on three sides it should work pretty well. Where windows are directly above radiators, the internal window cill should be extended so that curtains rest on it, allowing the warm air from the radiator to freely enter the room. It is important that radiators are not smothered by long curtains for energy efficiency as well as fire safety reasons.

Alternatives

- The above example describes several separate improvements to the original window and of course any combination of these will effect an improvement. Some properties may not have original windows to upgrade, nor shutters to refurbish, while those procuring for larger scale social housing retrofits may not have the budget to undertake more than one of the improvements noted above.
- A number of blinds options are available on the market, some of which aim to offer a degree of thermal performance. These can be considered as alternatives to, or in addition to other measures such as curtains.

Health & Safety

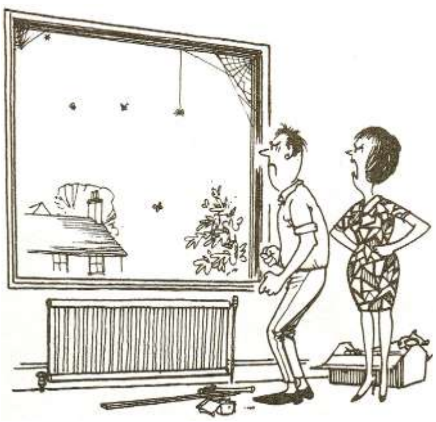
While the majority of windows can be replaced from inside, there is usually a requirement to provide a weather-sealing finish between the frame and the adjacent wall which necessitates external working at height, so all relevant risks then apply. Most windows and doors feature the use of glass which carries its own set of health and safety risks and many double and triple glazed windows, and some older but larger windows and doors can be very heavy to handle and care must always be taken when lifting and transporting heavy items.

Openings in Non-sensitive Buildings

Our Guidance vs Conventional Guidance

The conventional motivation to upgrade doors and windows is usually maintenance, although in some cases, energy efficiency will be relevant, for example where Energy Efficiency Standard for Social Housing (EESSH) compliance is being sought. Where this is the case it is likely to be a case of aiming for better U-values of the replacement windows in combination with any identified acoustic, regulatory or security aspirations. Replacing windows is an expensive way to improve SAP and RdSAP ratings and there are usually more cost effective ways to do this.

Assuming that windows are to be replaced, we look more closely at maintenance, aim for better energy efficiency in reality, along with engagement with occupants, as well as addressing wider sustainability and comfort issues. A number of planning and building warrant aspects may be pertinent and compliance with relevant regulation could be sought even when not technically required.



"I told you to dust it before you fixed the double glazing."

We've come a long way since the first 'double glazing'!

© The Estate of Norman Thelwell

Brand new windows installed but note the gap around the frame which is normally sealed with expanding foam

Expanding foam tends to become rigid and brittle leading to gaps through which air can travel. In this project sheepswool is being stuffed tightly into the gap. Sheepswool is preferable because it remains flexible.

In the same project note airtightness tape (black) is affixed externally to prevent air getting in through the gap

Preparation

- The comments made under the section above on historically sensitive windows remain relevant here and should be referenced. The difference is that since the new window is to be inserted into a 'blank' opening (there is no retained frame), it makes sense to install damp- proofing and should be easier to install the necessary airtightness and insulation around the frame.

Window / Door specification

- Because windows are often the 'weakest link' in terms of heat loss, and because the cost uplift between double and triple glazing tends to be relatively modest, if windows are to be replaced it almost always makes most sense to specify high performance triple glazing.
- Triple-glazing also brings benefits to acoustic performance (especially adjacent to busy roads or 'noisy neighbour' developments), and some security benefits.
- Because of the clear environmental benefits of specifying timber, the concerns over environmental issues linked to PVCu and the poor thermal performance of metal frames, we would propose that the window frames be made of timber, ideally from local manufacturers.
- Acknowledging the need to consider maintenance in the long-term, we would propose that the windows are painted with an opaque white (or pale coloured) paint if a painted timber finish is required, or a metal cladding system if preferred. Pale colours resist thermal movement better than darker colours so the traditional white paint is in fact the most durable option.
- Where a painted timber window is chosen, we would suggest that the base of all glazed elements be fitted with removable metal cills, along with any upward facing elements such as the main cill. This means that those parts of the window most prone to weathering damage are protected with long-lasting and replaceable components, pushing the overall lifespan of the window well beyond the conventional 30-year cycle.
- Items that are prone to breakage or wear and tear should be able to be repaired or replaced separately from the main window, such as handles, locking mechanisms, hinges, stays and so on. This aspect is rarely discussed and should form part of the specification decision, allowing repair and maintenance to be carried out without needing full-scale replacement of the window itself.
- Whether or not the windows come with trickle vents will depend on the ventilation strategy of the project. In any event, it is important that windows in every room can be opened to provide fresh air if needed and to help avoid overheating in warm weather.

Installation

- The main issue with installation is the care and attention devoted to the area surrounding the window. All gaps between the window frame and adjacent wall should be fully insulated and sealed against air leakage on all four sides. This is important because new and high performance windows are expensive, but their efficacy is compromised—and money is wasted—if they are not installed in an airtight and well insulated manner.
- A further item which improves the thermal performance of the installed window, and also reduces the risk of condensation and mould on the frame, is the practice of installing insulation (either internally or externally) partly across the face of the window frame itself. Obviously it mustn't come so far that it prevents

the operation of the opening casements, but some overlap is desirable. This is because, even with the best timber windows frames, the frame itself loses more heat than the glazed areas, and so additional insulation is welcome. The precise detail will depend on the surrounding construction and the exact window frame section.

Alternatives

- It may not be possible to replace all windows, or to replace them with high performance triple-glazing. Depending on other factors, such as condition of existing windows and aesthetics, one option might be to replace those windows which face north with higher performance windows, because these are the ones which only lose heat (no solar gain facing north) and so on balance will offer a better return on the investment and provide greater comfort improvement.
- Regardless of the quality of the windows installed, shutters which are drawn at night will always improve performance and should always be brought into use if possible. Most people use curtains at night and the comments made in the previous section still apply, as do the comments made about insulating blinds.

Health & Safety

- The comments made in the previous section apply, but it is worth noting again that triple-glazing can be much heavier, and contractors should be given due warning to ensure safe handling of all components.

4.7 Ground Floors

Floors often get overlooked when it comes to retrofit. This is partly because of a general perception that if heat goes up, then there's less need to consider the floor, partly because it is often difficult (or impossible) to access the space beneath, and partly because of the level of disruption if you factor in the moving of all bathroom furniture and kitchen units and, in some cases, the need to decant occupants.

However, the potential for saving energy and improving comfort by insulating ground floors is much greater than most people appreciate. In many homes across Scotland, there is little more than timber boarding and a carpet between your warm living spaces and the cold, winter air beyond. Unless your single-glazed windows are extremely draughty, then the floor is almost certainly the 'weakest link' in the thermal envelope of your building.

Another important factor is draughts. Suspended timber floors are normally relatively 'leaky' elements in a building (hence the popularity of wall-to-wall carpets in the UK) providing the source of a lot of the cold air flowing into the building. Making floors airtight, even if you don't add insulation, will make a useful contribution to reducing heat loss. This is less the case with solid floors, although the wall connections are also a source of air leakage.

Another reason floors are more important than people imagine is because that's what our feet touch. Certain parts of the human body are more sensitive to heat gain and loss and cold feet affect our discomfort disproportionately, so making your floor warm will bring more benefit to the occupants of the building than is described simply by energy efficiency.

Like loft insulation, there needn't be too much cost involved in making a large difference to thermal performance and also little risk to the building fabric or (usually) to conservation significance.

Suspended Floors

With suspended floors, the big issue is whether or not you can insulate from beneath. Insulating from beneath is usually a lot easier (if there's room) and means you do not have to disrupt the room above or lift floorboards etc. However, the benefits of insulating from below start to evaporate as the space available gets tighter. If the depth of solum is less than around 600mm, then it might be easier to install from above.

Important to Know

- It is critical that adequate ventilation is retained beneath, or if not present, created within and across the solum. This ensures that joists are kept dry and free from risk of decay or infestation.
- As with lofts, the aim is to get a layer of insulation without gaps, with air gaps sealed across and around the edges of the floor, and all services carefully managed.

Our Guidance vs Conventional Guidance

	Conventional Guidance	*Our Guidance*
Balance *ENERGY*	Insulate between joists, rigid board give better U-values, or roll type over netting	Emphasise importance of floors generally. Insulate between joists, supplement above or below if necessary. No gaps. Use soft or 'semi-rigid' rolls to fit snugly. Natural insulation reduces embodied energy. Emphasis on air leakage will improve performance considerably, especially around the edges. Use of membrane (or boards) will reduce thermal bypass. Consider hatch.
HEALTH	–	Warm floors provide greater comfort. Effective insulation reduces mould risk internally & improves comfort. Use of natural insulation reduces respiratory health risk (mainly when installing)
FABRIC	–	Measures noted for Energy, Health, Maintenance and Moisture will all serve to protect building fabric from long-term problems.
Reality *MODELLING*	–	As Energy above—emphasis on airtightness and details generally.
QUALITY	–	As Energy above.
MOISTURE	Ensure solum ventilation.	Solum ventilation removes moisture safely. Hygroscopic insulation helps protect timber.
People *PEOPLE*	–	Invest in upgrading services etc. before installing insulation (less cost and disruption later). Guidance on Health & Safety issues in relation to installation.
Heritage *CONSTRUCTION*	–	Soft insulation works better between timbers. Hygroscopic material helps protect timber from moisture problems.
MAINTENANCE	–	Review / upgrade existing joists and services before starting.
SIGNIFICANCE	–	Unlikely to be relevant, but important to protect listed, or otherwise significant floor finishes.

Common practice is to contain insulation within netting. However, this allows cold air moving in the solum to draw heat from the insulation (called wind-washing') and so our proposal replaces this netting with a airtight and vapour permeable membrane.

The air vent is above the level of the floor which had become rotten and needed complete replacement. Care was taken to ensure the passage of air was retained to the new solum space.

These joists are in reasonable condition but the masonry around is damp, so a sub-floor new vent is required and each joist end has been wrapped

The joists in this hallway were rotten, so new joists have been inserted, with protected ends and sitting on a new DPC

Probably the biggest difference between our guidance and conventional guidance is the importance we place on floors. After lofts, it is without doubt the next most important area to insulate for energy efficiency.

This is not necessarily because the savings will be the next largest, but because the risks are relatively low in comparison with wall insulation, for example.

Conventional guidance for suspended floors usually shows a net material to hold the insulation in place between joists, whereas we show an airtight, vapour-permeable membrane which will prevent cold air 'washing' heat from the open surface of the insulation. We also emphasise the importance of sealing this membrane to the surrounding walls, and this is to reduce the air leakage into the heated spaces above.

We propose a soft or semi-rigid insulation to ensure it forms a snug fit, because this is likely to be more effective than using a 'higher performance' (lower lambda) rigid insulant with even small gaps around, and as elsewhere we propose natural and hygroscopic materials which better protect the surrounding timber from moisture.

Insulating from Below

Preparation

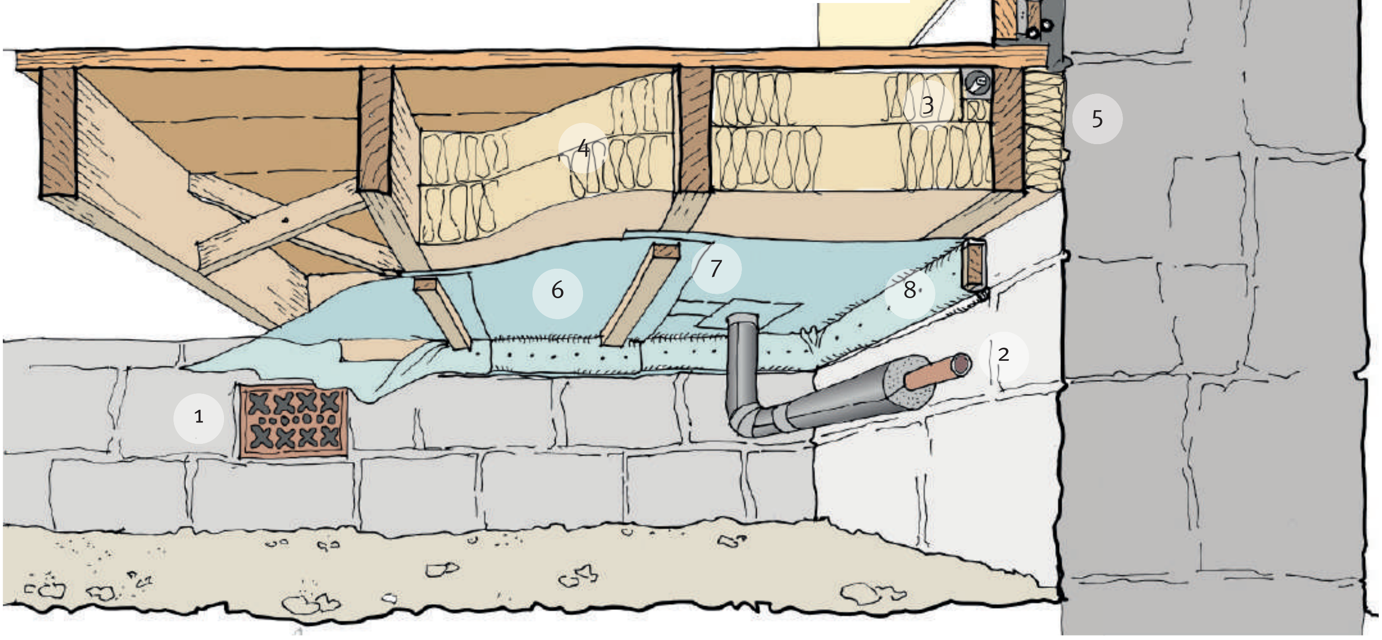
- Ensure that the access hatch is safely and easily used, and if necessary, enlarge and / or create other hatches. Larger / extra hatches provide more light, convenience and importantly safety. If you are insulating your own home, then Health & Safety legislation won't apply, but for contractors working on larger projects, guidance relating to 'working in small or confined spaces' is relevant, and the principles of making sure that working conditions are safe, and providing escape in the event of a fire, for example, are reasonably applied everywhere.
- Working beneath the floor can be uncomfortable and inconvenient, so it pays to prepare carefully, clearing debris, making sure all tools required are on hand and that there is sufficient light to work. Battery powered head torches work well with temporary background lighting.
- When insulating between joists in a floor, you are technically increasing the risk of decay because you are keeping them warm and reducing the air flow around them. For this reason it is important to use hygroscopic materials, but also to ensure that the air flow within and across the solum is adequate. As part of the work, ensure that the existing air bricks are not covered or damaged, and that there is an adequate flow of air to all spaces [1]. This means checking that there is adequate air flow from outside, but also across the solum, through gaps in internal partition foundations. Installing additional air bricks and forming gaps for air to pass through within the solum are jobs that should be undertaken by suitably qualified contractors.
- The guidance related to water pipes, electric and telecom cables in lofts applies equally to solum spaces. Ideally, it is worth reviewing all cables and pipework and removing anything redundant while adjusting anything that would compromise the insulation works.
- All water pipes are ideally removed from the solum but this is not always practical. It is important to fully insulate any water pipes [2] (including central heating pipework), as the temperatures in winter within the solum once insulated will be much colder and the risk of freezing increases. Doing so will save energy while improving the

ability of the system to heat the building as intended.

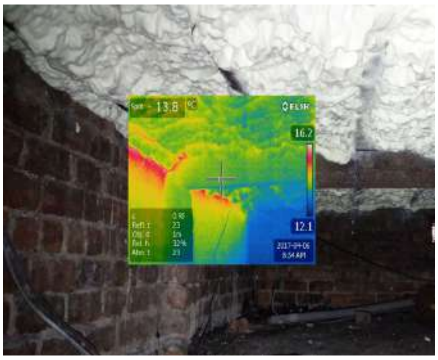
- Conversely, the risk for electric cables is that they overheat once insulation is applied. If they are run within the depth of joists then they should be run within conduit to allow some air flow around them, and to allow for upgrading in the future [3]. It is also possible to run cables beneath the joists and insulation. However this can be annoying as work continues because they get in the way and then need to be fixed back once insulation is completed. Telecom cables do not suffer from overheating but should be treated in the same manner.
- It is worth checking the condition of the joists, particularly as they meet the walls. It is quite common for joist ends to require replacement due to decay or infestation and it is wise to allow for this possibility.

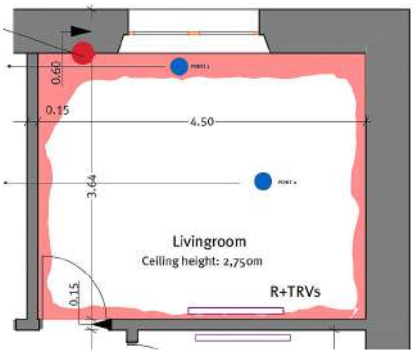
Installation

- The installation of the insulation itself is relatively straightforward, it is simply cut to fit neatly and pushed into place [4]. Using a semi-rigid insulation such as woodfibre is much easier than a soft roll type because they will tend to support themselves in place but the main thing with both types is that they fully fit, leaving no gaps between themselves, the joists and the adjacent walls. Even the smallest gap must be filled and the insulation should fill the full depth of the joists. Sometimes joists run close to a wall and the gaps between get left out, but these must be carefully filled [5].
- The next step is to install the membrane [6]. Many companies provide ‘breather membranes’ which allow vapour to pass through and these are a step up from netting. Better still are membranes which are also airtight, available from specialist sources - the phrase often used is “wind-tight”.
- The membrane is stretched neatly and tightly across the whole floor and carefully sealed at all laps and, importantly, around all edges where it meets the adjacent wall.
- In order to effectively seal laps, it helps if the laps can be organised to line up with the joists [7]. This allows you to firmly seal using double sided tape as well as the recommended tape over and then fixing firmly with battens as shown.
- Membranes are sometimes stapled to the underside of the joists



Sketch detail showing how insulation and airtightness can be installed to a suspended timber floor where there is access from below





A composite photo / thermal image of a sprayed insulation installed from beneath. Claiming to improve airtightness, it was not however equally applied and the image shows air leakage and thinner insulation around the edges. In tests done on the completed floor, the anticipated U value was met in the middle of the space, but was not met - nor was it airtight - around the edges. Impressive products are no substitute for good and careful workmanship.

but this is not a robust long-term solution as the insulation can drop onto the membrane pulling it away from the joists, although it makes sense as a temporary measure before using the battens.

- Sealing the membrane against the adjacent walls is arguably the trickiest bit because walls are generally of masonry, often irregular and usually dusty. If the walls are quite straight and smooth, one solution is to carefully dust down the walls and apply a primer which then allows the membrane to be confidently taped and sealed to the wall.
- More often, the surface is too irregular, so an alternative is to wrap the membrane around a batten which is mechanically fixed into the wall using a couple of beads of mastic to seal the irregular gap between the two [8].
- As with the loft, the hatch can become a weak link if not carefully treated. A snug fitting 'box' needs to be created to mimic the insulation levels elsewhere and ideally, a trim formed for the hatch to drop onto, and seal against air leakage. Here, the simplest solution is often to use rigid insulation cut neatly to shape and fixed to the underside of the floor finish, rather than soft insulation within a framework

Alternatives

- An alternative is to substitute a vapour permeable board for the membrane. This could be more robust but also potentially more expensive and difficult to manoeuvre into place.
- It is also possible to add insulation below the joists. This can be done instead of, or in addition to insulating between the joists. If it is possible to insulate between the joists then this is usually the best solution because it has no knock-on effect on levels, and is a robust solution in the long-term if undertaken well. The main advantage of adding insulation below is that doing so avoids the thermal bridging associated with the joists themselves.
- If adding insulation beneath the joists, then it is critical that the insulation is vapour permeable, and the most sensible type to use is a rigid board which can be simply affixed to the underside of the joists and held in place with battens that are also fixed back to the underside of the joists.
- Adding insulation above the joists is discussed in the next section.

Health & Safety

Some solums are in fact basements or semi-external spaces where access is straightforward and working practices are essentially normal. As depth beneath joists decreases however, the issue of access and safety becomes more acute and it is important to know the depth of solum (which can vary across the space to be insulated) before carrying out the work, and agreeing a sensible methodology for managing this. Critical issues are escape, general working conditions, air quality and lighting.

Most solum spaces are dusty. Almost any work in them will generate dust in the atmosphere which is both a risk to health and makes working more difficult. Clearing debris will raise dust, as will brushing down walls to affix membrane, and any work will need to address this aspect.

How Much is Enough?

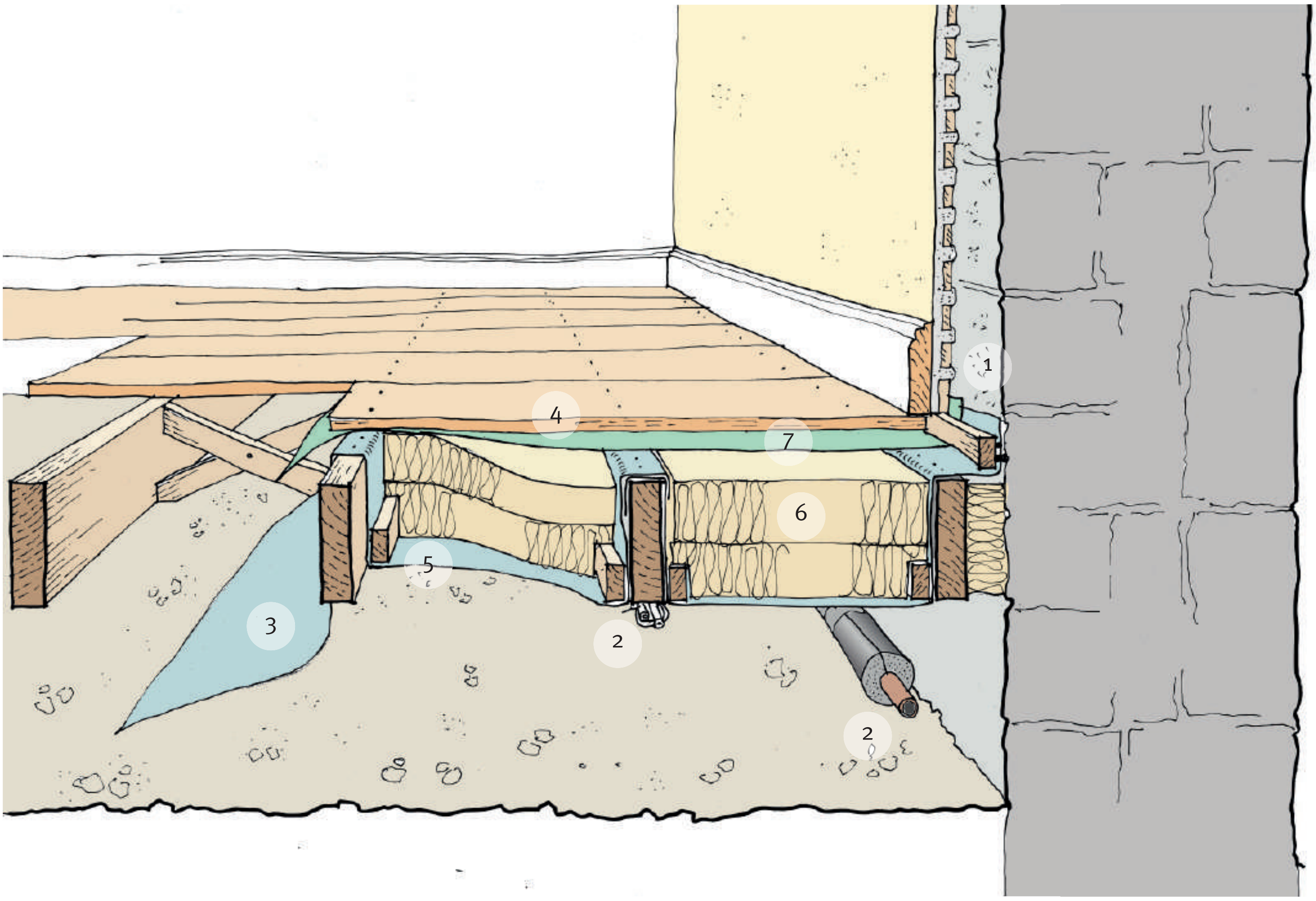
For most projects, filling the depth of the joists will be adequate to save energy and bring benefits to comfort. Most joists in older buildings are between 125mm and 200mm and filling these will provide a reasonable level of insulation. If the joists are only 125mm or 150mm it is better to supplement with insulation beneath but that may be difficult and it is more important to follow the guidance on preventing air leakage to the letter as this will have benefits beyond the discussion of U-values.

Insulating from Above

Preparation

- Depending on the space, fixed items like kitchen units and bathroom fittings will need to be removed along with all furniture and floor finishes.
- The floorboards will need to be removed. This is usually difficult to do without damaging the boards, so if the boards are to be reused, some care is required. In any event, all boards should have any nails removed to protect those handling them from that point onwards even if they are to be disposed of.
- It is possible to leave skirting boards in place, but removing skirting boards allows for easy access along the edges to form the airtight seal and also makes it easier to form a space for re-located cables [1].
- It is important to check both the ventilation beneath the floor and the condition of the joists, particularly as they meet the walls. It is quite common for joist ends to require replacement due to decay or infestation and it is always worth allowing for this possibility.
- The guidance related to water pipes and cables is the same as above but in some cases more difficult to achieve [2].

Insulation doesn't neatly fill the cavity, the membrane does not continue across the floor, nor is it sealed to the surrounding walls. This will lead to a drop in performance around the floor edges similar to that shown in the images and diagram on the previous page.



Sketch detail showing how insulation and airtightners can be installed to a suspended timber floor where there is only access from above

Installation

- Once boards are removed and services dealt with, it is possible to start the insulation works.
- The same vapour permeable and airtight membrane discussed in the section above should be draped across the joists to hold the insulation in [3]. Because of the importance of sealing the laps between membrane rolls, it is preferable to run the membrane roll in the same direction as the joists, so that the whole length of two or three joist runs is covered in one go, and then the lap can be made over the top of a joist, firmly sealed using double-sided tape [4]. It is important that the membrane is taut between the joists and tight against the joists to avoid the 'sagging' effect which pulls the insulation away from the joist. To this end, a small batten is affixed to the lower edge of each joist on both sides to ensure the insulation fills the whole space [5].
- The membrane also has to be sealed against the wall and this can be tricky. Along both sides where the joist ends meet the wall, one solution is to affix a batten (eg 50x50mm) to the underside of the joists and within 10mm of the wall. This allows the membrane to be fixed firmly to a solid background at every edge and the small resultant gap filled with a non-setting mastic, or tightly stuffed with insulation material to effect a complete air seal.
- The space is then fully filled with insulation [6]. The insulation should be hygroscopic, but can be a soft roll or a loose-fill material as it does not need to hold itself up, the important thing is to ensure that it fully and neatly fills the space without any gaps.
- Thereafter, the original floorboards, or an alternative board can be affixed back over the joists. If the floor finish is likely to be a single layer of timber floor boards, then it is advisable to install a vapour control layer beneath these boards, to minimise the air and vapour entering the floor from within the room [7]. If a deck is to be installed such as OSB sheeting with other finishes to go over, then a VCL is probably not required as long as the OSB is taped at the joints and to the wall.
- If services remain beneath the floor which might require access in the future, it may be worth creating an access hatch close by, and the comments regarding this hatch from the section above apply.
- If the existing floorboards are replaced or a similar finish is installed, then there is no issue with floor levels, existing skirting boards and doors can be left as they are. However, it is sometimes decided to raise the floor levels to accommodate a service void or underfloor heating, or simply to add more insulation above the joist level. Adding insulation is discussed in the following section on solid floors but the principles remain the same.

In this renovation, vapour permeable boards were used to contain the insulation, they were taped along all edges before the insulation was installed

Alternatives

- A common, but more expensive, alternative to the above is to form a cavity into which to place insulation by inserting first a board across the lower sections of the joists resting on battens. This gives a more robust 'base' for the installation generally, but requires quite a bit more work to cut the boards neatly. If supporting battens are placed on the lower sides of joists then you lose some of the potential depth of joist for insulation, but it is possible in some cases to run the battens beneath the joists. This detail does not provide full airtightness so all connections between boards and joists, on all four sides should be taped.

Health & Safety

Working from above is much easier than below, but there are risks associated with joists toppling if not adequately braced and this should be checked once the floorboards are removed. Joist ends should also be checked where they meet the walls to ensure they are sound and free from decay and infestation. It is important to always operate from a safe working platform and the best solution is to remove only part of the floorboards at one time, placing temporary boards over the working area until that is completed. Unless also forming improved ventilation beneath, there shouldn't be any reason to disturb the solum so dust raising needn't be a problem.

How Much is Enough?

The comments for insulating from beneath remain relevant, but it may be necessary to factor in the possibility of adding more insulation, or floor finishes or underfloor heating above the joists.

Solid Floors

Beyond cost, there are two main issues when insulating solid floors. The first is headroom. Adding insulation and another floor finish will usually raise the level of the floor and in many properties, there isn't much room to do this, or at least, it is not welcome. This creates pressure to find thinner solutions while still providing a reasonable level of insulation. There are solutions which are extremely thin, but they tend to be more expensive to buy. The second issue is disruption to internal doors and skirting boards, thresholds and other elements which interact with the floor. In order to be effective, the insulation and new floor should be continuous which means adjusting or removing and refitting a potentially large number of items.

Important to Know

- The importance of ground floors is discussed at the beginning of this section, and although solid floors tend not to suffer from the level of air leakage of suspended floors, they are still a priority for improvement, even if their importance is not widely appreciated.
- Even a small amount of insulation is much better than none.
- The issue of breathability is not as important in this situation, so our guidance is very much like conventional guidance—improve the U-value as much as practical and affordable.

Our Guidance vs Conventional Guidance

The main difference of this guide is that we believe insulating ground floors is much more important than commonly considered because of both the energy efficiency and comfort benefits it can bring. In terms of the detail of our proposals, the only difference is the emphasis we place on airtightness measures. Because there are no significant issues related to moisture, and also because of the pressure to keep insulation thin, while also providing as good a U-value as possible, we recommend the same sorts of products and materials as others. For this reason, we haven't produced a table of differences as elsewhere.

An exception is where the existing floor finish is of exceptional quality or conservation significance in which case it should be left in situ, repaired if necessary and maintained. Depending on location, the issue is that this may become the coldest surface onto which moisture can condense so this needs to be managed, either through maintaining lower temperatures or higher levels of ventilation. In many Victorian homes, for example, there is a mosaic covered entrance hall which may happily be left as it is. The key in this case is to treat the inner door, rather than the outer door, as the thermal envelope.

Preparation

Aerogel blanket bonded to chipboard used as a thin, but high performance insulation over a solid floor. These boards would need to be taped to each other and to the surrounding walls to reduce associated air leakage.
© Sam Foster Architects

- Depending on the thickness of the final floor makeup, doors may need to be re-cut to allow them to swing freely over the new finish, while it may also be necessary to raise all of the skirting boards. Alternatively, the skirting may remain in place and the new floor finish simply come up against it with an additional, usually very small skirting bead used to cover the gap. Because of the value of sealing the gap between the insulation and the wall, we recommend that the skirting is removed, raised and replaced but this obviously means greater work, disruption and cost. An alternative if possible is to cut the lower section of the skirting and slip the new floor finish beneath.
- It is tempting to avoid extending any new insulation and floor finish beneath fixed items like kitchen units, and baths. However, this then risks these areas becoming the coldest surface, and warm, moist air can then condense there, raising the risk of mould. In some cases, it is possible to use adjacent kitchen units to temporarily support unit carcasses, adjust the 'feet' upwards and extend the insulation and floor finish to the wall before re-adjusting the 'feet' back down to the new floor finish. It is usually possible to insulate beneath a bath if the side panel is removed whereas a floor mounted WC and wash basin will need to be disconnected by a plumber and re-connected afterwards.

Installation

- The material with the lowest lambda value currently is a vacuum insulated panel (VIP) but these are both expensive and vulnerable so are rarely used. Aerogel products have a lambda value almost half of the next nearest high performing insulation but are correspondingly expensive and the plastic boards such as PIR, PUR and Phenolic foam boards probably represent the best option in most cases, unless issues of head height and thickness are critical.
- If the solid floor is level, smooth and clean, then it is probably possible to install boards directly over it. However, if not, a number of levelling compounds may be poured first to provide both a level and suitable surface.
- Some insulation materials come in simple boards which then need to be laid neatly and without gaps. Some come with lapped or tongue and groove edges which are to be preferred. All junctions with the wall and each other should be taped to keep in place while working and reduce air movement between any gaps that could open up.
- Depending on materials chosen, it is advisable to install a vapour control layer which also acts as an air barrier and 'slip layer' above the insulation, but this is something that would be advised by the manufacturer or supplier of either the insulation or the finish above.
- Some insulation products come already bonded to a top floor deck which allows them to be laid in one go. Depending on what is to go over this, it is important to seal all joins between panels and to the wall.
- The final floor finish can then be installed along with all of the fixings/skirtings/doors and so on replaced in-situ.

Alternatives

- In many properties, there is a solid floor with battens fixed to it and then a timber floor or similar laid over. In these situations, it may be possible to install insulation and boards without raising the level of the floor. Alternatively it is possible to either leave the existing battens or install new ones and infill the gaps between with a suitable insulation. The significant disadvantage of this solution is that the battens themselves present a thermal bridge, losing more heat and raising the risk of cold surfaces. For this reason, the continuously insulated floor described above is preferable. Some people will prefer a traditionally nailed timber floor and so a compromise solution is also possible where some insulation is laid first (or affixed to the underside of the battens) and then the timber floor fixed to the battens as before.

Health & Safety

There are few health and safety concerns with this sort of work in the normal course of events. There may be dust associated with working on old concrete screed or removing older floor finishes, and removing old skirting boards can result in nails protruding from the back which should be dealt with immediately.

How Much is Enough?

Unless there is a particular U-value target then it is simply the case that more insulation / better lambda values and better airtightness will lead to improved performance. In most cases there is usually either a practical and / or cost limit to what can be achieved. It is worth bearing in mind that the first millimetre of insulation is the most effective, the second slightly less so etc., so even a small amount of insulation is much better than none. Even 10mm of Aerogel or 20mm of a PIR / PUR / PF product is normally sufficient to make a difference and provide better levels of comfort.

4.8 Heating Approach

One of the most important questions facing anyone contemplating a renovation project is what heating system to use, if the existing system is to be changed. This is almost impossible to answer because circumstances vary so greatly. The situation is complicated by the fact that a great deal of information is available, not all of which is helpful, and a heating system usually has to provide heat not just for the house, but for water, and sometimes for cooking as well.

There is no way a chapter in a publication like this could cover all eventualities on this subject, so we have tried instead to consider the many issues which can impact on the decision, so that the reader can work through the list below, better understand the relevant aspects and hopefully narrow down the options. We start with more strategic items first, but some will be more pertinent in some situations.

Space Heating

Reduce Demand for Heating (Need Less)

In this extension to an existing building, the existing heating system was extended and the existing boiler was retained despite the additional space. This was achieved by improving the insulation levels in the existing building and making sure the extension was energy efficient, meaning there was no overall increase in heat demand.

All of the issues in the following section discuss ways in which the amount of heat needed from the outset is reduced, making the task of providing heat less onerous and costly.

a. Insulation and Airtightness

In the battle to save energy, reduce carbon emissions, increase comfort and reduce fuel costs, there is no doubt that insulating a building effectively is the number one priority. This guide shows how this effort can be improved in order to benefit from savings in reality and not just on paper. The number two priority is airtightness because if this is not managed the heat will simply bypass the insulation through all the inevitable gaps. When considering a typical uninsulated property, carrying out the insulation measures described in the guide should result in savings of at least 50%, and if carried out thoroughly, perhaps even 90%. If heating a building is a problem that needs to be solved then reducing this problem to 10% of its original size will result in a much smaller problem to solve—both in initial and long-term costs—with more options for possible solutions.

b. Keep it Cooler

Average living room temperatures are now three degrees warmer than in the 1970s as people find it cheaper to keep homes warm, although this may not be so true more recently as energy costs have increased dramatically. Whilst this comfort improvement is largely welcome, it raises a question about potentially unnecessary carbon emissions. Historic Environment Scotland has published an excellent document (TP14 ‘Keeping Warm in a Cooler House’) which discusses ways in which people can remain comfortable in lower temperatures. It is important to emphasise that this does not mean ‘putting up with’ colder temperatures. The authors of the publication demonstrate how it is possible to be comfortable in a generally cooler home (around 16 degrees) if supplementary heating is used when required and appropriate clothing is worn.

The study arose from a concern that people are trying to ‘force’ older buildings to maintain contemporary ideas of comfort for which the buildings were not designed and that this mismatch between traditional properties and modern ideas of comfort was causing not just high fuel bills but wider problems for buildings and their occupants. Ultimately, the study shows that for most, the increasingly high temperatures we expect in our homes are not necessarily healthy. In the drive towards sustainable solutions, the potential to reduce energy consumption whilst maintaining comfort is too large to ignore.

The underlying logic is that, ultimately, we are not trying to keep *homes* warm, we are trying to keep *people* warm, and there are more creative ways of achieving this than heating a whole house. In practice this might mean that, in most cases, central heating systems can be turned down while supplementary heating (see below) is used when necessary.

c. Supplementary Heating

Many people living in cold homes will be familiar with supplementary heating; their main heating system does not provide sufficient warmth and they are forced to use small gas or electric heaters to provide supplementary warmth and make things tolerable. Unfortunately, these ad-hoc solutions are often more expensive to use and in the case of gas heaters, can create other problems with air quality and humidity.

Generally these heaters tend to heat a single room but at least they are responsive and can be turned off easily when not required. The principle is that these heaters are not the main system, they are used whenever needed and they only heat a small area to keep costs down.

The above situation is the unhappy cousin of the far more positive option discussed in the previous section and championed by Historic Environment Scotland. In this scenario, we consider that the house can be maintained at a lower than normal temperature, acknowledging that not all areas need to be kept warm to the same degree.

Recognising that people in the house need to be kept a little warmer than this, especially when resting, or when not moving (for example, seated at a desk) supplementary heating is used to provide warmth close to and focussed on the person. The most obvious example is the humble hot water bottle, but a number of other examples exist. Heated foot pads can be used to keep feet warm when sitting, small radiant panels can be used under desks to keep legs warm, heated seats can keep backs and bottoms warm and other solutions exist which operate locally to provide warmth and comfort. Beyond heated car seats and hot water bottles, the concept is not widely known in the UK, more examples exist in Europe and the US, but the potential to save energy and improve comfort is significant.

Portable heaters like this found during BPE investigations can provide evidence that the main heating system (in this case electric storage heating) is not able to maintain comfortable conditions.

Local radiant panel heaters like this are not common in the UK but can be used to provide comfort for those sitting for long periods, while the main spaces are kept cooler.

© Eco Infrared Technologies Ltd.

d. Zoning

It is possible to reduce energy consumption and the need for heating by considering the patterns and types of use in each room of the house, and then allowing for different spaces to be heated differently. For example, in some houses, guest bedrooms are rarely if ever used and could be kept at a much lower temperature than regularly used spaces. Another example is any room where people are generally standing or busy, such as a kitchen or workroom, and so the need for heat is less. Many people keep their bedrooms cooler than other rooms and this makes sense because the majority of time is spent beneath sheets or a duvet. Conversely, living rooms and bathrooms tend to be kept warmer.

The practical implication of this is that the heating system choice should, if possible, allow for different parts of the home to be heated differently. This can be done by fitting every radiator with a thermostatic radiator valve (TRV), or by fitting the house with two or more different 'zones' which can be controlled differently. This is readily done with more automated central heating systems, but can also be achieved in a more basic sense by heating the living room of a house with a wood stove, for example, making that the warmest room, while leaving doors open or closed as necessary to allow heat into other rooms as required.

e. Timers and Programmers

Thermostatic radiator valves, or TRVs, allow each radiator to be individually controlled meaning different rooms can be kept at different temperatures to suit different requirements

Most people are familiar with timers and programmers for central heating systems. It is the 'when' corollary of the 'where' of zoning noted above in which the heating system is set to come on only at times to suit the occupants. Typically, heating systems are set to come on for an hour or two in the morning just before and during the breakfast rush before everyone exits for work and school, coming on again for longer in the evening before switching off around the time people go to bed.

Programmers allow the system to be set over different days to reflect weekday / weekend patterns. The building regulations require that all new buildings are fitted with timers and programmers and in any given retrofit situation, it is important to ensure that, where possible, the heating system is able to be as closely controlled as possible.

f. Thermal Sensitivity of the Human Body 1: Cool Heads and Warm Feet

"If you don't like the skirting heaters, why don't you just say so."
Low level heating provides greater comfort, for most people.

Most people know intuitively that they feel better when their heads are cool and their feet warm. While a relatively mundane observation, this is in fact an important strategic goal for heating systems. It can allow designers to ensure comfortable conditions using less energy by working with the human body's inbuilt preferences. Human bodies have adapted over millennia such that different parts of the body—mainly the head, hands, and feet—respond more readily to temperature, meaning that working closely with these can increase the effectiveness, and thus efficiency, of any given heating system. The same level of comfort, in turn, is created using less energy.

The goal is to try and create a situation in which feet are warm while heads are relatively cool. This does not serve as a rigid rule, but it does mean that underfloor heating, for example, is preferable to ceiling-mounted heating which creates more or less the opposite effect. Less obviously, it also means that systems that mostly heat air (which then rises towards the ceiling) are less effective because they are largely providing heat to the wrong part of the room. They have to work harder, using more energy so that the warmer air builds up against the ceiling rather and down towards the floor, and this disadvantage is amplified where ceilings are high, which is often the case in older buildings.

g. Thermal Sensitivity of the Human Body 2: A Preference for Radiant Heating

Throughout human evolution, we have evolved with the sun and ever since the first human tamed fire, we have also benefited from this source of warmth. Both the sun and fire provide largely radiant heat and humans have evolved to respond well to this. Importantly, radiant sources of warmth can keep us warm even if the air is cold. This is because, very broadly, we gain or lose about half of our warmth through radiant heat transfer, and only about a quarter each from convection and conduction. The point of this is that if we use radiant heat, we can use less energy to achieve the same levels of comfort.

Although it is easy to visualise warmth from the sun and fire, a less obvious aspect of radiant comfort is that humans gain and lose heat all the time, not just from these two heat sources, but to and from *all* of our surrounding surfaces. If you stand in an empty room, your body surface is gaining and losing warmth in relation to the floor, ceiling and walls of the room. Given that we are largely vertical in form, most of this heat transfer happens between us and the walls. If the walls are warmer than us, we will feel warm even if the air is cool, and if they are colder, we will feel cold, even if the air is warm.

Typically this radiant heat transfer is rather uninteresting; houses are warmed by radiators which heat the air, but they and the warm air also heat the surfaces which are then fairly warm too. Everything in the house—air, walls and the people inside—are all reasonably warm and so the exchange of warmth between things is minimal. However, we are interested in optimising heating systems so that we can use less energy while still keeping comfortable, and so what *is* interesting is when we start to manipulate things. By designing buildings explicitly with 'warm surfaces' we can use less energy whilst maintaining or even improving comfort. Ideally these warm surfaces are in the floor (underfloor heating) but an equally effective solution is 'warm walls'. Another method which exploits the benefits of radiant heating is the use of 'radiant panels' which are separate usually metal or ceramic panels heated usually with electricity.

Underfloor and wall heating pipes installed on a small building in the Scottish Borders. Location of the pipes and the use of low level radiant heating pick up on both of the sections on human thermal sensitivity.

© Design: Gaia Architects

Free/Incidental Sources of Heat

The ideas above can all be employed to reduce the overall amount of heat required to maintain comfortable levels. This section describes two sources of 'free' heat the first of which can be employed to reduce the burden on the heating system, while the second needs to be acknowledged and controlled where possible.

a. Sunshine

Vast amounts of free solar energy radiate onto the surface of the planet and it makes sense to capture as much of this as possible, especially in a relatively cool country like Scotland. In a well designed, low energy retrofit project, solar gain might account for as much as a third of the heat input of the building.

The flow of warmth in and out of windows is a complex subject and it is discussed in Section 4.6. In most retrofit projects, changing window configuration is not considered, but if major alterations are planned, then it is worth considering the optimum layout of windows in the property before making any decisions about a heating system. However, the most important aspect of windows and heat is to make sure that options are available to add insulation at nights. This can take many forms and these are discussed in the section on windows, but from the perspective of a housing association, for example, ensuring that tenants have effective curtains, and are educated/motivated to use these regularly is potentially as important—and certainly cheaper—than upgrading windows wholesale.

b. Internal Heat Gains

'Internal heat gains' is the term used to describe any 'incidental' heat not specifically designed to deliver warmth. It includes heat given off by a fridge, TV and other electrical equipment, heat from uninsulated hot water pipes and tanks, as well as the warmth emitted by people themselves. In the past these gains were given little thought, but as houses have become better insulated, their contribution to heat gain has become more noticeable.

In cold weather the heat given off is arguably a benefit, but in warm weather, it can become a nuisance leading to overheating because it cannot necessarily be switched off and in the case of uninsulated hot water pipes leading from solar panels, the heat is only generated when it is sunny, and therefore least needed. While fridges, large TVs, and other electronic equipment can give off quite a bit of heat, when compared to the same amount of heat provided by an efficient heating system, it is an expensive, and rather wasteful source of warmth.

For this reason, it is worth trying to minimise incidental heat gains by specifying efficient appliances and making sure hot water pipes are insulated, leaving the 'proper' heating system to provide the bulk of the heating. However, some level of heat gain is unavoidable and the key thing is to acknowledge this and, to an extent, plan for it.

Characteristics of the Building and Occupants

The items discussed above all serve to reduce the demand for heating in any building and should therefore be considered in every project before opting for a heating system of any type. In many retrofit projects, the heating won't be changed, but where it is possible, before opting for a heating system, it is important to consider the context within which the system operates.

a. Occupancy/Lifestyle

For those organising their own renovation, it is possible to consider their own specific requirements. For those who spend a large amount of their time in the house (for example, elderly couples) keeping the house warm most of the time is important, while for those who are rarely in, a quick- response system is more effective. In large households, the capacity to provide hot water might be a prime concern, while for those few households who have access to a woodland and want to burn their own timber, for example, the particular requirements of timber storage, drying and wood stove will be uppermost in mind. The point is that specific occupancy requirements might determine how effective (and therefore 'sustainable') a chosen heating system would prove to be.

In this Edwardian retrofit, the ground floors were made airtight and carefully insulated before underfloor heating was installed beneath a parquet finish. This solution works well with a thermally massive, now draught-free home with high ceilings

For housing associations and council housing departments, it is not possible to identify specific occupancy patterns and the key is to have systems installed which are flexible and able to respond to very different demand requirements.

b. Type of Property

The type of home can make a significant difference to the viability of a heating system. A well-insulated, airtight home will reduce the demand on any system of course, but in such a house, any thermal mass will also be able to play a useful role (see below) doubling up on the potential benefits of older masonry buildings. By contrast, poorly insulated and draughty buildings will make more demands on any system, but also won't be able to benefit from any thermal mass inside because the heat will be lost before it has a chance to be stored.

House type is particularly relevant to heat pumps. Heat pumps work best when asked to do as little as possible. Installing them in poorly insulated and draughty houses with conventional radiators means they are being asked to deliver water at the higher temperatures required by radiators, and these radiators are losing that heat quickly. Heat pumps installed in these situations are unlikely to reach the levels of efficiency quoted. Conversely in a well-insulated and airtight home, with underfloor heating delivering heat at lower temperatures without great losses, heat pumps are more likely to be as effective as claimed.

Another consideration is ceiling heights. Buildings with high ceilings will benefit most from radiant heating because heating systems which produce largely warm air (such as conventional radiators) will heat air which then sits high above the people in the room. Underfloor heating works well in these situations because the heat is located nearer the people and being largely radiant and lower temperature is less susceptible to rising.

c. Thermal Mass

Thermal mass is at heart a very simple principle, it is the ability all materials have to absorb and store heat energy. Generally, denser materials can store more heat and designed as part of a system, these materials can be deployed to reduce excess warmth (by absorbing and thus 'removing' the heat from the space), store this heat and desorb, or give off this heat again when the surroundings cool down. Being able to manage fluctuation in temperatures like this is potentially valuable and thermal mass can be used to work interactively with solar gain as well as with conventional heating systems.

Although thermal mass is a simple principle, optimising its contribution to efficient heating systems is much more complicated in practice. The first reason is because it is not really houses we are trying to keep warm, but the people within them. Keeping a house warm over long periods when there is no-one within is a waste of energy, and so perhaps the first thing to consider in combination with thermal mass is occupancy. Simply put, the more people are going to be in the building, then the more valuable thermal mass may be. In housing for the elderly or infirm, it may well be a very good idea, but in starter homes for young couples who work and are out most weekends, it may make less sense.

Another aspect is that thermal mass works better where heat is largely radiant (like direct sunlight) but less well where the heat is convective, i.e., contained in the surrounding air. Since most houses in the UK are heated with radiators which are unfortunately misnamed and provide about 70% of their heat convectively, thermal mass isn't as helpful as might be imagined. Linked to this issue is the fact that thermal mass declines in usefulness as air movement increases. Thus in draughty houses, it doesn't get a chance to warm up before the heat is whisked away by draughts.

It is obvious that to work, thermal mass needs to be available, that is, 'open' to the warmth, usually in the air or radiant energy. For this reason, the thermal mass of older masonry walls are of little value if they are covered with a cavity and plasterboard, or lath and plaster. In addition, thermal mass is best used as close to the warmth as possible. For example, people often refer to the concrete of a floor slab as being useful thermal mass, while the majority of the warmth in the air is in the upper areas of the room, next to the ceiling. In these cases, thermal mass in the form of dense ceiling boards would be far more effective. Summer sun shining directly onto a solid floor will clearly be absorbed by materials such as tiling and concrete, but winter sunshine is better stored by walls which receive the low-angled winter light more directly.

There are many other aspects to adequately discuss thermal mass. One is the use of phase-change materials which are able to store much greater amounts of heat energy and thus able to be used in thinner layers - but are too expensive for most domestic applications. Another is the use of 'hygroscopic' materials which absorb both heat and moisture. Clay plasters are a good example of such materials and by being able to store both are able to work more effectively not just for thermal comfort but for air quality as well.

The subject of thermal mass is particularly relevant in retrofit because most older houses are made of masonry and so have large areas of potentially suitable thermal mass to use. However, this mass will not be much good if it is covered by internal wall insulation or some other lining, nor will it work if the house is draughty, and in situations with low occupancy, it may not be helpful. Conversely, externally insulated masonry walls, in homes that are relatively airtight and with high occupancy may well be able to help reduce energy consumption and improve comfort.

Overall Characteristics of Heating Systems

The following section describes the strategic characteristics of any heating system. Not all are relevant in every case, but all have the capacity to affect overall efficiency, leading to a smaller ultimate heating load.

a. Fuel Types and Carbon Intensity

Different fuels contain different levels of 'primary energy' which reflect the actual amount of damage done to the planet relative to the energy delivered to the householder. The subject is so complex that trying to provide a definitive guide to which is 'best' is almost meaningless because of the number of caveats that apply. However, it is worth having a very basic sense of the 'greenness' of various fuels, as long as it is clearly established that this is only a rough guide. The list below shows the most common fuels and their relative contribution to climate change, from worst at the top, to best at the bottom, based on the UK. Hydrogen is discussed later under 'Mains Gas'.

Worst

- Electricity (from mains grid in areas of high carbon intensity)
- fossil fuels:
  - Coal
  - Oils
  - Portable gases
  - mains gas
- Timber and other renewable biofuels
- Electricity (from the mains grid in areas of low carbon intensity, if locally renewably sourced, in a future de-carbonised grid, or possibly using a heat pump)

Best

Arguably the least controversial of the items on the list are the fossil fuels. There is little debate as to the relative climate change contribution of coal, oil and gas and no-one would suggest that they are as 'green' as any renewable material. Perhaps surprisingly, more controversial is the position of timber and other renewable biofuels. There is no doubt that timber, other biomass types and locally sourced biogas are not fossil fuels. Whilst burning them creates carbon emissions, it is obvious that they are renewable and as such can be replanted/recreated. However, this replanting does not necessarily take place, so we are left simply with carbon emissions. This subject is discussed more in the section below on burning wood.

More controversial again is the position of electricity as both the best and worst fuel. Perhaps the most compelling argument for not using electricity for heating is that it takes a lot of energy to generate heat and there are many sources which can be used, of which electricity is usually the most expensive. Conversely, it takes relatively little energy to create light and to power televisions, iPads and such like, but only electricity can do this. Electricity is 'high grade', the argument goes, and should be restricted to lighting, computers and other electronics, leaving heat to be produced by the other, 'low grade' fuels available.

About 30 years ago electricity in the UK was made by a mix of roughly a third coal, a third gas and a third nuclear energy. It was then run through the national grid at an efficiency of around 30%, meaning that every kilowatt used in your home represented at least 3 kilowatts 'burnt' at source using fossil fuel and nuclear. However, the picture is less clear today as the grid is slowly becoming 'de-carbonised'. The first phase of this shift was the 'dash for gas' which saw coal burning reduced drastically to be replaced with gas. More recently, renewables have provided an increasing share of the electricity and although this contribution fluctuates considerably, there are times when the carbon intensity of the grid is low and mains electricity actually represents quite a 'green' option. As things stand, this picture is set to improve in the future, making electricity increasingly benign.

Some projects benefit from locally available renewable electricity, perhaps in the form of photovoltaic panels or a community wind turbine. In these cases of course electricity represents an unambiguously 'green' option, although the comments on using electricity for heating still apply. In Scotland, around 100% of our electrical needs are met with renewable energy but around half is exported so it doesn't mean that all mains electrical use is 'green'. As noted above however, there is increasing renewable capacity and the move towards heat pumps should coincide with increased renewable electricity becoming available.

Ultimately, fossil fuel resources are finite, and whilst they may never be completely exhausted, as supplies are used up they will become harder and harder to extract. Whilst the likelihood and timing of this is hotly debated, no-one seriously believes that we can continue to use fossil fuels indefinitely. Another common argument used is that long before they do run out, we will have caused irreparable damage to the planet. Either way, there are compelling reasons to find alternative ways to provide energy and once our demands are reduced through more energy efficient buildings, it does look as if electricity is going to be the future for most people in the UK.

b. Combined Heat and Power (CHP)

In older power stations, electricity is produced involving steam generation, from which a by-product is heat. This heat is not needed, so it is dissipated through large cooling towers which are a feature of the countryside across the UK. CHP works on the principle that when producing this electricity, it makes more sense to use the heat generated, rather than waste it. CHP plants are essentially mini power stations which generate both electricity and heat by capturing the heat that would otherwise be lost. CHP plants work well at larger scales and whilst they do not necessarily generate heat more effectively or in a particularly sustainable fashion, they are worthy of mention in this guide simply because they are an efficient way of also generating electricity.

CHP works best where there is a constant 'base load' meaning a relatively stable load required at all times. This is commonly associated with buildings like swimming pools (keeping water warm) and hospitals (constant need for hot water). Typically, houses do not fit this profile since they tend to need much more heat in winter and little in summer, while needing peaks of heat to warm water for showers and baths. However, where large scale housing is being built or retrofitted in combination with another, more suitable building, then economies of scale can make CHP worthwhile.

c. District Heating (or 'Heat Networks')

District heating has not really taken off in the UK but in Denmark around 50% of all heat delivered to homes is via district heating and the proportion is higher in Russia and some other European countries. The advantage of district heating is one of scale; one large boiler can provide heat for many properties more efficiently than many small individual boilers. The main issue is then balancing this efficiency against the losses incurred piping hot water around the buildings. For this reason district heating works better when a large complex or many buildings are clustered close together to minimise distribution losses. Whilst this will make little sense therefore to someone wishing to refurbish their remote island cottage, it may well be worth consideration for housing associations looking to upgrade the heating on a block of tenement flats.

In district heating systems, there is usually a separate boiler house, hot water is then piped within highly insulated pipework to each home where the hot water is passed through a heat exchange unit. The boilers may use any fuel type so like CHP, whilst the fuel may not be particularly 'sustainable' the benefit is increased efficiency.

d. Instantaneous vs Stored Heat

Broadly speaking, there are two ways of strategically setting up your space and water heating system. One way is to have a boiler which is powerful enough to provide heat for everything in the house whenever required. The problem with this system—an instantaneous system—is that the peak demands made on the boiler might be very high, and so you have to install a large, powerful, and therefore relatively expensive boiler which is hardly ever used to full capacity. This can mean it works less efficiently and is a bit of a waste.

The solution to this problem is to choose a smaller boiler which works regularly to keep a tank of water hot, so that when needed, the hot water is there and the boiler doesn't have to overdo things to keep up. The tank works as a buffer between the peak demands of a household and the boiler working regularly and efficiently, particularly important for some wood fuel boilers and heat pumps. There are however a few problems with storing hot water. The first is that the tank takes up space, the second is that even when well insulated (which often isn't the case), the tank and hot water pipes tend to lose heat over time, so again heat is wasted.

Both strategies therefore have their benefits and drawbacks. A young couple in a small and well insulated flat may have little need for lots of hot water and little room to fit a tank, so might opt for an instantaneous system. A few years later, in a larger house with three children there may be a need for lots of hot water, often in peaks, and so a stored system might be more sensible. Broadly, the larger the demand, and the more likely there are to be peaks of demand, then the more efficient it is likely to be to store heat.

In practice, the decision as to which way to go is often taken for some other reason. For example, if you plan to use renewable energy to provide heat energy, then this input will come in quite randomly and will need to be stored, so a tank will be required anyway. Conversely, the use of waste water heat recovery can reduce the capacity needed to provide heat and make the use of instantaneous systems more feasible.

"Some friends of ours had one of those and it blew up"

Pressurised water storage is heavily regulated to ensure safety these days.

© The Estate of Norman Thelwell

e. Controls

Otherwise excellent heating systems are often let down by poorly considered controls. Zoning and programmers for systems have been discussed above, but there are lots of other, often mundane problems which undermine the effectiveness of a system. Since the controls are both the 'brains' of the system but also the place where the system interacts with people in the house, it makes sense to ensure these are both optimised, useful and easy to understand and use. A helpful document called 'Controls for End Users' is available from the Building Controls Industry Association (BCIA) which discusses this interface and the need to make controls intuitive and clear.

A common problem for heating systems is that the controls are too complicated for many people to understand. BPE investigations often find the occupants do not understand the controls of their systems, switching the entire system on or off regularly rather than programming for that to happen automatically, leaving it on and just opening windows when it gets warm, or supplementing with other heaters when the main system has been turned down in a particular room. Needless to say, it is important, as part of any retrofit programs that will alter the heating, to ensure that people living in the house will fully understand both the system and its controls.

Common Heating Systems

Although there are hundreds of variations, it is possible to group the three main types of heating systems according to fuel type. Heat can be added and recovered through the ventilation system and this is discussed briefly in the ventilation section.

a. Mains Gas

The majority of households in the UK—about 85%—are connected to the gas grid. Mains gas is the 'best' of the commonly used fossil fuels. Piping it directly into peoples' homes makes it extremely convenient and it is relatively cheap. The technologies which have grown up around it, mainly gas boilers and central heating systems are pretty efficient and controllable and so if we don't factor in long term environmental questions, mains gas is probably the 'best' fuel available.

The problem however is that we really do need to factor in the long term environmental consequences of burning fossil fuels and gas boilers are now seen as something of a long-term liability. Scottish Government has mandated that gas boilers may no longer be fitted in new homes from 2024 and it is possible that within the service life of boilers installed now, they will need to be removed due to incoming environmental legislation. Some large scale organisations in Scotland are now looking to replace mains gas boilers as part of their rolling programme of upgrading and maintenance.

An alternative is that more benign fuels and systems will be 'plugged in' to the existing gas infrastructure. It is an enticing possibility because most householders would not have to do anything much if this was a simple or likely option. One such fuel is hydrogen and significant efforts have been made to suggest that a hydrogen-dosed gas grid is a viable option. Unfortunately the vast majority of independent evaluation suggests that hydrogen will have little or no part to play in future domestic heating. There are several reasons. Among them is the issue that much of the supporting technology necessary does not exist yet, at least at a proven scale, so any large scale rollout is many years away. However, arguably the most compelling reason is that the supply of hydrogen will require between three and six times more energy than alternative solutions. With energy at a premium in any future scenario, this is a huge waste and will therefore also be costly in practice. Hydrogen does appear to have a future role in certain industrial processes and transportation, and will be useful for centralised energy storage to service peak loads, but not heating homes.

For those who wish to retain or upgrade their mains gas system, the best way to increase efficiency is to carry out the relevant improvements noted above and throughout this document. Newer boilers are undoubtedly more efficient (and probably safer) than older models, but there are conflicting issues of waste and resource use so whilst generic energy efficiency advice is always to upgrade an old boiler, it isn't quite so clear cut.

The most common arrangement is to have a boiler with radiators forming a central heating system, but the boiler can supply many types of heating appliance including underfloor heating, low level heaters such as skirting radiators and domestic hot water of course. The boiler can be instantaneous or send hot water to a tank which then feeds the heating systems and hot water demands, and there are various forms of controls.

b. Electricity

Although only about 15% of households in the UK live without mains gas, this percentage more than doubles in rural areas and these are also the areas where fuel poverty is often higher due to a higher ratio of poorly insulated older houses. These households have broadly two options: use electricity for heating which is expensive, or use solid or container-based liquid fuels which are also costly. It is a double whammy which hits many households hard. On the plus side, electricity is 'clean' and doesn't need to be stored on site. For those choosing electric heating, there are broadly five options for heating.

The most common form of all-electric heating is storage heating. Storage heaters were developed to use electricity at times when it suited the national grid to 'even out' the consumption of electricity generally. Tariffs were introduced to make electricity cheaper overnight (mainly) and these heaters are tied to these times and tariffs, charging up with heat overnight and giving that heat off over the following day. Storage heating makes an essentially expensive fuel relatively affordable, but they are inflexible and most people find them unsatisfactory, tending to make the house warm in the mornings but too cold in the evenings, which is when people spend most of their leisure time in the home. There are more efficient and controllable storage heaters on the market now which are undoubtedly an improvement. In a very well-insulated home, storage heating can be used to provide a relatively cost-effective heating system but you still have to find a way of heating water and overall it remains a fairly expensive and inflexible system.

There are many electric heaters which are not tied to any particular tariff and can be switched on at any time, and controlled with a variety of timers and thermostats. Some heat a liquid within and operate partly as radiant heaters, while others are entirely or mostly convective, often including a fan to increase the flow of air over the heating coils. All of these heaters are flexible but as they will often use peak time electricity, they represent a very expensive form of heating. In almost every case, these heaters should only be seen as supplementary heating.

There are boilers which use electricity only. These can be used in exactly the same way as gas boilers, providing hot water both for radiators and for hot water purposes. They are most efficiently installed in combination with a storage tank and set-up to use off-peak tariffs. Capital costs tend to be lower than heat pumps.

A relative newcomer to electric heating in the UK is the heat pump. Effectively a fridge in reverse, heat pumps take low level heat from somewhere—usually the surrounding air, ground, or water course—and 'upgrade' it for the purposes of household heating, leaving the heat source colder. Circumstances will dictate which heat source is best but if all other things are equal, ground source and water source systems tend to be more efficient while air source is often cheaper and easier to install in most situations. Heat pumps are expensive to install but can be very efficient if installed correctly and if only required to produce relatively low temperature outputs. For this reason the context is key as discussed in the section on 'Type of Property' above. Although electricity tends to cost around 3 times more than gas, a heat pump, in the right context, can operate at 300% efficiency, turning each kilowatt consumed into 3 kilowatts of heat and effectively removing the cost penalty of electricity.

Despite the high cost of heat pumps, and the higher relative cost of electricity compared to mains gas, it does appear that heat pumps are likely to play a large part in the future of heating in Scotland. Because of this, a new phenomenon has emerged in which properties are made 'heat pump-ready'. Where building works are undertaken, the opportunity can be taken to install pipework for a future heat pump and water cylinder, adjust down the flow temperatures from the existing boiler to mimic a future heat pump and (usually) increase the size of radiators to compensate for the lower flow temperatures.

The last option for electric heating is infrared radiant (IR) heating. IR heating is rare in the UK but more common on the continent. Radiant panels can also be created using hot water but IR panels are electric and emit heat at just beyond the visible light wavelength associated with the colour red, hence the name. 'Far' infrared is to be preferred over 'near' infrared. Radiant panels have a number of advantages; they only use radiant heat, tending to heat the surrounding surfaces of the room and anything / anyone inside, rather than the air. By avoiding heating air, they avoid convection currents (which tend to cool people even if they are warm), they avoid heating and scalding dust (which can exacerbate respiratory problems), and they are not subject to the inevitable heat losses associated with ventilation and draughts. Heat

Infrared panels can be used the same as radiators but don't work as well if they are shielded from the room by furniture, as shown here

© Eco Infrared Technologies Ltd.

is stored in the fabric of the building, surfaces are warmer meaning less likelihood of condensation and mould, and as discussed above, humans are more responsive to radiant heating so less energy need be expended to achieve the same levels of comfort. The disadvantages are that radiant panels tend to be a little more expensive than radiators or conventional convector panels and they don't work well if they are shielded by furniture, so they must be positioned in such a way as to be able to 'see' as much as possible.

c. Burning Wood and other Solid & Liquid Fuels

In areas not serviced by the mains gas network, many households still rely on oil and various forms of portable gas. Although the costs are higher than mains gas and delivery and storage issues come into play, the infrastructure of the heating system in the house is very much the same as for mains gas. There is normally a boiler and radiators and all of the comments are relevant to these fuels equally.

A very small number of homes still use varieties of coal or peat for space heating. A smaller number still have back boilers fitted to stoves or fireplaces which allow for heating hot water as well. The high carbon emissions associated with coal, the inefficiency of these systems compared to more modern arrangements and the air quality problems created mean it really makes sense to replace these.

Timber is renewable and although burning it causes carbon dioxide and other emissions, it can be re-planted and so it is universally considered a 'greener' option than fossil fuels and most other options. However, this is only the case if the timber really is re-planted and this is very hard to establish in most cases, making the case for timber less compelling. Another aspect which has recently become pertinent is that of carbon sequestration. What the logic of carbon sequestration amounts to is the idea that burning timber—even if it is less damaging than fossil fuels—is still contributing to climate change, whereas using it to build buildings is actually removing carbon from the natural carbon cycle and helping in the fight against climate change, so it represents a better option.

Carbon Sequestration

Climate change is largely driven by an accumulation of carbon dioxide and other gases in the atmosphere. There are many tactics to try and reduce the amount of carbon dioxide emissions, and others which look at trying to remove carbon from the system by 'locking it away' safely so it cannot contribute to climate change.

Consider a balanced forest environment: young trees are growing, absorbing carbon from the atmosphere, while other trees have grown old and died and are now decaying, releasing carbon back to the atmosphere as they do. Rather than allowing timber to rot in its natural state, we can harvest that timber and 'lock away' that carbon in buildings that hopefully last for many years, preventing the release of that carbon back into the atmosphere. In this way, using timber in buildings is actively working against climate change and is therefore a valuable tactic we can use in retrofit projects, whereas burning it, and letting it decay naturally, both contribute to climate change.

In this rural home, the householder goes to some length to source waste wood and timber from areas to be re-planted. His wood stove provides heat for the home and hot water, supplemented by solar thermal panels, making for a genuinely sustainable arrangement

Notwithstanding the arguments noted above, many households burn wood either as part of, or all of their heating system. In addition to traditional log stoves, timber can now be bought in chipped and pellet form. Chips and pellets are associated with more automated forms of boiler but automated log boilers are also available and such boilers can also be used on larger projects, providing heat to groups of houses with little need for human intervention.

Wood stoves can operate as stand-alone room heaters or can be linked into a back-boiler and radiators along with a water tank and hot water heating. Wood burning purists note that adding a back-boiler cools the chamber, reducing the efficacy of the burn and increasing the risk of deposits in the flue, but load units (also known as heat chargers) can help to overcome this. Modern stoves tend to be far more efficient, using a variety of techniques to burn hotter, keep the window clean and generally improve the experience and performance of wood burning. In relatively airtight homes with open-plan spaces, extract fans can create a negative pressure which could potentially draw toxic combustion gases from the stove into the room. Therefore it is important to ensure that the stove is linked to a separate, external combustion air supply, remaining sealed to the room when operational. All wood burning can cause particulate emissions, especially when combustion is not efficient meaning that the consensus nowadays is that wood stoves should not be used in residential areas.

Water Heating

In the average home, space heating accounts for around 60% of the total energy while water heating accounts for around 20%. The rest is made up of appliances, lighting and cooking. However, as space heating demands are reduced, the proportion of energy used for water heating increases. In Passivhaus projects, water heating is often the largest energy demand but in any event, it makes sense to consider options to reduce costs and emissions associated with water heating when undertaking a retrofit. Hot water solutions are often linked to wider space heating systems, and sometimes even cooking, and so not all solutions described here will be feasible.

a. Use Less

Depending on how extensive the renovation of a property, the simplest way to reduce hot water consumption and associated energy is to keep the pipe runs between boiler, storage tank (if there is one) and taps as short as possible. This is because a good deal of heat is lost via what are called 'standing losses' or 'distribution losses' of water, which has been heated, then sits in a pipe after it has been drawn from the boiler. The longer the pipework, the greater these losses. Short distances between boiler / tank and taps also mean you don't have to wait long for the warm water to appear.

It's also important to ensure that all pipework is carefully insulated across its whole length. This is rarely done and it leads to considerable wastage, and additional costs and emissions as a result. It can also contribute to overheating in summer. Pipework should be carefully checked as part of the normal review process. Insulation used should be 'closed cell' meaning that it is vapour impermeable and carefully sealed at all junctions. Lastly, it is important to insulate cold water pipes too, because where these pass through areas of warm, humid air (eg. bathrooms) their cold surfaces can attract condensation which can lead to moisture problems when hidden. The same is true of toilet cisterns and in the most conscientious low energy projects, these are carefully insulated.

Showering generally uses less hot water than having a bath although this depends a little on the duration of shower and flow rates. Another common solution is to reduce the flow of warm water—to use less of it to the same effect. Aerated shower heads and aerated taps for bathroom basins can be used to reduce the volume of water used, whilst still providing the 'feel' of a decent flow.

b. Heat Recovery

The simplest way to recover heat from a bath is to leave the water in after you've finished. The heat dissipates into the house, but so does the moisture, and the bath can be more effort to clean. There are also now a number of companies who provide heat recovery models for showers. The principle in all of them is that the incoming water is piped in such a way that it recovers heat from the warm water draining away. It then needs less 'top-up' from the heating system. Most systems on the market claim to reduce the heat needed by around 40% and in some cases by almost half. This is about the same as a traditional solar thermal system but doesn't involve any moving parts, the need for a water storage tank or panels on the roof.

Risks of Gas Hobs and Cooking Generally

Health and safety risks associated with gas installations are linked to faulty installation and air quality concerns associated with the products of combustion. Carbon monoxide (CO) is the most concerning of the gases potentially given off. It is the result of incomplete combustion, colourless with no smell or taste but can kill at high doses although more common low doses cause fatigue, headaches and flu-like symptoms. Other gases potentially given off include nitrogen oxides (also from incomplete combustion of gas) acrolein and formaldehyde. These are all known carcinogens. Cooking with hot oil and water can cause tiny oil droplets to be released into the air along with other ‘particulate matter’ (PM) which can also be carcinogenic. Adding large amounts of moisture into the air can also exacerbate issues with mould.

Induction hobs are as controllable as gas hobs, use less energy and do not carry the same risks to air quality and health

c. Solar Thermal Systems

Solar thermal systems make use of the free energy of the sun and can provide around 40-50% of the hot water needs of most households. They require to be linked to a water tank, and the solar panels and all pipework must be insulated. They also involve pumps and the controls of the system need to be properly commissioned to make sure the various sensors and interfaces are all working as intended.

Cooking

The most common cookers are either gas fired or electric. While electric ovens are commonplace, many people prefer to cook on a gas fired hob, the typical explanation being that they prefer the controllability provided by a gas hob. However, induction hobs are now widely available and these have the same levels of controllability as gas. In addition they tend to use less energy than both gas and older type electric hobs.

Although gas cooking will continue to be preferred by many, gas cooking is one of the well known sources of indoor air pollution. This can be more serious for children and the elderly as well as those with asthma, chronic obstructive pulmonary disease (COPD) or other respiratory issues. Replacing gas hobs will remove the risk, but if retained, make sure they are properly maintained and that there is adequate extract ventilation, ideally directly above the hob.

Once used in almost all houses, range units are no longer common but where they are used in most cases they can provide cooking, hot water and space heating to the whole property. A variety of fuel sources can be used. Although it can be efficient in some ways to use one item to provide all heating, the most obvious problem is that the unit needs to be fired during the summer for cooking or when hot water is needed, but as these units inevitably heat the room in which they are placed, this can lead to overheating and wasted heat. Many people grew up with, and are particularly fond of range units and whilst they have become more efficient recently, they are unlikely to represent an efficient option in most cases, unless they can be switched off in warmer months and both cooking and hot water produced by other means.

4.9 Ventilation

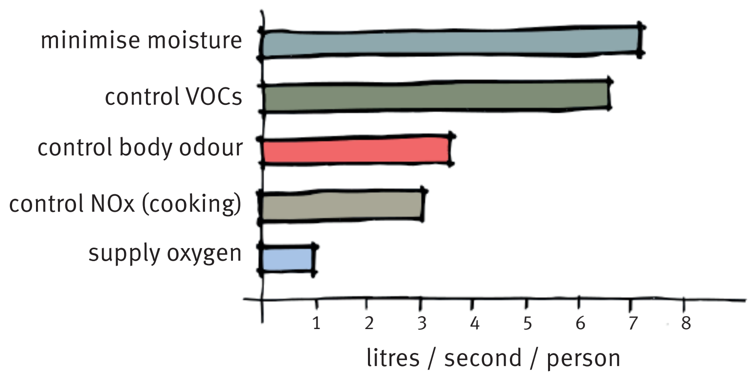
Ventilation is probably the subject most overlooked in the construction industry, while at the same time it has probably never been more important.

Conventional retrofit projects tend to be focussed on insulation and energy efficiency. Ventilation is not considered because it is not an energy efficiency measure, but the omission of this aspect is leading to significant 'unintended consequences'. Whilst a small number of designers, installers and manufacturers take ventilation very seriously, there is no doubt that the majority of mechanical ventilation installations are poorly considered, poorly installed using barely adequate equipment and then poorly maintained. Because they are often noisy, many are switched off altogether. As a result, a significant number of homes suffer from poor air quality with, in some cases, serious implications for occupants and the long-term durability of the building itself.

In this guide, we have dedicated more space to explaining the importance of ventilation and then to practically addressing the various circumstances that might be encountered on most retrofit projects.

The Need for Ventilation

Everyone knows that humans need fresh air. Beyond this fundamental understanding few people give the subject very much thought. As a result it tends to be passed over when considering buildings, environmental performance and the myriad issues which drive retrofit practice. Once again however, the practice of building performance evaluation has highlighted not only how important ventilation is, but also how intricately related it is to all manner of problems within the industry and practice of retrofit. Solve ventilation, and you solve, or at least alleviate many other problems in so doing.

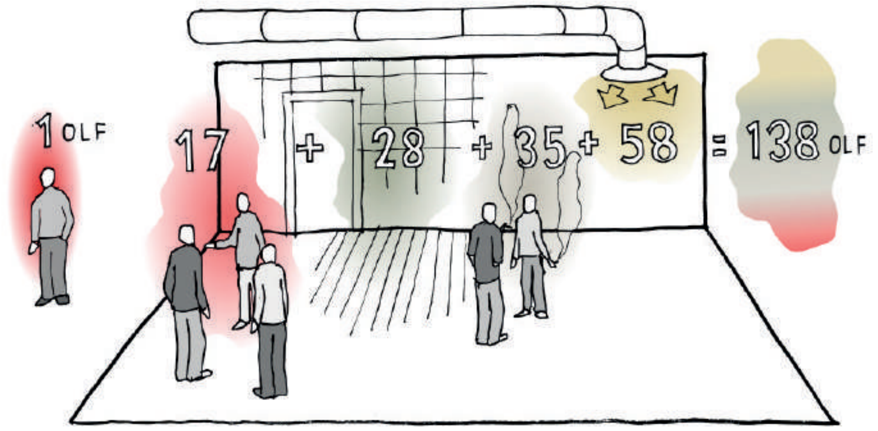


Graph showing 'pollution sources' in a typical home and their relative impact on the ventilation rates required by the building standards (in England and Wales)

The 2006 Approved Document F (Building Regulation in England and Wales) contained a very useful graph that no longer features but showed clearly why ventilation is needed and the relative importance of the various pollutants noted. For most people it is no surprise that the biggest reason we need to ventilate is to remove moisture, but it is a surprise that following close behind is the need to remove volatile organic compounds (VOCs) and other gaseous pollutants emitted from the many synthetic and treated elements of a modern house. At roughly half the significance is the need to control body odour and nitrous oxides from cooking and combustion. By far the far smallest reason is the need to replenish the oxygen we've transformed into carbon dioxide by breathing. There are other recognised benefits of ventilation, not least cooling in warm weather and distributing warmth throughout a home, but these aspects tend to be considered as secondary to the primary role of extracting pollutants.

Moisture is generated in homes by a variety of sources like showers, kettles and drying clothes, but it is little appreciated that one of the largest sources of moisture is us: when we breathe out, we breathe out 400 ml (about 3/4 pint) of moisture a day. One of the important implications of this is the need for adequate ventilation in bedrooms, because, where two people sleep in a main bedroom for eight hours, a good deal of moisture is generated and, being asleep, there are no opportunities for occupants to intervene manually to provide additional ventilation, like opening a window.

Another aspect of interest is the scale of the need to remove VOCs and other unwelcome gaseous pollutants which come from so many parts of a modern home. Most people honestly do not believe that the issue of toxicity and 'offgassing' of unwelcome gases is a serious issue. Hopefully the graph goes some way to persuading readers that it is important, and explains the importance we place in this guide on natural and 'healthy' products and processes which emit fewer or no VOCs.



Sketch showing the relative impacts of different 'pollution sources' in buildings,

In an office of 17 people, these people emit 17 'Olfs' which need to be removed and replaced with fresh air. An additional 28 Olfs are emitted as off gassing by the synthetic materials and finishes in the room, a further 35 Olfs emitted if the 17 people smoke. Finally a huge 58 Olfs are emitted by the intake ducting of the ventilation system itself because such ducts are so rarely cleaned. The ventilation system has to be designed to cope with a total of 138 Olfs.

This diagram is based on 'Olf's and Their Sources in Office Buildings' by Prof. Ole Fangar.

The graph is also helpful in reassuring those who believe that building airtight homes will somehow lead to a reduction in oxygen levels for breathing! A house is yet to be built that is so airtight and so poorly ventilated that it will lead to life-threatening oxygen levels. Far more important is the fact that very many properties have been built or retrofitted which are sufficiently airtight and poorly ventilated that humidity, air quality linked to VOCs, body odour and NOx (cooking) have become serious problems.

A second diagram (above) relates to office buildings but provides a couple more insights into ventilation which are worth mentioning, particularly because of the increase in mechanical, and often ducted, ventilation systems in housing.

The diagram is based on work by Danish building services engineer and researcher Ole Fanger and features the unit known as the "Olf". Coincidentally similar to Ole Fanger's name, the word derives from "Olfactory" and describes an amount of air which needs to be removed by the ventilation system in order to maintain adequate air quality. One 'Olf' represents the pollution provided by one person and is an amalgam of moisture generated, body odour, and carbon dioxide. The significance for the ventilation industry is that in any given room, 1 'Olf' needs to be removed for each person in the space. The diagram is based on a typical office in Copenhagen and shows 17 people in a room, for which therefore 17 'Olfs' will need to be removed by the ventilation system.

However, that is not all the system has to cope with. If everyone in the room smokes, the system capacity has to be tripled to maintain adequate air quality (the work was done in 1970s and '80s when this was more common) while it additionally has to increase capacity again, by almost the same amount, just to cope with the off-gassing of synthetic materials and furniture in the building, along with cleaning products etc. Once again, this shows that while most people do not realise the importance of off-gassing of materials, it is a recognised and serious issue and the reason we place such emphasis on natural and non-toxic materials in this guide.

Finally, the punch line is that the ventilation system itself is the source of the largest amount of pollution, due to the fact that the intake ducting is rarely, if ever cleaned and becomes very dirty, harbouring an array of pollutants. It must be emphasised that these ventilation systems were air conditioning systems where the air was heated, cooled, humidified and de-humidified so it is not directly comparable to the simple air ducting of most domestic properties, but the lessons to be learnt are obvious.

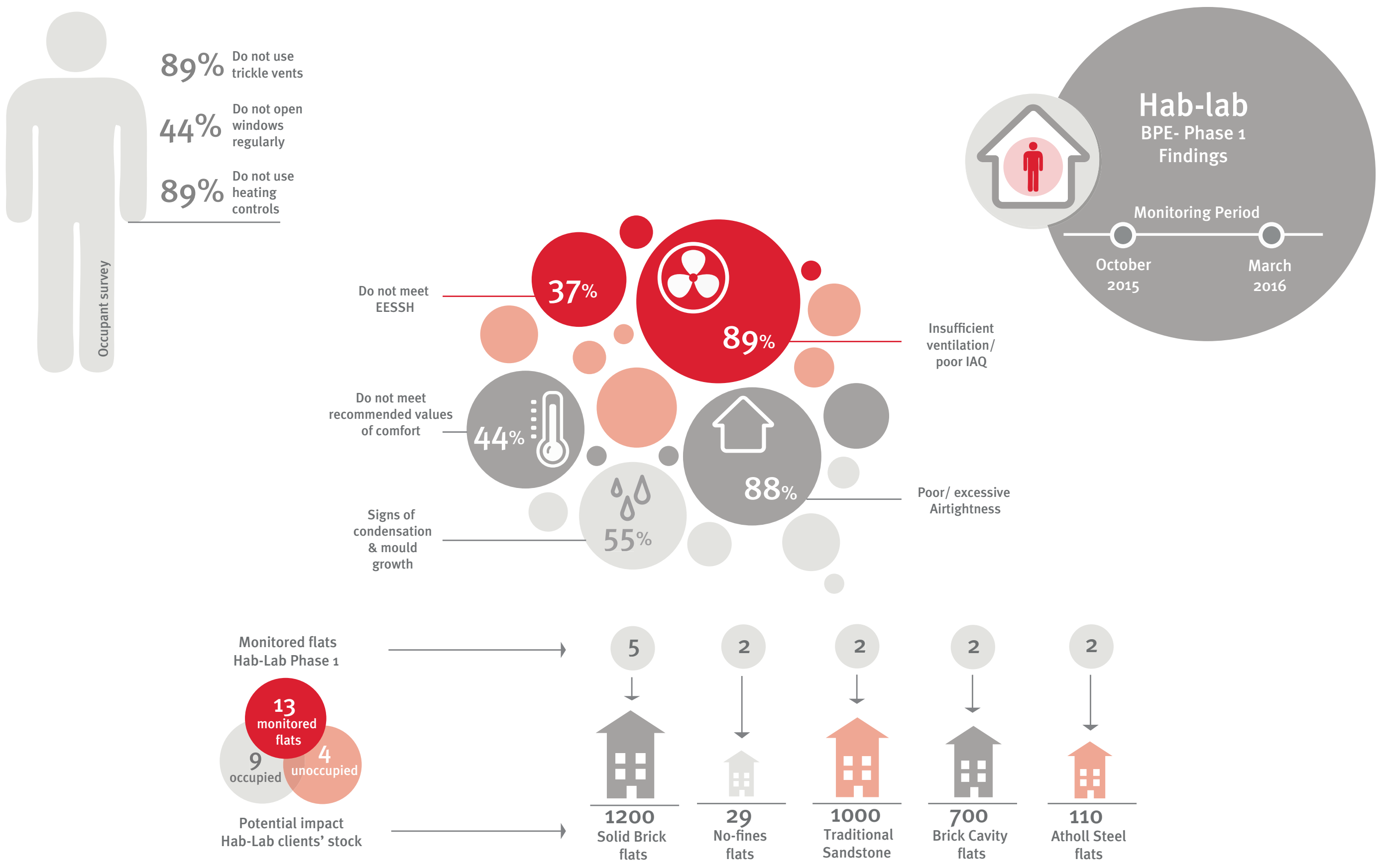
Whilst the example is of an office, not a house, and the ventilation is air conditioning, it is hopefully obvious that the risks to health in homes is similar; people are quite at liberty to smoke in their own homes, all modern buildings contain an equivalent spread of synthetic materials and finishes that off-gas in just the same way, while ducted air systems are becoming more common and maintenance of these is unlikely to be any better. Once again, this shows the importance of maintenance and its complex relationship with energy efficiency and health.

A further lesson that can be learnt from this diagram is that if we remove smoking from the equation, use only non-toxic and natural materials and finishes, and either avoid ducted air systems or ensure that they are well cleaned and maintained, then the potential to reduce the need for ventilation—and the associated costs and energy losses—is enormous.

The Inadequacy of Most Modern Ventilation Systems

All ventilation systems in buildings have three components in common, whether designed or not:

1. some form of extract system which removes stale air
2. some form of intake which allows fresh air into the building to replenish that lost
3. and some arrangement of transfer of air between these points.



This infographic shows some of the early findings of the 'Hab-Lab' project, perhaps the most significant of which was the widespread inadequacy of most existing ventilation systems

Some extract fans are too small to work well and can be too noisy leading many not to be used, or switched off completely

Extract fans placed near trickle vents will short circuit, meaning the rest of the room, and other rooms, can be under-ventilated

A number of recent studies in Scotland and the UK at large have shown that too often the real performance of the various ventilation strategies employed is inadequate in comparison to the requirements of the Technical Standards. The reasons for the poor performance of ventilation systems are complex, interrelated and often quite nuanced, but some of the main issues are noted below, relating to the three main components.

Extract Routes / Equipment are often inadequate because:

- passive stack ductwork does not exert the requisite draw
- other natural stack or cross-ventilation routes are compromised by fluctuating weather conditions
- extract fans are incorrectly sized
- fans are connected to ductwork which increases resistance without adjustment made
- extract fans are noisy and turned off, disconnected or simply not used
- fans are broken and have not been replaced
- filters are clogged with dirt or grease (eg. in kitchens) and no longer extracting effectively.

Inlets are often inadequate because:

- They are located too close to extract routes so creating short circuits which leave other areas under-ventilated
- They are located in wet rooms thereby creating a short circuit and other rooms under-ventilated
- inlets are left closed (occupants either don't know about them, or have left them closed deliberately)
- inlets are under-sized
- inlets are partially or fully blocked by dirt, and debris.

Finally, anticipated transfer routes often become blocked because:

- partition doors are kept closed, do not have the requisite undercut, or are blocked by carpets
- transfer grilles are blocked, sometimes intentionally, e.g. where related to contradictory fire regulations
- inlets are compromised by too many adjacent obstacles, such as net curtains, full curtains, blinds etc.

In some properties, the high levels of air leakage can mean that fans tend to draw incoming air from the gaps in the house rather than the designated inlets meaning the system doesn't work as intended. Ventilation systems that would ordinarily function correctly can also be overloaded by occupant behaviour such as overcrowding of rooms (particularly bedrooms), drying of washing indoors, venting tumble driers into a room rather than outside and what might be called 'excessive' or at least unanticipated use of showers, baths, kettles, cooking and so on.

Many of the above 'real-life' issues have been encountered on investigations and can lead to situations where levels of ventilation within a property are far from expected. Sometimes, this is deliberate—many people close off the various ventilation inlets when it is cold in order to keep the home warmer—while at other times it is unintended. Either way, while properties may well be warmer as a result, all of the moisture and pollutants that were supposed to be exhausted, build-up inside the home.

The most obvious problems occur when moisture or humidity levels increase beyond the point at which the air can contain them. At this point water condenses out of the air, usually at the coldest nearby surface leading to condensation, and if circumstances are right, to mould. While problems with mould are unwelcome, they also tend to be easily seen and therefore more readily dealt with. Equally unwelcome is the build-up of chemicals off-gassed from the plethora of synthetic furniture and fittings in most modern homes. The problem here is that the build-up of these chemicals is not easily sensed by occupants, they cannot be seen and while people often open windows to cool down, research shows that they are less likely to open windows to reduce 'stuffiness'. The harmful effects can go unnoticed and the effects can act upon occupants cumulatively for years.

It is very important that ventilation is considered an integral part of any retrofit project, even if it is simply a case of checking the existing system to ensure that it is operating effectively. In the next section we provide our practical recommendations for what to do in the most common retrofit scenario.

Existing Extract Fans with Openable Windows / Trickle Vents

These systems are by far the most common in Scotland. Working correctly, the systems can be effective at keeping both odour and moisture levels down to acceptable levels, at low capital and running cost. As discussed above, many systems do not operate adequately however, many suffer from being too noisy, and heat is not recovered.

This kitchen trickle vent was completely blocked by debris mixed with grease

Many planned 10mm clear undercuts are compromised by later carpet installations

The trickle vent in this bedroom window was kept closed, as was the door, meaning there was not enough fresh air to clear the moisture in the air, leading to condensation and mould on the coldest available surface: the window frame and reveals

Our Guidance vs Conventional Guidance

Generally, there is little guidance offered in relation to ventilation in typical domestic retrofit projects. If extract fans are found not to be working an electrician may notify the site foreman and suggest that the unit is replaced or repaired, but in many retrofit projects access into homes is limited. However, it really is critical that there is an effective ventilation system and the need for one increases if a property is to be better insulated and made more airtight under typical retrofit conditions. Our guidance is simply to ensure that this is the case, and to take proactive measures where necessary.

Preparation & Specification Considerations

- The existing ventilation system should be reviewed in each property. This review should include all extract units (operational, noise, extract flow rate ideally), all transfer routes (usually beneath doors) and all trickle vents or openable windows providing make-up air. Any faulty, stuck or blocked vents should be noted. If this review takes place at the pre-contract stage, during initial design and costings, then a reasonable indication of cost for any works necessary can be established early. It might make sense, for example, if the review is carried out at the same time as any pre-existing SAP/EPC survey is carried out.
- In a typical dwelling, there should be an extract fan in each wet room, ie each bathroom, toilet, utility room and kitchen. Some properties refurbished in the 1970s and 1980s have extract fans only in the bathroom.
- Some ducting may be required to connect internal rooms to outside and will need to be coordinated with other internal works. Where excessive ductwork or core drilling is required it is sometimes possible to connect two or more extract grilles together and use a single extract unit, which then exhausts through a single existing outlet. This can be cheaper and much easier than installing new outlets through roofs and walls at high level.
- Some units can be switched between intermittent and continuous operation. If possible, it is best to switch them to continuous extract because this is more effective and also creates a more stable environment. If the units cannot be altered and are sufficiently old, ineffective or noisy, then it makes sense to upgrade them to new, quiet and effective continuous extract models.
- It is common to hear that occupants have switched off or disconnected fans due to what they perceive as excessive noise. While understandable, it can easily lead to stuffiness, condensation and mould problems and so it is worth avoiding from the outset. The problem is often noted with intermittent type fans which come on at night when going to the toilet. If existing units are considered noisy, this might in itself be a reason to upgrade. Units should be chosen which operate at less than 30 dB. Units are available that operate at 25dB which is the same as whisper. An alternative which reduces noise is to locate the extract fan itself somewhere remote from bedrooms in particular, and duct air to the unit if there is space to do so.

This occupant cannot reach her trickle vent so it is not readily controllable. It is open, but air flow to the room is reduced by the net curtains.

Installation

- The extract unit should be installed according to all relevant guidance including the manufacturer's instructions. It is important that the installation itself is airtight, it is quite common when investigating air leakage to see gaps around the extract fans.

- All opening windows and or trickle vents should be assessed to ensure that they operate as intended and are easily reached / controlled by the occupants.
- All transfer routes should be checked to ensure that even if partition doors are closed at night, for example, sufficient air flow remains possible beneath (10mm to all doors). It is worth noting that there are potentially contradictory regulations in properties where there is a central hallway onto which rooms may require fire resistant doorsets. In these cases, the doors themselves are more robust and sealed precisely to resist the passage of fire, but 10mm gaps beneath are considered acceptable and the most common way to adhere to both sets of requirements. Intumescent grilles may also be acceptable being open generally, but closing up in the event of fire.
- A commissioning sheet should be completed by the installer and included as part of the 'as-built' drawings and final certificates for services.

Alternatives

- A version of the above is to centralise the extract unit. Although this introduces more ductwork, it enables the fan to be located somewhere (such as an attic or cupboard) where it cannot be heard if noise is a problem.
- An improvement on the above is to introduce an element of demand control. This can involve various measures. One is to introduce humidity-sensitive inlets or trickle vents which open more when humidity is higher, thereby providing greater make-up air when the need is greatest. This can be combined with a variety of sensor- based systems to increase extract rates when conditions suggest, such as in relation to higher humidity, higher CO2 levels and higher temperatures. Demand control does tend to introduce sensors and added complexity but can reduce energy consumption associated with ventilation and makes it much more responsive to actual conditions.
- Another option would be to consider MVHR—Mechanical Ventilation with Heat Recovery. This is usually only worth doing if the building is relatively airtight, no more than 3 m3/hr/m2 @ 50 Pa. Introducing MVHR makes things more complicated but it does mean that almost all of the heat extracted can be recovered making the building significantly more energy efficient. The primary issue is that trickle vents are no longer required and all supply air needs to be ducted into the property via the central unit. This can become difficult in some properties but there are also stand-alone or room-only units which can be deployed as part of the overall strategy if ductwork becomes too problematic. MVHR requires ongoing maintenance and replacement of filters on a regular basis but if designed and installed well will make a significant improvement on comfort and energy consumption overall. Note that combined demand control / MVHR systems are available.

Health & Safety

Beyond the safety aspects of wiring in electrical equipment there are no obvious health or safety risks associated with this kind of work.

4.10 Lighting and Appliances

There are three compelling reasons to look at the efficiency of lighting and electrical appliances in a little more detail when undertaking a retrofit project.

The first is that although the national grid is in the process of becoming ‘de-carbonised’, electricity from the grid is still relatively ‘carbon dense’ that is, it emits more carbon dioxide than most other fuels, and this also tends to make it relatively expensive. The second is that the grid faces considerable pressure at certain times—periods of ‘peak demand’—which creates a range of additional problems surrounding the supply and security of energy in the UK. The more we can do to reduce this pressure the better. Finally, while buildings are, on the whole, becoming more energy efficient, the proliferation of electrical and electronic gadgets, the likely uptake in heat pumps and anticipated electrification of transport mean that *actual electricity consumption* is likely to increase in the future. Again, anything we can do to ameliorate this is to be welcomed.

Most guidance on this subject tends to centre around changing inefficient light bulbs for more efficient ones, and possibly considering smart meters. But there is a lot more to the subject than this, so as in the previous chapters, we have chosen to outline some of the issues which impact on electrical efficiency and sustainability in the hope that this will help inform decision making.

Electrical Energy Efficiency

Avoiding the Need for Electricity

As with heating, the simplest way to reduce electrical consumption is not to need it in the first place.

a. Go Without

Across the UK individual households and in some places whole villages manage without the mains grid. It is not an option for most, but there are many valuable lessons to be learnt from those who manage this, most of which centre around a profound reduction in the need for electricity in the first place and a strong focus on storage options.

This room demonstrates a number of the points made in this chapter: large windows allow lots of light into the space, good for mental health and meaning the space is bright enough most days without artificial lighting. Task lighting (side lights) is used in the evenings and each ceiling light is separately switched. White walls and window frames increase light into the room, blinds are drawn back fully and the full height glazing also allows a closer connection to the adjacent garden.

b. Sunlight

The benefits of daylight and sunlight extend far beyond energy efficiency into aspects of physical and mental health, especially in Scotland with long winters and short days. At a prosaic level however every living room should have adequate levels of daylight and this should be optimised as far as possible to enable occupants to operate without the need for artificial lighting, at least for some parts of the day.

Curtains and blinds should be drawn fully back and arranged so as to avoid obscuring parts of the window if possible and plants externally should be kept back from windows for the same reasons. White window frames will reflect more light than dark brown ones, and mirrors internally, and even ponds externally can be used to reflect light deeper into a room. Keeping glass clean of course also improves the penetration of light into a room.

If undertaking a more extensive renovation it may be worth altering or adding windows if a room is too dark. A good rule of thumb is that if you can see the sky from where you are standing, then there is likely to be sufficient light. Roof lights let in much more light than vertical windows (but also let out more heat) and in some cases it might be worth considering opening up a light well into the centre of a particularly dark building. A much cheaper option is to consider the use of rooms, so that you organise to work, or simply be, in the room which receives the greater part of the light throughout the day, thus east facing rooms will be lighter in the morning and west-facing ones lighter in the evenings.

These bookshelf lights are an example of 'accent lighting' —they don't provide sufficient light for the room, nor do they help with any task, but they are pleasant and make a feature of the bookshelves

Light coloured finishes internally will significantly affect the overall light levels in a room and while the higher reaches of a window allow light to reach deeper into a room, lower cills also provide a view out onto the garden, if you have one, and these views carry their own benefits for health and wellbeing. Windows which are too large can lead to overheating, especially in well insulated homes, so an option for external shading and ventilation is important, while glare can be a problem in some cases, when working with a computer screen, for example.

Contextual Efficiency: Lighting Strategy

Generally lighting is used for three quite distinct reasons. The first is usually termed 'background' or 'ambient' lighting and simply means that an adequate amount of light fills any given space so that you can move about and do whatever you need to do with sufficient clarity. In a typical room in a house, this is the pendant fitting in the centre of the ceiling.

The second form of lighting is usually termed 'task lighting' and is specifically designed to help people undertake a task. The assumption is that the background level of light is insufficient for the task. In working environments, task lighting is often a critical aspect of health and safety, whereas in homes, it is more commonly associated with under-cabinet lighting in kitchens which light the worktop, bathroom mirror lamps or bedside lights used when the main light is switched off.

The third form of lighting is usually called 'accent' lighting and is used to highlight special features such as a painting on the wall. It is mainly aesthetic and is almost always in the form of spotlighting.

The main thing when aiming to make lighting more efficient is to consider these three strategies and see how the overall energy used can be reduced. The most common tactic is simply to reduce the ambient lighting to a sensible minimum (because this is usually trying to light a large area, it involves more energy), and focus more on task lighting, which can be used to provide adequate light precisely where it is needed. Because it usually means lighting a smaller area and from closer at hand, it typically uses less energy and can be switched off as soon as that task is finished.

In smaller spaces, one tactic sometimes employed is to use task and accent lighting to create different 'pools' or 'rooms' of light, thereby giving the sense of different spaces within the whole. This can be more effective at compensating for a smaller room than simply providing lots of light. As ever, it is the context and the way light is used, rather than simply the amount.

Another aspect of this is the way a light is designed. Some lighting is designed to be 'direct', whereas other lighting is designed to be ‘indirect’ meaning that it is used more to light a surface (such as a feature stone wall). Clearly direct lighting is more efficient because all of the light created is gained for the space, but it is worth noting that if you can see a light source while carrying out a task, it can have the opposite effect of reducing your pupil size and actually making things appear darker so it is always worth trying to provide shade from a light source while ensuring it is shining on whatever it is you want to see. Again, context is everything.

Many light fittings are fitted with shades. These range from being highly decorative to plain and simple, from obscuring most of the light to being reflective and directional. Clearly, lighter shades which do not obscure the light are more efficient, while reflective inner surfaces can help direct light. LED and halogen bulbs tend to come with reflective surfaces by default and keeping shades clean also improves the amount of light gained.

Component Efficiency

LED bulb in a standard bayonet light fitting. It looks like a traditional incandescent bulb but is far more efficient—this 15W bulb is roughly equivalent to an old 60W or 100W bulb. Note a white and simple shade, which does not obscure any of the light to the area directly beneath.

In this section we discuss the intrinsic efficiency of the main components used, being light bulbs and appliances generally.

a. Bulbs

The best known tactic to reduce energy consumption in lighting and electrical is to replace bulbs with more energy efficient versions. This is one of the very few areas where there is very little disagreement or complexity.

Traditional incandescent (or tungsten filament) bulbs are now almost entirely phased out so for the majority of purposes we are left with halogen bulbs, compact fluorescent (CFL) bulbs and light emitting diode (LED) bulbs. Halogen bulbs are versions of the old incandescent bulbs, but are more efficient and last longer due to the presence of halogen gas within the bulb which protects the tungsten filament.

LED bulbs use around a sixth of the energy used by traditional incandescent bulbs and around three-quarters of the energy of CFL bulbs for the same light output. They last perhaps 25 times longer than incandescent bulbs and at least three times longer than CFLs. There is no start-up time as there has been with CFLs and repeated switching on and off does not shorten the lifespan of them as with CFLs. LEDs do not contain mercury, lead and cadmium and they are smart-home compatible, dimmable and capable of replicating a number of colours and colour temperatures. Apart from personal preference, there is no reason not to use LED for almost every purpose.

b. Appliances

Over the course of its lifespan, the cost of running most appliances outstrips the initial cost, so there is every reason to buy more energy efficient models, even if they are initially more expensive. All appliances are now sold along with an energy efficiency label with a rating from more to less energy efficient.

It is important to note that energy ratings are given to products based on their size category. Thus a small fridge may well use less energy than a better rated fridge which is much larger so it is also important to look at the overall energy consumption figures which are printed on the label. The Energy Saving Trust and a number of consumer websites offer good advice on the energy consumption of appliances and how to use them efficiently.

c. Standby

Most appliances can be left unused but remain switched on and in the ‘standby’ mode continue to use electricity, sometimes known as ‘phantom loads’. The amounts used tend to be very small, recent EU legislation means that these cannot be more than 1W each, but the problem is that most households have very many items, often with many of them left on standby 24 hours a day. Lots of small amounts over a long time makes for a significant number and it is estimated that the average UK household spends around £30 per annum powering appliances simply left in standby mode.

There are a number of products available to help cut down on standby electricity consumption. Some allow for many items to be turned off in one go, but it is important to remember that some items rely on an internal clock which makes turning them off problematic.

People and Usage

Everyone has seen posters reminding them to turn lights off, and whilst the issue of lights left on overnight in offices remains a sizeable problem, it is much less of an issue in homes. It will probably always be useful to periodically remind people to think about the issue, and there are a number of ways we can help cut down unnecessary usage of lighting in particular.

a. Awareness

Being aware of electricity being used in real time is perhaps one of the most effective ways of raising awareness of the issue. It is also helpful to relate real time information to historical consumption (“we used less this week than last week”) and to relate it all to cost. There are a range of products on the market now which allow occupants to see how much electricity is being used, and a variety of tactics employed to encourage a reduction in use overall.

There are several options for display units like this which tell you how much electricity is being used at that moment, and how it relates to previous days / weeks etc. Note that it is better if these are located somewhere you use often, helping you regularly keep an eye on things.

An interesting option is to place the meter readings of different properties together, so that these can be immediately compared. Natural competitive tendencies take over and conservation of energy can become motivating! This may not be appropriate in all situations but has been employed to good effect in student residences, for example.

A more mundane example of raising awareness is to include neon indicators where there is a risk of lights or other appliances being left on. A good example is for attic lights, where the switch is in the space below, the neon indicator meaning that the light is on in the loft above where this might not otherwise be detectable. Neon or LED lights can also be indicators of ‘phantom loads’ too, where appliances are partially switched off.

b. Controls

Broadly speaking there are four types of control for lighting. The first is manual (the good old-fashioned switch), along with three types of automated control: daylight or ambient light-related, occupancy-related and timer-based. These control options can be extremely helpful in more commercial situations but tend not to be needed much in homes.

It is worth considering however where the likelihood of lights being left on is possible.

In larger rooms, it is worth considering arranging the switching of lights so that on brighter days, those lights nearer the windows can be switched off separately from those further away. Too often all lights are put onto one circuit making this differentiation impossible.

Many lights can be dimmed, but in many cases the light output is reduced without reducing the electrical input accordingly. Where dimmable lighting is to be employed, it is worth ensuring that this will lead to an associated reduction in electricity consumption.

c. Maintenance

Most of us have at some point cleaned a light fitting and found it covered in dust. Dust and other dirt covering light bulbs and associated fittings is generally assumed to reduce the efficiency of lighting systems by up to 10%. Thus it stands to reason that keeping all light fittings in your home clean will improve the efficiency of the system and provide more light for the same cost. The same is true of all appliances but the circumstances vary too greatly to note more than the fact that appliances kept clean and free of dirt that could affect performance makes good sense.

Wider Sustainability Issues

There are other issues at stake beyond energy efficiency, and in the following section we briefly introduce a few of these to consider when choosing electrical appliances and lighting.

a. Variable Rate Tariffs and Smart Meters

Some electricity tariffs now encourage customers to shift their usage away from times of peak demand, and reflect the varying output from renewable generators. This is essentially the same logic as that developed for storage heaters - to try and align consumer use to the optimum grid requirements. Smart meters can help in this regard, as can more complex home-based battery storage and controls.

b. Access for Upgrading

Electrical and communications items are among those most frequently upgraded and so it makes sense to enable upgrading of equipment and associated cabling with as little disruption as possible. Providing service voids, or running cables within conduits, and providing easy access to these means the inevitable upgrading will be simpler, cheaper and involve less disruption and waste in the long-term.

c. Embodied Toxicity

Although there were compelling energy efficiency arguments for the drive to change traditional tungsten filament ('incandescent') bulbs to compact fluorescent bulbs, there was a downside which is the fluorescent bulbs contain small amounts of mercury and other toxic substances. Another issue raised was the potential to cause headaches due to the flicker of certain, older fluorescent bulbs. Both of these problems can now be avoided by choosing LED bulbs which are also more energy efficient.

d. Longevity

Our consumption of 'consumables' is increasing both in quantity and rapidity with considerable implications for the planet. Longevity is perhaps one of the main selling points of the most recent LED bulbs in comparison with older bulb types. Generally with appliances the more you pay, the greater the quality and robustness meaning the items should last longer. The benefits of buying longer-lasting items is not just in financial savings to the customer, but a reduction in the waste created.

e. ELFs and EMFs

All electrical items when plugged in emit an electric field (ELF) and also emit an electro-magnetic field (EMF) when they are switched on. These fields are very small, but there are many of them and we are surrounded by them. Much larger fields are emitted by high voltage power cables. A small number of people believe that these fields are hazardous to health. Evidence of this is scant, but does exist, and there is evidence to link child leukaemia, in particular, with proximity to electric and electro-magnetic fields. There is also evidence of risks to health associated with the very high fields associated with high voltage power lines.

It is difficult to be certain that health risks beyond these can be linked to electric cabling within homes, but there is enough to suggest a possible cause and so it makes sense to adopt a precautionary approach where possible, for those who are concerned. The two key factors appear to be proximity and size of field. The closer you are, and the larger the field, the more potential concern. Practically, it is possible to install cabling within sheathing which provides a shield from the effects of the field.

f. Colour and Light

Colour therapy is a form of alternative medicine which links health issues to colour, usually in combination with light. While this is not for everyone, there is increasing evidence of the health benefits of different types of light with the underlying principle that light which most closely mimics daylight brings the greatest benefit. With people spending on average 90% of their time indoors, this becomes more of an issue than in previous generations and for those with seasonally affective disorder (SAD) or similar issues.

Different bulbs have different 'temperatures' measured in Kelvin, so that 'warmer, softer' light has a temperature of around 2700K while 'cool, blue' light tends to be around 6500K. Daylight is closer to the cool, blue light and daylight bulbs can therefore be used to ameliorate the effects of being indoors for long periods. It should be noted that daylight becomes noticeably 'warmer' in the evenings and therefore these sorts of light sources should be employed then. 'Evening' light settings are often found on electronic devices and this is something that can be readily employed by those interested in the subject. A development of the 'daylight bulb' is the 'full spectrum bulb' which takes the principle further and although more expensive, will be of greater interest to those concerned about this issue.

This dishwasher was a more expensive one, but much quieter than normal which was considered important in an open plan home

g. Noise

One of the most irritating things in houses can be the background noise of certain fittings. Ventilation systems are often switched off due to the noise they make while equipment like fridges and washing machines can be very noisy.

Switching off ventilation can lead to issues with condensation and mould while switching off a fridge is unlikely to be an option and so it pays to consider the noise of items in the house before purchasing them. Some items can be used when not at home (like a washing machine) and others can be moved into adjacent rooms, or somehow insulated, however this is not possible in many cases. Most appliances are sold with labels which will confirm the noise made and if it is likely to be an issue, then it will make sense to buy a quieter model.

h. LSF Cabling

Low smoke and fumes (LSF) cabling is available which as its name suggests, emits less, and less hazardous smoke in a fire. Most cabling is made with PVC as a sheath and there are known risks to health from PVC when it burns so a sensible precaution is to buy, or specify LSF cabling where feasible.

Renewables

For many people, renewables are the symbol of sustainability—having a solar panel on your roof instantly makes a home an 'ecohome'—whereas they are in fact just one of many pieces of the jigsaw that need to be considered. The efficiencies, and therefore environmental/financial benefits of renewables are constantly improving, but it remains the case that they should always be considered only after all other avenues for reducing energy demand have been exhausted.

There are three main ways of generating electricity renewably by harnessing the power of the sun, wind and rivers: using photovoltaic panels, using wind turbines and using hydropower plants, respectively. Combined heat and power (CHP) is sometimes considered a renewable technology and is discussed briefly in the previous section. Wind power and hydropower are not usually included as part of retrofit projects and are not considered here, but solar electric power (photovoltaic) is sometimes an integral part of a renovation project and is considered a little below.

These PV panels are mounted on an existing slate roof

Photovoltaic panels produce direct current (DC) electricity from light which is then converted to alternating current (AC) by an inverter before it can be used in the building. Some applications (especially those associated with caravans and yachts) can use the DC without inversion but for most purposes there is an inverter required.

A combination of improving technologies, increasing economies of scale, occasional grant support, increasing electricity prices has meant that the environmental and financial viability of photovoltaic (PV) panels has been improving over the last few years such that there is now a stronger case for considering PV.

Systems come in several forms: some can be integrated into the roof or glazing of a building but most come as panels which are separately mounted on roofs or on the ground.

Clearly any system is most efficient when facing as close to due south as possible and at an angle of between 30º and 50º. Panels which are closer to 30º will collect more energy when the sun is higher in the summer, but far less in winter, whereas panels closer to vertical will collect more light during winter and at the extreme ends of the day, but efficiencies drop off in summer. Panels produce electricity in relation to the amount of light they receive and so on cloudy days, they generally produce around a quarter of the output from sunny days. It is worth emphasising that shading of the array can significantly affect the performance of the system, so systems should be carefully designed to avoid shading, from adjacent dormers or nearby buildings or trees.

Increasingly it is possible to source PV units which resemble conventional slates or tiles and this is a valuable development in situations where ‘unsightly’ installations might be unwelcome, such as in conservation areas, or on listed or otherwise attractive older buildings and contexts.

A complication for larger scale clients such as housing associations or council housing departments when undertaking retrofit projects is how to divide up the benefits of the ‘free’ electricity. In many cases, the electricity generated is simply sold to the grid and the financial benefits split evenly in preference to managing the complex technical aspects of separately metering the consumption of the PV-generated electricity to each household.

In every case, it is important to get quotes from a number of companies who will also provide estimations of output and a scheme design to determine the most appropriate layout of the panels. The companies will also advise on the best inverter, storage and grid connection options which are an important part of the overall installation. Unless the project is off-grid, installations usually connect to the main grid, effectively using it as a ‘battery’ to offload excess production, drawing it back when needed at other times. Domestic-scale batteries have recently become widely available, enabling householders to store electricity on site. The tariffs available for both buying and selling back power are in constant flux, but as a general principle it is usually the case that the most effective solution is the one where most energy can be used ‘on site’ ie in the home rather than exporting to the grid. Thus both direct use and battery or hot water storage of onsite generated electricity become important parts of the overall system.

5. RESOURCES, GLOSSARY, AND ACRONYMS

Organisations

Many of the organisations listed below have a huge range of advice and downloadable guidance, not all of which agrees with guidance by other organisations. For this document, we have drawn most heavily from the STBA (Sustainable Traditional Buildings Alliance) and Historic Environment Scotland, both of whom offer a wide range of supporting documentation.

Association for Decentralised Energy (ADE).
https://www.theade.co.uk
Working to support energy efficiency through policy and investment across the UK.

Association for Environment Conscious Building (AECB).
https://www.aecb.net
Network promoting sustainable building.

Building Research Establishment (BRE).
https://bregroup.com
Huge range of research, reports, the developers of SAP and EPCs, BREEAM and much more.

Carbon Trust.
https://www.carbontrust.com/home/
Focus mainly on business and commercial sector, but wide range of useful information and support.

Centre for Sustainable Energy (CSE).
https://www.cse.org.uk
Independent national charity focussed on energy and sustainability, helpful guidance for householders.

Changeworks.
http://www.changeworks.org.uk
Sustainable development charity, good publications on domestic energy efficiency.

Chartered Institute of Building Service Engineers (CIBSE).
https://www.cibse.org
Supporting best practice in building services engineering, lots of helpful guidance.

Construction Industry Research and Information Association (CIRIA).
https://www.ciria.org
Supports collaborative work, innovation and research across the construction industry.

Energy Action Scotland.
http://www.eas.org.uk
National fuel poverty charity.

Energy Saving Trust (EST).
http://www.energysavingtrust.org.uk
Domestic energy advice agency, lots of information

Good Homes Alliance (GHA).
http://goodhomes.org.uk
An organisation dedicated to high quality and sustainable housing, new and refurbished.

Historic England.
https://historicengland.org.uk
The public body that cares for England's historic environment.

Home Energy Scotland.
http://www.energysavingtrust.org.uk/scotland/home-energy-scotland
Scottish Government free support for households, delivered via the Energy Saving Trust

Historic Environment Scotland (HES).
https://www.historicenvironment.scot
Primarily conservation based, but acknowledging in many cases the need to address sustainability in its wider sense and a good deal of helpful primary research in the Technical Papers in particular.

Institute for Sustainability.
https://www.instituteforsustainability.co.uk
Now defunct, but above webpage retains links to several useful documents on retrofit.

Institute for Historic Building Conservation (IHBC).
https://www.ihbc.org.uk
Building Conservation

The National Trust for Scotland.
https://www.nts.org.uk
Scottish members organisation linked to the National Trust across the UK and heavily engaged in conservation of buildings, places, monuments and landscapes.

Retrofit Scotland.
http://www.retrofitscotland.org
A collaboration between a number of organisations focussing on retrofit in Scotland with a range of useful case studies and other resources.

Royal Incorporation of Architects in Scotland (RIAS)
https://www.rias.org.uk
Professional body representing most Architects in Scotland, provides accreditation in acknowledged expertise in both conservation and sustainable design practice.

Royal Institute of Chartered Surveyors (RICS)
https://www.rics.org/uk/
Professional body promoting and enforcing best practice in the many areas of surveying.

Scottish Ecological Design Association (SEDA).
https://www.seda.uk.net
A members' organisation with good events across Scotland and a number of downloadable documents, all with sustainability at their core.

Society for the Protection of Ancient Buildings (SPAB).
https://www.spab.org.uk
Organisation dedicated to the future of old buildings.

Sustainable Traditional Buildings Alliance (STBA).
http://stbauk.org
A valuable source of information and guidance which often challenges current orthodoxy on retrofit and construction practice.

United Kingdom Centre for Moisture in Buildings (UKCMB).
http://www.ukcmb.org
A collaborative group dedicated to moisture issues, including decay and health in buildings.

General Guides

3ENCULT: Energy Efficient Solutions for Historic Buildings. A Handbook (2014)

Marion Baeli: Residential Retrofit. 20 Case Studies (2013)

British Standards Institute: BS 7913: 2013 Guide to the conservation of historic buildings (2013)

British Standards Institute: PAS 2035: 2019 Specification for the energy retrofit of domestic buildings

Changeworks: Energy Heritage: A Guide to Improving Energy Efficiency in Traditional and Historic Homes (2008)

Changeworks: Renewable Heritage: A Guide to Microgeneration in Traditional and Historic Homes (2009)

CIBSE: Guide to building services for historic buildings – Sustainable services for traditional buildings (2002)

Edward Harland: Ecorenovation (1994)

Historic England: Energy Efficiency and Historic Buildings – application of part L of the Building Regulations to historic and traditionally constructed buildings (2012)

Historic England: Energy Efficiency in Historic Buildings (2012) – 12 guides covering the upgrade of different building elements.

Historic England: Practical Building Conservation: Building Environment (2014)

Historic Scotland: Short Guide to Fabric Improvements for Energy Efficiency in Traditional Buildings (2012)

Roger Hunt and Marianne Suhr: Old House Handbook (2008)

Roger Hunt and Marianne Suhr: Old House Eco Handbook (2013)

ICOMOS: The Venice Charter (1964/5) (www.icomos.org)

Donald Insall: Living buildings (2008)

Society for the Protection of Ancient Buildings: Energy Efficiency in Old Buildings (2014)

Stewart Brand: How Buildings Learn (1995)

Miscellaneous Relevant

BRE: BR262 Thermal insulation: avoiding risks (2002)

BRE: IP1/00 Air tightness in UK dwellings (2000)

Changeworks: Solid Wall Insulation in Scotland (2012)

Department of Energy and Climate Change (Palmer, J and Cooper, I): Great Britain's Housing Energy Fact File (2011)

Environmental Change Institute: 40% House (2005)

SPAB: The SPAB Research Report 1: U-Value Report (2011)

Sustainable Dunblane: 'Improving energy efficiency in 'Hard to Treat' houses (2011)

Sustainable Uist: Uist HtT Housing Report Part 1 and Part 2 (2012)

Glossary and Acronyms

Adaptive comfort: Adaptive thermal comfort is a theory that suggests a human connection to the outdoors and control over the immediate environment allow them to adapt to (and even prefer) a wider range of thermal conditions than is generally considered comfortable.

Air permeability: The leakage of air ($m^3.h^{-1}$) in or out of a building space, per unit area (m^2) of envelope (including ground floor area) at a reference pressure of 50 Pa between inside and outside the building.

Airtightness: A term describing the leakiness of a building. The smaller the leakage for a given pressure difference across a building, the tighter the building envelope.

Airtightness layer: A layer built in to the external envelope to minimise air infiltration/exfiltration. It may consist of a wide range of materials (for example,sealants, gaskets, glazing or membranes) and should be continuous to be effective.

BRE: Building Research Establishment

Breather membrane: A water-resistant sheet which allows transmission of water vapour, but which provides resistance to airflow.

Breathable: usually used to describe the vapour (not air) permeability of materials or constructions

Building Performance Evaluation (BPE): The process of evaluating how a building performs in use, and can be carried out on both new and existing buildings. It attempts to identify energy inefficiencies, other potentially unintended consequences and occupant dissatisfaction that result from not performing in accordance with design intentions.

Climate change: A change in global or regional climate patterns, in particular a change apparent from the mid to late 20th century onwards and attributed largely to the increased levels of atmospheric carbon dioxide produced by the use of fossil fuels.

Condensation: The conversion of a vapour or gas to a liquid, in practice this tends to be water which collects as droplets on a cold surface when humid air is in contact with it.

Conduction: heat flow through solid materials by microscopic collisions of particles and movement of electrons within the material.

Convection: heat flow through liquids and gases (usually air when referring to buildings)

Cross ventilation: Air circulation in a room that is caused by outside breezes or wind. It is achieved by placing vents or windows on opposite facing walls in a room. Also described as wind driven ventilation

CWI: Cavity Wall Insulation

Draughtproofing: Filling gaps between opening parts of components and their frames.

Energy Performance Certificate (EPC): All domestic and commercial buildings in the UK available to buy or rent must have an Energy Performance Certificate (EPC). EPCs tell you how energy efficient a building is and give it a rating from A (very efficient) to G (inefficient). EPCs let the person who will use the building know how costly it will be to heat and light, and what its carbon dioxide emissions are likely to be. The EPC will also state what the energy-efficiency rating could be if improvements are made, and highlights cost-effective ways to achieve a better rating.

EWI: External Wall Insulation

Fuel poverty: A household is said to be in fuel poverty when its members cannot afford to keep adequately warm at a reasonable cost, given their income.

Infiltration: Infiltration is the unintentional or accidental introduction of outside air into a building, typically through cracks in the building envelope and through use of doors for passage. Infiltration is sometimes called air leakage. The leakage of room air out of a building, intentionally or not, is called exfiltration.

IWI: Internal Wall Insulation

Lambda: see thermal conductivity

Natural ventilation: The movement (caused by wind and outside temperature) of outdoor air into a room or space through intentionally provided openings, such as windows and doors and non-powered ventilators.

Psi value: see thermal bridge

Radiation (of heat): in this document refers to short wave radiation of infrared electromagnetic radiation

RH: Relative humidity: the amount of water vapour present in air expressed as a percentage of the amount needed for saturation at the same temperature.

SEDA: Scottish Ecological Design Association

Stack effect/ventilation: the upward movement of air through openings in a building fabric due to thermal buoyancy and/or negative pressure generated by the wind over the roof.

Thermal bridge (psi value): A thermal bridge, also called a cold bridge, is an area or component of an object which has higher thermal conductivity than the surrounding materials, creating a path of least resistance for heat transfer. The heat loss associated with these thermal bridges is expressed as a linear thermal transmittance (Ψ-value) or 'psi-value'.

Thermal bypass: Thermal bypass is heat transfer that exploits air movement between two regions but not necessarily air movement that penetrates all the way through the building fabric.

Thermal Conductivity: Thermal conductivity λ (lambda) is defined as ability of material to transmit heat and it is measured in watts per square metre of surface area for a temperature gradient of 1 K per unit thickness of 1 m.

Thermal mass: In building design, thermal mass is a property of the mass of a building which enables it to store heat, providing "inertia" against temperature fluctuations. It is sometimes also known as the thermal flywheel effect.

Thermal transmittance (U-value): measure of how readily heat flows through a component or set of materials (such as a wall), expressed in W/ mK.

Thermographic camera: A camera sensitive to the infrared part of the spectrum, which can be used to 'see' locally cooled areas on the internal surfaces or heated areas on internal and external surfaces of the envelope of a building. Sometimes referred to as an Infrared camera.

Thermography: The use of cameras sensitive to infrared radiation to identify thermal weak spots in the envelope of the building and to help identify air leakage paths through gaps and cracks in the building.

U-value: (see thermal transmittance)

VB: Vapour Barrier

Vapour control layer (VCL): A layer mostly, but not completely, impervious to water vapour and usually enclosing an occupied space.

VOC: Volatile Organic Compound

Ventilation: Supplying or removing air, by natural or mechanical means, to or from a space.

Water vapour: Water in its gaseous form.

In this guide, we describe ten ways in which those involved in the retrofit and renovation of Scotland's homes can improve upon current practice, achieving better energy performance while simultaneously gaining wider sustainability benefits. We look at a more balanced approach that values energy efficiency equally with the health of occupants and the long-term durability of buildings, and that considers the reality of buildings as built, rather than the theoretical models which tend to inform policy and practice. We look at how we can better engage with people, and learn from established conservation practice to help with the practicalities of working with existing buildings.

This guide will be of interest to anyone working with existing buildings, from those working in government, housing associations and councils, as well as architects, surveyors, builders and those wanting to refurbish their own homes. The guide includes detailed information and drawings of exactly how parts of a building can be upgraded along with a commentary on practical issues to look out for, and why our guidance differs from most conventional wisdom on the subject.

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