# Improving Energy Efficiency In 'Hard to Treat' Houses

March 2011

**Project Report**

*Version prepared for the benefit of those Dunblane residents wanting to find out more about the issues raised, and for those in the 'community of interest' surrounding energy efficiency and Hard to Treat housing refurbishment generally.*

**Contents**



***Abbreviations used in this document:***

| | |
|---|---|
| EPC | Energy Performance Certificate |
| EST | Energy Saving Trust |
| HIS | Home Insulation Scheme |
| SD | Sustainable Dunblane |
| HtT | 'Hard to Treat' |
| CCF | Climate Challenge Fund |
| HEC | Home Energy Check |
| CERT | Carbon Emission Reduction Target |
| SAP | Standard Assessment Procedure |
| rdSAP | Reduced data [version of the] Standard Assessment Procedure |
| PhPP | Passivhaus Planning Package |
| NHER | National Home Energy Rating |
| kWh/a | kilowatt hours per annum |
| $kg/(m^2/a)$ | kilograms per metre squared per annum |
| $m^3/hr/m^2$ @50 pa | meters cubed per hour per meter squared at 50 Pascal's |
| RSL | Registered Social Landlord |


***Acknowledgements***

The Authors, Chris Morgan of Locate Architects and Elaine Hill of Sustainable Dunblane, would like to thank the following:

The 18 households who volunteered to have their houses surveyed and endured the attentions of our Surveyors, and the many householders who offered to have their houses surveyed but missed out, David Seel for tirelessly pounding the streets of the Dunblane area to visually survey every one of the 3297 homes, Graham Drummond of Passivhaus Associates in Fife for the survey work and PhPP calculations, Gordon Allan, Alan Little & Stuart Little and James Richardson of IRT Surveys in Dundee who undertook the surveys and SAP calculations, thermographic camerawork and organised the air pressure tests, and Rebecca Vivers of the Climate Challenge Fund who supported us through the whole process and whose organisation funded the entire undertaking.

**Summary**

Sustainable Dunblane was awarded funding from the Government's Climate Challenge Fund to study 'Hard to Treat' Housing in Dunblane. This is the housing that cannot currently take advantage of Government grants to help with energy efficiency measures due to their construction type.

We have established that there are around 1375 'Hard to Treat' homes in the Dunblane Community Council area which amounts to around 42% of Dunblane Community Council's housing stock. 18 representative houses were surveyed and studied using a variety of techniques in order to gain a greater level of understanding than is normally the case with standard survey techniques.

The results have been sent to all residents of the 'Hard to Treat' properties along with a comprehensive description of potential measures to reduce energy use.

Whilst there were no discernible differences between the types of property, we did establish that each different survey method used to model the houses energy performance gives a significantly different result. This leads to natural speculation about which is the most accurate, which we have tried to answer in the report. From this discussion, we are led to the two conclusions to this study, both of which have significant ramifications for incoming policies and priorities concerning support for, and works to, the built stock in Scotland and the UK.

The first is that, if our study is at all representative, we appear to be underestimating the amount of energy used in our buildings when using RdSAP, SAP and related tools. Since almost all UK or national level discussion on refurbishment is based on the results of these tools, we may be dealing with fundamentally inaccurate, and optimistic, information.

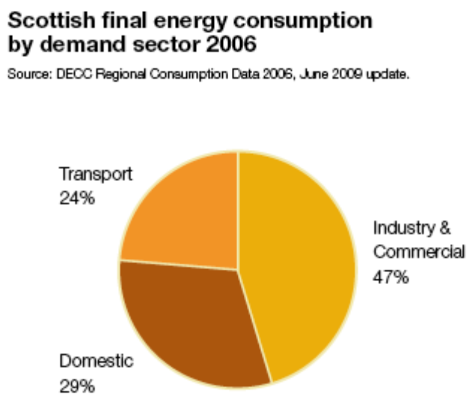
The second conclusion is that, in many cases at least, it is not solid wall insulation that should be the main focus of our energies and monies in the years to come (which appears to be the priority when using RdSAP, SAP etc.), but 'Hard to Treat' roofs and ceilings, and air leakage. The associated good news is that both of these options are likely to be less disruptive and more cost effective.

Given the significance of the issue, the national commitment to reduce carbon emissions by 80% by 2050, and the recognition that the built environment is expected to account for half of this reduction, we would suggest an urgent review of the current assumptions before the large amounts of anticipated monies are spent so that we can be certain that they are being spent wisely.

## 1 Introduction

### 1.1 The Wider Context

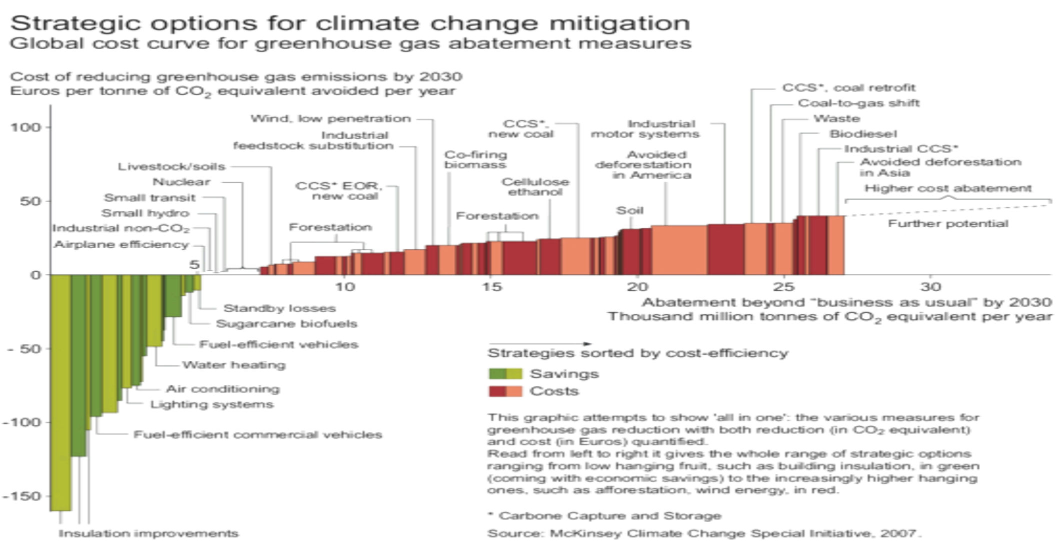
The UK has made a commitment to reduce its greenhouse gas emissions by 80% by 2050 and the built environment is expected to account for about half of this reduction. Most studies on the subject do not include the UK's 'outsourced' energy consumption[1] but it is clear that energy consumption is an area where most progress can be made to combat climate change.




The graphic shown, left, indicates the breakdown of final energy use by sector in Scotland. Whilst energy use in buildings is part of the Industrial & Commercial section and so some of what is said in this report is relevant to that section, it is the 29% of domestic energy use to which this report is particularly directed. With reductions proving harder to achieve in other sectors such as transport, it is clear we will not make the climate change targets set without meaningful progress in this sector.

By looking at energy consumption in housing, we are also addressing fuel poverty. The 2008 Review of Fuel Poverty indicates that over half a million households in Scotland, with nearly one million people, are now classed as fuel poor. This figure has risen dramatically in the last few years due to huge increases in fuel prices and this situation is likely to worsen. All of this is despite the fact that the UK has had the cheapest gas in Europe since 2000 and the cost of electricity has been below average. However, in 2004, Britain became a net importer of gas, despite the presence of North Sea gas. Currently, the UK can only store 13 day's reserve of gas, compared to 99 days in Germany and 122 in France. So the issue also impacts on fuel security on a national scale.

By seeking to reduce energy consumption in homes and buildings we are tackling climate change, we are helping to alleviate fuel poverty, and we are improving our national fuel security. Seen in isolation, the costs associated with these efforts are significant, but it must be remembered that the benefits are widely spread and when these are taken into account, the analysis is altered. On the subject of costs, another useful perspective is that offered by the McKinsey Climate Change Special Initiative 2007, see below, which tabulated the major strategic options for climate change mitigation at a global level, in relation to their relative costs, in euros per tonne of $CO_2$ equivalent avoided per year. The results are interesting: the three most cost effective measures are all associated with insulation improvements, while most measures on the 'savings' side of the equation related to improvements to building fabric and services.




[1] See for example work by the 'RESOLVE' team based at Surrey University

Turning back to the national scale, it has been widely appreciated for some time that we cannot fully address energy consumption simply through improvements in Building Regulations and new-build. The vast majority of that chunk of energy consumption labelled 'Domestic' is, and more importantly still will in 2050, consist of buildings which are already built. To achieve the reductions we need to see in the coming years, it is crucial we find an effective mechanism to cut energy use in the existing built stock.

Progress thus far has not been encouraging. Mainstream energy efficiency programmes such as the Carbon Energy Reduction Target (CERT) and its predecessors have focussed only on the most cost effective two measures – (simple) loft insulation and cavity fill – but after a decade of such efforts there is still much to do and this is recognised by Scottish Government[2].

Recent efforts have included 'Street-by-Street' approaches and these have met with some success. The recent publication by WWF 'Street by Street House by House' prepared by Changeworks looks in detail at these approaches and suggests that these can help with a more effective rolling-out of improvement measures. Recent measures have been heavily reliant on CERT funding while future measures are likely to be similarly reliant on the Community Energy Saving programme (CESP) which will be the successor to CERT which runs to the end of 2012.

Importantly, this programme will include a requirement to tackle 'Hard to Treat' properties which are currently excluded from help. The programme ensures fuel companies target areas of multiple deprivation and to use a 'Whole House approach' which is likely to include measures to tackle solid walls and heating system upgrades. The scheme appears to be biased towards urban areas with high levels of social housing.

### 1.2 'Hard to Treat' Housing

'Hard to Treat' (HtT) properties are those which cannot benefit from current Government-supported grants because the property is built with one or more of the following:

- solid walls;
- combed roof, or flat roof;
- high-rise / tenement buildings;
- timber framed walls constructed prior to 1982;
- Park Homes or residential mobile homes.

Older, 'Hard to Treat' properties in Dunblane
(Photo courtesy of Holmhill Community Buyout)

Around 25% of Scotland's dwellings fall within this category. The problems can be: technical (e.g. where insulation is difficult to install); economic (e.g. where the cost / benefit is unfavourable; social (e.g. where all residents in a tenement need to be equally involved); or any combination of these.

### 1.3 Sustainable Dunblane

Sustainable Dunblane is a voluntary association dedicated to reducing carbon emissions and maximising sustainability across the Dunblane Community Council area. The group is made up of passionate and committed members of the local community.

In 2009, Sustainable Dunblane was awarded funding from the Climate Challenge Fund to carry out a project to offer free or discounted insulation to homes in Dunblane and the surrounding area. However, this project had to be stopped in March 2010 due to the expansion of the Government's Home Insulation Scheme into Dunblane. With the continued support of the Climate Challenge Fund (CCF), the Sustainable Dunblane Energy Group decided that, as the Government was assisting all the homes which could benefit from cavity wall or loft insulation, we should use the remaining grant money to help those in 'Hard to Treat' houses for whom this support was not available.

[2] 'Conserve and Save Consultation on the Energy Efficiency Action Plan for Scotland', Scottish Government, October 2009, p.25

## 2 The Project

### 2.1 Objectives

The main objective of the project was to offer guidance to the residents occupying the 1375 houses within the Dunblane Community Council area that are classified as 'Hard to Treat', as to the energy saving measures might be best for their particular property. We also sought to broaden the technical energy assessment well beyond the normal rdSAP evaluation in the belief that in doing so we can give much better guidance, based on a much fuller understanding of the nature of the individual dwellings than is normally the case.

This use of a broad range of assessment tools has created a secondary objective which is to highlight the shortcomings of relying on the rather over-simplistic rdSAP assessments normally used, and upon which a great deal of policy and funding is based. We've included as part of the report discussions as to the relative merits of each assessment methodology in the hope that this will be of interest to a wider community of interest in the field of building and housing refurbishment.

A great deal of money and effort is going to be expended in the next few years by government and others in the pursuit of a lower carbon built environment and we hope that our modest project can help inform the debate.

### 2.2 Process

Briefly, the project has been undertaken through the following tasks:

- Conducting a visual survey, and logging the basic construction data, of ALL the houses in the Dunblane Community Council area;
- Identifying the range of dwellings defined as 'Hard to Treat' and defining six house types;
- Calculating, from the survey data, the numbers of each 'Hard to Treat' house type* (see below);
- Identifying three properties from each of six house types that would be suitable for inclusion in the project;
- Surveying each of these properties;
- Carrying out an infra-red thermal imaging survey;
- Carrying out an air pressure test;
- Carrying out four separate energy performance analyses for each of these dwellings;
- Identifying practical solutions for improving the energy performance of each of the 18 houses surveyed;
- Assessing the relative merits of the proposed improvements using the SAP and PhPP modelling tools;
- Providing a final type-specific report to all 'Hard to Treat' householders in the Dunblane area.

*In this project we have classed different Hard to Treat types as functions of their construction type, rather than say, as detached, semi-detached, terraced etc. This is because, in our view the vast majority of solutions for, for example, a solid wall, are applicable regardless of the building type, with the possible exception of high rise.

### 2.3 Initial House Survey

An architect was employed to carry out a visual survey of all the properties within the Dunblane Community Council area. The survey established that there were 1375 'Hard to Treat' residential properties in the Dunblane Community Council area. The breakdown of each type of property as a percentage of the total is shown below.

| *Type* | *Description* | *Percentage %* |
|---|---|---|
| Type A | Solid walls, combed (room in the) roof, solid floor | 1.6 |
| Type B | Solid walls, combed roof, suspended floor | 27.1 |
| Type C | Solid walls, full roof, solid floor | 3.1 |
| Type D | Solid walls, full roof, suspended floor | 23.6 |
| Type E | Cavity wall, coombed roof | 39.4 |
| Type F | Flat Roof | 1.1 |
| Type G | Other / unclassified | 4.1 |

## 2.4 Energy Modelling

Having invited everyone to volunteer their own home for further study (which elicited a great deal of interest) we then chose 18 properties which were as broadly representative of the 6no main house types as we could find, 3no of each type.

Four separate energy assessments were made of each of the 18 dwellings surveyed. The four were:

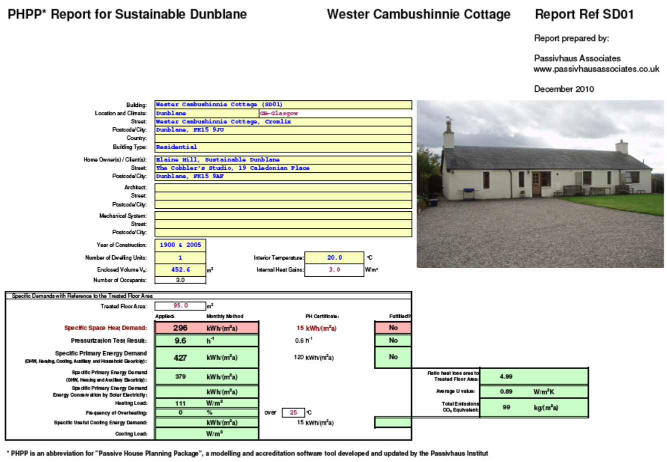
- RdSAP (Reduced data Standard Assessment Procedure) - the National Calculation Method for assessing the energy efficiency and environmental impact of existing dwellings. As its name implies, this is a reduced dataset of the full SAP assessment, and is therefore not as sensitive as the full SAP.
- SAP (Standard Assessment Procedure) – the National Calculation Method for assessing the energy efficiency and environmental impact of a new-build dwellings in the UK. It can be used to assess existing buildings too and should give a more accurate picture of the specific dwelling.
- NHER (National Home Energy Report) - an accreditation scheme for energy assessors and a rating scale for the energy efficiency of housing. The method uses the same basic data as the previous two, but in addition, this system takes into account the local environment and the additional effects of cooking, lights and appliances.
- PhPP (Passivhaus Planning Package) – a German standard used to predict energy use in buildings to a much greater level of detail than SAP. PhPP calculates a building’s heating, cooling and primary energy demand, as well as its tendency to overheat in the summer. PhPP was developed specifically for modern low energy projects.

The first three are in fact all developments of the same base model – BREDEM (Building Research Establishment Domestic Energy Model) – but to varying levels of detail, whilst PhPP was developed by the Passivhaus Institut in Germany.

The development of RdSAP recognised that SAP is a desk-based exercise undertaken with a full knowledge of the geometry, fabric and services of a building, something that is not possible on a short inspection visit to a property. It is the methodology used for surveying and issuing EPCs for existing domestic properties and provides the technical scope and database for the majority of efforts and policy development surrounding the existing built stock.

By using the four different methods (and the supplementary thermographic imagery and pressure testing), our intention with this project has been to give the householders a greater depth and breadth of information than is normally the case, while it also gives us the opportunity to highlight the shortcomings of relying too heavily on RdSAP.

The four different assessments don’t necessarily give results in the same formats, so a degree of interpolation has had to be undertaken to be able to give direct comparisons between figures. The results of the assessments, and a discussion of the results are given in Section 2.7.


PHPP* Report for Sustainable Dunblane — Wester Cambushinnie Cottage — Report Ref SD01

Report prepared by:
Passivhaus Associates
www.passivhausassociates.co.uk
December 2010

| | |
|---|---|
| Building: | Wester Cambushinnie Cottage (SD01) |
| Location and Climate: | Dunblane / GB-Glasgow |
| Street: | Wester Cambushinnie Cottage, Cromlix |
| Postcode/City: | Dunblane, FK15 9JU |
| Country: | |
| Building Type: | Residential |
| Home Owner(s) / Client(s): | Elaine Hill, Sustainable Dunblane |
| Street: | The Cobbler's Studio, 19 Caledonian Place |
| Postcode/City: | Dunblane, FK15 9AF |
| Architect: | |
| Street: | |
| Postcode/City: | |
| Mechanical System: | |
| Street: | |
| Postcode/City: | |
| Year of Construction: | 1900 & 2005 |
| Number of Dwelling Units: | 1 |
| Enclosed Volume $V_e$: | 452.6 m³ |
| Number of Occupants: | 3.0 |
| Interior Temperature: | 20.0 °C |
| Internal Heat Gains: | 3.0 W/m² |

Specific Demands with Reference to the Treated Floor Area

Treated Floor Area: 95.0 m²

| | Applied: | Monthly Method | PH Certificate: | Fulfilled? |
|---|---|---|---|---|
| Specific Space Heat Demand: | 296 | kWh/(m²a) | 15 kWh/(m²a) | No |
| Pressurization Test Result: | 9.6 | $h^{-1}$ | 0.6 $h^{-1}$ | No |
| Specific Primary Energy Demand (DHW, Heating, Cooling, Auxiliary and Household Electricity): | 427 | kWh/(m²a) | 120 kWh/(m²a) | No |
| Specific Primary Energy Demand (DHW, Heating and Auxiliary Electricity): | 379 | kWh/(m²a) | | |
| Specific Primary Energy Demand Energy Conservation by Solar Electricity: | | kWh/(m²a) | | |
| Heating Load: | 111 | W/m² | | |
| Frequency of Overheating: | 0 | % | over 25 °C | |
| Specific Useful Cooling Energy Demand: | | kWh/(m²a) | 15 kWh/(m²a) | |
| Cooling Load: | | W/m² | | |

| | | |
|---|---|---|
| Ratio heat loss area to Treated Floor Area: | 4.99 | |
| Average U value: | 0.89 | W/m²K |
| Total Emissions $CO_2$ Equivalent: | 99 | kg/(m²a) |

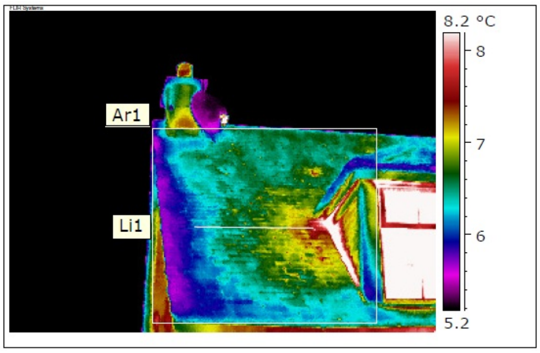
* PHPP is an abbreviation for "Passive House Planning Package", a modelling and accreditation software tool developed and updated by the Passivhaus Institut

Snapshot taken from the front cover of the PhPP analysis of one property showing the property details and salient results in the pink and green boxes below

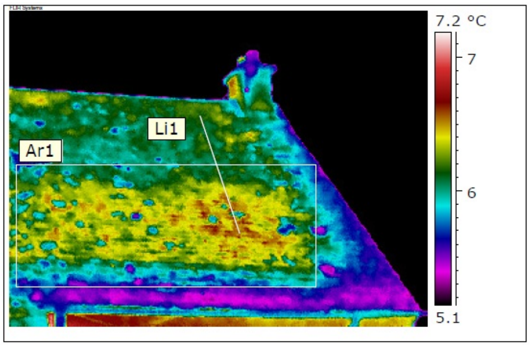
## 2.5 Thermographic Imagery

Thermographic cameras ‘see’ heat rather than light and can differentiate between warmer and colder surfaces by allocating different colours to the temperatures they ‘see’. In each case, white is the warmest and red is warm, while blue is cool and black is the coldest, but beware that the scale in each case can be different, usually in order to clarify anomalies or avoid excessive colour spread, so it is not necessarily possible to transfer one colour from one image to the next.

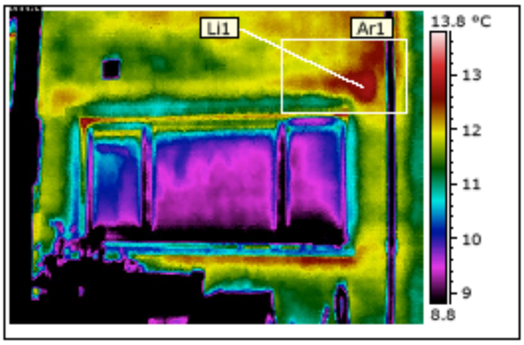
Another complication is that while in some cases, the differentiation of colour will be solely to do with the different ways in which heat is escaping through the fabric of the building, surfaces can be heavily affected by reflectivity too, so that, for example, when you are looking up at a roof or windows, the fact that they reflect the sky means that they usually appear colder than when compared to the walls. Very reflective surfaces like metal and glass cannot easily be read reliably for this reason.




The most common function of thermographic imagery is to locate anomalies in the construction which would go undetected otherwise. For example, the image on the right shows excessive heat escaping from the junction between a dormer window and the roof adjacent. This may be due to air gaps which are allowing warm air out (and cold air in), or because there are ‘thermal bridges’ which are drawing heat out at a much greater rate than adjacent, relatively well insulated areas. What is also worrying about this image is that it shows this spread of heat loss in the adjacent roof, the reasons for which are not obvious and investigation would be advised.




Elsewhere, the images show rather more straightforward problems. The image, right, is quite easy to interpolate. The red/yellow area of roof is where there is a ‘coomb’ internally and insulation has almost certainly not been installed in this hard-to-reach area, while it has been installed in the flat ceiling to what would be a small attic above. The guidance given here, would be to find a way of insulating the coomb, either by removing the internal lining and installing insulation between rafters, or by installing an insulated lining of some sort over the existing ceiling finish. Both solutions however will involve some disruption.




Finally, on the wall of this relatively new building, we can see excessive heat loss in a discreet panel above and to the right of the window. The most likely culprit is missing insulation within the timber frame. Another common fault is highlighted beneath the window where it is likely that the installers of the window forgot to fully seal between the window frame and surrounding construction leaving an air gap. A similar lapse is exposed in the top left of the window, although this may also be to do with faulty seals in the window itself – further investigation would be needed.

The principal value of these images is that they can help us locate anomalies and faults, but in doing so they also offer us an invaluable insight into the additional heat loss which buildings suffer over and above the theoretical heat loss anticipated by the various energy modelling tools discussed above. Our Consultants on this project have developed an extremely interesting way of using this information too, which has been issued to each of the 18 householders whose homes were surveyed. In this method, the information is analysed and the anomalies quantified so that the actual quantity of additional heat loss can be calculated and an energy, and financial cost associated with it. We have used this additional information to help inform the proposals offered to the householders but also as generic guidance.

### 2.6 Air Pressure Testing

Like thermographic images, air pressure testing helps us locate faults in the construction, but in so doing allows us an insight into the additional heat losses suffered by the building which are not accounted for in the conventional SAP, rdSAP and NHER software. PhPP does account for air leakage and one reason for including PhPP in our study was for this reason, that in so doing we can show the major effect such air leakage has, and subsequently the major benefits of addressing the air leakage in terms of improved performance.

Air leakage is important because it generally accounts for about 40% of all heat loss in most buildings[3] – both new-build and existing older buildings like these. This is a huge and largely unappreciated issue. It means that in an average home spending £1,000 a year on heating, £400 of this is due simply to unwanted draughts. At a UK level, since roughly half of all energy use is in buildings, and almost half of all heat loss is due to draughts – that's almost a quarter of ALL energy in the UK down to air leakage, as much as the entire energy use due to transportation.

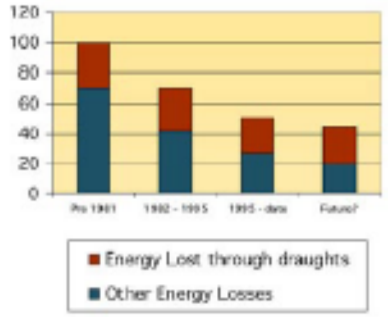



Figure of heat losses per P. Jennings, 'Airtightness in Buildings' Building for a Future Winter '00/'01

As the graph right shows, the proportion of energy loss due to draughts has increased as energy efficiency requirements – largely to do with improved insulation levels – have improved.

In addressing air leakage, we save on energy – good for the environment – and also cost. In addition, we significantly improve comfort levels. There are many dwellings, particularly in windy parts of the UK where the heating system is conventionally sized and can handle the coldest days, except when it is windy. On windy days, one of the Authors has heard of several instances where the installed heating is simply unable to keep the house warm.

Importantly, warm (and often moist) air leaking out of a building also brings the risk of interstitial condensation, that is, condensing on cold surfaces somewhere within the building fabric where it can lead to decay of timber, corrosion of metal, potential frost damage (for example, 'blowing' external renders) and saturation of areas leading to increased heat loss through conduction.

An example of a door fan within a panel affixed to the main entrance door of a new built house. Source: P. Jennings.

Air pressure testing is the method for determining how 'leaky' a building is. The process usually involves fitting a large fan to the main door (see left) and, after checking that windows etc. are closed, using this fan to pressurise or de-pressurise the building. The airtightness is derived by working out how hard the fan has to work to maintain a certain pressure differential. In an airtight house, the fan won't have to work too hard to achieve a constant pressure differential, whereas in a leaky house, it will have to exert a good deal of effort to achieve it. It is sometimes useful to undertake the thermographic testing at the same time because you can more readily see cold air getting in, and warm air getting out.

Most existing buildings, and new buildings too, tend to fall between 10 and 20 m3/hr/m2 at 50 Pascals (the pressure differential achieved). Low energy buildings aim to get this number to less than about 3, while 'Passivhaus' buildings aim for less than 1.

Of all the ways to save energy and money, reducing air leakage is almost always the cheapest and most effective. It can be much more hassle once a building is built, but does not itself often involve lots of expensive materials, just time and effort. For this reason, we have indicated significant improvements in airtightness on our proposals for the dwellings in Dunblane.

---

[3] BRE, Airtightness in Commercial and Public Buildings, 2002, p3

## 2.7 Existing Buildings, Results and Discussion

The average results of the four assessment methods for all property types are shown below.

**Calculated estimate of dwelling energy usage**

The following table shows the total predicted energy used per annum, according to each model, in each case averaged over the three properties surveyed for each property type

| Property Type | Average Floor Area | Average Space Heating kWh per annum RdSAP | SAP | NHER | PhPP |
|---|---|---|---|---|---|
| A | 100 | 16,823 | 29,249 | 45,328 | 47,920 |
| B | 214 | 62,366 | 64,824 | 70,467 | 111,029 |
| C | 85 | 23,493 | 21,991 | 29,781 | 34,805 |
| D | 104 | 27,455 | 23,811 | 35,499 | 56,399 |
| E | 134 | 36,130 | 25,550 | 36,229 | 41,642 |
| F | 167 | 37,281 | 41,207 | 37,839 | 43,563 |

The following breaks down the results into results *per square metre*:

| Property Type | Average Floor Area | Average Space Heating kWh/m$^2$ per annum RdSAP | SAP | NHER | PhPP |
|---|---|---|---|---|---|
| A | 100 | 273 | 301 | 449 | 505 |
| B | 214 | 275 | 272 | 277 | 481 |
| C | 85 | 268 | 234 | 341 | 398 |
| D | 104 | 268 | 233 | 320 | 623 |
| E | 134 | 227 | 202 | 283 | 321 |
| F | 167 | 224 | 256 | 233 | 267 |

And as a reminder of what these property types are:

| *Type* | *Description* | *Percentage %* |
|---|---|---|
| Type A | Solid walls, combed (room in the) roof, solid floor | 1.6 |
| Type B | Solid walls, combed roof, suspended floor | 27.1 |
| Type C | Solid walls, full roof, solid floor | 3.1 |
| Type D | Solid walls, full roof, suspended floor | 23.6 |
| Type E | Cavity wall, coombed roof | 39.4 |
| Type F | Flat Roof | 1.1 |

Given the small number of case studies, it is hard to draw any meaningful conclusions as to the relative performance of the different property types. The more striking and consistent differences appear to be between the four assessment methods, with PhPP assuming much higher energy use in almost every case. For reasons which are described in detail later we believe the PhPP figure is likely to be the closest to reality.

The average size of a dwelling in the UK is approximately 80sq.m, so on average, the houses surveyed are larger than the UK average. The average space heating demand for a house in the UK is around 13,000 kWh per annum, ranging from 11,000 for a 2 bed terraced house, 15,000 for a 3-bed semi, to 23,000 for a 4-bed detached house. The figures shown above are pretty high, which is perhaps not surprising given the size of the properties and the fact that they are in Scotland which is colder than the UK average.

The UK average annual space heating demand per square metre is about 140 kWh, so we can see that the dwellings are well above the UK average, regardless of their size. Knowing this, we can agree that there is clearly room for improvement.

**Predicted Dwelling $CO_2$ emissions**

The assessments also predicted the $CO_2$ emissions for all buildings and the averages are presented below. The average $CO_2$ emissions for a UK dwelling is about 80 kg/($m^2$/a) (according to RdSAP /SAP).

| Property Type | Average $CO_2$ emissions in kg/$m^2$ per annum | | |
|---|---|---|---|
| | RdSAP | SAP | PhPP |
| A | 71 | 80 | 168 |
| B | 75 | 58 | 151 |
| C | 59 | 67 | 153 |
| D | 57 | 52 | 90 |
| E | 58 | 44 | 127 |
| F | 57 | 53 | 93 |

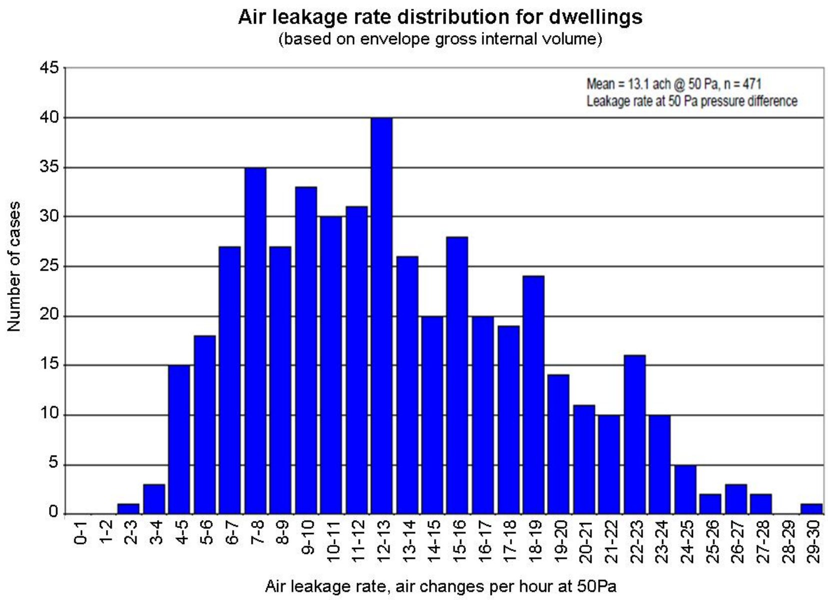
When comparing the $CO_2$ emissions calculated by the RdSAP, SAP and PhPP methodologies, the same pattern is evident. It is hard to discern a property type which appears intrinsically more energy efficient, while again, the PhPP assessment suggests far higher emission rates in every case.

Some of this difference is certainly because SAP and RdSAP assume lower emission rates for the various fuels used than PhPP. The Primary Energy factors used by PhPP are almost certainly more accurate, this is discussed in more detail below.

It would be safe to conclude however, from an admittedly small case study pool, that there is no discernible difference in energy efficiency between property types as defined by us, that is, in terms of construction type. Thus there is no particular construction type – of those investigated – which appears to be in noticeably more pressing need of attention than any other, meaning no clear next area of focus for policy.

**Pressure test results**

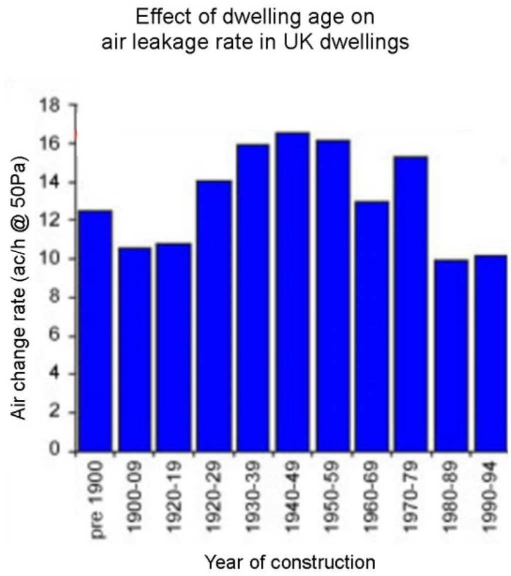
The air pressure test results ranged from 6 – 30 ($m^3$/hr/$m^2$ @ 50 pa) over all properties with most being in the range between 10 and 20. For smaller buildings like houses, these results can be compared directly with the air change rate presented, right[4] which show the range of typical airtightness levels in housing across the UK. Our range of test results is typical for older properties and, as can be seen from the graph, fits very much within the bell curve of results for buildings across the UK, albeit slightly on the high side.




What is more surprising is that conventional wisdom suggests that houses with suspended timber floors tend to be draughtier than those with solid floors. Clearly we cannot derive any great meaning from eighteen properties, but that discrepancy is not borne out in our results.

[4] Both this and the graph on the following page are taken from BRE Report 359: Airtightness in UK dwellings

What may be of interest is that, whilst it is usually assumed that new buildings are 'better built' than older houses, according to the graph on the right, it is clear that in terms of airtightness, this is certainly not the case, with pre-1919 properties performing more or less as well as houses built after 1980 and the main culprits being those built in between.




In recognition of this poor performance, new buildings in Scotland will soon be required to be tested for air leakage using the same sort of tests that we have commissioned in Dunblane. The target for new buildings will probably start at 10 $m^3/hr/m^2$ @ 50 pa, which is not an especially high target. Low energy buildings normally aim for levels below 3 $m^3/hr/m^2$ @ 50 pa, while 'Passivhaus' buildings must achieve a tested figure lower than around 0.75 $m^3/hr/m^2$ @ 50 pa.

In our proposals, we have assumed that all the dwellings can be improved to a level near 3 $m^3/hr/m^2$ @ 50 pa.

**Why the differences?**

There is a small, but growing number of studies[5] which highlight the differences between energy modelling systems and the importance of understanding the assumptions which are hidden within each, to gain a fuller picture of what is happening in our buildings.

There are a huge number of reasons why the results are different from each other, the majority of which relate to minor differences well 'below the radar' of most investigations. What we have done here is to try and pick out the most significant of the differences to help explain why the results are so varied, and to help answer the question posed by the next section; which of the results are most accurate?

In most cases, many differences will be simply the result of inaccuracies or variations in the inputting of data. This may seem odd to the layman – surely a house dimensions and information are what they are? – but in practice, and particularly under time pressure a single house could be described quite differently, due perhaps to basic mistakes, but more likely differences between individual Surveyors[6].

In this study, for each property, one survey only was carried out by both sets of Surveyors together and basic data agreed and monitored by Sustainable Dunblane who were also present. This means comparisons between our four sets of data are free from the variability noted.

In all cases though, by far the main reason for the variability is the difference between the myriad assumptions made by each system, a few of which we highlight below. Because each assumption is a default which may not relate to the building, we can say that the more detailed the investigation, the fewer default figures are used and the more accurate – in theory – the results. This would tend to suggest that the PhPP modelling is the most accurate, but as becomes clear below, it is not quite so simple.

---

[5] Some of the work included here is based on three very useful publications which discuss the differences between the various energy assessment methods. These are:

- Historic Scotland Technical Paper 8: Energy Modelling of the Garden Bothy, Dumfries House by Changeworks and HEADS, May 2010.
- AECB (Association of Environment Conscious Building) Carbonlite Programme: Projecting Energy Use and CO2 Emissions from Low Energy Buildings, A Comparison of the Passivhaus Planning Package and SAP.
- Scottish Government, Directorate of the Built Environment, ESRU, University of Strathclyde: Benchmarking Scottish Energy Standards: Passive House and CarbonLite Standards: A comparison of space heating energy demand using SAP, SBEM and PHPP methodologies.

[6] This point is reinforced in the Historic Scotland Document where two different Surveyors gave two different results for the same building, using the same software.

*Internal Temperatures* – SAP assumes a two-zone model whereby the Living Room is heated to 21$^{o}$C and the rest of the house to 18 $^{o}$C because this system was developed in the 1980's when such an arrangement was common in the UK. PhPP on the other hand is designed with modern high performance buildings in mind and assumes that the whole house is heated to 20 $^{o}$C. In the case of relatively old, HtT houses in the UK, we can only imagine that the SAP assumption is likely to be more representative. Interestingly, although central heating has meant that now more buildings are heated to the same degree throughout, as fuel prices rise, and in relatively uninsulated buildings, this two-zone model is likely to become even more relevant.

*Internal Gains* – In verification mode (for certification), PhPP sets the internal gains at 2.1W/m$^2$, the internal gains in SAP can be varied but remain essentially around three or four times higher. This means that SAP assumes that a much smaller amount of heat needs to be input by the heating system than PhPP. In many comparisons, this will account for some discrepancy, but in our study, the PhPP results were based (more accurately) on the real occupancy rates and so this impacted less on the results.

*Defaults generally* – Several assumptions in PhPP default to a higher / worse figure, but allow the Designer to input a better figure if this can be substantiated. This incentivises the user to use the software as a design tool, but this of course requires much greater effort. SAP, conversely, often assumes a more energy efficient answer than would be likely in reality. For example the default frame and g value factors for windows allow for more solar gain than is likely in most cases and the y-value approximation for thermal bridges often underestimate heat loss, whilst giving no incentive to Designers to calculate their own figure and improve the rating. Both the over-estimation of PhPP and under-estimation of SAP and its cousins will have played a small part in the variation between the results shown.

*Dimensions* – this is a surprisingly complex subject, but briefly, whilst the total floor area of a building in PhPP excludes the area taken up by the stairs and internal walls, these are included by SAP and others. In the final analysis, it means that the total floor area in PhPP tends to be about 10% smaller than in SAP and the others. This in turn means that any energy figure divided by the smaller area will be a larger amount.

*Location and Weather* – PhPP assessments are location specific and temperature and insolation data are available for a variety of European locations. SAP and related assessments are independent of location – all assessments assume that the dwelling is located in the East Pennines, near Derby. In the Author's own experience, the inputting of different weather data can have a dramatic effect on the figures in a PhPP assessment so it can only be assumed that this serves to underestimate the energy use of a building located in any colder part of the UK, such as the whole of Scotland. This is one of the most persuasive factors in pushing us towards the PhPP results as being the most accurate.

*Air Leakage* – SAP and the other two UK based assessments do not really deal with air leakage except to include an average annual default figure which is rather on the low side. Moreover, if air leakage rates are varied in SAP, the overall energy use is not noticeably affected and this is not consistent with the evidence, noted above in Section 2.6 that air leakage is responsible for a huge percentage of the overall heat loss in all buildings. PhPP on the other hand is extremely responsive to air leakage rates, the difference between a passivhaus level of air leakage, and the levels common in the buildings surveyed in Dunblane would be sufficient to double the energy loss. Given the relatively high levels of air leakage in the Dunblane buildings, the PhPP results are likely – in this respect at least – to be more representative.

*Windows and Solar gain* – PhPP requires an extremely high level of detail into every aspect of windows while SAP and its counterparts in the UK give relatively little time to the subject and assume a number of defaults which tend to be slightly generous. The differences due to this will depend greatly on the actual window configuration.

*$CO_2$ emissions* – the basic data used by PhPP is different from that used by SAP and the other UK systems. In each case, SAP assumes a lower emission rate for each fuel and we believe it would be fair to say that the figures used by PhPP are more accurate, the latest SAP version appears to be heading in the same direction with (upwardly) revised figures.

**Which is most accurate?**

Both the PhPP and SAP / RdSAP / NHER models are fundamentally accurate in terms of the calculations being undertaken, but the different assumptions and default values lead to significantly different results.

Simply put, the order in which the four methods are shown in the tables earlier is the order in which the level of detail increases, so that while RdSAP is a very blunt tool indeed in order to facilitate its widespread use, SAP is more detailed, NHER, more detailed still, while PhPP is considerably more detailed again.

What appears clearly in our study, and this is reflected on the whole in other studies, that PhPP estimates that there is a great deal more energy being used than the other methods. In our study, it also appears that NHER usually estimates higher energy use, so the temptation is to suggest that the greater the level of detail of investigation, the greater the energy use appears to be. However, this simple correlation is not borne out in the comparison between SAP and RdSAP, nor is it upheld consistently in all other studies.

What can be said with some certainty is that SAP and its cousins do underestimate the energy used. We know this from work undertaken by Prof. Malcolm Bell and others at Leeds Metropolitan University who have shown the discrepancy between SAP-predicted heat loss (mauve columns, right, and actual heat loss (blue columns). These results were for new houses, but we can reasonably predict similar results in existing buildings, so the 'real figure' will without doubt be higher than the figures indicated in the first of our three columns.

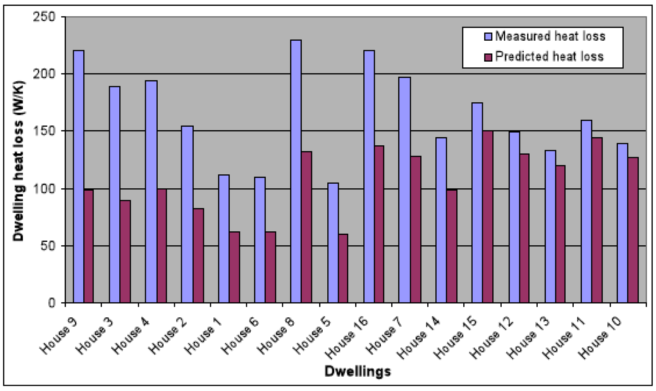



Figure 1 Measured v Predicted whole house heat loss for 16 dwellings*

What is less clear is whether the far more detailed PhPP assessment is closer to the true figure. It is a tool developed very much with modern low energy buildings in mind and there are some indications that it is not always well suited to older, poorly insulated and leaky buildings.

The only way known to the Authors to find out the 'true figure' of heat loss in a building is to undertake a 'Co-heating Test' developed by the same Prof. Malcolm Bell. Such a test however is expensive and disruptive involving moving out all occupants for two or three weeks, unless the house in question is anyway unoccupied. Unfortunately, the existence of this methodology was not known when funding was sought for this study, and even if it had been, it is unlikely we would have been able to find occupants who would have been amenable to the idea of moving out of their home for several weeks.

Without the benefit of this test, another way would be to look at the 'real world' energy bills but this does not really provide us with an accurate picture of the heat loss of the building because of the variability of the occupants' use of the building. In study after study, it is clear that the greatest variable of all is the behaviour of occupants so that the actual energy use of different occupants in the same house can be different by factors of five or more.

Thus we are left to reflect on the energy modelling results we have gathered. We would estimate that a sensible conclusion will be a figure which is close to the PhPP figure but probably not as high. This may seem an innocuous and reasonable conclusion in a small study like this dealing with a few houses in Dunblane, but the ramifications for the UK as a whole are rather dramatic, since all our policy is based on the sorts of figures generated by RdSAP and SAP, which we would contend are almost certainly unrepresentative of reality and crucially, underestimate the real energy use of our buildings.

## 2.8 Recommended Energy Efficiency Improvement Measures, Results and Priorities

In order to assess which efficiency measures would be most effective, a variety of proposed improvements were modelled using the conventional SAP software, and the more detailed PhPP software.

The SAP-based analysis suggested that wall insulation was the most important measure to undertake in the majority of properties. Beyond this, there was no consistency, with the next most effective measures appearing to be entirely dependent on individual properties and what was, or was not already insulated. So whilst these results give us little by way of a trend, we can safely say that wall insulation is deemed the most important measure generally by SAP-based software, with all other options appearing much more dependent on circumstance.

Using the PhPP software, the most effective measure was always insulating the roof, accounting for between a 24% and 36% reduction in energy use. The only exceptions to this were where the roof was already insulated. The next most effective measure in every case was addressing air leakage, which accounted for between an 11% and 29% improvement. In all but one example, insulating the walls came next, accounting for between a 7.5% to 20% reduction in heat loss. On a couple of houses, insulating the floor registered as being worthwhile whereas window upgrading did not appear to afford any great benefit.

Using PhPP, we were able to find between 44% and 73% savings when all measures were combined.

In summary, insulating the roof is the most effective measure to undertake using PhPP. Where the roof is insulated, then PhPP modelling assumes that improving airtightness is the most effective measure to undertake, while insulating walls is less effective but still registers as being worthwhile. Insulating floors does not usually appear worthwhile, nor does upgrading the windows, but as noted above, we must remember that that figure for airtightness includes improvements to the floor and windows so these cannot be discounted entirely.

## 2.9 Conclusion and Discussion

The conventional SAP-based modelling that underpins the vast majority of discussion on retrofitting older houses tends to prioritise the need for wall insulation, and our study is no different.

However, by using a different modelling technique, supplemented by additional surveys of air leakage, we are offered a very different set of results. The highly-detailed PhPP calculations tend to show, not only greater heat loss overall, but that the two biggest sources of heat loss are the (uninsulated) roofs of many properties, and air leakage generally, with wall insulation coming in third.

So, as a householder, who or what are you supposed to believe? As yet, there is no definitive answer to this, but research[7] by one of the Authors on the subject of airtightness makes it clear that this is truly a significant source of heat loss, and for reasons described in some detail above, we are confident that the predictions made by the PhPP software are more accurate.

**Thus we recommend, contrary to most current thinking, that you concentrate on insulating your <u>roofs first</u>, <u>then sealing the draughts,</u> <u>then insulating the external walls</u>. After this, think about floor insulation and window upgrading, and then perhaps, the introduction of renewable technologies.**

We wish you all the best with your own houses and hope that this study has been useful to you.

From a wider strategy perspective, there are two very important conclusions to this study, which have significant ramifications for incoming policies and priorities concerning support for, and works to, the built stock in Scotland and the UK.

---

[7] See, for example, http://www.seda.uk.net/design_and_detailing_for_airtightness.html

The first is that, if our study is at all representative, we appear to be underestimating the amount of energy used in our buildings when using RdSAP, SAP and related tools. Since almost all UK or national level discussion on refurbishment is based on the results of these tools, we may be dealing with fundamentally inaccurate, and optimistic, information.

The second conclusion is that, in many cases at least, it is not solid wall insulation that should be the main focus of our energies and monies in the years to come (which appears to be the priority when using RdSAP, SAP etc.), but 'Hard to Treat' roofs and ceilings, and air leakage. The associated good news is that both of these options are likely to be less disruptive and more cost effective.

Given the significance of the issue, the national commitment to reduce carbon emissions by 80% by 2050, and the recognition that the built environment is expected to account for half of this reduction, we would suggest an urgent review of the current assumptions before the large amounts of anticipated monies are spent so that we can be certain that they are being spent wisely.

## Appendix 1 General energy efficiency measures

In this study we have used a set of proposed improvements and modelled these to see which would make the most difference to the houses in terms of energy efficiency. The following is a brief description of each measure.

### Roofs

*Flat ceilinged attic*
In several of the dwellings there is already some insulation in the roof, and in each case we have proposed that the existing insulation between rafters be checked to ensure that it is complete, without gaps, and then another layer of quilt-type insulation is laid crossways over the joists. This is to ensure that there are no gaps between the insulation and to make sure the joists themselves are adequately covered. Where flooring is still required, this needs to be formed by additional timber joists, again run crossways over the existing joists, to support new flooring without compressing the insulation. Good practice must be followed, maintaining a ventilation path over the insulation layer, insulating over, not below water tanks, ensuring all water pipes are insulated and that electrical cables run over, not under the insulation, or are run within conduit or similar to avoid overheating. Care should be taken to ensure that insulation is taken snugly to all edges in order to reduce air leakage down into wall cavities below.

*Coombs – within rafters*
Where these can be easily insulated by inserting rolls of insulation from within the attic, then this should be done. However, in most properties, the length of these coombs prohibits such a simple solution. We have proposed that a longitudinal central section of the coomb ceiling, ideally the same width (600mm) as a readily available plasterboard replacement board be removed. From this access point, it should be possible to reach both up toward the attic space, and down toward the wallhead such that a reasonable effort can be made to fit a roll-type Insulant into the coomb, leaving an air gap between the outer face of the Insulant and the underside of the slates or sarking boards. A plasterboard replacement board can then be installed and a skim coat applied, along with redecoration.

Whilst this work is not straightforward and the redecoration is an additional burden, there is no doubt that without an insulated coomb, other works are rendered relatively meaningless (except airtightness works) so it is certainly a priority. Care should be taken at all times to ensure that air leakage is reduced in all work undertaken.

*Coombs – applied insulated boards*
In almost every case, rooms with coombed ceilings are tight for space and so reducing ceiling heights tends to be unwelcome. Where there is a flat ceiling with attic access, therefore, it is far better to add the insulation above the line of plaster as noted above. Equally, it is usually preferable, despite the hassle, to insulate between the rafters and behind the plaster in a coomb, so that the ceiling levels are unaffected. Two disadvantages of only insulating between the rafters however, are that a) rafters are not usually more than 150 or 200mm thick, so insulating between these is not sufficient to bring the building up to a good level or insulation, and b) the ‘thermal bridges’ of the rafters themselves remain which compromise the efficacy of the insulation.

To help resolve both these issues, it can be very helpful to add an additional layer of insulation over the top of the existing ceiling layer. The scope for doing this is restricted since we do not wish to reduce ceiling levels too much, but the advantages of another 50, 75, or 100mm or insulation is very valuable for the overall energy performance of this area of the building. Thus we have proposed an additional layer in several of the properties.

*Dormers*
Dormers are very rarely insulated because the effort to do so is high, and the perceived rewards relatively small. However, as with all aspects of insulation, if they are avoided, they will represent a ‘weak spot’ or ‘hole in the bucket’ through which heat will flow at a higher rate than before, increasing the thermal stresses in the construction and increasing risks of interstitial condensation[8] where the construction is not air- and vapour-proof.

---

[8] Interstitial condensation is the term used when warm air or moisture gets into the middle of the fabric of the wall, floor or roof. As it nears the outside edge of the construction it cools down and can then form condensation. No-one can see this so it tends to go unnoticed, until the effects of it start to show on either the inside (often, mould) or outside (render spalling or falling off).

The dormer ceiling may be able to be insulated from above via the main attic, and if not, will require to be opened up and insulated from beneath, maintaining the good practice as noted above for main attic spaces.

Dormer cheeks (sides) also need to be insulated as far as possible. Dormer cheek walls are usually 150mm thick. The internal lining needs to be removed entirely and the whole construction insulated fully. The external faces of dormer cheeks are often boarded and covered in a metal or other impervious sheeting which means that vapour cannot escape, so a vapour barrier (polythene) should be applied internally before replacing plasterboard and decorating. This vapour issue is the reason for ensuring all internal linings are removed. Where the cheeks are insulated with slate on sarking, or some other vapour permeable construction, then this vapour control membrane is not required.

Because there is usually no space to increase the cheek wall depth internally because of the windows, we have opted for a higher performance board-type insulant in these areas. The disadvantage of these is that any air gaps between board and timber frame will create air paths which can leak heat extremely effectively so it is important that every board edge is sealed with a impervious tape before the internal membrane is installed.
Care should be taken to ensure that airtightness is addressed with all new construction.

*Flat roofs*

Flat roofs can be insulated by inserting insulation between the existing joists or by adding an insulating layer to the underside. The merits and problems of each method are essentially the same as for pitched roofs. Where insulation has not been installed between the joists, then it is important to undertake this before adding (what we assume will be) a smaller amount directly beneath. If you have an uninsulated roof then given the disruption of redecoration, it is probably worth carrying out both in order to bring the performance of the element up to a high standard, unless there are height restrictions.

The difference between a flat roof and most pitched roofs is that, usually, the outer membrane is a continuous membrane which is entirely impervious to moisture. This means that if moisture gets into the fabric of the roof, it will not be able to escape safely (unless specifically designed to do so, which is unlikely) so it is important where undertaking any sort of work to ensure that a vapour control layer is installed on the warm side of any insulation fitted and any penetrations (eg, subsequent holes for light fittings) in this membrane avoided.

In one of the case studies, the roof construction was of concrete slab under which an insulated timber frame had been installed. We have suggested insulation be added here but again it is important to stress the need for a vapour control layer near the inside of the build-up to avoid any risks of interstitial condensation.

*<u>Walls</u>*

*Solid Walls*
With the insulation of solid walls, there are two options; to insulate externally or internally. Technically, external insulation is always the preferable option, but this is not always possible or desirable:

- Internal insulation is usually cheaper. It depends greatly, but this is usually true
- Few people are happy to see old stonework covered, and insulating internally avoids any concerns with Local Authority Planning or neighbours
- Internal insulation avoids problems with external features, gutters, downpipes, roof overhangs etc.
- There are no problems with weather restrictions, or access (for example to high rise blocks)
- Internal insulation is less of a specialist activity and can often be installed in a DIY capacity, also making it cheaper for some

On the other hand, there are situations where external insulation is preferable:

- Where it is not possible for the occupants to move out temporarily during the works
- Where Council or RSL-owned multi-occupancy buildings can be simply insulated externally and where other maintenance of external fabric arrangements exist
- Where space is at a premium, often in smaller rooms or properties
- Where there are particularly valuable or significant internal features or finishes (e.g. extensive cornicing)

- Where thermal bridging is likely to provide a significant problem

Each of the ten points noted can swing the balance one way or the other in any individual case, but we have assumed in each case that, where solid wall improvement is mooted, that the insulation will be applied internally.

Some solid walls have a plaster coat directly onto the stone internally but more often than not, there is a small cavity (usually about 50mm) on the inside, with vertical timber battens supporting a lath and plaster finish, or a modern equivalent like plasterboard.

Ongoing research by Historic Scotland is investigating the efficacy of a range of internal insulation strategies. One technique involves the use of injected polystyrene beads into the aforementioned cavity. The major advantage of this strategy being that there is relatively little disruption internally since the internal finish remains, though there is patching to be done where the injections were made. Initial results have shown that the interventions have been successful with improvements of around 70% in terms of heat loss. We have proposed this particular technique in a number of the solid walled houses as it involves a large improvement in performance for relatively little disturbance and cost.

*Masonry Cavity Wall*

Masonry cavity walls should always have their cavity filled unless there is some certainty that to do so would be to risk moisture penetration across the cavity to the inner leaf. Insulation installers should be able to offer this guidance. Filling masonry cavities is one of the few “no brainers” in this field which is why it has been one of only two techniques supported by the UK Government for the last few years under a variety of programmes. The insulation performance of the wall will in most cases be improved by approximately 200%, or to put it another way, for almost no disruption and very little cost (no cost in some cases) you can cut heat loss by two thirds through your walls. One or two of the case studies have areas of unfilled cavity masonry wall and we have duly proposed that these be fully filled. Arguably the best form of fill is the graphite enhanced polystyrene beads which are considered to be less likely to ‘wick’ moisture across the cavity than some more fibrous insulation options.

*Timber Frame Walls with Outer Masonry Leaf*

One of the case studies featured a relatively modern timber framed internal wall with a cavity and then a masonry outer leaf. In most cases, this internal timber frame would be insulated, but in this particular case it is not. The first priority not surprisingly is to insulate between the studs of the timber frame.

These forms of construction offer a problem for improvement because they are relatively hard to gauge. On one hand they are usually considered better insulated (they have insulation for a start!) than their older neighbours. However, it is the Author’s experience that they are in practice often rather poorly built and so suffer from a range of faults that combine to render their overall performance much poorer than supposed. This problem is beginning to be addressed, in England at least, through a small but growing number of studies looking at what is being termed “the Performance Gap” arguably led by Professor Malcolm Bell at Leeds Metropolitan University. One of the main problems is the widespread occurrence of air leakage throughout the construction, problems of ‘thermal bridging’, where the percentage of timber in a timber frame is much higher than anticipated for example, and ‘thermal bypass’ where cold air compromises the insulation layer, along with major problems at party walls and poorly installed joinery components. The combined effect of these and other faults means that in practice many modern buildings perform little better than the older masonry buildings.

It is difficult to know where or how best to intervene in these constructions. The simplest, and least prone to poor workmanship is likely to be to simply install insulated plasterboard over the existing wall finish. The obvious and significant disadvantage is that you lose space and have to entirely redecorate, so we have only suggested this in a few places, but where the insulated wall is not particularly deep, this is probably the simplest and safest way to improve the performance of that wall.

*<u>Windows</u>*

*Double Glazed Windows*

Where properties have double glazing, we have suggested in every case that this is left as it is, except where heat, presumably air leakage, can be seen emanating from the sides of frames in the thermographic images. Generally, double glazing loses about half of the heat of single glazing, and because it is more airtight, this improvement is often more marked still. The most recent high performance triple glazing can halve again the heat loss compared to double glazing. However, these windows and doors are very expensive and unless there are other reasons for replacing the double glazing, it is unlikely that replacement would be cost effective.

Single Glazing

Single glazing loses, very roughly, five times the heat, per square metre, of a typical uninsulated masonry wall and since older single glazed windows are also very draughty, this ratio is only worsened. Historic Scotland has been fighting a somewhat rearguard action to prevent widespread removal and replacement of such apparently inefficient windows and recently, they and others have identified potential improvements which can bring their performance up to the standard of more modern and double glazed versions while the aesthetic and cultural qualities inherent in older buildings are preserved. Readers interested in finding out more should consult the Historic Scotland website.

We have taken up their advice and suggested, where there is single (usually sash & case) windows that they be carefully draughtstrippped, repaired as required and all single glass panels replaced with “Slimlite” or a similar thin double glazed panels which fit within the existing window panes. This brings the windows up to roughly the level of new double glazing and with equally good airtightness. To improve performance further still (or instead) Historic Scotland have shown that using traditional shutters can improve night time energy efficiency considerably whilst certain blinds and curtains can also cut down heat loss and draughts at night and at other times if required.

*Floors*

*Solid Floors*

Most of the older properties studies would have been built before the widespread use of concrete so those with solid floors would have likely been simply an earthen floor, or with stone slabs set directly into the ground. Since it is not usually practical to dig up the overlaid concrete and install insulation beneath, we are left with how to add insulation over the top. The problem in so doing is that all skirting boards and doors are affected, in addition to the fact that we need to either provide a new floor finish, or lift and replace the existing finish.

To minimise the disruption, the usual approach is to try to install something thin. The issue then becomes finding something which is as insulative as possible. For the same thickness, some closed cell foam board-type insulants halve the heat loss of more conventional insulation, and there also some relative newcomers, such as ‘aerogel’ based insulation which roughly halves the heat loss again. These materials are currently much more expensive than conventional insulants, but we have proposed their use here, because we are not proposing a large amount in most cases and their use will minimise other disruption and costs.

*Suspended Timber Floors*

There are two reasons why insulating suspended timber floors can help heat loss. One is due to the increased level of insulation afforded, the other is that such floors tend to be significant sources of air leakage (forming a pathway for cold air into the wall cavities), and so by sealing these, you greatly reduce the air leakage throughout the house generally, as well as directly through the floor.

Before starting, check that any previous air bricks / grilles are not blocked and that the space generally is well ventilated as originally intended. This is important, because if not, there is a real danger that any moisture finding its way into the floor construction could not evaporate and could build-up, leading to decay of the joists. Ideally, it is possible to gain access to the space beneath the floor, but if not, it will be necessary to remove the current flooring and do the work from above. It is difficult to cleanly remove (and replace) nailed floorboards so direct access from beneath is certainly less work and more desirable, if not a particularly pleasant undertaking. It also avoids any disruption to the inside of the house since everything can be left in place while the work is done.

In any event, we have proposed that the full depth of the joists is filled with a quilt-type insulation. To the underside, we propose that a windtight, but vapour permeable membrane is used.

If at all possible, it is important to ensure that both insulation and membrane are firmly and durably sealed to the walls at the floor perimeter. This is often hard to do because it is difficult to adhere to the, usually dry and dusty, masonry, but it is important because this seals off potential air paths to the wall cavities as noted.

*Airtightness*

To an extent, each of the previous sections have dealt with airtightness and, if all have been undertaken as described, then it is likely that most areas of air leakage will have been addressed.

One exception to this is the service penetration. All utilities – water, electricity etc. – will enter the building via ducts in the floor or wall, while there will also be drainpipes, vents, flues, cables and other elements having to penetrate the external fabric of the building. Another common area for leaks is between heated and unheated areas of the house, most commonly, the attic. Attic hatches are notoriously leaky while pipes running to and from the attic are often run within cupboards and both insulation and airtightness is missing in areas like this. Another common feature uncovered by thermographic imaging is that of the badly installed door, window, conservatory, extension etc. Many of the anomalies uncovered in our surveys appeared to indicate either thermal bridging, or air leakage, or probably both, at junctions where new elements had been inserted into or against the building. Unfortunately, there is no 'magic bullet' with airtightness, and no substitute for rigorous, if somewhat uninteresting investigation into every nook and cranny of the building.

It is important to differentiate between air leakage and ventilation. Ventilation is the *designed* supply and extraction of air, via elements that were designed to do that job: extract fans, supply vents, openable windows and so on. Air leakage is air that is leaking because of faults in the construction. None of these gaps are supposed to be there but a mix of poorly considered details and lax building practice conspire to create a myriad of gaps within most buildings through which cold air can seep in, and warm air out.

In modern buildings, designed ventilation is included in the build – extract fans in the Kitchen, bathroom and Utility normally - and any (other) air leakage can be safely sealed. In older buildings, it is always possible of course to leave windows open, but where there is no designed ventilation, the effect of really sealing up a building could increase problems just as others are solved. In bathrooms, for example, where there is no extract or other designed ventilation, it may not be wise to fully seal the room. Most people are familiar with the sight of mould or staining on bathroom walls and ceilings and this is due to a trio of issues (lack of ventilation, high moisture levels and cold surfaces) which may be playing out a variety of scenarios, some of which will lead to mould growth. It is important to stress that in our proposals, we would strongly advise that where insulation and airtightness measures are being undertaken, that adequate ventilation is also installed.