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A study of the thermal improvement methods employed on traditional building fabric

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Specific to traditional Scottish stone walls and slate roofs.

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Acknowledgements and Interviewees

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Carsten Hermann	Senior Technical Officer, Historic Scotland, (interview at Historic Scotland, 2nd July 2013).
Chiara Ronchini	Energy Efficiency Officer, Edinburgh World Heritage Trust, (interview by phone 29th July 2013).
Colin Wishart	Senior Building Standards Surveyor at Edinburgh City Council (interview at Edinburgh City Council, 1st July 2013)
Craig Cameron	W.D. Cameron Roofing, (interview by phone, July 16th, 2013).
Cristina Gonzalez-Longo	Conservation Architect and Lecturer, (interview at University of Edinburgh, July 22nd 2013)
Eleanor Egan	Associate Conservation Architect at Simpson and Brown Architects (interview at Simpson and Brown Offices, 25th June 2013)
Fiona MacDonald	Conservation Architect at Edinburgh World Heritage Trust (interview at Edinburgh World Heritage Trust, July 17th 2013).
Graeme Miller	President of NFRC (National Federation of Roofing Contractors) and owner of Graeme Miller Roofing Consultancy, (interview in Peebles, April 4th, 2013)
Jo Parry	Conservation Architect at Hypostyle Architects (interview at Hypostyle Architects, July 19th 2013).
John McKinney	NFRC (National Federation of Roofing Contractors), Chairman (interview by phone 19th June 2013).
Natasha Huq	Architect at Adam Dudley Architects (interview at Adam Dudley Offices, 27th June 2013).
Neil Grieve	Research Fellow and Lecturer, University of Dundee (interview by phone, 5th July 2013)
Paul Baker	RICH Centre Associate, Glasgow Caledonian University (interview in Glasgow, 8th July 2013).
Roger Curtis	Technical Research Manager, Historic Scotland, (interview at Historic Scotland, 26th June 2013).
Scott MacDonald	Owner of Traditional Roofing and Building Ltd., interview and site visit 7th August 2013).

Abstract

The energy efficiency of traditional buildings has become increasingly important in the design and construction industry over the past forty years or so. Instigated initially by the oil crisis in the seventies, when it became apparent that many existing buildings were consuming far too much fuel, it has been furthered since then with significant research into energy consumption. The conservation of traditional buildings is inherently sustainable. The building is already constructed, often of natural materials such as stone or wood, and in most cases still has considerable life left in it. Its impact on energy resource consumption in terms of construction has passed. A traditional building, which retains its built fabric when adapted or reused, is considered to have low embodied energy[1].

In order to maintain and further this inherent sustainability, the buildings operational energy use should be improved upon. There is a common misconception that traditional buildings cannot be energy efficient ones. It is imperative that we dispel this notion as it is usually founded on an inability to understand how a traditional building works. However when it comes to altering the building fabric to improve it, conflicts can arise between the significance of the fabric in historic or architectural terms, and its ability to function as an energy efficient piece of construction. Modifications should not be to the detriment of the existing fabric, but improvements must be explored, to ensure these buildings continue to be used and continue to be sustainable.

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[1] See definitions. Note many buildings constructed before the last century would have been subjected to less processing and manufacturing, and often utilised bio-mass fuel rather than fossil fuels.

Introduction

Sustainable Design, and the carbon emission of buildings, has become increasingly important as the world has awakened itself to the reality of climate change. However the importance of these issues within the Building Conservation Sector has been slower to develop, generally attributable to long-standing policies which showed a reluctance to modify old buildings unless absolutely necessary. Alterations or replacements were usually only considered in cases where fabric was damaged beyond repair, or structurally unsound. When the addition of insulation was considered, it was often implemented without a proper understanding of its impact on the existing fabric.[1] This was primarily due to the lack of adequate guidance and legislation relating to energy efficiency in traditional buildings. Fortunately over the past fifteen years the obvious link between Building Conservation and Sustainability has become much more integral to guidance and legislation that is available today in the UK. Hesitancy to put pen to paper was understandable as there is always a risk involved in the alteration of historic building fabric; of losing irreplaceable heritage,[2] particularly in cases where the longer term impact of alterations is still unknown.

Many traditional buildings in Scotland today are used as commercial and residential premises. As well as maintaining their properties the owners also have a duty to try and conserve energy as much as is practicable. A 'hands off' approach should not be applied to the multitude of traditional buildings currently in daily use. It would appear that Historic Scotland, the public body in Scotland charged with protecting built heritage, may have shied away from dealing with the issue initially, but have since come to the forefront of the discussion.

It is not the intention of this study to provide a solution to the technical question of how to improve traditional building fabric thermally, but rather to document its progression in terms of policy and guidance and to understand how successful/unsuccessful current methods and areas of study are at present. It is also important to chart the rise of interest in this area among key participants and institutions, particularly public organisations such as Historic Scotland, Local Authorities, Architects and Contractors, as they have considerable influence over how traditional buildings are altered and adapted.

The concept of energy efficiency relating to traditional building fabric will be discussed quite broadly in terms of guidance and policy in the first section, giving the reader an overview of the situation at present in Scotland and the roles of various bodies involved. Following this, two specific traditional Scottish building envelope/fabric types, The Scottish Stone Wall and the Scottish Slate Roof will be reviewed and analysed in greater detail. The focus of this analysis will be how these elements have been altered and modified in recent years to incorporate insulation.

Improving the energy efficiency of any traditional building should be approached holistically as there are many interventions which can be undertaken. This dissertation is focusing on modifications to the building fabric itself, and more specifically the modifications employed on traditional stone walls and slate roofs. It is not the intention of this study to preclude other measures, nor state that the measures described within are the most significant or appropriate ones to take.

For the purposes of this dissertation, a traditional building shall be defined as "one that is of a solid wall construction built with porous fabric that both absorbs and readily allows the evaporation of moisture".

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[1] With the addition of insulation in a loft, the slates and rafters above are almost immediately affected by temperature change as the heat generated within the rooms below no longer reaches them. This is the same for stone walls with new insulation added.

[2] Carsten Hermann, Senior Technical Officer at Historic Scotland, interview by author, Edinburgh, 02/072013.

1. Guidance and Policy for Traditional Buildings

1.1 Climate Change in Scotland

The Scottish Government has begun to address the issue of climate change and sustainability in a number of Acts in recent years. The Climate Change (Scotland) Act 2009 (currently in force) ambitiously aims at reducing greenhouse gas emissions by 42% by the year 2020, and hopes to see an 80% reduction by 2050[1]. Under Part 5, Chapter 3 of the Act, relating to Energy Efficiency, energy assessment reports must now be generated for existing buildings, with an overall push to improve existing buildings where possible, along with an "energy efficiency discount scheme"[2] which will promote modifications to existing buildings.

This Act was generated off the back of the UK's Climate Change Act in 2008 of which Scotland is a partner.[3] 'Conserve and Save, The Energy Efficiency Action Plan for Scotland,'[4] was released in October 2010. This document outlines the importance of tackling climate change now, rather than later. Although energy efficiency has been an aspect of energy policy since the 1970s[5], it is now acknowledged that a much more aggressive approach must be taken, and that it must be achieved on a national level, through policy change, new legislation and appropriate guidance. Major building refurbishment projects are generally undertaken approximately every fifty years,[6] so in order to meet the 2020 and 2050 targets, refurbishment work undertaken now should be addressing these requirements and aiming for these reductions in carbon emissions.

There are many ways to improve energy efficiency in existing buildings, and certainly a holistic approach is advocated. Conserving energy use can be achieved through various implementations, such as boiler upgrades, the supply of renewable fuel, or even the installation of energy efficient lighting, all of which cause little or no disruption to the built fabric. While effective, these interventions can be very expensive, in the case of a new boiler or fuel supply, or minimal, in the case of efficient lighting. The focus of this dissertation is the upgrade measures taken on existing built fabric, with a primary focus on traditional stone walls and slate roofs, in traditional building stock. Tackling the building fabric directly and improving its insulative capacity can be very effective, but is not suitable in all cases. As with all work on traditional buildings, improvements should be considered on a case by case basis.

In the UK it is estimated that about 25% of all housing currently in existence was built a century or more ago.[7] Also roughly half of the UK Construction Industry expenditure each year is attributable to repair, refurbishment and/or maintenance work.[8] If we were currently spending this much time, effort and money on bringing old buildings back into use, or upgrading them, it is certainly worth our while to ensure they are being improved in terms of energy efficiency at the same time. It is also imperative that we address the improvement of these buildings if the ambitious targets set out in The Climate Change (Scotland) Act 2009 are to be met. So what has been put in place to ensure that we do so?

1.2 The Planning and Building Warrant Process

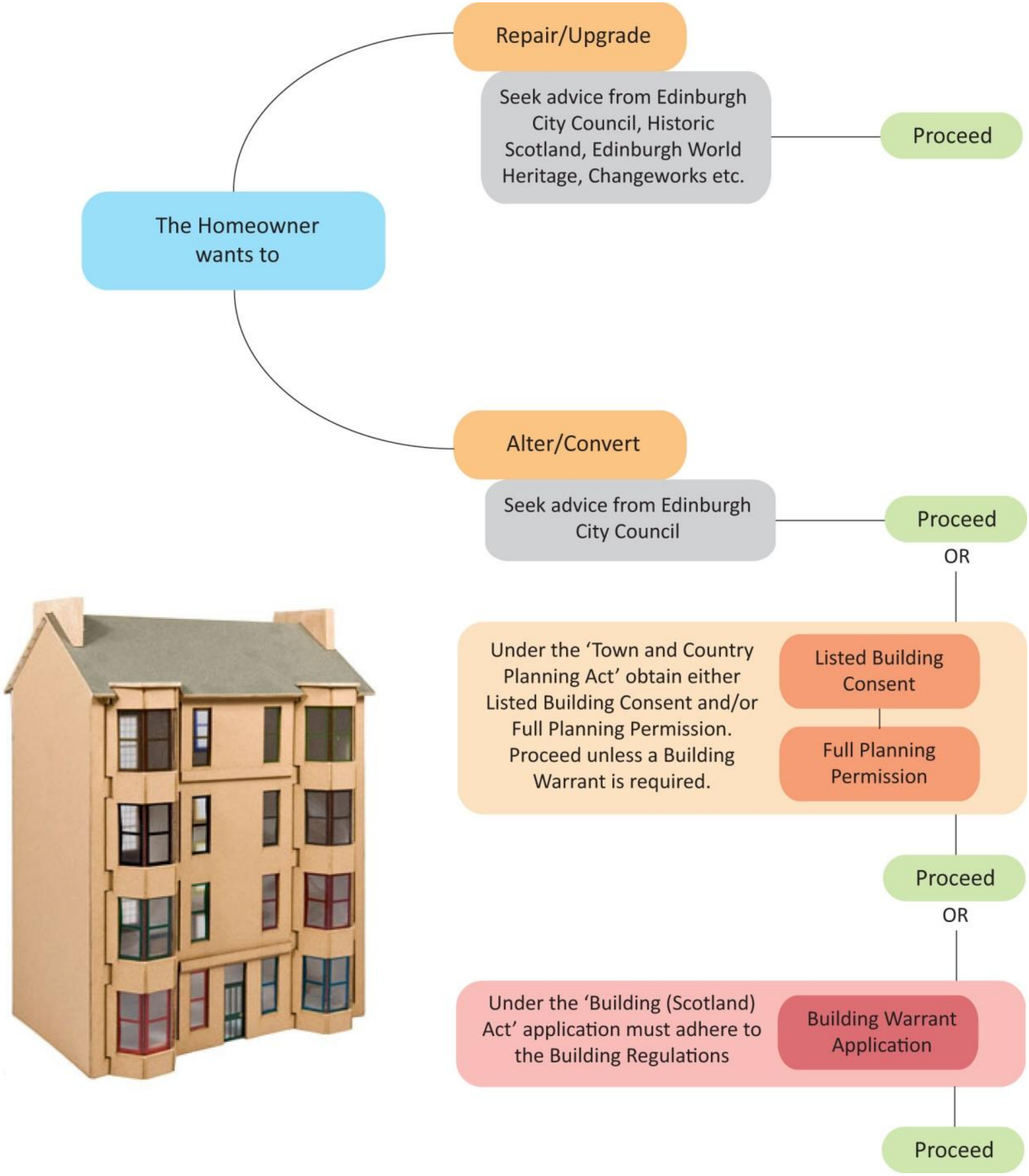


Figure 1.Process Outline for Planning and Building Control

As a prelude to this section figure 1 outlines the process involved when dealing with proposals to alter traditional buildings. It is important to understand the steps taken when work is planned on a traditional building. In many cases building repairs and upgrades do not need to go through the Planning or Building Warrant process. Conversions, large extensions and some alterations (particularly to Listed Buildings) will be subject to the process. Changes in policy and legislation are important to note, as they have an effect on all approaches taken to conserving traditional buildings, whether they are listed or not.

There has been considerable change in legislation over the past fifteen years in relation to energy efficiency in traditional and listed buildings. Prior to this there was little to no legislation in place. The changes in policy, legislation and guidance are outlined below, with particular reference to the role of Historic Scotland, the government body assigned the task of "safeguarding the nation's historic environment and promoting its understanding and enjoyment on behalf of Scottish Ministers".[9]

1.3 Planning Policy in relation to Sustainability and Energy Efficiency in Traditional Buildings

The Town and Country Planning (Scotland) Act 1972 provided "statutory protection for listed buildings" and also established the role of Conservation Officers in Local Authorities to administer planning applications for Listed Buildings. In 1973, the Department of Environment released the 'Memorandum on Listed Buildings and Conservation Areas'[10], a guidance booklet to aid the public with planning applications and modifications to Listed Buildings. It detailed the planning process which Listed Buildings and buildings in Conservation Areas must undergo, and provided guidance on how to retain a traditional buildings character if repair or alteration work was carried out. In 1983 the National Heritage Act moved responsibility for Scotland's historic environment from the Department of Environment to the Historic Buildings and Monuments Directorate, of the 'Scottish Development Department'.[11] At the same time both English Heritage (the English body) and CADW (the Welsh body) were also established. The Department changed its name officially to Historic Scotland in 1991.[12] A further two updated editions of the Memorandum were released from Historic Scotland in 1993[13] and 1998[14]. The Memorandum makes detailed and continual reference to the Planning Acts of Scotland throughout the entire front section of the text, establishing it as a very helpful guide dealing with Planning and Listed Building Consent requirements for listed buildings. At this time Historic Scotland was advised of all applications relating to Listed Buildings, and was in a position to object to any that were deemed inappropriate. In the Appendix section of the Memorandum, under a section titled 'Power to Relax Building Regulations' it advises that "early discussions"[15] between Building Control, the Architect and Historic Scotland are undertaken when the building cannot fully comply. This is the only advice given regarding the Building Regulations. It is an indication of the typically 'hands-off' approach taken towards the modification of Listed/Historic/Traditional Buildings under the Building Regulations during this time.

What is also interesting to note is that while these Memorandums do provide guidance on how to upgrade various parts of the building, such as window repair, re-pointing, re-roofing etc., the motive of the text is only to preserve the buildings character, with no mention of implementations which might improve energy efficiency, or the environmental sustainability of the building.

The Town and Country Planning (Scotland) Act of 1997 saw the introduction of 'sustainable development' into its mandate[16] and following that NPPG 18 'Planning and the Historic Environment' [17] released in 1998 also addressed sustainability. However, as noted above, sustainability failed to be mentioned in the Historic Scotland 'Memorandum of Guidance on Listed Buildings and Conservation Areas' in 1998. It is apparent that at this time Historic Scotland's primary concern was the preservation of the 'character' of a listed/historic/traditional building, rather than the issue of energy efficiency.

By the turn of the century there was a noted change within the UK Government, and further emphasis on sustainability in the historic environment began to emerge. The Stirling Charter[18] released in 2000, which is concerned with built heritage, and spear-headed by Historic Scotland, specifically mentions sustainability as an important aim for the future. In the same year Historic Scotland also issued 'Passed to the Future, Historic Scotland's Policy for the Sustainable Management of the Historic Environment'[19], which states in the introduction that "the principles of sustainability have in practice always been central to the conservation and management of our historic environment”.[20] This was an important development as it opened up the way for discussion on how to make these buildings, which are inherently sustainable by their very existence, operate in today’s world as energy efficient, sustainable spaces.

1.4 The Building Standards System in relation to Energy Efficiency in Existing Buildings

Construction in Scotland is governed by the Building Standards system, which is administered through Local Authorities, utilising Building Regulations and Technical Guidance documents. Within the Building Standards system, between 2001 and 2005, ‘Technical Standards’[21] were issued, which in relation to existing buildings stated that “the regulations apply to the alteration or extension but not to the existing unaffected parts of the building even where these do not comply with present regulations”.[22] This loose terminology allowed for the retained fabric of existing buildings to be kept as is and modified only as the Architects and Planners saw fit, subject only to the limitations of aesthetic based Planning guidance which protected the buildings historic character. So, while the existing building was now acknowledged to be a sustainable entity in itself, there was no requirement to touch or improve it further. If the building was deemed ‘change of use’ (meaning if the building changes to a class of use which must comply with the Regulations, e.g. a public building) it would be called upon to address certain Regulations, though none relating to Energy Efficiency. These ‘Technical Standards’ were considered highly prescriptive, and mandatory compliance was required within them, so admittedly it would have been difficult to enforce existing built fabric interventions under them, without a large range of types and varying conditions being addressed.

A major shift occurred with the implementation of The Building (Scotland) Act of 2003 which overhauled the way in which the Building Standards system in Scotland was administered, demanding increased focus on the conservation of fuel and power for new and existing buildings.[23] Under the purvey of this Act the Building (Scotland) Regulations 2004[24] were issued (coming into force in 2005), which stated the requirements which new and existing buildings were to meet, also providing a set of 'Technical Handbooks'[25] as guidance on how to do so. The most important aspect to note here is that these handbooks are *guidance* documents, and do not have to be followed in a prescriptive manner. They merely outline methods which can be employed to meet the Regulations, however other means and methods may also be acceptable once it can be proven to the Local Authority that the Regulation has been met.

These Regulations state that existing buildings are required to address Section 6 on Energy. Schedule 6 of the Regulations relates to 'Conversions' which covers changes in "the occupation or use of a building".[26] Under Schedule 6, Regulation 12, Conversions (and some extensions/alterations) must comply with a number of requirements, and "must be improved to as close to the requirement of that standard as is reasonably practicable"[27] for a number of other requirements. Conversions of Listed/Traditional/Historic Buildings are now subject to increased scrutiny by Building Control who will no longer accept a 'do nothing' approach.

Local Authorities are now in a position to assess on a case by case basis what was considered 'reasonably practicable' in terms of energy efficiency improvements for existing buildings, still allowing for some latitude when dealing with particularly sensitive, important historic buildings. These Regulations have been in force for eight years now, and while change in approach has been slow, it is underway. One key issue is use of the term 'reasonably practicable', which can be argued effectively from both sides, as what is reasonably practicable to one person, say a Building Standards Officer, might not be considered reasonably practicable to an Owner or Architect, or the Planning Officer. In a lot of cases it is the owner who is difficult to convince, as Architects are generally aware of the need to improve energy efficiency in buildings where possible. It is interesting to note that cost can be a factor in ascertaining what is reasonably practicable.[28] When determining whether or not to press a recommendation, Colin Wishart, a Senior Building Standards Surveyor at Edinburgh City Council[29] says that if the cost of the intervention is very low compared to the overall project cost (e.g. 1% for the addition of insulation behind plasterboard) then he will push for it more aggressively. If however, it is 20-25% of the project budget, he will relent as it might not be feasible for the owner. While this process is not ideal, all parties interviewed for this dissertation, including Edinburgh City Council, feel that it is the most appropriate approach at present, as mandatory, prescriptive measures should not be put in place for traditional/historic/listed buildings. If they were significant historic fabric may be destroyed or damaged as a result.

Energy efficiency in new construction by comparison is relatively straight forward, as the Regulations set mandatory U-Value minimums, as well as detailed heating and cooling requirements. There are many ways and means for new buildings to achieve the required levels, leaving Architects and Engineers opportunities to explore various approaches.

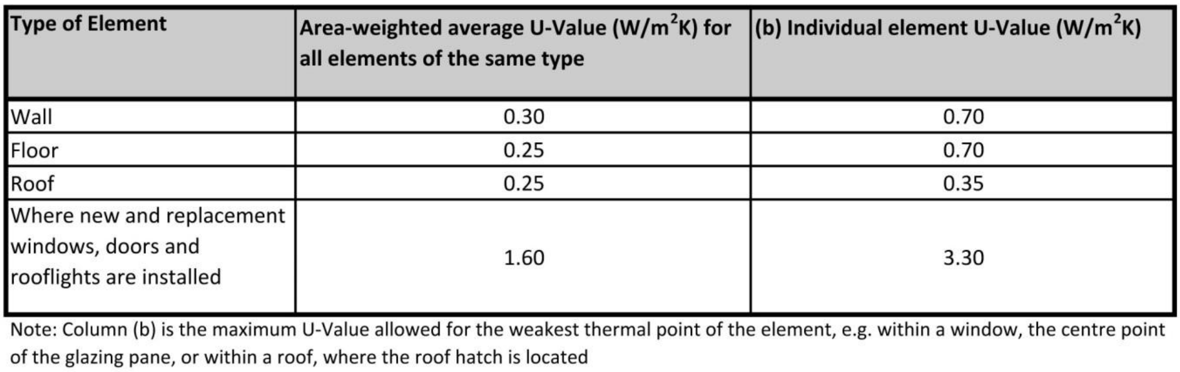
Off the back of the 2004 Regulations Historic Scotland issued SHEP (Scottish Historic Environmental Policy)[30] in 2006 which sets out the Government's policies for the historic built environment, and following this, 'The Guide for Practitioners – Conversion of Traditional Buildings'[31] in 2007, a very significant publication released as official guidance under the Building (Scotland) Act 2003, and endorsed by the Scottish Building Standards Agency.

This publication tackles the application of The Scottish Building Standards to Traditional Building Conversion projects (note not just Listed Buildings), addressing the various sections of the Building Standards and their application to traditional construction. Section 6 of the Building Standards which deals with Energy is also addressed. This guide is a departure from the Memorandum of Guidance on Listed Buildings and Conservation Areas as it relates directly to the Building Standards rather than Planning legislation and is considerably more helpful for architects and contractors carrying out work on traditional buildings. It addresses each Section of the Building Standards, point by point. And, more importantly, its endorsement by the Scottish Building Standards Agency gives it considerable weight with Building Control and Planning

Authorities, who refer to this document regularly because it was issued as official guidance.[32] Prior to this, Historic Scotland guidance, in the form of the Memorandum, was primarily referred to by Planners in the Local Authorities and was not used by Building Control Officers.[33] With the new Regulations calling for existing buildings (including traditional/historic ones) to adhere more stringently to the Regulations, not only in Energy but other areas, it was important that Historic Scotland develop guidance that aided Practitioners to do so. This publication has also proved useful and beneficial as it provides diagrammatic examples of how walls or roofs might be insulated. However it is now out of date. Issued in 2007, it deals primarily with the 2004 Regulations, making mention of the forthcoming changes in 2006, without fully incorporating them. Also new approaches to insulating building fabric have developed in the interim which now need to be included. The guidance is currently being updated by Historic Scotland and hopefully will be published in 2014.[34] The importance of updating this publication cannot be stressed enough. Further informative guides have been issued by Historic Scotland since 2007, such as 'Fabric Improvements for Energy Efficiency in Traditional Buildings'[35] (2012), which discusses methods to insulate traditional building fabric, however Building Control cannot refer to it officially as it is not endorsed by The Scottish Building Standards Agency.[36] There have been a variety of amendments to Section 6 of the Building Regulations 2004 (see Appendix A).

1.5 Building Regulations Section 6 Energy – What is required today?

There are several parts of Section 6 of the Building Regulations which Conversions/Alterations/Extensions (unless exempted) must adhere to. In the Technical Handbooks Part 6 deals with Energy, with one handbook for Domestic Buildings and a separate one for Non-Domestic. Conversions and alterations which require a building warrant are required to address Section 6, item 6.2 in the Regulations which refers to 'building insulation envelope.' The envelope must be improved upon, as far as is 'reasonably practicable'. The methodology of assessment for this section is through the use of U-Values, which measure the rate at which an element, such as a wall, loses heat. Within the Handbooks, item 6.2 is discussed in direct relation to Historic/Listed/Traditional Buildings under item 6.2.8.[37] It is acknowledged that with these buildings it is difficult to demand that the building envelope reach certain U-Values, as it may be detrimental to the fabric to force it to do so, instead it should meet them where 'reasonably practicable'. The U-Values set out in table 1.1 are the maximum acceptable levels for conversions which are not deemed a historic/listed or traditional building. Section 6.2.8 states that the achievement of these U-Values (or lower) should "remain the aim"[38] for historic/listed/traditional building conversions also.

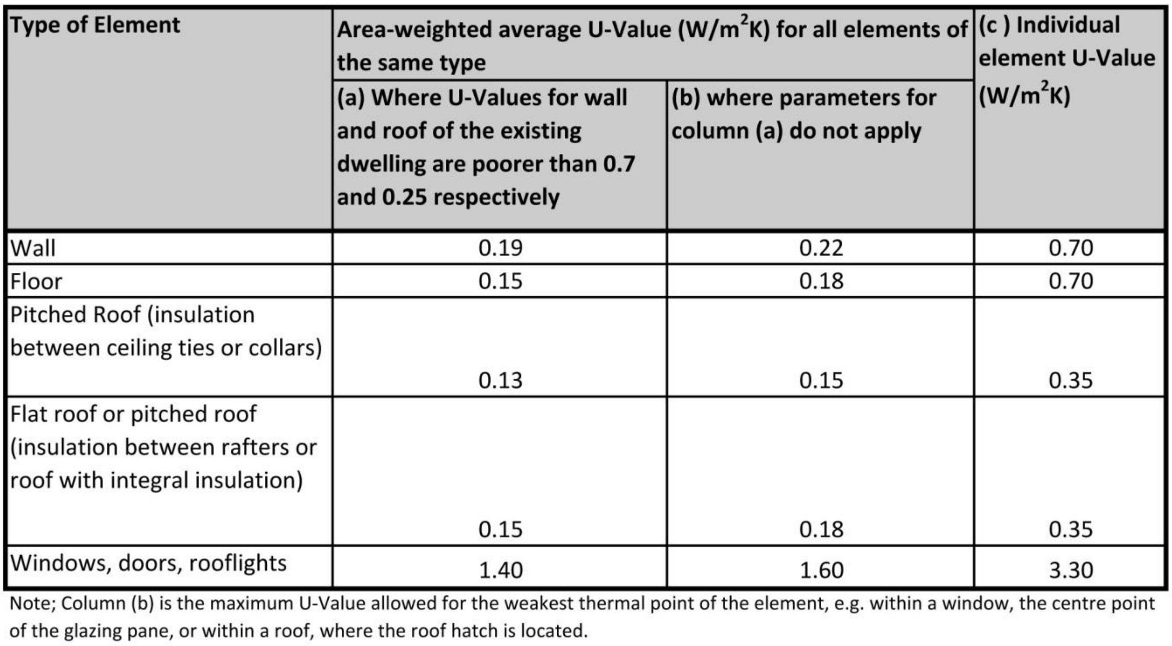


Type of Element	Area-weighted average U-Value (W/m^{2}K) for all elements of the same type	(b) Individual element U-Value (W/m^{2}K)
Wall	0.30	0.70
Floor	0.25	0.70
Roof	0.25	0.35
Where new and replacement windows, doors and rooflights are installed	1.60	3.30

Note: Column (b) is the maximum U-Value allowed for the weakest thermal point of the element, e.g. within a window, the centre point of the glazing pane, or within a roof, where the roof hatch is located

Table 1.1 Extracted from Section 6.2.7 of the Building Regulations

It also states that "at least the U-values given in column (c) in clause 6.2.9 (individual element U-values)"[39] should be attained (Table 1.2 below) for any new components introduced.



Type of Element	Area-weighted average U-Value (W/m^{2}K) for all elements of the same type		(c) Individual element U-Value (W/m^{2}K)
	(a) Where U-Values for wall and roof of the existing dwelling are poorer than 0.7 and 0.25 respectively	(b) where parameters for column (a) do not apply	
Wall	0.19	0.22	0.70
Floor	0.15	0.18	0.70
Pitched Roof (insulation between ceiling ties or collars)	0.13	0.15	0.35
Flat roof or pitched roof (insulation between rafters or roof with integral insulation)	0.15	0.18	0.35
Windows, doors, rooflights	1.40	1.60	3.30

Note; Column (b) is the maximum U-Value allowed for the weakest thermal point of the element, e.g. within a window, the centre point of the glazing pane, or within a roof, where the roof hatch is located.

Table 1.2 Extracted from Section 6.2.9 of the Building Regulations

This Section makes it clear that it is not possible to enforce limiting U-Values on Historic/Listed/Traditional Buildings, as the construction type varies from case to case, and also the importance of the existing fabric varies depending on the building. In some cases the building may have a completely intact historic interior, leaving no room for modification to the existing fabric. It does however state that "In all cases the 'do nothing' approach should not be considered initially"[40] which at least means the Architect/Owner must consider intervention. Prior to 2010, the Technical Handbook did not recommend that traditional buildings try to meet the U-Values outlined in the tables under Section 6.2, so it is interesting to note that the Standards are gradually trying to elaborate further on what should be achieved in listed/historic/traditional buildings.

If a warrant is required, Building Control officers usually review submitted drawings outlining the work and then meet with the Architect/Owner. They do not often see the building prior to work starting, and so rely on the Architect/Owner to inform them of the feasibility options for improving the existing fabric.[41] It is then a case of each side (Building Control and the Architect/Owner) determining what they deem to be reasonably practicable and arguing their case accordingly. It is not unusual, according to Colin Wishart, for a Surveyor inspecting the site after work has commenced to note that more could have been done than was outlined in the drawings.[42]

One project currently under discussion at Edinburgh City Council revolves around the raising of a lead roof on a listed building currently under refurbishment. The roof has been removed, and is to be reinstated. If it were to accommodate the recommended amount of insulation it would have to go back 100mm higher than its previous location. Building Control is pushing to raise the roofline, to accommodate the insulation, while the Planning Officer and Architect are requesting it goes back in its previous location.[43] It remains to be seen if the Architect/Owner will relent and accept the recommendation.

As previously mentioned the Edinburgh City Council is still referring to the Historic Scotland 'Guide for Practitioners' publication as are many Architects and Owners which is apparent in the proposals being submitted.[44] Aside from this document, Colin Wishart is urging his team to recommend to Architects/Owners that they read Historic Scotland's latest publication 'Fabric Improvements for Energy Efficiency in Traditional Buildings.' However this isn't official guidance at present, and so cannot be referenced with the same weight.

It would appear that while progress has been made within the area of legislation and policy, public bodies such as Edinburgh City Council are still finding this a difficult area to tackle, as much discussion is still required between the Building Standards Officer and Architect/Owner on a case by case basis. Their hands are somewhat tied when it comes to addressing Energy Efficiency in traditional buildings as they cannot be prescriptive, and must be careful not to overstep the fine line between improvement and irreparable damage. Certainly the official guidance provided by Historic Scotland has helped with this, giving both parties a good basis for discussion. The production of more informed, officially-recognised guidance, which Local Authorities can endorse with confidence, seems to be key to the success of the new Building Regulations.

As for the guidance itself, it would be beneficial if it could become more detailed, perhaps providing some recommended approaches for typologies such as 19th Century tenements, and stand-alone cottages. It could also address specific occupancy types, such as residential and commercial use. The way in which a residential building operates is quite different to how a commercial one does in terms of heating and cooling.

1.6 Guidance and Incentives for Property Owners

Today, several different groups are working towards improving the energy efficiency of traditional buildings. Many of the publications produced by these groups are directed at home owners or commercial properties, who can upgrade their buildings without Planning Permission. This is a particularly important area to address, as much modification work undertaken internally in unlisted traditional buildings does not require any planning permission.

The Energy Saving Trust[45], formed in 1992, describes itself as an impartial advice enterprise helping communities and households become more energy efficient. Changeworks[46], established in 1989 and based in Edinburgh, is also dedicated towards improving the sustainability of our built environment. The 'Conserve and Save Plan' mentioned in the Introduction acknowledges input from both the Energy Saving Trust and Historic Scotland within its 'Summary of Actions'.[47] It will provide support to the Energy Saving Trust initiatives under Action item 1.4[48] and states that Historic Scotland "will take the lead in researching and promoting energy efficiency in traditional buildings"[49] by carrying out research through case studies, and addressing energy efficiency in their regeneration and grant schemes. To date, the Technical Research Team at Historic Scotland has published thirteen technical papers[50] and carried out thirteen case studies[51] on thermal improvements to traditional buildings, eight of which have been published on its website, and are free to download. They have also launched an interactive 'Energy House' tool on their website, directed at home owners.[52]

Since 2000, Historic Scotland has also published a number of pamphlets under the INFORM series (Information for Historic Building Owners) which indicate how to repair and upgrade traditional buildings.[53] Edinburgh World Heritage Trust (EWHT) has also begun to publish a number of pamphlets aimed at homeowners under the 'Historic Home Guide' series.[54] The most successful aspect of these publications is that they are short, illustrated guides, which aren't too technical for a property owner to understand. They are careful to direct home owners to suitably trained professionals and Local Authorities where required and are also all available free online. The accessibility of these publications is extremely important as a number of other sources, which also hold important information, are not readily available to the public. For instance research carried out by BRE[55] or articles in various Architectural Journals must be purchased and can be difficult to locate. In a wider context across the rest of the UK both the SPAB[56] and English Heritage[57] are also publishing free informative reports and case studies online. The SPAB has just published 'Old House Eco Handbook'[58] which is quite a detailed 192 page book again directed at the general public, and the Conservation Sector.

Under the aforementioned Climate Change (Scotland) Act many grant and loan schemes have been initiated by the government in an effort to encourage owners to improve the energy efficiency of their properties. A selection of these are listed in last year's 'Energy Efficiency'[59] guide from the EWHT. They provide financial incentive for property owners to upgrade their homes, under a managed system. While this is certainly a good way to encourage the private sector to upgrade buildings, from cursory review it would appear that these grants and loans are not tailored specifically enough towards traditional buildings.

One such scheme, 'The Green Deal'[60], run with the Energy Saving Trust, has been analysed in some detail in Historic Scotland's Technical Paper 17.[61] This deal effectively grants loans to homeowners for improvements based upon the financial payback generated over time. This paper highlights a number of issues that make the Green Deal prohibitive for application to traditional buildings, as its generalised approach is based primarily on estimated long-term financial returns, with little acknowledgement of traditional construction types. While it is encouraging to see a push towards more energy efficiency related refurbishment projects, there are still issues surrounding how this is applied to traditional buildings. It is important to ensure that public money put forward for the improvement of traditional buildings is spent in the most beneficial manner.

One particular issue which arises when work is undertaken outside the supervision of the Local Authorities and/or an Architect is that the disconnect of knowledge within the Construction industry is heightened. Tradesmen/construction companies who understand and are familiar with traditional construction are usually not involved when it comes to installing insulation on site. It is not uncommon for slate roofs to be insulated at loft or even rafter level, with little to no inspection of the existing roof and its ventilation.[62] Invariably if the roof appears to be functioning well prior to the installation of insulation, it is assumed it will continue to do so. Many roofing companies get calls after insulation has been installed because owners think their slate roof is leaking, when in fact the 'leak' is caused by condensation as the roof has not been adequately ventilated.[63] This is the downside of low-cost, easy-to-install loft insulation, people do not consider its impact on the roof. It is a difficult area to negotiate as many roofing companies are not interested in insulation installation work, and are not familiar with it, particularly larger ones.[64] Smaller roofing companies, such as W.D. Cameron and Traditional Roofing who are somewhat familiar with rafter insulation applications, note that requests for rafter level insulation in cooms is not common in Edinburgh due to cost.[65] This is unfortunate as when a slate roof is overhauled (re-slated) it is a good opportunity to insulate the roof and deal with ventilation all in one go.

Under the 'Green Deal' the government has pre-approved 'assessors' visit properties to recommend what interventions would meet the requirements - improved U-values and long term financial payback. They are dealing with a multitude of different building types throughout Scotland and are energy assessment companies, not architects or surveyors, with no background in Building Conservation.

While it is understandably difficult for over-arching Government initiatives to address the variety of building types specifically, there is potential for improvement within the assessment process.

The Government have provided funding for a position within the EWHT[66], of Energy Efficiency Officer (fulfilled by Chiara Ronchini) who "is responsible for initiating, managing and delivering energy efficiency programmes and advice"[67] within the Edinburgh World Heritage site. This role bridges the gap between energy efficiency improvements and conservation work within the Edinburgh World Heritage site, and it is anticipated that future grant schemes for Edinburgh World Heritage may incorporate energy efficiency upgrades. Perhaps this type of role needs to be brought into the energy assessment process for other grant schemes involving traditional buildings.

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2. Traditional Scottish Stone Walls and Slate Roofs

2.1 The Scottish Stone Wall

The traditional stone wall, for the purpose of this paper is described as follows; mass rubble stone wall construction of sandstone (or similar) with ashlar/rubble face, held together with lime mortar. Typically there is a layer of lath and plaster on the interior side, with a 20-40mm gap/air space behind the plaster. The exterior may or may not have a layer of lime render.

This building envelope is considered to be vapour-open ('breathable') which means the wall can absorb and release water, and so the construction is considered to be hydroscopic,[1] (see figure 2). This is typically how traditional building envelopes work, channelling moisture and air through its walls, roof and floors, in relatively even distribution (see figure 3).

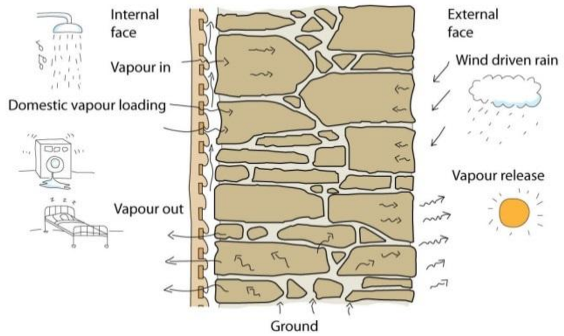


Figure 2 Vapour-open Stone Wall Construction

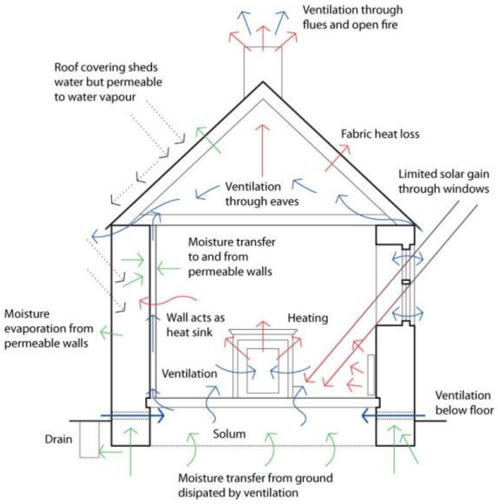


Figure 3 Movement of air and moisture through a Traditional Building

The traditional building is ventilated naturally, as air moves through air spaces in its walls, roof and floors, and through its vents, windows, doors and chimneys. This suited internal environments in the past, when the temperature differential between inside and outside was less pronounced. However nowadays people expect warmer interiors[2] and generate more heat and steam indoors in rooms such as kitchens and bathrooms. In efforts to save on heating bills and create warmer environments occupants have added insulation in attic spaces, inserted double/triple glazed windows and sealed up draughts around doors and up chimneys. All this has put the traditional building envelope under increased pressure to find routes to dispel air and moisture. When it cannot do so adequately, condensation build-up or mould growth occurs.

Modern forms of construction typically seal the walls, roof and floors so they are impermeable to moisture and air movement. This is achieved through the use of air/vapour barriers. The building expels moisture and air through mechanical or passive ventilation systems which are designed the meet today's interior environmental conditions.

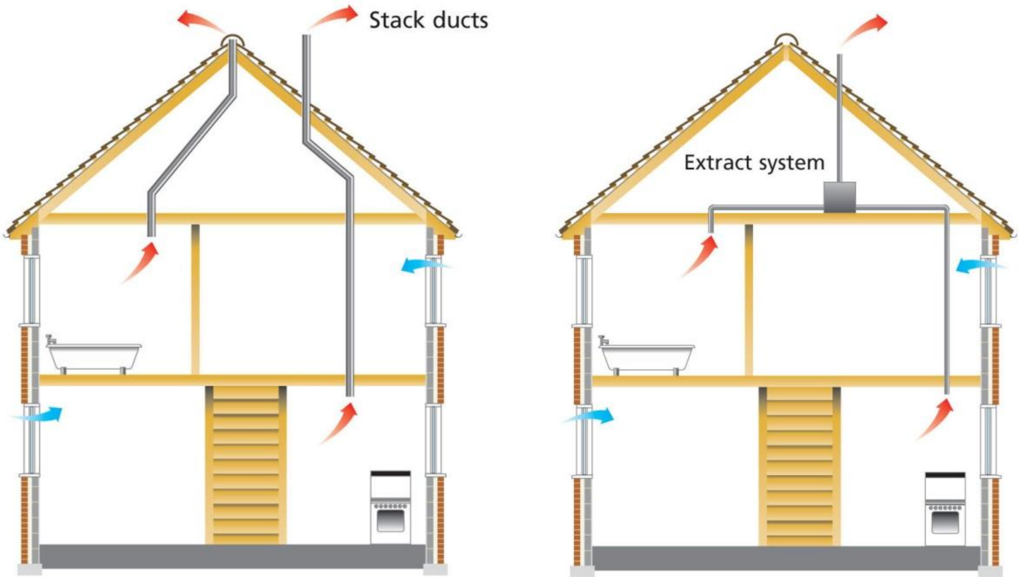


Figure 4 Continuous Mechanical Extract Ventilation (left) and Passive Stack Ventilation (right)

These two forms are indicated above (figure 4). Air circulation is generally encouraged through vents in windows (which can be opened and closed) and warm air/steam etc. is generally dispelled through internal venting systems up to the roof. There is no air/moisture movement accounted for through walls, roof or floors.

There have been moves to modify traditional buildings by installing passive or mechanical ventilation systems, which can certainly reduce problems with condensation. It is important to consider new methods of ventilation when modifying an existing building envelope with the addition of new products, e.g. ensuring there are trickle vents built into newly installed double glazed windows, allowing for some air flow, and ensuring your bathroom has a means of natural (operable window) or mechanical (electrical vent) ventilation if you install an electric shower where there previously was none.

In stone buildings it is important to maintain some degree of air and moisture movement through the traditional building envelope itself, as this is in essence how the construction operates. For this reason insulation products used in traditional buildings should always be 'breathable', complimenting how the wall works rather than preventing it from doing so.

Over the course of the twentieth century traditional stone walls in buildings were modified, sometimes to their detriment, with the addition of impermeable membranes. It was not uncommon to find cement renders applied to the exterior of stone walls, which can trap water behind them, causing moisture build-up and damage to the exterior stonework.[3] On the interior the lath and plaster was on occasion removed, and replaced with new plasterboard, sometimes incorporating a vapour/air barrier within it. In this situation if an air space was maintained behind the plasterboard it usually still allowed for adequate ventilation along the face of the wall, but in cases where it wasn't interstitial condensation could occur. New impermeable floors were sometimes installed at ground level, e.g. poured concrete slabs with a DPC layer, forcing moisture from under the building to move out to the edges and up through the permeable walls, often causing rising damp[4]. The installation of high efficiency double or triple glazed windows could also upset the balance within a room, causing condensation on either the window or wall as previously existing air flows were disrupted. Much work is being carried out at present by Changeworks, Historic Scotland and the Energy Saving Trust[5] in relation to improvement options for windows in traditional buildings.

2.2 The Scottish Slate Roof

The traditional Scottish slate roof operates under similar ‘breathable’ principles allowing air and moisture to move through it. Scottish slates are traditionally laid in diminishing courses, ranging in size, from large to small, from eaves to ridge respectively.

Scottish slates are traditionally head-nailed, in a double-lap system, which as seen in figure 5, allows for a double covering of slate over the entire roof. The slates are nailed onto sarking boards, which were butt-jointed, and laid across the supporting roof structure. This is a variation from the typical English or Welsh slate roof, which is composed of standard sized slates, on regularly spaced battens. Sarking boards, forming a contiguous surface, are more suitable for attachment than regularly spaced battens, due to the varied size of the Scottish slate. The sarking boards also act as a secondary barrier to wind and rain, but due to its butt jointing, still allow for some air and moisture movement through them. This gap between each sarking board is known as a ‘penny gap’.[6] Sarking also adds structural stability and even some insulative value.[7]

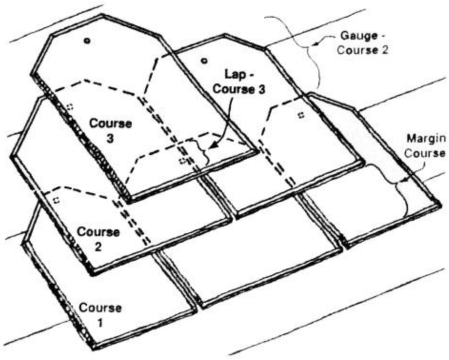


Figure 5 Double Lap Slating

The slate roof is not air-tight, but if laid correctly only allows a small degree of wind penetration, which actually serves to keep the roof dry and well-ventilated.[8] However the degree of wind penetration is also dependant on the pitch of the roof and the exposure of the building.

The traditional slate roof did not incorporate any membranes, although the underside of the slate was occasionally ‘torched’ (application of course lime and hair mortar) to further prevent ingress of wind and rain. In the 1930s bituminous roofing felts began to be installed on traditional slate roofs overtop of the sarking boards,[9] and under the slate, as a means to seal the roof further from wind and rain, though roofers in Scotland were still applying a horse hair and mortar mix (torching) in the mid 1940s.[10] Unfortunately the majority of these new membranes were quite impermeable, preventing much air or moisture movement through them at all. Issues started to arise later during the 1970s, when insulation was added in lofts and between roof rafters, in cases where attics were occupied.[11] Often in these situations, little consideration was given to ventilating the roof, which, with increased temperature differentials after insulation was added, could lead to interstitial condensation within the roof itself.

Within the British Standards Code of Practice from 1968 it is noted that "an apparent increase in the incidence of condensation in roofs during the past few years is probably due to higher standards of heating and the more widespread use of insulation at ceiling level."[12] It goes on to note that this condensation build up "will be observed most commonly on the underside of the underlay"[13] which, as mentioned above, was typically bitumen underlay. Ventilation is noted in the Standard as a way to mitigate this problem. Typical traditional slate roof details of a wall head and ridge are shown in figures 6 and 7.

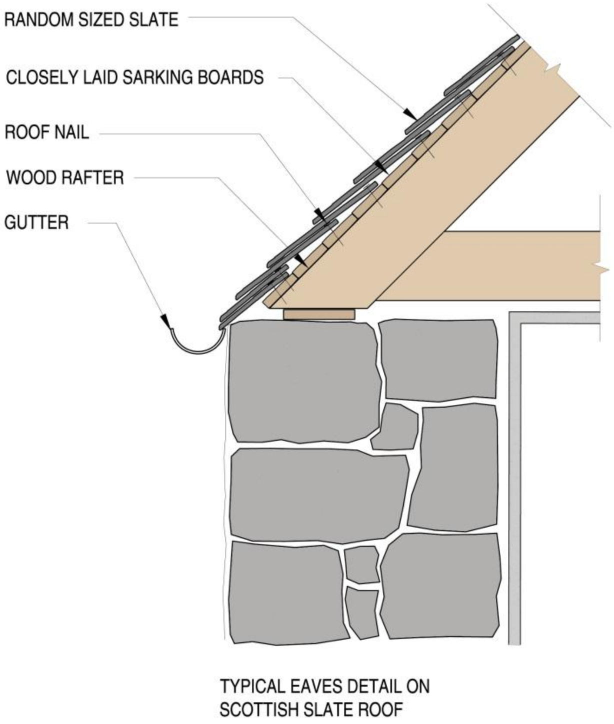


Figure 6 Traditional Slate Roof Wall head

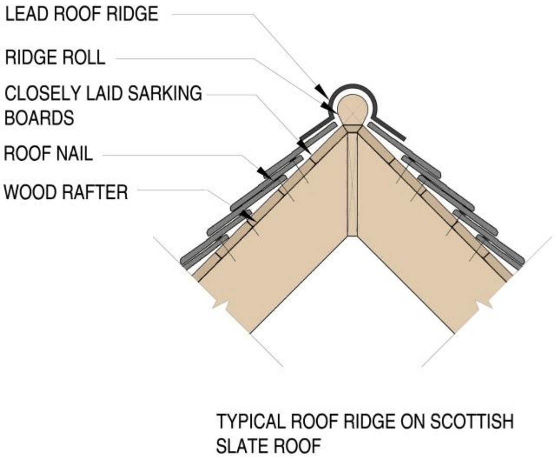


Figure 7 Traditional Slate Roof Ridge

2.3 The Thermal Efficiency of Traditional Stone Walls and Slate Roofs

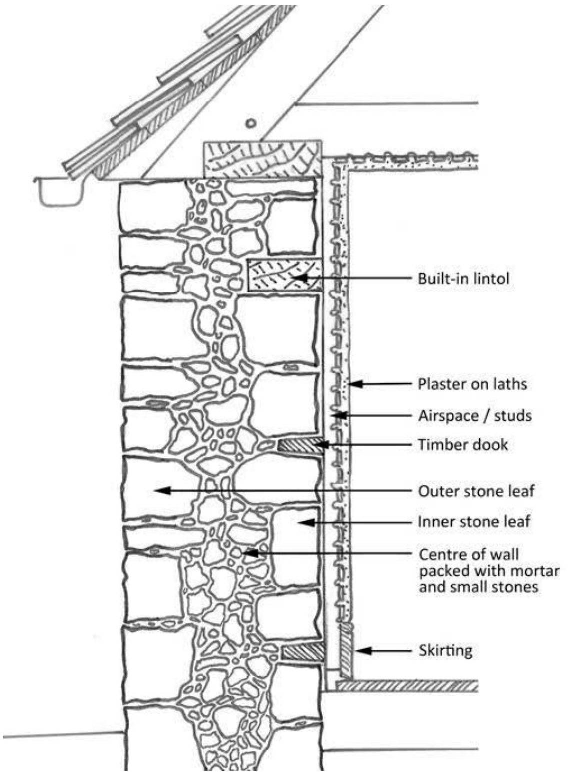


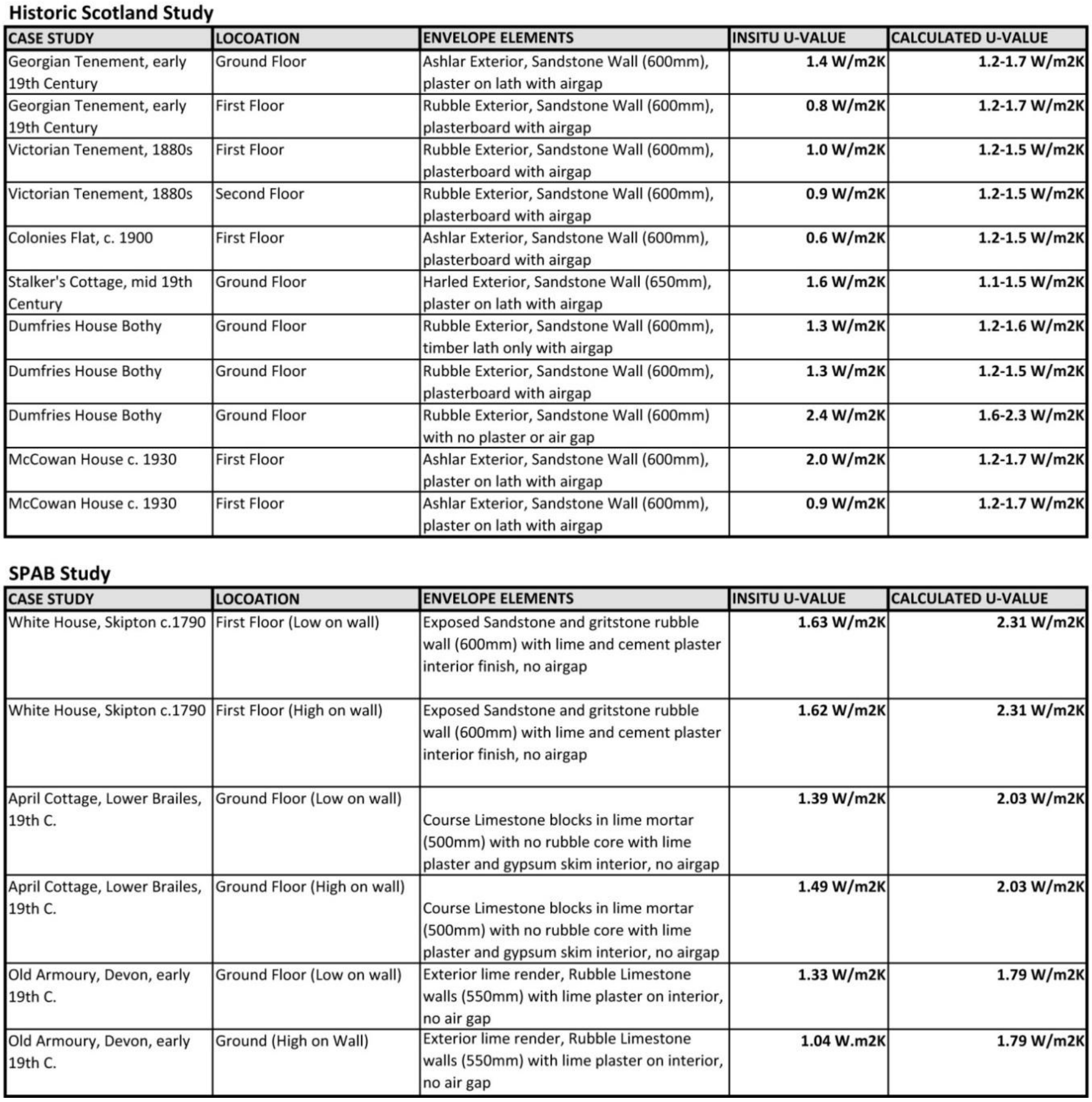
Figure 8 Traditional Solid Masonry Wall

The U-Value measures for mass stone walls have been determined in three different ways to date; a 'default U-Value' (a prescribed U-Value given in a table, based on an accepted calculation method), a 'calculated U-Value' where the practitioner generates a U-Value utilizing a computer program such as BuildDesk or BRE U-value Calculator[14] and an 'in-situ U-Value', taken on site using appropriate testing equipment. Default U-Values seem to vary across publications, with examples ranging from 1.45 W/m2K[15] to 1.7 W/m2K[16] to 2.31 W/m2K[17] to 2.4 W/m2K[18] for mass stone walls. It is not even clear in all of these examples exactly what type of mass stone wall is being analysed. Nowadays the Building Regulations accept U-Values calculated using computer programs, which is very effective for new build, but can be problematic for older construction. The problem is two-fold; lack of adequate information about the composition of a stone wall within the program itself, and a lack of understanding of stone wall composition by the user. For example, it is possible to simply insert data for a mass stone wall of sandstone, 600mm deep, with little to no provision for joints, mortar or voids within the wall. This gives an inaccurate reading, as a stone wall is not entirely constructed of stone. The wall differs across its thickness, typically comprised of an inner and outer leaf of larger stone, with rubble infill (smaller stones) at its centre (see figure 8).

Traditional walls are "conglomerate in nature with a number of different materials combined in varying proportions to form a heterogeneous whole."[19] Often the proportions of mortar void and stone is unknown. This can make it difficult to assess under the calculated method, and often some educated guesswork is required.[20]

A recent study[21], carried out by Paul Baker (Glasgow Caledonian University) between 2007 and 2010 estimated a 70/30 split between stone and mortar in a traditional stone wall and applied this to the computer program. A significant difference in the U-Value calculation was noted. The U-Value dropped from just under 2.2 W/m2K to 1.7 W/m2K.

Within the same study, the insitu U-Value of some 57 stone walls around Scotland were taken in order to compare them with the calculated ones, (see results in Appendix B). The insitu values tend to vary from the calculated U-Values, with 44% of the insitu values coming out lower than the calculated equivalent, and 42% coming out with the range of calculated values.[22] The SPAB (Society for the Protection of Ancient Buildings) also tested a number of traditional stone walls for insitu U-Values[23] publishing similar findings and discrepancies. Within their test set of 15 stone walls, 69% yielded higher U-Values using the calculated method.[24] A selection of the findings by both studies have been summarised in the following table (see Table 2.1).



Historic Scotland Study

CASE STUDY	LOCOATION	ENVELOPE ELEMENTS	INSITU U-VALUE	CALCULATED U-VALUE
Georgian Tenement, early 19th Century	Ground Floor	Ashlar Exterior, Sandstone Wall (600mm), plaster on lath with airgap	**1.4 W/m2K**	**1.2-1.7 W/m2K**
Georgian Tenement, early 19th Century	First Floor	Rubble Exterior, Sandstone Wall (600mm), plasterboard with airgap	**0.8 W/m2K**	**1.2-1.7 W/m2K**
Victorian Tenement, 1880s	First Floor	Rubble Exterior, Sandstone Wall (600mm), plasterboard with airgap	**1.0 W/m2K**	**1.2-1.5 W/m2K**
Victorian Tenement, 1880s	Second Floor	Rubble Exterior, Sandstone Wall (600mm), plasterboard with airgap	**0.9 W/m2K**	**1.2-1.5 W/m2K**
Colonies Flat, c. 1900	First Floor	Ashlar Exterior, Sandstone Wall (600mm), plasterboard with airgap	**0.6 W/m2K**	**1.2-1.5 W/m2K**
Stalker's Cottage, mid 19th Century	Ground Floor	Harled Exterior, Sandstone Wall (650mm), plaster on lath with airgap	**1.6 W/m2K**	**1.1-1.5 W/m2K**
Dumfries House Bothy	Ground Floor	Rubble Exterior, Sandstone Wall (600mm), timber lath only with airgap	**1.3 W/m2K**	**1.2-1.6 W/m2K**
Dumfries House Bothy	Ground Floor	Rubble Exterior, Sandstone Wall (600mm), plasterboard with airgap	**1.3 W/m2K**	**1.2-1.5 W/m2K**
Dumfries House Bothy	Ground Floor	Rubble Exterior, Sandstone Wall (600mm) with no plaster or air gap	**2.4 W/m2K**	**1.6-2.3 W/m2K**
McCowan House c. 1930	First Floor	Ashlar Exterior, Sandstone Wall (600mm), plaster on lath with airgap	**2.0 W/m2K**	**1.2-1.7 W/m2K**
McCowan House c. 1930	First Floor	Ashlar Exterior, Sandstone Wall (600mm), plaster on lath with airgap	**0.9 W/m2K**	**1.2-1.7 W/m2K**

SPAB Study

CASE STUDY	LOCOATION	ENVELOPE ELEMENTS	INSITU U-VALUE	CALCULATED U-VALUE
White House, Skipton c.1790	First Floor (Low on wall)	Exposed Sandstone and gritstone rubble wall (600mm) with lime and cement plaster interior finish, no airgap	**1.63 W/m2K**	**2.31 W/m2K**
White House, Skipton c.1790	First Floor (High on wall)	Exposed Sandstone and gritstone rubble wall (600mm) with lime and cement plaster interior finish, no airgap	**1.62 W/m2K**	**2.31 W/m2K**
April Cottage, Lower Brailes, 19th C.	Ground Floor (Low on wall)	Course Limestone blocks in lime mortar (500mm) with no rubble core with lime plaster and gypsum skim interior, no airgap	**1.39 W/m2K**	**2.03 W/m2K**
April Cottage, Lower Brailes, 19th C.	Ground Floor (High on wall)	Course Limestone blocks in lime mortar (500mm) with no rubble core with lime plaster and gypsum skim interior, no airgap	**1.49 W/m2K**	**2.03 W/m2K**
Old Armoury, Devon, early 19th C.	Ground Floor (Low on wall)	Exterior lime render, Rubble Limestone walls (550mm) with lime plaster on interior, no air gap	**1.33 W/m2K**	**1.79 W/m2K**
Old Armoury, Devon, early 19th C.	Ground (High on Wall)	Exterior lime render, Rubble Limestone walls (550mm) with lime plaster on interior, no air gap	**1.04 W.m2K**	**1.79 W/m2K**

Table 2.1 Insitu U-Values from Historic Scotland/Glasgow Caledonian University and the SPAB

It is interesting to note the range of insitu U-Values obtained, which vary for a variety of reasons (discussed in more detail in the reports). They are summarised below;

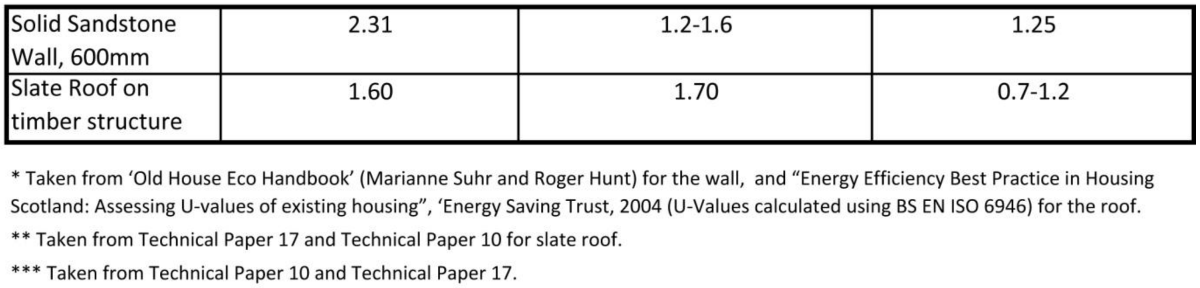
- The presence of an interior finish, e.g. plaster on lath/plasterboard with a cavity will impact the overall U-Value of the wall – see Dumfries House measurements.
- The insulating effect the existing cavity itself. This can vary depending on the degree of ventilation through the cavity, and the depth of the cavity. This may explain the variation seen in the McCowan House measurements.
- The SPAB study tested the same wall in two locations (below 1200mm from ground, and above 1200mm)[25], in order to determine if there was any variation depending on

> location. Measurements taken below 1200mm tended to have higher U-Values which were attributed to the presence of moisture – see Old Armoury. April Cottage appeared to be in conflict with this theory until it became apparent that the wall tested was suffering from some degree of water ingress from outside (above the 1200mm mark).

Off the back of the Historic Scotland study, the data collected was used in the NHER (National Home Energy Rating) procedure to generate an average insitu U-Value of 1.25 W/m2K[26] for a 600mm solid sandstone wall, while a default U-Value was taken from the RdSAP[27] program which puts a stone wall at 1.8 W/m2K. The RdSAP default value is used for calculations in the Green Deal.[28] If the default U-Value is inaccurate, then the estimated savings made by adding insulation will be inaccurate too.[29] The Historic Scotland/Changeworks publication 'Technical Paper 17 Green Deal, Energy Company Obligation and traditional buildings'[30] which highlighted this discrepancy also highlights the fact that ECO (Energy Company Obligation) subsidies are currently only available in cases where the addition of insulation will reduce the U-Value of a solid masonry wall to 0.3 W/m2K[31] or less. In such cases the accuracy of the default U-Value could mean the difference between a subsidy or not.

Similarly, in two instances an uninsulated coom ceiling of timber construction and slate finish, with an internal finish of plaster and lath, yielded insitu U-Values of 0.7 W/m2K and 1.2 W/m2K respectively, while the calculated U-Value from a computer program gave a value of 1.7 W/m2K.[32] The default U-Value at present for a slate roof on sarking (uninsulated) seems to be around the 1.6 W/m2K mark.[33]

It would appear that at present the default U-Values are not accurate enough for these two forms of traditional construction (see Table 2.2).



Solid Sandstone Wall, 600mm	2.31	1.2-1.6	1.25
Slate Roof on timber structure	1.60	1.70	0.7-1.2

* Taken from 'Old House Eco Handbook' (Marianne Suhr and Roger Hunt) for the wall, and "Energy Efficiency Best Practice in Housing Scotland: Assessing U-values of existing housing", 'Energy Saving Trust, 2004 (U-Values calculated using BS EN ISO 6946) for the roof.

** Taken from Technical Paper 17 and Technical Paper 10 for slate roof.

*** Taken from Technical Paper 10 and Technical Paper 17.

Table 2.2 U-Values for Solid Stone Walls and Slate Roofs

What is primarily noticeable is that the in-situ U-values are lower, indicating that stone walls and slate roofs may be performing better than assumed. However the calculated U-Value for the stone wall above (based on correctly input information in the BuildDesk calculator) does come closer to the insitu value than the default (SPAB) one. There seems to be potential here for computing software to generate more accurate readings for traditional construction. This is especially important for calculation programs such as RdSAP, which is being used to generate data applicable to the Green Deal. Naturally this must go hand in hand with proper on-site assessment of the walls and roofs. If the wall is damp, or suffering from water ingress through its joints, then the U-Value will be affected.

Improved calculation is important because when it comes to upgrading a traditional building to increase its energy efficiency capacity it is important to look at the building holistically. This means that the whole of the building should be assessed, to determine what interventions will have the most impact in terms of energy savings, while also minimising disruption and potentially irreversible damage. The condition of the building, the type of building fabric and the historic significance of the fabric are all key factors in this assessment. For owners, cost is a big concern and they will generally want to know whether or not the upfront cost will be repaid quickly over time. Ideally in each project a list of potential interventions/alterations/modifications is created, with the most effective and suitable placed at the top, working down to the least effective. Green Deal takes this approach with list of upgrade recommendations list (in itself worrying, as it does not account for different types of existing buildings) where it places "Internal or external solid wall insulation"[34] at number 5 (see Appendix C for full list). The rationale for placing this at number 5 is based on the return for money this intervention will generate using Green Deals calculations (RdSAP). However with inaccurate U-Values the addition of insulation may not generate the savings expected, and though it might be cheaper to install than say, double glazing, its impact on the building may not be as financially effective as predicted by Green Deal calculations.

This analysis also highlighted the importance of maintenance of stone walls and slate roofs. A mass stone wall should be a relatively dry wall. If it is in some way compromised and taking in more moisture than it can evaporate the U-Value is seen to increase. In short, damp or wet walls are less thermally efficient. It is estimated that a 'wet' wall doubles it's U-value in comparison with a 'dry' one.[35] The application of cement renders, or the breakdown of an existing lime render can contribute to water accumulation in stone walls.[36] Leaky/faulty gutters or inadequate ground drainage can also cause problems. As pointed out by two Conservation Architects interviewed, ensuring the walls are operating as they should is first and foremost before contemplating thermally improving a building.[37] There is also a case for carrying out insitu U-Value testing on walls before and after repair, particularly after application of a new lime render on the exterior, to explore if U-Values improve with the addition of fresh coats of render.[38]

All in all the use of current default U-Values for traditional construction needs to be reviewed for accuracy. The studies undertaken by Historic Scotland with Glasgow Caledonian University, Changeworks and the SPAB have established that there are discrepancies and a means of ensuring that more accurate U-Values are determined for traditional construction must be established. It is not practical to advocate that owners and clients take insitu measurements, but existing computer programs and calculation methods could be improved. Insitu testing could be carried out by assessors or Architects for larger projects (see Appendix D). Also if Historic Scotland continues their testing on various walls throughout Scotland perhaps a detailed database of U-Values for traditional wall and roof types could be generated based on insitu calculations, generating more accurate 'default' values for use.[39] The 'solid stone wall' could also be broken up into various sub-categories according to composition and type. The SPAB is already generating a database of insitu U-Values for a variety of wall types in the UK.[40]

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[1] Moses Jenkins, *Fabric Improvements for Energy Efficiency in Traditional Buildings,* 5.

[2] "Even as recently as 1970, the average UK house was heated to a temperature of only 54F (12C) – this had risen to 64F (18C) by 2003, and is probably in the seventies F (twenties C) by now." Cook, Martin Godfrey, *Energy Efficiency in Old Houses,* 2009, 13.

[3] Roger Curtis, *INFORM Damp Causes and Solutions,* (Edinburgh: Historic Scotland, 2007), [2].

[4] Ibid.

[5] Changeworks, "Energy Heritage: A guide to improving energy efficiency in historic and traditional homes", 2008, http://www.changeworks.org.uk/uploads/83096-EnergyHeritage_online1.pdf (accessed 4th April 2013).

[6] Moses Jenkins, *Fabric Improvements for Energy Efficiency in Traditional Buildings,* 9.

[7] The Centre for Conservation and Urban Studies (CCUS), School of Town Planning and Regional Planning, University of Dundee, *Scottish Slate – The Potential for Use*, (Edinburgh: Historic Scotland, 2000), 92.

[8] Neil Grieve, Research Fellow and Lecturer, University of Dundee, School of the Built Environment, interview by author, by phone, July 5th 2013.

[9] Richard Oxley, "The Need for Roofs to Breathe", 2001, http://www.buildingconservation.com/articles/roof/roof-ventilation.html (accessed online 12th February 2013), 1.

[10] Craig Cameron, interview by author.

[11] Richard Oxley, "The Need for Roofs to Breathe", 1.

[12] British Standards, Code of Practice, *CP 142(1968) Slating and Tiling*, 19.

[13] Ibid.

[14] Paul Baker, "Technical Paper 10- U-Values and Traditional Buildings", Historic Scotland and Glasgow Caledonian University, 2011, http://www.historic-scotland.gov.uk/technicalpapers, (accessed 24th March 2013).10.

[15] Davey, Andy, et al, *The Care and Conservation of Georgian Houses – A maintenance manual for Edinburgh New Town,* 4th Rev., (Oxford, Butterworth-Heinemann, 1995), 170.

[16] Energy Saving Trust, "Energy Efficiency Best Practice in Housing Scotland: Assessing U-values of existing housing", 2004, http://www.energysavingtrust.org.uk/Publications2/Housing-professionals/Insulation-and-ventilation/Scotland-assessing-U-values-of-existing-housing-2004-edition (accessed online 9th June 2013), 4.

[17] Marianne Suhr and Roger Hunt, *Old House Eco Handbook,* In Association with the Society for the Protection of Ancient Buildings (SPAB), (London: Frances Lincoln Ltd., 2013),101.

[18] David JC MacKay, *Sustainable Energy – Without the Hot Air*, (Cambrigde: Cambridge UIT Ltd., 2009), 290.

[19] Caroline Rye and Cameron Scott, "The SPAB Research Report 1 - U-Value report", November 2010, http://www.spab.org.uk/downloads/Courses_2010/TheSPABU-valueReportFINAL.pdf, (accessed 20th July 2013), 10.

[20] Partly as a result of the work carried out by Paul Baker, Historic Scotland and SPAB, BuildDesk has modified its program to allow for a separate mortar fraction to be included in the calculation for stone walls. Prior to 2009-10 this was not possible in the program.

[21] Paul Baker, "Technical Paper 10- U-Values and Traditional Buildings", 12.

[22] Ibid., 24

[23] Caroline Rye and Diane Hubbard, "The SPAB Research Report 2 - The SPAB Building Performance Survey 2011 Interim Report", October 2011, http://www.spab.org.uk/downloads/The%20SPAB%20Research%20Report%202.%20The%20SPAB%20Building%20Performance%20Survey%202011%20Interim%20Report.%20October%202011.pdf (accessed July 15th, 2013).

[24] Ibid., 10.

[25] Ibid., 17.

[26] Nicholas Heath, Tessa Clark and Gary Pearson, "Technical Paper 16 - Green Deal financial modelling of a Traditional Cottage and Tenement Flat", Historic Scotland, http://www.historic-scotland.gov.uk/historic-scotland-technical-paper-16.pdf, (accessed July 11th, 2013), 5 & 6.

[27] "RdSAP is a simplified version of the Standard Assessment procedure (SAP), the UK Government's recommended method system for measuring the energy rating of residential dwellings…RdSAP and SAP are software packages developed by BRE." TP 16, 5. "The revised version of RdSAP (v9.91) started being used in Scotland for EPCs from 1st October 2012.", (Technical Paper 17, Historic Scotland, 8).

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[28] "The Green Deal is the UK Government's plan to drive increased energy efficiency in UK homes. From October 2012, finance will be available to householders to pay for improvement measures to their homes… The key element of the Green Deal is the 'Golden Rule', which states that the improvements must save more money than the householder repays." (Technical Paper 16, Historic Scotland, 7).

[29] Ibid., 26.

[30] Stuart Hay, Nicholas Heath and Gary Pearson, "Technical Paper 17 - Green Deal, Energy Company Obligation and Traditional Buildings".

[31] Ibid., 42.

[32] Paul Baker, "Technical Paper 10- U-Values and Traditional Buildings", 17.

[33] Energy Saving Trust, "Energy Efficiency Best Practice in Housing Scotland: Assessing U-values of existing housing", 6.

[34] Stuart Hay, Nicholas Heath and Gary Pearson, "Technical Paper 17 - Green Deal, Energy Company Obligation and Traditional Buildings" 2013, 9.

[35] Paul Baker, Glasgow Caledonian University, RICH Associate, School of Engineering and Built Environment, interview by author, Glasgow, July 8th, 2013.

[36] Roger Curtis, *INFORM – Damp, Causes and Solutions,* Edinburgh: Historic Scotland, 2007.

[37] Christina Gonzalez-Longo, Conservation Architect, interview by author, July 22nd, 2013 and Jo Parry, Conservation Architect, interview by author, July 19th 2013.

[38] Christina Gonzalez-Longo, interview by author.

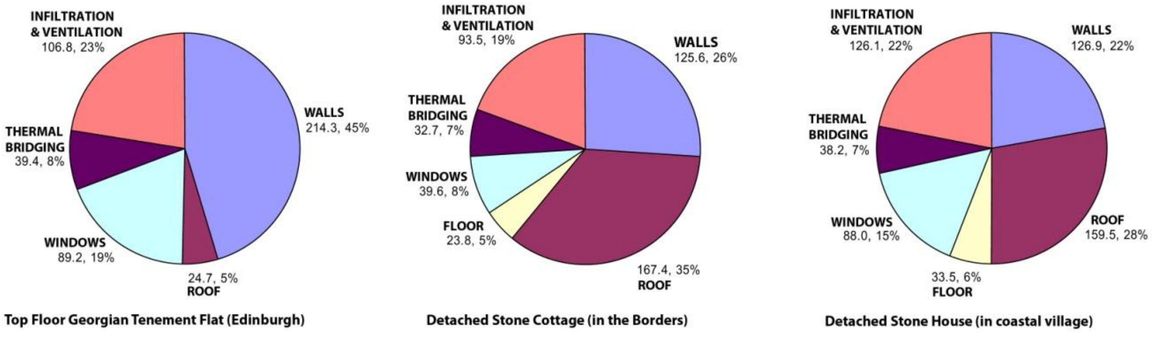
[39] Roger Curtis, interview by author.

[40] Marianne Suhr and Roger Hunt, *Old House Eco Handbook,* 101.

3. Thermal Improvement Options for Traditional Stone Walls

3.1 Advocated Approaches to date on Stone Walls

Most Conservation Architects interviewed for this paper would rate insulating existing stone walls in traditional buildings as a low priority item[1] when it comes to improving overall energy efficiency. This is because there is an understandable reluctance to tamper with the existing building fabric, particularly when it involves the introduction of new materials, which may or may not prove compatible with traditional fabric. The existing fabric may be considered too important architecturally and historically to tamper with, a situation often seen with Edinburgh's many listed buildings in the New Town.[2] Also there is much debate as to whether or not the improvements shown warrant the work and cost involved. There are the existing interior finishes to consider, where lath, plaster, and cornices are still in place, and also the potential loss of space within the rooms if insulation is added to the interior. Simpler solutions such as the replacement of windows and addition of loft insulation are generally considered less intrusive. Historic Scotland carried out a study in 2008[3] to gain an understanding of the percentage of heat lost through various elements of buildings in Scotland. It should be noted that calculated U-Values were used for all elements but it is interesting to see the results generated for different building types. The three pie charts are shown below in figure 9.



Top Floor Georgian Tenement Flat (Edinburgh) **Detached Stone Cottage (in the Borders)** **Detached Stone House (in coastal village)**

Figure 9 Pie Charts showing Heat Loss through various parts of the building

Although this pie chart indicates that in a 'tenement flat' the walls are losing a considerable amount of heat (45% heat loss), the report does not go on to recommend adding insulation to the interior walls but details other possible alterations such as loft insulation and new boilers. It is generally thought that when dealing with a high window wall ratio, typical in a Georgian tenement, the benefits of insulating the walls might not be worth the "technical challenges"[4] involved. However since the publication of this paper Historic Scotland has gone on to explore thermal improvements to stone walls in much greater detail,[5] in the hope of developing solutions that are worth implementing.

A number of factors must be discussed when applying a new layer of internal insulation to an existing stone wall. These are as follows;

- Type of insulation, the main consideration being it's permeability (breathability)
- Provision of an air gap or cavity behind the insulation
- Provision of a VCL (vapour control layer) or AVCL (air and vapour control layer)
- Cold/Thermal bridging

The risk of surface and/or interstitial condensation is the main concern tied to all four points. The type of insulation is important when dealing with a traditional stone wall due to the 'breathable' nature of the existing construction. Modern insulations used in new construction tend to be impermeable, (not 'breathable'), restricting/ prohibiting air and vapour flow through them. They generally have higher thermal capacities than permeable insulations. Impermeable insulation boards have been applied to traditional stone walls, often the rationale behind using these is their high thermal efficiency, cost and availability. When using impermeable insulation a VCL is recommended on the 'warm' side of the insulation. The purpose of the VCL is to minimise the amount of warm air (air holding vapour) passing from the room into the wall. The new insulation is placed directly against the existing stone wall, assuming that the stone wall is dry. This immediately gives rise to two potential failures, moisture ingress from the outside or from the inside. While the VCL operates successfully in theory, its failure usually occurs where it has been breached, for example with wall sockets or wall brackets inserted post construction[6]. Water ingress from the exterior side can occur where the exterior façade has begun to fail from

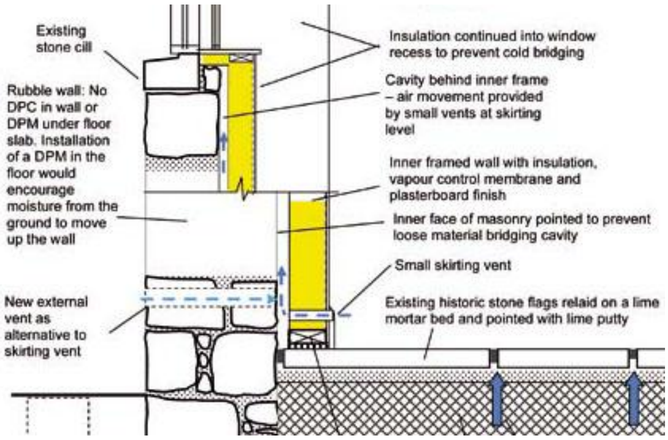
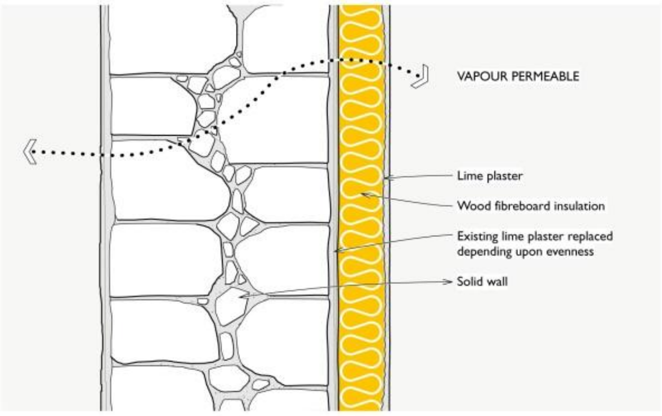


Figure 10 Historic Scotland - Insulation with Cavity (2007)

incorrectly applied renders or broken gutters leading to water flow down the face of the wall. If moisture does move through the wall to the interior side, it becomes trapped in/against the impermeable insulation. One method of mitigating this problem is the inclusion of a cavity between the insulation and the wall, which Historic Scotland has advised in the past (see figure 10).

Conservation Architects[7] nowadays will usually propose a permeable type of insulation, such as wood fibreboard (rigid) because of its ability to allow a degree of air and moisture to move through it. Sustainable materials are becoming an increasingly popular choice for Architects, as they are both environmentally friendly, and in most cases naturally permeable e.g. sheep's wool and hemp. Also with the use of a permeable insulation there is the option to leave out the VCL layer, and apply a 'breathable' lime plaster as the interior wall finish. This approach basically allows the wall to continue to function as it did. The same levels of thermal efficiency may not be achieved (see chart in Appendix F) but the intervention is much more compatible with the existing wall. It is interesting to note that Historic Scotland's diagram (figure 10) taken from the 'Guide to Practitioners' in 2007 has now been super-ceded in their own publications by the approach outlined in the 'Fabric Improvements' publication which recommends choosing from a "wide choice of appropriate vapour permeable insulation materials"[8] and makes no



This shows a fully permeable insulation system using wood-fibre board and lime plaster. A new lime plaster may need to be added to the existing wall to provide an even surface if the existing plaster surface is particularly uneven.

Figure 11 English Heritage - Solid Wall with Permeable Insulation (2012) mention of incorporating a VCL. It remains to be seen what recommendations will be incorporated into the updated version of the 'Guide for Practitioners'. This change has occurred off the back of numerous trials undertaken by the Research Team at Historic Scotland. The results have indicated that the walls, once dry, do not require a VCL, or a cavity, just vapour permeable insulation. English Heritage's guidance is also proposing this option (see figure 11) as is the SPAB (see figure 12).

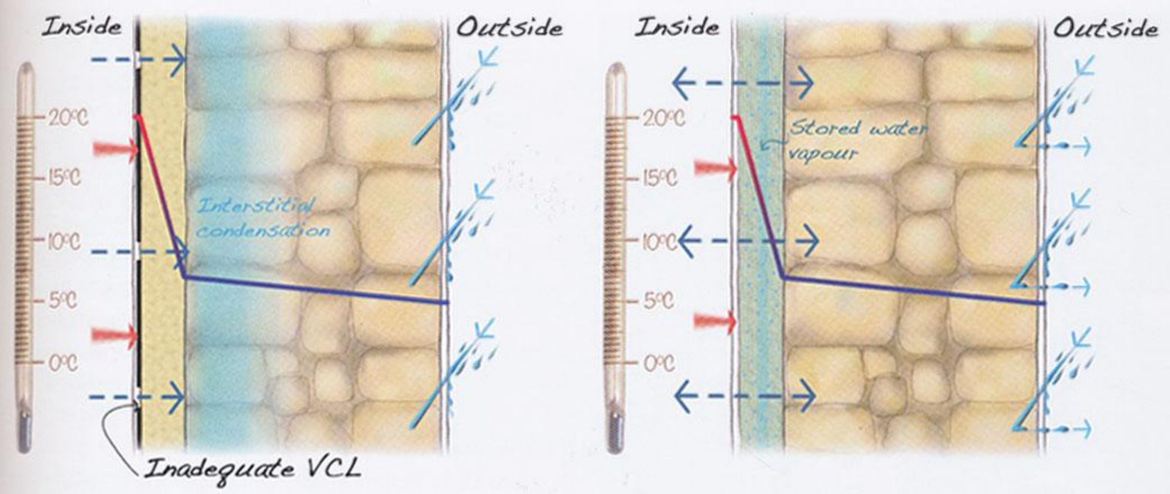


Figure 12 The SPAB - exclusion of VCL

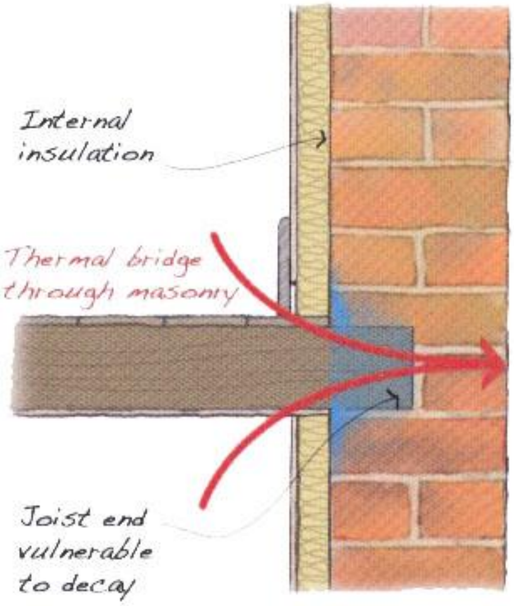


Figure 13 Thermal/Cold Bridging at Floor

The SPAB diagram (figure 12) indicates how much moisture can become trapped leading to interstitial condensation when a VCL performs inadequately. The final point is thermal bridging which can occur where floors interrupt the insulation cover. Here the overall all efficiency of the insulation is compromised due to cold spots, which lose heat rapidly. This is increased risk of condensation at these locations also due to temperature differentials (see figure 13).

Following this outline, a selection of approaches (1-5) will be discussed, which is by no means extensive in nature, nor indicative of all approaches taken;

1. Insulation between timber/metal studs with a plaster(board) finish, i.e. 'dry-lining' (air gap may or may not be incorporated).
2. Insulation directly onto an existing stone wall with or without a plaster finish (no air gap).
3. Insulation applied to the surface of the existing plaster and lath.
4. Insulation in the void behind the existing lath and plaster (usually a 20-40mm gap).
5. Insulation applied to the exterior of the building with render finish (may or may not have air gap)

These five types of insulation correspond with the five types discussed in Historic Scotland's 'Fabric Improvements'[9] publication which references thirteen refurbishment case studies (Appendix E for full list and example case study) carried out recently by Historic Scotland. While the 'Fabric Improvements' publication discusses the findings in these case studies/trials, the following sections are based on the case studies themselves. Figure 14 shows the wall unaltered before the trial. (Note see 'Definitions' for types of insulation).

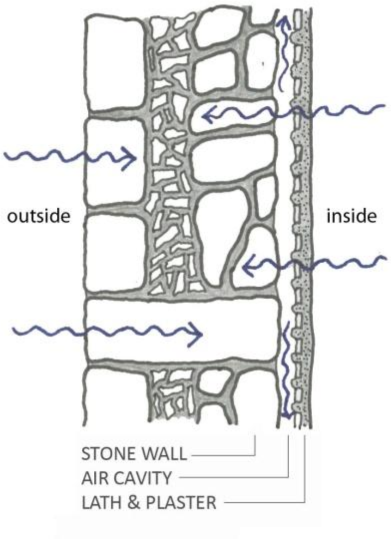


Figure 14 Traditional Stone Wall prior to intervention

1. Insulation between timber/metal studs with a plaster(board) finish, i.e. ‘dry-lining’ (air gap may or may not be incorporated).

Certainly within the residential sector the most common approach taken to improve the thermal capacity of a mass stone wall when it is attempted, has been ‘dry-lining’[10] it. This interior insulation approach is usually taken when existing plaster and lath has already been removed. Timber or metal studs were installed, with soft or rigid insulation placed between them (such as mineral wool) and a layer of plasterboard applied as the finish. It is the most common approach taken in an old unoccupied building, such as a stone cottage, which is being brought back into use and has no interior finish worth retaining. A VCL and/or air gap may be included. Typical ‘dry-lining’ is shown in figure 15, and without an air cavity in figure 16, and application of a permeable insulation is shown in figure 17, with no VCL or air cavity.

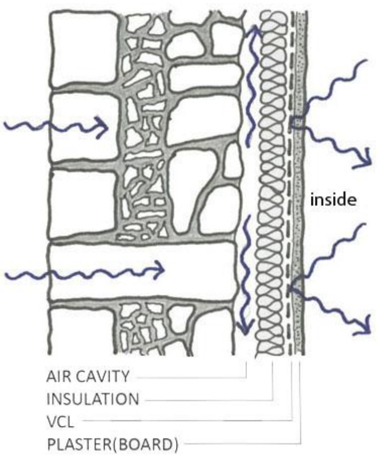


Figure 15 Typical ‘dry-lining’

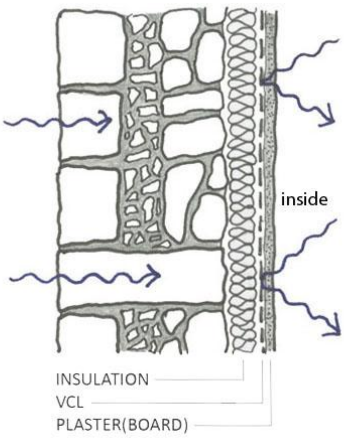


Figure 16 ‘Dry-lining’without air cavity

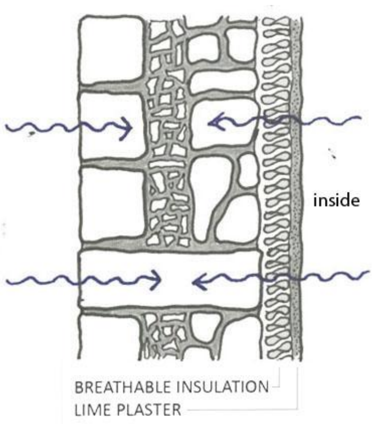


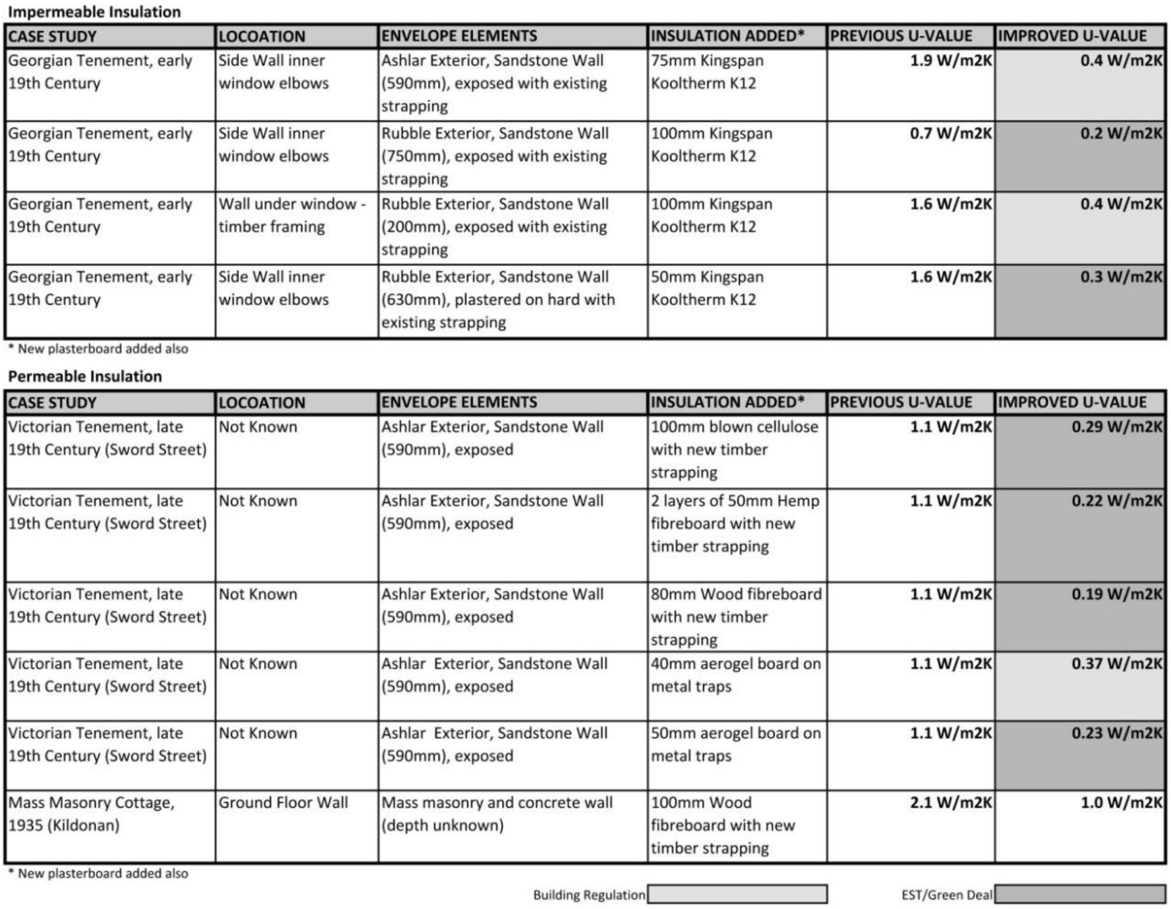
Figure 17 Permeable Insulation

Figure 18 Framing for Insulation

Figure 19 Wood fibreboard insulation

Figure 20 Cellulose insulation

Permeable and impermeable insulations were tested in these trials (see figures 18,19 and 20). In a number of locations Kingspan Kooltherm foil backed insulation was used, which is a rigid impermeable board insulation under and around windows. The motivation for using this seems to have been to provide high efficiency in problem areas, such as around windows, while permeable insulation was used on the main wall areas. The permeable insulations were installed without a VCL or air gap (wood fibreboard, hemp board, polystyrene bead, cellulose and aerogel board). The aerogel board has a "reasonable level of permeability"[11] and so could be used in this type of application. The results are shown in Table 3.1.



Impermeable Insulation

CASE STUDY	LOCOATION	ENVELOPE ELEMENTS	INSULATION ADDED*	PREVIOUS U-VALUE	IMPROVED U-VALUE
Georgian Tenement, early 19th Century	Side Wall inner window elbows	Ashlar Exterior, Sandstone Wall (590mm), exposed with existing strapping	75mm Kingspan Kooltherm K12	**1.9 W/m2K**	**0.4 W/m2K**
Georgian Tenement, early 19th Century	Side Wall inner window elbows	Rubble Exterior, Sandstone Wall (750mm), exposed with existing strapping	100mm Kingspan Kooltherm K12	**0.7 W/m2K**	**0.2 W/m2K**
Georgian Tenement, early 19th Century	Wall under window - timber framing	Rubble Exterior, Sandstone Wall (200mm), exposed with existing strapping	100mm Kingspan Kooltherm K12	**1.6 W/m2K**	**0.4 W/m2K**
Georgian Tenement, early 19th Century	Side Wall inner window elbows	Rubble Exterior, Sandstone Wall (630mm), plastered on hard with existing strapping	50mm Kingspan Kooltherm K12	**1.6 W/m2K**	**0.3 W/m2K**

* New plasterboard added also

Permeable Insulation

CASE STUDY	LOCOATION	ENVELOPE ELEMENTS	INSULATION ADDED*	PREVIOUS U-VALUE	IMPROVED U-VALUE
Victorian Tenement, late 19th Century (Sword Street)	Not Known	Ashlar Exterior, Sandstone Wall (590mm), exposed	100mm blown cellulose with new timber strapping	**1.1 W/m2K**	**0.29 W/m2K**
Victorian Tenement, late 19th Century (Sword Street)	Not Known	Ashlar Exterior, Sandstone Wall (590mm), exposed	2 layers of 50mm Hemp fibreboard with new timber strapping	**1.1 W/m2K**	**0.22 W/m2K**
Victorian Tenement, late 19th Century (Sword Street)	Not Known	Ashlar Exterior, Sandstone Wall (590mm), exposed	80mm Wood fibreboard with new timber strapping	**1.1 W/m2K**	**0.19 W/m2K**
Victorian Tenement, late 19th Century (Sword Street)	Not Known	Ashlar Exterior, Sandstone Wall (590mm), exposed	40mm aerogel board on metal traps	**1.1 W/m2K**	**0.37 W/m2K**
Victorian Tenement, late 19th Century (Sword Street)	Not Known	Ashlar Exterior, Sandstone Wall (590mm), exposed	50mm aerogel board on metal traps	**1.1 W/m2K**	**0.23 W/m2K**
Mass Masonry Cottage, 1935 (Kildonan)	Ground Floor Wall	Mass masonry and concrete wall (depth unknown)	100mm Wood fibreboard with new timber strapping	**2.1 W/m2K**	**1.0 W/m2K**

* New plasterboard added also

Building Regulation ░ EST/Green Deal ▓

Table 3.1 U-Values for Interior Insulation

All U-Values shown were taken in-situ before and after work was carried out. All improvements which achieve a U-Value of 0.7 W/m2K are high-lighted in light grey, as per Table 1.2, this is the recommended U-Value for walls in Conversion projects under the Building Regulations. Improvements which achieved a U-Value of 0.3 W/m2K are high-lighted in dark grey (the recommended EST and Green Deal required U-Value).

It is difficult to compare the impermeable (Kingspan) insulation with the permeable kinds as the Kingspan was used in limited amounts around windows, while the permeable insulation was used on larger wall areas. However it is evident from the Kingspan calculations that the thermal capacity was greatly improved, proving this type of insulation is very efficient.

The permeable insulations show considerable improvement also, with five examples meeting the 0.7 W/m2K U-Value and four of them meeting the EST recommended U-Value of 0.3 W/m2K for refurbishment[12]. This highlights the importance of having an accurate pre-improvement U-Value, as we can see from the 'previous' U-Values that the walls were in fact more efficient than the default values might have shown. Had default values been used, and the improvement calculated on the basis of product sheet information, the 'improved' U-Value would not have been as low. These are encouraging results, once further testing can prove that the wall is continuing to 'breathe' adequately and there is no risk of interstitial condensation. While the aerogel board provided the best result for the thickness shown, it was noted in the trial that it was the most expensive intervention.[13] Where timber or metal strapping (studwork) is used there is also some degree of worry about thermal bridging across the studs, which do not have a layer of insulation over them. One way of mitigating this is to cross batten with an additional layer of insulation. See figure 21.

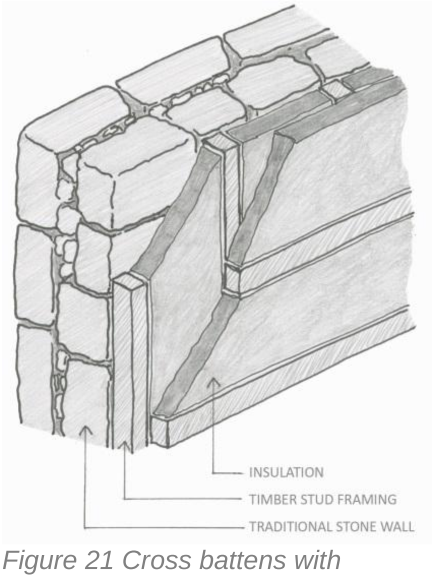


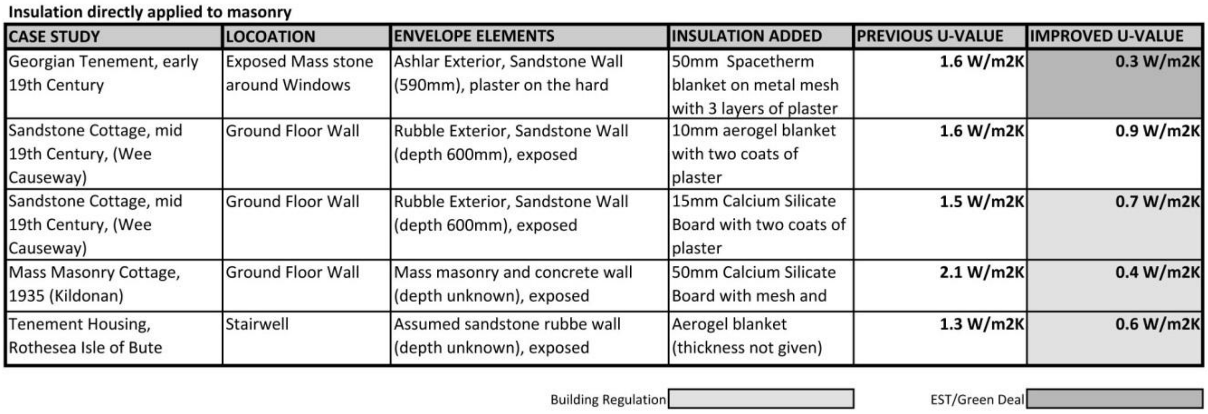
Figure 21 Cross battens with insulation

2. Insulation directly onto an existing stone wall with or without a plaster finish (no air gap).


Figure 22 Aerogel board on masonry


Figure 23 Calcium silicate board

Historic Scotland also tested several newer types of insulation which are applied directly to masonry or plastered masonry (called plaster on the hard) and then finished with a breathable lime plaster. See figures 22 and 23 for examples. The improvements seen are quite good, considering the depth of material used (15mm to 50mm boards), however only one meets the EST U-Value of 0.3 W/m2K. Historic Scotland has stated that this calcium silicate board has sufficient vapour permeability[14] to operate with the existing wall, with no inclusion of an air gap or VCL. for this type of application. See Table 3.2 for results.


Insulation directly applied to masonry

CASE STUDY	LOCOATION	ENVELOPE ELEMENTS	INSULATION ADDED	PREVIOUS U-VALUE	IMPROVED U-VALUE
Georgian Tenement, early 19th Century	Exposed Mass stone around Windows	Ashlar Exterior, Sandstone Wall (590mm), plaster on the hard	50mm Spacetherm blanket on metal mesh with 3 layers of plaster	**1.6 W/m2K**	**0.3 W/m2K**
Sandstone Cottage, mid 19th Century, (Wee Causeway)	Ground Floor Wall	Rubble Exterior, Sandstone Wall (depth 600mm), exposed	10mm aerogel blanket with two coats of plaster	**1.6 W/m2K**	**0.9 W/m2K**
Sandstone Cottage, mid 19th Century, (Wee Causeway)	Ground Floor Wall	Rubble Exterior, Sandstone Wall (depth 600mm), exposed	15mm Calcium Silicate Board with two coats of plaster	**1.5 W/m2K**	**0.7 W/m2K**
Mass Masonry Cottage, 1935 (Kildonan)	Ground Floor Wall	Mass masonry and concrete wall (depth unknown), exposed	50mm Calcium Silicate Board with mesh and	**2.1 W/m2K**	**0.4 W/m2K**
Tenement Housing, Rothesea Isle of Bute	Stairwell	Assumed sandstone rubbe wall (depth unknown), exposed	Aerogel blanket (thickness not given)	**1.3 W/m2K**	**0.6 W/m2K**

Building Regulation ░ EST/Green Deal ▓

Table 3.2 Insulation directly masonry

3. Insulation applied to the surface of the existing plaster and lath.

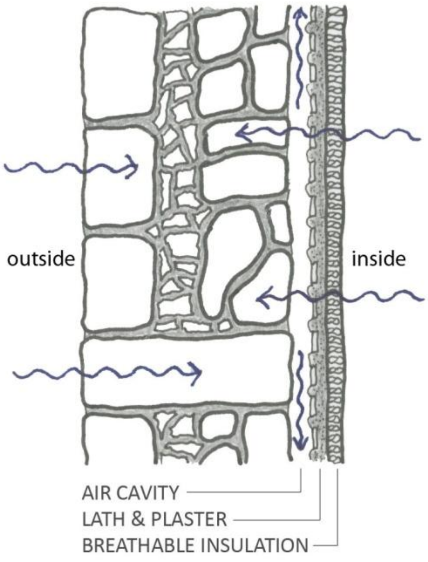
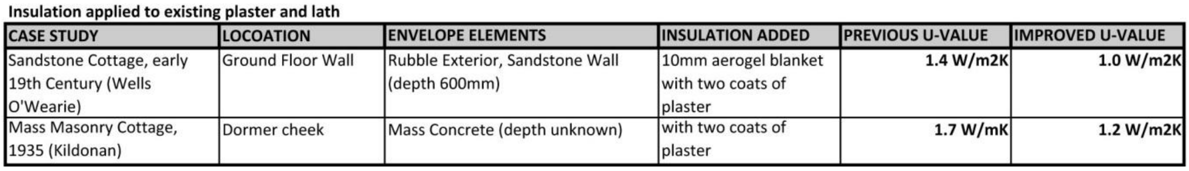


Figure 24 Insulation on plaster

As noted above aerogel is quite expensive to purchase. Here 10mm boards were applied directly to the plaster and then plastered overtop (see figure 24). The rationale behind this approach is assumed to be that all the existing fabric is retained, with minimum additional depth to the wall. However the improvement in terms of thermal gain is very modest.

This type of application would have to be scrutinised carefully in terms of cost and long term payback, particularly in relation to other interventions that might be possible for similar costs. Neither result meets the Building Regulation U-Value or the EST U-Value. See Table 3.3 for results.


Insulation applied to existing plaster and lath

CASE STUDY	LOCOATION	ENVELOPE ELEMENTS	INSULATION ADDED	PREVIOUS U-VALUE	IMPROVED U-VALUE
Sandstone Cottage, early 19th Century (Wells O'Wearie)	Ground Floor Wall	Rubble Exterior, Sandstone Wall (depth 600mm)	10mm aerogel blanket with two coats of plaster	**1.4 W/m2K**	**1.0 W/m2K**
Mass Masonry Cottage, 1935 (Kildonan)	Dormer cheek	Mass Concrete (depth unknown)	with two coats of plaster	**1.7 W/mK**	**1.2 W/m2K**

Table 3.3 Application of aerogel board.

4. Insulation in the void behind the existing lath and plaster (usually a 20-40mm gap).

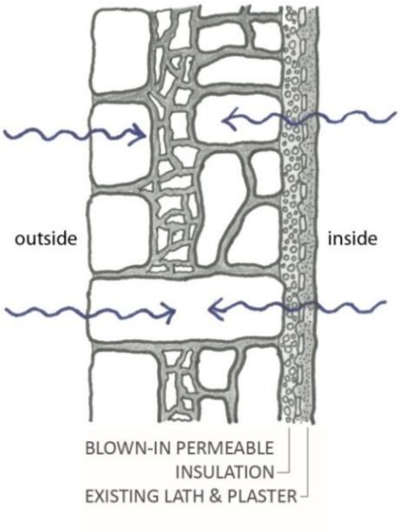


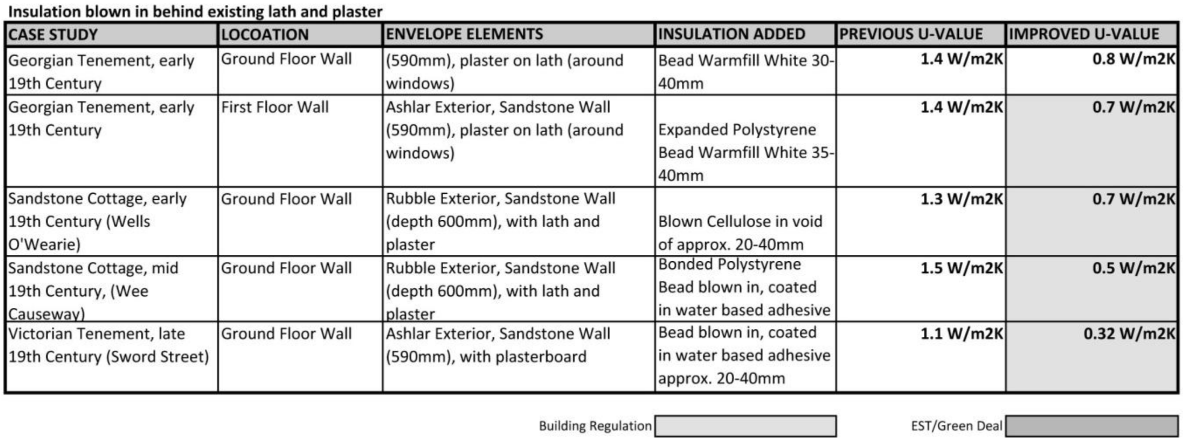
Figure 25 Blown bead insulation

This is probably the most controversial intervention as it proposes filling an existing cavity in a wall, whose operational capacity is unknown. Typically there is a 20-40mm cavity behind the existing lath and plaster. The cavity is filled with vapour permeable blown insulation (see figure 25,26 and 27) through a series of holes in the plaster.

Figure 26 Blown cellulose insulation

Figure 27 Blown polystyrene bead insulation

There a number of immediate concerns. One, it is difficult to ascertain if there are obstructions throughout the cavity which could lead to un-even coverage within the wall, which in turn could lead to thermal bridging. Two, the spread of the insulation must be controlled, ensuring it does not get into the foundations, or into the roof space, and three, the functionality of the wall may be compromised. If the cavity is operating as a ventilation space, and is mitigating condensation build-up on the warm side of the wall, filling the cavity will lead to issues with interstitial condensation. These concerns were raised by a number of architects[15] interviewed. Historic Scotland, together with Adam Dudley Architects[16], is fully aware of all these concerns and is testing this intervention in order to determine how well-founded these concerns really are. The results (Table 3.4) show an acceptable improvement in U-Values, but none of the walls meet the EST U-Value.



Insulation blown in behind existing lath and plaster

CASE STUDY	LOCOATION	ENVELOPE ELEMENTS	INSULATION ADDED	PREVIOUS U-VALUE	IMPROVED U-VALUE
Georgian Tenement, early 19th Century	Ground Floor Wall	(590mm), plaster on lath (around windows)	Bead Warmfill White 30-40mm	**1.4 W/m2K**	**0.8 W/m2K**
Georgian Tenement, early 19th Century	First Floor Wall	Ashlar Exterior, Sandstone Wall (590mm), plaster on lath (around windows)	Expanded Polystyrene Bead Warmfill White 35-40mm	**1.4 W/m2K**	**0.7 W/m2K**
Sandstone Cottage, early 19th Century (Wells O'Wearie)	Ground Floor Wall	Rubble Exterior, Sandstone Wall (depth 600mm), with lath and plaster	Blown Cellulose in void of approx. 20-40mm	**1.3 W/m2K**	**0.7 W/m2K**
Sandstone Cottage, mid 19th Century, (Wee Causeway)	Ground Floor Wall	Rubble Exterior, Sandstone Wall (depth 600mm), with lath and plaster	Bonded Polystyrene Bead blown in, coated in water based adhesive	**1.5 W/m2K**	**0.5 W/m2K**
Victorian Tenement, late 19th Century (Sword Street)	Ground Floor Wall	Ashlar Exterior, Sandstone Wall (590mm), with plasterboard	Bead blown in, coated in water based adhesive approx. 20-40mm	**1.1 W/m2K**	**0.32 W/m2K**

Building Regulation

EST/Green Deal

Table 3.4 Insulation in existing cavity

This intervention is also considered cost effective with minimal disruption to the home owner, and also (if successful) minimum disruption to the aesthetic[17]. This intervention type, among others, is currently under continuous assessment at the Dumfries Estate Garden Bothy[18]. Sensors have been installed to measure the relative humidity levels on and in the walls which will indicate if a problem with condensation is going to arise and to date a gradual decrease in the relative humidity has been noted (see Appendix G).

5. Insulation applied to the exterior of the building with render finish (may or may not have air gap)

Externally insulating a mass stone wall is widely considered to provide a better result in terms of thermal efficiency[19] as it provides much more uniform coverage of the wall, eliminating thermal bridging, and also utilises the existing stone wall as thermal mass. It also has the advantage of providing a new protective skin to the building. It is however more complicated to install, has a visual impact on the exterior and requires planning permission. Also in the majority of cases in Scotland, traditional stone buildings have exposed facades, and it would be completely inappropriate to cover these with a new skin. This type of application is most suited to buildings with facades that are not architecturally/historically significant, or are already rendered externally (see figure 28).

Within the Scottish context it is very difficult to find examples of exterior insulation due to the proliferation of exposed stone buildings in traditional stock. There may be some cases in which external insulation might be utilised though. For instance, as part of a Historic Scotland trial (Case Study 13) 40mm wood fibreboard and plaster finish was applied to the external wall of a pend in Glasgow. Insitu U-Values showed a reduction from 1.3 W/m2K (before intervention) to 0.4 W/m2K

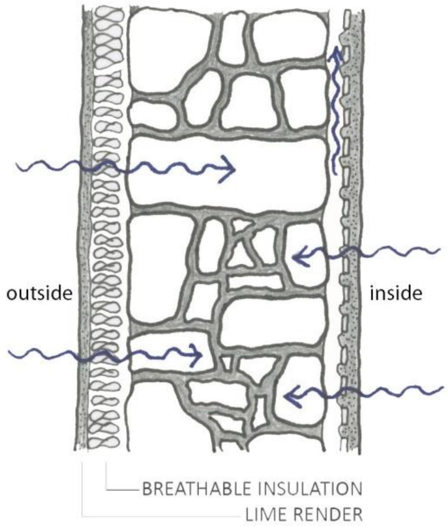
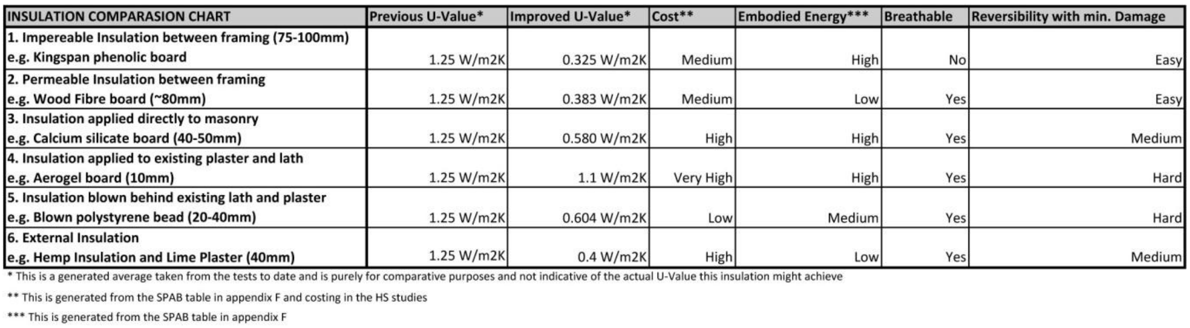


Figure 28 External Insulation

after.[20] According to Roger Curtis at Historic Scotland[21], there may be future cases where it could be utilised, on the back of tenements in Conservation areas, or on gable ends which may be suffering from rain and wind exposure. This system does have the added benefit of serving as a protective skin, and with current studies underway using permeable systems such as hemp-lime or wood-fibre batt, with a 'breathable' lime render, there are suitable options for older buildings. It should be noted that when used externally often cement must be added to the hemp-lime mix[22], and there are some questions about the viability of using it in the wet Scottish climate.[23] Unfortunately it was not possible to locate an example of an externally insulated traditional building in Edinburgh for this study, but the SPAB recently carried out a case study on a nineteenth century cobb cottage which involved the removal of 40mm of cement render and replacement with 40mm of insulating lime render[24]. The improvement thermally was minor, only a 0.04 W/m2K was recorded from insitu readings. However according to the SPAB, using calculated U-Values a mass stone wall can be improved to 1.2 W/m2K with the application of 50mm of insulating lime hemp plaster, and improved up to 0.3 W/m2K with 100mm of wool/hemp or wood wool board.[25]

3.2 Findings

It is difficult to generate comparative analysis for these approaches due to the wide range of parameters under which insulation can be assessed, e.g. cost, sustainability of material, U-Value, difficulty of application, potential for reversibility and damage to existing fabric. This further enforces the need to assess buildings always on a case by case basis, gaining a full understanding of how the building is operating as is, and then developing a list of potential interventions based on the improvement requirements of that building. The insulations analysed above have been compared in a rudimentary chart (table 3.5). A more comprehensive chart from the SPAB is shown in Appendix E.



INSULATION COMPARASION CHART	Previous U-Value*	Improved U-Value*	Cost**	Embodied Energy***	Breathable	Reversibility with min. Damage
1. Impereable Insulation between framing (75-100mm) **e.g. Kingspan phenolic board**	1.25 W/m2K	0.325 W/m2K	Medium	High	No	Easy
2. Permeable Insulation between framing **e.g. Wood Fibre board (~80mm)**	1.25 W/m2K	0.383 W/m2K	Medium	Low	Yes	Easy
3. Insulation applied directly to masonry **e.g. Calcium silicate board (40-50mm)**	1.25 W/m2K	0.580 W/m2K	High	High	Yes	Medium
4. Insulation applied to existing plaster and lath **e.g. Aerogel board (10mm)**	1.25 W/m2K	1.1 W/m2K	Very High	High	Yes	Hard
5. Insulation blown behind existing lath and plaster **e.g. Blown polystyrene bead (20-40mm)**	1.25 W/m2K	0.604 W/m2K	Low	Medium	Yes	Hard
6. External Insulation **e.g. Hemp Insulation and Lime Plaster (40mm)**	1.25 W/m2K	0.4 W/m2K	High	Low	Yes	Medium

* This is a generated average taken from the tests to date and is purely for comparative purposes and not indicative of the actual U-Value this insulation might achieve

** This is generated from the SPAB table in appendix F and costing in the HS studies

*** This is generated from the SPAB table in appendix F

Table 3.5 Insulation Comparison Chart

The application of interior breathable insulation between a new stud system (item no 2) still seems to be the best solution for stone wall insulation. As discussed above with the removal of the previously recommended cavity, the rooms will not lose as much interior square footage, so this is a positive development. Unfortunately though this approach is not suitable where the existing interior is being retained. In cases where the existing interior is being retained item no. 5 shows some good results. This approach is also relatively quick, easy and inexpensive, but is still in the preliminary stages of testing and is treated suspiciously by many in the Conservation Sector as it directly disrupts the existing fabric and how the wall is operating.

Application of insulation directly onto existing lath and plaster (item 4) is at present too ineffective and expensive to really be considered a good option. It is also not suitable in cases where original historic plaster is in place.

External insulation certainly in theory has provided good results but unfortunately isn’t practicable in many cases in Scotland. However there are options where the insulating lime render (40mm or less) could be used, doubling as a means to provide a new protective skin on a building which has cement render removed from it, or requires a new lime coat. More research is needed in this area, to ensure it is suited to the Scottish climate.

As mentioned Paul Baker is currently undertaking testing of relative humidity levels in situ in some of the case studies carried out by Historic Scotland[26] to determine if condensation could become a problem between the stone wall and new insulation over time. Results so far have been quite good, with initial numbers staying within the required levels. Continuous testing is currently underway at the Garden Bothy in Dumfries.[27] This is an interesting case study to monitor as the whole building was improved rather than just one room. Sensors have been installed in four rooms which have had three types of insulation applied. Levels were quite high in some locations 18 months ago, but a very gradual decrease has been seen since then. (See Appendix G for detailed results to date). According to Baker the walls may not have been fully dry prior to the addition of the insulation, due to some long term leaking in the building,[28] so some degree of 'drying out' might be underway.

3.3 Theory versus Practice

These various approaches give rise to an interesting debate within the Building Conservation Sector, where one sees a slight divide between theory and practice. Several of the Conservation Architects interviewed exercised caution regarding the removal of the air cavity and VCL (though they stressed the need to assess the wall in question first as conditions vary from wall to wall). So it would appear the incorporation of a cavity and a VCL is still considered a good cautionary measure, even with the use of permeable insulation.[29] The rationale behind this seems to be the desire to minimise impact to the existing stone wall, in keeping with the SPAB manifesto, "to resist all tampering with either the fabric or ornament of the building as it stands".[30] Maintaining an air gap is the surest way of divorcing the new insulation and plasterboard from the existing wall, framing it out to form an almost separate sub-structure. With regard to walls with existing lath and plaster in place, the SPAB approach would be to leave them as is, an approach still advocated by several Conservation Architects interviewed.[31] Historic Scotland's trials with insulation applied to plaster, or behind it, whether or not effective in terms of energy efficiency, also raise the bigger question of what is deemed appropriate intervention to existing fabric.

BS:5250, the British Standard dealing with condensation control advocates the use of an AVCL (Air Vapour Control Layer) on the warm side of insulation on a 'solid masonry wall'[32] though this is under the assumption that less permeable insulation is used. However the Architects interviewed also noted that in general the construction industry is slow to adapt to change and Architects and Contractors need to be entirely convinced of new approaches, through comprehensive studies, guidance and research, before implementing them. This is particularly the case when past approaches have been recommended by very reliable sources such as in comprehensive handbooks like 'The Care and Conservation of Georgian Houses'.[33] While several preliminary case studies have been undertaken, and there is much product information online, there is no official guidance in place yet relating to this. Further detailed study and research should be undertaken to ascertain what insulations work well without a VCL/AVCL and air cavity on traditional masonry walls and the findings should be incorporated into official guidance.

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[1] Eleanor Egan, Simpson & Brown Architects, Fiona MacDonald, Conservation Architect at Edinburgh World Heritage Trust, Jo Parry, Hypostyle Architects and Natasha Huq Adam Dudley Architects, interviewed by author (see 'Acknowledgements' page for dates).

[2] In the case of Edinburgh's New Town, which includes many listed buildings of high Architectural merit "it is not practical to insulate walls…it is certainly possible to insulate the roof spaces and the basement floors" Davey, et al, *The Care and Conservation of Georgian Houses – A maintenance manual for Edinburgh New Town,* 4th Rev., Oxford, Butterworth-Heinemann, 1995, xxii.

[3] David Jenkins, "Technical Paper 4 - Energy Modeling In Traditional Scottish Houses (EMITSH), Historic Scotland & Heriot Watt University, November 2008, http://www.historic-scotland.gov.uk/technicalpapers, (accessed 24th March 2013).

[4] Marianne Suhr and Roger Hunt, *Old House Eco Handbook,* 103.

[5] Historic Scotland website, Refurbishment Case Studies 1-13, http://www.historic-scotland.gov.uk/index/heritage/technicalconservation/conservationpublications/refurbcasestudies.htm (accessed May 10th, 2013).

[6] Colin Wishart, interview by author.

[7] Eleanor Egan, Simpson & Brown Architects, Fiona MacDonald, Conservation Architect at Edinburgh World Heritage Trust, Jo Parry, Hypostyle Architects and Natasha Huq Adam Dudley Architects, interviewed by author

[8] Moses Jenkins, *Fabric Improvements for Energy Efficiency in Traditional Buildings*, 25

[9] Ibid., 20.

[10] Sustainable Energy Ireland, *Retrofitted Passive Homes – Guidelines for Upgrading Existing Dwellings in Ireland to Passivhaus Standard,* (Dublin: Sustainable Energy Ireland, 2009), 29

[11] Jenkins, Moses, ""Refurbishment Case Study 3 – Wee Causeway, Culross", Historic Scotland, 2012, http://www.historic-scotland.gov.uk/index/heritage/technicalconservation/conservationpublications/refurbcasestudies.htm (accessed June 6th, 2013), 6.

[12] Energy Saving Trust, "CE138 - Energy Efficient Historic Homes – Case Studies", 2005, http://www.energysavingtrust.org.uk/Publications2/Housing-professionals/Refurbishment/Energy-efficient-historic-homes-case-studies-2005-edition (accessed online 12th June 2013), 4.

[13] Jenkins, Moses, ""Refurbishment Case Study 4 – Sword Street, Glasgow", Historic Scotland, 2012, http://www.historic-scotland.gov.uk/index/heritage/technicalconservation/conservationpublications/refurbcasestudies.htm (accessed June 6th, 2013), 10.

[14] Jenkins, Moses, "Refurbishment Case Study 3 – Wee Causeway, Culross", 10.

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[15] Eleanor Egan, Simpson & Brown Architects, Fiona MacDonald, Conservation Architect at Edinburgh World Heritage Trust, Jo Parry, Hypostyle Architects and Natasha Huq Adam Dudley Architects, interviewed by author

[16] Natasha Huq, interview by author.

[17] Ibid.

[18] Jenkins, Moses, "“Refurbishment Case Study 8– Garden Bothy, Cumnock”, Historic Scotland, 2012, http://www.historic-scotland.gov.uk/index/heritage/technicalconservation/conservationpublications/refurbcasestudies.htm (accessed June 6th, 2013).

[19] Energy Saving Trust, “Energy Efficiency Best Practice in Housing - Refurbishing dwellings with solid walls”, February 2004, http://regulations.completepicture.co.uk/pdf/Energy%20Conservation/Best%20Practice%20Guidance%20and%20Case%20Studies/Refurbishing%20dwellings%20with%20solid%20walls.pdf (accessed June 6th, 2013), 2. Marianne Suhr and Roger Hunt, Old House Eco Handbook, 104.

[20] Moses Jenkins, *Fabric Improvements for Energy Efficiency in Traditional Buildings*, 26.

[21] Roger Curtis, interview by author.

[22] M. McKee, “The Thermal Improvement of Historic Dwellings”. Master’s thesis, University of Edinburgh, 2011, 40 & 41.

[23] Ibid.

[24] Caroline Rye, Cameron Scott and Diane Hubbard, “The SPAB Research Report 2 - The SPAB Building Performance Survey 2012 Interim Report”, October 2012, http://www.spab.org.uk/downloads/SPAB%20Building%20Performace%20Survey%202012%20Report%202.pdfhttp://www.spab.org.uk/downloads/SPAB%20Building%20Performace%20Survey%202012%20Report%202.pdf (accessed July 15th, 2013), 52-71.

[25] Ty-Mawr, “Ecological Building Products, http://www.lime.org.uk/directlinkdownloads/10209Ty-Mawr_insulation.pdf (accessed 28th July 2013), [2].

[26] Jenkins, Moses, “Refurbishment Case Study 8– Garden Bothy, Cumnock”, Historic Scotland, 2012.
Snow, Jessica, "“Refurbishment Case Study 5 – The Pleasance”, Historic Scotland, 2012, http://www.historic-scotland.gov.uk/index/heritage/technicalconservation/conservationpublications/refurbcasestudies.htm (accessed 6th June 2013).

[27] Jenkins, Moses, “Refurbishment Case Study 8– Garden Bothy, Cumnock”.

[28] Paul Baker, interview by author.

[29] Eleanor Egan, interview by author.

[30] Morris, William, “The Manifesto of the SPAB”, 1877, http://www.spab.org.uk/what-is-spab-/the-manifesto/ (accessed August 6th, 2013).

[31] Eleanor Egan, Simpson & Brown Architects, Fiona MacDonald, Conservation Architect at Edinburgh World Heritage Trust, Jo Parry, Hypostyle Architects and Natasha Huq Adam Dudley Architects, interviewed by author

[32] British Standard, “Code of practice for control of condensation in buildings”, BS 5250:2011, 45.

[33] Chapter on ‘Insulation’ recommends inclusion of vapour barriers where new insulation is installed. Davey, et al, *The Care and Conservation of Georgian Houses – A maintenance manual for Edinburgh New Town,* 4th Rev., 1995, 170-174.

4. Thermal Improvement Options for Traditional Slate Roofs

4.1 Advocated Approaches for Slate Roofs

For the purposes of this dissertation two different types of roof space will be discussed, a Scotch slate roof with an unoccupied attic space and a Scotch slate roof with an occupied attic, incorporating a coom ceiling (sloped ceiling under the roof structure). See figure 29.

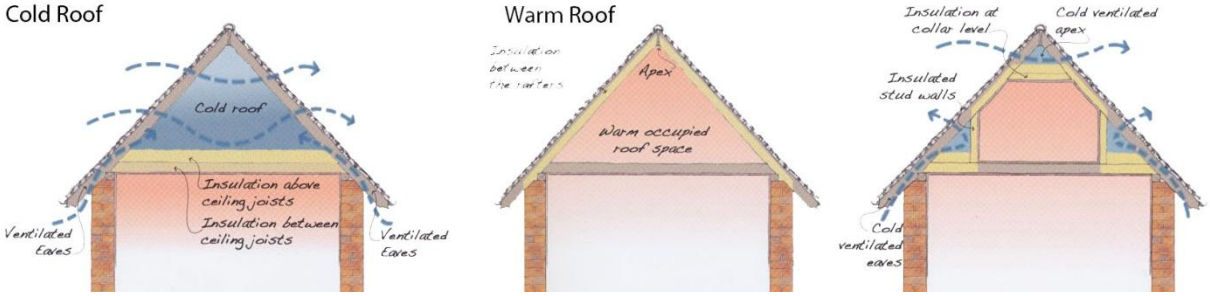


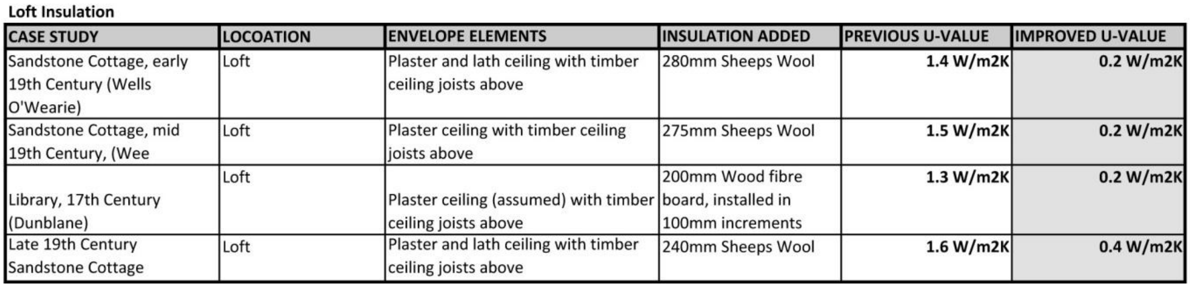
Figure 29 Cold and Warm Roofs

Generally when approaching energy efficiency upgrades in an old house, roof insulation is one of the first measures recommended,[1] as “typically around 25% of heat is lost through the roof of a building.”[2] The main cause of problems after insulating a slate roof is inadequate ventilation. Slate roofs need to be ventilated properly in order to mitigate condensation build up. With the addition of insulation the roof ventilation must be reviewed, to determine if increased ventilation will be required. Existing pathways for ventilation must not be blocked accidentally, and the presence of a non-breathable roofing felt, such as a bitumen one, must be accounted for. Ventilation will be looked at in further detail later in this chapter.

Another cause of condensation is cold/thermal bridging, when warm, moist air meets a cold surface, that was uninsulated, e.g. at a rafter, or where a pipe or roof hatch penetrated the insulation[3] and without adequate means of ventilation for escape, will condense.

1. Loft Insulation

Insulating an unoccupied roof space with loft insulation (insulation laid on the floor of the attic) is simple, easy to install and very effective. If there is an option to install loft insulation it should be undertaken, as it causes minimal disruption and provides significant results. Current practice recommends a minimum of 250mm insulation in lofts to achieve good results.[4] Trials carried out by Historic Scotland indicate low U-values achieved after intervention, using a natural, breathable material (see Table 4.1). The Green Deal recommends loft insulation as number one on its list (see Appendix C) primarily due to how inexpensive it is to install, (return for money is quickly seen) and how effective it is.



Loft Insulation

CASE STUDY	LOCOATION	ENVELOPE ELEMENTS	INSULATION ADDED	PREVIOUS U-VALUE	IMPROVED U-VALUE
Sandstone Cottage, early 19th Century (Wells O'Wearie)	Loft	Plaster and lath ceiling with timber ceiling joists above	280mm Sheeps Wool	**1.4 W/m2K**	**0.2 W/m2K**
Sandstone Cottage, mid 19th Century, (Wee	Loft	Plaster ceiling with timber ceiling joists above	275mm Sheeps Wool	**1.5 W/m2K**	**0.2 W/m2K**
Library, 17th Century (Dunblane)	Loft	Plaster ceiling (assumed) with timber ceiling joists above	200mm Wood fibre board, installed in 100mm increments	**1.3 W/m2K**	**0.2 W/m2K**
Late 19th Century Sandstone Cottage	Loft	Plaster and lath ceiling with timber ceiling joists above	240mm Sheeps Wool	**1.6 W/m2K**	**0.4 W/m2K**

Table 4.1 Loft Insulation

When taking this approach it is imperative to examine the means of ventilation in the roof space. When insulating at loft level, where there previously was no insulation, the roof space is changing from a 'warm' one (where warm air from the rest of the building could previously enter the roof space) to a 'cold' one (warm air is now trapped below the insulation, the roof space is cold). This change in temperature in the roof space can cause problems. If existing ventilation pathways (e.g. roof vents) exist, they can often be sufficient, but the roof should always be closely monitored after insulation is installed to ensure no condensation or mould appears. When insulating at loft level the most effective approach is to put one layer of insulation between the floor joists, and a second layer above, covering all the joists, in order to provide a continuous covering. Generally it is recommended that between 250-275mm of insulation is added in lofts to gain good results.

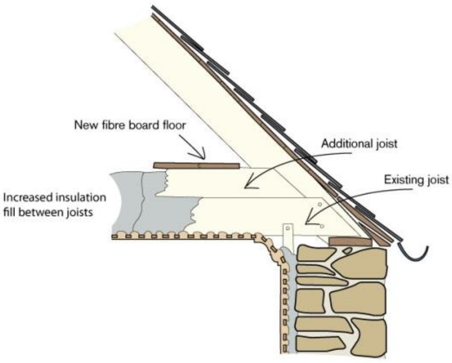


Figure 30 Loft Insulation (Historic Scotland)

Figure 31 Loft insulation covering joists

If the attic requires a floor, a substructure can be built up to accommodate the extra insulation (see figures 30 and 31). If there is little to no means of ventilation then eaves/ridge ventilation, roof vents or application of a suitable breather membrane must be considered.

Vapour barriers are recommended under loft insulation in the ‘Care and Conservation of Georgian Houses’[5] book, either underneath the floor joists (i.e. above the plaster ceiling) or incorporated into rigid insulation boards placed between the joists. However the ‘Guide for Practitioners’ from Historic Scotland does not mention VCL’s under loft insulation.

2. Insulating at Rafter Level

In the case of an occupied roof, insulation is usually installed at roof level, between or under the existing rafters (or, in very rare circumstances, over them). Usually it is installed between the existing rafters, in an effort to maintain as much head height as possible in the attic space. If an existing ceiling is in place, and the owner does not wish to remove it, there are options to install insulation behind it. Historic Scotland looked into this approach in recent trials.

Oftentimes, in domestic work, where the underside of the rafters is open, soft batt or mineral wool type insulation was installed, filling the space entirely, before closing up the underside with plasterboard.[6] While mineral wool insulation is deemed quite ‘breathable, this could lead to

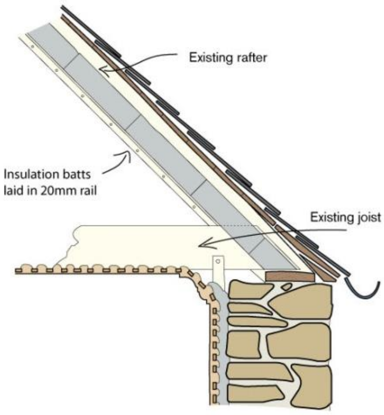


Figure 32 Rafter Insulation (Historic Scotland)

Figure 33 Rigid insulation on site (Doune 2013)

Figure 34 Rigid insulation on site (Edinburgh 2013)

problems as there is no air space left to ventilate the roof. Existing paths of ventilation to ridges/eaves/slate vents may be cut off, and if there is bitumen felt in place, the roof will not be able to vent through it. Nowadays it is more common to see the insertion of a rigid type of insulation between the rafters, with most Architects and Contractors[7] recommending that an air gap of 50mm is retained above it. As rafters can range in depth from 100-210mm this does affect the amount of insulation that can be installed. Rigid insulation recommended for roofs is usually more thermally efficient than the mineral wool type, so less is required to meet the same U-Value.[8] See figure 32, 33 and 34 for application.

Historic Scotland have not yet completed any case studies measuring U-Value improvements of rigid fibreboard between rafters, however according to the Energy Saving Trust on a typical slate roof (default U-Value of 1.6 W/m^{2}K), U-Values of between 0.2 W/m^{2}K and 0.3 W/m^{2}K can be achieved with 50-100mm of wood fibreboard.[9]

As mentioned above Historic Scotland have undertaken trials in coom ceilings where they have blown in insulation behind the existing lath and plaster, in a similar way to the approach taken with walls (see figures 34 and 35). Again the premise is that the bead insulation is sufficiently permeable to allow for air and moisture movement across it. As seen from Table 4.2, both cases yielded good results in terms of U-Values.

Figure 34 Polystyrene bead inserted into void

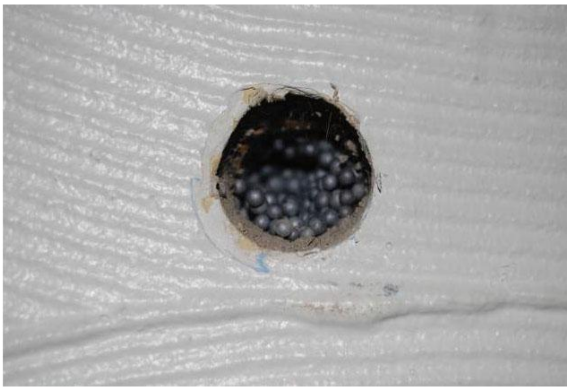
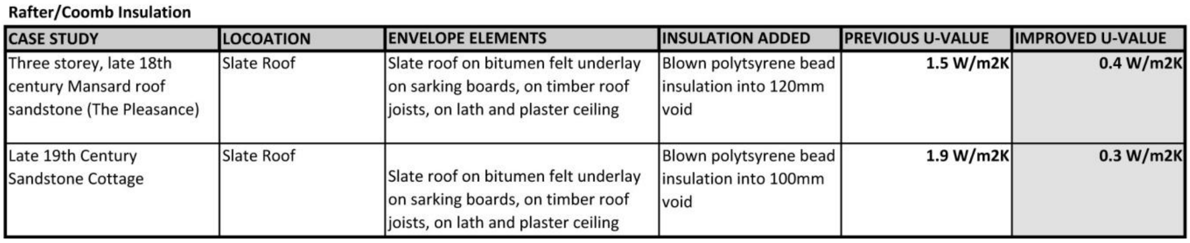


Figure 35 Polystyrene bead in void behind plaster



Rafter/Coomb Insulation

CASE STUDY	LOCOATION	ENVELOPE ELEMENTS	INSULATION ADDED	PREVIOUS U-VALUE	IMPROVED U-VALUE
Three storey, late 18th century Mansard roof sandstone (The Pleasance)	Slate Roof	Slate roof on bitumen felt underlay on sarking boards, on timber roof joists, on lath and plaster ceiling	Blown polytsyrene bead insulation into 120mm void	1.5 W/m2K	0.4 W/m2K
Late 19th Century Sandstone Cottage	Slate Roof	Slate roof on bitumen felt underlay on sarking boards, on timber roof joists, on lath and plaster ceiling	Blown polytsyrene bead insulation into 100mm void	1.9 W/m2K	0.3 W/m2K

Table 4.2 Rafter Insulation

Both roofs have insitu bitumen felt underlays which had to be taken into account in terms of ventilation. In the case of 'The Pleasance' (Case Study 5)[10] it was determined that although "filling the void behind the roof linings without leaving a ventilation gap is not normally advisable"[11] due to condensation risk, the bonded polystyrene bead insulation was considered sufficiently permeable to mitigate moisture build-up. This seems quite risky considering that a bitumen felt is already in place, which is restricting air and vapour flow through the roof. Edinburgh Napier University, along with Historic Scotland, is monitoring this roof at present. Sheep's wool was also added at the eaves in this case study, from the outside, to prevent the bonded bead from spilling out.[12]

For Case Study 12[13], a similar approach was taken in another coom ceiling. However this time failure was noted within weeks, as white mould began to appear on the underside of the sarking within the first year after insulation was installed. It was discovered that some batt insulation, installed under a previous modification, was blocking the eaves ventilation. As the plasterboard was not removed for this work (the bead as blown in behind the plaster) this insulation was not visible at the time of the intervention. This old insulation restricted air movement once the blown bead was added. This indicates how important it is to ventilate the roof. While it is too early to determine if this method of intervention is successful or unsuccessful, it does appear to have a high level of risk attached to it at present.

4.2 Ventilation in Slate Roofs

There are three ways of ventilating a slate roof;

- Provision of roof vents, usually between each rafter in the case of an occupied roof
- Provision of eaves and ridge ventilation – in the form of continuous strip ventilation
- Provision of a fully ‘breathable’ roofing membrane which has been approved for use and meets the Building Regulations as sufficiently ‘breathable’ without additional venting

From a conservation point of view the last option is the least disruptive, though only practical if the roof is to be stripped and re-slated. The first and second options disrupt the character and aesthetic of the slate roof, but are more practical when the slate roof is being kept in place. See figures 37, 38 and 39 for examples.

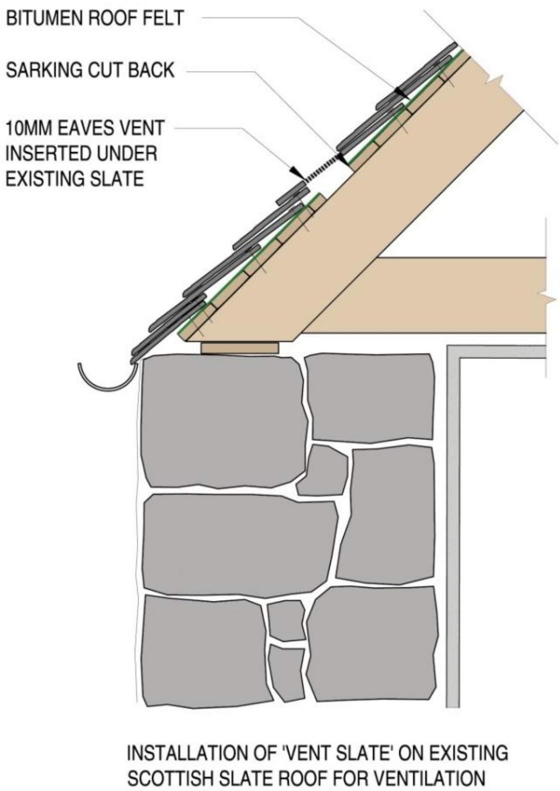


Figure 37 Slate Vent

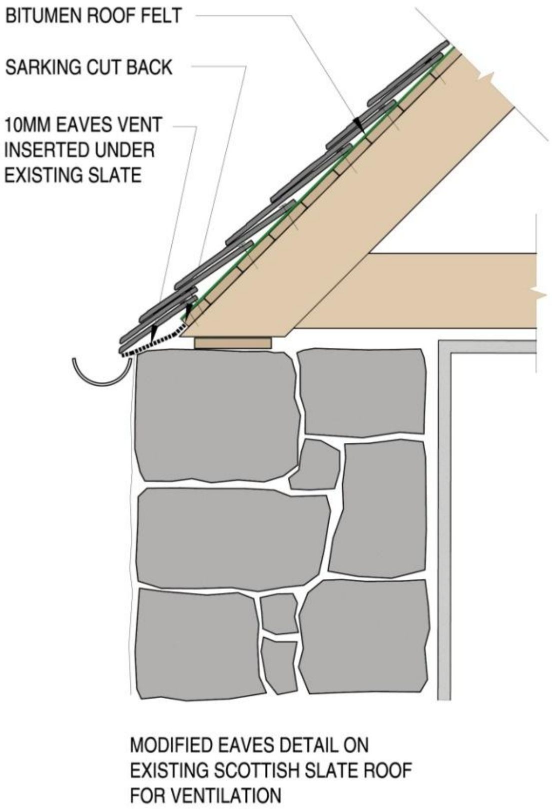


Figure 38 Wall Head Ventilation

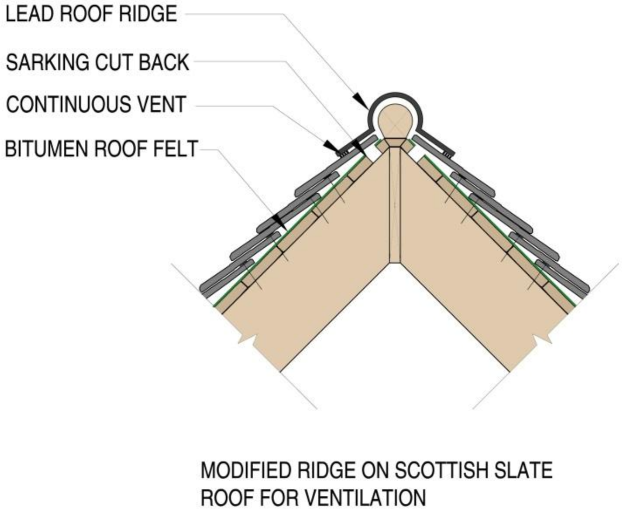


Figure 39 Ridge ventilation

Altering the wall head or putting in vent slates was recommended as the approach to take by Historic Scotland in the Guide for Practitioners,[14] however the 'Fabric Improvements'[15] guide states that "if such materials [breathable roofing membranes] are properly specified, roof vents are not required."[16] This is in reference to a number of membranes which have come on the market in recent years which are sufficiently permeable to allow air and moisture movement through them, without need additional venting. These B.B.A.[17] certified membranes have been approved for use by Building Control in lieu of additional venting on most slate roofs.

The Proctor Group carried out a series of tests and case studies on Scottish Slate Roofs together with the BRE to test their roofing membrane 'Roofshield,' in order to prove that when used in cold and warm roof spaces it provided sufficient ventilation.[18] B.B.A. and NHBC[19] certification states that if correctly installed it can provide sufficient roof ventilation without additional venting.[20] Architects and Contractors[21] usually still recommend an air space is retained under the sarking boards in warm roofs to ensure the air can reach the membrane, however is not required according to the B.B.A. certificate. The advent of this type of roofing membrane is an important development, as if proven successful long-term, means far less modification to traditional Scottish slate roofs (no alterations at the wall-head, ridge, or removal of slates to accommodate slate vents). It is in fact an intervention much more in keeping with conservation ideology, and is also reversible.

In order to gain a different viewpoint on insulating slate roofs and to gain a better understanding of the use of 'breathable' roofing membranes a number of interviews with roofing contractors were conducted.[22] General consensus among the contractors was that if stripping a slate roof is required, the installation of a permeable roofing membrane (all recommended Roofshield) to provide ventilation was much simpler than adding eaves/ridge venting or slate vents, and more cost effective. One issue pointed out by two of the roofers was that even with the addition of eaves/ridge ventilation or slate vents, there were still pockets of the roof e.g. around a roof hatch that may get overlooked, and may not have sufficient ventilation near or around it.[23] However with a breathable felt covering the whole roof, there is more confidence that the roof is evenly ventilated. These contractors still recommend leaving a gap above any insulation installed between the rafters to facilitate this air movement.[24]

Examples of modified eaves roofing details (by contractor W.D. Cameron) are shown in figures 40 and 41. Wall heads were cut back, or in more complicated situations (figure 41) the eave was rebuilt to accommodate venting. This roofer now advocates using only a breather membrane when he re-slates a roof for venting, finding it more reliable and effective than modifying the eave/ridge or inserting vents.[25]

A typical detail used by Simpson and Brown Architects is shown in figure 42, who, to date, have advocated a cautionary approach, providing an air gap and venting at eaves and ridge, along with a breather membrane. They are not adverse to using only a breather membrane, but are nervous about applying it on complicated roof profiles. They still recommend always incorporating an airgap above the insulation.[26]

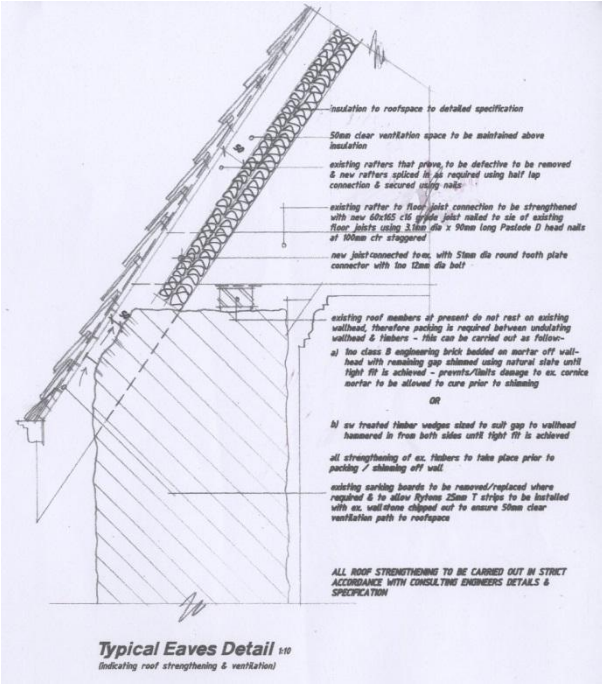


Figure 40 Detail of eaves venting (contractor sketch)

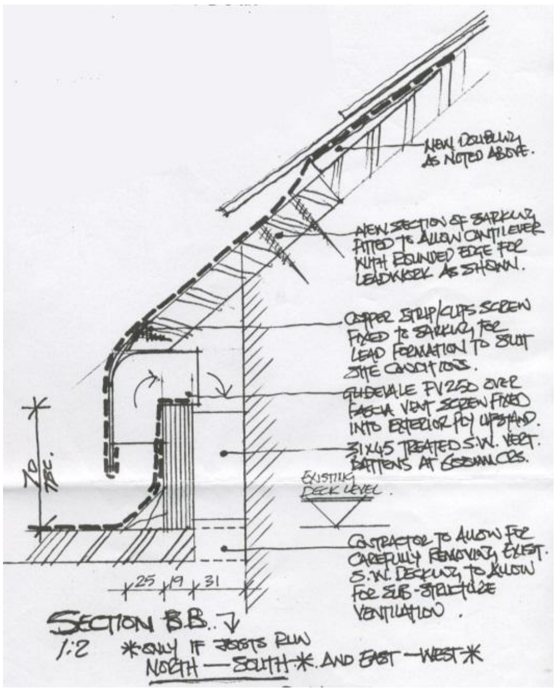
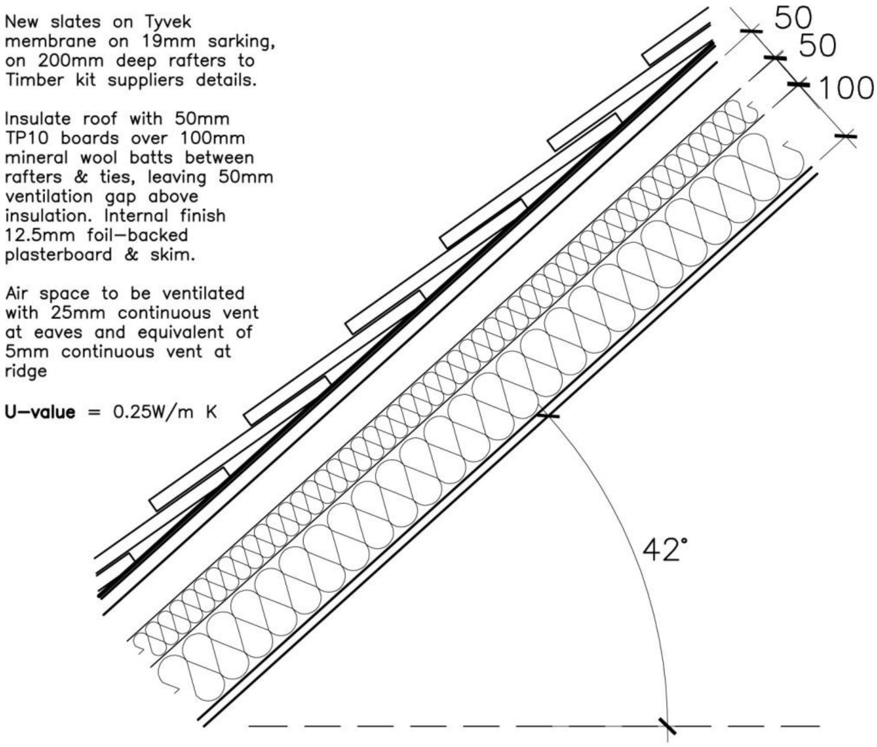


Figure 41 Modified eave (contractor sketch)


New slates on Tyvek membrane on 19mm sarking, on 200mm deep rafters to Timber kit suppliers details.

Insulate roof with 50mm TP10 boards over 100mm mineral wool batts between rafters & ties, leaving 50mm ventilation gap above insulation. Internal finish 12.5mm foil–backed plasterboard & skim.

Air space to be ventilated with 25mm continuous vent at eaves and equivalent of 5mm continuous vent at ridge

U–value = 0.25W/m K

Figure 42 Roof insulation detail (Simpson and Brown)

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[1] In Top 5 Tips, number 1 is ‘insulate your loft’, EWHT, Historic Home Guide, Energy Efficiency, 2.

[2] Moses Jenkins, *Fabric Improvements for Energy Efficiency in Traditional Buildings*, 2012.

[3] English Heritage, *Energy Efficiency and Historic Buildings – Insulating Roofs at Ceiling Level,* (London: English Heritage, 2012), 9.

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[4] Changeworks, "Energy Heritage: A guide to improving energy efficiency in historic and traditional homes", 2008, http://www.changeworks.org.uk/uploads/83096-EnergyHeritage_online1.pdf (accessed April 4th, 2013), 47.

[5] Davey, Andy et al, *The Care and Conservation of Georgian Houses – A maintenance manual for Edinburgh New Town,* 4th Rev., Oxford, Butterworth-Heinemann, 1995, 172-173.

[6] Craig Cameron interview, interview by author, in reference to work by other roofers in the trade

[7] Graeme Miller, Craig Cameron, Scott McDonald, interview by author.

[8] See Table 4.1 for U-values of insulation types

[9] Energy Saving Trust, "CE309 – Sustainable Refurbishment", 2010, http://www.energysavingtrust.org.uk/Publications2/Housing-professionals/Refurbishment/Sustainable-Refurbishment-2010-edition (accessed June 9th, 2013), 19 & 20.

[10] Snow, Jessica, "Refurbishment Case Study 5 – The Pleasance", Historic Scotland, 2012,

[11] Ibid., 15

[12] Ibid., 12.

[13] Historic Scotland, "Refurbishment Case Study 12 - Main Street, Newtongrange, Edinburgh", Historic Scotland, DRAFT, September 2012, word document provided by Roger Curtis, Historic Scotland, 8th August 2013.

[14] Guide for Practitioners

[15] Moses Jenkins, *Fabric Improvements for Energy Efficiency in Traditional Buildings*, 2012.

[16] Ibid., 9

[17] B.B.A. British Board of Agrement. "BBA Approval is recognised by building control, government departments, architects, local authorities, specifiers, and industry insurers like the NHBC" Depending on the roof size and complexity there are calculations in place to ensure the roof can be adequately without additional venting. http://www.bbacerts.co.uk/ (accessed 25th July 2013).The certificates make particular reference to cold and warm pitched roofs, and to roofs with sarking boards as opposed to battens. (Certificates 96/3220 and 99/3648).

[18] The Proctor Group, "Roofshield-the breathable, water resistant membrane", http://www.proctorgroup.com/Portals/0/literature/condensation-control/Proctors%20-%20Roofshield%20Technical%20Guide.pdf, (accessed 25th July 2013).

[19] National House Building Council

[20] The Proctor Group, "Roofshield-the breathable, water resistant membrane", 7 & 11.

[21] Eleanor Egan, Fiona McDonald, Natasha Huq, Craig Cameron, Graeme Miller, Scott MacDonald

[22] Craig Cameron, Graeme Miller, Scott MacDonald, interview by author

[23] Craig Cameron, interview by author

[24] Craig Cameron, Graeme Miller, Scott MacDonald, interview by author

[25] Craig Cameron, interview by author

[26] Eleanor Egan, interview by author

5. Conclusion

Policy change and new legislation has certainly done much to bring the issue of energy efficiency to the forefront of many minds in the Building Conservation Sector. There are varied opinions on the type or extent of intervention suitable for traditional buildings, however all parties involved seem to now acknowledge the importance of doing something. At present this seems to be the most that the SBSA and the Local Authorities can strive for, short of developing mandatory minimums for traditional buildings, something that everyone seems to agree, should not be undertaken. Instead, detailed, official guidance, which Architects and Owners can utilise, is what's required. While this has begun ('Guide to Practitioners') much more needs to be generated in the area of energy efficiency for traditional buildings. Conservation Architects are wary of new approaches which could be detrimental to existing fabric, and they are reluctant to follow recommendations from bodies which have different vested interests, (e.g. contractors, energy assessors, product suppliers and even the SBSA). This is still a relatively new area of work for many of them; the integration of energy efficient design measures in building conservation projects. While aware of more recent approaches, many have not yet had the opportunity to implement them, and are wary of doing so.

In new construction the integration of Sustainability into construction has been relatively straightforward, as research groups have forged ahead with new materials and methods to create highly efficient buildings. Practitioners can work under the requirements of the Regulations or to parameters set out by groups such as Passivhaus.[1] This is not so easy in the world of Building Conservation, where the practitioner is now faced with finding a balance between Conservation and Sustainable intervention, two concepts which are compatible in theory (as established in the 'Abstract') but are at times in conflict in practice. Historic Scotland is in a prime position to alleviate these fears and bring together guidance which can be relied upon by all parties, as their mandate is to protect historic fabric, while also taking "the lead in researching and promoting energy efficiency in traditional buildings."[2]

As seen with the advent of breathable roofing membranes, now used on many traditional slate roofs which have been re-slated, much research is often carried out in the private sector (BRE testing and Proctor Case Studies). Research, trials and product development in relation to traditional buildings should be funnelled through Historic Scotland, so they can generate official guidance, providing the Building Conservation Sector with information they have confidence in. The Technical Research team at Historic Scotland is in the best position to fulfil this role, as they are currently researching energy efficiency in traditional buildings, and publishing their findings. However more resources are required within this team if it is to fulfil the role of issuing official guidance specific to this area.[3]

At present information is still quite disparate and disjointed. That is not to say that different bodies shouldn't continue to generate their own research, but there is a need for some form of official guidance under one umbrella. Figure 42 gives an indication of how work could progress on this front.

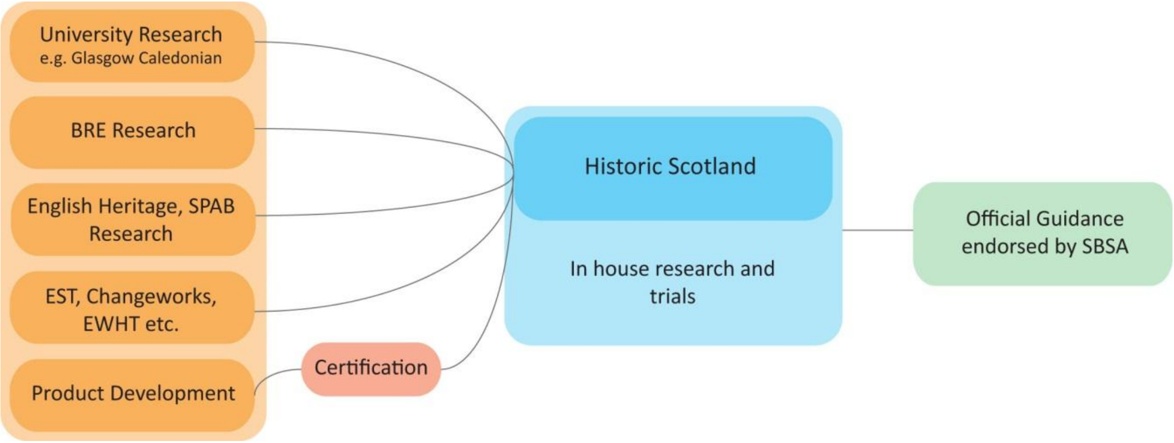

Figure 42 Generation of Official guidance

It would also be beneficial if remedial and/or maintenance work was further emphasised under the parameters of energy efficiency itself. Ensuring stone walls are dry by repairing joints or removing damaging cement render, or removing bitumen felts from roofs if the opportunity arises, ensures that insulation added to walls and roofs will perform better. The INFORM series already touches upon the detrimental effects of cement render, and the EWHT Roof Guide recommends removal of bitumen felts under maintenance, but items such as these should also be fully reinforced under Energy Efficiency as part of a holistic approach to upgrades.

Certainly guidance for property owners has come a long way in recent years and it appears to be on the right track. This is a difficult area to address as there is little control over the interventions property owners undertake inside their own homes. It is important to ensure the information they need is readily available and accurate. And that incentivised programs like Green Deal are suitable for traditional buildings. The disconnect between trades within the construction industry must also be addressed, particularly in cases where insulation installation is being considered. Government funded projects have a role to play here, if there were provisions put in place for the appointment of 'traditional building assessors' who could generate assessments which are more holistic in nature, improving the energy efficiency of the building, without detriment to the fabric. These assessors could be appointed through bodies like Historic Scotland, or Edinburgh World Heritage, who already has an 'Energy Efficiency Officer'[4] on staff. These 'assessors' would also come in direct contact with contractors, giving them suitable direction on how to insulate traditional fabric.

Guidance for Energy Efficiency upgrades to Traditional Buildings should include methods to more accurately test/obtain U-values for traditional construction, using an insitu method, computer calculations or a traditional construction database of U-values (for default values).

The scope of this research did not allow for an in-depth review of the various interventions and modifications made to building envelope in traditional buildings. However in order to gain an understanding of how these approaches were developing it was interesting to look at how stone walls and slate roofs are insulated. In particular, having charted the changes in recent years, it is interesting to see the current method of blown bead insulation into the existing cavity in stone walls, and the advent of the fully breathable membrane for slate roofs (see sections 3.1.4 and 4.2). Both are developments which are cost effective and minimise aesthetic impact when upgrades occur.

The blown bead insulation however is still very much in experimental stages, although the inclusion of it in Historic Scotland's recent 'Fabric Improvements' guide indicates the researchers growing confidence in this approach. It is apparently reversible[5] though only time will tell if this intervention doesn't cause lasting damage to the fabric.

The slate roof membrane, used in conjunction with rafter insulation, seems to have already been accepted into wider-spread practice, and has not caused problems to date. It is embraced by contractors and conservators alike, as it removes the need for unsightly vents, or altered ridge/wall head conditions.

Thermal Improvements to stone walls and slate roofs have come a long way in recent years, undoubtedly due to a better understanding of how stone walls and slate roofs operate as breathable construction. It is now apparent that simply installing insulation in traditional buildings in not sufficient, existing fabric must be analysed and understood, leading to an informed selection of insulation and supporting membranes, cavities, renders as required. The intervention must be approached holistically.

Stone walls are posing greater difficulty than slate roofs when it comes to adding insulation. As was seen this is due to the wide and varied wall compositions (which are not well represented under current U-value calculation methods) and the difficultly of adding insulation in many cases, e.g. on exposed ashlar stone walls with existing lath and plaster on interior. Filling the existing cavity with a permeable blown insulation has proven successful to date, but poses bigger questions such as whether or not it is tampering too much with the existing fabric? Also its long term effect is still unknown.

Slate roofs, when insulated with a considered approach to the ventilation of the roof, have proven successful to date. While the addition of loft insulation is common, undoubtedly because it is inexpensive and easy to implement, the insulating of occupied roofs is less so. Getting property owners to add insulation in the rafter space during a re-slate job is not usual,[6] though it is the perfect opportunity to do so. The introduction of breather membranes have made it a more cost effective approach (it is cheaper to add a new membrane than add roof vents when re-slating) so hopefully this alteration will continue to gain ground.

There is no doubt that in certain cases there are effective, suitable ways to insulate traditional stone walls and slate roofs in order to improve their energy efficiency without compromising the existing fabric. Problems arise due to a lack of understanding of traditional construction. There is now a need for official guidance for practitioners who are striving to find the right balance between the conserving traditional building fabric, and ensuring it is operating efficiently. The role of the Conservator has broadened; policy, guidance and the principles of design intervention must be readdressed accordingly. .

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[1] http://www.passivhaus.org.uk/

[2] Ibid., 3

[3] Roger Curtis, interview by author

[4] Chiara Ronchini, interview by author

[5] Natasha Huq, interview by author

[6] Scott McDonald, interview by author

DEFINITIONS AND ABBREVIATIONS

Aerogel	A synthetic porous material derived from a gel, in which the liquid component of the gel has been replaced with a gas, resulting in a material with a low density and thermal conductivity. (HS)
Batt	Semi rigid insulation board.(HS)
Biomass	The generation of energy through the combustion of organic material, such as wood and organic waste. Biomass stoves and boilers provide heat or hot water to buildings. (EWHT)
Breathability	It is the capacity of particular buildings and building material to allow the passage of air and water vapour through them. (EWHT)
Calcium Silicate Board	A rigid, micro porous mineral board, Its high capillary action assists in humidity regulation. The nature of the material means that mould cannot form on its surface. (HS)
Cellulose Insulation	Formed of cellulose fibre commonly derived from recycled newspapers. (HS)
Condensation	The formation of liquid water on a surface from a gas or vapour state due to the air temperature falling below its dewpoint. (HS)
Cold Roof	The method of applying insulation above a ceiling in a loft space so that everything above the insulation is colder than that below, hence the term cold roof. (HS)
Coom Ceiling	A Scottish term for a sloping ceiling, the upper side of which forms part of the roof of the building. (HS)
Cold/Thermal Bridge	Sections of building fabric which have considerably lower thermal resistance than neighbouring areas, when, for instance, an element travels from the interior to the exterior surface of a building element or where an area is insufficiently well insulated. (HS)
Dewpoint	The dew point is the temperature where the water vapour in a volume of humid air at a constant barometric pressure will condense into liquid water. (HS)
Draught-proofing	The process of reducing air leakage in the frames of windows, doors or loft hatches. (HS)
DPC	Damp Proof Course - Impervious layer of polythene, bitumen or slate laid about 150mm above ground in the base of a masonry wall to prevent rising damp. (EEOH)
Eaves	The lower edges of a roof that usually project over a side wall in order to carry rain water away from the fabric. (HS)
Embodied energy	The energy used in the construction of the building: from the extraction of raw materials, through to manufacture of components, processing and packaging, transportation, installation, and finally, demolition and disposal. (SRTB)
Fossil Fuels	They originate from the remains of plant substances, hermetically sealed and under high pressure. Fossil fuels are non-renewable sources of energy. (EWHT)
Hemp Board	A rigid board based insulation formed of fibres from hemp plants. Hemp/wool insulation is a semi rigid insulation formed of a mixture of hemp and wool fibres. (HS)

Hydroscopic	A material which can absorb and release moisture. (HS)
Interstitial Condensation	Condensation occurring within or between the layers of the building envelope (BS)
Lath and plaster	The building process used for lining internal walls from the 18th century up until the mid-20th century. Vertical timber battens are fixed to the masonry; thin timber laths are then horizontally mounted. Three coats of lime plaster completes this lining. The gap behind the laths and plaster is normally 25-30mm. (HS)
Listed Building	Buildings of architectural and historic interest. They are protected by being A, B or C (s) listed if they have international, regional or local importance respectively. (EWHT)
Listed Building Consent	Permission required from the local planning authority to carry out alterations to listed buildings. (EWHT)
Mineral Wool	A type of thermal insulation made from an inorganic fibrous substance that is produced by steam blasting and cooling molten glass, slag or rock. (HS)
Operational Energy	The energy required to run a building once it is in use (GGHB)
Phenolic Foam	A synthetic polymer made from thermosetting foam plastic and used in thermal insulation. (HS)
Plaster 'on the hard'	The application of lime plaster directly onto the surface of masonry walls without any laths. (HS)
Relative Humidity	The term used to describe the amount of water vapour existing within a mixture of air and water vapour and expressed as a percentage. (HS)
Sarking	A continuous layer of timber boards onto which slates or tiles are laid. (HS)
Sustainability	Development that meets the needs of the present without compromising the ability of future generations to meet their own needs. (BR)
Thermal Mass	Measures the capacity of the building to retain and release heat. The thicker an external wall, the more heat that can be retained. (EWHT)
Trickle Vent	A small opening in a window or building component to allow for ventilation, where natural ventilation should occur but is impinged. (HS)
U-Value	The measurement of the rate of heat loss through a building component, the lower the U-Value the less heat is lost through that building element. U-Value is expressed in W/m2K. (HS)
Warm Roof	Insulation is usually placed on or adjacent to the roof rafters, so that everything below the insulation is as warm as the roofs in the house. (HS)
Wood fibreboard	Rigid insulating board, available in various forms and is made from a wood based material. (HS)
VCL (Vapour Control Layer)	A material, usually a membrane, that substantially reduces the water vapour transfer through any building component in which it is incorporated. (TI)

Sources

(BR) The Brundtland Report, United Nations World Commission on Environmental and Development, 1987.

(BS) British Standard, “Code of practice for control of condensation in buildings”, BS 5250:2011,

(EEOH) Cook, Martin Godfrey, Energy Efficiency in Old Houses, Wiltshire : The Crowood Press Ltd., 2009.

(EWHT) Ronchini, Chiara and Kirsten Haase, Historic Home Guide – Energy Efficiency, Edinburgh: Edinburgh World Heritage.

(GGHB) The Prince’s Regeneration Trust, The Green Guide for Historic Buildings, United Kingdom: TSO, 2010.

(HS) Moses Jenkins, Fabric Improvements for Energy Efficiency in Traditional Buildings, (Edinburgh: Historic Scotland, 2012).

(SRTB) Richard Oxley, Survey and Repair of Traditional Buildings – A Sustainable Approach, (London: Donhead, 2003.

(TI) Stirling, Charles, Thermal Insulation: avoiding risks, London: BRE Scotland, 2002.

ABBREVIATIONS

B.B.A.	British Board of Agrement
BRE	Building Research Establishment
EWHT	Edinburgh World Heritage
NFRC	National Federation of Roofing Contractors
NHER	National Home Energy Rating
SPAB	Society for the Protection of Ancient Building

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