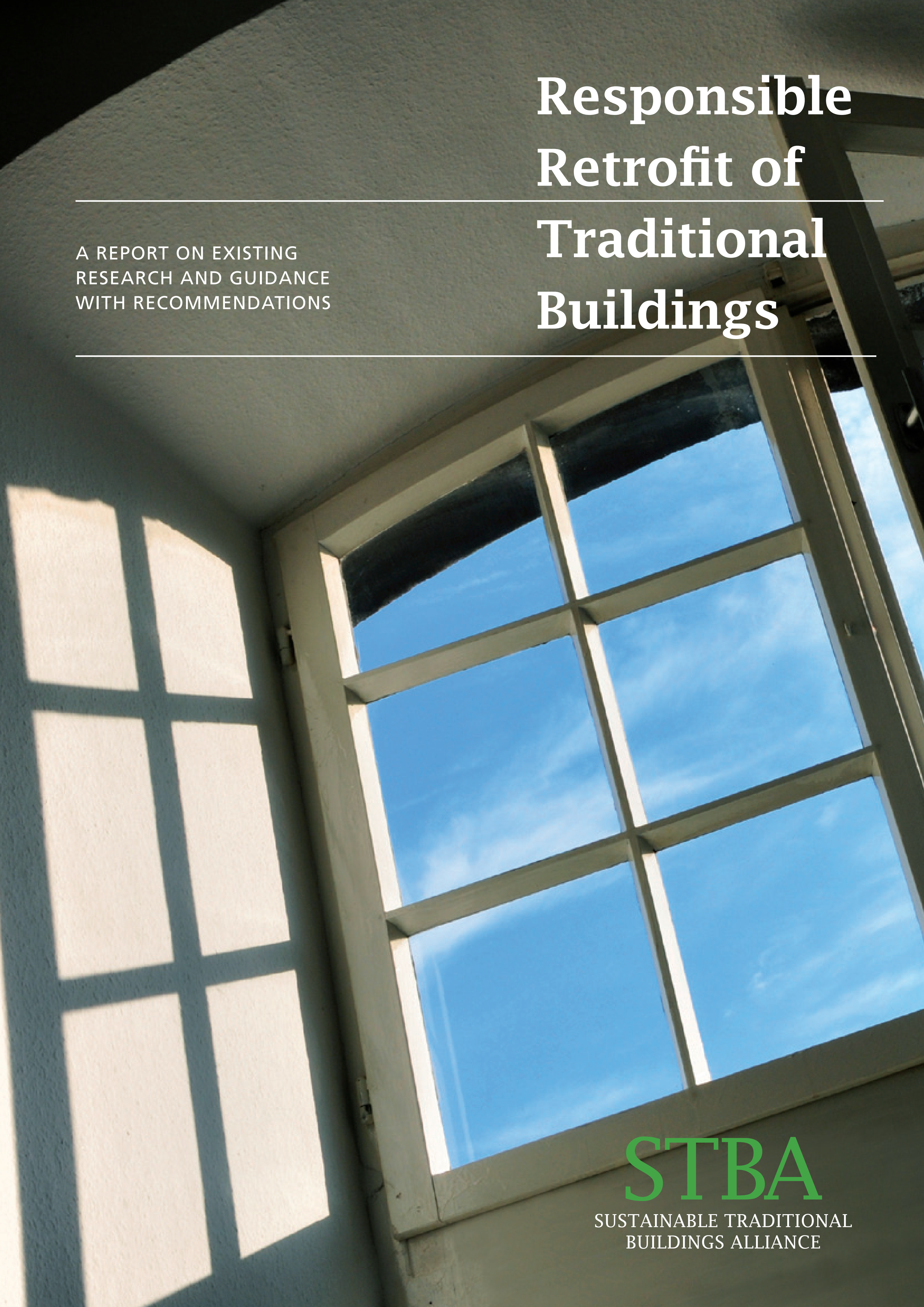
Responsible Retrofit of Traditional Buildings

A REPORT ON EXISTING RESEARCH AND GUIDANCE WITH RECOMMENDATIONS



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About STBA

The Sustainable Traditional Buildings Alliance (STBA) is a not-for-profit, public-good alliance of historic building groups and environmental and professional building organisations working together to actively promote and deliver a more sustainable traditionally built environment in the UK through research, education, training and promotion of best practice.

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Table of contents

1

Executive Summary

Introduction

This report looks into key aspects of the responsible retrofit of traditional buildings on behalf of the Department of Energy and Climate Change (DECC). This work was undertaken by the Sustainable Traditional Buildings Alliance (STBA) which represents most of the main historic building groups in the UK as well as mainstream construction-related organisations.[1]

The work was carried out following concerns raised with regard to the application of certain retrofit measures, including those incorporated into the Green Deal, in respect of the UK's traditional building stock. A traditional building is defined as a property built prior to 1919 with solid walls constructed of moisture-permeable materials.[2] It is estimated that traditional buildings number over 6 million, almost one quarter of the UK domestic housing stock. The concerns around retrofitting this class of buildings include possible failures of financial and energy payback, fabric and human health issues, and potential damage to heritage, as well as missed opportunities for the radical improvement of traditional building performance.

The report begins by identifying existing national and international research and guidance work of relevance to the subject of the retrofitting of traditional buildings and recognises significant gaps in this knowledge base. It also considers a series of diverse documents that influence retrofitting practices grouped under the term Implicit Guidance and reveals short comings in these texts and their methods. A discussion then follows which draws out the consequences of this lack of good quality research and guidance in all its forms with regard to a variety of pertinent issues related to energy saving refurbishment and the performance and value of traditional buildings. The report concludes with a 'Way Forward' and makes suggestions as to how uncertainties within this field can be managed in order to ensure that traditional buildings can contribute to significantly reducing energy demand in the UK without placing these buildings or their occupants at undue risk.

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[1] For a list of organisations affiliated with the STBA see Appendix A of the full report.

[2] This definition is given in English Heritage's publication Energy Efficiency and Historic Buildings (p. 17) and can also be found in the Building Regulation's Approved Document Part L1B&L2B Conservation of Fuel and Power 2010, 3.8,c and the Scottish Building Regulations Technical Handbooks.

Key Findings

- Traditional buildings perform differently in some respects from modern buildings, both in their existing state and when subjected to retrofit measures.
- There is a lack of understanding of traditional building performance in industry and in policy, and a lack of connection between good research, standards, certification processes, guidance and practice.
- There is a lack of connection between high-quality research intelligence and the guidance documents which inform retrofitting procedures.
- There is significant uncertainty with regard to the application of models and performance simulation software to this class of buildings.
- Some methods for assessing traditional buildings are inappropriate and give incorrect results, and some are misapplied and thus give false confidence in some measures.
- Traditional buildings often perform better in terms of heat loss through fabric than as stated in standard models and assessment methods. This means that the likely paybacks from some retrofit measures, such as solid wall insulation, may be less than assumed.
- Traditional buildings require different assessment and practice with regard to the control of moisture in buildings, which is vital for fabric and human health.
- A systemic approach is necessary regarding the assessment and retrofit of traditional buildings if rebound effects and unintended consequences are to be avoided and opportunities for long-term improvements seized. This process should include the whole supply chain and users.
- There are good opportunities for the development of safe, robust, energy-efficient and cost-effective retrofit measures for many areas of traditional buildings. However these will have to be developed on a different basis and structure from some current Green Deal proposals.

Key Recommendations

Policy Issues

- Different assessment procedures are required for traditional buildings based on an understanding of the performance of these buildings, along with different skills training for contractors and different engagement with occupants and owners by retrofit providers.

- Additional conventions specifically for assessing the heat loss of solid walls need to be established as soon as possible. BR 443, RdSAP and commercial U-value calculators should not be used for the assessment of these walls without an understanding of their limitations and reference to alternative sources of heat loss data.

- The only convention currently used in industry to assess moisture risk in traditional buildings is BS 5250:2011 which is very limited in scope. It should be required that BS EN 15026:2007 is also used for modelling of traditional buildings, particularly internal wall insulation, but also for other fabric-related measures. Ultimately, a new convention is required for assessing all the risks posed by moisture to a traditional building.

- Documents that require U-value improvements for solid walls should set targets that are appropriate for these constructions with regard to the limits of realistic heat loss due to thermal bridging, and in order to avoid condensation as a result of over-cooled wall fabric.

- The wider consequences of individual retrofit measures on traditional buildings need be taken into account in policy. For example, work to improve the airtightness of a building may have negative consequences for fabric moisture loads (leading to possible fabric degradation and human health issues). These consequential and systemic effects must be acknowledged in terms of liability.

- Good maintenance, repair and improvement work that is of benefit to the energy-performance and value of the building should be considered as a valid retrofit measure and be brought into the Green Deal. The repair of shutters and/or the addition of secondary glazing for older windows would be an example of this.

Delivery Issues

- The development of a national strategy and mechanism for ensuring that evidence, methodologies and tools from best research are quickly incorporated into relevant regulatory standards, certification methods, leading guidance and Implicit Guidance.

- Short-term research to provide:
    - Altered or different conventions for judging the performance of traditional buildings. This research needs to provide a robust basis for accurate interpretations of traditional building performance with regard to heat loss and air permeability rates, based on current evidence.
    - A new convention for assessing the moisture risks to traditional buildings and the effect of retrofit. This is more complicated, but a short-term workable solution could be put in place while longer-term research is undertaken.

- A new approach to delivery which requires learning to be integrated into all parts of the process including assessment, design, application of measures, use, monitoring and maintenance. Such an approach is suggested in the Guidance Structure section of this report. If learning is properly integrated then it will be possible to achieve a safer and faster development of retrofit of traditional buildings in the UK over the next few years.

• Training and skills programmes for retrofitting, including the Green Deal, need to be based upon a revised understanding of the specific requirements, risks and opportunities associated with traditional buildings. In particular a systemic approach including all parts of the supply chain as well as users, owners and managers should be taken.

• Insurance, warranty and other schemes should follow, not precede the above, and be linked to monitoring and learning processes wherever possible.

• There should be an informed programme to raise public awareness of opportunity, risk and benefit issues involved in the retrofit of traditional buildings. This should emphasise the opportunity for real benefits through engagement and learning.

Development Issues

• A considerable programme of research into the following is required:

- The performance of traditional buildings in terms of energy, heat, moisture, overheating, indoor air quality, and comfort.
- Case studies of retrofit programmes in traditional buildings (both technical and user-focused) to further understand rebound effects and opportunities for better and more cost-effective retrofit programmes. The Green Deal provides an ideal opportunity for large-scale monitoring and feedback at low cost.
- Data for the material properties of traditional UK building materials for use in modelling software.
- Better models for traditional buildings including the effects of driven rain, location-specific weather data and improved understanding of moisture mechanisms.
- The development of systemic understanding, methodology, and analysis of traditional buildings (as existing and when retrofitted) which incorporates the many interactions both within specific elements and at a whole house level and includes both technical factors and user behaviour.

• Training and skills programmes need to be developed and promoted to the industry on the basis of this research and in conjunction with traditional building skills experts and providers, thereby beginning to bridge the gap between conservation and mainstream practice. This should be a two way process.

Conclusion

If these recommendations are taken up, then some of the main risks to traditional buildings of retrofitting practices may be averted. Furthermore, it is believed by the STBA that, if these recommendations are carried through, the Green Deal and other retrofit schemes could be undertaken with more financial, energy and environmental benefits than previously envisaged. In addition, the retrofitting of traditional buildings can become a driver for significant positive change in the construction industry in terms of employment and skills, in user behaviour and for public understanding and engagement with older buildings.

Introduction to the Report

Project Background

The Sustainable Traditional Buildings Alliance (STBA) is made up of historic building groups and environmental and professional building organisations, working together to actively promote and deliver a more sustainable traditionally built environment in the UK through research, education, training and promotion of best practice. The Alliance supports efforts to substantially improve the energy and carbon performance of the existing building stock, providing this is on the basis of proper understanding and that issues of fabric health, occupant health, historic, cultural and social value are fully taken into account. (For details of STBA supporting organisations and aims see Appendix a).

The Alliance was set up during 2011 and launched at Somerset House in November 2011. Its first piece of research was a gap analysis of research on the performance of traditional buildings in the UK. This was funded by Construction Skills and English Heritage and undertaken by Dr Caroline Rye. This work to some extent led to the commissioning of this current report by DECC and is to a large extent incorporated in this current report.

In response to concerns raised by historic buildings groups, in the autumn of 2011 three stakeholder workshops were held by the Department of Energy and Climate Change (DECC) on the subject of the proposed national refurbishment scheme – the Green Deal – and older properties. Older properties in this context signified pre-1919 solid-wall traditional buildings, sometimes also referred to as 'historic', 'heritage' and 'conservation buildings'. From these workshops it was clear that:

- When it delivers the Green Deal, DECC is aiming to ensure the most appropriate retrofit solutions are chosen for all properties, including older properties.
- The evidence base about the impact of retrofit on properties, including older properties, is unclear.
- That there is limited understanding of the specific requirements of traditional buildings within retrofit practices and amongst the construction industry in general.

As a response to the need to clarify the evidence base relating to older properties and the impact on them of retrofit measures, the STBA was funded by DECC to undertake a project to assess the issues and create a structure for communicating the findings. This report is the result of this work.

The project initially planned to identify research work pertinent to the subject of the performance of existing and retrofitted traditional buildings. In addition, the project also looked at current guidance work. During the project it became obvious that other documents and sources of information, such as Building Regulations, standards, certifications and commercial technical manuals were commonly used in decision making in the retrofit of older properties. We called these 'Implicit Guidance'. All this material (i.e. research, guidance and Implicit Guidance) was analysed and gaps in the evidence base identified. Further work was then undertaken to quantify the consequences of these gaps with regard to the risks and benefits of retrofitting traditional buildings, and to propose solutions for the mitigation of risk and the maximisation of benefits. One of these solutions was a guidance structure which could be developed into a tool for assessing the risks and benefits of individual or combined retrofit measures according to context.

This report presents this work in four parts: Chapter One concerns the compilation and analysis of research and guidance work; Chapter Two looks at the subject of Implicit Guidance; Chapter Three discusses the findings with regard to overarching concerns of significance to the retrofitting of traditional buildings and makes recommendations for their amelioration; the final chapter, A Way Forward, summarises the findings of work and proposes a guidance structure to aid the retrofit decision-making process for traditional buildings.

Whilst this research has attempted to take the broadest possible approach to the subject of the performance and retrofitting of traditional buildings, there are limitations to this study. Firstly, there are many types of traditional building, from those built with large-mass masonry walls, or walls made of earth and/or straw and/or chalk, to timber-frame buildings infilled with a variety of materials. All these buildings display immense regional variation both in construction style and materials. Absent from this account is any attempt to differentiate between different types of traditional buildings. They are unified by common attributes (such as solid walls made of permeable fabric, and natural ventilation through chimneys), but the specific risks to these buildings may vary in relation to their exact details. Secondly, underpinning the imperative to retrofit our existing buildings is the phenomenon of climate change, which has radical consequences for our environment. The effects of climate change upon UK traditional building stock is not directly dealt with in this report and the effects of changing patterns of weather have not been accounted for within the descriptions of risk laid out in this account[3].

[3] The publication *The Atlas on Climate Change Impact on European Cultural Heritage*, Sabbioni, Cassar & Brimble-combe (2010) is a source of more information concerning climate change and the historic built environment

2

Research & Guidance

The need to improve the energy performance of our existing building stock has provided the impetus for various kinds of research activity over recent years. Both within an academic context and beyond, work has been undertaken to identify and quantify types of interventions that can have a significant positive effect on the energy consumption of buildings in general. Although some of this work has involved traditionally built, pre-1919 buildings, research is not often framed with this particular group of buildings in mind. Yet these buildings are significantly different, both in terms of their materials and construction type, from later buildings. We will only be able to intervene with confidence in this specific class of buildings if we are able to understand fully the implications of various retrofitting measures – individual interventions as well as packages of measures.

Methodology

This research project set out to identify:

- **Current research and guidance** into the energy performance of older properties and the impact of retrofit, repair, improvement and maintenance measures with regard to building performance and other consequences, both intended and unintended
- **The areas covered** by the current research and guidance
- **The gaps** in knowledge remaining

Literature Search

Due to funding requirements the research was undertaken within a compressed timescale, and a number of overlapping or parallel searching strategies were pursued in order to ensure maximum coverage of the subject area. Groups of UK and international experts made up of leading academics and researchers in the field, including the 14 members of the International Energy

Agency's Annex 55 group[4] were approached (See Appendix B for individuals contacted). These experts were asked to identify significant sources of research and guidance literature for the subject of the performance and retrofitting of traditional buildings.

Following this an extended literature search was conducted. This consulted major pertinent sources of academic literature via searches of databases such as Sage, ScienceDirect, and Jstor. Science, Arts and Humanities collections were searched to ensure a multidisciplinary approach that covered the fields of building physics and energy sciences as well as building conservation and architecture. These searches revealed books, journal articles and conference proceedings and papers. Beyond a purely academic context web-based searches were undertaken; these looked at specialist building conservation websites and publication lists and were conducted partly to ensure that the search revealed prominent sources of guidance. Specifically, the websites of English Heritage, Historic Scotland and Cadw were mined for guidance documents[5]. General search terms such as 'traditional buildings', 'old buildings' and 'historic buildings', as well as 'building performance', 'retrofit', 'refurbishment' and 'energy' were used to look for projects and case studies that referred to the performance of traditional buildings, retrofit and refurbishment. This revealed sources of work produced by, for example, the Carbon Trust, AECB, Passivhaus Trust, as well as other sources of guidance produced by the Energy Saving Trust (EST), Building Research Establishment (BRE), TSB's Retrofit for the Future programme and other associations concerned with energy consumption in the built environment.

Call for Information

In order to extend the search for research and guidance literature to a wide audience an open 'call for information' was sent out to interested parties. These included organisations concerned with the historic environment and/or a sustainable built environment, construction industry networks, representative organisations of building product manufacturers and installers, and research networks. The organisations and networks we approached are listed in Appendix C. The call was made using the following routes:

- Emails to key individuals requesting their own information and also requesting that they pass on the request to relevant colleagues.
- Contact with network managers of relevant organisations asking them to publicise the call for information and research through their mailing lists, newsletters, Twitter and online forums.

The 'call for information' was an open invitation to anyone working on the performance and refurbishment of traditional buildings to contribute references to either their own findings or work that they were aware of and to provide details of any work in progress. Responses were encouraged via an online survey. Crucially, this survey included an upload function allowing participants the option of sending documents directly to us, or sending them via email. A completed survey allowed us to verify the availability of the document to the general public.

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[4] The title of this group's collective work is *Reliability of Energy Efficient Building Retrofitting – Probability Assessment of Performance & Cost* see www.ecbcs.org/docs/Annex_55_Factsheet.pdf

[5] Published guidance covering the retrofitting of buildings is widespread, ranging from that produced by organisations with a statutory duty to protect the historic built environment to amenity societies, local government planning departments and various campaigning and other interest groups. Due to the compressed timescale of the research project we restricted searches for guidance work to bodies with statutory protection duties as it was felt that much guidance took its lead from these 'primary' documents. Outside of these organisations a few other principal sources of guidance were reviewed, such as those produced by the Energy Saving Trust and BRE and a number of other associations concerned with energy consumption in the built environment. For a list of all the publishers of guidance documents consulted in this study see Appendix F.

Gap Identification

During the searching exercises, we also asked all respondents to tell us if there were any gaps in information or knowledge that they were aware of in relation to the design, installation and performance of retrofit measures (particularly with regard to traditional buildings) including those to be promoted by the Green Deal.

Overview of Responses

Our searches, including texts suggested by our expert groups and both academic and general literature searches, recovered a total of 435 research and guidance documents. Of these 435 items, 105 consisted of guidance documents. In addition to this the 'call for information' provided a total of 120 additional references; however this figure was reduced to 84 once duplicate texts that had already been identified in the other searches were excluded from the count. Altogether the searching exercises provided a total of 516 separate items of research and guidance that were either explicitly concerned with, or of relevance to, the subject of the performance and retrofit of traditional buildings.

Active, Unpublished Research

During the searching exercises, including the 'call for information', note was taken of significant work currently 'in progress' that had not yet made findings public, either in the form of research reports, case studies or other similar dissemination. Here we note the subjects of this research work and its potential value.

There are currently nine projects that the report's authors are aware of that may offer significant information with regard to the subject of the performance and retrofit of traditional buildings. Some findings from the Technology Strategy Board's 'Retrofit for the Future' project are available via the Low Energy Buildings database[6]. This was a £17m project which looked at the retrofitting of social housing stock via case studies of 87 houses. Of these 87 buildings, one was solid stone walled and 34 were solid brick properties. Importantly a number of aspects of the performance of these buildings were measured including energy meter readings, airtightness, internal and external temperature, RH and CO_2. Whilst the database gives details of the retrofit measures undertaken and the predicted changes in energy consumption for each of the properties, the findings resulting from measured data are not yet available.

Another significant UK-based study is that carried out by the Energy Saving Trust into the insulation of solid walls. Once again this work has included an element of measured performance with a series of 'before' and 'after' retrofit conditions monitored. The monitoring has included airtightness testing, gas/electricity use, internal/external temperatures, wall U-value measurements, internal/external thermography, SAP assessments, and measurements of wall surface temperature and internal humidity. A set of field trials involving 75 properties began in 2010 and baseline data was collected during 2011 prior to refurbishments. These are now complete and a report is expected of findings from this work during the summer of 2012.

University College London, as part of a Knowledge Transfer Partnership research project with Natural Building Technologies, is investigating and comparing 'breathable' and 'non-breathable' internal insulation systems for solid-wall buildings, using a combination of laboratory-originated monitored and measured data compared to hygrothermal transient modelling. This work has provided some interesting initial findings regarding the accuracy of modelling, moisture performance of different kinds of insulation and the importance of location and wall orientation. However, this research is still ongoing and UCL is yet to formally publish its findings.

[6] http://www.retrofitforthefuture.org/

English Heritage is currently researching a number of issues related to the refurbishment of solid-wall brick buildings via a case study of such a building in New Bolsover Model Village. Working with Glasgow Caledonian University the research involves an extensive monitoring programme and aims to test whole-house thermal performance and the impacts of interventions, as well as evaluating the technical risks from insulation and the efficacy of energy models.

On a European level the IEA Annexe 55 Reliability of Energy-Efficient Building probability assessment of performance and cost (RAP-RETRO) led by Dr Carl-Eric Hagentoft runs from 2009 to 2013 (many of our European experts, contacted during the literature search, were part of this research group). This project aims "to develop and provide decision support data and tools for energy retrofitting measures… to ensure that the anticipated energy benefits can be realized. These will give reliable information about the true outcome of retrofitting measures regarding energy use, cost and functional performance."[7] This research has not yet produced any published outcomes.

[7] http://www.ecbcs.org/annexes/annex55.htm

Data Processing

All of the documents and other intelligence identified had to be categorised in order for them to be fully appraised. That appraisal sought to achieve two things:

1 To establish what areas of retrofit decision-making and installation processes were covered by the available research, i.e. to map the intelligence

2 To make a judgement as to the genuine worth of the research base

By carrying out these two processes we can not only see where retrofit is adequately covered by intelligence, but how well that intelligence has dealt with it.

The Intelligence Map

A map was created of the key topics of research, relating to the performance of traditional buildings in their original state and when retrofitted, and individual items of research and guidance were logged against this index (Figure1).

Figure 1 *The Intelligence Map used to plot research and guidance work*

			A Original state	B Retrofitted
BUILDING ELEMENTS	PERFORMANCE OF STOCKS OF BUILDINGS			
	WHOLE HOUSE PERFORMANCE			
	FABRIC	Materials science		
		Walls All		
		U-values		
		Moisture		
		Floors		
		Windows/doors		
		Roof		
		Thermal bridges		
		Airtightness		
	SERVICES	Heating approach		
		Heating fuel		
		Electricity source		
		Cooling		
		Ventilation		
		Lighting		
	OCCUPANT INTERACTION	User interface (controls, etc)		
	OCCUPANT OUTCOME	Internal comfort		
		Good health		
AESTHETICS, CHARACTER AND SIGNIFICANCE				

Material gathered during the searching exercises was placed in one of two overarching categories. Category A contained work that was concerned with traditional buildings *per se*, that is the performance and characteristics of these buildings without additional energy-saving refurbishment measures. Category B, research and guidance, dealt specifically with retrofit and refurbished properties. Within category B particular attention was paid to work that explicitly referenced traditional or historic buildings. However, other studies concerned topics that were not dependent upon a building's construction or age, such as for example the usability of heating controls; these were included because they were of relevance to retrofitted older buildings.

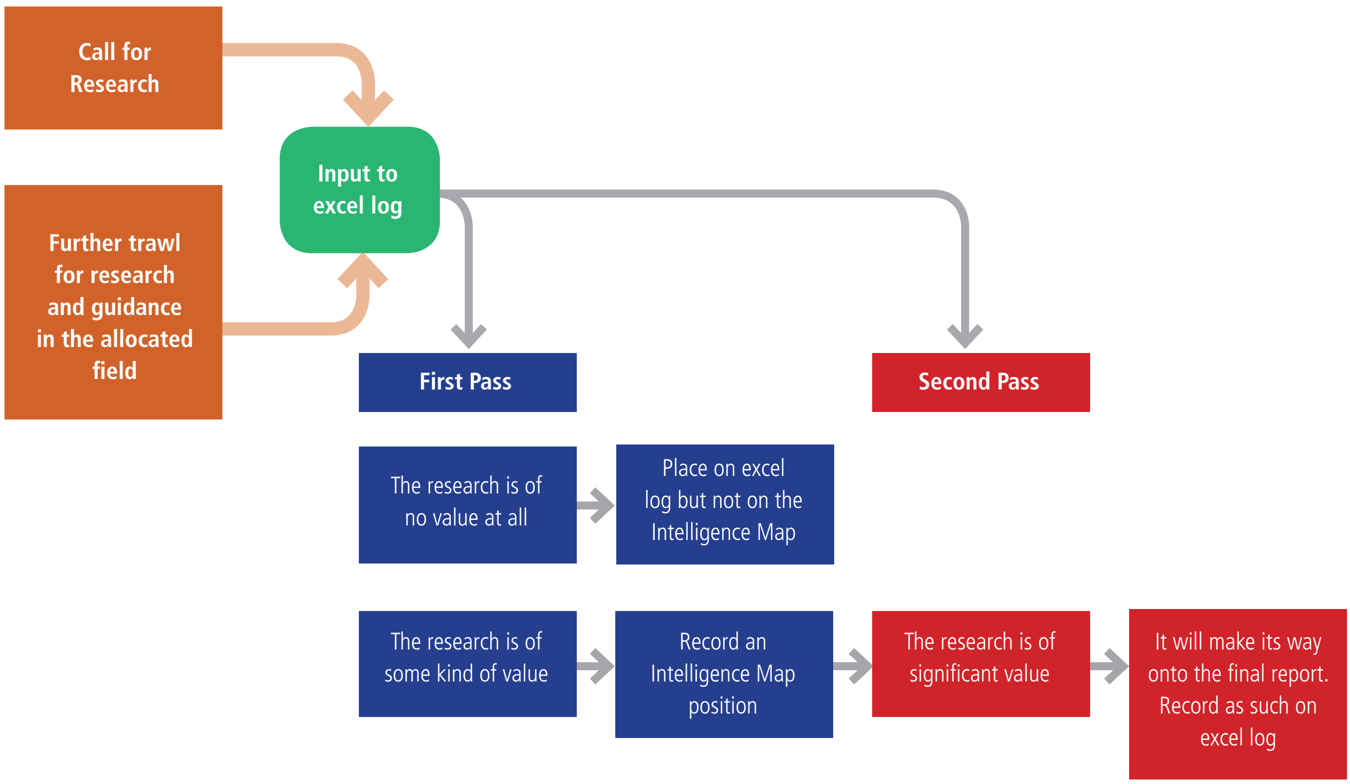
In order to determine the range of references covered by the literature, the papers collected were then mapped against a set of fields derived from a variety of energy-improvement interventions involving fabric and services, as well as issues of significance with regard to occupancy, cultural heritage and energy assessment methods.

The Tier Judgement Process

In order that the research and guidance collected could be collated to provide a list of robust references to inform the application of Green Deal and other retrofit measures to traditional buildings, it was necessary to determine the quality of each individual reference. It is intended that these references will be used to form a future 'Guidance Structure' (see Conclusion).

The following schematic illustrates how all evidence was judged according to its value and significance (Figure 2).

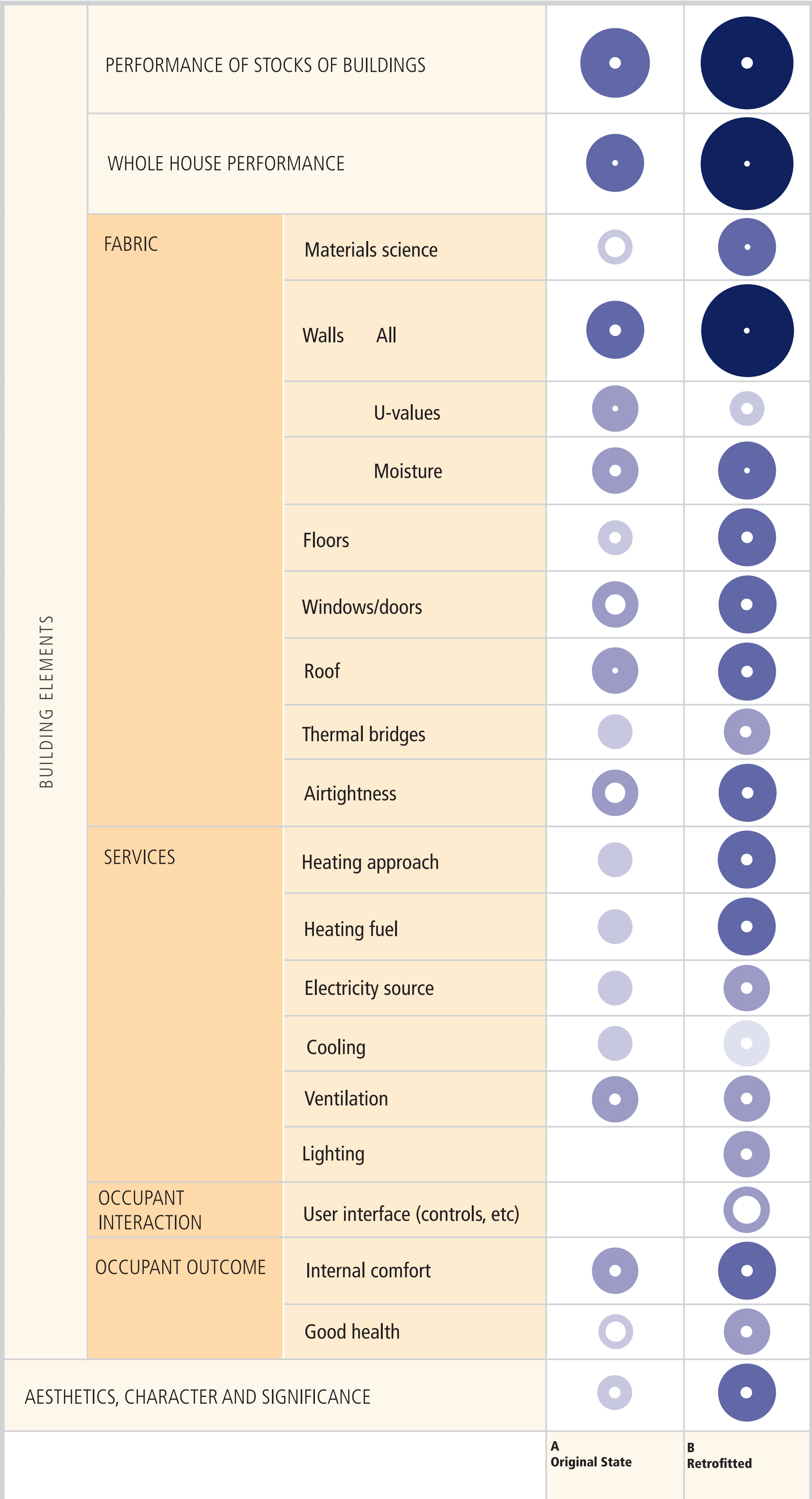
Figure 2 *Process for Judging Research and Guidance*

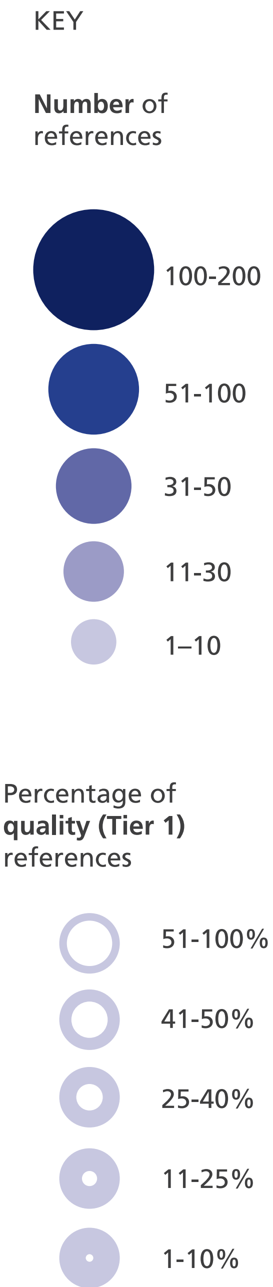


All documents were allocated to a particular 'tier' of quality and relevance. The tier structure was based upon four categories of value: evidence base, level of independent review, significance within Intelligence Map grouping and relevance to the Green Deal. There were four tiers in total: Tier 4 contained poor-quality work, with little evidence from research and without independent review. Tier 3, though based on some evidence and perhaps a degree of independent review, was not immediately relevant to the Green Deal. Tier 2 and Tier 1 were reserved for work with a substantial evidence base or rigorous analytical methodology; Tier 2, although deemed highly significant, lacked peer review or sufficient qualification, whereas Tier 1 contained the most seminal work – highly relevant research with a solid evidence base or rigorous analytical methodology that had undergone either independent review and/or was self-reflective acknowledging and assessing its own limitations. In an effort to minimise subjectivity, four people independently looked at and assessed every document from the top two tier levels. A detailed version of the criteria to be met by documents in each tier is given in Appendix D, and a list of the Tier 1 references is given in Appendix E.

Plotting documents against the intelligence map and then grading these documents into particular tiers allowed an assessment of both the quantity and quality of research and guidance work available. In addition, it provided an indication of the proportion of significant and pertinent research in relation to the total number of references gathered for each of the 18 key topics of relevance to traditional building performance and retrofit. Figure 3 (overleaf) illustrates the quantity of references gathered for each heading and the proportion of quality research work identified for the key topics. The size of the outer circle conveys the quantity of intelligence material gathered for each category of the map. The size of the black spot in the middle of each circle is derived from the number of Tier 1 & 2 documents logged against each one of these categories.

Figure 3
Populated Intelligence Map





Gap Analysis

Working from the headings and data summarised in the Populated Intelligence Map (Fig. 3) this section looks at the evidence provided by the various research and guidance documents uncovered by the searches. The aim is to establish the existence of robust research and identify areas that are not well covered or where current research may be weak.

Examining the final documents collected for the two overarching categories – original buildings and retrofitted buildings (A and B) – immediately reveals a gap, one that is also mentioned within the literature itself. In total, 516 documents were sourced and when these documents were mapped against specific intelligence categories this provided a total number of 1241 individual references. By far the greatest proportion of all these references, 79%, originated in work concerned with retrofitted buildings; only 21% of total references was concerned with the nature of traditional buildings in an, as it were, 'unimproved' condition. **There is a general absence of literature surrounding the energy behaviour and performance of traditional buildings, including a lack of baseline data on which to base judgements relating to energy improvements.** This latter point is made by Gentry, Shipworth, Shipworth and Summerfield (2010, p. 34) amongst others, when they quote from evidence given by Oreszczyn & Lowe to a House of Lords Select Committee on Science and Technology. This lack of information, or gap, creates a significant degree of uncertainty around energy-improvement measures for traditional buildings compared to other parts of the existing building stock.

Performance of Stock of Buildings and Whole House Performance

Within the individual intelligence fields the largest proportion of research references found overall, 19%, were concerned with the assessment of the performance of building stocks. 24% of these references concerned the assessment of existing building stocks in general; a much larger proportion, 76%, focused on the assessment of stocks in relation to energy-efficient refurbishments. Much of this work was constructed around hypothetical scenarios in order to inform a cost/benefit analysis or retrofit policy-making. The second largest proportion of all research references, 14%, were also concerned with performance assessments, but focused on individual house or building performance. Again many more papers dealt with the subject of retrofitted buildings (81%) in comparison with work examining buildings in their existing or 'unimproved' condition.

Building performance assessments are the products of building energy performance modelling software. One reason for the predominance of this type of analysis within the collected literature is given in an observation by Gentry *et al* (2010, p. 34) concerning practices within the field of construction: "[T]he widespread use of energy models is a consequence of their ease of use". The use of energy models dominates research within this field, just as it does the practices of retrofitting. This has significant consequences for both the knowledge about and methods employed for building refurbishment because it is widely acknowledged that energy models do not provide robust data concerning the performance of traditional buildings (Gentry *et al* (2010), Heath (2010b), Barnham (2008), Moran (2012), Gupta (2010) and others). Gentry *et al* (2010, p. 3) quote an uncertainty ratio of up to 50% when applying BREDEM (Building Research Establishment Domestic Energy Model) based models, which include SAP assessments, to traditional building types. **There is a great deal of uncertainty surrounding the performance of traditional buildings as modelled by building energy performance software.**

An examination of these and other references in the study provides a number of reasons for this high degree of uncertainty.

Older properties are very diverse (this is a function of their age and the highly localised building patterns and materials used in their construction) however they are normally treated a single generic type – 'pre-1919' – within stock description databases. Consequently **there is a lack of typological analysis and distinction of traditional buildings in stock modelling** and a dearth of base-case performance data for traditional buildings with which to calibrate and inform energy assessment models in general.

Much numerically based simulation, ranging from simple heat loss calculations through to dynamic three-dimensional whole building models, relies on high quality data input and this places a strong emphasis on accurate material properties as well as user operation. Kavgic *et al* (2010, p. 1683) point to the "the lack of publicly available detailed data relating to inputs and assumptions" for building physics-based stock models. It is also noted by Little (2012), Rye (2010 & 2011), Baker (2011) and others that, specifically, **for the building materials found in the traditional buildings of the UK and Ireland, there is almost no well-defined traditional or vernacular material properties data for use in modelling and calculation programmes.**

Modelling outputs are also highly dependent upon operator skill and interpretation and **there is poor understanding of traditional building construction forms and the consequences that these may have for determining building performance.** Additionally, Kavgic *et al* (2010) as well as others remark that **modelling assessments are often unable to take account of human and physical rebound effects**, such as raised internal temperatures, and subsequently produce over-optimistic energy-saving predictions. Performance assessment models are also criticised for their narrow scope of focus, being **primarily conceived around immediate, short-term and localised energy reduction targets** rather than a broader-based value system which would consider factors such as durability, complete life cycle costs and long-term human health effects as well as heritage values (see Heath 2010b, Powter & Ross, 2005).

The multiple limitations of model-based assessments of traditional buildings means that, in the limited examples of real-life case studies, a gap is commonly found between modelled assessments and the monitored realities of traditional building performance (Rye, 2010, Baker, 2011, Moran, 2012).

Traditional buildings are not well served by current buildings energy assessment models; this is of significant concern given the prevalence of modelling within the disciplines that guide construction practices, including overarching policy decisions. Lomas (2009, p. 9) in his paper *Carbon Reduction In Existing Buildings: A Transdisciplinary Approach* emphasises the **"shortage of information and tools by which the effectiveness of policy can be assessed"** and stresses that "valuable new insights can be gained by collecting hard data, i.e. measurement, monitoring, questionnaires and surveys". There are at present a small number of projects, most of which are ongoing, which attempt to inform the gap between modelled and actual performance by pursuing concurrent modelling and monitoring programmes. Heath (2010b), in Technical Paper 8 for Historic Scotland, calls for an improvement in retrofit practices and understanding through the "development of a new software package to provide a truly accurate energy efficiency model for older, traditionally built, Scottish housing qualities". Such a model, or similar, would be of benefit to the retrofit of traditional buildings throughout the UK and beyond.

The problem of providing accurate models for traditional constructions affects many aspects of retrofit and is not confined to whole stock or individual building energy assessment processes. The problem of models extends into the analysis of other aspects of building performance such as heat loss and moisture behaviour of individual elements, as well as air permeability and ventilation.

Walls

It is well known that solid walls create particular challenges for retrofit processes, and the fact that quite a high proportion of references, 13%, have been mapped under this subject heading reflects a concentration of effort in this area. As a result of work undertaken by Historic Scotland (Baker, 2011) the Society for the Protection of Ancient Buildings (Rye, 2010) and English Heritage (Baker & Rhee-Duverne, 2012) there is a small body of consistent research concerning the heat loss of traditionally-built (solid) walls. This research shows that there is a discrepancy between the heat loss (U-value) of these walls as measured *in situ* and the standard calculated U-value; the calculated U-value underestimates the thermal performance of the traditional wall. **With regard to the understanding of the heat loss of solid walls, there is a gap between the theoretical assumption and the measured reality.**

This discrepancy, in part, originates with the document BR 443 *Conventions for U-value Calculations* that determines the means for calculating U-values required in Building Regulation Approved Documents. This document promotes the use of BS EN 1SO 6946:1997 – a standard based on the use of discretely layered (e.g. cavity) forms of building consisting of known materials; this is a problematic model for some existing solid walls. Although some progress has been made in understanding the reasons for this discrepancy, **the consequence of this gap needs to be more widely understood within retrofit processes** and steps taken to alter calculation practices to provide more accurate heat loss estimates for solid walls.

Increasingly it is also understood that it is not sufficient to examine thermal processes in isolation particularly with regard to solid walls. It is acknowledged in much of the literature that the behaviour of moisture within traditional constructions is likely to be different from that within a modern building and that the insulation of these buildings alters moisture balances. Hygrothermal performance and particularly moisture behaviour has also been the subject of a degree of research activity (4% of overall references) but the outcomes in this area, like its subject matter, are more diverse and complex.

Joseph Little's work for Historic Scotland's forthcoming Technical Paper 15 is partly concerned with the methodologies used to assess the hygrothermal performance of traditional buildings. Little critiques the use of the Glaser Method (as set out in BS EN ISO 13788:2002) which is referred to as the method of calculation used to determine surface and interstitial condensation risks in BS 5250:2011 *Code of practice for control of condensation in buildings*. These standards are clear about the limitations of their scope, being only concerned with water vapour and its movement by diffusion; therefore neither standard accounts for the effects of other sources of moisture within a building: "This standard deals with critical surface humidity and interstitial condensation, and does not cover other aspects of moisture, e.g. ground water, precipitation, built-in moisture and moisture convection, which can be considered in the design of a building component" (British Standards Institute, 2002, p. 3).

BS 5250:2011 is clear that designers need to also consider "the much greater risk of condensation occurring as a result of air leakage, which transports water vapour through gaps, joints and cracks in the building fabric" (p. 5) as well as the effects of exposure to sunlight, clear night skies, wind and driving rain, particularly in exposed positions subject to high wind speeds. In solid wall buildings made of permeable fabric constructed without a damp-proof course (dpc) phenomena such as driving rain and ground water will clearly have a significant impact on the moisture behaviour of the building envelope. **At present BS 5250:2011 is used almost universally as the test of moisture performance of buildings and building components when even the standard itself states, in relation to the calculation methodology given in BS EN ISO 13788: 2002 that "it does not provide an accurate prediction of moisture conditions within the structure under service conditions"**. Whilst this statement must, to some extent, be pertinent to all buildings it must be particularly significant with regard to pre-1919 moisture-permeable solid-wall buildings.

There is an alternative standard available, BS EN 15026:2007 *Hygrothermal performance of building components and building elements. Assessment of moisture transfer by numerical simulation*. Unlike BS 13788 this method does not assume a dry building operating in a steady-state but promotes the use of dynamic modelling which is able to take into account the effects on a building, over time, of specific material properties and the local environment. These models use a more detailed description of the characteristics of moisture behaviour within individual building materials and therefore are able to model the behaviour of water both as a liquid and a vapour, including the phenomenon of wind-driven rain. When applications are modelled under the dynamic or numerical system then entirely different results occur. However, **the physics of moisture behaviour is not thoroughly understood and there are a number of technical problems inherent in monitoring and modelling the behaviour of moisture, particularly liquid water within solid walls** (Baker 2007, Wood 2010). These difficulties inevitably lead to **problems in creating accurate numerical simulation models for hygrothermal modelling** – a problem which is compounded by the previously cited issues of poor material property data and data input quality (Little, 2012). Additionally, for this type of modelling there is a need for site-specific weather data as the location and even orientation of a building can radically alter its moisture behaviour. **It can be difficult to establish accurate weather data for modelling purposes; there is also a lack of understanding of its significance** (Heath, 2010b). Despite an acknowledgment, in some quarters, of these limitations and calls for research which include an iterative relationship between modelled outcomes and on-site observations (Badami, 2011) there is still **little work being undertaken which looks jointly at modelled and monitored moisture consequences for buildings.**

There is a particular concern about the possibility of degradation and structural damage in less moisture-tolerant fabric, such as timber joist ends, that are embedded in solid walls. Altamirano-Medina, Mumovic, Davies, Ridley and Oreszczyn (2009) provide a review of the literature covering the environmental conditions required to cause decay due to mould growth, and reveal differences between accounts. Viitanen *et al* (2010), Sedlbauer (2001) and others have also provided work in this area with Viitanen noting a difference between modelled predictions of mould growth and *in situ* observations. From this work it is clear that **more research is required to gain a thorough understanding of the complex mechanisms of moisture-related decay and their relationships with building environments. Furthermore, the viability and role of vapour-control products in relation to the movement of moisture in retrofitted or traditional buildings is also not well understood** with different research placing different emphasis on either the necessity for, or the counter-effectiveness of, these treatments (Selves, Bell & Irving 2011, Little, 2012).

Floors

There is no research available which specifically concerns the heat loss of pre-1919 floor types. Of the information available to guide the insulation of traditional floors almost none is based on any field tests or trials (with the exception of one modern floor that was insulated as part of a Changeworks/Historic Scotland project). The lack of research in this area is evidenced in the lower proportion of references (3%) mapped against the floor category within the Intelligence Map.

Windows and Doors

In contrast to the dearth of work relating to traditional floors, the timber windows found in most traditional buildings are comparatively well served by both research and guidance literature (and make up to 5% of overall references). And, almost uniquely, the guidance for these elements is based on the results of experimental research and testing carried out by Historic Scotland (Baker, 2008) and English Heritage (Wood, 2009). The findings – that a secondary glazed historic window can reduce heat loss more effectively than a replacement double glazed window – is an important one, and provides a straightforward example of sympathy between the concerns of conservation and energy efficiency in traditional buildings. However, the effectiveness of secondary glazing for traditional windows **does not seem to have made its way into more mainstream refurbishment literature which frequently only provides the message that replacing windows will save energy** (for example, see the 'Refurbishing Living Spaces' literature produced by the Energy Saving Trust).

Very little work has been undertaken specifically in relation to the doors of traditional buildings and this is an area more normally discussed within the context of doors, windows and draught-proofing. Some advice on upgrading doors is available from both English Heritage and Historic Scotland, but unlike the windows guidance this is not based on any measured trials or tests. In this respect it shares a characteristic with most guidance documents for the retrofitting of traditional buildings, which is to say that **in most cases guidance is not based on robust research evidence.**

Roofs

References for roofs tend to exist within broader work on roofs in general. They are therefore **not concerned with the specific characteristics of traditional roofs that can present problematic issues for insulation, such as sloping ceilings, rooms open to rafters and historic timbers**. On roofs in general Selves *et al* (2011, p 26 – 27) conclude **"There is a shortage of independent research into the performance of both traditional ventilated roofs and unventilated construction"** and that **"Many of the commercial documents available promoting the use of unventilated roofs fail to take a holistic approach" which he notes is required by the standard BS 5250:2011 Code of practice for control of condensation in buildings.** Selves *et al* (2011, p. 28) also note a series of difficulties in the calculation of condensation risk for unventilated roofs including uncertainty around simulations and models similar to those previously cited: **"due to uncertainties in the input parameters it was not possible to determine the reliability of the calculation methods"**. Maybe as a result of these difficulties, Selves *et al* also believe that "it is unrealistic to expect designers to make these [surface and interstitial condensation risk] calculations for each project". **It would seem therefore that additional work is required to gain a comprehensive understanding of traditionally built roofs and format suitable standards** particularly when many of these constructions may become less ventilated as a result of retrofitting.

Thermal Bridges

Thermal bridging is an important issue with regard to heat loss (leading to increased energy use) and potential health and fabric risks. There is an increasing understanding of this issue in new-build in policy, regulation and practice, although research often reveals a gap between designed and as-built performance with regard to thermal bridges. There is however very little research work on the subject as it relates to traditional building performance and the retrofit of traditional buildings, and most of the guidance, where it exists (such as in the Energy Savings Trust CE17 Internal Insulation document) seems to be based upon theoretical modelling and not testing. **There is therefore a general gap in the understanding and the effect of actual thermal bridging in existing traditional buildings, and of the consequences of thermal bridging in retrofit.**

With regard to the effects of thermal bridging on overall heat loss of a traditional building, the work of Andersson (1980) and Schnieder (2005) identifies limits to the effectiveness of internal insulation in reducing heat loss due to thermal bridging around windows, doors, floors, party and partition walls, roof-wall junctions and lintels. In Schnieder's assessment of the passivhaus retrofit of a German solid-wall masonry building, there are decreasing marginal returns on the thickness of insulation to walls due to unavoidable thermal bridges, even when these are expertly detailed. In Schnieder's calculation insulating solid walls internally with more than 100mm of insulation with a k value of 0.035W/K will provide no additional thermal benefit even in a passivhaus refurbishment. Where little or no insulation is possible on certain thermal bridges, such as window reveals, the possible insulation values of the whole wall are further reduced considerably (Andersson). However, while the German studies identify that there are definite limits to the effectiveness of IWI (Internal Wall Insulation) in energy terms due to unavoidable thermal bridging, there is no sensitivity analysis or practical testing of the findings; it is therefore not possible from this work to quantify the actual limits of IWI in UK traditional buildings. It is possible to say, however, that **the limits to internal wall insulation in UK traditional buildings, including the variables according to building type, insulation thickness, and location, have not yet been sufficiently recognised in guidance and until now have not been researched properly.**

The possible effects of thermal bridges on vulnerable fabric such as joist ends in external walls are dealt with by, amongst others, Little (2012) and May (2005). They identify that internal insulation will reduce heat flow to walls and thereby increase the likelihood of condensation on joist ends where the insulation layer is bridged. This problem can be exacerbated and interact with higher moisture levels in the wall generally, due to loss of heat to the wall from the inside and loss of drying potential to the wall in the case of vapour-closed insulation and linings (Künzel & Holm, 2009). **However, much of this research is based on modelled scenarios and there is uncertainty concerning these, as well a lack of good monitored case studies to quantify this risk.**

Regarding external wall insulation (EWI), Hooper *et al*'s (2012) research undertaken in Swansea is important as, based on an *in situ* study, it shows the difficulty of dealing with thermal bridging when applying such external wall insulation. Hooper found numerous examples of thermal bridging in houses fitted with EWI which resulted initially from poor survey practices and the inability of the insulation supplier and contractor to address thermal bridging issues. **This demonstrates a failure of understanding on the part of the retrofitting supply/delivery chain to address thermal bridging risks resulting from EWI.**

Airtightness

Measuring the airtightness or air permeability of a building is relatively straightforward and such a test is mandatory for new buildings. The subject of airtightness is represented by 4% of overall references in the Intelligence Map, but outside of specific retrofit research projects the air permeability of existing building stock has not been greatly researched. **Knowledge of representative air permeability rates for traditional buildings is extremely scarce.** In 2000 Stephen produced a report on behalf of the BRE which collated measurements from across all parts of the existing housing stock. This work, alongside smaller scale work by Hubbard (2011) suggests that the conventional view that traditional buildings are particularly leaky may not be correct. Stephen ((2000, p. 4)) found that buildings built between 1930 and 1959 had the highest rates of air permeability. In research projects that have measured air permeability before and after refurbishment, air permeability across building stocks was found to be extremely varied and no simple correlation between building age and permeability could be found. Refurbishment projects that have addressed improvements to airtightness are found to have established only marginal decreases (4% lower air permeability – Hong, 2006b). And indeed when refurbishment projects include the installation of a central heating system air permeability rates increased (Hong, 2006b).

Because air exchange can act as a drying mechanism, the degree and quantity of air changes within a building affects rates of humidity and moisture both within the air and within the fabric of a building enclosure. The presence of moisture and air also enable mould growth and insect infestation in certain building materials, particularly those of organic origin, found in traditional buildings. Just as very little is known about current rates of air permeability in traditional buildings **nothing is known about what constitutes safe levels of air exchange for buildings constructed of moisture-permeable materials** (Halliday, 2009).

Ventilation

Ventilation also contributes to the rate of air exchange experienced by a building and its occupants, although this exchange is, at least in theory, deliberate and controllable. **Work on the ventilation of traditional buildings, retrofitted or existing, is, once more, scant** and forms 3% of the overall references found. **Suitable levels of ventilation for traditional buildings constructed of moisture-active (i.e. 'breathable') materials are, like air permeability rates, unknown.**

Mechanical ventilation and heat recovery systems (MVHR) are sometimes specified as part of energy-efficient refurbishments; **such systems rely on buildings being well-sealed to function effectively, but once again no specific studies have been conducted as to the suitability or practicality of such systems for traditional buildings.** A recent study by the Good Homes Alliance (Taylor & Morgan, 2011) has found that **in relation to MVHR systems in general there was little measured evidence to support performance claims, no consistent methodology for test measurements, and issues of poor design, installation and maintenance that impinged upon air quality.**

Good Health

Questions of air permeability and ventilation inevitably intersect with issues of indoor air quality (IAQ) but references concerning issues of health in the retrofit of traditional buildings form only 2% of overall references found. Halliday (2009, p. 6), in a scoping study on the subject of IAQ and retrofit for Historic Scotland, similarly found **"very little published research into chemical loads in buildings" and [also] found that "issues associated with maintaining a healthy indoor environment are barely touched upon". It identified no studies of the effect on human health of making changes to traditional buildings to meet energy efficiency targets.** Hobday (2011, p. 4) in *Historic Scotland Technical Paper 12* makes a similar point; **"There is also a notable lack of published data on indoor environmental quality in highly energy-efficient buildings (including both indoor air quality and other health factors, such as heating, lighting and ventilation)".**

In a more recent paper, *Will drivers for home energy efficiency harm occupant health?* Bone, Murray, Myers Dengel and Crump (2010, p. 6) are clear that **"evidence on the impacts on health of highly energy-efficient homes in the UK is insufficient.... While there is evidence to link ventilation to indoor air pollutants, and indoor air pollutants to health, there is less information about the direct links. There has never been a comprehensive study on the role of home ventilation for ensuring health; of ventilation rates achieved in practice in UK homes; or a definitive assessment of a safe minimum level of ventilation (**although 0.5 air changes per hour is widely recommended)." They continue **"There is a real need for large-scale, longitudinal studies to assess the relationships between energy efficiency, ventilation, indoor air quality and health....** As buildings become more airtight, there will be a greater reliance on mechanical ventilation systems. **There is an urgent need for a better understanding of the performance of these products post-occupancy, as well as guidance for those commissioning, installing, maintaining and using such products"** (see also Taylor & Morgan, 2011).

Thermal Comfort

Changes to thermal comfort levels are used in many studies as an indicator of the success or otherwise of energy-efficient retrofit interventions, and make up 4% of references found during this research. In a small ongoing study carried out by the Society for the Protection of Ancient Buildings (Rye, Scott & Hubbard, 2011) the comfort levels in seven dwellings prior to retrofit work were found to be outside ideal or even in some instances acceptable ranges. Other research carried out by the Warm Front study group project (Oreszcyn, Hong, Ridley & Wilkinson, 2006) found older buildings with lower than 'normal' dwelling temperatures. Comfort levels and general well-being can be much improved by refurbishment work; however this improvement in comfort levels is not necessarily accompanied by a reduction in fuel consumption (Gilbertson, Stevens, Stiell & Thorogood, 2006).

Work by Lloyd, Callau, Bishop, and Smith (2008) in New Zealand undermined the concept of a simple relationship between refurbishment and raised comfort levels, because a study of houses that had been refurbished found less than desirable comfort levels, apparently due to householder choice. Significantly, another study by Hutchinson, Wilkinson, Hong and Oreszczyn (2006, p. 1199) involving the same Warm Front study group found "Property and household characteristics provide only limited potential for identifying dwellings where winter indoor temperatures are likely to be low, presumably because of the multiple influences on home heating, including personal choice and behaviour." This research suggests that the factors that affect low indoor temperatures are multiple and that **there is no simple relationship between low indoor temperatures and the (supposed) poor thermal performance of pre-1919 buildings – or indeed that refurbishment work automatically leads to raised comfort levels and lower fuel consumption.** Improvements to thermal comfort are one of the prime motivating principals that underlies retrofit programmes; however **the relationship between retrofit and thermal comfort in traditional buildings remains unclear.**

Aesthetics, Character and Significance

Guidance regarding the energy-efficient refurbishment (included the provision of renewables and micro-generation plant) for traditional buildings is often mindful of the potential aesthetic risk this work poses to older buildings. This is understandable as most historic building legislation is constructed around protecting listed buildings from non-technical aesthetic risks. Work in this area forms 4% of overall references gathered and is often, quite necessarily, formed of expert subjective judgments concerning the 'value' or 'significance' of a 'heritage asset'. **Whilst authors often cite a potential alignment between building conservation and energy conservation this is rarely substantiated** in the literature. With regard to the contribution existing buildings in general and particularly solid-wall buildings can make to energy saving, Power (2008, p. 11) notes **"Further work is needed on the wider environmental impacts of demolition, new build, renovation, density, materials and other issues to clarify the arguments"**. An interesting intervention in this debate is found in Powter and Ross (2005) who provide an analysis of assessment methods used to measure the environmental impact of buildings via tools such as the Building Research Establishment Environmental Assessment Method (BREEAM) and Leadership in Energy and Environmental Design (LEED). **They find that the value systems embedded within these tools are misaligned and limited with regard to heritage buildings**. Such assessments are unable to provide a value for the qualitative aspects of heritage buildings such as community and cultural sustainability and therefore some values represented by traditional buildings are not well served by these methods. Power and Ross make recommendations for ways in which these assessments could be improved that are similar to calls made elsewhere for improved modelling tools for traditional buildings.

Heating Approach

The subject of heating approach made up 4% of the overall references collected from the literature but **once again work related specifically to heating approaches with regard to traditional buildings was very limited**. There is one research publication on this subject, Historic Scotland Technical Paper 14 *Keeping Warm in a Cooler House*, and no appreciable guidance other than the Oxley & Warm CIBSE *Guide to Building Services for Historic Buildings*, which was published in 2002 and is in need of updating. The Historic Scotland paper challenges the convention of ubiquitous heating approaches and **calls for more research to establish the energy benefits of supplementary heating approaches, and to develop suitable devices, controls and guidance to help deliver such a strategy.** The issue of service runs in traditional and particularly historic buildings is mentioned in the CIBSE Guide and **concerns about damage to fabric and lack of reversibility are often voiced with regard to the provision of services in these types of buildings, but there seems to be no literature which addresses this particular issue.**

The energy benefits of thermal mass are often quoted in relation to the heavyweight characteristics of many traditional buildings (i.e. solid masonry walls). Although there are some studies which touch upon this subject the positive contribution of solid masonry walls to overall energy saving is not substantiated within the literature. **There is no work specifically on the way that thermal mass can improve heating energy use within older buildings situated in colder northerly climates, nor indeed on how this feature may be best incorporated into energy efficiency retrofit through design and heating regimes that might use the storage capacity of heavy masonry walls to best effect**. Sharpe and Shearer's (2012) study of the retrofit of a nineteenth-century Edinburgh tenant building **references the problem of correctly sized plant for better insulated properties**. In this case study even the smallest ground-source heat pump did not match the small heat demand of the property and therefore did not run efficiently (plant size matching, particularly for low demand, is a problem that extends beyond traditional buildings to more efficient building stock in general). As was seen in the earlier cited example from New Zealand, user behaviour is a significant factor in determining heating patterns. Lomas (2009) calls for more research in the area of user variability and consumer patterns of heating set points and controller variability, as well a greater understanding of the way building type affects control setting where detached and semi-detached houses seem to use, on average, an additional hour of heating.

Heating Fuel and Electricity Source

With regards to heating fuel this subject constituted 3% of the total references collected and 2% were concerned with electricity source and generation. **There is no work available to inform a hierarchy of preference with regard to approach or fuel choice for traditional buildings** i.e. passive design, renewables, or efficient use of fossil fuels. The Changeworks guidance document, *Renewable Heritage*, provides a thorough review of renewable and microgeneration options supported by case studies from various traditional buildings. The document emphasises the contribution that these technologies can make to the ongoing sustainability of traditional buildings. It also emphasises the need for a sensitive approach based on thorough research and good communication with all interested parties. However, **there is confusion concerning planning restrictions for renewables**, and outside of this specific context **Friedman and Cooke (2012) have found a lack of consistency in application of planning policies with regard to historic buildings** and suggests that this might be a barrier to energy improvements for this class of buildings.

Cooling

With the gradual increase in global temperatures, overheating and the energy demands of cooling have become factors in the overall energy demand and carbon cost of buildings. Lomas' paper (2012), *The Resilience Of 'Nightingale' Hospital Wards In A Changing Climate* identifies a number of features common to many traditional buildings: narrow sections, high floor-to-ceiling heights and high-mass walls which provide excellent potential for cooling. Elsewhere, in work by Historic Scotland, the passive design features of many Victorian-era institutional buildings are remarked upon. Frith and Wright (2008, p. 12) speculate that "Pre-1919 dwellings are the least likely to overheat, possibly due to their high thermal mass". However in another paper Wright, Young and Natarajan (2005, p. 13) establish some findings that appear to contradict the assumption that thermal mass can have a beneficial cooling effect during a heat wave, particularly within bedroom constructions, and they call for more research: "Clearly further work needs to be done on the benefits and disadvantages of thermal mass and night ventilation in bedrooms during hot summer weather". Porritt, Cropper, Shao and Goodier (2012) have found that internal wall insulation can increase overheating in some scenarios. Some internal wall insulation systems 'decouple' the wall from its cooler heavy masonry element thus perhaps unwittingly depriving the building of an inherent cooling effect. **Clearly the benefits for cooling found in traditional buildings and the opportunities to use these for energy efficiency gains need to be more widely understood.**

Lighting

There was very little work found specifically on the subject of energy-efficient lighting in traditional buildings (a total of only 1% of the overall references). It is recognised that, outside of historic lamp fittings and other protected features such as decorative ceilings, the deployment of low energy bulbs is relatively unproblematic and is encouraged. The longer lifespans of compact fluorescent lamps reduces replacement frequency which is advantageous for the high-ceilinged rooms found in some types of traditional buildings.

User Interface and Occupant Interaction

It is widely acknowledged that one of the most significant determinants of a building's energy use is the behaviour of its occupants, but work on 'user interfaces' and 'occupant interactions' constitutes only 1% of the references uncovered by this research. **There is no work on user behaviour focused specifically on traditional buildings, neither on whether the behaviour of users of traditional buildings might be any different to that of occupants of any other types of building stock, nor, indeed, whether a retrofitted traditional building determines or requires particular behavioural responses**.

The consequences of user behaviour and interactions have been previously referenced under different sub-headings within this account. These relate particularly to the difficulty of accounting for behavioural effects within building energy modelling programmes and the uncertainty that this brings to modelled outcomes, and unintended consequences such as the lack of improvement to thermal comfort and the failure to reduce energy consumption following refurbishment programmes. Specifically, Mulligan and Broadway (2012) in research as part of two Retrofit for the Future projects, noted control features which people found difficult to use. Sharpe and Shearer's (2012) study found that occupants' lack of control over heating meant they reverted to window opening to control their environment, resulting in energy waste. **More research and guidance is needed in the areas both of system design, control and on-going maintenance to improve user interactions with buildings** in general and particularly for systems that require maintenance to sustain a healthy as well as an energy-efficient environment. Gupta and Chandiwala (2010, p. 19) demonstrate the value of deep engagement with users and occupiers: “Pre-refurbishment feedback and evaluation has also led to the active and ongoing engagement of the occupants in the retrofit process, and generated awareness of energy use and wastage, thereby positively influencing user behaviour”.

Given that, ultimately, it is people not buildings that use energy, productive engagement based on good-quality research would seem vital to deliver meaningful energy reduction interventions in the traditionally built environment.

3

Implicit Guidance

What is Implicit Guidance?

In many circumstances the information commonly used by specifiers and contractors to inform the retrofit of traditional buildings does not come directly from research or even formal guidance, but from other sources that include Building Regulations, certifications, trade literature and other industry documents. We have called this category of information Implicit Guidance, as it implicitly leads to a certain way of understanding traditional buildings and guides designers and contractors to specific retrofit applications, without necessarily taking account of issues that are particular to traditional buildings. There is, therefore, a need to understand whether or not Implicit Guidance is aligned with the best research and guidance, and whether there may also be gaps in these sources' of information with regard to the retrofitting of older buildings.

Some of the areas of Implicit Guidance considered were:

Building Regulations

Standards

Certifications

Manufacturers' technical information

Trade association technical guidance

Warranties

This work has focused on one area of particular concern – the insulation of solid walls – in order to illustrate the role and mechanics of Implicit Guidance. As such this work does not represent a comprehensive analysis of all issues pertinent to retrofitting practices, but rather is an effort to identify the key element of an approach. It is hoped that this example will serve to identify issues that may be important to the delivery of successful retrofit over the mid-term, particularly with regard to ensuring that best research and guidance is properly incorporated into Implicit Guidance of all sorts.

Methodology

The methodology of the review of Implicit Guidance was as follows:

- Identify from a user's perspective (i.e. owner, designer, contractor), the Implicit Guidance that may be referred to when making decisions on retrofit measures to an older property
- Identify, as far as possible, the connection between these documents and the standards and methods behind them
- Assess the relationship between standards and other types of Implicit Guidance and the information contained within the previously identified Tier 1 research and guidance

Information was sourced via internet searches, and by contacting selected people involved in the retrofit industry including:

Membership organisations involved in the construction sector

Representative bodies of manufacturers and installers

Manufacturers of products used in retrofit measures

UKAS (United Kingdom Accreditation Service) accredited organisations

The Call for Research carried out by STBA on behalf of DECC did not explicitly ask for Implicit Guidance to be identified. Any information received that fell within Implicit Guidance was looked at to assess its contribution to the guidance available.

The Identification of Implicit Guidance

The identification of Implicit Guidance started with an assessment of the regulations that are mandatory when carrying out retrofit measures to older properties, and their purpose in the construction sector. Following this search we considered standards, certificates, technical commercial documents and warranties. Within each section we briefly consider how each type of Implicit Guidance deals with the issues of traditional buildings.

Building Regulations

The Building Regulations are statutory instruments conferred by the 1984 Building Act to promote national standards for most aspects of a building's design and construction[8]. The requirements for building work are set out in Schedule 1 of the Regulations, with different requirements given for various aspects of building work. More detail is then provided via a set of Approved Documents (ADs) for England and Wales, Technical Handbooks in Scotland and Technical Booklets in Northern Ireland. These are intended to provide guidance and although they do not, in themselves, have a legal basis they include methods and standards of building which, if followed, will tend to show compliance with the Building Regulations.

The Building Regulations apply to most new buildings and many alterations to existing buildings, whether domestic, commercial or industrial. Accordingly they largely refer to modern building techniques, terminology and practices. However all ADs and Technical Handbooks make reference to historic and traditional properties and the exemptions or special considerations that may apply.

Most retrofit measures form 'controlled works' under the Building Regulations. The Approved Documents relevant to Green Deal qualifying measures are:

Part C (2010)	Site preparation and resistance to contaminants and moisture
Part F (2000)	Means of Ventilation
Part G (2010)	Sanitation, hot water safety and water efficiency
Part J (2010)	Heat Producing Appliances
Part L1B (2000)	Conservation of Fuel and Power (Existing buildings)
Part L2B (2000)	Conservation of Fuel and Power (Existing buildings other than dwellings)

And for Scotland, from Technical Handbooks Domestic and Non Domestic, include:

Section 3 (2010)	Environment
Section 6 (2010)	Energy

Relationship to traditional buildings

Using the Approved Documents Part L1B and L2B *Conservation of Fuel and Power* as an example shows how, within the Building Regulations, there is recognition of the need to consider the impact of proposed 'controlled works' on the host building when this is a historic (listed) or

[8] England and Wales at present share the same Buildings Regulations (Part L is currently under review in Wales) there are separate Building Regulations for Scotland and Northern Ireland, in general the Regulations are broadly similar across all areas of the UK.

traditional building. Upgrading works to the thermal elements of older properties are subject to the relevant provisions in AD Part L1B and L2B. In the case of older properties most of them meet the definition set out in Clause 3.8c "buildings of traditional construction with permeable fabric that both absorbs and readily allows the evaporation of moisture". Where this clause applies, then the aim should be "to improve energy efficiency as far as is reasonably practical". The AD goes on to state that the works "should not prejudice the character of the host building or increase the risk of long-term deterioration of the building fabric or fittings". In Clause 3.10 it recommends consulting guidance produced by English Heritage in order to determine appropriate energy performance standards for these buildings. And in Appendix 1 it states that where it is not possible to achieve the performance level set in the AD, it should be as close to this as practically possible. When deciding appropriate performance standards for building work in historic buildings reference to BS7913 'Principles of the conservation of historic buildings' is indicated. Also noted is for the BCB [Building Control Body] to take into account the advice of the local authority's conservation officer when assessing 'reasonable'.

The Scottish Technical Handbooks exhibit similar clauses, specifically 6.2.8 'Conversion of historic, listed or traditional buildings' (6.2.10 in Non Domestic Handbook) which differentiates between heated and unheated buildings as well as extensions to existing buildings and states: "each building will have to be dealt with on its own merits. Improvements to the fabric insulation of the building will often depend on factors such as whether or not improvement work can be carried out in a non-disruptive manner without damaging existing fabric… or whether potential solutions are compatible with the existing construction." The clause also recommends that early consultation with the relevant authorities is advisable when dealing with this class of buildings.

Nonetheless it should be noted that in many other guidance documents (such as the Energy Savings Trust website advice on Solid Wall Insulation[9]) and in nearly all trade literature reviewed, the Building Regulations Approved Documents U-value target of 0.30W/m^{2}K is quoted as the level of compliance for solid walls without any mention of possible exceptions for traditional buildings, the need to consult relevant authorities or the importance of understanding and preserving traditional fabric.

Standards

Standardisation is a voluntary process used to develop technical specifications to show that products or services are fit for purpose and interoperable (usable in conjunction with others). The process offers buyers of products and services:

- Minimum safety level for products put on market
- Rules for main characteristics
- Minimum quality level of products

Standards are shaped by consensus among enterprises, public authorities, consumers, and trade unions, through a consultation process organised by independent, recognised standardisation bodies at national, European and international level. In the UK this body is the British Standards Institution (BSI).

The BSI defines a standard as 'an agreed, repeatable way of doing something'. British Standards are designed to make life simpler and to increase safety, efficiency and effectiveness of products and services used. They also enable companies who comply with such standards to do business across Europe more easily.

[9] http://www.energysavingtrust.org.uk/In-your-home/Roofs-floors-walls-and-windows/Solid-wall-insulation

The BSI also publishes Publicly Available Specifications (PAS) documents. A PAS is a sponsored piece of work allowing organisations flexibility in the rapid creation of a standard while also allowing for a greater degree of control over the document's development. Once published, a PAS has all the functionality of a British Standard and is reviewed after two years when it is decided, with the client, as to whether or not it should become a formal British Standard.

In February 2012, the BSI published PAS 2030:2012 *Improving the energy efficiency of existing buildings. Specification for installation process, process management and service* primarily aimed at installers of energy efficiency measures.

Relationship to traditional buildings

One specific standard for traditional buildings was found: BS 7913:1998 *Guide to the principles of the conservation of historic buildings*. There is a short mention of insulation but mainly in regard to possible damage to aesthetics. There is also some comment on proper understanding of traditional construction: "[The] structure, materials and method of construction and patterns of air and moisture movement [of a traditional building] should be properly understood." (British Standards Institute, 1998, p. 8).

PAS 2030 does not identify traditional buildings as a distinct category. The issue of moisture in buildings is raised only with regard to the need to comply with Building Regulations. PAS 2030:2012 does reference Common Minimum Technical Competencies (CMTC) documents for some types of Green Deal measures including external and internal wall insulation (IWI and EWI). Under the CMTC requirement for EWI a person is required to "Know how to assess and be able to assess the suitability of the building structure for the application of external wall insulation in relation to: dampness, efflorescence/lime bloom, dusty or chalky surfaces, absorptive capacity, strength and load bearing capacity, evenness" (Annexe EWI 1 Version 8), and a list of competency reference numbers is given.

Product and System Certification

Product and system certification is the process of verifying that a certain product or system has passed performance and quality assurance tests. The main focus of the process is evaluation of the extent to which the product or system enables compliance with relevant Building Regulations and other statutory or non-statutory requirements (such as building warranties). Accreditation is by a third party recognised as competent in carrying out these tests.

Whilst there are several UKAS accredited bodies for building products and systems, the largest is the *British Board of Agrément* (BBA) Testing Services. An Agrément Certificate is awarded to a product successfully passing a comprehensive assessment, which can involve laboratory testing, thorough checking of other testing approvals, on-site evaluations and inspections of production.

A certificate can be issued for a product to be used as a component, such as a PIR insulation board for dry lining, or for a system, such as an external wall insulation system. The certificate defines the scope of use of the component/system and where it can be applied. The standard BBA Certification signature strip states "this system has been assessed… fit for its intended use provided it is installed, used and maintained as set out in this certificate". The assessment process is defined by the intended scope of use for the product stated by the manufacturer when the product is submitted for certification. Product and system certification is meant to provide sufficient information for a designer to decide if the product or system is suitable for a particular application.

Relationship to traditional buildings

Each certificate states the scope of use for the product including the type of building it can be used in. In the review of external and internal wall insulation products and systems there were no specific certifications for the use of products or systems in traditional buildings, nor were there any specific criteria of assessment within more general certificates. Instead common terminology is used on the certificates in reference to all buildings: existing, new, domestic and non-domestic. There are a few certifications that include use of products or systems grafted onto existing buildings and specifically onto solid walls (nearly always nine-inch brick walls). However the standards and methodology used for assessment are the same for all buildings and seem to be no different to those for new buildings. This is made clear in the examples given in the next section.

EST Quality Mark

The Energy Savings Trust runs a quality mark scheme that enables manufacturers to badge their products or systems as "Recommended by the Energy Savings Trust". The criteria for gaining the quality mark vary according to the product. For external wall insulation systems all that is required is a BBA Agrément Certificate, and 38 systems have the quality mark. In the case of internal wall insulation systems there are six approved products which have to comply with a number of criteria, including that the product literature shall contain a booklet that contains reference to the Energy Saving Trust's publication Best Practice CE17 *Internal wall insulation in existing housing – a guide for specifiers and contractors*[10].

It is worth making some brief comments about the EST Best Practice CE17[11] document on internal wall insulation, as the quality mark requires a reference to it and it is referenced frequently in trade literature for Internal Wall Insulation. This document makes special recommendations about solid walls in relation to moisture, referring to the SPAB (Society for the Protection of Ancient Buildings) document The Control of Damp in Old Buildings and acknowledging issues of driven rain. However the advice about avoiding interstitial condensation is as follows "It is therefore important to separate the inside air from the insulation by applying a 'vapour barrier', also known as a 'vapour control layer', to the warm side of the insulation". This advice is in contradiction to the SPAB technical sheet but rather follows the approach of BS 5250:2011. Consequently, most of the details of insulation application also follow this approach. In regard to thermal performance, U-values tables appear to use RdSAP default values for solid walls and BR443 is the convention which is recommended for calculation. Only three types of wall are listed and only one is traditional (215mm solid brickwork).

Trade Literature

These are technical manuals, information, editorial and advertising published by membership and trade bodies and manufacturers.

Relationship to traditional buildings

Most of the trade literature reviewed does not deal with traditional buildings as a special category. The literature for the most part contains no reference to the standards or methodology used in forming advice given. Where there is reference this is to Part L1(B) setting out the requirements triggered when refurbishing/renovating elements and the U-values required for these elements.

[10] http://www.energysavingtrust.org.uk/Consultancy-and-certification/Energy-Saving-Trust-Recommended/Product-certification/Dry-lining-insulation

[11] http://www.energysavingtrust.org.uk/Publications2/Housing-professionals/Insulation-and-ventilation/Internal-wall-insulation-in-existing-housing-2008-edition

Some of the technical literature and marketing for internal wall insulation refer to the EST's Best Practice documents such as CE17 *Internal Wall Insulation in Existing Housing*, to support their claims that insulation systems applied to solid walls result in energy savings.

There are now trade bodies such as the National Insulation Association (NIA) with specific programmes for the insulation of solid-wall buildings. There are also many companies promoting solutions for traditional buildings, particularly the external or internal insulation of solid walls. However there is very little if any reference to the specific requirements of solid wall buildings in contrast to other existing buildings.

Warranties and Guarantees

A warranty is a promise or assurance given in contract by a party to the other party to the contract. Warranties come in different forms but in this case the installer is assuring the customer of a certain level of performance over a pre-agreed period of time. If this is beyond the statutory minimum, normally the customer will have to pay for this 'extended warranty'. If the seller's goods are not free from defects in material and workmanship, they are in breach of a warranty under the agreement.
In contrast, guarantees are offered by manufacturers of products. They are free of charge but legally binding under the Sale and Supply of Goods to Consumers Regulations 2002. In UK law, a guarantee is considered to be "an agreement to provide some benefit for a set period of time in the event of the goods or services being defective".

Relationship to traditional buildings

The Green Deal has led to some activity in this area. In particular the new Solid Wall Insulation Guarantee Scheme (SWIGA), set up by the NIA, provides a 25-year guarantee in accordance with Green Deal requirements. At the time of writing (August 2012) there is little information about the scheme on the SWIGA website (www.swiga.co.uk). The NIA website has press releases about the scheme but again there is no information about what is involved or why traditional buildings require a different approach.

case study

Implicit Guidance: EWI and IWI systems

In this section we examine two Green Deal measures in some detail to understand better how the Implicit Guidance present in the marketplace is linked to standards, and how these standards themselves relate to current Tier 1 Research and Guidance, particularly in the light of our earlier 'Gap Analysis'.

The two Green Deal measures chosen for this brief analysis are external wall insulation (EWI) and internal wall insulation (IWI). They have been chosen because both are being heavily promoted by trade bodies, companies and, to some extent, Government, as necessary for the retrofit of solid-wall buildings, which are almost entirely traditional pre-1919 buildings. They have also been chosen because the walls of traditional buildings have some distinctly different performance and technical qualities from the cavity walls of modern buildings. Finally, the two applications form a good contrast in terms of the links between Implicit Guidance and Tier 1 research and guidance.

This section is only an illustration of the relationship between Implicit Guidance and Tier 1 research and guidance. It covers only two Green Deal applications. This does not mean that other applications have acceptable links, or that there are no major concerns.

For reasons of time, we have focused mainly on the British Board of Agrément (BBA) process and data.

Number of Systems and Status

Most EWI systems commonly used in the UK have BBA approval, because this is often required for warranties or insurance. There are currently 30 EWI systems in the UK with Agrément Certificates plus two other systems with European Technical Approvals[12]. There are a total of 69 product sheets (a certificate can have more than one product application or system) with BBA approval in the UK.

There are approximately 10 components/systems with BBA approval as an internal wall insulation system or as part of an internal dry lining system[13]. However there are many other systems being promoted in their marketing and technical literature by suppliers of insulation without any approval, reference to standards or, it seems, any evidence of effectiveness.

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[12] These are all listed on the BBA website
http://www.bbacerts.co.uk/certificates.aspx?ca=External+Wall+Insulation&ob=0&pg=1&
[13] http://www.bbacerts.co.uk/certificates.aspx?ca=Insulated+Wall+Lining&ob=0&pg=1&

Significantly the BBA report that a large number of wall insulation components and systems submissions have been lodged in recent months.

Certifications and Standards

EWI systems are relatively well established in terms of standards and certification processes. In contrast, it seems that there is no fixed protocol for IWI systems and assessment will be determined by a number of factors. However similar conventions and standards are used in assessment of both. A major difference between the two systems is that there is no physical testing of moisture-related issues required in internal wall insulation systems. No distinction however is made in either EWI or IWI system certifications between solid or cavity walls, except in the calculation of thermal performance.

The BBA assessment of both EWI and IWI systems has changed over time as standards and regulations have changed. Many of the systems currently holding BBA certificates have been approved under different testing regimes, with two going back to the 1980s and 11 going back to the 1990s (i.e. 13 out of 40 total certifications are pre-2000). However, even with products tested at the same time there can be considerable differences in the assessment procedures, particularly in regard to thermal properties, laboratory testing and on-site investigation[14]. This means that there are considerable differences in the certifications of different products and that some certified products may not necessarily meet current standards.

EWI certification

The BBA EWI assessment is now based on a European Technical Approval (ETA), known as ETAG 04[15]. Regional variations are permitted under European Standards according to different building types, local weather or other conditions.

There are extensive requirements under this assessment including a range of physical and theoretical assessments. These include extensive hygrothermal testing[16] to ensure the durability and weather resistance of systems.

The calculation methodologies used in ETAG 04 for thermal resistance are BS EN ISO 6946:2007 Building components and building elements and BS EN 12524:2000 Building materials and products – Hygrothermal properties. Determination of water vapour permeability is in accordance with BS EN 12086[17]. The standard used for assessment of condensation is BS 5250:2011 (EN ISO 13788).

There is no specific reference to, or requirements for, traditional buildings in the standards. BS EN 15026:2007 is not referenced. Issues that may be of concern such as residual (service) moisture and rising damp are not considered.

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[14] For example, in relation to thermal conductivity while many of the BBA EWI certificates simply instruct the manufacturer declared conductivity to be used, others give a conductivity value without stating its origin. None of the 2010 BBA certificates provide information on conductivity testing standards, while certificates under previous Building Regulations might state a specific testing standard, such as BS 874. Most new BBA certificate conductivity values are lambda 90/90 values, while the older certificates do not state if they are or not. Lambda 90/90 values tend to be higher than other standards for reporting conductivity, so this will yield inconsistencies when product certificates are compared.

[15] See http://www.ue.itb.pl/files/ue/etag/etag_004.pdf for the full ETAG 04 assessment method

[16] For weathertightness to be assessed a rig of specified size and type is tested under severe conditions for 80 cycles of heat/ rain and 5 long cycles of heat/cold. This is similar to the MOAT 22 test formerly used by BBA, though not as extreme.

[17] This Standard is currently in development.

None of the certificates examined noted any special requirements for traditional buildings. In cases where thermal values are quoted there is no acknowledgement of the different thermal performance of traditional buildings. Neither is there any acknowledgement of particular moisture conditions of traditional buildings, or any special requirement in terms of assessment or application.

IWI certification

There is no equivalent European technical guidance for internal wall insulation assessment.

The majority of products holding a BBA Agrément Certificate that may be used for improving the thermal performance of the inner face of a wall have been assessed only as individual components, for example PIR insulation boards for dry lining, multifoil insulations or sheepswool between studding. However there are several certifications for what are effectively IWI systems. The assessment has varied considerably over time, as noted above, and in none of the assessments is any testing carried out in regard to moisture apart from vapour permeability testing, which tested the product, not its application. Moisture risk is assessed entirely by the BS 5250:2011 Code of practice for the control of condensation. In one certificate only[18] is there a reference to the use of BS EN 15027: 2007 where it is advised in order to determine the necessity of a vapour barrier in the construction if the application shows "persistent condensation" according to BS5250. In another[19] it is stated: "Since the system is not intended to offer resistance to rain penetration, walls must be rain resistant and show no signs of rain penetration or damp from ground moisture. Wall surfaces should be sound, clean and free from loose material, and if present, mould or fungal growth should be treated prior to the application of the system". However this certificate later states: "Walls will limit the risk of interstitial condensation adequately when they are designed and constructed in accordance with BS 5250 : 2002, Section 8.3 and Annex D".

Thermal standards are assessed by BS EN ISO 6946:2007 Building components and building elements. Building Regulations requirements in England and Wales for U-values in retrofitted buildings are shown as 0.30W/m^{2}K (and in Scotland 0.30, 0.22 or 0.19 according to building type, in Northern Ireland 0.35W/m^{2}K) without any note about traditional buildings and the possible relaxation of such targets if fabric was put at risk. One of the certificates appears to use the RdSAP default U-value of 2.1W/m^{2}K for a 215mm solid brick wall in its thermal performance table. As with EWI certificates no acknowledgement, in any certificate, is made of the different thermal performance of different traditional walls. Several of the systems also assume that U-values as low as 0.20 can be reached, without taking consideration of thermal bridging limits or the possible risk to traditional building fabric.

Trade Literature

The trade literature examined for EWI and IWI systems makes much greater reference to traditional buildings (typically referring to "solid walls" and "hard-to-treat properties"), frequently offering bespoke calculations and solutions (including in one case "the perfect SWI solution"). One manufacturer claims that their systems were developed "particularly for application onto solid wall and "hard to treat homes". On examination however all the systems, where any reference is actually made, refer to BR 443 or BS EN ISO 6946:2007 for thermal calculations and to BS 5250:2011 for condensation calculations. No acknowledgement of the specific thermal and moisture conditions of traditional buildings is made.

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[18] Kingspan Kooltherma Insulation certificate 10/4798

[19] Knauf Internal Wall Insulation System certificate 11/4849

Certification and Links to other Implicit Guidance

Eligibility for warranties for EWI systems for new homes and some retrofit applications through organisations such as National House Building Council (NHBC), Local Authority Building Control (LABC), New Homes Warranty and the Insulated Cladding Association (INCA) is usually dependent upon BBA or occasionally European certification. With regard to Solid Wall retrofit, BBA Certification is also likely to be a criterion for SWIGA, the Solid Wall Insulation Guarantee Scheme. Importantly the Office of Gas and Electricity Markets (Ofgem) also considers BBA as a requirement for eligibility for Community Energy Saving Programme (CESP) and Carbon Emissions Reduction Target (CERT) funding which is aimed at Solid Walls, in regard to EWI systems. It is expected that this will also apply to the Energy Company Obligation (ECO) and for IWI systems once certification is properly set up. At present IWI systems can gain eligibility for CESP through approval or an independent architect or engineer.

For Building Regulations approval, BBA certification is a means of compliance as it is often seen by inspectors and specifiers as confirmation that the product is fit for purpose. However BBA approval does not automatically ensure Building Regulations approval, nor does the lack of BBA certification mean that there will not be approval. This is ultimately at the discretion of the Building Inspector.

Nonetheless, overall, it is the experience of the research team that BBA approval is possibly the single most influential factor in guiding industry (including specifiers, inspectors, warranty providers, insurers and others) in what is acceptable in most building applications. Consequently it is vital that certification processes are robust and that the standards used for certification are correct.

Gaps between Implicit Guidance and Tier 1 Research and Guidance

Gaps have only been considered in terms of thermal and moisture performance, as these issues have been highlighted in the Gap Analysis.

Thermal performance

It has been clearly identified by the Gap Analysis that the standard EN BS 6946:2007 (required as the basis for U-value assessment by Approved Documents L1B and L2B via the document BR443 ‘Conventions for U-value Calculation’ and used in U-value calculating software programmes) is, in many cases, inappropriate for the assessment of the U-values of solid walls. **As well as the Approved Documents, without exception all certifications, technical literature, advertising, and other Implicit Guidance used this standard directly or indirectly (for example by referring to EST guidance) for the assessment of existing solid wall U-values and the consequent possible cost savings for both EWI and IWI systems and components.**

Target U-values for wall improvements, 0.3 W/m^{2}K, are taken from Approved Document Part L, or in the case of Scotland 0.3 W/m^{2}K, 0.22 W/m^{2}K or 0.19 W/m^{2}K from the Technical Handbooks. In relation to IWI, as noted by Andersson (1980) and Schnieder (2005) there is evidence that there are limits to the amount of IWI insulation that is energy- or cost-effective because of unavoidable thermal bridging from party and partition walling, windows, floors, and roofs. Therefore, with regard to thermal bridging, **there is also a gap between this understanding and the Implicit Guidance, where limits are not acknowledged**. Furthermore, the more insulation that is applied the greater the risks to fabric decay particularly in areas where there is thermal bridging such as joist ends. **This issue of whole wall thermal bridging in internal wall insulation is not properly acknowledged in policy, Building Regulations (Approved Documents), certification or technical commercial literature**. In regard specifically to external wall insulation Hooper *et al* (2012) found numerous examples of thermal bridging in houses fitted with EWI that resulted from poor survey practices and the inability of the insulation supplier and contractor to address thermal bridging issues.This **demonstrates a failure of understanding on the part of the retrofitting supply/delivery chain to address thermal bridging risks resulting from EWI**.

Moisture performance

It has been clearly identified in the Gap Analysis that moisture issues in traditional buildings are complex and there are large areas of uncertainty. With regard to Standards, Little (2012) as well as the text found in the Standards themselves make it clear that the use of BS 5250:2011 and BS EN ISO 13788:2002 will not be appropriate to assess all aspects of moisture and condensation risk within a property, particularly a traditionally built (solid-wall) one. However **without exception all certifications, technical literature, advertising, and other Implicit Guidance used these standards as methods of moisture assessment**, if they used a standard at all. Overall very few other acknowledgements were found of the issues of moisture that may occur in traditional buildings, and where such references are found they are nearly always contradicted by other references, particularly to BS 5250 and the need for vapour barriers. Only two references to the hygrothermal numerical modelling Standard BS EN 15026:2007 were found in all the relevant technical literature, and one of these was as an alternative if there was a failure to comply through BS 5250:2011, and not as a method of analysing the basic risk of an application.
The failure to use the numerical dynamic moisture modelling is also highly relevant to EWI systems particularly where application is not perfect – possibly a common occurrence, as shown by Hooper *et al* (2012) – or where walls are damp from other causes. This will be a common occurrence in traditional buildings due to the fact that most buildings will have some moisture in the fabric due to many decades of exposure to weather, and nearly all traditional buildings will also have greater moisture at the bottom of walls due to a lack of damp-proof courses. It is likely that this will be a more serious matter in areas of greater exposure to driven rain. This needs urgent further testing and research to ensure that the certification process is correct for traditional buildings in all areas.

Conclusion

As the solid wall insulation case study illustrates there is no direct link between the current best research information relevant to retrofit issues and the Implicit Guidance used by the industry. In fact there is a significant gap leading in many cases to contradiction between best research and nearly all Implicit Guidance. There is also a lot of poor primary guidance in this area that is further confusing the situation, for example the assertion of the need to use vapour-control layers with internal wall insulation irrespective of specific circumstances[20]. This situation may well exist in other areas of retrofit application, particularly where traditional building performance differs substantially from modern or new building performance, for example in roofs, floors, windows, ventilation, and user controls.

This problem of disconnection or even contradiction between current best research and the guidance and standards is not new; it was noted in work carried out by the International Energy Agency (IEA) Annexe 24 on Heat, Air and Moisture Transport that was finished in 1995: "Many of the results of Annex 24 will be lost if the knowledge gained is not embedded in an upgrade of existing national codes of practice and improved standardisation. As long as simple engineering tools, such as the Glaser method, form the ultimate proof for moisture tolerance, no changes should be expected in everyday practices" (Hens, 2002, p. 21).

The consequences of this gap and recommendations for addressing it are set out in the discussion of this issue in the next section and in the policy recommendations in the final section.

[20] in EST CE17 document page 12

4

Discussion

Overview

In this section we have drawn together the main issues emerging from the Gap Analysis and Implicit Guidance research. These issues do not necessarily relate to specific parts of the Intelligence Map or to particular Green Deal measures, and may be of significance to a number of applications or categories. The key issues are:

- Heat Loss
- Moisture
- Modelling/monitoring
- Ventilation and Indoor Air Quality
- Overheating
- Users
- Guidance
- Implicit Guidance
- Design and Installation Issues
- Cultural Significance

It is important to note that the headings given above do not represent discrete items. The performance and behaviour of all buildings is, to a greater or lesser extent, systemic – that is to say actions to, or in, one part of a construction will have an effect on other parts. A simple example of this would be that a damp wall will lose more heat. This phenomenon is not just restricted to the realm of building physics, and it is particularly significant in more unified forms of construction, such as traditional buildings, where elements are not isolated or separated by barriers or cavities. Therefore in order to progress our understanding of these types of buildings it is necessary to be aware of the workings of the whole structure and the interrelationships between different elements, including the affects of occupation. Whilst, for ease of expression, the following account follows individual headings, the interdependent nature of the individual subjects should be borne in mind at all times.

Heat Loss

The subject of heat loss relates to both the fabric and airtightness of a building. Here we will deal with it primarily in terms of the building fabric, and its relationship particularly to retrofit measures for the thermal upgrade of walls, windows, doors, roofs and floors. (Heat loss as a function of air permeability is dealt with in the section on Ventilation and IAQ.) Heat loss is a key issue because of the large amount of energy used in space heating in existing buildings in the UK (estimated as 56% of delivered energy use, the other energy use being in appliances, hot water, lighting and cooking)[21]. Energy use relates both to carbon and cost, both key drivers for retrofit policy. However, the majority of UK space heating is by gas, which has a lower cost and carbon content than electricity.

Summary of Findings

It would appear that the current standard methods and material data used to assess fabric heat losses in traditional buildings do not represent certain types of solid wall constructions well. When *in situ* U-value measurements have been made of solid walls these elements often perform significantly better than conventional U-value calculations predict. Furthermore, current mainstream measures of retrofit to walls, floors and windows may not be the optimal solutions in reality.

Findings

• Empirical evidence shows that traditionally built solid walls often have lower U-values than modelled (calculated) U-values for the same walls.

• The convention document BR 443 *Conventions for U-value Calculations* is required for U-value estimates by Part L of the Approved Documents; it also underpins SAP, RdSAP and U-value calculating software programmes. This convention and its accompanying standard BS EN ISO 6946:1997 is based upon a modern conception of wall construction where the build-up of an element can be clearly defined and given appropriate material conductivities. The BR443 convention is less satisfactory when the make-up of an element is not discrete and/or is ambiguous. Therefore in its current state it is not suitable for modelling many traditional solid-wall structures.

• In particular RdSAP default U-values tend to overestimate the amount of heat loss from traditional walls. RdSAP default values for solid stone and brick walls of 2.3–2.1 W/m^{2}K (1.9–1.6 W/m^{2}K for Scotland) are often out by 30% or more compared with *in situ* measurements of many traditional walls with measured U-values of between 1.0 and 1.6W/m^{2}K (Rye, 2011).

• There is a dearth of material data for traditional building materials (which can be very variable); where these have been measured they can be very different from the default values included in standard programmes.

• There are limits to the amount of IWI insulation that is energy- or cost-effective because of unavoidable thermal bridging from party and partition walling, floors, and roofs. Going below a U-value of 0.3 W/m^{2}K for an individual wall element does not seem viable even in passivhaus total refurbishments (Schnieder), and in less ambitious retrofits even lower U-values may in reality be difficult to achieve (Andersson, 1980).

• The roles of both thermal bridging and thermal mass in UK (retrofit) traditional buildings require more research.

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[21] From DECC 2009 data as reported in Vale and Vale (2010) 'Domestic energy use, lifestyles and POE: past lessons for current problems', Building Research & Information, 38: 5, 578 – 588

• Empirical work shows that secondary glazed historic windows and other conservation measures such as shutters can reduce heat loss as much as, and sometimes more effectively than replacement double glazing.

• The correct repair and maintenance of traditional building fabric (including roof, gutter, pointing, drainage, window, door, internal linings and other repairs) may considerably improve the thermal performance of the existing building fabric.

• The correct repair and maintenance of traditional building fabric may also have an influence on the thermal effectiveness of insulation measures as applied in retrofit (in addition to those related to moisture issues).

• Heat losses in traditional buildings are also affected by air permeability and the presence of moisture. A systemic approach, taking into account the interactions between heat, moisture and air in their constructions would lead to an improved refurbishment understanding and practice.

• In general, the insulation of floors and roofs in traditional buildings is not understood and requires more research.

Recommendations

• BR 443 and RdSAP 2009 v.9.91 (Appendix S, issued 2012) should not be used in their current form as the basis for estimating the U-values of traditional buildings, either for policy decisions or for energy and cost payback calculations in the Green Deal.

• BR443 and RdSAP should be amended to provide more representative U-values for solid-wall constructions so that suitable treatments and accurate energy-saving predictions can be made. There is a growing body of measured *in situ* U-value data for traditional solid walls; this provides an opportunity to alter the current modelling conventions to better reflect the heat loss of these walls. (Rye, 2010, Baker 2011, Baker & Rhee-Duverne, 2012).

• Measured U-values should be adopted as a standard procedure in the short term for buildings consisting of complex or indefinable wall build-ups, or of particular significance. (This is an approach currently encouraged by English Heritage).

• These measured U-values should be collated to form a database to aid the accurate estimation of fabric heat losses for traditional building types.

• A measured *in situ* U-values resource could provide a range of U-values for common forms of vernacular construction based on small number of variables, e.g. different building types, levels of exposure, and types, thicknesses and conditions of construction materials. This would allow for more confidence in the estimation of U-values for older walls.

• Approved Documents such as L1B and/ L2B, along with the Scottish Technical Handbooks and Northern Ireland's Technical Booklets, should differentiate between internal and external wall insulation approaches in retrofit and set realistic and safe U-value targets for the internal insulation of solid walls.

• Development of well-defined (thermal) material properties for a range of UK traditional building materials, e.g. stone and brick types, historic mortars etc., is required for more accurate calculation of U-values.

• The use of secondary glazing, shutters and other proven measures should be supported by policy and mainstream guidance for traditional building retrofit where appropriate.

• The correct repair and maintenance of traditional building fabric (including walls, floors, roofs, windows and doors) should be researched with regard to its cost and energy- and carbon-effectiveness. If it is shown to have a significant effect it should be promoted as part of retrofit policy and guidance.

• A systemic approach should be taken to improving the thermal performance of traditional buildings through interactions between building elements, technologies and users.

Moisture

Moisture issues are important because they can affect both the health of building occupants and also the health, durability and value of the building fabric. Sufficient evidence is available to show that the occupants of damp or mouldy buildings are at increased risk of respiratory symptoms, respiratory infections and the exacerbation of asthma[22]. As identified in Wilkinson, Smith, Beevers, Tonne and Oreszczyn (2007) occupant health has the potential to improve with increased energy-efficiency if interventions are implemented appropriately. However, increasing airtightness in buildings, without proper attention to changing other moisture control mechanisms (such as ventilation) can lead to increased levels of indoor relative humidity with associated potential threats to health. For example, Ucci *et al* (2011) have shown that such actions can considerably increase the risk of dust mite infestations. With regard to fabric decay, studies including Ridout (2000) and Viitanen (2010) clearly show the link between high moisture levels and timber decay. There are also links with fabric damage to plaster, masonry and other materials.

Summary of findings

Traditional buildings deal with moisture in a very different way to modern buildings. On the whole traditional buildings allow the absorption, movement and evaporation of moisture within the building fabric rather than attempting to exclude it, as is the case with most modern buildings. Consequently retrofit interventions of traditional buildings based upon modern building methods and concepts can radically change their moisture performance and bring considerable risks. On the other hand good understanding and practice in retrofit can benefit old building fabric performance as well as occupant health and general well-being. However this situation is complicated by a lack of understanding of moisture physics, lack of data concerning material properties and the use of inappropriate models. The interaction of a number of factors (including environment, fabric, technologies, and occupant behaviour) leads to a requirement for a systemic rather than an elemental or product based approach.

Findings

- Moisture physics is a developing science and there are still many uncertainties and unknowns.
- The application of moisture physics to buildings, particularly in traditional complex building types, is at nascent stage of development.
- Traditional buildings deal with moisture in a different way to modern buildings. Traditional buildings 'breathe' using vapour permeability, hygroscopicity and capillarity of fabric in combination with controlled and uncontrolled ventilation to create a safe environment (Hughes, 1987), while modern buildings are usually designed to rely on moisture barriers and have specific ventilation systems to deal with moisture.
- Excess moisture in buildings can cause building fabric decay and can also be a contributory cause of ill health in human occupants.
- The development of moisture-related pathologies in fabric or occupants can happen over several years or even decades (Ridout, 2000) therefore moisture-related problems are often not immediately apparent following the completion of work which causes them. This can create a problem in terms of liabilities, as well as a false sense of the success of a particular measure.

[22] WHO. (2009). *WHO Guidelines for Indoor Air Quality: Dampness and Mould*. World Health Organisation, Copenhagen

- The use of BS 5250:2011 (and its recommended calculations given in BS EN ISO 13788:2002) which form the basis for most moisture-risk calculations within the building industry is not sufficient to provide an accurate interpretation of risks, particularly for traditional buildings. These moisture models cannot account for situations where excess air leakage or penetrating moisture from driving rain or ground water is a factor, "[T]he Glaser method does neither account for hygroscopic sorption nor for liquid transport. Therefore its application is more or less limited to light-weight structures." (Künzel, 2000, para. 2.1). This means it is not suitable for traditional masonry buildings.

- A more sophisticated protocol is BS EN 15026:2007, which is a dynamic hygrothermal model that takes account of driven rain and moisture mechanisms in materials, but even here there are still uncertainties regarding building physics, data and operation.

- Driven rain data is a particular concern.

- Material properties data is also lacking (or default values applied to traditional building materials can be incorrect). Material properties data also vastly influences the effect of driven rain in models.

- All models struggle to represent the complexity of traditional buildings and building elements, in comparison with new buildings.

- There is still considerable uncertainty and many unknowns in relation to mould growth, both in models and in reality. Mould growth however is definitely proven to be predominantly caused by moisture, and some mould spores are toxic.

- It is acknowledged in much literature that the insulation of traditional buildings will alter moisture balances.

- There are particular concerns about internal wall insulation (IWI) on which much work is currently being undertaken in the UK, Europe and North America.

- There is a concern about too much internal insulation preventing heat flow into walls which may be needed to help drive out latent moisture and thus prevent external surface or interstitial condensation (Künzel, 2009). The effect of this is the possibility of fabric decay (frost damage, timber decay where timber is in walls etc.), and related indoor air quality issues owing to the potential presence of moulds.

- As moisture responses in buildings will be location-specific, the appropriate type and amount of insulation, particularly of IWI, may need to vary in response to different regions, locations, orientations and building forms. What works in London may be unsuitable on the west coast.

- Traditionally constructed walls often dry out to the inside as well as the outside, particularly when subject to driven rain. In such situations, which may be common in the UK, it is considered to be important to allow the wall to dry out to the interior. Where internal insulation is used this raises questions about the wisdom of including vapour control layers which act to prevent or slow down the diffusion of vapour from the interior of the building to the exterior. The presence of a VCL could prevent the movement of moisture from the exterior to the interior (Künzel, 2005).

- While there is often scope to improve comfort and save energy by reducing air infiltration and avoiding draughts, if this is overdone there is a concern that it could lead to raised internal moisture levels and subsequent moisture-related building fabric problems and associated health problems.

- There are concerns about the installation and operation of effective ventilation systems to reduce internal moisture build-up in all buildings, and particularly in traditional buildings.

- All these issues are subject to application and design errors, and require proper understanding by designers and contractors. Because of the seriousness and complexity of such issues, safety margins should be built into standards, models and designs wherever possible. Furthermore proper education and training of all parts of the supply chain is essential.

Recommendations

• BS 5250:2011 (and the calculations given in BS EN ISO 13788:2002) should not be used as the sole form of moisture calculation risk for traditional buildings.

• Those responsible for the specification and fitting of insulation to solid wall buildings must be urgently made aware of all the factors that present moisture risks to these buildings; namely local climate, orientation, construction type, materials (both existing and new insulation) the condition of fabric and finishes and building use.

• Where sufficient weather and material properties data exist the use of BS EN 15026 as a method of calculating moisture risks should be encouraged.

• Further urgent research is required to identify the correct range of moisture qualities for traditional materials and elements, as well as driven rain data for all models and calculations of moisture effects in traditional buildings.

• Standards, modelling and all guidance should incorporate safety margins as a precaution against incorrect design and application.

• A non-optimised robust approach should be encouraged rather than an optimised approach. An optimised approach relies on a known and correct understanding of performance; at the present time this is not possible given the multiplicity of interacting elements and the large number of unknowns.

• A systemic design approach is necessary, which involves not only whole house design but also user and contractor interactions.

• Policy and guidance in this area should bear in mind the possible long gestation period of moisture-related problems, as well as the difficulty of tracing direct cause and liability (due to the often systemic nature of the problem).

• Training and education of all parts of the supply chain and users is and will be necessary.

• A new approach, including a 'rule of thumb' for moisture behaviour in traditional buildings, should be developed quickly to enable the retrofit of traditional buildings to proceed safely and effectively in the near future. Such an approach will not necessarily rely on expensive research and complex modelling if good case studies, fully systemic thinking, and ongoing learning through monitoring and feedback are utilised. Government policy and funding should be actively directed towards this work.

Modelling/Monitoring

Modelling is relied upon to predict both technical and financial outcomes from interventions in buildings. If it is inaccurate then outcomes may vary hugely, with either adverse effects or missed opportunities. Monitoring is a way of checking whether the models are accurate and whether design intentions are met. Monitoring is essential both to provide confidence in models and to help policy makers and building professionals know real outcomes.

Summary of Findings

There is cause for concern about both the theories and practices of modelling and monitoring for all types and ages of building, and many of the assertions given below are pertinent for all parts of the national building stock. The gaps in this area relate to the other key issues but are worth a section on their own, particularly because of the reliance on modelling in the assessment of traditional buildings. There is a clear gap between current monitored research evidence and most modelling of traditional building performance. It is also clear that both modelling and monitoring in traditional buildings still need further development to be used as standardised tools for assessment. Furthermore, in certain areas operator errors can be considerable and this indicates a need for caution in the use of outputs from both monitoring and modelling, and the requirement for stricter protocols, training and oversight.

Findings

- Models tend to focus on single issues and usually do not capture other relevant factors. Reliance on them without a holistic and systemic understanding can lead to unintended consequences and rebound effects in many areas.
- There is generally a lack of data to validate the assessment models used.
- There is no differentiation of traditional buildings from other building types in assessment models and as such the calculations are likely to diverge from reality.
- There is a specific lack of data about traditional building materials and elements.
- Generally models are unable to deal with complex mixed building elements such as those commonly present in traditional buildings.
- There are no proper case studies to test out modelling or monitoring methods.
- The modelling of traditional building performance can be very inaccurate; for example up to 50% inaccuracy in a BREDEM based (SAP) model (Gentry *et al*, 2010).
- The performance gap between the model of a traditional building and as-built reality may be considerable, but it also could be the reverse of the performance gap that has been identified for new buildings that do not achieve anything like their predicted design targets. It would seem that, in practice, traditional buildings often perform much better than predicted owing to processes and interactions that are not well captured by models[23].
- There is a lack of evidence and understanding about 'rebound' effects in traditional buildings, leading to a failure of models to describe the real effect of retrofit measures.

[23] See Leeds Metropolitan's work (Wingfield, Bell, Miles-Shenton & Seavers, 2011) and Good Home Alliance (Thompson & Bootland, 2011, Taylor & Morgan, 2011) on the performance gap for new build, in comparison with work by Rye (2010 & 2011) Baker (2011) and Hubbard (2011) on traditional buildings.

- Currently industry standard programmes are not designed or easily able to deal with the interactions between building fabric, overheating, ventilation systems and indoor air quality issues, thereby making systemic analysis by modelling problematic.
- There are concerns about the mechanics of models themselves, particularly with regard to moisture modelling[24].
- There are concerns about the use of modelling per se, particularly where traditional buildings are complex and require skilled and knowledgeable modellers[25].
- There are concerns about the methods and technology used for monitoring buildings. Many monitoring techniques such as co-heating tests require further work, while the appropriateness of certain techniques for traditional buildings requires further research[26]. With regard to moisture monitoring there are even greater unknowns.
- Concerns about the practical use of monitoring are considerable, with the possibility of large operator errors and misinterpretation of results[27].

Recommendations

- Current standard thermal and moisture modelling of building stock (based upon BR 443, BS EN ISO 6946:2007 and BS 5250:2011) should NOT be used as main evidence for policy decisions about traditional building retrofit. Any modelling must take into account the issues outlined above.
- The development of specific models, data sets and tools for traditional buildings is urgently required.
- Further urgent research into modelling and monitoring methods particularly for moisture, IAQ, and overheating is needed.
- Protocols for modelling and monitoring should be tested and then established for industry.
- In-depth training and proper oversight of people undertaking modelling and monitoring is essential.

[24] The Fraunhofer Institute is revising the methodology of capillary moisture movement in their WUFI model at the moment. The Natural Building Technologies/ University College London Knowledge Transfer Partnership (NBT/ UCL KTP) has also potentially uncovered issues in the desorption algorithms for Internal Wall Insulation: this work is on-going.

[25] See Chapman 1991. Also, for example, current work on New Court, Trinity College, Cambridge involved 4 iterations of advanced WUFI modelling by 3 different expert teams before results started to align with observed and monitored evidence, changing completely the perceived performance of the buildings and the possible Internal Wall Insulation solutions. Initial results are now accepted as incorrect by a considerable factor.

[26] "The co-heating test is still a relatively young and evolving methodology and is still being refined as the number of tests being undertaken increases. It proved difficult to completely standardise the approaches taken by the three different research teams involved in this programme, even though significant steps were taken to try to harmonise the approaches" (Thompson & Bootland, 2011, p 25).

[27] In recent work at New Court, Trinity College, Cambridge test results differed considerably (wall U-values were initially measured as 1.05W/m2K and second tests gave 0.68W/m2K and air permeability was given as 22m3/m2/hr and re-tested as 11m3/m2/hr). The methodologies were the same, but the way the tests were undertaken and results were calculated were different. The first set of results have been found to be incorrect, but without the further tests this would not have been discovered.

Ventilation & Indoor Air Quality (IAQ)

Air permeability and ventilation play a vital role in ensuring a good-quality building environment both in terms of fabric and human health. This is linked to high moisture levels and to levels of microbiological and chemical pollutants (e.g. VOCs, carbon monoxide, formaldehyde, nitrogen oxides, particulates and radon). CO_2 levels and over-dry conditions are other major concerns (CIBSE, 2006). It is essential in the retrofit of traditional buildings that these issues are taken into account so that we do not create building-related health problems[28].

Summary of Findings

The challenge of ensuring good air quality in traditional buildings as opposed to new buildings has not been met and there is little conclusive research or guidance on the subject. This is a major cause for concern.

Key Issues

- There is a lack of comprehensive or accurate data concerning air permeability and ventilation rates of traditional buildings. This is the subject of frequent comment in the literature on this subject.
- Consequently, there is uncertainty as to the contribution of ventilation to heat losses from traditional buildings.
- The orthodox view that traditional buildings are the most 'leaky' of all UK stock is disproven by measured evidence.
- There is a lack of understanding of what constitutes acceptable IAQ with regard to chemical loads and air changes in traditional buildings.
- In particular there are almost no studies on the effect on human health of retrofitting traditional buildings for energy efficiency.
- Consequently there is uncertainty about appropriate levels or methods of air exchange for traditional buildings that have been retrofitted to improve airtightness.
- There are examples where the air permeability of buildings has increased after retrofitting has taken place.
- There is concern about the suitability and applicability of mechanical ventilation systems for traditional buildings.
- There are concerns about user behaviour and understanding in relation to ventilation systems, energy use and indoor air quality.
- Issues of ventilation and air quality are not linked in the Green Deal to measures such as insulation, draught-proofing, energy-efficient windows and others that may change ventilation within a property. Furthermore they are not linked to user behaviour and understanding. This is another example of the need for a systemic approach rather than a product- or element-based approach.

[28] This concern and focus on health and IAQ is supported by the Low Carbon Construction IGT Final Report Executive Summary (HMGovernment) recommendation 8.3 "That, to avoid the risk of a new generation of sick buildings, the promotion of the health and well-being of occupiers should be placed on an equal footing with the current emphasis on carbon reduction."

Recommendations

- Further research is necessary into the actual performance of traditional buildings with regard to ventilation and indoor air quality, and to establish acceptable air change rates for buildings constructed of moisture-permeable materials.
- All measures that directly or indirectly affect planned or unplanned ventilation of buildings should require an assessment of the ventilation requirements of each building (both in terms of occupant and fabric requirements) and appropriate measures should be taken to ensure that a suitable ventilation strategy operates in the retrofitted building.

Overheating

This is an increasingly important consideration, owing to emerging evidence of high and sometimes dangerous temperatures being found in many buildings both new and old. Overheating can lead to discomfort, ill health and even death in certain instances. It can also lead to energy-inefficient use of buildings, or the installation of high-energy cooling devices such as air conditioning, thereby increasing carbon emissions and fuel bills and potentially undermining any energy savings from reduced heat loss.

Summary of Findings

There is relatively little specific research about overheating in traditional buildings either as existing or retrofitted. It is suspected that unrenovated traditional buildings of high thermal mass may be less prone to overheating that those retrofitted with insulation, draught proofing, energy-efficient glazing and other fabric measures. However there is no work at present to prove this. The limited case studies of traditional buildings indicate that issues of design, application, orientation, and user behaviour are all vital to ensuring that overheating does not occur. At one level, these issues are no different for traditional and modern buildings. However, traditional buildings are often more robust in terms of environmental design, for example with higher ceilings, good natural ventilation, and more thermal mass, some of which may be adversely affected by retrofits aimed at reducing energy use for heating.

Recommendations

- Research is undertaken into the performance of traditional buildings with a view to understanding how traditional building elements (such as heavy masonry walls, floors or roofs) may be best used as part of a retrofit strategy to prevent overheating.

- Thermal and whole-building modelling must take more account of overheating outcomes from interventions. This modelling must be based on solid evidence from research into building performance in use, and in the hands of occupiers.

- A systemic approach must be taken which includes an understanding of building performance and the effects of exposure, orientation, design, application and user behaviour, as well as the potential embodied within a traditional building for avoiding of overheating.

Users

It is widely acknowledged that the behaviour of occupants is a very significant determinant of a building's energy use, any health issues arising from interactions with buildings and technologies, and building fabric health and durability. The complexity of interactions between occupants, fabric, and services makes it essential that users are considered in the retrofit of any building.

Summary of Findings

There is no major work on user behaviour focused specifically on traditional buildings – neither on whether the behaviour of users of traditional buildings might be any different to that of occupants of any other types of building stock, nor, indeed, whether a retrofitted traditional building determines or requires particular behavioural responses. Where case studies have been carried out the relationship between building type and thermal performance or other aspects of building performance is not well-defined, either in unimproved or retrofitted buildings.

Key Issues

- User behaviour hugely affects the energy use and health of all buildings. Traditional buildings are probably no different[29].
- This behaviour can affect internal temperature levels, services and appliance use, efficiency, ventilation rates, indoor air quality and other factors in many ways. Not all of these are due to lack of understanding; they may also be influenced by cultural, psychological, financial or other factors.
- There is therefore a great deal of uncertainty about the relationship between user behaviour and building performance. This causes uncertainty in modelling and predictions of outcomes from retrofit measures.
- Understanding user behaviour better is therefore a key issue in developing effective energy policy, standards and guidance.
- The effects of user behaviour in traditional buildings may have different consequences from those in newer buildings due to the different types of building fabric, spatial design and operation involved. This applies particularly to the effects on moisture, indoor air quality, and fabric health, performance and durability.
- User behaviour may change, bringing current assumptions into question. For example, recent increases in gas prices seem to have encouraged people to be more frugal. Comfort is to some degree socially determined.

[29] See, for example, the studies on the Usable Buildings Trust website: http://www.usablebuildings.co.uk/

Recommendations

- Users must be included and where possible involved in the assessment, planning, delivery and use of retrofit measures.
- Further research is required to understand user behaviour and the potential for improving delivery of successful retrofit through user engagement.
- Policies must allow for increased user engagement and positive behaviour change and not rely solely on technological solutions.
- Economic considerations under the Green Deal need to take some account of existing user behaviour[30] to avoid disappointment and to maximise opportunities in payback of energy and finance.

[30] For example, where the occupants are already frugal the expected savings in energy cost may not materialise and they may be left paying higher overall bills. In the worst case, the repayment costs could be as high as their fuel bills previously, leaving them with no surplus at all.

Guidance

Guidance documents form the basis for much of the decision making with regard to operations, retrofitting or otherwise, in the building sphere. For this reason it is vital that all guidance should be based upon the best available research, should clearly identify risks and unknowns, and if necessary point to its own limitations.

Summary of Findings

The rationale for much of the advice provided in various guidance documents is somewhat obscure and frequently points to a narrow knowledge base rooted in modern building techniques and understanding. Some of the guidance for traditional buildings is dated or focused only on very narrow issues, and there seems to be only one example where thorough empirical research work had resulted in practical guidance[31]. So long as the level of knowledge about traditional building performance and the effect of retrofit measures remains weak, it is essential that guidance is based on the best available high-quality research, and remains cautious and open to learning and change.

Key Points

• Some key (explicit) guidance documents are urgently in need of updating due to their reliance on incorrect standards and out of date research[32].

• All the guidance judged to be 'Tier 1' documents within this study were produced by English Heritage, Historic Scotland or the Scottish environmental charity Changeworks (apart from one document on solar thermal by the Energy Savings Trust). This shows that there is either a lack of work or a lack of knowledge regarding traditional buildings, outside of the historic building sector.

• Guidance on the thermal performance of timber windows by English Heritage and Historic Scotland was based on experimental research practices and should be seen as an exemplar.

• However, where specific activities or technologies inevitably affect other parts of building performance (such as moisture, health or thermal performance), a different kind of guidance is required. For example, guidance for improving a building element such as windows may need to acknowledge or be incorporated into a broader or more systemic guidance document that integrates window upgrades with thermal bridging of window reveals, ventilation strategies and usability issues, all of which could be affected by certain window alterations.

Recommendations

• There is a strong need to develop an open and iterative guidance tool which lays out risks and opportunities at all stages of the retrofit process and which encourages a systemic and learning-based approach (including monitoring and feedback) at all levels including policy.

• Poor and incorrect guidance (whether general or specific to traditional buildings) should be withdrawn from the public domain or clearly limited with regard to its application to traditional buildings.

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[31] This is the Historic Scotland & English Heritage work on Energy Efficiency and Timber Windows.

[32] For example, BRE guidance document Thermal Insulation: Avoiding Risks does not deal with the subject of wind-driven rain for existing solid walls, merely stating minimum construct sizes for solid walls made of brick, block work or concrete and with no reference to stone-built walls whatsoever.

Implicit Guidance

Implicit Guidance is the product of standards, regulations, certifications, warranties and technical manuals designed to guide decisions of designers, contractors and clients in terms of the choice of solutions available on the market. In reality, this tends to be the guidance most commonly used. In theory these documents should be based on the best research and formal guidance. In practice, the relationship is often less clear or non-existent.

The work on Implicit Guidance focused on solid-wall insulation and the findings and recommendations are consequently mainly to do with this application area. This does not mean that there are not gaps between best research and Implicit Guidance in other areas; in fact it is likely that similar gaps exist, particularly in areas where traditional building performance or use differs significantly from modern or new buildings[33].

Summary of Findings

In some important areas there is a disconnection between the standards that are used as the basis of regulation, certification and technical commercial advice and the performance and requirements of actual buildings. In some cases, particularly in relation to traditional buildings, this leads to construction practices that are counter to current research findings. Consequently, following Implicit Guidance could incur considerable risks to building fabric, human health, energy performance and financial payback. This issue must be addressed as a matter of urgency.

Key Issues

- As currently configured, U-value calculation conventions given in BR443 (and its attendant standard BS EN ISO 6946:1997) are not fit for the calculation of solid-wall U-values (see earlier section on Heat Loss).

- Nearly all statements concerning U-values commonly used in current regulations, certificates, technical commercial documents, warranties and other documents are based upon BR443 and BS EN ISO 6946:1997 and will therefore probably create inaccurate estimates of energy savings from improvements to the building fabric of traditionally built walls.

- The misapprehension of the degree of heat loss through a solid wall may also lead to the specification of inappropriate forms of insulation in an attempt to meet the target U-values suggested in approved documents and technical handbooks.

- The over-insulation of moisture-active solid-wall constructions may lead to increased risk of trapped moisture, interstitial condensation or external surface frost damage due to fabric cooling.

- With regard to internal wall insulation there is a further problem, which is that thermal bridging is often not taken into account in standards or assessments. Research shows that it is almost impossible for a whole wall to achieve a U-value of 0.3 W/m^2K[34] when thermal bridging of floors, partition and party walls, and junctions is taken into account. Despite this, commercial guidance documents often claim to be able to provide U-values as low or lower than 0.20W/m^2K, in a similar way to external wall insulation systems where such low values are possible because there is no thermal bridging. These U-values are unrealistic and calculations using them for whole walls will give incorrect results in terms of whole-house heat loss, and also lead to waste of materials, money and internal space.

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[33] For example in roofs, ventilation systems, user controls and interaction, and workmanship

[34] This is the target recommended for the refurbishment of existing buildings in England and Wales; in Scotland the U-value required can be also low as 0.19 W/m2k when a previously unheated building is converted.

- The use of BS 5250:2011 (and the calculations given in BS EN ISO 13788:2002 *The 'Glaser Method' moisture model for new buildings*) is insufficient for solid-wall buildings where driven rain and other sources of fabric moisture are a factor. This makes it inadequate as a means to assess all risks posed by moisture to the building fabric and occupants of traditional buildings (see earlier section on Moisture). BS 5250:2011 used in isolation will also indicate the need for vapour control layers in most IWI retrofit situations for solid walls, thus not recognising the need for some solid walls, on occasions, to dry to the interior.
- Nearly all current regulations, certificates, technical commercial documents, warranties and other documents are based upon BS 5250:2011. In traditional buildings with capillary-open walls, the main dangers of continuing to use only this standard to assess moisture risks will tend to occur in areas of high driven rain, particularly with internal wall insulation systems or where external wall insulation is not entirely weathertight. In these circumstances there will be significant risks of moulds, fabric decay and damage to human health.
- A more appropriate protocol is BS EN 15026:2007, a dynamic hygrothermal model that takes account of driven rain and moisture mechanisms in materials, but even here there are still uncertainties in building physics, data and operation.
- BS EN 15026:2007 shows considerable risks for internal wall insulation applications in areas of high driven rain in capillary-open traditional walls if the correct materials are not applied or if walls have too much insulation (as heat is required in solid walls to dry out driven rain). Issues of location, orientation, building type, building construction, width of walls, internal linings and openings all have an impact. These are also of concern in EWI systems where application is not correct, or where there are related issues such as rising damp.

Recommendations

- All Implicit Guidance should be based upon the correct principles, together with appropriate standards, where available.
- The best research and guidance should be clearly and rapidly integrated into commonly used standards, protocols, regulations as well as certification processes. A mechanism needs to be developed by Government, research institutes and industry to ensure that evidence, methodologies and tools from best research are quickly incorporated into relevant regulatory standards, certification methods and other forms of Implicit Guidance.
- Where Implicit Guidance uses inappropriate principles or standards there should be some way to identify this, and to discourage applications that incur risk.
- Moisture risk assessment needs to extend beyond the scope currently promoted in BS 5250 to include all aspects of moisture behaviour in buildings.
- BR 443 and RdSAP 2009 v.9.91 (Appendix S, issued 2012) should not be used in their current form as the basis for estimating U-values of traditional buildings, either for policy decisions or for energy and cost payback calculations in the Green Deal or other retrofitting exercises.
- Approved documents and technical handbooks should set realistic and safe U-value targets for Internal Wall Insulation.
- Certification processes or warranties based upon incorrect principles or inadequate standards should not be allowed in legislative or grant-funded programmes, unless corrected to take account of more appropriate standards and best research.
- The examination of the shortcomings of Implicit Guidance needs to extend beyond the scope of solid-wall insulation to other areas of retrofit activity.

Design and Installation issues

Correct design and installation of retrofit measures is a key issue for traditional buildings because of the complexity and interaction of elements and factors that determine the performance of these buildings. The consequent possible failure if design and installation is incorrect could have serious financial, energy, health, durability and cultural consequences.

Summary of Findings

Design and installation issues have been discovered in many situations in new buildings, where it should be much easier to avoid such problems. There have been fewer case studies of design and installation issues in existing buildings, and particularly in traditional buildings. In those limited case studies of traditional buildings which do cover such issues it is apparent that problems have arisen for a number of reasons, the primary ones being a lack of understanding of traditional buildings, a lack of joined-up (systemic) thinking, and a lack understanding of user needs and behaviour. There was also a reliance on Implicit Guidance including insufficient technical instructions from manufacturers (including certifications). However the evidence in this area is very limited due to the lack of studies.

Recommendations

- All forms of guidance with regard to traditional buildings should be relevant to traditional buildings and should be clear about limitations and the need for considered or expert advice.
- Education and training in traditional building issues should be made an essential part of mainstream design and skills educational programmes. This should include both theoretical and practical issues.
- Soft Landings, as developed by the Usable Buildings Trust[35,] or a similar joined-up approach should be used in retrofit work on traditional buildings wherever possible, so that all parts of the supply chain, as well as the user, learn about risks and opportunities through the process.
- The learning from the practice of retrofitting buildings should be fed back into research, guidance and policy.

[35] See www.usablebuildings.co.uk

Cultural Significance

Traditional buildings make up almost a quarter of the UK building stock and as such are part of our heritage and culture. By their very survival, they have already demonstrated their sustainability in some respects. Culture is not just an issue of aesthetics, but of community character and cohesion, as well as deeper relationships to the natural environment, history, work, language and imagination. These can all affect human behaviour in many ways, including our energy use and resource consumption, and so need to be handled with appropriate sensitivity.

Summary of Findings

While the methods for expressing the value or cultural significance of an older building or groups of buildings are well established[36], the degree to which 'heritage assets' are at risk due to refurbishment practices are less defined and tend to focus solely on aesthetic harm. There is some work looking at wider issues which shows a disconnect between energy/environmental assessments and cultural/community values, and Powter and Ross (2005) make recommendations for addressing this. There is no work that covers long-term cultural or community issues, or the opportunity that the Green Deal and similar schemes offer for community transformation.

Recommendations

- Current policy on retrofit should take into account the cultural significance of buildings in its broadest possible sense.
- Further research should be undertaken to understand the value of traditional buildings to communities, and the potential benefit of accounting for and using this 'value' in retrofit programmes to enhance long-term continuity and hence sustainability.

[36] See English Heritage's *Conservation principles, policies and guidance for the sustainable management of the historic environment.*

5

A Way Forward

Policy & Delivery Recommendations

There are a number of overarching issues arising from the previous chapters that have consequences for both policy decisions with regard to traditional buildings and the delivery of any energy-improvement retrofitting schemes, including the Green Deal. These issues have been summarised under their relevant headings.

Policy Issues

The main issues that need to be addressed by policy with regard to the Green Deal and other retrofit policies in the short term are as follows:

- The research shows that, for reasons including energy performance, risks to fabric and human health, and heritage and cultural issues, most traditional buildings need to be treated differently from modern buildings in terms of assumed characteristics of building elements, assessment methods, specified solutions and ongoing use, maintenance and monitoring. In comparison with more modern existing buildings this will require different retrofit assessment procedures, different skills (and sometimes materials) in contracting, and different engagement with occupants and owners by retrofit providers.
- The Convention BR 443 and RdSAP 2009 v.9.91 (Appendix S, issued 2012) documents should not be used in their current form as the basis for estimating the U-values of solid, traditionally built walls. Therefore neither should they be used for whole-stock modelling, individual house modelling, or as the basis for thermal performance estimates given in certificates and other Implicit Guidance for traditional buildings. An adjusted Convention and RdSAP default wall U-values need to be established as soon as possible to facilitate realistic assessments of energy and financial payback in projects where traditional buildings are being retrofitted.
- The use of BS 5250:2011 (and the calculations given in BS EN ISO 13788:2002) is insufficient for solid-wall buildings where driven rain and other sources of fabric moisture are present. This makes it inadequate as a means to assess all risks posed by moisture to the building fabric and occupants of traditional buildings. In particular, for all internal wall insulation applications to solid walls, numerical modelling according to BS EN 15026:2007 should be used, with substantial safety margins built in due to the lack of data and research. (This effectively means that all current BBA certification is not valid for internal wall insulation of traditional buildings unless

further calculations to BS EN15026:2007 are undertaken.) A similar approach should also be taken for external wall insulation and other elements, particularly in exposed areas, with safety factors built into the models[37]. Ultimately a whole new standard is required that assesses all moisture risks arising within buildings.

- Owing to the practical difficulty of achieving overall wall U-values of less than 0.3 W/m^{2}K, and the dangers of reducing heat flow through a masonry wall, attention should be given to documents which present definitive targets for heat loss in wall elements, particularly for solid moisture-permeable walls. Approved Documents such as L1B & L2B, Scottish Technical Handbooks, and Northern Ireland Technical Booklets should differentiate between internal and external wall insulation approaches and set realistic and safe U-value targets for the internal insulation of solid walls.

- The wider consequences of individual retrofit measures on traditional buildings need to be taken into account in policy. For example, work to improve the airtightness of a building may have negative consequences for fabric moisture loads (leading to possible fabric degradation and human health issues). These consequential and systemic affects must be acknowledged in terms of liability.

- Good maintenance, repair and improvement work which increases the energy efficiency of buildings, such as the repair, draught-proofing and secondary glazing of timber windows, should be considered as a valid retrofit measure, and as such should be supported by funding and financing schemes.

Delivery Issues

For safe and effective delivery of the retrofit of traditional buildings the following subjects are also important in the short term:

- The development of a national strategy and mechanism for ensuring that evidence, methodologies and tools from best research are quickly and correctly incorporated into relevant regulatory standards, certification methods and leading guidance.

- A soft start to any delivery programme of retrofit for traditional buildings, not only in terms of speed of roll-out but also with regard to the specification of safe and non-optimised solutions that allow for failure without serious or irreversible consequences. This is necessary due to current lack of research, evidence, knowledge and skills in all areas of this work, and will be more necessary for some higher-risk measures.

- A new approach to delivery which requires learning to be integrated into all parts of the process including assessment, design, application of measures, use, monitoring and maintenance. Meaningful and accurate feedback is an integral part of learning and should be fed into all parts of the supply chain, as well as to users, researchers and policy makers. If learning is properly integrated then it will be possible to achieve a safer and faster development of retrofit of traditional buildings in the UK over the next few years.

- Training and skills programmes based upon a revised understanding of the specific requirements, risks and opportunities represented by traditional buildings should be put into place once the above actions have been taken and the results properly assessed and processed. In particular a systemic approach including all parts of the supply chain as well as users, owners and managers should be taken.

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[37] Note that due to the current lack of correct material, construction and weather data for inputs into hygrothermal models **BS EN 15026:2007** should not be used without an awareness of these limitations and without sufficient understanding of traditional building construction.

• Insurance, warranty and other schemes should follow, not precede the above, and be linked to monitoring and learning processes wherever possible so that the levels of risk on which they are fundamentally based are understood.

• There should be an informed programme to raise public awareness of issues of opportunity, risk and benefit in the retrofit of traditional buildings. This should emphasise the opportunity for real benefits through engagement and learning.

Development Issues

The findings of this report suggest that over the next two years the following are necessary (in addition to the policy and delivery recommendations) for the development of a long-term sustainable approach to the retrofit of the traditional buildings in the UK:

• A considerable programme of research into the following:

  – The performance of traditional buildings in terms of energy, heat, moisture, overheating, indoor air quality, and comfort.

  – Case studies on retrofit programmes for traditional buildings (both technical and user-focused) to further understand rebound effects and opportunities for better and more cost-effective measures. The Green Deal provides an ideal opportunity for large-scale monitoring and feedback at low cost.

  – Data for the material properties of traditional UK building materials for use in modelling software.

  – Better models for traditional buildings, including the effects of driven rain, location-specific weather data and improved understanding of moisture mechanisms.

  – Systemic thinking development to incorporate the many aspects of traditional buildings into processes of retrofit and use.

• Training and skills programmes need to be developed and promoted to the industry on the basis of this research and in conjunction with traditional building skills experts and providers, thereby beginning to bridge the gap between conservation and mainstream practice. This should be a two-way process.

A Guidance Structure

One of the key findings of this research is that there is a significant lack of relevant research and data about traditional building performance, both as existing and when retrofitted. This cannot be remedied in the short term, particularly before the start of the Green Deal programme. Another key finding is that the building elements, services and users of traditional buildings interact in complex ways that require a holistic and systemic approach. Finally, it is apparent from some of the research that there may be values and aims with regard to the retrofit of traditional buildings which are incommensurable. For example, the aims of energy-use reduction, financial payback, human wellbeing, fabric health, and heritage and cultural enhancement may not always be compatible in a project and will almost certainly require a different approach in different buildings.

These three factors of uncertainty (of research and data), complexity (or interactions) and different (and possibly incommensurable) values have major consequences for the future of traditional buildings and their inhabitants, as neither the risks nor benefits of retrofitting this part of the building stock can be clearly identified from the research and guidance currently available. And yet there is an urgent imperative to proceed quickly with the improvement and retrofit of traditional buildings.

The key question is: how can we move forward quickly with confidence and get the best outcomes with the least risk?

In the previous sections of this report we have recommended the development of a guidance tool (along with other measures) to address issues of confidence and risk and enable the UK to move forward rapidly and relatively safely with a mass retrofit programme. This tool, in combination with a Knowledge Centre (where data and feedback from the Tool would be processed, further research commissioned and the Tool developed in accordance with these inputs), would develop and promote a systemic approach linking all parts and participants of the retrofit process in a structured and interactive manner. The tool and knowledge centre would also link retrofit practices with current best research in order to clearly identify risks and opportunities at all stages. Reflectivity would be embedded within the tool via *in situ* monitoring of buildings and pre- and post-occupancy engagement to provide feedback on measures undertaken. The tool would have an open and iterative structure that would allow the guidance to change and develop (through the work of the knowledge centre) in the light of new theoretical research work and practical findings made within the field. The tool would be presented in different formats for different users in order to ensure understanding and engagement.

The following section suggests a structure that could be developed to provide such a tool.

The Guidance Tool Structure

The proposed structure provides a means to analyse the opportunity, benefits and risks of carrying out a proposed upgrade measure or group of measures. It provides an insight into the potential benefits of the measure and flags up issues that require special attention; it identifies contexts and constraints (such as location, building type, listed building status) which can be used as a filter, and from these it derives specific opportunities and risks; it provides information about related actions that need to occur before, during and after the measure is implemented, in order to minimise any residual risks. It also provides an opportunity to identify areas where further knowledge is needed and where monitoring and feedback would help to close knowledge gaps that have been identified.

An upgrade measure is described as an action that seeks an improvement in the performance of a building in terms of energy use and thus associated CO_2 emissions.

The actions can be grouped in three types:

Changes to fabric Normally this would include improving the insulation properties of the building elements. It can also mean making building features operational (for instance recovering the use of timber shutters).

Changes to services and energy source Improving the efficiency of the engineering systems and decarbonising supply.

Behavioural changes Improving the way people interact with the building by designing better interfaces or increasing the involvement of users and maintenance staff

Based on the current best research, it is also possible to integrate a triage approach to risk and opportunity into the tool, using red, amber and green indicators. Initially these have been developed to look at the three areas where values and aims may differ, which are:

- Energy savings
- Technical issues (including particularly human health and fabric decay issues)
- Heritage (possibly including community value)

The following are the category headings that have been developed for the upgrade measure analysis structure and which would form the foundation of the guidance tool.

Type of measure (fabric/services/behaviour) This identifies the main element that the upgrade affects. Links between related measures can also be made by grouping those that go well together.

Potential upgrades For each element, a range of potential upgrades is listed. This includes all proposed Green Deal measures (as listed in the consultation document) plus other measures not covered by the Green Deal but which may be essential for a complete solution. These are listed in Appendix G.

Importance of context This section identifies the variability of the analysis with regard to contextual issues such as site, exposure, tenure, heritage value, orientation, availability of gas supplies, etc.

Analysis benefits and risks with regard to energy, technical issues and heritage value
Each upgrade is indicated in terms of red, amber or green:

> **Red** Very high risk – upgrade option unlikely to be appropriate
>
> **Amber** Risks exist and should be investigated – these may be known risks or risks due to gaps in knowledge
>
> **Green** Low risk – upgrade option probably appropriate

Identifying the right opportunity This section indicates what events (for example change of tenure, whole building refurbishment, partial refurbishment) provide good opportunities to implement a particular measure.

Additional measures before/during/after implementation This identifies additional measures at each stage of implementation that may be necessary to help ensure that the upgrade being considered is robust, for example stopping a roof leak or damp in a wall before applying insulation.

Monitoring/feedback This would be used where there might be some residual performance risk, for example it might be related to the build-up of moisture. This has been separated from 'additional measures', 'after' installation because 'monitoring/feedback' is about understanding performance, while 'additionalmeasures' covers correct operation and maintenance.

Management and maintenance issues These highlight the likely management and maintenance requirements once an upgrade has been implemented.

User issues This section identifies interaction between people and the effect an upgrade measure might have on the occupants' environment, health or behaviour.

Guidance/research/case study references A link to the relevant list provides relevant information for the upgrade measure in question.

In all cases, where possible, the information or guidance given in the different categories will refer to research and guidance documents (or specific sections of these) in the Relevant References database for further information, background and discussion.

The following is an example of how these sit together in an upgrade measure analysis structure (which can be developed into a guidance tool) in general terms for a building with heritage value (for example it might be listed or in a conservation area), where the measure of external wall insulation is being considered.

FABRIC														
							ASSOCIATED MEASURES REQUIRED							
Upgrade	GD Eligible	Context dependence (H/M/L)	Energy benefit or risk	Technical benefit or risk	Heritage benefit or risk	Right opportunity?	BEFORE Pre-implementation checks	DURING Quality contol	AFTER Maintenance requirement	Monitoring/ feedback	User issues	Guidance	Research	Case studies
WALL(S)														
External wall insulation	Yes	Eg: H – High Suitability of measure depends on: ·Fabric quality and make up ·Exposure ·Heritage value	Likely reduction of heat loss but less reduction than expected? Check U-value	Risk of trapped moisture? Check fabric quality	Damages character? Unlikely measure if listed building	Easier to implement as a whole block/terrace measure	Check U-value of original fabric and compare with modelled values. See research ID 14 and 15	Careful detailing to keep character and minimise thermal bridges	Check integrity of drains and gutters and that external wall is kept dry, in good condition. Ensure ground levels are kept low	Check U-value of insulated fabric	Comfort 'take back' effect means less energy saved?	[See docs list] 2 No Tier 1 Guidance refs	[See docs list] 12 No Tier 1 Research refs	[See docs list] 6 No Tier 1 Case Study refs
						In conjunction with fabric measures	Check hygrothermal properties of wall and exposure. Thickness of insulation and risk? See guidance and research ID 39	Carry out condensation/ moisture risk for proposed solution and detail [Various research] Check installation needs and carry our as per detail – see research ID 50	Moisture monitoring at risk locations at thermal bridges	Feed back any moisture/ mould problems	Sufficient dwelling ventilation when draughtiness improved? Research ID 1, 15			
							Check external detailing – survey to identify what needs moving (pipes, etc), existing thermal bridges (research ID53)	Installation of quality checks – thermal imaging?						

This structure can be developed in different formats and with slightly different language for different participants in the process, but using the same categories. In this way all participants can be informed properly so that positive engagement, discussion and feedback can occur at all stages. It should be emphasised that this structure in its developed form as a guidance tool will not be a 'tick-box' process pointing in one direction, but will lead to different outcomes with different buildings and contexts in response to different discussions, conditions and needs.

Appendix I provides further examples and considers how this structure might be developed using examples of two different retrofitting measures (internal and external wall insulation), in different contexts.

Relevant References

The upgrade measure analysis structure (and future guidance tool) needs to link specific retrofit improvement measures to best practice research, guidance and case study work (currently identified as the Tier 1 documents in this report). For each of the different retrofit measures, relevant documents or parts of documents are grouped together so that anybody considering such a measure can refer to them for further detail if they wish. It is expected that the collection of 'relevant references' would increase as part of the development of a guidance tool. Current references to relevant Tier 1 research, guidance and case study documents can be found in Appendix E and the allocation of Tier 1 research into a relevant references database linked to Green Deal measures through the upgrade measures analysis structure categories is in Appendix H.

Knowledge Centre

These relevant references will need to sit in a fully accessible knowledge centre, which will be responsible for updating references from new research and guidance and for overseeing and integrating feedback from actual projects (including, importantly, Green Deal projects where the use of the guidance tool should be encouraged if not mandated), both in terms of process improvement and monitored data and information. This feedback will inform further research and analysis as well as the ongoing development of the guidance tool itself.

Holistic Thinking and The Intelligence Thread

The relevant references and Guidance Tool Structure show how existing information (incomplete and complex as it is) could be organised to provide guidance on the impact of retrofitting traditional buildings. We believe this structure will ensure that an 'intelligence thread' runs through from research to guidance to practice and back again to help inform a joined-up understanding and process, whereby each measure is not considered in isolation but refers to other possible measures that need to be considered to provide a more systemic, holistic and appropriate solution. this intelligence thread also needs to link to standards, certifications and other forms of Implicit Guidance, either through the proposed knowledge centre or through a related process.

Conclusion

This project has sought to establish a picture of the baseline intelligence on which the design and implementation of retrofit decisions can be made. It has found that there are significant gaps in our knowledge of the performance of traditional buildings as well in our understanding of the effects of energy-efficiency refurbishment on these buildings. There are gaps in our understanding in almost all areas of significance to the performance of traditional buildings and the well-being of their occupants, including issues of heat loss, moisture, ventilation, indoor air quality, overheating and the effects of user behaviour. These gaps in comprehension lead to uncertainty and this uncertainty leads to an increase in risk, particularly when traditional buildings are subject to retrofitting interventions.

Whilst uncertainty can never be removed from our relationships with buildings (and the world in general) there are certain steps that can be taken to mitigate the risks present in the retrofitting of solid-wall pre-1919 properties. Some of these steps are related to specific research, standards, guidance or training. Primarily, however, a systemic and holistic approach is needed, which considers buildings and building users, specifiers, contractors and other stakeholders (including the community) not as a collection of independent elements but as integral and interactive parts of a whole. By adopting a more comprehensive vision and educating ourselves with the best information, training and research we will be able to accept uncertainties and create strategies that allow genuinely beneficial improvements to be made to the energy performance of traditional buildings and to the whole of our built and natural environment.

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Acronym Index

ACE	Association for the Conservation of Energy
AD	Approved Document
AECB	Association of Energy Conscious Builders
BBA	British Board of Agrément
BCB	Building Control Body
BRE	Building Research Establishment
BREDEM	Building Research Establishment Domestic Energy Model
BREEAM	Building Research Establishment Environmental Assessment Method
BS	British Standards
BSI	British Standards Institution
CEO	Chief Executive Officer
CERT	Carbon Emissions Reduction Target
CESP	Community Energy Saving Program
CHP	Combined Heat & Power Plant
CIAT	Chartered Institute of Architectural Technologists
CIBSE	Chartered Institution of Building Services Engineers
CIOB	Chartered Institute of Building
CIRIA	Construction Industry Research and Information Association
CMTC	Common Minimum Technical Competencies
CO_2	Carbon Dioxide
CoP	Coefficient of Performance
CPA	Construction Products Association
DECC	Department of Energy and Climate Change
DHW	Domestic Hot Water
ECO	Energy Company Obligation
EN	European Norm
EST	Energy Saving Trust
ETA	European Technical Approval
ETAG	European Technical Approval Guideline
EWI	External Wall Insulation
FGHR	Flue Gas Heat Recovery
GD	Green Deal
GHA	Good Homes Alliance
H/M/L	High / Medium / Low
HEADS	Home Energy and Data Services Ltd
IAQ	Indoor Air Quality
IBP	Institute of Building Physics
IEA	International Energy Agency
IGT	Innovation and Growth Team
INCA	Insulated Cladding Association
ISO	International Organization for Standardization
IWI	Internal Wall Insulation
KTP	Knowledge Transfer Partnership
LABC	Local Authority Building Control
LEED	Leadership in Energy and Environmental Design
LPG	Liquid Petroleum Gas
MEng	Master of Engineering
mm	Millimeters
MVHR	Mechanical Ventilation with Heat Recovery
NBT	Natural Building Technologies
NHBC	National House Building Council
NIA	National Insulation Association
Ofgem	Office of Gas and Electricity Markets
PAS	Publicly Available Specifications
PhD	Doctor of Philosophy
PIR	Passive Infrared Sensor (in reference to light sensors)
PIR	Polyisocyanurate (in reference to insulation)
POE	Post Occupancy Evaluation
RAP-RETRO	Risk assessment of building physics performance with a special focus on retrofitting of existing buildings
RdSAP	Reduced Data Standard Assessment Procedure
RH	Relative humidity
RIBA	Royal Institute of British Architects
RICS	Royal Institution of Chartered Surveyors
SAP	Standard Assessment Procedure
SBEM	Simplified Building Energy Model
SEDBUK	Seasonal Efficiency of Domestic Boilers in the UK
SFP	Specific Fan Power
SPAB	Society for the Protection of Ancient Buildings
STBA	Sustainable Traditional Buildings Alliance
SWIGA	Solid Wall Insulation Guarantee Scheme
TRV	Thermostatic Radiator Valve
TSB	Technology Strategy Board
UCATT	Union of Construction, Allied Trades and Technicians
UCL	University College London
UK	United Kingdom
UKAS	United Kingdom Accreditation Service
UKGBC	United Kingdom Green Building Council
VCL	Vapour Control Layer
VOC	Volatile Organic Compound
W/K	Watts per Degree Kelvin
W/m^2K	Watts per Square Meter Degree Kelvin
WUFI	Wärme und Feuchte Instationär
WWHR	Waste Water Heat Recovery

Glossary

Air changes per hour (ACH)	The ACH (also known as air change value) is, like air permeability, a measure of infiltration (unplanned air changes) used for energy calculations to indicate the performance of a building in terms of both energy use and fabric integrity.
Air permeability	The air permeability is measure of infiltration (unplanned air changes) to indicate the performance of a building in terms of both energy use and fabric integrity. It indicates the cubic metres of air leakage per square metre of external area of the building per hour – [m^3 m^{-2} h^{-1}]. It is calculated by creating a particular pressure difference between the outside and inside of the building when all intentional openings and ventilation systems are closed and by then measuring the amount of air that leaks through the external structure. The standard pressure difference is 50 Pascal.
Air source heat pumps	Air source heat pumps work in the same way as GSHPs but using lower level heat energy found in air. They are therefore not as efficient as GSHPs.
Air tightness	A measure of air permeability. New buildings are required to meet particular air tightness targets as set out in the Building Regulations.
Air tightness test	Also called Blower-Door-Test. Measurement of air changes per hour or air permeability. During this test areas of air leakage can be identified by using smoke guns and other means.
BCB	Building Control Bodies enforce the Building Regulations as set out in the Approved Documents.
Breathability, Breathable insulations	Breathability in buildings should not be confused with air movement but entirely refers to the way water moves in relation to the building fabric. Breathability is based upon three essential mechanisms: Vapour permeability, hygroscopicity and capillarity.
BREDEM	Building Research Establishment Domestic Energy Model. An energy assessment method which predicts building performance.
BREEAM	Building Research Establishment Environmental Assessment Method. A tool to assess environmental sustainability across categories including energy, water, materials, waste, ecology and management.
British Standards Institution (BSI)	A business that provides training, testing assessment and certification services, as well as writing Standards.

Building fabric	The building fabric is a critical component of any building, since it both protects the building occupants and plays a major role in regulating the indoor environment. Consisting of the building's roof, floor slabs, walls, windows, and doors, the fabric controls the flow of energy between the interior and exterior of a building.
Building modelling	Building energy performance modelling software uses building physics to predict performance from a set of data including material properties, building services and weather files. Also referred to as performance simulation software, it varies in complexity and usability.
Building physics	The fundamental scientific principles that are used to explain and predict a building's performance.
Building Regulations	Statutory instruments that ensure that the policies contained within Building Acts are complied with.
Capillarity	Refers to the absorption/desorption of water as liquid and is a function of pore structure. These are much larger sized pores to those used in hygroscopic activity or as regards vapour permeability. Capillarity can be altered by coatings and additives and many of these act as hydrophobic agents by blocking these larger pores, but still allowing the smaller pores to remain open. In this way the pore structure may be kept open for hygroscopic and vapour permeable transfer of moisture but closed to capillary transfer of moisture. On the other hand coatings and additives which physically block all sizes of pores in a material can close off all three modes of water transfer.
Cavity wall	A wall made of two or more layers separated by a cavity, which would typically be insulated in most new builds post 1980s.
CERT	Carbon Emissions Reduction Target is a funding mechanism whereby energy suppliers apply a change to customer bills and redistribute the funds to building projects and users that meet a set of criteria. Measures include loft and cavity insulation. CERT Funding is due to end Dec 2012.
CESP	Community Energy Saving Programme is similar to CERT but applies only to buildings in 'areas of deprivation'. Funding is more complicated and increases with multiple measures which are given different ratings. CESP is often associated with solid wall insulation.
Climate change	Refers to anthropogenic climate change due to greenhouse gasses produced by humans since the industrial revolution.
CO_2	Carbon dioxide is a naturally occurring chemical compound which is produced when fossil fuels are burned. It is one of the main greenhouse gasses which contribute to anthropogenic climate change.
Code for Sustainable Homes	Similar to BREEAM but specifically for new build housing.

Co-heating tests	A means by which to measure whole building heat loss. Performed by adding heat energy continuously to a sealed building until a stable internal temperature is reached, and measuring the heat input required to maintain this equilibrium at which point the heating energy is equal to the heat loss through the fabric.
Comfort 'take back' effect	Where users consume the same or more energy post improvement works in order to achieve higher levels of comfort.
Compact fluorescent lamps	Energy-saving fluorescent lamp designed to replace an incandescent lamp.
Condensation	Air has only a limited capacity to store humidity at any given temperature. The absolute amount of the humidity which can be absorbed at the most is dependent mainly on the air temperature – warm air can hold more humidity than cold air. Air saturated with water vapour has a relative air humidity of 100%. If air is cooled down, the relative humidity increases. When relative humidity reaches 100 % this leads to the formation of condensate (rain and condensation are two forms of condensate). There is surface condensation and interstitial condensation.
Condensing boiler	A boiler that achieves high efficiency by using the waste heat in the flue gases, condensed into hot water to pre-heat the cold water entering the boiler.
CoP	Coefficient of performance refers to the ratio of electrical energy input to heat energy output in a heat pump.
Damp-proof course	The DPC is a horizontal barrier in a wall designed to resist ground water rising into the structure.
Decarbonising supply	Reducing the environmental impact of the energy supplied to buildings, for example by use of renewables for generating grid energy.
Delivered energy	Also known as end-use energy. The energy that remains after distribution, transmission and any other losses from generating and transporting energy.
Desorption	The release of a substance from or through a material. Opposite of sorption.
Desorption algorithms	Used to predict the pattern or rate of desorption for a material.
Dry lining	The internal lining to a wall element, for instance plasterboard.
ECO	The Energy Company Obligation provides financial support for energy efficiency measures as part of the Green Deal, and aims to fill gaps in Green Deal funding. For example by funding measures that would not normally meet the 'golden rule' such as solid wall insulation.
Efflorescence	Staining, incrustation or build up of white powder on a surface due to the presence of water borne salts.

Empirical evidence	Data produced by an observation or experiment, rather than through computer modelling.
External Wall Insulation (EWI)	Insulation applied to the external face of a wall.
Green Deal	Essentially a 'pay as you save' scheme for funding energy efficiency measures. The measures have to meet a 'golden rule' ensuring that they pay for themselves through reducing a building's energy costs.
Ground source heat pumps	Ground source heat pumps (GSHP) can be used to supply space heating by applying electrical energy to the low level heat energy drawn from the ground.
Heating set point	Is the desirable temperature level or range in a space where heating and cooling is required. It is controlled by the thermostat.
Hydrophobic	Materials with hydrophobic properties restrict the absorption/desorption of moisture.
Hygroscopic	Materials with hygroscopic properties allow the absorption/desorption of moisture, and this process causes their physical properties, for example their volume or texture, to change.
Hygrothermal modelling	Complex computer based simulation of heat and moisture transfer in buildings to predict performance. Also referred to as hygrothermal transient modelling or hygrothermal numerical modelling. WUFI (Wärme und Feuchte Instationär) modelling is a type of hygrothermal modelling.
Hygrothermal performance	The performance of a building resulting from the combined effects of heat and moisture.
IAQ	Indoor air quality refers to the quality of the air experienced by building users. Poor IAQ may result from microbiological and chemical pollutants found in materials, damp or mould, or air-borne pollutants such as smoke. Good IQA depends on adequate ventilation.
In situ monitoring	Monitoring of actual building performance, rather than in laboratory conditions.
Internal wall insulation (IWI)	Insulation applied to the internal face of a solid wall.
Interstitial condensation	The deposition of liquid water inside building elements due to local water vapour reaching saturation point. As the water vapour meets cooler conditions or surfaces the relative air humidity increases and if the relative humidity reaches 100 % then condensation forms inside the structural element. The location of the saturation vapour pressure point is called dew point.
LEED	Leadership in Energy and Environmental Design is an environmental assessment tool similar to BREEAM developed by the U.S. Green Building Council.
Life cycle analysis, Life cycle costs	An attempt to calculate the impact of a product from 'cradle to grave'. It uses environmental weightings across categories from CO_2 emissions to social and ecological impact to evaluate the overall cost to the environment.

Lighting controls	Daylight controlled dimming, Passive Infrared Sensors and timers are ways of ensuring that lights are not on when they are not required.
Lintel	Used to form a structural opening in a wall, above a window for example.
Listed buildings	Statutorily protected buildings, due to their special architectural and historic interest.
Loft insulation	Installed horizontally above the ceiling lining.
Micro CHP	Domestic scale Combined Heat and Power plant that produces heat as a by-product of electricity generation. CHP is sometimes referred to as co-generation.
Micro wind generation	Wind turbines convert the wind's energy into electricity. Small turbines, less than 10kw, are generally for domestic use or for powering standalone apparatus (such as road signage). Suitability is dependent on microclimate and topography.
Microgeneration	Refers to small scale energy generation at site, often but not necessarily from renewables.
MOAT 22 test	Testing methodology for External Wall Insulation Systems formerly used by British Board of Agrément.
Moisture mechanisms	The properties that allow the movement of moisture in materials.
Moisture permeability	Also known as vapour permeability. The permeability of each material is dependent on the vapour resistivity of the material which is a function of the pore structure of a material or of a set of materials in the case of a wall, floor or roof build up and the size and weight of the gaseous water molecule.
Multifoil insulation	Also referred to as thermo reflective foil insulation, a series of reflective sheet layers interspersed with wadding and foam to form a radiant heat barrier.
MVHR	Mechanical Ventilation with Heat Recovery transfers the heat energy from expelled air to the fresh air entering a building, thereby reducing heat loss through ventilation.
Narrow sections	Refers to the distance between the front and back, or sides of a building, allowing cross ventilation and penetration of light.
Party and partition walls	Internal walls, which do not form part of the external thermal envelope. However, they may form a direct thermal bridge to uninsulated building components or enable heat loss to untreated spaces.
Passivhaus	Voluntary standard for ultra-low energy buildings that require little energy for space heating or cooling. The EnerPHit standard for refurbishments has less stringent energy performance requirements.

Photovoltaics	Photovoltaic panels or tiles are used to generate electricity from solar energy. Panels can be building or ground mounted.
PIR insulation board	Polyisocyanurate insulation boards are rigid foam lined with foil used for internal & external wall insulation.
Planning restrictions	Planning permission is required in order to be allowed to build on, or change the use of land or buildings in the UK. Planning restrictions are limitations on development that may be area specific.
POE	Post Occupancy Evaluation is the assessments, including monitoring and inhabitant surveys that take place once a building is occupied.
Pointing	Refers to the mortar between brick or stone courses to bond the wall and prevent water ingress.
Pre- and post-occupancy engagement	Analysing how the building is used, and teaching the occupants how the building could be used to maximise efficiency and comfort and minimise energy use, before and after the improvement works have taken place.
Rafter insulation	Installed between the rafters on a pitched roof.
RdSAP	Reduced Data Standard Assessment Procedure, is a simplified version of SAP used for Energy Performance Certificates for new and existing buildings.
Rebound effects, Systemic effects	Accumulative or side effects in response to the building improvements that can be hard to predict, an example is comfort 'take back' effect where users consume the same or more energy in order to achieve higher levels of comfort.
Relative humidity (RH)	Relative humidity is the amount of water that can be carried as a vapour in air at a particular temperature. It is dependent on both the temperature and pressure of the air.
Renewables	Refers to technologies that use renewable resources, i.e. those that are not finite, for example sun, wind, rain, tides, and geothermal heat to create energy.
Rising damp	Water rising from the ground through capillary action into the walls of a building.
Roof-wall junction	The junction where the top of a wall meets the roof of a building, also sometimes referred to as the eaves detail. An important consideration in terms of thermal bridging and ventilation.
Room in roof	Refers to rooms in roofs often open to rafters where there is limited space to install insulation.
SAP	The 'Standard Assessment Procedure' which provides an indication of the overall energy efficiency of a dwelling. It is measured on a scale of 1 – 100 where the higher the number, the better the performance.
Secondary glazing	A separate unit of glazing installed on the internal side of the original single glazed window. An alternative measure to replacing a single glazed unit with a double glazed unit.

Solar water heating	Solar thermal panels are used to generate hot water from solar heat energy.
Solid slab insulation (floors)	Rigid insulation that sits on top of the floor slab instead of between floor joists.
Solid wall insulation	This can refer to internal or external wall insulation (IWI or EWI).
Solid walls	Usually made of brick or stone with no cavity.
Sorption	Process by which one substance becomes attached to another. Absorption is where one substance is incorporated (absorbed) into another. Adsorption is the bonding of molecules onto the surface of another.
Studding	Normally a timber stud wall or timber carcassing.
Systemic approach	Considers interactions between building fabric, overheating, ventilation systems and indoor air quality issues, in contrast to elemental or product based approaches, which are one dimensional.
Thermal comfort	A range of temperature and humidities deemed to provide a suitable i.e. 'comfortable' environment for humans. Requirements for thermal comfort are stated in BS EN ISO 7730.
Thermal conductivity	Thermal conductivity (λ), also called k-value is a material property, regardless of its shape or size. It is measured as heat flow density [W m^{-2}] in a 1m thick body of the material with 10 K temperature difference between the two surfaces. Unit: W $(mK)^{-1}$.
Thermal elements	Refers to the external facing facades including roof, floor, wall and any thermal bridges.
Thermal Imaging, Thermography	A non-invasive means of observing and diagnosing the condition of dwellings through temperature differentials. It can be used to check for high heat loss paths in dwellings. It can also assist in identifying building features that create thermal bridges, to check or prove insulation continuity, to find hidden leaks, and a source of damp in a dwelling. Thermal imaging can be used to evaluate and verify improvements and remedial works made to the fabric of dwellings subsequent to problems being diagnosed.
Thermal mass, Large-mass, High-mass	A characteristic of dense building materials. Thermal mass is calculated by multiplying the mass of a product by its specific heat capacity. The higher the figure the better a product protects from summer overheating and usually acoustic noise.
Timber joist ends	The ends of timber members used to support a floor or ceiling often supported in pockets within a solid wall.

Timber stud wall	Also known as a stud partition. Normally a non load bearing internal wall constructed from timber 'studs' running vertically between a horizontal 'top rail' fixed to the ceiling and a 'footer' fixed to the floor, with short horizontal 'noggings' fixed between studs for added stability. A lining, for example plasterboard is fixed to either side.
Traditional building, Traditionally built	A traditional building is defined as a property built prior to 1919, constructed of moisture-permeable materials, with solid walls and no moisture barriers, such as cavities or damp-proof courses.
Typological analysis	Refers to analysis within a category to enable a more thorough representation of building types.
Under-floor heating	Under-floor heating uses hot water in pipes or an electrically heated element to provide low level heat underneath a floor finish.
U-Value	The measure of rate of heat loss through a material, such as a wall, floor or roof. The higher the U-value the more heat loss. Modelled U-values are calculated using material data and equations. *In situ* U-values are calculated by measuring heat flux through the material over time. Unit W/m^2K.
Vapour barrier	A membrane that prevents or slows the passage of water as a vapour. Often applied to the warm side of insulation to prevent moisture penetration. Also referred to as Vapour Control Layer.
Vapour permeability	Also known as moisture permeability. The permeability of each material is dependent on the vapour resistivity of the material which is a function of the pore structure of a material or of a set of materials in the case of a wall, floor or roof build up and the size and weight of the gaseous water molecule.
Ventilation	Ventilation is the intentional movement of air from the outside of a building to the inside (as opposed to infiltration, which is unplanned movement of air). When people or animals are present in buildings, ventilation air is necessary to provide acceptable indoor air quality and to protect building fabric from high levels of moisture.
Vernacular material	Local, regionally specific, historic building material.
Warm Air Units	Warm Air Units blow heated air around ductwork and out through grilles or vents throughout the house.
Weather data	Derived or actual historical data used in building modelling software to predict building performance at a specific location.
Whole-Stock Modelling	Performance overview of multiple buildings, for example a city or a borough, by grouping, and making assumptions based on shared physical properties.

APPENDIX A STBA Supporting Organisations

Cadw

Changeworks

Chartered Institute of Architectural Technologists (CIAT)

Chartered Institute of Building (CIOB)

CITB Construction Skills

English Heritage

Federation of Master Builders

Glasgow Caledonian University

Good Homes Alliance

Historic Scotland

International Council on Monuments and Sites (ICOMOS)

Institute of Historic Building Conservation

National Trust

Prince's Regeneration Trust

Royal Institute of British Architects (RIBA)

Royal Institute of Chartered Surveyors (RICS)

Society for the Protection of Ancient Buildings

Somerset House Trust

University College London (UCL) Energy Institute

Usable Buildings Trust

APPENDIX B Research Experts List

UK Experts

Dr Caroline Rye	Archimetrics Ltd
Valentina Marincioni	Bartlett School of Graduate Studies, UCL
Dr Paul Baker	Glasgow Caledonian University
Prof Tadj Oreszczyn	UCL Energy Institute
Prof Mike Davies	UCL Energy Institute
Prof Bob Lowe	UCL Energy Institute
Dr Bill Bordass	William Bordass Associates
Isabel Carmona	William Bordass Associates

International Experts

Prof Andreas Holm	Fraunhofer Institute Germany
Assoc Prof Angela Sasic Kalagasidis	Chalmers Sweden
Prof Carl-Eric Hagentoft	Chalmers Sweden
Prof Carsten Rode	DTU Denmark
Assoc Prof Hans Janssen	Katholieke Universiteit Leuven Belgium
Prof John Grunewald	TU Dresden Germany
Nuno Ramos	University of Porto Portugal
Prof Staf Roels	Katholieke Universiteit Leuven Belgium
Prof Vasco Peixoto de Freitas	University of Porto Portugal
Dr Chris Sanders	Glasgow Caledonian University United Kingdom
Dr Paul Fazio	Concordia University Canada
Prof Jan Hensen	Eindhoven University of Technology Netherlands
Dr Kaisa Svennberg	Swedish Environmental Institute (IVL) Sweden
Assoc Prof Thomas Bednar	Vienna University of Technology

APPENDIX C List of Networks and Organisations Contacted and Respondents

Networks

- AECB
- Alliance of Sustainable Building Products
- BEAMA
- BRE
- Cadw
- CIAT
- CIOB
- CIRIA
- Constructing Excellence
- Construction Alliance
- Construction Clients' Group
- Construction Industry Council
- Construction Products Association
- Construction Skills
- Energy Efficiency Partnership for Homes
- Energy Saving Trust
- English Heritage
- Federation of Master Builders
- Good Homes Alliance
- Historic Scotland
- INCA
- Institute for Sustainability
- Institute of Historic Building Conservation
- MBE KTN (Modern Built Environment Knowledge Transfer Network)
- National Federation of Roofing Contractors
- National Trust
- NIA
- Passivhaus Trust
- RIBA
- RICS
- Sustainable Development Research Network
- Severn Wye Energy Agency
- Society for the Protection of Ancient Buildings
- Specialist Engineering Contractors' (SEC) Group
- Strategic Forum for Construction
- Super Homes Alliance
- TSB
- UCATT
- UK Contractors Group

Respondents

- Adam & Frances Voelcker Architects AND Sustainable Gwynedd Gynaladwy
- bere:architects
- Bradford Council
- BRE Wales
- Bristol Green Doors
- Building Life Consultancy
- Cadw
- Cardiff University
- Centre for Sustainable Energy
- Changeworks (sustainability advisors)
- CIC, Glasgow Caledonian University
- Conker Conservation Ltd (chartered surveyors)
- Construction Skills
- David Rawlins Ltd
- Eco-Slab
- EcoDesign Architectural Practice
- Eight Associates (environmental consultants)
- English Heritage
- Federation of Master Builders
- Heritage Structural Ventilation Ltd
- Historic Scotland
- Kennedy FitzGerald Architects LLP
- Kingspan
- Kingston University
- Lifespacedesign
- London Borough of Camden
- Low Zero Carbon Hub Wales
- MBE Consultants in Technical Refurbishment LLP
- Mould Growth Consultants Ltd
- National Society of Master Thatchers
- National Trust
- NBT
- Paul Davis + Partners
- private landlord
- retired senior lecturer
- Scottish and Southern Energy
- SPAB (Society for the Protection of Ancient Buildings)
- Sustainable Buildings
- Swansea Metropolitan University
- Touchstone Glazing Solutions Ltd
- Ty-Mawr (building products suppliers)
- University of Sheffield (Department of Landscape)
- Wales Low Zero Carbon Hub
- Web Dynamics Ltd
- Westdale Services Ltd.
- Westminster City Council
- Wienerberger Ltd (brick, paving manufacturers)
- Williams and Browne
- BRE Wales

APPENDIX D The Tiered Approach to Research Guidance and Judging

The following table specifies what was expected from a document in each tier of quality (GD = Green Deal)

TIER	IN GENERAL	QUALITIES TO EXPECT IN EACH TIER			
		EVIDENCE BASE	INDEPENDENTLY REVIEWED	SIGNIFICANCE TO A DEFINED AREA ON THE INTELLIGENCE MAP (may be more than one)	RELEVANCE
TIER 4	Poor quality but record that we know it exists	Little real evidence base to the research; guidance is selectively based on evidence or based on no evidence.	No independent review	N/A	Misleading, wrong or harmless?
TIER 3	The research is of value and makes some contribution to issues of retrofit of older properties and the in GD context	Evidence backs up the research	Some evidence of independent review.	It offers an insight to a particular area or areas on the Intelligence Map.	May have longer term relevance if not immediately relevant
TIER 2	The research is of value and makes some contribution to issues of retrofit of older properties esp. in GD context	Research evidence is based on modelling and simulation; guidance is based on Tier 1 or 2 research.	The research has not undergone peer-review.	It offers the strongest information in its area on the Intelligence Map	Immediate relevance
TIER 1	Seminal research that identifies issues of greatest relevance to retrofit of older properties esp. in GD context	Evidence backs up the research; guidance is based on Tier 1 research.	The research has been independently reviewed and verified as being derived from the evidence or is sufficiently critically reflective.	It offers the strongest information in its area on the Intelligence Map	Immediate relevance

Research

Reference Title	Author	Year
Guidelines to avoid mould growth in buildings, Advanced Buildings Energy Research, 3, pp. 221–236.	Altamirano-Medina H., Mumovic D., Davies M., Ridley I., Oreszczyn T.	2009
Integrating Environmental and Cultural Sustainability for Heritage Properties	Andrew Powter and Susan Ross	2005
Tech Paper 3 – Energy Modelling Analysis of a Scottish Tenement Flat	Bob Barnham, Nicholas Heath (Sustainable Futures) Gary Pearson (Technical Energy Services)	2008
Will drivers for home energy efficiency harm occupant health? Perspectives in Public Health. 130 (5) 233-238	Bone, Murray, Myers, Dengel and Crump	2010
The SPAB Research Report 1: The U-value Report	Caroline Rye	2010
Research into the thermal performance of traditional windows: timber sash windows, English Heritage	Chris Wood, Bill Bordas and Paul Baker	2009
The impact of physical rebound effects on the heat losses in a retrofitted dwelling	Deurinck M, Saelens D, Roels S (KULeuven)	2011
Thermal Performance of Traditional Windows and Low-Cost Energy-Saving Retrofits	Dr. Paul Baker for Historic Scotland	2008
Internal Environments in Historic Buildings: Monitoring, Diagnosis and Modelling	Dr Bill Bordass (William Bordass Associates), Dr Tadj Oreszczyn (UCL0	1998 2011
FutureFit:Report part 1	EST/Affinity Sutton	2011
FutureFit: Installation Phase in depth findings Developing a database of energy use of historic dwellings in Bath, UK	EST/Affinity Sutton Francis Moran, Marialena Nikolopoulou and Sukumar Natarajan	2012
Home is where the hearth is: grant recipients' views of England's home energy efficiency scheme (Warm Front)	Gilbertson, J., Stevens, M., Stiell, B., Thorogood, N.	2006
Understanding occupants: feedback techniques for large-scale low-carbon domestic refurbishments	Gupta, Rajat, Chandiwala, Smita	2010
Drying of brick walls after impregnation	H.M. Künzel and K. Kießl	1996
The impact of housing energy efficiency improvements on reduced exposure to cold – the 'temperature take back factor'	Hamilton, I., Davies, M., Ridley, I., Oreszczyn, T., Barrett, M., Lowe, R., Hong, S., Wilkinson, P., Chalabi, Z.	2011

Reference Title	Author	Year
Moisture and Bio-deterioration Risk of Building Materials and Structures	Hannu Viitanen, Juha Vinha, Kati Salminen, Tuomo Ojanen, Ruut Peuhkuri, Leena Paajanen, and Kimmo Lähdesmäki	2010
Historic Scotland Technical Paper 16 – Green Deal Financial Modelling of a traditional cottage and tenement flat (available by end March 2012)	Historic Scotland / Changeworks	2010 Draft
The Impact of energy efficient refurbishmnent on the airtightness in English dwellings	Hong,S., Ridley, I., Oreszcyn, T., Warm Front Study Group	2006
The impact of energy efficient refurbishment on the space heating fuel consumption in English dwellings, Energy and Buildings 38(10): 1171 – 1181.	Hong, S. H., T. Oreszczyn, *et al*.	2006
Ventilation, Infiltration and Air Permeability of Traditional UK Dwellings	Hubbard, D	2011
Assessing the execution of retrofitted external wall insulation for pre-1919 dwellings in Swansea (UK)	Joanne Hopper, Dr John Littlewood, Professor Andrew Geens, Professor George Karani, John Counsell, Nick Evans and Andrew Thomas	2010
Tech Paper 15 – Assessing insulation retrofits with hygrothermal simulations – Heat and moisture transfer in insulated solid stone walls	Joseph Little	2011 Draft
Resilience of 'Nightingale' hospital wards in a changing climate	KJ Lomas, R Giridharan, CA Short, and AJ Fair	2012
The efficacy of an energy efficient upgrade program in New Zealand	Lloyd, CR; Callau, MF; Bishop, T; Smith, IJ	2008
Carbon reduction in existing buildings: a transdisciplinary approach. Building Research Information (2010)	Lomas, K. J.	2010
English Heritage Hearth and Home Scoping Study Final Report	M. Gentry, D. Shipworth, M. Shipworth, A Summerfield	2010
A review of bottom-up building stock models for energy consumption in the residential sector	M. Kavgic a, *, A. Mavrogianni a, D. Mumovic a, A. Summerfield b, Z. Stevanovic c, M. Djurovic-Petrovic	2010
Breathability: The Key to Building Performance	Neil May	2005
Tech Paper 8 – Energy Modelling of the Garden Bothy, Dumfries House	Nicholas Heath, Gary Pearson, Bob Barnham (Changeworks) Richard Atkins (HEADS)	2010
Tech Paper 9 – Slim-profile double glazing	Nicholas Heath, Dr. Paul Baker and Dr. Gillian Menzies	2010

Reference Title	Author	Year
Performance and control of domestic ground-source heat pumps in retrofit installations	P.J. Boait, D. Fan, A. Stafford	2011
Tech Paper 10 – U-values and Traditional Buildings	Paul Baker	2011
Thermal Performance of Traditional Windows and Low-Cost Energy-Saving Retrofits	Paul Baker, Roger Curtis, Craig Kennedy, Chris Wood	2010
Does demolition or refurbishment of old and inefficient homes help to increase our environmental, social and economic viability?	Power, A	2008
Tech Paper 12 – Indoor Environmental Quality in Refurbishment	Richard Hobday	2011
The Performance of Traditional Buildings: the SPAB Building Performance Survey 2011 Interim Findings	Rye, C., Scott, C., & Hubbard, D.	2012
Ranking of interventions to reduce dwelling overheating during heat waves	S.M. Porritt, P.C. Cropper, L. Shao, C.I. Goodier	2012
Tech Paper 6 – Indoor Air Quality and Energy Efficiency in Traditional Buildings	Sandy Halliday (Gaia Research)	2009
Findings from a Post Occupancy Evaluation of adaptive restoration and performance enhancement of a 19th century 'Category B' listed tenement block in Edinburgh	Tim Sharpe and Donald Shearer	2011
Hygrothermal Modeling of Brick Masonry Using Empirically Determined Properties	Vinay V. Badami	2011

Guidance

Reference Title	Author	Year
Energy Heritage: A guide to improving energy efficiency in traditional and historic homes	Change Works	2008
Renewable Heritage: A guide to microgeneration in traditional and historic homes	Change Works	2009
Guide to building servicesfor historic buildings – Sustainable services for traditional buildings	CIBSE	2002
Here comes the sun: a field trial of solar water heating systems	Energy Saving Trust	2011
Energy Efficiency In Historic Buildings – Secondary glazing for windows	English Heritage	2010
Energy Efficiency In Historic Buildings – Draught-proofing windows and doors	English Heritage	2010
Energy Efficiency And Historic Buildings – Application of Part L of the Building Regulations to historic and traditionally constructed buildings	English Heritage	2011
Improving Energy Efficiency in Traditional Buildings	Historic Scotland	

APPENDIX F Authors/Publishers of Guidance Documents

Association for the Conservation of Energy ACE

Bath Preservation Trust

Building Research Establishment BRE

Cadw

Carbon Trust

Centre for Sustainable Energy

Changeworks

Chartered Institute of Building Service Engineers CIBSE

Construction Industry Research and Information Association CIRIA

Construction Products Association CPA

Energy Saving Trust EST

English Heritage

Forum for the Future

Historic Scotland

Housing Corporation

Institute for Sustainability

United Kingdom Green Building Council UKGBC

APPENDIX G

Upgrade Measures for the Guidance Tool Structure and Relevant References

Assumed Definitions of Green Deal and Other Measures

FABRIC		
Upgrade	**Green Deal eligible ***	**Definition** Where **RdSAP** ref is given, see Appendix T SAP 2009 version 9.91 (applicable from April 2012) and SBEM [suggested in GD document 2.19 & 2.24]. Definition Text as per BRE document for RdSAP2005. Previous RdSAP09 v9.90 did not make the recommendation if SAP rating improvement was less than 0.95
WALLS		
Cavity wall insulation	Y	**RdSAP09 AppT item B** – *Full cavity filled wall* . Upgrade is not applicable to solid wall homes, but if home was extended may be possible for some walls. U-value depends on construction – RdSAP tables for Age of wall.
External wall insulation	Y	**RdSAP09 AppT item Q** – *Application of an insulant and a weather-protective finish to the outside of the wall*. Upgrade is applicable to solid wall construction or as an alternative measure for walls that already have cavity wall insulation. It aims to achieve U-value = 0.3
Internal wall insulation	Y	**RdSAP09 AppT item Q** – *A layer of insulation is fixed to the inside surface of external walls*. Upgrade is applicable to solid wall construction only. It aims to achieve U-value = 0.3
ROOF(S)		
Loft hatch insulation	Y	**RdSAP09 AppT item A** – *Loft insulation 250mm insulation at ceiling level.*
Loft insulation	Y	**RdSAP09 AppT item A** – *Loft insulation 250mm insulation at ceiling level.* RdSAP2005 recommended adequate ventilation of loft space. We have assumed upgrade would aim to meet Part L1B 2010 Table A1 U-value = 0.16
Rafter insulation	Y	*Insulation between and below rafters or between and above rafters*. Upgrade needs assessment of condensation risk and provision of ventilation if necessary. We have assumed upgrade would aim to meet Part L1B 2010 Table A1 U-value = 0.18
Flat roof insulation	Y	**RdSAP09 AppT item A2** – *Flat roof insulation upgrade if less original is less than 100mm*. We have assumed it needs adequate condensation check and aims to achieve U-value = 0.18
Room in roof insulation	Y	**RdSAP09 AppT item A3** – Upgrade all element of roof rooms to achieve U-value = 0.25
FLOOR(S)		
Floor insulation	Y	**RdSAP09 AppT item W** – *Retrofit floor insulation when below the floor there is either ground, external air or an unheated space* –150mm of floor insulation. We assumed this to be one of the three options below:
Insulation between floor joists	Y	For suspended timber floor: insulation between floor joists, keeping ventilation paths below plus replacement of floor deck We have assumed upgrade would aim to meet Part L1B 2010 Table A1 U-value = 0.25
Solid slab insulation	Y	For solid floor: Screed replacement with insulation and deck. We have assumed upgrade would aim to meet Part L1B 2010 Table A1 U-value = 0.25, floor levels permitting.
Exposed upper floor insulation	Y	For exposed upper floors: insulation between floor joists above porches or garage. We have assumed upgrade would aim to meet part L1B 2010 Table 3 U-value = 0.25

WINDOW(S)		
Draught proofing	Y	**RdSAP09 AppT item D** – *Fitting draughtproofing strips around all windows and doors*. This aims to achieve 100% draught proofing.
Energy efficient glazing	Y	**RdSAP09 AppT item O** – *Changing single glazed windows for double glazed with U-value U = 1.5 g = 0.63*
Refurbishment	N	*Repair of existing windows to make operational and tight fitting.*
Secondary Glazing	Y	**RdSAP09 AppT item P** – *Addition of a second pane of glass inside the existing window (secondary glazing).* This upgrade is recommended if the building is listed or in conservation area where double glazing would not be appropriate. Secondary glazing U-value assumed by RdSAP: U = 2.4, g = 0.76.
Window shutters	N	*Refurbishment of existing window shutters to make them operational.*
Window shading	N	*Existing or new external window shading to control summer overheating.*
DOORS		
Draught proofing	Y	RdSAP09 AppT item D – *Fitting draughtproofing strips around all windows and doors*. This aims to achieve 100% draught proofing.
High thermal performance external doors	Y	RdSAP09 AppT item X – *Change doors directly to outside to insulated doors with U = 1.5*
Refurbishment	N	*Repair of existing doors to make operational and tight fitting.*

SERVICES

Upgrade	**Green Deal eligible ***	**Definition** Where RdSAP ref is given, see Appendix T SAP 2009 version 9.91 (applicable from April 2012) and SBEM [suggested in GD document 2.19 & 2.24]. Definition Text as per BRE document for RdSAP2005. Previous RdSAP09 v9.90 did not make the recommendation if SAP rating improvement is less than 0.95.
ELECTRICITY GENERATION		
Micro combined heat and power	Y	RdSAP09 App T item Z3- *Provision of CHP on site to provide all heating requirements of building(s on site). It needs to meet either the Domestic Building Compliance Guides 2010 section 13* or *Non Domestic section 6* requirements. The heating controls suggested are programmer, room thermostat and TRVs. This upgrade assumes the water cylinder remains unchanged.
Micro wind generation	Y	RdSAP09 App T item V- *Wind turbine, blade diameter 2m, hub height 2m*. RdSAP05 warns: Planning restrictions may apply. Building regulations apply. Wind turbines are not suitable for all properties. The system's effectiveness depends on local wind speeds and the presence of nearby obstructions, and a site survey.
Photovoltaics	Y	RdSAP09 App T item U – *2.5kWp array in total including any existing.* Upgrade not to be considered on thatched roofs. RdSAP05 warns: Planning restrictions may apply. Building regulations apply.

Services continued >

HEAT GENERATION 1		
Air source heat pumps	Y	**RdSAP09 App T item Z1** (with radiators) or **Z2** (with underfloor heating) – *Installation of Air Source Heat pump*. We have assumed the CoP and SFP minimum needs to meet *Domestic Building Compliance Guides 2010 section 9* or/and *Non Domestic section 3* requirements. Upgrade assumed to serve underfloor heating or radiators with high volume water (lower water temperature). The heating controls suggested are programmer and room thermostat. This upgrade assumes the water cylinder is within the heat pump casing and replaces any existing one.
Biomass boilers	Y	**RdSAP09 App T item J** – *Manual feed biomass boiler in heated space (wood logs) with radiators*. Upgrade suggested by RdSAP when previous boiler solid fuel (not biomass or dual fuel), or no gas available or as an alternative measure. The heating controls suggested are programmer, room thermostat and TRVs. This upgrade assumes the water cylinder remains unchanged.
Biomass room heater (with radiators)	Y	**RdSAP09 App T item K** – *Wood pellet stove with radiators*. Upgrade suggested by RdSAP when previous boiler is a solid fuel open fire or room heater (not biomass or dual fuel) or no gas available. The heating controls suggested are programmer, room thermostat and TRVs. This upgrade assumes the water cylinder unchanged.
Fan-assisted replacement storage heaters	Y	**RdSAP09 AppT item L** – *Improvement to fan assisted storage heaters with automatic charge control and dual immersion heater with large cylinder with 50mm factory applied insulation.* Upgrade suggested by RdSAP when previous heating was storage heaters or electric room heaters or ceiling heaters AND there is no main gas available. Previous hot water heating assumed to be by immersion or solid fuel secondary heater. Upgrade assumes 7 hour off-peak tariff.
Flue gas heat recovery devices	Y	**RdSAP09 App T item T2** – *FGHR is a system (i.e. one or more connected devices) for recovering heat from flue gases that would otherwise be wasted*. Upgrade suggested by RdSAP when a replacement gas condensing boiler providing DHW is proposed.
Ground source heat pumps	Y	**RdSAP09 App T item Z1** (with radiators) or **Z2** (with underfloor heating) – Installation of Ground Source Heat pump. We have assumed the CoP and SFP minimum needs to meet Domestic Building Compliance Guides 2010 section 9 or/and Non Domestic section 3 requirements. Upgrade assumed to serve underfloor heating or radiators with high volume water (lower water temperature). The heating controls suggested are programmer and room thermostat. This upgrade assumes the water cylinder is within the heat pump casing and replaces any existing one.
Micro combined heat *requirements* and power	Y	**RdSAP09 App T item Z3** – *Provision of CHP on site to provide all heating of building (s)* on site. It needs to meet either the *Domestic Building Compliance Guides 2010 section 13* or *Non Domestic section 6 requirements*. The heating controls suggested are programmer, room thermostat and TRVs. This upgrade assumes the water cylinder remains unchanged.
High efficiency gas fired condensing boilers	Y	**RdSAP09 App T items I, S & T** – Installation of a gas condensing boiler (regular or combi). This can be either an upgrade to the old boiler or a change of heating system (no boiler before). We assume efficiency requirement to be 90% SEDBUK2005. Boiler assumed to provide space and water heating. We assume the controls might need to be upgraded.
Oil-fired condensing boilers	Y	**RdSAP09 App T items I & R** – Installation of an oil condensing boiler (regular or combi). This can be either an upgrade to the old boiler or a change to heating system if gas is not available. We assume the controls might need to be upgraded.
Refurbishment	N	*Servicing and check of current heating system to fine-tune its efficiency*

HEAT GENERATION 1 continued		
Solar water heating	Y	**RdSAp09 AppT item N** – Solar panel in South facing roof 3m² aperture and other parameters as per table S18 RdSAP09 and increase of hot water cylinder to medium size. This upgrade is not suitablefor thatched roofs.
Waste water heat recovery devices attached to showers	Y	**RdSAp09 AppT item Y** – WWHR is a system for recovering heat from grey water that would otherwise be wasted. The recovered heat is transferred to the mains, water which may be fed directly into the consuming appliance and/or into the hot water generation system.
HEAT STORAGE 1		
Cylinder thermostats	Y	**RdSAp09 AppT item F** – *A hot water cylinder thermostat that enables the boiler to switch off when the water in the cylinder reaches the required temperature*. Upgrade suggested by RdSAP if not present before.
Hot water cylinder insulation	Y	**RdSAp09 AppT item C** – *Increase hot water cylinder jacket to between 80-160mm.* Thickness depends on what was installed before.
HEAT DISTRIBUTION 1		
Heating controls for wet and warm air system	Y	**RdSAP09 App T items G & H** – *Upgraded controls to heating system*. For a radiator system, RdSAP suggested controls are: programmer, room stat and TRVs (or time and temperature zone control if already present), interlocked system, separate timing of space and hot water heating control (if regular boiler). For a warm air system, RdSAP suggested controls are: programmer, room stat.
High efficiency replacement warm air units	Y	**RdSAP09 App T item M** – *New (non condensing) warm air unit.* Upgrade suggested for buildings with main heating by main gas or LPG warm air units pre 1998. It assumes the same fuel as original, on-off controls and fan assisted flue.
Refurbishment	N	*Reuse of current distribution system, fine-tuning for efficiency.*
Pipe insulation	N	*Insulation of heating and hot water pipes as required by Domestic and Non Domestic Building Compliance Guides 2010.*
Under-floor heating	Y	We assume underfloor heating upgrades to be water based and designed to comply with *Domestic Building Compliance Guide 2010 Section 7*
LIGHTING 1		
Systems	Y	We assume upgrade to be focused on metering displays
Controls	Y	We assume upgrade to be focused on non domestic controls for lighting such as daylight controlled dimming, PIRs, timers
Fittings	Y	**RdSAP09 App T item E** – Low energy lighting in all fixed outlets. RdSAP09 v9.90 does not make the recommendation if SAP rating improvement is less than 0.45
VENTILATION 1		
Mechanical ventilation with heat recovery	Y	*Provision of a new MVHR system (supply and extract and ducting) to provide a balanced whole house ventilation system to property with minimum ventilation rates compliant with Domestic Building Compliance Guide 2010 section 8 or non Domestic section 10.* Upgrade assumed to meet best practice minimum SFP and efficiency.
Natural ventilation	N	*Retaining natural ventilation strategy (with localised mechanical extract): ensuring sufficient passive air intakes (trickle vents) are provided for background ventilation and opening windows for purge ventilation.*

BEHAVIOUR

Upgrade	Green Deal eligible *	Definition
PEOPLE INTERACTION cont		
User interfaces for usability	N	*Choice of user interfaces for ease of usability and understanding*
User education	N	*User education on reasons for energy efficient measures and on understanding the systems operation and controls.*
User interest and involvement	N	*Involvement of user on defining their needs and creating interest and motivation to save energy and involving them in choice making.*
Maintenance	N	*Correct maintenance at regular intervals of either fabric or service items to ensure optimum function by either the users themselves if appropriate or by competent persons. Associated measure to service items (see upgrade analysis). Need to have a strategy*

The majority of Tier 1 references allocated to upgrade measures, divided into 3 areas: Fabric, Services and Behaviour, as per appendix G. Columns G, R and C stand for Guidance, Research, Case studies.

1. GREEN DEAL MEASURES – Type: Fabric – relevant references

ID	**1**
UPGRADE SUBTYPE	**WALL(S)**
Measure ID	**1**
Measure	**Cavity Wall Insulation**

Ref ID	Reference Title	Author	Year	G	R	C
41	Home is where the hearth is: grant recipients' views of England's home energy efficiency scheme (Warm Front)	Gilbertson, J., Stevens, M., Stiell, B., Thorogood, N.	2006	0	1	0
32	The impact of energy efficient refurbishment on the space heating fuel consumption in English dwellings, Energy and Buildings 38(10): 1171-1181.	Hong, S. H., T. Oreszczyn, *et al.*	2006	0	1	0
28	Future Fit: Installation Phase in depth findings	EST/Affinity Sutton	2011	0	1	1
22	Energy Efficiency And Historic Buildings – Application of Part L of the Building Regulations to historic and traditionally constructed buildings	English Heritage	2011	1	0	0
20	The Impact of energy efficient refurbishment on the airtightness in English dwellings	Hong,S., Ridley, I., Oreszcyn, T., Warm Front Study Group	2006	0	1	0
18	Resilience of 'Nightingale' hospital wards in a changing climate	KJ Lomas, R Giridharan, CA Short, and AJ Fair	2012	0	1	1
17	Moisture and Bio-deterioration Risk of Building Materials and Structures	Viitanen, H., Vinha, J., Salminen, K., Ojanen, T., Peuhkuri, R., Paajanen, L., and Lähdesmäki, K.	2010	0	1	0
15	The Performance of Traditional Buildings: the SPAB Building Performance Survey 2011 Interim Findings	Rye, C & Hubbard, D.	2012	0	1	1
14	The SPAB Research Report 1: The U-value Report	Caroline Rye	2010	0	1	0
13	Tech Paper 15 – Assessing insulation retrofits with hygrothermal simulations – Heat and moisture transfer in insulated solid stone walls	Joseph Little	2011 DRAFT	0	1	1
12	Tech Paper 10 – U-values and Traditional Buildings	Paul Baker	2011	0	1	0
1	Ventilation, Infiltration and Air Permeability of Traditional UK Dwellings	Hubbard, D	2011	0	1	1

Measure ID	2
Measure	External Wall Insulation

Ref ID	Reference Title	Author	Year	G	R	C
57	Guide to building services for historic buildings – Sustainable services for traditional buildings	CIBSE	2002	1	0	1
53	Assessing the execution of retrofitted external wall insulation for pre-1919 dwellings in Swansea (UK)	Joanne Hopper, Dr John Littlewood, Professor Andrew Geens, Professor George Karani, John Counsell, Nick Evans and Andrew Thomas	2010	0	1	1
44	Ranking of interventions to reduce dwelling overheating during heat waves	S.M. Porritt, P.C. Cropper, L. Shao, C.I. Goodier	2012	0	1	0
33	Breathability: The Key to Building Performance	Neil May	2005	0	1	0
28	FutureFit: Installation Phase in depth findings	EST/Affinity Sutton	2011	0	1	1
26	Internal Environments in Historic Buildings: Monitoring, Diagnosis and Modelling	Dr Bill Bordass (William Bordass Associates), Dr Tadj Oreszczyn (UCL0	1998	0	1	0
25	Improving Energy Efficiency in Traditional Buildings	Historic Scotland	–	1	0	0
22	Energy Efficiency And Historic Buildings – Application of Part L of the Building Regulations to historic and traditionally constructed buildings	English Heritage	2011	1	0	0
17	Moisture and Bio-deterioration Risk of Building Materials and Structures	Viitanen, H., Vinha, J., Salminen, K., Ojanen, T., Peuhkuri, R., Paajanen, L., and Lähdesmäki, K.	2010	0	1	0
15	The Performance of Traditional Buildings: the SPAB Building Performance Survey 2011 Interim Findings	Rye, C., Scott, C., & Hubbard, D.	2012	0	1	1
14	The SPAB Research Report 1: The U-value Report	Caroline Rye	2010	0	1	0
13	Tech Paper 15 – Assessing insulation retrofits with hygrothermal simulations – Heat and moisture transfer in insulated solid stone walls	Joseph Little	2011 DRAFT	0	1	1
12	Tech Paper 10 – U-values and Traditional Buildings	Paul Baker	2011	0	1	0
8	Tech Paper 6 – Indoor Air Quality and Energy Efficiency in Traditional Buildings	Sandy Halliday (Gaia Research)	2009	0	1	1
1	Ventilation, Infiltration and Air Permeability of Traditional UK Dwellings	Hubbard, D	2011	0	1	1

Measure ID	3
Measure	Internal Wall Insulation

Ref ID	Reference Title	Author	Year	G	R	C
57	Guide to building services for historic buildings – Sustainable services for traditional buildings	CIBSE	2002	1	0	1
54	Findings from a Post Occupancy Evaluation of adaptive restoration and performance enhancement of a 19th century 'Category B' listed tenement block in Edinburgh	Tim Sharpe and Donald Shearer	2011	0	1	1
52	Drying of brick walls after impregnation	H.M. Künzel and K. Kießl	1996	0	1	0
46	Energy Heritage: A guide to improving energy efficiency in traditional and historic homes	Change Works	2008	1	0	1
45	Historic Scotland Technical Paper 16 – Green Deal Financial Modelling of a traditional cottage and tenement flat (available by end March 2012)	Historic Scotland / Changeworks	2010_ Draft	0	1	1
44	Ranking of interventions to reduce dwelling overheating during heat waves	S.M. Porritt, P.C. Cropper, L. Shao, C.I. Goodier	2012	0	1	0
40	Hygrothermal Modelling of Brick Masonry Using Empirically Determined Properties	Vinay V. Badami	2011	0	1	1
33	Breathability: The Key to Building Performance	Neil May	2005	0	1	0
28	Future Fit: Installation Phase in depth findings	EST/Affinity Sutton	2011	0	1	1
26	Internal Environments in Historic Buildings: Monitoring, Diagnosis and Modelling	Dr Bill Bordass *et al*	1998	0	1	0
25	Improving Energy Efficiency in Traditional Buildings	Historic Scotland		1	0	0
22	Energy Efficiency And Historic Buildings – Application of Part L of the Building Regulations to historic and traditionally constructed buildings	English Heritage	2011	1	0	0
17	Moisture and Bio-deterioration Risk of Building Materials and Structures	Hannu Viitanen, Juha Vinha, *et al*	2010	0	1	0
15	The Performance of Traditional Buildings: the SPAB Building Performance Survey 2011 Interim Findings	Rye, C. Scott, C., & Hubbard, D.	2012	0	1	1
14	The SPAB Research Report 1: The U-value Report	Caroline Rye	2010	0	1	0
13	Tech Paper 15 – Assessing insulation retrofits with hygrothermal simulations – Heat and moisture transfer in insulated solid stone walls	Joseph Little	2011 DRAFT	0	1	1
12	Tech Paper 10 – U-values and Traditional Buildings	Paul Baker	2011	0	1	0

8	Tech Paper 6 – Indoor Air Quality and Energy Efficiency in Traditional Buildings	Sandy Halliday (Gaia Research)	2009	0	1	1
1	Ventilation, Infiltration and Air Permeability of Traditional UK Dwellings	Hubbard, D	2011	0	1	1

ID	2
Upgrade Subtype	Roof(s)
Measure ID	4
Measure	Loft or rafter insulation and loft hatch insulation

Ref ID	Reference Title	Author	Year	G	R	C
57	Guide to building services for historic buildings – Sustainable services for traditional buildings	CIBSE	2002	1	0	1
46	Energy Heritage: A guide to improving energy efficiency in traditional and historic homes	Change Works	2008	1	0	1
45	Historic Scotland Technical Paper 16 – Green Deal Financial Modelling of a traditional cottage and tenement flat (available by end March 2012)	Historic Scotland / Changeworks	2010 DRAFT	0	1	1
41	Home is where the hearth is: grant recipients' views of England's home energy efficiency scheme (Warm Front)	Gilbertson, J., Stevens, M., Stiell, B., Thorogood, N.	2006	0	1	0
33	Breathability: The Key to Building Performance	Neil May	2005	0	1	0
32	The impact of energy efficient refurbishment on the space heating fuel consumption in English dwellings, Energy and Buildings 38(10): 1171-1181	Hong, S. H., T. Oreszczyn, *et al.*	2006	0	1	0
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26	Internal Environments in Historic Buildings: Monitoring, Diagnosis and Modelling	Dr Bill Bordass (William Bordass Associates), Dr Tadj Oreszczyn (UCL0)	1998	0	1	0
25	Improving Energy Efficiency in Traditional Buildings	Historic Scotland		1	0	0
22	Energy Efficiency And Historic Buildings – Application of Part L of the Building Regulations to historic and traditionally constructed buildings	English Heritage	2011	1	0	0
20	The Impact of energy efficient refurbishment on the airtightness in English dwellings	Hong,S., Ridley, I., Oreszcyn, T., Warm Front Study Group	2006	0	1	0
12	Tech Paper 10 – U-values and Traditional Buildings	Paul Baker	2011	0	1	0
1	Ventilation, Infiltration and Air Permeability of Traditional UK Dwellings	Hubbard, D	2011	0	1	1

Measure ID	5
Measure	Roof insulation

Ref ID	Reference Title	Author	Year	G	R	C
57	Guide to building services for historic buildings – Sustainable services for traditional buildings	CIBSE	2002	1	0	1
46	Energy Heritage: A guide to improving energy efficiency in traditional and historic homes	Change Works	2008	1	0	1
33	Breathability: The Key to Building Performance	Neil May	2005	0	1	0
32	The impact of energy efficient refurbishment on the space heating fuel consumption in English dwellings, Energy and Buildings 38(10): 1171-1181.	Hong, S. H., T. Oreszczyn, *et al.*	2006	0	1	0
28	FutureFit: Installation Phase in depth findings	EST/Affinity Sutton	2011	0	1	1
26	Internal Environments in Historic Buildings: Monitoring, Diagnosis and Modelling	Dr Bill Bordass (William Bordass Associates), Dr Tadj Oreszczyn (UCL)	1998	0	1	0
25	Improving Energy Efficiency in Traditional Buildings	Historic Scotland		1	0	0
22	Energy Efficiency And Historic Buildings – Application of Part L of the Building Regulations to historic and traditionally constructed buildings	English Heritage	2011	1	0	0
20	The Impact of energy efficient refurbishment on the airtightness in English dwellings	Hong,S., Ridley, I., Oreszcyn, T., Warm Front Study Group	2006	0	1	0
19	The efficacy of an energy efficient upgrade program in New Zealand	Lloyd, CR; Callau, MF; Bishop, T; Smith, IJ	2008	0	1	1
18	Resilience of 'Nightingale' hospital wards in a changing climate	KJ Lomas, R Giridharan, CA Short, and AJ Fair	2012	0	1	1
12	Tech Paper 10 – U-values and Traditional Buildings	Paul Baker	2011	0	1	0
1	Ventilation, Infiltration and Air Permeability of Traditional UK Dwellings	Hubbard, D	2011	0	1	1

Measure ID	6
Measure	Room in roof insulation

Ref ID	Reference Title	Author	Year	G	R	C
57	Guide to building services for historic buildings – Sustainable services for traditional buildings	CIBSE	2002	1	0	1
33	Breathability: The Key to Building Performance	Neil May	2005	0	1	0
32	The impact of energy efficient refurbishment on the space heating fuel consumption in English dwellings, Energy and Buildings 38(10): 1171 – 1181.	Hong, S. H., T. Oreszczyn, *et al.*	2006	0	1	0
28	FutureFit: Installation Phase in depth findings	EST/Affinity Sutton	2011	0	1	1
26	Internal Environments in Historic Buildings: Monitoring, Diagnosis and Modelling	Dr Bill Bordass (William Bordass Associates), Dr Tadj Oreszczyn (UCL)	1998	0	1	0
12	Tech Paper 10 – U-values and Traditional Buildings	Paul Baker	2011	0	1	0
1	Ventilation, Infiltration and Air Permeability of Traditional UK Dwellings	Hubbard, D	2011	0	1	1

ID	3
Upgrade Subtype	Floor(s)
Measure ID	7
Measure	Under Floor Insulation

Ref ID	Reference Title	Author	Year	G	R	C
46	Energy Heritage: A guide to improving energy efficiency in traditional and historic homes	Change Works	2008	1	0	1
45	Historic Scotland Technical Paper 16 – Green Deal Financial Modelling of a traditional cottage and tenement flat (available by end March 2012)	Historic Scotland / Changeworks	2010 DRAFT	0	1	1
28	FutureFit: Installation Phase in depth findings	EST/Affinity Sutton	2011	0	1	1
26	Internal Environments in Historic Buildings: Monitoring, Diagnosis and Modelling	Dr Bill Bordass (William Bordass Associates), Dr Tadj Oreszczyn (UCL0)	1998	0	1	0
25	Improving Energy Efficiency in Traditional Buildings	Historic Scotland		1	0	0
22	Energy Efficiency And Historic Buildings – Application of Part L of the Building Regulations to historic and traditionally constructed buildings	English Heritage	2011	1	0	0
20	The Impact of energy efficient refurbishment on the airtightness in English dwellings	Hong,S., Ridley, I., Oreszcyn, T., Warm Front Study Group	2006	0	1	0
19	The efficacy of an energy efficient upgrade program in New Zealand	Lloyd, CR; Callau, MF; Bishop, T; Smith, IJ	2008	0	1	1
17	Moisture and Bio-deterioration Risk of Building Materials and Structures	Viitanen, H., Vinha, J., Salminen, K., Ojanen, T., Peuhkuri, R., Paajanen, L., and Lähdesmäki, K.	2010	0	1	0
12	Tech Paper 10 – U-values and Traditional Buildings	Paul Baker	2011	0	1	0
1	Ventilation, Infiltration and Air Permeability of Traditional UK Dwellings	Hubbard, D	2011	0	1	1

ID	4
Upgrade Subtype	Window(s)
Measure ID	8
Measure	Draught proofing

Ref ID	Reference Title	Author	Year	G	R	C
46	Energy Heritage: A guide to improving energy efficiency in traditional and historic homes	Change Works	2008	1	0	1
45	Historic Scotland Technical Paper 16 – Green Deal Financial Modelling of a traditional cottage and tenement flat (available by end March 2012)	Historic Scotland / Changeworks	2010 DRAFT	0	1	1
41	Home is where the hearth is: grant recipients' views of England's home energy efficiency scheme (Warm Front)	Gilbertson, J., Stevens, M., Stiell, B., Thorogood, N.	2006	0	1	0
32	The impact of energy efficient refurbishment on the space heating fuel consumption in English dwellings, Energy and Buildings 38(10): 1171-1181.	Hong, S. H., T. Oreszczyn, *et al.*	2006	0	1	0
30	Will drivers for home energy efficiency harm occupant health? Perspectives in Public Health. 130 (5) 233-238	Bone, Murray, Myers, Dengel and Crump.	2010	0	1	0
25	Improving Energy Efficiency in Traditional Buildings	Historic Scotland		1	0	0
23	Energy Efficiency In Historic Buildings – Secondary glazing for windows	English Heritage	2010	1	0	0
22	Energy Efficiency And Historic Buildings – Application of Part L of the Building Regulations to historic and traditionally constructed buildings	English Heritage	2011	1	0	0
21	Energy Efficiency In Historic Buildings – Draught-proofing windows and doors	English Heritage	2010	1	0	0
20	The Impact of energy efficient refurbishment on the airtightness in English dwellings	Hong,S., Ridley, I., Oreszcyn, T., Warm Front Study Group	2006	0	1	0
8	Tech Paper 6 – Indoor Air Quality and Energy Efficiency in Traditional Buildings	Sandy Halliday (Gaia Research)	2009	0	1	1
6	Thermal Performance of Traditional Windows and Low-Cost Energy-Saving Retrofits	Dr. Paul Baker for Historic Scotland	2008	0	1	0
5	Thermal Performance of Traditional Windows and Low-Cost Energy-Saving Retrofits	Paul Baker, Roger Curtis, Craig Kennedy, Chris Wood	2010	0	1	0
1	Ventilation, Infiltration and Air Permeability of Traditional UK Dwellings	Hubbard, D	2011	0	1	1

Measure ID	9
Measure	Energy Efficient Glazing

Ref ID	Reference Title	Author	Year	G	R	C
46	Energy Heritage: A guide to improving energy efficiency in traditional and historic homes	Change Works	2008	1	0	1
45	Historic Scotland Technical Paper 16 – Green Deal Financial Modelling of a traditional cottage and tenement flat (available by end March 2012)	Historic Scotland / Changeworks	2010 DRAFT	0	1	1
44	Ranking of interventions to reduce dwelling overheating during heat waves	S.M. Porritt, P.C. Cropper, L. Shao, C.I. Goodier	2012	0	1	0
27	Research into the thermal performance of traditional windows: timber sash windows, English Heritage	Chris Wood, Bill Bordass and Paul Baker	2009	0	1	0
25	Improving Energy Efficiency in Traditional Buildings	Historic Scotland		1	0	0
23	Energy Efficiency In Historic Buildings – Secondary glazing for windows	English Heritage	2010	1	0	0
22	Energy Efficiency And Historic Buildings – Application of Part L of the Building Regulations to historic and traditionally constructed buildings	English Heritage	2011	1	0	0
21	Energy Efficiency In Historic Buildings – Draught-proofing windows and doors	English Heritage	2010	1	1	0
11	Tech Paper 9 – Slim-profile double glazing	Nicholas Heath (Changeworks), Dr. Paul Baker (Glasgow Caledonian University) and Dr. Gillian Menzies (Heriot-Watt University)	2010	0	1	0
8	Tech Paper 6 – Indoor Air Quality and Energy Efficiency in Traditional Buildings	Sandy Halliday (Gaia Research)	2009	0	1	1
6	Thermal Performance of Traditional Windows and Low-Cost Energy-Saving Retrofits	Dr. Paul Baker for Historic Scotland	2008	0	1	0
5	Thermal Performance of Traditional Windows and Low-Cost Energy-Saving Retrofits	Paul Baker, Roger Curtis, Craig Kennedy, Chris Wood	2010	0	1	0
1	Ventilation, Infiltration and Air Permeability of Traditional UK Dwellings	Hubbard, D	2011	0	1	1

ID	5
Upgrade Subtype	Door(s)
Measure ID	8
Measure	Draught proofing

Ref ID	Reference Title	Author	Year	G	R	C
46	Energy Heritage: A guide to improving energy efficiency in traditional and historic homes	Change Works	2008	1	0	1
45	Historic Scotland Technical Paper 16 – Green Deal Financial Modelling of a traditional cottage and tenement flat (available by end March 2012)	Historic Scotland / Changeworks	2010 DRAFT	0	1	1
41	Home is where the hearth is: grant recipients' views of England's home energy efficiency scheme (Warm Front)	Gilbertson, J., Stevens, M., Stiell, B., Thorogood, N.	2006	0	1	0
32	The impact of energy efficient refurbishment on the space heating fuel consumption in English dwellings, Energy and Buildings 38(10): 1171-1181.	Hong, S. H., T. Oreszczyn, *et al*.	2006	0	1	0
30	Will drivers for home energy efficiency harm occupant health? Perspectives in Public Health. 130 (5) 233-238	Bone, Murray, Myers, Dengel and Crump.	2010	0	1	0
25	Improving Energy Efficiency in Traditional Buildings	Historic Scotland		1	0	0
23	Energy Efficiency In Historic Buildings – Secondary glazing for windows	English Heritage	2010	1	0	0
22	Energy Efficiency And Historic Buildings – Application of Part L of the Building Regulations to historic and traditionally constructed buildings	English Heritage	2011	1	0	0
21	Energy Efficiency In Historic Buildings – Draught-proofing windows and doors	English Heritage	2010	1	0	0
20	The Impact of energy efficient refurbishment on the airtightness in English dwellings	Hong,S., Ridley, I., Oreszcyn, T., Warm Front Study Group	2006	0	1	0
8	Tech Paper 6 – Indoor Air Quality and Energy Efficiency in Traditional Buildings	Sandy Halliday (Gaia Research)	2009	0	1	1
6	Thermal Performance of Traditional Windows and Low-Cost Energy-Saving Retrofits	Dr. Paul Baker for Historic Scotland	2008	0	1	0
5	Thermal Performance of Traditional Windows and Low-Cost Energy-Saving Retrofits	Paul Baker, Roger Curtis, Craig Kennedy, Chris Wood	2010	0	1	0
1	Ventilation, Infiltration and Air Permeability of Traditional UK Dwellings	Hubbard, D	2011	0	1	1

Measure ID	10
Measure	High Thermal Performance External Doors

Ref ID	Reference Title	Author	Year	G	R	C
45	Historic Scotland Technical Paper 16 – Green Deal Financial Modelling of a traditional cottage and tenement flat (available by end March 2012)	Historic Scotland / Changeworks	2010 DRAFT	0	1	1
25	Improving Energy Efficiency in Traditional Buildings	Historic Scotland		1	0	0
21	Energy Efficiency In Historic Buildings – Draught-proofing windows and doors	English Heritage	2010	1	0	0
1	Ventilation, Infiltration and Air Permeability of Traditional UK Dwellings	Hubbard, D	2011	0	1	1

Measure ID	43
Measure	Secondary Glazing

Ref ID	Reference Title	Author	Year	G	R	C
45	Historic Scotland Technical Paper 16 – Green Deal Financial Modelling of a traditional cottage and tenement flat (available by end March 2012)	Historic Scotland / Changeworks	2010 DRAFT	0	1	1
54	Findings from a Post Occupancy Evaluation of adaptive restoration and performance enhancement of a 19th century ‘Category B’ listed tenement block in Edinburgh	Tim Sharpe and Donald Shearer	2011	0	1	1
25	Improving Energy Efficiency in Traditional Buildings	Historic Scotland		1	0	0
27	Research into the thermal performance of traditional windows: timber sash windows, English Heritage	Chris Wood, Bill Bordass and Paul Baker	2009	0	1	0
22	Energy Efficiency And Historic Buildings – Application of Part L of the Building Regulations to historic and traditionally constructed buildings	English Heritage	2011	1	0	0
23	Energy Efficiency In Historic Buildings – Secondary glazing for windows	English Heritage	2010	1	0	0
6	Thermal Performance of Traditional Windows and Low-Cost Energy-Saving Retrofits	Dr. Paul Baker for Historic Scotland	2008	0	1	0
11	Tech Paper 9 – Slim-profile double glazing	Nicholas Heath, Dr. Paul Baker and Dr. Gillian Menzies	2010	0	1	0
5	Thermal Performance of Traditional Windows and Low-Cost Energy-Saving Retrofits	Paul Baker, Roger Curtis, Craig Kennedy, Chris Wood	2010	0	1	0

2. GREEN DEAL MEASURES – Type: Services – relevant references

ID	6
Upgrade Subtype	Electricity Generation
Measure ID	11
Measure	Micro CHP

Ref ID	Reference Title	Author	Year	G	R	C
22	Energy Efficiency And Historic Buildings – Application of Part L of the Building Regulations to historic and traditionally constructed buildings	English Heritage	2011	1	0	0
49	Micro CHP Accelerator – final report (CTC788)	Guy, R., Sykes, B.	2011	0	0	1

Measure ID	12
Measure	Micro Wind Generation

Ref ID	Reference Title	Author	Year	G	R	C
22	Energy Efficiency And Historic Buildings – Application of Part L of the Building Regulations to historic and traditionally constructed buildings	English Heritage	2011	1	0	0
47	Renewable Heritage: A guide to microgeneration in traditional and historic homes	Change Works	2009	1	0	1

Measure ID	13
Measure	Photovoltaics

Ref ID	Reference Title	Author	Year	G	R	C
47	Renewable Heritage: A guide to microgeneration in traditional and historic homes	Change Works	2009	1	0	0
22	Energy Efficiency And Historic Buildings – Application of Part L of the Building Regulations to historic and traditionally constructed buildings	English Heritage	2011	1	0	1
28	FutureFit: Installation Phase in depth findings	EST/Affinity Sutton	2011	0	1	1

ID	7
Upgrade Subtype	Heat Generation
Measure ID	11
Measure	Micro CHP

Ref ID	Reference Title	Author	Year	G	R	C
22	Energy Efficiency And Historic Buildings – Application of Part L of the Building Regulations to historic and traditionally constructed buildings	English Heritage	2011	1	0	0
49	Micro CHP Accelerator – final report (CTC788)	Guy, R., Sykes, B.	2011	0	0	1

Measure ID	14
Measure	ASHP

Ref ID	Reference Title	Author	Year	G	R	C
22	Energy Efficiency And Historic Buildings – Application of Part L of the Building Regulations to historic and traditionally constructed buildings	English Heritage	2011	1	0	0
47	Renewable Heritage: A guide to microgeneration in traditional and historic homes	Change Works	2009	1	0	1

Measure ID	15
Measure	Biomass Boiler

Ref ID	Reference Title	Author	Year	G	R	C
57	Guide to building services for historic buildings – Sustainable services for traditional buildings	CIBSE	2002	1	0	1
45	Historic Scotland Technical Paper 16 – Green Deal Financial Modelling of a traditional cottage and tenement flat (available by end March 2012)	Historic Scotland / Changeworks	2010 DRAFT	0	1	1
47	Renewable Heritage: A guide to microgeneration in traditional and historic homes	Change Works	2009	1	0	1
22	Energy Efficiency And Historic Buildings – Application of Part L of the Building Regulations to historic and traditionally constructed buildings	English Heritage	2011	1	0	0

Measure ID	16
Measure	Biomass Room Heater (with Radiators)

Ref ID	Reference Title	Author	Year	G	R	C
57	Guide to building services for historic buildings – Sustainable services for traditional buildings	CIBSE	2002	1	0	1
22	Energy Efficiency And Historic Buildings – Application of Part L of the Building Regulations to historic and traditionally constructed buildings	English Heritage	2011	1	0	0
47	Renewable Heritage: A guide to microgeneration in traditional and historic homes	Change Works	2009	1	0	1
20	The Impact of energy efficient refurbishment on the airtightness in English dwellings	Hong,S., Ridley, I., Oreszcyn, T., Warm Front Study Group	2006	0	1	0

Measure ID	19
Measure	Ground Source Heat Pump

Ref ID	Reference Title	Author	Year	G	R	C
54	Findings from a Post Occupancy Evaluation of adaptive restoration and performance enhancement of a 19th century 'Category B' listed tenement block in Edinburgh	Tim Sharpe and Donald Shearer	2011	0	1	1
38	Performance and control of domestic ground-source heat pumps in retrofit installations	P.J. Boait, D. Fan, A. Stafford	2011	0	1	1
47	Renewable Heritage: A guide to microgeneration in traditional and historic homes	Change Works	2009	1	0	1
22	Energy Efficiency And Historic Buildings – Application of Part L of the Building Regulations to historic and traditionally constructed buildings	English Heritage	2011	1	0	0

Measure ID	20
Measure	HIgh Efficiency Gas Fired Concensing Boilers

Ref ID	Reference Title	Author	Year	G	R	C
46	Energy Heritage: A guide to improving energy efficiency in traditional and historic homes	Change Works	2008	1	0	1
57	Guide to building services for historic buildings – Sustainable services for traditional buildings	CIBSE	2002	1	0	1
43	The impact of housing energy efficiency improvements on reduced exposure to cold – the 'temperature take back factor'	Hamilton, I., Davies, M., Ridley, I., Oreszczyn, T., Barrett, M., Lowe, R., Hong, S., Wilkinson, P., Chalabi, Z.	2011	0	1	0
45	Historic Scotland Technical Paper 16 – Green Deal Financial Modelling of a traditional cottage and tenement flat (available by end March 2012)	Historic Scotland / Changeworks	2010 Draft	0	1	1
32	The impact of energy efficient refurbishment on the space heating fuel consumption in English dwellings, Energy and Buildings 38(10): 1171-1181.	Hong, S. H., T. Oreszczyn, *et al.* Gilbertson, J., Stevens, M., Stiell, B.,	2006	0	1	0
41	Home is where the hearth is: grant recipients' views of England's home energy efficiency scheme (Warm Front)	Thorogood, N.	2006	0	1	0
20	The Impact of energy efficient refurbishment on the airtightness in English dwellings	Hong,S., Ridley, I., Oreszcyn, T., Warm Front Study Group	2006	0	1	0

Measure ID	21
Measure	Oil Fired Condensing Boilers

Ref ID	Reference Title	Author	Year	G	R	C
57	Guide to building services for historic buildings – Sustainable services for traditional buildings	CIBSE	2002	1	0	1
20	The Impact of energy efficient refurbishment on the airtightness in English dwellings	Hong,S., Ridley, I., Oreszcyn, T., Warm Front Study Group	2006	0	1	0
32	The impact of energy efficient refurbishment on the space heating fuel consumption in English dwellings, Energy and Buildings 38(10): 1171-1181.	Hong, S. H., T. Oreszczyn, *et al.*	2006	0	1	0

Measure ID	22
Measure	Solar Water Heating

Ref ID	Reference Title	Author	Year	G	R	C
24	Here comes the sun: a field trial of solar water heating systems	Energy Saving Trust	2011	1	0	0
47	Renewable Heritage: A guide to microgeneration in traditional and historic homes	Change Works	2009	1	0	1
22	Energy Efficiency And Historic Buildings – Application of Part L of the Building Regulations to historic and traditionally constructed buildings	English Heritage	2011	1	0	0

Measure ID	26
Measure	Heating Controls (for wet central heating system and warm air system)

Ref ID	Reference Title	Author	Year	G	R	C
54	Findings from a Post Occupancy Evaluation of adaptive restoration and performance enhancement of a 19th century 'Category B' listed tenement block in Edinburgh	Tim Sharpe and Donald Shearer	2011	0	1	1
57	Guide to building services for historic buildings – Sustainable services for traditional buildings	CIBSE	2002	1	0	1
41	Home is where the hearth is: grant recipients' views of England's home energy efficiency scheme (Warm Front)	Gilbertson, J., Stevens, M., Stiell, B., Thorogood, N.	2006	0	1	0
46	Energy Heritage: A guide to improving energy efficiency in traditional and historic homes	Change Works	2008	1	0	1
28	FutureFit: Installation Phase in depth findings	EST/Affinity Sutton	2011	0	1	1
38	Performance and control of domestic ground-source heat pumps in retrofit installations	P.J. Boait, D. Fan, A. Stafford	2011	0	1	1

ID	8
Upgrade Subtype	Heat Storage
Measure ID	24
Measure	Cylinder Thermostats

Ref ID	Reference Title	Author	Year	G	R	C
45	Historic Scotland Technical Paper 16 – Green Deal Financial Modelling of a traditional cottage and tenement flat (available by end March 2012)	Historic Scotland / Changeworks	2010 DRAFT	0	1	1

Measure ID	26
Measure	Heating Controls (for wet central heating system and warm air system)

Ref ID	Reference Title	Author	Year	G	R	C
54	Findings from a Post Occupancy Evaluation of adaptive restoration and performance enhancement of a 19th century 'Category B' listed tenement block in Edinburgh	Tim Sharpe and Donald Shearer	2011	0	1	1
57	Guide to building services for historic buildings – Sustainable services for traditional buildings	CIBSE	2002	1	0	1
41	Home is where the hearth is: grant recipients' views of England's home energy efficiency scheme (Warm Front)	Gilbertson, J., Stevens, M., Stiell, B., Thorogood, N.	2006	0	1	0
46	Energy Heritage: A guide to improving energy efficiency in traditional and historic homes	Change Works	2008	1	0	1
28	FutureFit: Installation Phase in depth findings	EST/Affinity Sutton	2011	0	1	1
38	Performance and control of domestic ground-source heat pumps in retrofit installations	P.J. Boait, D. Fan, A. Stafford	2011	0	1	1

ID	9
Upgrade Subtype	Heat Distribution
Measure ID	16
Measure	Biomass Room Heater (with Radiators)

Ref ID	Reference Title	Author	Year	G	R	C
57	Guide to building services for historic buildings – Sustainable services for traditional buildings	CIBSE	2002	1	0	1
22	Energy Efficiency And Historic Buildings – Application of Part L of the Building Regulations to historic and traditionally constructed buildings	English Heritage	2011	1	0	0
47	Renewable Heritage: A guide to microgeneration in traditional and historic homes	Change Works	2009	1	0	1
20	The Impact of energy efficient refurbishment on the airtightness in English dwellings	Hong,S., Ridley, I., Oreszcyn, T., Warm Front Study Group	2006	0	1	0

Measure ID	26
Measure	Heating Controls (for wet central heating system and warm air system)

Ref ID	Reference Title	Author	Year	G	R	C
54	Findings from a Post Occupancy Evaluation of adaptive restoration and performance enhancement of a 19th century 'Category B' listed tenement block in Edinburgh	Tim Sharpe and Donald Shearer	2011	0	1	1
57	Guide to building services for historic buildings – Sustainable services for traditional buildings	CIBSE	2002	1	0	1
41	Home is where the hearth is: grant recipients' views of England's home energy efficiency scheme (Warm Front)	Gilbertson, J., Stevens, M., Stiell, B., Thorogood, N.	2006	0	1	0
28	FutureFit: Installation Phase in depth findings	EST/Affinity Sutton	2011	0	1	1
38	Performance and control of domestic ground-source heat pumps in retrofit installations	P.J. Boait, D. Fan, A. Stafford	2011	0	1	1

Measure ID	28
Measure	Underfloor Heating

Ref ID	Reference Title	Author	Year	G	R	C
54	Findings from a Post Occupancy Evaluation of adaptive restoration and performance enhancement of a 19th century 'Category B' listed tenement block in Edinburgh	Tim Sharpe and Donald Shearer	2011	0	1	1

ID	10
Upgrade Subtype	Lighting
Measure ID	29
Measure	Lighting Systems, Fittings and Controls

Ref ID	Reference Title	Author	Year	G	R	C
57	Guide to building services for historic buildings – Sustainable services for traditional buildings	CIBSE	2002	1	0	1
28	FutureFit: Installation Phase in depth findings	EST/Affinity Sutton	2011	0	1	1
46	Energy Heritage: A guide to improving energy efficiency in traditional and historic homes	Change Works	2008	1	0	1

ID	11
Upgrade Subtype	Ventilation
Measure ID	30
Measure	Mechanical Ventelation and Heat Recovery

Ref ID	Reference Title	Author	Year	G	R	C
54	Findings from a Post Occupancy Evaluation of adaptive restoration and performance enhancement of a 19th century 'Category B' listed tenement block in Edinburgh	Tim Sharpe and Donald Shearer	2011	0	1	1
57	Guide to building services for historic buildings – Sustainable services for traditional buildings	CIBSE	2002	1	0	1
30	Will drivers for home energy efficiency harm occupant health? Perspectives in Public Health. 130 (5) 233-238	Bone, Murray, Myers, Dengel and Crump.	2010	0	1	0
46	Energy Heritage: A guide to improving energy efficiency in traditional and historic homes	Change Works	2008	1	0	1
8	Tech Paper 6 – Indoor Air Quality and Energy Efficiency in Traditional Buildings	Sandy Halliday (Gaia Research)	2009	0	1	1
28	Future Fit: Installation Phase in depth findings	EST/Affinity Sutton	2011	0	1	1
1	Ventilation, Infiltration and Air Permeability of Traditional UK Dwellings	Hubbard, D	2011	0	1	1

3. OTHER MEASURES – Type: Fabric – relevant references

ID	4
Upgrade Subtype	Window(s)
Measure ID	31
Measure	Window Refurbishment

Ref ID	Reference Title	Author	Year	G	R	C
46	Energy Heritage: A guide to improving energy efficiency in traditional and historic homes	Change Works	2008	1	0	1
45	Historic Scotland Technical Paper 16 – Green Deal Financial Modelling of a traditional cottage and tenement flat (available by end March 2012)	Historic Scotland / Changeworks	2010 DRAFT	0	1	1
27	Research into the thermal performance of traditional windows: timber sash windows, English Heritage	Chris Wood, Bill Bordass and Paul Baker	2009	0	1	0
25	Improving Energy Efficiency in Traditional Buildings	Historic Scotland		1	0	0
23	Energy Efficiency In Historic Buildings – Secondary glazing for windows	English Heritage	2010	1	0	0
22	Energy Efficiency And Historic Buildings – Application of Part L of the Building Regulations to historic and traditionally constructed buildings	English Heritage	2011	1	0	0
21	Energy Efficiency In Historic Buildings – Draught-proofing windows and doors	English Heritage	2010	1	0	0
18	Resilience of 'Nightingale' hospital wards in a changing climate	KJ Lomas, R Giridharan, CA Short, and AJ Fair	2012	0	1	1
11	Tech Paper 9 – Slim-profile double glazing	Nicholas Heath (Changeworks), Dr.	2010	0	1	0
8	Tech Paper 6 – Indoor Air Quality and Energy Efficiency in Traditional Buildings	Paul Baker (Glasgow Caledonian University) and Dr. Gillian Menzies (Heriot-Watt University)	2009	0	1	1
6	Thermal Performance of Traditional Windows and Low-Cost Energy-Saving Retrofits	Sandy Halliday (Gaia Research) Dr. Paul Baker for Historic Scotland	2008	0	1	0
5	Thermal Performance of Traditional Windows and Low-Cost Energy-Saving Retrofits	Paul Baker, Roger Curtis, Craig Kennedy, Chris Wood	2010	0	1	0
1	Ventilation, Infiltration and Air Permeability of Traditional UK Dwellings	Hubbard, D	2011	0	1	1

Measure ID	32
Measure	Window Shutters

Ref ID	Reference Title	Author	Year	G	R	C
46	Energy Heritage: A guide to improving energy efficiency in traditional and historic homes	Change Works	2008	1	0	1
45	Historic Scotland Technical Paper 16 – Green Deal Financial Modelling of a traditional cottage and tenement flat (available by end March 2012)	Historic Scotland / Changeworks	2010 DRAFT	0	1	1
44	Ranking of interventions to reduce dwelling overheating during heat waves	S.M. Porritt, P.C. Cropper, L. Shao, C.I. Goodier	2012	0	1	0
27	Research into the thermal performance of traditional windows: timber sash windows, English Heritage	Chris Wood, Bill Bordass and Paul Baker	2009	0	1	0
25	Improving Energy Efficiency in Traditional Buildings	Historic Scotland		1	0	0
23	Energy Efficiency In Historic Buildings – Secondary glazing for windows	English Heritage	2010	1	0	0
22	Energy Efficiency And Historic Buildings – Application of Part L of the Building Regulations to historic and traditionally constructed buildings	English Heritage	2011	1	0	0
21	Energy Efficiency In Historic Buildings – Draught-proofing windows and doors	English Heritage	2010	1	0	0
8	Tech Paper 6 – Indoor Air Quality and Energy Efficiency in Traditional Buildings	Sandy Halliday (Gaia Research)	2009	0	1	1
6	Thermal Performance of Traditional Windows and Low-Cost Energy-Saving Retrofits	Dr. Paul Baker for Historic Scotland	2008	0	1	0
5	Thermal Performance of Traditional Windows and Low-Cost Energy-Saving Retrofits	Paul Baker, Roger Curtis, Craig Kennedy, Chris Wood	2010	0	1	0

Measure ID	33
Measure	Window Shading

Ref ID	Reference Title	Author	Year	G	R	C
44	Ranking of interventions to reduce dwelling overheating during heat waves	S.M. Porritt, P.C. Cropper, L. Shao, C.I. Goodier	2012	0	1	0
18	Resilience of 'Nightingale' hospital wards in a changing climate	KJ Lomas, R Giridharan, CA Short, and AJ Fair	2012	0	1	1
5	Thermal Performance of Traditional Windows and Low-Cost Energy-Saving Retrofits	Paul Baker, Roger Curtis, Craig Kennedy, Chris Wood	2010	0	1	0

ID	5
Upgrade Subtype	Door(s)
Measure ID	34
Measure	Door Refurbishment

Ref ID	Reference Title	Author	Year	G	R	C
45	Historic Scotland Technical Paper 16 – Green Deal Financial Modelling of a traditional cottage and tenement flat (available by end March 2012)	Historic Scotland / Changeworks	2010 DRAFT	0	1	1
25	Improving Energy Efficiency in Traditional Buildings	Historic Scotland		1	0	0
22	Energy Efficiency And Historic Buildings – Application of Part L of the Building Regulations to historic and traditionally constructed buildings	English Heritage	2011	1	0	0
21	Energy Efficiency In Historic Buildings – Draught-proofing windows and doors	English Heritage	2010	1	0	0
8	Tech Paper 6 – Indoor Air Quality and Energy Efficiency in Traditional Buildings	Sandy Halliday (Gaia Research)	2009	0	1	1
1	Ventilation, Infiltration and Air Permeability of Traditional UK Dwellings	Hubbard, D	2011	0	1	1

4. OTHER MEASURES – Type: Services – relevant references

ID	7
Upgrade Subtype	Heat Generation
Measure ID	35
Measure	Heat Generator Refurbishment

Ref ID	Reference Title	Author	Year	G	R	C
57	Guide to building services for historic buildings – Sustainable services for traditional buildings	CIBSE	2002	1	0	1
20	The Impact of energy efficient refurbishment on the airtightness in English dwellings	Hong,S., Ridley, I., Oreszcyn, T., Warm Front Study Group	2006	0	1	0
41	Home is where the hearth is: grant recipients' views of England's home energy efficiency scheme (Warm Front)	Gilbertson, J., Stevens, M., Stiell, B., Thorogood, N.	2006	0	1	0

ID	9
Upgrade Subtype	Heat Distribution
Measure ID	36
Measure	Heat Distribution Refurbishment

Ref ID	Reference Title	Author	Year	G	R	C
57	Guide to building services for historic buildings – Sustainable services for traditional buildings	CIBSE	2002	1	0	1
20	The Impact of energy efficient refurbishment on the airtightness in English dwellings	Hong,S., Ridley, I., Oreszcyn, T., Warm Front Study Group	2006	0	1	0

Measure ID	37
Measure	Pipe Insulation

Ref ID	Reference Title	Author	Year	G	R	C
57	Guide to building services for historic buildings – Sustainable services for traditional buildings	CIBSE	2002	1	0	1
45	Historic Scotland Technical Paper 16 – Green Deal Financial Modelling of a traditional cottage and tenement flat (available by end March 2012)	Historic Scotland / Changeworks	2010 DRAFT	0	1	1
46	Energy Heritage: A guide to improving energy efficiency in traditional and historic homes	Change Works	2008	1	0	1
24	Here comes the sun: a field trial of solar water heating systems	Energy Saving Trust	2011	1	0	0

ID	11
Upgrade Subtype	Ventilation
Measure ID	38
Measure	Natural Ventilation

Ref ID	Reference Title	Author	Year	G	R	C
44	Ranking of interventions to reduce dwelling overheating during heat waves	S.M. Porritt, P.C. Cropper, L. Shao, C.I. Goodier	2012	0	1	0
57	Guide to building services for historic buildings – Sustainable services for traditional buildings	CIBSE	2002	1	0	1
23	Energy Efficiency In Historic Buildings – Secondary glazing for windows	English Heritage	2010	1	0	0
30	Will drivers for home energy efficiency harm occupant health? Perspectives in Public Health. 130 (5) 233-238	Bone, Murray, Myers, Dengel and Crump.	2010	0	1	0
21	Energy Efficiency In Historic Buildings – Draught-proofing windows and doors	English Heritage	2010	1	0	0
22	Energy Efficiency And Historic Buildings – Application of Part L of the Building Regulations to historic and traditionally constructed buildings	English Heritage	2011	1	0	0
8	Tech Paper 6 – Indoor Air Quality and Energy Efficiency in Traditional Buildings	Sandy Halliday (Gaia Research)	2009	0	1	1
18	Resilience of 'Nightingale' hospital wards in a changing climate	KJ Lomas, R Giridharan, CA Short, and AJ Fair	2012	0	1	1
1	Ventilation, Infiltration and Air Permeability of Traditional UK Dwellings	Hubbard, D	2011	0	1	1

5. OTHER MEASURES – Type: Behaviour – relevant references

ID	12
Upgrade Subtype	People Interaction
Measure ID	40
Measure	User Education

Ref ID	Reference Title	Author	Year	G	R	C
46	Energy Heritage: A guide to improving energy efficiency in traditional and historic homes	Change Works	2008	1	0	1
44	Ranking of interventions to reduce dwelling overheating during heat waves	S.M. Porritt, P.C. Cropper, L. Shao, C.I. Goodier	2012	0	1	0
38	Performance and control of domestic ground-source heat pumps in retrofit installations	P.J. Boait, D. Fan, A. Stafford	2011	0	1	1
28	Future Fit: Installation Phase in depth findings	EST/Affinity Sutton	2011	0	1	1
24	Here comes the sun: a field trial of solar water heating systems	Energy Saving Trust	2011	1	0	0

Measure ID	41
Measure	User Interest and !nvolvement

Ref ID	Reference Title	Author	Year	G	R	C
46	Energy Heritage: A guide to improving energy efficiency in traditional and historic homes	Change Works	2008	1	0	1
42	Understanding occupants: feedback techniques for large-scale low-carbon domestic refurbishments	Gupta, Rajat, Chandiwala, Smita	2010	0	1	1
35	Carbon reduction in existing buildings: a transdisciplinary approach. Building Research Information (2010)	Lomas, K. J.	2010	0	1	0

Measure ID	42
Measure	Maintenance

Ref ID	Reference Title	Author	Year	G	R	C
22	Energy Efficiency And Historic Buildings – Application of Part L of the Building Regulations to historic and traditionally constructed buildings	English Heritage	2011	1	0	0

APPENDIX I Guidance Tool Structure Examples and Development Case Study

As described in the main text, the **Guidance Tool Structure** separates upgrade measures into categories of **fabric**, **services** and **behaviour** and from there into specific measures, both Green Deal eligible and as recommended by the STBA. These measures can then be analysed in terms of **context**, **risk/benefit** and **process** and linked to **best practice guidance**, **research** and **case studies**.

Figure 1 below presents the information in a table format in a single line. Other ways of presenting the information will be considered in the development of the guidance tool.

MEASURE TYPE (SERVICE/FABRIC/BEHAVIOUR)														
							ASSOCIATED MEASURES REQUIRED							
Upgrade	GD Eligible	Context dependence (H/M/L)	Energy benefit or risk	Technical benefit or risk	Heritage benefit or risk	Right opportunity?	BEFORE Pre-implementation checks	DURING Quality contol	AFTER Maintenance requirement	Monitoring/ feedback	User issues	Guidance	Research	Case studies
MEASURE SUBTYPE (EG WALL, ROOF, HEAT GENERATION, PEOPLE INTERACTION)														
Upgrade type														

Examples for selected upgrade measures

To illustrate the use of the structure of upgrade measure analysis we have taken three examples, the first two relate to insulation measures: **external wall insulation (Figure 2)** and **internal wall insulation (Figure 3)**, whilst the third looks at an upgrade to the **heating system** – the installation of an energy-efficient boiler **(Figure 4)**.

FABRIC														
							ASSOCIATED MEASURES REQUIRED							
Upgrade	GD Eligible	Context dependence (H/M/L)	Energy benefit or risk	Technical benefit or risk	Heritage benefit or risk	Right opportunity?	BEFORE Pre-implementation checks	DURING Quality contol	AFTER Maintenance requirement	Monitoring/ feedback	User issues	Guidance	Research	Case studies
WALL(S)														
External wall insulation	Yes	Eg: H – High Suitability of measure depends on: -Fabric quality and make up -Exposure -Heritage value	Likely reduction of heat loss but less reduction than expected? Check U-value	Risk of trapped moisture? Check fabric quality	Damages character? Unlikely measure if listed building	Easier to implement as a whole block/terrace measure	Check U-value of original fabric and compare with modelled values. See research ID 14 and 15	Careful detailing to keep character and minimise thermal bridges	Check integrity of drains and gutters and that external wall is kept dry, in good condition. Ensure ground levels are kept low	Check U-value of insulated fabric	Comfort 'take back' effect means less energy saved?	[See docs list] 2 No Tier 1 Guidance refs	See docs list] 12 No Tier 1 Research refs	[See docs list] 6 No Tier 1 Case Study refs
						In conjunction with fabric measures	Check hygrothermal properties of wall and exposure. Thickness of insulation and risk? See guidance and research ID 39	Carry out condensation/ moisture risk for proposed solution and detail [Various research] Check installation needs and carry our as per detail – see research ID 50	Moisture monitoring at risk locations at thermal bridges	Feed back any moisture/ mould problems	Sufficient dwelling ventilation when draughtiness improved? Research ID 1, 15			
							Check external detailing – survey to identify what needs moving (pipes, etc), existing thermal bridges (research ID53)	Installation of quality checks – thermal imaging?						

Figure 2 Guidance Tool Structure – External wall insulation

In these first examples we have not defined any specific context and we encounter some difficulty in finding a clearly green – low risk – measure. The importance of defining the context in some detail becomes apparent.

With external wall insulation, if the building is listed and the fabric is not rendered this measure is unlikely to be suitable as the heritage risk is high. However, if the building was originally rendered and the state of repair is poor, enhancing the heritage character may be possible as well as improving the fabric performance.

The desired performance in terms of U-value still needs to be decided, as well as consideration given to moisture risks and the hygrothermal properties of the fabric to arrive at a suitable solution. In deciding the appropriateness of the solution, buildability and intricacy of the detailing necessary may be a determining factor.

FABRIC														
							ASSOCIATED MEASURES REQUIRED							
Upgrade	GD Eligible	Context dependence (H/M/L)	Energy benefit or risk	Technical benefit or risk	Heritage benefit or risk	Right opportunity?	BEFORE Pre-implementation checks	DURING Quality contol	AFTER Maintenance requirement	Monitoring/ feedback	User issues	Guidance	Research	Case studies
WALL(S)														
Internal wall insulation	Yes	H – High Fabric quality and make up, state of repair. Exposure. Heritage value	Likely reduction of heat loss but less reduction than expected? Check U-value	Risk of trapped moisture? Check fabric quality	Uncertain – check internal character	When decorating room with external wall	Check U-value of original fabric and compare with modelled values. See research ID 14 and 15	Careful detailing to keep character and minimise thermal bridges	Check integrity of drains and gutters and that external wall is kept dry, in good condition. Ensure ground levels are kept low	Check U-value of insulated fabric	Floor space reduction. See Case Study ID 28. Restric-tions on use (restricted picture hanging?)	[See docs list] 3 No Tier 1 Guidance refs	See docs list] 14 No Tier 1 Research refs	[See docs list] 6 No Tier 1 Case Study refs
						At change of tenancy or ownership When carrying out repairs	Check hygrothermal properties of wall and exposure. Thickness of insulation and risk? See guidance and research ID 39	Carry out condensation/ moisture risk for proposed solution and detail [various research]. Check installation needs and carry our as per detail – see research ID 50	Keep an eye on mould/surface condensation or damp	Feed back any moisture/ mould problems. Moisture monitoring at risk locations (eg joist ends, thermal bridges)	Restrictions on furniture location? See research ID50 – increased mould growth risk. Restriction on finishes – breathability retained where appropriate			
							Investigate internal fabric – check there are no hidden heritage features – see guidance	Installation of quality checks – continuity of insulation – thermal imaging?	Maintain air barriers on insulated wall surfaces – don't make holes!		Sufficient dwelling ventilation when draughtiness improved? Research ID 1, 15			

Figure 3 Guidance Tool Structure – Internal wall insulation

With internal wall insulation, heritage risk is crucial if there are internal features of character. A survey looking at the building fabric would need to determine its quality to note any features of character and estate of repair of the fabric. If the fabric is damp this measure would not be appropriate. The location context is also crucial for this measure as the exposure to driving rain would increase the risk of moisture being trapped between the fabric and the new insulation. As before, the desired performance in terms of U-value still needs to be decided and consideration given to the hygrothermal properties of the fabric and insulation proposed before arriving at a suitable solution.

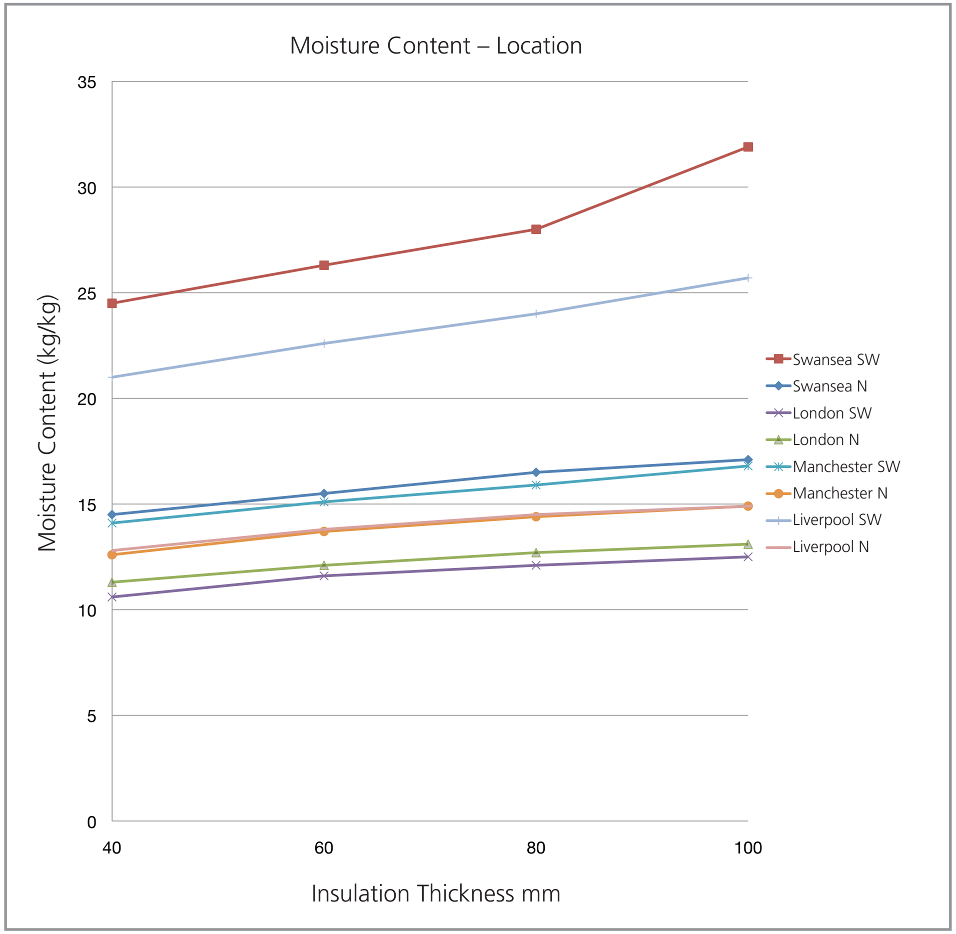
Later on in this report, we explore further the variations of context in more detail for this upgrade measure.

SERVICES														
							ASSOCIATED MEASURES REQUIRED							
Upgrade	GD Eligible	Context dependence (H/M/L)	Energy benefit or risk	Technical benefit or risk	Heritage benefit or risk	Right opportunity?	BEFORE Pre-implementation checks	DURING Quality contol	AFTER Maintenance requirement	Monitoring/ feedback	User issues	Guidance	Research	Case studies
HEAT GENERATION 1														
High efficiency gas-fired condensing boilers	Yes	M – Medium gas availability. Suitable route for flue. User energy comsumption profile (h/m/l)	Likely improved efficiency. Less CO_2? See research ID32	Increase air permeabiliy? Moisture condensing plume may dampen fabric?	Same as before if same heating mode	On appliance breakdown	Check potential routes for pipework and flue don't clash with original features. Also aesthetics of radiators if new	Quality control in positioning boiler flue and routing pipework	Yearly service	Energy savings realised? Comfort 'take back'		[See docs list] 1 No Tier 1 Guidance refs	See docs list] 5 No Tier 1 Research refs	[See docs list] 2 No Tier 1 Case Study refs
						In conjunction with fabric measures	Are there suitable insulation measures to combine with boiler change? See Guidance ID46	Careful installaton to avoid increasing fabric permeability – see research ID20						
							Check usability of controls – see under guidance/ research ID56	Choice of controls – user involvement?		Usability of controls? User difficulites?	Need advice on controls and operation	BSRIA publication: *Controls for end users: a guide for good design and imple- mentation*		

Figure 4 Guidance Tool Structure – High Efficiency Gas Condensing Boiler

When upgrading to a high-efficiency gas condensing boiler there needs to be gas available and a suitable route for the pipe runs has to be found within the building without damaging its character (we have assumed in this case that gas was the original fuel). The main unknown in this upgrade is energy use before (users' energy consumptions varies by a factor of three) and after (when occupants may take up the increase efficiency in attaining a more comfortable environment). Research on the Warm Front initiative showed that installing gas efficient boilers had no significant impact on reduced fuel consumption, even after taking into account comfort 'take back' (Hong et al 2006). Care is also needed not to increase air permeability of the fabric when installing new flues.

This measure has a strong link with the installation of controls, which need to be thought out in terms of usability and user education as they need to be engaged on the efficient operation of the boiler and controls.



To understand context variations resulting from location and exposure when considering internal wall insulation we have looked at both regional and orientation variations of the moisture content encountered at the interface between insulation and the wall substrate (the risk area) in areas of different exposure for an internal wall insulation proposal. The following diagrams illustrate how significant both location and orientation are in assessing risk of IWI installation onto a solid-wall building with a capillary-open external surface (such as brick or stone). The modelling used is the WUFI dynamic numerical modelling, as discussed and recommended in the main body of the STBA report. Furthermore a safety factor has been applied to allow for less than perfect construction and building maintenance over the life of the building. **It should be noted that due to the uncertainties in material and weather data as well as in modelling, these diagrams should be taken as indications only of the potential moisture risks. Furthermore they only deal with one kind of insulation according to its particular material properties.**

Figure 5 Moisture Content for different insulation thicknesses at insulation fabric interface for different locations – source NBT[37]

[37]The tests were done by NBT for their Pavadentro product. The moisture content analysis is carried out by means of a 1D transient hygrothermal simulation (with WUFI® pro 5.1 software) for a wall section composed by 215mm solid brick,20mm levelling coat, 5mm bonding plaster, 40 to 100mm Pavadentro woodfibre board for internal insulation, 8mm lime plaster. A moisture source of 1% of the driving rain load is inserted in the wall section, according to ASHRAE standard 160-2009; the selected depth for the water penetration is corresponding to the window position (100mm to the external surface), as the Standard Project Committee for ASHRAE 160 realised that "occasional intrusion of a small amount of water, especially around doors and windows, is probably inevitable". (Ten Wolde, 2008, p.168)

The selection of 1% wind-driven rain is explained by Künzel and Zirkelbach (2008, p.2): "The selected leakage rate in this standard is not meant to be a worst case scenario. It is not based on field test results but on hygrothermal simulations that showed that more than 1% of rainwater penetration may be detrimental for a large portion of existing wall structures".

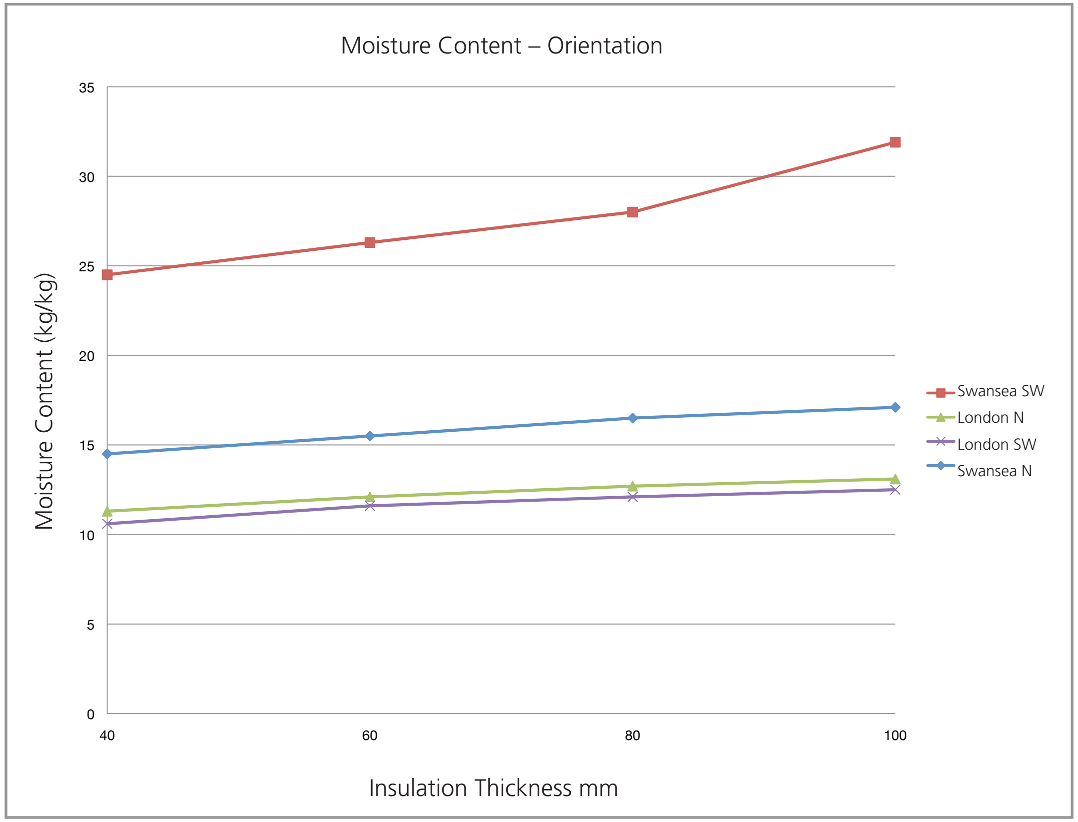


Figure 6 Moisture Content at insulation fabric interface for different orientations – Swansea and London

Figure 5 and **Figure 6** show that the risk of going above the maximum desired moisture content (roughly about 20% moisture content by weight) is apparent in Swansea or Liverpool but not so in London. Orientation of the wall in question is important in Swansea (apparent in the SW wall but not in the N) but not so critical in London (both orientations below critical value). The risk of moisture at the interface increases as the insulation gets thicker. The consequences of exceeding 20% moisture content are moulds, fabric decay, structural failure (particularly where timber such as joist ends is present) and human health risks. **Again, due to uncertainties these diagrams should only be taken as indicative.**

See **Figure 7** to **Figure 9** to see how the Guidance Tool for internal insulation would vary for the different locations and orientation.

References

ASHRAE (2009). ASHRAE 160-2009 Criteria for Moisture Control Design Analysis in Buildings, American Society for Heating Refrigerating and Air-conditioning Engineers Inc.: Atlanta, GA

Ten Wolde, Anton (2008). ASHRAE Standard 160P – criteria for moisture control design analysis in buildings, ASHRAE transactions vol. 114, pt. 1(2008): pages 167-171
Künzel, H. M., Zirkelbach, D. (2008). Influence of rain water leakage on the hygrothermal performance of exterior insulation systems, 8th Nordic Symposium on Building Physics in the Nordic Countries 2008. Proceedings. Vol.1: Copenhagen, June 16-18, 2008, pp. 253-260

From the previous evidence, the proposal of adding internal solid wall insulation in a solid wall capillary-open brick or stone building in Swansea would be considered high risk in terms of trapped moisture for SW orientations and would not be recommended.

FABRIC														
							ASSOCIATED MEASURES REQUIRED							
Upgrade	GD Eligible	Context dependence (H/M/L)	Energy benefit or risk	Technical benefit or risk	Heritage benefit or risk	Right opportunity?	BEFORE pre-implementation checks	DURING Quality contol	AFTER Maintenance requirement	Monitoring/ feedback	User issues	Guidance	Research	Case studies
WALL(S)														
Internal wall insulation	Yes	H – High Fabric quality good Make-up solid wall, brick State of repair normal Exposure: **high risk, Swansea SW wall** Heritage value Conserva-tion area but no internal features	Likely reduction of heat loss but less reduction than expected? Check U-value	Risk of trapped moisture: **high** Check fabric quality	Acceptable – possible to make reversable?	When decorating room with external wall	Check U-value of original fabric and compare with modelled values. See research ID 14 and 15	Careful detailing to keep character and minimise thermal bridges	Check integrity of drains and gutters and that external wall is kept dry, in good condition. Ensure ground levels are kept low	Check U-value of insulated fabric	Floor space reduction. See Case Study ID 28. Restrictions on use (restricted picture hanging?)	[See docs list] 3 No Tier 1 Guidance refs	See docs list] 14 No Tier 1 Research refs	[See docs list] 6 No Tier 1 Case Study refs
						At change of tenancy or ownership	Hygrothermal properties of wall and exposure: **high risk – Swansea SW wall** Thickness of insulation: **High, even at low insulation thickness. See guidance and research ID 39 and attached slides. Carry out condensation/ moisture risk for proposed solution and detail to Standard EN15026**	**Check wall fabric against hydrothermic models. If different, re-model with correct data. Check suitability of insulation system. Understand installation detail**	Keep an eye on mould/surface condensation or damp	Feed back any moisture/ mould problems. Moisture monitoring at risk locations (eg joist ends, thermal bridges)	Restrictions on furniture location? See research ID50 – increased mould growth risk. Restriction on finishes – breathability retained where appropriate			
						When carrying out repairs	Investigate internal fabric – check there are no hidden heritage features – see guidance	Check quality of installation: check continuity of insulation, e.g. thermal imaging	Maintain air barriers on wall surfaces – don't make holes!		Sufficient dwelling ventilation when draughtiness improved? Research ID 1, 15			

Figure 7 Guidance Tool Structure – **Internal wall insulation** Location **Swansea** Orientation **SW**

From the previous evidence, the proposal of adding internal solid wall insulation in a solid-wall capillary open-brick or stone building in Swansea would be considered medium risk in terms of trapped moisture for N wall orientations, and it would be advisable to proceed with great care, looking at the appropriate thickness of insulation in detail, checking the installation follows good practice and that there is no leaks into the fabric from drains or gutters. Even then it would be recommended to keep a watching eye for the appearance of surface condensation, damp or mould in the wall.

FABRIC							ASSOCIATED MEASURES REQUIRED							
Upgrade	GD Eligible	Context dependence (H/M/L)	Energy benefit or risk	Technical benefit or risk	Heritage benefit or risk	Right opportunity?	BEFORE Pre-implementation checks	DURING Quality contol	AFTER Maintenance requirement	Monitoring/ feedback	User issues	Guidance	Research	Case studies
WALL(S)														
Internal wall insulation	Yes	H – High Fabric quality good Make-up solid wall, brick State of repair normal Exposure: **high risk, Swansea N wall** Heritage value Conserva-tion area but no internal features	Likely reduction of heat loss but less reduction than expected? Check U-value	Risk of trapped moisture: **high risk,** check fabric quality	Acceptable – possible to make reversible?	When decorating room with external wall	Check U-value of original fabric and compare with modelled values. See research ID 14 and 15	Careful detailing to keep character and minimise thermal bridges	Check integrity of drains and gutters and that external wall is kept dry, in good condition. Ensure ground levels are kept low	Check U-value of insulated fabric	Floor space reduction. See Case Study ID 28. Restrictions on use (restircted picture hanging?)	[See docs list] 3 No Tier 1 Guidance refs	See docs list] 14 No Tier 1 Research refs	[See docs list] 6 No Tier 1 Case Study refs
						At change of tenancy or ownership	Hygrothermal properties of wall and exposure: **medium risk, Swansea N wall** Thickness of insulation: **medium risk, keep insulation below 60mm? See guidance and research ID 39 and attached slides. Carry out condensation/ moisture risk for proposed solution and detail to Standard EN15026**	**Check wall fabric against hydrothermic models. If different, re-model with correct data. Check suitability of insulation system. Understand installation detail**	Keep an eye on mould/surface condensation or damp	Feed back any moisture/ mould problems. Moisture monitoring at risk locations (eg joist ends, thermal bridges)	Restrictions on furniture location? See research ID50 – increased mould growth risk. Restriction on finishes – breathability retained where appropriate			
						When carrying out repairs	Investigate internal fabric – check there are no hidden heritage features – see guidance	Check quality of installation: check continuity of insulation, e.g. thermal imaging	Maintain air barriers on wall surfaces – don't make holes!		Sufficient dwelling ventilation when draughtiness improved? Research ID 1, 15			

Figure 8 Guidance Tool Structure – **Internal wall insulation** Location **Swansea** Orientation **N**

From the previous evidence, the proposal of adding internal solid wall insulation in a solid-wall capillary open-brick or stone building in London would be considered Medium risk in terms of trapped moisture but the evidence would allow proceeding with caution but with some confidence that the risk is manageable.

The appropriate thickness of insulation needs to be decided. We would still need to check the installation follows good practice and that there are no leaks into the fabric from drains or gutters. We should also keep a watching eye on mould growth and surface condensation or damp.

FABRIC														
							ASSOCIATED MEASURES REQUIRED							
Upgrade	GD Eligible	Context dependence (H/M/L)	Energy benefit or risk	Technical benefit or risk	Heritage benefit or risk	Right opportunity?	BEFORE pre-implementation checks	DURING Quality contol	AFTER Maintenance requirement	Monitoring/ feedback	User issues	Guidance	Research	Case studies
WALL(S)														
Internal wall insulation	Yes	H – High Fabric quality: good Make-up: solid wall brick State of repair: normal Exposure: **low risk, London** Heritage value: Conserva-tion area but no internal features	Likely reduction of heat loss but less reduction than expected? Check U-value	Risk of trapped moisture: **medium risk** Check fabric quality	Acceptable – possible to make reversible?	When decorating room with external wall	Check U-value of original fabric and compare with modelled values. See research ID 14 and 15	Careful detailing to keep character and minimise thermal bridges	Check integrity of drains and gutters and that external wall is kept dry, in good condition. Ensure ground levels are kept low	Check U-value of insulated fabric	Floor space reduction. See Case Study ID 28. Restrictions on use (picture hanging?)	[See docs list] 3 No Tier 1 Guidance refs	[See docs list] 14 No Tier 1 Research refs	[See docs list] 6 No Tier 1 Case Study refs
						At change of tenancy or ownership	Hygrothermal properties of wall and exposure: **low risk – London** Thickness of insulation: **low risk, insulation thicknesses up to 100mm. See guidance and research ID 39 and attached slides. Check condensation/ moisture risk to Standard EN15026**	**Check wall fabric against hydrothermic models. If different, re-model with correct data. Check suitability of insulation system. Understand installation detail**	Keep an eye on mould/surface condensation or damp	Feed back any moisture/ mould problems. Moisture monitoring at risk locations (eg joist ends, thermal bridges)	Restrictions on furniture location? See research ID50 – increased mould growth risk. Restriction on finishes – breathability retained where appropriate			
						When carrying out repairs	Investigate internal fabric – check there are no hidden heritage features – see guidance	Check quality of installation: check continuity of insulation, e.g. thermal imaging	Maintain air barriers on wall surfaces – don't make holes!		Sufficient dwelling ventilation when draughtiness improved? Research ID 1, 15			

Figure 9 Guidance Tool Structure – **Internal wall insulation** Location **London**

Even though location and orientation might make the risk of trapped moisture when installing internal insulation manageable, other context variables also need to be considered, such as having intricate internal features of value for heritage. Losing the building's original features, whether listed or in a conservation area, or simply if it adds character, may swing the judgement on the suitability of the measure. Above we have assumed a listed building with intricate internal features which would make internal insulation not an acceptable measure.

FABRIC														
							ASSOCIATED MEASURES REQUIRED							
Upgrade	GD Eligible	Context dependence (H/M/L)	Energy benefit or risk	Technical benefit or risk	Heritage benefit or risk	Right opportunity?	BEFORE pre-implementation checks	DURING Quality contol	AFTER Maintenance requirement	Monitoring/ feedback	User issues	Guidance	Research	Case studies
WALL(S)														
Internal wall insulation	Yes	H – High Fabric quality good Make-up solid wall, brick State of repair: normal Exposure: **low risk, London** Heritage value **Listed. Good internal features**	Likely reduction of heat loss but less reduction than expected? Check U-value	Risk of trapped moisture: **medium risk,** check fabric quality	**Not acceptable. Intricate internal features would be lost**	When decorating room with external wall	Check U-value of original fabric and compare with modelled values. See research ID 14 and 15	Careful detailing to keep character and minimise thermal bridges	Check integrity of drains and gutters and that external wall is kept dry, in good condition. Ensure ground levels are kept low	Check U-value of insulated fabric	Floor space reduction. See Case Study ID 28. Restrictions on use (restricted picture hanging?)	[See docs list] 3 No Tier 1 Guidance refs	[See docs list] 14 No Tier 1 Research refs	[See docs list] 6 No Tier 1 Case Study refs
						At change of tenancy or ownership	Hygrothermal properties of wall and exposure **Low – London** Thickness of insulation and risk **Low, insulation thicknesses up tp 100mm. See guidance and research ID 39 and attached slides. Check condensation/ moisture risk to Standard EN15026**	**Check wall fabric against hydrothermic models. If different, re-model with correct data. Check suitability of insulation system. Understand installation detail**	Keep an eye on mould/surface condensation or damp	Feed back any moisture/ mould problems. Moisture monitoring at risk locations (eg joist ends, thermal bridges)	Restrictions on furniture location? See research ID50 – increased mould growth risk. Restriction on finishes – breathability retained where appropriate			
						When carrying out repairs	Investigate internal fabric – check there are no hidden heritage features – see guidance, **Internal features valuable and in good state of repair**	Check quality of installation: check continuity of insulation, e.g. thermal imaging	Maintain air barriers on wall surfaces – don't make holes!		Sufficient dwelling ventilation when draughtiness improved? Research ID 1, 15			

Figure 10 Guidance Tool Structure – **Internal wall insulation** Location **London** Heritage Value **Listed**