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Performance and Energy Efficiency of Traditional Buildings: Gap Analysis Update 2020

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Performance and Energy Efficiency of Traditional Buildings: Gap Analysis Update 2020

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STBA
SUSTAINABLE TRADITIONAL BUILDINGS ALLIANCE

The Sustainable Traditional Buildings Alliance is a collaboration of organisations that acts as a forum for sustaining and improving traditional buildings. It is an independent programme of the Sustainable Development Foundation and is governed by a board representing heritage, industry and sustainability.

The STBA develops policy, research, guidance and training to minimise risks and maximise benefits to traditional buildings and their owners.

Membership of the alliance comprises patrons, affiliates, members and supporting organisations.

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BACKGROUND TO THE RESEARCH

STBA was launched in 2012 to act as a forum for organisations interested in trying to better understand the performance of traditional buildings as well as improving the coordination of research, policy, training, practice and guidance. As a starting point, English Heritage and CITB Construction Skills funded and commissioned a 'gap analysis' study in partnership with STBA. The report, *Performance and Energy Efficiency of Traditional Buildings: Gap Analysis Study* (2012)[1], attempted to identify the current state of knowledge by means of a literature review supported by a qualitative analysis. This focused on examining and synthesising existing relevant research and information on the thermal performance and energy efficiency of traditional buildings. The study also acted as a reference source and a means to stimulate debate and further investigation. The report helped to shape thinking on areas requiring new or further research and inform relevant related activities including training and skills development as well as promoting best practice.

In 2012, STBA was also commissioned by the Department of Energy and Climate Change (DECC) to do a similar more in depth exercise. This commission arose from concerns raised with the application of certain potential Green Deal retrofit measures to traditional buildings including possible failures of financial and energy payback, fabric and human health issues, the possible damage to heritage as well as missed opportunities for the improvement of traditional building performance. This report, *Responsible Retrofit for Traditional Buildings*[2], focused on identifying significant gaps in research as well as guidance. It also looked at how the best research information and practice might be conveyed, in particular to areas of policy and practice.

This new study commissioned by Historic England takes stock of the considerable research that has taken place since 2012, building on those two formative studies previously mentioned. Like the previous reports this study focuses on a literature review but does not include a qualitative analysis. It uses an expanded report classification based on the areas examined in *Responsible Retrofit for Traditional Buildings*. Thirteen subject areas are explored and a synopsis is provided for each area that defines its strategic importance and analyses the existing research that underpins current knowledge. Further research is explored by means of an overview of 15 current academic research programmes.

It is envisaged that a more detailed second stage study will follow with a more formal evaluation of the literature review with a view to clearly highlighting future research needs including Historic England's own energy efficiency and retrofit research:
https://historicengland.org.uk/research/current/conservation-research/energy-efficiency/

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[1] See http://www.sdfoundation.org.uk/downloads/STBA-Gap-Analysis-Study-Performance-and-Energy-Efficiency-of-Traditional-Buildings-Final-Version-(2).pdf
[2] See http://www.sdfoundation.org.uk/downloads/RESPONSIBLE-RETROFIT_FINAL_20_SEPT_2012.pdf

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1) INTRODUCTION

In 2012 the STBA produced a report entitled *Performance and Energy Efficiency of Traditional Buildings - Gap Analysis Study*. The report was sponsored by CITB and English Heritage. At that stage there was very limited published evidence on traditional buildings. The original study identified huge gaps in understanding and in data regarding how buildings perform, and how they behave when changed.

A considerable amount of research has been undertaken since this date but this has been fragmentary and largely time-limited.[3] While there have been significant advances including, not least, research undertaken by Historic England, Historic Environment Scotland and the Society for the Protection of Ancient Buildings, the work of the STBA and the establishment of the UK Centre for Moisture in Buildings, very substantial gaps remain and there has been no other strategic attempt to identify or address the remaining gaps through research.

UK Government commitments to climate change targets have focused research on strategies to achieve CO_2 emissions (in use) reductions. This has often led to unintended consequences[4] and ignored environmental or social goals for the built environment, including consideration of health and heritage. As a response to the risks of poor retrofit, the "Whole Building" approach to retrofit has been developed, and this of itself raises other research issues.

The aim of this study is to identify areas where new research is still required. It is envisaged that this will result in a more detailed study with more formal evaluation of the reports underlying this study - their abstracts are provided in Appendix 2[5].

The classifications used in the gap analysis within the Responsible Retrofit Report (STBA 2012) have been used but in a revised form. No classifications were used in the original 2012 Gap Analysis.

- Ventilation
- Thermal comfort
- Character and significance
- Moisture performance
- Energy and thermal performance
  - Energy performance data
  - Building fabric elements (walls, floors, roof, windows)
  - Thermal bridging
  - Airtightness
  - Heating approach
  - Heating and fuel sources
  - Cooling and overheating

[3] This highlights the fact that there is a structural / systemic issue with how research is identified and commissioned which may need to be addressed separately.
[4] 100 unintended consequences of policies to improve the energy efficiency of the UK housing stock (UCL, 2014).
[5] As this is only a scoping study we have not subjected any new material to formal peer review (as was done in the 2012 Gap Analysis) so we have not commented on the quality of the underlying research.

- Lighting
- Occupant interaction

We have also added several new classifications:

- Health
- Embodied carbon
- Public understanding
- Repair, maintenance and enabling works
- Professional understanding
- Costs of retrofit measures
- Material properties and technical specifications

The reasons for inclusion of these additional categories are set out below.

Health: There has been a desire by policy makers to see if there is a direct link between retrofit and health. This has been partly driven by the hope that additional funding might flow from Government to help support the retrofit agenda. In this study we have tried to identify those research projects where some evidence has been shown to prove a link. There are several areas where health might be affected by retrofit works. The most notable being an increase in internal warmth leading to fewer cold related illnesses. However, retrofit works might also have a positive or negative impact on a variety of other health issues, for example respiratory illnesses like asthma linked to indoor air quality.

Embodied carbon: Any retrofit project requires energy to enact and the role of embodied carbon both within the existing building and the materials used for any works will play a proportionally greater role as 'in-use' carbon reduces. Embodied carbon can also be an important factor in decision making when it comes to choices between demolition and re-build compared to retention and retrofit.

Public understanding: A key factor with regards to the uptake of retrofit is the willingness of the public to spend their money on measures / improvements. It was deemed important that there should be some attention given to any research that can lead to the general public being encouraged to act in regard to the improvement of their homes.

Repair, maintenance and enabling work: Heritage bodies have focused much attention on the need for a building to be in good condition in order to fulfil its potential and for a basis of any retrofit works. The need for this is longstanding but poorly understood in many tenure sectors. Research into the beneficial effects of regular maintenance and repair has not appeared before so this is an area that needs to be explored and an evidential base created.

Professional understanding: As with public understanding, there has historically been a deficit in skills associated with the heritage sector. With the drive towards deeper retrofit growing as the low hanging fruit disappears, there is a need to see how well the professionals understand the complexities associated with the retrofit of traditional buildings.

Costs of retrofit measures: As more work has been carried out across the country there is a clearer picture emerging of the costs associated with retrofit. However, there is also an explicit drive to reduce the costs associated with deep retrofit. It is important therefore to look at the type of realistic/actual costs that have been associated with retrofit to date.

Material properties and technical specifications: Traditional buildings require compatible materials in order to preserve moisture open structures and this means that there is a real need to prove the effectiveness of these materials and any emerging ones. It is also imperative that any unintended consequences associated with material choices are highlighted and the lessons learned. Materials and their associated specifications need to be tested both in the laboratory and in the real world and so case studies as well as research papers can be useful in identifying appropriate solutions for a wider large scale roll out of retrofit on traditional stock.

2) METHODOLOGY

An independent researcher was commissioned and guided by STBA to produce a long list of reports which were potentially relevant to the gap analysis, and to compile the reports into a library. The following sources of data were examined:

- Historic England
- Historic Environment Scotland
- Society for the Protection of Ancient Buildings
- UK Government Departments
- Wales Government Decarbonisation Library
- Universities[6]
- Built environment research bodies[7]
- British Standards
- Technical building journals

More than 500 published reports were identified as being potentially relevant to this study. STBA then filtered this library to produce a list of 240 reports which are considered relevant to this gap analysis, discarding purely policy documents and focusing on those based on original research or providing good quality guidance.

Reports were then classified according to the subjects set out in Section 1 above. Our Gap Analysis Codes are presented in Appendix 1. These classifications were then grouped so that all reports with a particular classification could be considered at the same time.

Titles, dates, authors, abstracts and URLs are presented in Appendix 2. Only reports which are publicly available free of charge were considered in detail but further reports and articles which appear highly relevant but are behind paywalls have been included in case the scope of the study is to be extended.

[6] UCL, Cardiff, Bath and Cambridge Universities were searched using keywords: energy, housing, retrofit, moisture and a much wider group was reviewed.
[7] For example, BRE, UKCMB.

3) GAP ANALYSIS

The need for this analysis is driven by the interest in sustainable retrofit. A 'whole building' approach to retrofit considers health and heritage as well as energy, and this is the perspective set out in the *Each Home Counts* report (2016) and the ensuing BSI publication PAS 2035 - *Standard for domestic retrofit* (2019). It is expected that the document PAS 2038 for non-domestic buildings (due 2021) will take a similar approach. The resulting aim of retrofit is that every building should be as good as it can be in terms of health, energy, and heritage.

The central question to be asked is do we have sufficient information to make judgments about a suite of potential retrofit measures? This is especially important at this time as the retrofit industry will need to start to change to a holistic approach that it is not naturally set up to achieve. In each specific subject, it has been found necessary to define the issues to be addressed, before analysing the extent of the research currently available and identifying the gaps which remain.

Some of the gaps identified by the 2012 Gap Analysis have been filled by policy and guidance. Councils and voluntary organisations have published wide ranging documents that embrace a whole house approach. These include excellent resources from Grosvenor Estates 2013, City of Westminster (Soho) 2013, Bristol City Council 2015, Cornwall County Council 2016, SEDA 2018, and National Standards for Ireland 2019, and some are relevant to the analysis which follows. These resources need to be expanded to ensure availability of such advice, tailored to local building traditions and conditions across the UK as a whole.

3.1 Human health

The issue:

Understanding the impact on health that changes to buildings can have, particularly those due to retrofit, is important. This covers both mental and physical health, and can include the impact of materials, daylight, internal floor space and ceiling heights, year round indoor temperatures, indoor air quality (see also 3.2 and 3.5), and the retention of heritage features which can enhance the quality of life.

Many of these questions do not have easily measurable metrics, so qualitative research may be required.

Summary of the existing research:

Retrofit has positive and negative effects on human health. The impact of improved thermal performance on winter morbidity has been demonstrated,

and research shows that reductions in fuel poverty lead to reductions in the incidence of specific ailments.

The seminal study *100 unintended consequences of policies to improve the energy efficiency of the UK Housing Stock* (UCL 2014), though limited to domestic buildings, references numerous studies on health including the impact of retrofit on specific aspects of indoor air quality.

There is much research indicating that damp and mould can occur as a result of retrofit and some of this does examine the effects of solid wall insulation (SWI), which is by definition mostly related to traditional buildings.

There is research on the impact of daylight reductions from double glazing on vitamin D levels, but little else on the impact of daylight reduction or other links to mental health.

Some of the more recent research was conducted outside the UK, and has a limited focus on specific age groups. Studies on co-benefits of energy efficiency programmes (*Capturing the multiple benefits of energy efficiency,* IEA 2014) tend to mention health benefits but ignore health risks. There is good evidence in Arbed Phase 2 of the community benefits of retrofit, but this was not focused on traditional buildings.

Much of the research does not clearly differentiate between construction types, so there is a lack of any recent balanced UK based research on the impact of retrofit on the mental and physical health of occupants of traditionally-constructed buildings, especially non-domestic buildings.

3.2 Ventilation

The issue:

Buildings and their occupants require a certain amount of fresh air to preserve human health and the health of the building fabric by removing moisture and pollutants whilst introducing fresh air.

Part F of the Building Regulations gives a minimum standard for air changes per hour (ACH) or extraction rates from specific rooms but does not include air quality. However, ventilation is a complex topic where laboratory testing and theoretical levels of ventilation may not be perfectly achievable in reality.

Too much un-controlled ventilation is detrimental to both energy efficiency and thermal comfort, whilst too little can encourage mould, damp and overheating. Finding the balance and having examples and associated practical research can help to illustrate best practice in a range of situations. This is important both for the individual aspects of a building's structure (floor, walls) but also across the various micro-climates across the UK.

Retrofit measures to building fabric almost inevitably will reduce natural air leakage and this can compromise ventilation, unless appropriate systems are

introduced. Therefore, it is important to know which ventilation system works best for a particular type of building or situation, particularly with regard to issues around indoor air quality (IAQ) and mould/damp in retrofitted buildings to guide appropriate solutions. Knowing ventilation strategies and assessing their effectiveness both pre and post retrofit is important for this key area.

Summary of the existing research:

Despite the increased understanding of the risks of poor ventilation to human health, the majority of the research to date is not based around retrofit, but around the failure of buildings to meet regulations, and the failure of even theoretically compliant buildings to deliver the required IAQ. This was highlighted in the MHCLG research around Part L1A in 2019.

There is also good research on occupier influence on air quality in dwellings. More broadly, much of the research is based on modelling rather than measured data. The current STBA Melin Homes Project and the SMETER project collect actual data on IAQ (temperature, CO2 and relative humidity) from homes in South Wales. However, the timing of the monitoring means that there is a lack data prior to retrofit.

IAQ also needs to consider common gaseous pollutants which are found to affect human health. These include carbon monoxide, nitrogen oxide, nitrogen dioxide, sulphur dioxide, naturally occurring radon and VOCs such as formaldehyde.

Research does indicate problems with MVHR systems and that such systems cannot be relied upon to address potential deficiencies in the supply of fresh air following retrofit.

A significant research programme will be required to assess the effects of retrofit on air quality in traditional buildings. This will require pre and post retrofit monitoring, both with and without additional ventilation installed. The research will need to be at scale as there are considerable variables in terms of fabric condition, air leakage, patterns of occupancy/use and packages of retrofit measures.

3.3 Thermal comfort

The issue:

Buildings may be heated well below or above ‘accepted’ standards of thermal comfort. Thermal comfort is not just about temperature but also air movement, mean radiant temperature and relative humidity.

It is important to assess the boundaries of acceptability rather than necessarily having a fixed temperature that is accepted as a benchmark. For academic research, there is a standard and it is important to know the extent to which occupiers will take any potential energy savings in the form of lower energy bills

or via an improvement in the warmth of the property. The existence of the rebound effect (largely comfort-taking) demonstrates that many people would choose higher living temperatures in the winter if it becomes more affordable, usually due to boiler replacement or thermal insulation. However, many people choose not to heat their dwellings to accepted standards.

Non-domestic buildings require a slightly different approach as thermal comfort depends on the nature of the physical activity taking place, and employers also have a duty to provide thermal comfort at the very least for relatively inactive workers. Many types of more modern buildings, particularly those up to the 1970s, and certain types of retrofitted buildings, are also prone to overheating, especially where thermal mass has been reduced and ventilation has been compromised, lofts converted with inadequate insulation, rooms divided for multiple occupation and where solar gain has been increased often by the addition of conservatories.

Summary of the existing research:

There is quite a wide discrepancy in the estimates and measurements for comfort taking. Where measured data has been collected, it indicates that a significant percentage of the benefits of retrofit are taken as improvements in thermal comfort, which is in accordance with the theory, from Jevons onwards.

In part, the high comfort taking in domestic buildings may be based on the selection of properties for retrofit based on fuel poverty. However, one significant practical study (Poortinga et al 2017) on fuel-poor housing showed very small comfort taking but substantial falls in gas use; this study does include data for pre-1919 dwellings.

HES TP14 also challenges the notion that properties need be heated to modern standards of thermal comfort, as many occupants choose to live in thermally massive buildings using background heating and local sources, often a stove or a highly energy inefficient open fire. There are useful case studies of individual non-domestic buildings including a historic building in Venice and a church in the UK. Available research on overheating has been largely focused on new builds but a report from BRE (2014) and an article by Lomas, K and Porritt, S (2016) set out some examples of pre-1919 overheating research and predictions. The MHCLG (2019) research into overheating in new builds is also relevant as it looks at mitigation factors that would be equally applicable to traditional building stock facing similar issues. Other research is more related to climate change predictions rather than to retrofit and the loss of thermal mass or natural ventilation.

There are useful historic approaches to dealing with discomfort, specifically relating to traditional buildings, which indicate that buildings need not be heated to accepted thermal standards of air temperature. Further research is needed here, including the effects of radiant heat and the emissivity of building surfaces.

3.4 Character and significance

The issue:

The character and significance of much of the UK's non-protected traditional building stock has been eroded, especially during the last 50 years with the installation of PVCu windows and doors. Retrofit has accelerated this process.

In order to determine a retrofit path for any particular building which protects and enhances heritage significance for any building, we need to understand what it is about traditional buildings that people value and how they make their decisions about acceptable change.

Summary of the existing knowledge:

The need for a special consideration of older buildings was first codified, in an industry wide context, in British Standard BS 7913:1998. The Building Regulations Parts L1B and L2B (2002) set out a basis for special consideration for historic and traditional buildings, balancing energy conservation, heritage and building fabric. A broader concept of historic significance arose from English Heritage's *Conservation Principles* (2008). This was not fully articulated back in 2012 and rarely used outside statements of significance. Since then, the term has been embraced by the main conservation bodies and by the updated standard BS7913 *Guide to the Conservation of Historic Buildings*, published in 2013.

The importance of conserving and enhancing heritage significance has also been included as an aim in PAS 2035 *Standard for Domestic Retrofit, 2019*. The STBA has developed the Guidance for Assessing Significance for non-nationally designated buildings to which the standard refers. PAS 2038 is expected to follow the same path for non-domestic buildings.

However, many retrofit strategies are still based on limited metrics which do not include the protection and enhancement of architectural heritage. Research by Fouseki and Bobrova (2018) examines the process by which homeowners take decisions about retrofit and specifically why they choose to retain or replace features of significance. Socio-mathematical research from the University of Bath also begins to assess the dialogue between conservation and the retrofit agenda.

Data on the retention of heritage in undesignated buildings is not always easily accessible. For example, the numbers of original windows and historic glazing which remain are not known. Secondary glazing systems and slim-profile double glazing have both improved since 2012, so it may be more relevant to have this data now so that we know how many windows can be retained and improved, either with secondary glazing or slim profile double glazing.

For the domestic stock, data on solid walls is available through the English Housing Survey (and similar for other home nations). Data is also available for the number of solid walls insulated under ECO, so the remaining number of uninsulated walls can be derived. No such statistics are available for the non-domestic stock.

3.5 Moisture management

Traditional buildings deal with internally generated moisture loads through natural air leakage but also through the moisture buffering capacity of certain construction materials. We need to understand how traditional buildings perform in terms of vapour and liquid water both pre and post retrofit.

Internal wall insulation, for example, may reduce moisture buffering capacity if moisture closed materials are used. Both internal and external wall insulation and many other retrofit measures will reduce uncontrolled heat loss and air movement and will also reduce natural air infiltration. This research is difficult to assess due to the number of variables: internal moisture loads vary hugely according to the density and patterns of occupation, ventilation of kitchens and bathrooms, and whether washing is dried indoors without direct extract to outside. There may also be gains to the internal moisture load through leaks or other faults in the building structure, so rain penetration in particular can add to the moisture load in moisture open buildings.

Of the recommendations in the *Responsible Retrofit of Traditional Buildings* (2012), several have been or are being addressed. BS5250 was amended in 2016 and BSI published a 'white paper' that reviewed moisture guidance in a whole new language, whilst PAS 2035 addresses the need for knowledge of building physics and context.

Modelling of moisture has improved with more detailed programmes like WUFI becoming more prevalent, but there is not yet a systemic design approach across the industry. PAS 2035 should help to address this in the longer term. Creation of risked based 'rules of thumb' were raised as they are commonly used in the industry and are embedded in the white paper. The UK Centre for Moisture in Buildings (UKCMB) has produced a range of interactive tools to help understand moisture for home owners, but it is not known whether these have yet been taken up by the industry and incorporated in design decisions.

Changes to product regime testing for moisture were highlighted as a key factor for informed decision making. Long term research projects are needed as most tend to look at immediate results and certain moisture issues may well take years to appear.

3.5.1 Relative humidity

The issue:

For a healthy environment, indoor air quality is principally assessed in terms of relative humidity (RH) and levels of carbon dioxide (CO_2). Moisture levels in the air vary according to temperature, which is why RH is used as a measure. RH also has to be considered in relation to the potential for pests and dust mites.

RH affects both human and building health as well as thermal comfort. Indoor air quality (IAQ) is principally assessed in terms of RH and levels of CO_2. Moisture levels in the air vary according to temperature, which is why RH is used as a

measure. CO_2 acts as a proxy measure here for general IAQ as it is seen as an easier way of taking all pollutants, like VOCs, radon, dust mites and pests, formaldehyde into account. Safe moisture levels in the air vary according to temperature, which is why RH is used as a measure.

Summary of the existing research:

Relative humidity (RH) and its effects on human and building health were well documented prior to 2012. However, the understanding of moisture has been summarised by SPAB (2018) and translated into draft practical surveying requirements by the industry (PCA 2019), although these have not yet been publicly released.

There have been some additional studies that have highlighted the increase in RH associated with retrofits (Jiang, S et al 2015). Heritage issues have been identified with potential damage caused by condensation associated with heating regimes (Varas-Muriel, M J, Fort, R 2019, Anaf, W, Schalm, O 2019) and solutions using HVAC (Ferdyn-Grygierek, J, Grygierek, K 2019). There remains a lack of long term analysis on RH levels in buildings retrofitted using a 'whole building approach'.

3.5.2 Structural moisture content

The issue:

Moisture enters the fabric of traditional buildings more easily than modern buildings, as older fabric is generally more permeable. Sources of moisture ingress include:

- faulty rainwater goods
- leaks (due to plumbing defects and building faults) and flooding
- ground moisture and incorrect external levels
- impermeable ground surfaces and lack of perimeter drainage
- rain penetration
- excessive internal moisture loads

Moisture then escapes largely through evaporation. We need to understand drying rates better, so that we can specify the period before a repaired building can be retrofitted, to avoid sealing in damp. Crucially buildings need to be well maintained before retrofitting works are carried out so that the building fabric is working to its optimal thermal performance.

We also need to improve our understanding of hygrothermal behaviour and the effect of adding moisture-open and impervious materials to moisture-open structures as part of the retrofit process. More work is also needed looking at the effects of orientation, exposure, location of buildings and on different building typologies.

Summary of the existing research:

Lack of knowledge within this key area of retrofit was highlighted the 2012 Gap Analysis. The establishment of the UKCMB has done much to focus attention and resources into filling this area of research and publications like HES' 2013 short guide provide useful tools for identification of appropriate materials for use in retrofit.

The underpinning physics of moisture movement within structures is relatively well known and can be predicted. Modelling for internal wall insulation (IWI) (Marincioni et al 2018) is available and long term observations have been collated (Archimetrics 2019). Research addresses different types of wall (HES TP15 2015, HE (Baker, P) 2015, Latif, E et al 2019, Whitman, C et al 2020, Frick, J et al 2016, Whitman, C et al 2015).

The ramifications of any energy efficiency improvements have also been well documented with the HE *Energy Efficiency and Historic Buildings* series. This is backed by the analysis of hygroscopic IWI materials by Smith, M 2017. Embedded joist ends can be particularly prone to moisture damage if IWI is not carried out correctly as part of a whole building approach to retrofit. Little, J and Arregi, B 2016 showed that both 'best' and 'commercial' practices were riskier than their 'low carbon approach', this is backed up by Gorse, C et al 2017.

The practical ramifications of real life energy efficiency work has also been documented for large scale external wall insulation (EWI) projects (Atkinson, J 2015 and HE (Heath, N) 2014) and some of the quality issues surrounding these (Glew, D et al 2017). Individual research projects have also yielded interesting reports, for example Bolsover HE (Rhee-Duverne, S and Baker, P) 2015.

The response of traditional buildings to flood water and subsequent drying has also been explored by Historic England (HE (Ridout, B) 2017).

This area of research is quite well funded as the moisture impact on materials is now understood to be a vital area in any retrofit, so research continues across various academic institutions although there is a lack of long term in-situ monitoring. Soon to be published is *Comparison of moisture buffering properties of plasters in full scale simulations and laboratory testing* (Valeria Cascione, Pete Walker, Dan Maskell, Andrew Shea, Monto Mani 2020).

HE have recently commissioned work from BRE Centre for Innovative Construction Materials (BRE CICM) look at ground water under the working title: *Moisture movement beneath solid ground floors in historic buildings.*

3.6 Energy performance

The retrofit agenda for the mainstream industry is being driven by a primary focus on reducing energy demand, especially that derived from carbon based fuels. It is important to have accurate and reliable research that can guide decision making so that this aim is actually achieved.

This section is divided into a number of distinct sections, although research projects often cover more than one topic.

The *Responsible Retrofit of Traditional Buildings* report focused on the need for accurate U-values and their integration into RdSAP calculations. This has been largely addressed for brick walls by the revisions associated with SAP and consequently RdSAP, but inaccuracies still exist around other elements like floors and windows. However, decisions based on the recommendations in energy performance certificates (EPCs) are still a great risk. Industry and Government have developed an approach to interventions based on these estimating models as design rather just than compliance tools. (HE Pickles, D, Cattini, C 2015, Better Buildings Partnership 2018 and STBA 2018).

3.6.1 Energy performance data

The issue:

It is important to understand how much energy buildings use both before and after any intervention. Data prior to retrofit should enable an accurate understanding of the performance of that stock, whilst data post-retrofit should indicate the effectiveness of the measures taken in reducing energy use or relative unknowns like comfort taking. Ideally, we need to know what measured data exists, and how this relates to predictive modelling, which is known to be inaccurate in RdSAP.

We also need a better understanding of the 'performance gap' and the extent to which this arises from a failure of the strategy due to inaccurate predictions, poor specification or workmanship, or from comfort taking.

Summary of the existing research:

There have been numerous research projects looking at energy within the built environment since the 2012 Gap Analysis. Data is predominantly modelled rather than measured. HES produced a useful document looking at the various different types of modelling in use (HES TP18 2013) that underpin domestic energy use projections.

Software continues to improve and new variants and models continue to emerge like AiBATROS® (Groß, M et al 2020). Alternative structural ways of finding energy savings have been explored including the Architectural Energy Retrofit

strategy (Eliopoulou, E and Mantziou, E 2017) and multi-layer modelling (Ravelo, B et al 2020). Cardiff University has looked at creating archetypes to be able to model them on a national scale to see which interventions provide the best value for money (Green, E et al 2018).

However, the wider industry and Government have continued to use the much more basic Energy Performance Certificate (EPC) data to inform larger scale refurbishment projections and projects. This data can be compared to the NEED database (BEIS 2019) and stock surveys (DCLG 2015).

The existence of the 'performance gap' between predicted and actual has driven many projects to look at actual savings (Hardy, A L R et al 2018 and Summerfield, A 2019), whilst others have looked at meter data to assess (Beagon, P et al 2018) or by using a post occupancy evaluation (Atkins, R and Emmanuel, R 2014). The reasons behind the performance gap have been explored in a number of ways. Jones, P et al 2013 compared three approaches: elemental, multiple and whole house measures. Attempts have also been made to suggest how to model the gap (Marshall, A et al 2017) and how to reduce it (Topouzi, M, Killip, G, Owen, A 2017).

Large scale projects built upon predicted energy savings to alleviate fuel poverty have been reviewed in depth, for example the Arbed scheme in Wales (Atkinson, J et al 2015 and Littlewood, J 2017). Leeds Beckett University also looked at a large number of buildings to see where improvements could have been made (Gorse, C et al 2017).

The pre-1919 test house erected at Salford University has provided some insight into the impact of different stages of retrofit (Farmer, D 2017). Topouzi, M, Owen A, Killip, G 2017 and Topouzi, M 2019 have investigated the construction phases and design issues that might affect building performance.

Individual studies on domestic buildings also add to the overall picture, notably those from HE in Bolsover (HE (Rhee-Duverne, S and Baker, P) 2015) and Reading (HE (Newman, C) 2017). A South Wales deep retrofit was written up by Perisoglou, E et al 2019. In Scotland we have Gilmour's Close (Mackintosh Environmental Architecture Research Unit 2012) and HES TP24 case studies provide individual insight into a range of different measures applied to a range of house types.

Non-domestic work has also been carried out, notably Innovate UK 2016 and HE (Baker, P) 2015 and it continues with Oxford Brookes University who currently have a community building under refurbishment with results expected in 2021.

The need for any intervention to be fully sustainable requires that it be reversible to ensure minimal carbon costs. This has been explored at an EU level by Scuderi, G 2019. It is also important to know if it has any impact on property value or rental income. Again this has been looked at within a European context (European Commission (DG Energy) 2013).

3.6.2 Building fabric elements (walls, floors, roof, windows)

The issue:

In order to understand the real performance of traditional buildings, rather than as predicted by models, we need to know the measured energy use of the building and the associated U-values for different thermal elements, both before and after retrofit. The impact of retrofit measures on air tightness and the effect which this has on heat losses is addressed in Section 3.6.4.

Summary of the existing research:

U-values are often used for basic energy calculations and their modelled values tend to be different from their *in-situ* measured ones. HE's 2013 (Rhee-Duverne, S and Baker, P) report on brick walls highlighted the discrepancy and DECC recognised this in their 2014 report on wall U-values.

Further research on walls has focused more on their hygrothermal properties (Biseniece, E et al 2018 and Chambers, J et al 2015), and complications with interventions like freeze/thaw (Zhou, X 2020) or EWI/CWI performance (*Constructing Excellence in Wales 2013*). Salford University has also looked at walls during retrofit (Farmer, D et al 2017).

Research on walls has focused on standard brick and stone masonry but more recent research has looked at a wider range of structural elements including:

- wall panels (Latif, E et al 2015 and Whitman, C et al 2020)
- lath walls (Benadji, A 2012)
- windows (HE (Baker, P) 2017 and HES TP 20 2013
- floors (Pelsmakers, S 2016 and Pelsmakers, S et al 2017)
- roofs (Elwell, C A et al 2017)
- chimneys (HE Pickles, D 2016)

Case studies from HES give excellent examples on individual interventions (HES Case Studies 2013 – present) and how these have been monitored (HES TP 19 2013).

The ability to get data on individual U-values is difficult and expensive at the moment but research has looked at different calculation systems (Sakkas, N 2015, De Simon, L 2017 and Scarpa, M et al 2017). Being able to readily assess a building's U-value could be key to identifying appropriate solutions in difficult buildings. Research presented at Energy Efficiency and Comfort of Historic Buildings - 2nd International Conference in 2016[8] on trials of an insulating lime in a church vault appeared to provide a potential solution for historic fabric thermal improvements. This research from Hansen, T K et al 2016 is set to be updated and released at the November 2020 IIC conference in Edinburgh.

[8] See https://www.eechb.eu/wp-content/uploads/2016/12/Proceedings_EECHB.pdf

3.6.3 Thermal bridging

The issue:

When improving the performance of thermal elements, there will be areas where it is difficult or impossible to apply insulation. Such areas can then create thermal bridges that render the original intention of the works void, or worse, attract moisture and cause damp and mould which were not there previously.

Understanding where these bridges may be created, and how they might be designed out, or mitigated is a key issue. We also need to know the overall impact of thermal bridges on energy savings within a whole-building retrofit strategy.

Summary of the existing research:

The main causes of thermal bridges in retrofit are the misapplication of insulation either internally or externally. These have been examined in depth by BRE (King et al 2013) and Marincioni et al 2016 with special reference to reveals.

Thermal bridging in EWI has also been researched by Atkinson 2015. Minor questions remain about punctures through the envelope and their effect as a thermal bridge and differences in EWI attachment systems (metal versus plastic), but their impact is minor.

3.6.4 Airtightness

The issue:

Uncontrolled ventilation is a major source of heat losses. Reducing these losses is usually a low cost measure but for this very reason is often excluded from major retrofit programmes where these are driven by the insulation industry.

We need to know the actual effects of airtightness measures on energy use, and whether these measures largely lead to comfort taking. The impact of air tightness measures on ventilation levels and unintended consequences arising from fabric insulation measures are addressed under Section 3.2.

3.6.5 Heating approach

The issue:

Traditional buildings were built with a completely different approach to heating that was driven by the occupancy patterns, available fuels and appliances of the time. National energy grids and technology have developed and this alongside the sub-division of many houses and non-domestic buildings into flats has driven the changes seen in our homes.

Central heating has largely replaced individual room-based heating. This change in heating approach has knock-on effects that alters the dynamics of the whole building and its effect on building fabric needs to be better understood.

We need to understand how to operate heating systems to optimise energy use. Is it more economical to heat buildings with high thermal mass continuously rather than intermittently? For the same reason, we also need to know which delivery mechanisms for central heating (radiators, underfloor heating or air heating) are more efficient at providing the requisite levels of thermal comfort. We also need to know more about how heat pumps can work with traditional buildings as the grid is gradually decarbonised.

Summary of the existing research:

The research available here has looked at two main areas. Firstly, at existing systems and how this affects energy efficiency, and secondly where choices may be made to change our heating approach away from the conventional.

Bennett G 2019 looked at the efficiency and in-use patterns of our existing boilers and how this may well affect how energy efficient they are and how this learning might influence future choices. Occupancy patterns also appear to influence how we heat our homes and this was explored by Stevenson, V and McNaboe, B in 2014. Whether we could heat our homes using low background heating appears in HES TP 14, 2011.

Alternative heating and their potential benefits have been researched for various heating options. The largest amount of work appears to be on heat pumps (BEIS 2018, HE Cattini, C 2017) or a combination of heat pump and ventilation system (Schibuola, L 2018 and Mackintosh Environmental Architecture Research Unit 2012). One innovative area of progress can be seen by Wales and West Utilities 2018. Here a system has been used to internally monitor and 'learn' how a building performs so that a retrofitted hybridised system of existing boiler combined with ASHP can be used most efficiently. Latest news from Swiss Federal Laboratories for Materials Science and Technology (EMPA) suggests that 'self-learning heating control systems' should be able to save around 25 per cent on energy[9]. Lastly, HES TP 22 2014 researched the opportunities afforded by radiant panels.

[9] https://www.sciencedaily.com/releases/2020/01/200130144423.htm

3.6.6 Heating and fuel sources

The issue:

This is a dynamic topic and one that requires some future gazing as the energy grids that supply homes are undergoing substantial change, with the CO_2 emissions per kWh of electricity now falling to approach those of gas. There are also proposals to decarbonize the gas grid to a limited degree.

Traditionally we have classified homes as either on- or off-grid. On-grid properties are those served by the gas network and have benefitted from the low carbon and cost rating factors applied to them. Off-grid properties, including a higher than average proportion of traditional buildings, have been seen as more problematic due to their higher EPC ratings.

This is largely because the EPC rating is a cost rating not a carbon rating so measures to reduce carbon emissions, such as switching to biomass boilers, bio LPG or heat pumps, can make the EPC score worse. Consequently we need to know the impact of fuel switching on carbon emissions - especially if the Government can be persuaded to switch the headline EPC rating to a carbon metric, to align with their policy intent.

We also need to understand the potential for hydrogen to be used as a domestic heating fuel, and to be generated (as a means of energy storage) from spare solar and wind capacity.

Summary of the existing research:

Gas decarbonisation has been explored under a couple of scenarios and these were published in 2019 by the Energy Networks Association. Decarbonising the electricity grid is reported by BEIS at https://www.gov.uk/government/collections/energy-and-emissions-projections. These projections helped to inform the carbon measurements in the publication for the Welsh Government (Green, E et al 2019).

The other research identified looked at the possibility and effectiveness of electric storage combined with renewable energy in refurbishments (Perisoglou, E et al 2019), the use of electric vehicles as storage (Chatzivasileiadi, A et al 2019) or the wider use of micro grids and community energy (Xiaojun, L et al 2017).

3.6.7 Overheating and cooling

The issue:

Improved insulation to reduce heat losses has an impact on the ability of buildings to cool. Insulation will naturally help buildings retain their heat and if not designed properly can lead to overheating. This would be either through reductions in the effective thermal mass of traditional buildings to reduce peak daytime temperatures or through heat not being so readily able to dissipate to the exterior at night.

More needs to be known about the extent to which retrofit has increased the incidence of overheating, and the required level of knowledge amongst retrofit designers to prevent future incidences of this unintended consequence. We need to know also whether it has increased the demand for air conditioning and the extent this can be avoided by good design or its impacts mitigated by combining with renewable electricity generation.

Summary of the existing research:

There is an in-depth laboratory study on a retrofit of a pre-1919 building at Salford University. The research examined the effects of adding insulation on the ability of the building to cool, based on current and projected weather data (Ji, Y et al 2014). Of course this was for a given material (brick), location, orientation, exposure, condition. This research needs to be used to inform a much wider range of building typologies, which would require long term modelling using predicted summer temperatures.

One piece of work from Shikder, S 2012 does highlight the projected issues associated with overheating. This is more focused on new build construction, but the building and personal adaptations, as a response to overheating, will apply to many existing buildings. The report used four climate regions to give a balanced view across the UK.

Research has otherwise been focused on particular regions. This is probably due to the expected incidence of overheating being focused on the South East of England. Other work has looked at householders' awareness (Murtagh, N et al 2017) and an appraisal of their potential coping strategies (Murtagh, N et al 2019). Weng, K 2016 used modelling to project the effect of opening windows in a domestic setting.

For traditional buildings in particular, passive cooling and heating are being investigated under a current PhD thesis.[10]

[10] https://www.ribaj.com/intelligence/traditional-passive-methods-can-improve-thermal-comfort-in-old-buildings-architectural-association-sarah-khan

3.6.8 Lighting

The issue:

Until recently, lighting accounted for a significant proportion of (non-heating) electricity use. However, since 2018 'D-class' halogen lamps have started to be phased out, although retailers were allowed to clear existing stock so they have not completely disappeared.

The advent of LED lighting is leading to a gradual reduction in energy use as lamps are progressively replaced. The Jevons paradox suggests though that these improvements in efficiency may be negated by increased use.

There is a need to know the potential for energy savings that may still be achieved through lamp replacement, as a contribution towards overall national targets. Reductions may also be achieved through automation of controls, especially in the non-domestic sector.

Summary of the existing research:

There appears to have been little technical research work in this area. The policy question raised above remains unanswered but there seems to be wide public acceptance of LEDs and their performance has improved considerably.

3.7 Embodied carbon and the circular economy

The issue:

Embodied carbon is poorly understood and hard to measure. One of the arguments frequently made for the retention of traditional buildings is that they have stood for a long period and were built with lower embodied energy materials than many modern buildings. Since 2012, understanding of the circular economy has also grown in Government policymaking, and the phrase has come into common parlance.

In order to make informed decisions about the relative importance of ongoing energy use and other environmental impacts compared to the impact of making substantial change, we need to know the embodied energy and environmental impact of demolition and new build. We need then to be able to compare it with the carbon costs and savings of retrofitting existing buildings to given standards of energy efficiency.

Summary of the existing research:

The Building Carbon Database originally developed by WRAP and the Green Building Council has recently been updated and expanded by the RICS.

Building on HES TP13 *Embodied Energy Considerations for Existing Buildings*, the 2019 HE report on *Understanding Carbon in the Historic Environment* primarily used the ICE database, supplemented by data from Environmental Product Declarations (EPDs). There are some technical issues with using this data which are discussed in the report. Lifecycle assessment (LCA) tools were also assessed and the report notes that there is no LCA tool for refurbishment projects available at present. The report does compare the embodied and operational carbon impact of refurbishment strategies against demolition and new build (in a limited number of cases as data is very hard to gather) and concludes unsurprisingly in favour of retention.

Academic studies have also modelled the impact of retrofit at a national scale, to investigate where a balance may lie between operational carbon savings and the embodied investment necessary to achieve them. One such study (Hosain et al 2018) focuses purely on insulation materials. Research also indicates that the Enerphit model of deep retrofit was a less viable approach (Neroutsou 2016).

There are LCA and other impact assessment tools available[11] but these are principally designed for use on new buildings. A tool is now needed which will allow the comparison of embodied carbon and all other environmental impacts of different retrofit strategies with the savings that they may achieve for a particular building, over a variety of timescales.

3.8 Occupant interactions

The issue:

Occupant interactions with building fabric and services affect levels of thermal comfort, distribution of heat within a building, relative and absolute humidity in the building and within its structure. Heating controls vary and in many non-domestic buildings the occupants may have no control over heating or even be able to open windows.

For traditional buildings in particular, the effect of thermal mass on warming and cooling needs to be understood, so that heat distribution settings can be optimised. Occupant behaviour such as drying washing indoors, habitually leaving windows open or closed and blocking permanent background ventilation can all have a substantial impact on heat demand, IAQ and humidity levels.

[11] For example, One Click LCA, eTool, BRE Impact Database

Summary of the existing research:

Although 'rebound effects' are relatively well understood, the research on aspects of occupant interactions is patchy. There is some research on the role of thermal mass (Stevenson 2014) and some of the performance gap research can inform this topic. The paper *Smart people in stupid homes (2016)* is probably the best available research on this topic to date.

In practical terms, it would be difficult if not impossible to gather meaningful data on occupant interactions at sufficient scale to account for the many variables.

3.9 Public and political understanding

The issue:

In order to formulate a balanced approach to retrofit that includes health and heritage, we need to know the extent to which the public understand:

- retrofit - its aims and the way it is accomplished
- who carries out which functions - assessment, design, installation
- heritage values
- the way in which traditional buildings differ technically from modern buildings

There has long been a perception that traditional buildings are among the least efficient of building typologies. As is well known amongst the heritage sector, this is a misperception. In terms of energy per m^2 for space heating, many later building types can perform worse than pre-1919 stock. It would be useful to know whether this perception has changed.

Summary of the existing research:

There is guidance available for landlords (for example, the Better Buildings Partnership's report on non-domestic EPCs) and homeowners, but no data on actual levels of public understanding. Chapter 3 of the BEIS guidance to landlords and enforcement authorities on the *Private Rented Property Minimum Standard* (2017) sets out the distinctions between traditional and modern construction and provides good technical advice, but it is for landlords not for the wider public. One 2016 paper, *Reflections on retrofits,* examines public perception and barriers, and there has been some limited research in social marketing, but all other reports rely on anecdotal evidence to demonstrate the lack of appreciation of the unique attributes of traditional buildings and their particular sensitivity in retrofit.

Two reports from Cardiff University, *Smart people in stupid homes* (2016), and *Heritage Retrofit and Cultural Empathy* (2020), begin to address these questions but the reports are limited in scope. Research by Fouseki and Bobrova (2018) also examines the process by which homeowners take decisions about retrofit and specifically why they choose to retain or replace features with historic significance.

Quantitative research, probably at regional level, on awareness of traditional buildings would at least identify the scale of the issue and reveal the mechanisms needed to disseminate critical information to the public.

3.10 Repair, maintenance and enabling works

The issue:

It is well known by those familiar with traditional building construction that basic relatively low cost repair and maintenance leads to reductions in heat demand. This understanding is not prevalent in the retrofit industry or the construction industry generally, partly because both policy and practice have often been influenced by insulation manufacturers, whose interest is to sell more insulation rather than encouraging low cost measures. A dry wall is much more thermally efficient than a wet wall. Sealing up leaks around doors and window frames reduces draughts and unwanted heat loss.

We need to better understand the impact of simply carrying out basic repair and maintenance on heat demand. We also need to understand the effect of basic maintenance in preventing major repairs, as the embodied energy of fixing building faults can well exceed any savings from retrofit measures over a long period. We also need to know the level of understanding among the industry (including installers) that enabling works must precede retrofit works to avoid sealing in or exacerbating existing problems, especially damp.

Summary of the existing research:

There is good guidance from the conservation bodies about how to carry out repair and maintenance of traditionally constructed buildings. This advice though is commonly perceived to be only relevant to protected 'heritage' structures. In terms of retrofit, there is plenty of guidance which points out the value of repair and effective maintenance, and explains that a dry wall conducts energy more slowly than a wet wall. However, nowhere is this researched and quantified.

Exploring the link between maintenance and energy efficiency has been attempted but unfortunately the scoping paper which identified the needs for further research (HE (Whitman, C et al) 2016) failed to attract further funding.

There appears to be no data on energy use before and after a package of basic repairs such as sealing round windows, draught proofing, repointing, repairing leaks, lowering external levels and drying out the building.

3.11 Professional understanding

The issue:

There is a significant lack of understanding among professionals regarding:

- the way that traditional buildings are constructed and perform;
- the interactions between potential retrofit measures;
- unintended consequences;
- heritage significance.

All the professionals involved with a retrofit project need to understand all these issues in order to carry out a refurbishment with minimal risks. Can we identify research that highlights areas of good and poor knowledge and how best practice is disseminated effectively?

Summary of the existing research:

There is research on the performance gap which identifies limitations in the design process as a reason for failure to achieve the stated aims. However, while there is some excellent guidance available to designers (for example, STBA's Bristol SWI Guidance) which highlight moisture risks of retrofitting traditional buildings, many installations continue with moisture closed insulation with a vapour permeable membrane (VPM) on the internal face, which is known to increase the risk of interstitial condensation in moisture open walls. Often this is at the insistence of Building Control officers which indicates a lack of understanding of the exemptions and special considerations in Parts L1B and L2B of the Building Regulations, documents which they should know well.

Improvement in retrofit assessment procedures was a recommendation of the *Each Home Counts report* (2016). Until recently, the subject of survey prior to the formulation of retrofit strategies has received little formal attention. However, under the STBA's project "Testing out a whole-house approach to retrofit," a survey protocol has been developed which includes a full condition assessment of the building fabric, an assessment of significance as well as ventilation. Training for surveyors has also been developed under this project. The results are expected to be published in 2021 but the survey templates are already being used to inform the survey workstream of the Retrofit Standards Task Group run by BSI.

Proceedings of the 2nd International Conference on Energy Efficiency and Comfort of Historic Buildings (2016) raised the important issue of designers understanding historic buildings. In the UK, both the RIBA and RICS have conservation accreditation schemes which originated in an effort to secure better quality grant aided work, but the number of accredited professionals is tiny in comparison with the number of traditional buildings. There is no evidence to suggest that many designers who work on traditional buildings have such accreditation. For many domestic retrofit projects, it is important to recognise that the contractor or the householder is often effectively the 'designer'. There is also a lack of education and training in traditional buildings throughout the industry, including at HNC level.

In the meantime, standards such as EN16883 *Guidelines for Improving the Energy Performance of Historic Buildings* (2017) have emerged, which is helpful but these standards have not yet been embedded in the professional institutions. PAS 2035 requires designers working on traditional building retrofits to have the appropriate qualifications.

The HE report by the Centre for Sustainable Environments, *The Sustainable Use of Energy in Traditional Dwellings: Using legislation and policy to guide decision-making* (2017), begins to address this issue for local authorities, but is limited to designated buildings. Building Regulations Parts L1B and L2B and the Private Rented Sector Regulations advise consultation with the local authority's conservation officer in relation to designated and traditional buildings. Conservation officers (where they exist) can be vital sources of impartial advice, but may not have the training, experience, status or resources to be able to influence decisions at the levels or in the quantity needed.

It is encouraging that Trustmark want to make the STBA's Guidance Wheel available to all their registered users, hence the update currently being carried out by STBA. What is now needed is research to assess the current level of knowledge about traditional buildings amongst designers, local authority officers (building control, conservation officers, energy efficiency and sustainability officers) and contractors. A route map can then ensure all professionals involved in the retrofit process, from survey to post-occupancy monitoring, have the requisite understanding of traditional buildings. The research is likely be most effective if the relevant institutions including CITB, CIAT, CIOB, IHBC, LABC, RICS and RIBA are involved in its commissioning.

3.12 Costs of retrofit measures

The issue:

There are safeguards in Building Regulations and in the Minimum Energy Efficiency Standards (MEES) Regulations for the private rented sector which specify that improvement should be "cost-effective", among other things. There is a need therefore to know the costs of a suite of measures such as those set out in PAS 2035.

For non-domestic buildings the measures can be more complex, especially where HVAC systems are in place. For traditional buildings where there is any kind of industrial process taking place, the efficiency measures would be excluded from this analysis. It is important to know how much retrofit costs as many homeowners and organisations work on simple 15 year payback calculations used in the Building Regulations. Clarity over retrofit costs will also enable an estimation of the added value to refurbished buildings. This is a complex area since maintenance measures are also retrofit measures, but may not be counted. Some of the measures will increase the value of the building, others are requirements of building standards.

Summary of the existing research:

It is a truism in this field that every property is different and will thus require a different suite of measures. Budgets for individual retrofits can be £50k or even over £100k depending on the size of the property. Individual case studies are of little use unless the precise number and sizes of thermal elements are recorded, to derive a cost per m² or similar for measures such as SWI, secondary glazing and window replacement.

Clarity on cost can only be achieved where multiple properties are retrofitted under the same scheme, are relatively homogenous, and where economies of scale start to come into play. The HE report *Reducing energy use in traditional dwellings: Analysis of four solid wall houses in Reading,* and Jones et al 2017, may serve as a good basis for assessing measures for traditionally-constructed dwellings but it is noted that the costs were taken from a database. Detailed data on *actual* costs may be available through Arbed 2, but this is not in the public domain and there was no deep retrofit of traditional buildings under the scheme.

To work out the real payback of measures, it is necessary to pool actual costs from a variety of individual retrofit schemes to come up with a reliable method of estimating costs per m² of various strategies. It is then necessary to allow for the rebound effect and the interactions between them, for example boiler replacement or draught proofing reduces the savings available from SWI. The 2017 BEIS report *What does it cost to retrofit homes?* by Cambridge Architectural Research (CAR) begins to do this, but in many areas such as secondary glazing, floors and flat roofs, the data was very limited. For non-domestic buildings, no such study exists so this is the primary data gap.

3.13 Material properties and technical specifications

The issue:

Material properties affect embodied carbon, health, moisture and energy performance. It is included here as a distinct topic as there is a need to develop sympathetic measures that enable traditional buildings to become 'as good as they can be'. There is also a requirement in PAS 2035 for 'Medium Term Improvement Plans', which will require materials to fulfil a range of criteria including: energy performance, thermal performance (heat retention or delay), moisture performance, health implications (IAQ and concentrations of volatile organic compounds), lifecycle analysis, recyclability and reversibility.

Summary of the existing research:

The conservation bodies in the UK principally HE and HES have produced high quality research on many materials, including:

- stone (where to source it (HE Willett, C and Wood, C 2018))
- stone consolidants (Odgers, D 2018)

- lime mortars (Forster, A M et al 2019 and HES TP27 2018)
- heritage plasters (Frick, J et al 2016)
- glazing (HE Curteis, T and Seliger, L 2017)
- aerogels (Ganobjak, M 2019)
- hemp lime (Strandberg-de Bruijn, P B and Balksten, K 2019, Barclay, M, Holcroft, N and Shea, A 2014)
- natural insulations (Palumbo, M et al 2016)
- replacement panels for timber frames (Whitman, C et al 2020, Latif, E et al 2018)

The increasing importance of and reliance on hygrothermal analysis tools such as WUFI makes it absolutely critical that we have more and better data on the moisture characteristics of building materials, otherwise designers are guessing (using unknown material types taken from a worldwide database) and most of our risk assessments will remain flawed.

Databases of materials such as Greenspec, address the properties of insulation and other materials, including health impacts, and provide specifications. Understanding and awareness of lime has also improved, though only marginally among both contractors and specifiers. Gaps remain in the understanding of the relative properties of hydraulic and non-hydraulic lime and how to choose the right lime for the job. The issue of aggregates is still under researched and hence poorly understood.

Insulated lime renders and plasters present a viable solution for many solid walls especially where render is already in place; even though they may not achieve the R values of more modern materials. Further research may be needed on the actual (not modelled) impact of insulated lime renders in terms of energy efficiency, embodied carbon, moisture, humidity and impact on thermal mass, as ‘wet’ insulation products will not de-couple thermal mass from the underlying structure.

4) RECOMMENDATIONS FOR FURTHER RESEARCH

The recommendations for further research are based on the gaps identified in Section 3. In drawing up recommendations for future research, it is necessary to have some idea of existing research programmes. Some key ongoing Academic Research is described in Section 4.2. The table below in 4.1 takes account of these programmes.

4.1 Potential research requirements

As this is only a scoping study, the underlying reports (URLs provided in Appendix 2) would need to be subjected to formal peer review prior to the design of any specific research project. In some cases, no research has been identified where the subject was well covered in the original 2012 analysis.

Section	Topic	Research requirement
-	Overall research strategy (See 4.2)	Track current and future planned research from all key institutes, government departments and industry bodies.
3.1	Human health	Broad-ranging research on the impact of retrofit on the mental and physical health of occupants of traditionally-constructed buildings, especially non-domestic buildings.
3.2	Ventilation	A significant research programme will be required to assess the effects of retrofit on air quality in traditional buildings; this will require pre-retrofit monitoring, and post retrofit monitoring both with and without additional ventilation installed. The research will need to be at large scale as there are considerable variables in terms of fabric condition and air leakage, patterns of occupancy and use, and packages of retrofit measures.
3.3	Thermal comfort	In traditional buildings the potential for passive cooling and heating needs to be explored further, including the influence of emissivity of building surfaces.
3.4	Character and significance	There is little meta data on the extent of changes to the (remaining) traditional built environment. Results might inform efforts to retain particular features which may be under threat - such as timber windows. Also see 3.9 below.
3.5.1	Relative humidity	(See 3.2)
3.5.2	Structural moisture content	Long term analysis on interstitial moisture in buildings retrofitted using a Whole Building approach. Assessment of interventions that improve both thermal efficiency and moisture risk within solid walls.

3.6.1	Energy performance data	There is still no evidence-based assessment of the savings attributable to individual or combined retrofit measures - because the variables are so numerous. Can smart metering (due 2020) be used to gather energy use data at sufficient scale so that policy can be informed by data rather than predictions? The required analysis would also require more research on the embodied energy of retrofit (see 3.7 below).
3.6.6	Heating and fuel sources	Work out the impact on EPC ratings of traditional buildings, of changing to the EIR as the headline rating, then switching to a range of Bio fuels including bioLPG and a partially decarbonised gas grid. Note that NT and others in the MEES group have undertaken to do this modelling so the results should be available by summer 2020. Consider the potential for greater use of hydrogen as an inter-seasonal energy store (summer power to winter heat).
3.6.7	Overheating and cooling	The Salford research needs to be used to inform a much wider range of buildings, which would require long term modeling for different build types using predicted summer temperatures.
3.7	Embodied carbon and the circular economy	A tool is needed which will allow comparison of embodied carbon and all other environmental impacts of different retrofit strategies with the savings that they may achieve, for a particular building, over a variable timescales.
3.9	Public and political understanding	Assess the level of public understanding of traditional buildings, and identify the mechanisms needed to disseminate key information to protect energy, health and heritage.
3.10	Repair, maintenance and enabling works	A research project is needed to gather data on energy use before and after a package of basic repairs (sealing round windows, draught proofing, repointing, repairing leaks, fixing ground levels and vents and drying out the building). Also identify co-benefits.
3.11	Professional understanding	What is now needed is research to assess the current level of knowledge about traditional buildings among designers, BCOs and contractors, and then a route map to ensure that all professionals involved in the retrofit process, from survey to post-occupancy monitoring, have the requisite understanding of traditional buildings. The research is likely to be most effective if the relevant institutions (including CITB, CIAT, CIOB, IHBC, LABC, RICS, RIBA) were involved in its commissioning.
3.12	Costs of retrofit measures	For non-domestic buildings, it would be necessary to pool actual costs (inflation-adjusted up to the current year) from a variety of individual retrofits to come up with a reliable method of estimating costs per m^2 of various retrofit strategies, including all associated work.
3.13	Material properties and technical specifications	Thermal and moisture performance of insulated lime renders.

4.2 Ongoing academic research programmes

This section only addresses academic programmes and should not be regarded as exhaustive. Indeed one key recommendation is that a mechanism is put in place to track current and future planned research from all key institutes, government departments and industry bodies operating in this sector.

1. CREDS (Centre for Research into Energy Demand Solutions) @ Oxford University Centre for the Environment https://www.creds.ac.uk/

Health and energy efficiency (April 2018 to March 2020)
There is growing evidence that energy efficiency can improve health. In recognising this impact, the UK Government's main model for evaluating domestic energy efficiency incorporates a health impact assessment to allow policy makers to evaluate the health cost benefit of different energy efficiency technologies. In many cases, health savings are greater than fuel savings. However, the model needs to be grounded in more robust empirical evidence, the UK is uniquely placed to do this as it has world-leading databases of health, temperature, energy use and energy efficiency interventions, which if linked can develop our understanding of the relationship between temperature, energy demand, energy performance, and health, particularly among vulnerable and fuel poor households. What we are asking:

- What is the impact of building energy efficiency, energy demand and temperatures on health (physical and mental) and wellbeing?
- What health and wellbeing metrics have direct causal links to energy efficiency?
- What are the potential deleterious effects of isothermal temperatures on humans?
- What is the impact of cold homes on physical and mental health?
- What are the health implications of improving lower EPC band housing?

2. CREDS (Centre for Research into Energy Demand Solutions) @ Oxford University Centre for the Environment

In-use energy performance certificates (EPCs) (April 2018 to April 2020)
What analysis and data is required to deliver digitally generated in-use building efficiency certificates, consistently outperforming Energy Performance Certificates (EPCs)? The uptake and rate of deployment of energy efficiency technologies is constrained by their performance within the system in which they are installed. EPCs were introduced to support energy demand reductions in the built stock, yet they don't close the performance gap because they are not based on in-use energy data and have been repeatedly shown to be inaccurate. This project develops data analysis methods to automatically create in-use EPCs from smart meter data that are more reliable than those derived from site survey and SAP calculation. It enumerates the energy performance of the property and the uncertainty in the result, plus the improvements to the accuracy and insights available from additional low-cost data streams, such as internal temperatures. What we are asking:

- Is it possible to develop a domestic Energy Performance Certificate (EPC) using just smart meter and other data which is more reliable, and cheaper than a physical survey based EPC?

3. Welsh School of Architecture – Sustainable Design of the Built Environment http://www.sudobe.co.uk/

Improving the performance of existing buildings
New buildings form the central focus of most research on the sustainability of the built environment. However, most of the buildings we will be using in 60 years from now have already been built. Many of these buildings embody precious resources and can be seen as important assets for future generations. Many, however, are also wasteful in their use of energy and potentially harmful to their occupants. The prevailing emphasis on new build solutions, perhaps because they offer fewer obstacles and are arguably more exciting, diverts attention from the problems of making our existing stock more sustainable. This is a neglected area of research, which C-SuDOBE proposes to address in future research.

4. Energy Efficiency in the Built Environment (EEBE) Research Programme – https://www-csd.eng.cam.ac.uk/themes0/energy-demand/energy

5. University of Nottingham: Buildings, Energy and Environment Research Group – https://www.nottingham.ac.uk/research/groups/buildings-energy-and- environment/index.aspx

Research includes:
- EU-HERB Project – Holistic Energy Efficient Retrofitting of Residential Buildings
- EnviroUp External Wall Insulation
- SCiNET – Greening the Box: Retrofit of hard to treat housing
- In-Use and Post Occupancy Evaluation – The Green Street
- CALEBRE – Consumer Appealing Low Energy Technologies for Building Retrofitting

6. Loughborough University – School of Architecture, Building and Civil Engineering https://www.lboro.ac.uk/departments/abce/research/

Department on Building Energy has worked with HE in daylighting in heritage buildings.

7. Salford University – Applied Buildings and Energy Research Group - https://www.salford.ac.uk/research/uprise/research-groups/applied-buildings-and- energy

The core principle of the Applied Buildings and Energy Research Group is to fulfil the need for an inter-disciplinary, evidence-led research team to support the delivery of a reduction in the end use energy demand of buildings.

This principle leads to of the following key aims:

- Support the development of effective data collection and monitoring approaches to assess the energy performance of buildings
- Collect evidence with regards to the performance of buildings in terms of their fabric and systems performance
- Collect evidence with regards to the influence of human behaviours and the impact on adoption of building improvements and the influence on end use energy demand
- Collect evidence with regards to the implementation of sustainable building refurbishment
- Work with relevant stakeholders to develop practical solutions to improve the performance of buildings as driven by the evidence.

8. York University – Centre for Conservation Studies
https://www.york.ac.uk/archaeology/research/research-strengths/heritage- conservation/centre-for-conservation-studies/#tab-4

With an outstanding international reputation, the Centre for Conservation Studies leads research, education and training in the conservation of cultural heritage for students and professionals around the world. It maintains its established links, and welcomes new ones, with key organisations, institutions and professionals in the conservation and management of cultural heritage. York University has worked with English Heritage on practical projects based around York.

9. Coventry University – several projects running:

See: https://www.coventry.ac.uk/research/research-directories/?var2=938

OWLS – Off-Site Wrap-Around Large Scale Retrofit:
OWLS is a collaboration between Cogent Labs, Encraft, Solihull Community Housing, and Beattie Passive. This project aims to develop a rapid, highly replicable, and innovative approach to external insulation of walls and roofs by applying modern methods of construction to retrofit, complemented by innovative approaches to performance monitoring.

Smarter Households
Smarter Households is a five-year research project that aims to develop an interactive digital system designed to make it easier for households to see, understand and manage their energy consumption and bills.

RESSEEPE: REtrofitting Solutions and Services for the enhancement of Energy Efficiency in Public Edification
(RESSEEPE) – Non domestic – brings together design and decision making tools, innovative building fabric manufacturers and a strong demonstration programme to demonstrate the improved building performance through retrofitting. The core idea of the RESSEEPE project is to technically advance, adapt, demonstrate and assess a number of innovative retrofit technologies. Reductions in the area of 50 per cent will be achieved in terms of energy consumption. A systemic process will be also implemented that will allow

the selection of the best possible retrofitting mix, customised to the needs of the particular buildings.

10. Caledonian University – BEAM – https://www.gcu.ac.uk/assetmanagement/
    News: Study aims to stamp out fire risk to historic buildings

11. University of Bath – Centre for Energy and the Design of Environments https://www.bath.ac.uk/research-centres/centre-for-energy-and-the-design-of- environments/

Moisture movement beneath solid ground floors in historic buildings https://www.bath.ac.uk/projects/moisture-movement-beneath-solid-ground-floors- in-historic-buildings/ (Predicted 2022)

12. University of Bath – BRE Centre for Innovative Construction Materials https://www.bath.ac.uk/research-centres/bre-centre-for-innovative-construction- materials/

13. UCL Bartlett https://www.ucl.ac.uk/bartlett/energy/research/energy-and- buildings

PACE Research Group: People, Adaptability, Comfort and smart Energy
Physical Characterisation of Buildings (PCB) Group: investigates the energy performance of buildings. Primarily addressing (hygro)thermal performance and ventilation, the group applies physics and statistical techniques to both develop methods for the evaluation of the thermodynamic behaviour of buildings and to derive a greater appreciation of the performance of the built stock.

14. University of Southampton – Sustainable Energy Research Group (SERG) http://www.energy.soton.ac.uk/about/

SERG's research includes:
- Studies and system analyses of renewable energy systems
- Development of novel design methods for renewable energy systems and for energy conservation

15. Heriot Watt University – Institute for Sustainable Building Design https://researchportal.hw.ac.uk/en/organisations/institute-for-sustainable-building-design

APPENDIX 1: GAP ANALYSIS CODES

Section	Code	Title
3.1	A	Human health
3.2	B	Ventilation
3.3	C	Thermal comfort
3.4	D	Character and significance
3.5		Moisture management
3.5.1	E	Relative humidity
3.5.2	F	Structural moisture content
3.6		Energy performance
3.6.1	G	Energy performance data
3.6.2	H	Building fabric elements (walls, floors, roof, windows)
3.6.3	J	Thermal bridging
3.6.4	K	Airtightness
3.6.5	M	Heating approach
3.6.6	N	Heating and fuel sources
3.6.7	P	Overheating and cooling
3.6.8	Q	Lighting
3.7	R	Embodied carbon and the circular economy
3.8	S	Occupant interactions
3.9	T	Public and political understanding
3.10	U	Repair, maintenance and enabling works
3.11	V	Professional understanding
3.12	W	Costs of retrofit measures
3.13	X	Material properties and technical specifications

APPENDIX 2: REPORTS, CLASSIFICATIONS, URLS AND ABSTRACTS

The list below contains some items of guidance, in addition to original research, as it demonstrates that certain knowledge has entered the mainstream and been embedded into best practice - thus potentially diminishing the research requirement in certain areas.

Author(s)	Date	Title	GA Code	URL	Free/ pay	Abstract
Ahrentzen, S, Erickson, J and Fonseca, E	2015	Thermal and Health Outcomes of Energy Efficiency Retrofits of Homes of Older Adults	A	https://www.researchgate.net/publication/280869189_Thermal_and_health_outcomes_of_energy_efficiency_retrofits_of_homes_of_older_adults	Pay	Mitigation of thermal stress and adverse indoor climatic conditions is important to older low-income populations whose age, health and economic circumstances make them vulnerable to indoor environmental conditions. This research examines whether energy retrofits in affordable housing for older adults can also improve indoor climatic (such as temperature, humidity, air infiltration) conditions and whether such improvements correspond with improved health and comfort of residents. An apartment complex for low-income older adults in Phoenix was the study site.
Aktas, Y D et al	2019	Mould Testing and Benchmarking: a public report	E, F	https://ukcmb.org/2019/10/27/mould-testing-and-benchmarking-a-public-report/	Free	The understanding of indoor mould is complex and sometimes contentious. Reputable organisations including the World Health Organisation (WHO), the US based Institute of Medicine (IoM) and the National Health Service (NHS) all affirm that high levels of mould in

						buildings are unhealthy for occupants, and can lead to respiratory and other health problems. Furthermore, moulds can clearly cause fabric decay as well as surface degradation and staining. The environmental conditions and building context within which such moulds develop and affect the building fabric are relatively well understood. However, moulds which might affect human health are not so well understood, partly because the connections between moulds and health are highly complex, but also because we do not currently have a standardised or robust method of measuring indoor mould, or benchmarks for what is a “normal” or “acceptable” level in houses. The research outlined in this report is an attempt to address this problem of measurement, and provide a way forward for research in this area.

Author(s)	Date	Title	GA Code	URL	Free/ pay	Abstract
Anaf, W and Schalm, O	2019	Climatic quality evaluation by peak analysis and segregation of low-, mid-, and high-frequency fluctuations, applied on a historic chapel, Building and Environment, Volume 148, 15 January 2019, Pages 286-293	B, E, M, P	https://www.sciencedirect.com/science/article/abs/pii/S0360132318307133	Pay	Heritage-related guidelines and standards recommend stable climatic conditions, since these contribute to the extension of heritage collections life. As a result, numerous museums and other heritage institutions implement (expensive) mitigation measures to achieve stable conditions. Nevertheless, temperature and relative humidity fluctuations are often still observed. This contribution demonstrates that the analysis of temperature and humidity peaks and drops helps to identify hazards which cause fluctuations in different frequency ranges. This hazard identification provides information on the type of mitigation actions that are required in the near future and in which order they need to be implemented. The approach is illustrated with a case study. A 22 month monitoring campaign was performed in a chapel in the centre of Antwerp (Belgium) where the climatic conditions are controlled with a heating, ventilation and air conditioning (HVAC) system. Low-, mid- and high-frequency fluctuations were separated and discussed for their hazards.

Author(s)	Date	Title	GA Code	URL	Free/ pay	Abstract
Archimetrics	2019	The SPAB Building Performance Survey Final Report	F, G	https://www.spab.org.uk/sites/default/files/documents/MainSociety/Advice/SPAB%20Building%20Performance%20Survey%20Final%20Report%202019-small.pdf	Free	In 2011, the Society for the Protection of Ancient Buildings embarked on a long-term research project to assess the effects of energy efficiency refurbishment in a variety of traditional buildings. The project measured several metrics in seven buildings prior to changes made in the name of improving energy efficiency. This 'base case' performance data included: wall U-values; interstitial and internal surface wall moisture; room conditions, including air quality, air permeability, and a thermographic survey. Following refurbishment these measurements were repeated, some over six years, with the project focusing, in particular, on the performance of moisture within insulated wall fabric.
Atkins, R and Emmanuel, R	2014	Could refurbishment of traditional buildings reduce carbon emissions?	G, S	https://www.researchgate.net/publication/270799495_Could_refurbishment_of_traditional_buildings_reduce_carbon_emissions	Free	Evaluate the post occupancy performance of a typical "traditional" building using multiple post occupancy evaluation (PoE) protocols against design intents to learn lessons about their suitability in meeting UK's climate change reduction targets. The paper aims to discuss these issues. Design/methodology/approach – PoE studies of a single case study, Norton Park, using three PoE methodologies. Gaps and overlaps between the PoE protocols are assessed and their role in

						improving energy and carbon emission performance of traditional buildings is explored. Findings – Refurbishment of the type undertaken in this case study could halve the energy use in traditional buildings with comparable savings in CO2 emissions.
Atkinson, J	2015	Evaluating retrofitted external wall insulation	C, G, J, H, W	https://repository.cardiffmet.ac.uk/handle/10369/7515	Free	This paper presents an overview of an evaluation of the installation of retrofitted external wall insulation (EWI) at existing dwellings in Swansea. The EWI was funded and installed through the Welsh Government's Arbed scheme. The main focus of the evaluation was identifying the occurrence of potential thermal bridges as these can undermine the overall effectiveness of the EWI. Furthermore, thermal bridging can lead to internal condensation on the walls and ceilings and thus damp and mould growth, which poses a health risk to occupants. Working in collaboration with two housing associations who implemented the retrofitted EWI, the data collection involved field observations to record the technical solutions that were implemented on site and pre-retrofit and post-retrofit thermographic surveys to assess heat loss through the external walls of the

						dwellings. The key findings from the evaluation are the occurrence of potential thermal bridges due to a lack of preliminary surveys and appropriate technical details at the design stage of the retrofit process and poor execution quality on site. This paper will be of interest to stakeholders involved in retrofitting EWI, in particular Architectural Technologists who are responsible for the detailing of critical junctions at the design stage of a retrofit project.
Atkinson, J et al	2017	Relieving Fuel Poverty in Wales with External Wall Insulation	G, W	https://repository.cardiffmet.ac.uk/handle/10369/9120	Free	This paper discusses the results of five case studies of dwellings in Swansea, UK, that received retrofitted external wall insulation through the first phase of the Welsh government's 'Arbed' scheme in Wales between 2010 and 2012.

Author(s)	Date	Title	GA Code	URL	Free/ pay	Abstract
Barclay, M, Holcroft, N and Shea, A	2014	Methods to determine whole building hygrothermal performance of Hemp-lime buildings	X	https://purehost.bath.ac.uk/ws/portalfiles/portal/62481971/MB_BldgEnv.pdf	Free	Hemp-lime is a potentially useful building material with relatively low embodied energy and moderate-to-good thermal performance, coupled with good moisture buffering capacity. However, some uncertainty remains with regards to its in-situ thermal performance and the capability of building energy simulation tools to accurately predict envelope performance and subsequent energy demand of buildings constructed of such vapour-active materials. In this paper we investigate the hygrothermal performance of buildings with walls constructed from hemp-lime.
Beagon, P, Boland, F and O'Donnell, J	2018	Quantitative evaluation of deep retrofitted social housing using metered gas data, Energy and Buildings, Volume 170, 1 July 2018, Pages 242-256	G, S	https://www.sciencedirect.com/science/article/abs/pii/S0378778817339592	Pay	Research into home energy retrofit is important because most existing homes will operate in 2050. A lack of funding or incentives often prevents home energy retrofit, particularly of social housing. This study analysed retrofitted Irish social housing and their gas meter data, including pre-payment meters that require regular "top-ups" purchased from shops. The data comprised records from 100 retrofit and control group homes throughout 2013–2015. A novel evaluation of retrofitted rented homes processed meter data into multiple metrics. Gas consumption is computed

						per house and weather correction is incorporated, enabling statistical testing of the retrofit. A “difference in difference” technique compared the retrofit and control groups. Gas consumptions of the most popular building type are plotted as distribution curves before and after retrofit. Subsequently the energy use intensity (kWh/m2/year) is computed per home; leading to calculation of the prebound effect. In social housing, the prebound effect quantifies energy under consumption due to self-rationing. Retrofit significantly reduced gas consumption, and reduced its variance among homes. A small positive skewness in the statistical distribution of home gas consumption prevented characterisation as a normal distribution. The prebound effect is high, but alleviated by the retrofit. Finally, retrofit extended average pre-payment intervals.

Author(s)	Date	Title	GA Code	URL	Free/ pay	Abstract
Becherini, F et al	2018	Characterisation and thermal performance evaluation of infrared reflective coatings compatible with historic buildings, Building and Environment, Volume 134, 15 April 2018, Pages 35-46	D, H	https://www.sciencedirect.com/science/article/abs/pii/S0360132318301069	Pay	Two infrared reflective coatings recently developed as part of the EFFESUS European research project are characterised and evaluated in this paper. Thermal performance, durability, compatibility with historic fabric, and reversibility are all analysed. The results of extensive research that include laboratory analysis of selected substrates, measurements on a large-scale traditional masonry mock-up, thermodynamic simulations, and finally application in to a real historic building in Istanbul, all support the potential of the new coatings to improve the thermal performance of historic buildings, in keeping with their visual integrity and cultural value. Besides their reflective properties, proven by the thermal stress reductions on the treated surfaces, the new coatings are characterised by low visual impact, easy application, material compatibility, and reversibility after application, as well as durability over time.

Author(s)	Date	Title	GA Code	URL	Free/ pay	Abstract
BEIS	2019	NEED database	G	https://www.gov.uk/government/statistics/national-energy-efficiency-data-framework-need-report-summary-of-analysis-2019	Free	Summary of analysis using the National Energy Efficiency Data Framework using consumption data from 2005 to 2017.
BEIS	2017	What does it cost to retrofit homes?	W	https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/656866/BEIS_Update_of_Domestic_Cost_Assumptions_031017.pdf	Free	DECC wishes to update its assumptions about the cost of upgrading the energy efficiency of homes. CAR interviewed organisations carrying out energy improvements to homes, asking how much it actually costs to do the work. We also collected data from retailers about the current cost of energy efficiency measures – from insulation to LED lights.
BEIS	2017, updated 2020	Domestic private rented property: minimum energy efficiency standard - landlord guidance	A, B, C, D, E, F, S, T, V	https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/882957/Domestic_Private_Rented_Property_Minimum_Standard_-_Landlord_Guidance_2020.pdf	Free	Technical advice for landlords on making energy efficiency improvements is notable in Government guidance, and has relevance far beyond its intended audience. It explains the need for special care in retrofitting heritage buildings, and the different moisture properties of traditional as opposed to modern buildings. It promotes the whole house approach. It cautions against the cumulative effect on buildings of even small energy efficiency improvements.

Author(s)	Date	Title	GA Code	URL	Free/ pay	Abstract
Benadji, A	2012	Testing of a method for insulation of masonry and lath walls in a traditional Scottish domestic building	H	http://www.cicstart.org/userfiles/file/IR12_60-69.pdf	Free	The main aim of this research project is to develop and test the feasibility of a method of insulating an existing house whilst maintaining its original architectural features. The project comprised the following phases: Phase 1 - Building selection and site surveying; Phase 2 - Testing method preparation; Phase 3 - Site preparation; Phase 4 - Application, and Phase 5 - Remedial work.
Bennett, G	2019	Heating systems through the lens of the boiler: Detailed case studies to inform current and future heating system design	M, N	https://doi.org/10.1177/0143624419893662	Pay	Boilers in hydronic heating systems are the norm in the UK. Through case study analysis, covering four houses with gas central heating systems for over one year and utilising novel monitoring of the on-board diagnostic data of the boilers, performance issues were identified in this mature technology. ON/OFF cycling behaviour and oversizing were prevalent with boilers consistently unable to modulate low enough to match the building space heating demand. Cycling behaviour resulted, known to be detrimental to efficiency, with the majority of boiler operations lasting less than 10 minutes. Targeted case study analysis of incumbent technologies, such as boilers, utilising the latest in data collection techniques and connected appliances provides a cost effective

						insight to broader issues. Implications for domestic energy demand range from incremental improvements in boiler system efficiency by addressing cycling to the updating of building energy assessment models (such as the Standard Assessment Procedure) to reflect and reward the benefits of good installation practices. An improved understanding of boiler operation may support improved product design and installation practices and are beneficial to the next generation of domestic heat, such as heat pumps.
Better Buildings Partnership	2018	Minimum Energy Efficiency Standards and Heritage Properties: Mitigating risks through the procurement and interpretation of Energy Performance Certificates	B, D, G, K, N, Q, T	http://www.betterbuildingspartnership.co.uk/mees-and-heritage-properties	Free	The introduction of Minimum Energy Efficiency Standards has brought EPC ratings sharply into focus as an important factor in leasing and investment decisions. However, as EPCs are predominately designed to rate modern buildings, they do not always account for the traditional characteristics of heritage properties or propose the most appropriate energy efficiency recommendations.

Author(s)	Date	Title	GA Code	URL	Free/ pay	Abstract
Bio Intelligence Service, Ronan Lyons, IEEP	2013	Energy performance certificates in buildings and their impact on transaction prices and rents in selected EU countries	G, T	https://ec.europa.eu/energy/sites/ener/files/documents/20130619-energy_performance_certificates_in_buildings.pdf	Free	Provision of clear and reliable information at affordable cost and at the appropriate time to prospective tenants and buyers is crucial for making energy efficiency investments more attractive. The EPC can thus be expected to provide an incentive for builders and owners to invest in improving energy efficiency, as it can be hypothesised that improving the energy performance of a building should lead to higher sale prices and rents on the market. This study explores whether there is a link between the energy performance of buildings as expressed by EPCs and their value, whether rented or sold; in other words, whether or not the EPC energy rating of a property has an effect on the purchase or rental price when a property is listed or transacted.

Author(s)	Date	Title	GA Code	URL	Free/ pay	Abstract
Biseniece, E et al	2018	Study of Hygrothermal Processes in External Walls with Internal Insulation	F	https://content.sciendo.com/view/journals/rtuect/22/1/article-p22.xml	Free	Being an important contributor to the final energy consumption, historic buildings built before 1945 have high specific heating energy consumption compared to current energy standards and norms. However, they often cannot be insulated from the outside due to their heritage and culture value. Internal insulation is an alternative. However internal insulation faces challenges related to hygrothermal behaviour leading to mold growth, freezing, deterioration and other risks. The goal of this research is to link hygrothermal simulation results with experimental results for internally insulated historic brick masonry to assess correlation between simulated and measured data as well as the most influential parameters. The study is carried out by both a mathematical simulation tool and laboratory tests of historic masonry with internal insulation with four insulation materials (mineral wool, EPS, wood fibre and granulated aerogel) in a cold climate (average 4,000 heating degree days). We found disparity between measured and simulated hygrothermal performance of studied constructions due to differences in material parameters and initial conditions of materials.

BMJ	2014	Home Energy Efficiency and Radon Related Risk of Lung Cancer: Modelling Study	A	https://www.bmj.com/content/348/bmj.f7493.long	Free	Investigate the effect of reducing home ventilation as part of household energy efficiency measures on deaths from radon related lung cancer.
BRE	2014	External Wall Insulation Current Practice Review and Guidance for Improvement	F, G, H, J, P, V	https://www.serslt d.co.uk/wp-content/uploads/2018/01/SERS-BRE-Report-External-Wall-Insulation-Current-Practice-Review-and-Guidance-for-Improvement.pdf	Free	This review and report undertaken on behalf of SERS Energy Solutions Ltd to understand the current standard of workmanship and quality control on site looks to analyse current practice and methods of work when undertaking external wall insulation. It applies equally to when it is located either externally or internally. It delivers a critical assessment of current practice in the industry and provides a suggested route for improvement.
BRE	2014	The risks to housing from overheating	C	https://www.theccc.org.uk/wp-content/uploads/2014/07/2-The-risk-to-housing-from-overheating-FINAL-4_PDF_2-with-foreword-BRE.pdf	Free	In 2010 around 122,000 English dwellings assessed as at risk from overheating, of which 1,000 were assessed as having an extreme risk. This report was commissioned to: • understand what data is available on overheating risk • what sort of results the data provides at a national level • what sort of dwellings are affected by the risk of overheating • whether the research can be used as a benchmark to re-visit in future years in order to establish whether the risk is becoming greater or not.

Author(s)	Date	Title	GA Code	URL	Free/ pay	Abstract
BRE	2016	Solid wall heat losses and the potential for energy saving: Consequences for consideration to maximise SWI benefits: A route-map for change	F, H, J	https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/787456/Solid_wall_heat_losses_and_the_potential_for_energy_saving_route-map.pdf	Free	To enable DECC to consider changes to the methods of undertaking external wall insulation it is important to understand the context and complexity of the issues currently faced. A number of detailed reports on these issues have been produced by bodies such as BRE, EST, English Heritage, Historic Scotland, STBA and SPAB. This document builds on these reports and offers a route map understanding the issues and risks that can affect the performance of solid wall insulation (particularly external wall insulation) more fully and safely. These include the assessment of the buildings (condition and exposure), selection of materials to be used (suitability), workmanship used to undertake the works, and the effect on the fabric of moisture. Further research into the whole approach to improving performance including moisture physics, modelling and material data forms a significant part of this. An important factor affecting damp specifically in older buildings is the difference in building physics and construction between older and more modern buildings. Unfortunately a one size fits all solution to SWI is therefore not appropriate and can result in underperformance and/or premature failure of the system or building

						components. Additionally historical buildings may be at greater risk of disrepair which also complicates the installation of SWI. More modern construction methods rely on the creation of a cavity or the use of cementitious or impervious materials to provide protection from moisture ingress, whereas in older buildings in their original state moisture penetrated the structure and then that moisture was allowed to evaporate and vacate the building through the chimney and other openings (such as air bricks and infiltration). To allow this process to continue it is important that improvements or interventions that may alter or restrict the passage of the moisture receive careful assessment and consideration.
BRE for DECC	2015	Solid wall heat losses and the potential for energy saving – Literature review	A, B, C, D, E, F, G, H, J, K, S, T, V, X	https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/396363/solid_wall_insulation_literature_review.pdf	Free	The key publication to emerge from BRE's Solid Wall Study for DECC. It highlights issues relating to: measurement of heat losses; actual savings achieved being far less than those predicted; the flaws arising from using standard approaches for materials with variable properties, and from assumptions which misrepresent construction quality and energy consumption prior to the retrofit; unintended consequences due to poor workmanship as well as mistaken initial

						assessments of suitability of the building for wall insulation, with potentially severe effects on occupants' health as well as on the building, arising from 1) overheating in buildings with SWI, and 2) changes to the distribution of moisture in a building following an intervention; the need for heritage buildings (which it notes "represent approximately 35 per cent of the existing dwellings in the UK as a whole and a large proportion of solid wall buildings") to be considered as complex system; and the increased likelihood of moisture problems if impermeable insulation and vapour barriers are installed.
Bristol City Council	2015	Bristolian's guide to Solid Wall Insulation: A guide to the responsible retrofit of traditional homes in Bristol	D, E, F, H, J, K, S, U, V	http://files.site-fusion.co.uk/webfusion58199/file/2015_bristolsolidwallinsulationguidance.pdf	Free	This guidance has been produced specifically for people living in and working on solid-walled houses in Bristol. Its primary audience is householders, but professionals and installers will also benefit from reading the guidance as many of the details are vital for effective retrofit projects.

Author(s)	Date	Title	GA Code	URL	Free/ pay	Abstract
BSI	2013	British Standard BS7913:2013 Guide to the conservation of historic buildings	B, C, D, E, F, G, H, J, K, S, U, V, X	https://shop.bsigroup.com/ProductDetail/?pid=000000000030248522	Pay	This British Standard covers heritage values and significance, and using significance as a framework for managing the historic environment. It promotes repair ("elements such as walls can be over a third less energy efficient if damp"), retaining and re-using existing buildings: "The most effective way of ensuring energy efficiency and sustainability is to keep historic buildings in good repair so that they last as long as possible, do not need replacement and do not suffer from avoidable decay that would require energy and carbon to rectify." It sets out processes for planning and assessing, from strategic level to individual buildings, including condition surveys, building pathology, and repair issues. It covers interventions, maintenance and project management.
BSI	2017	Conservation of cultural heritage. Guidelines for improving the energy performance of historic buildings: EN16883:2017	D, V	https://shop.bsigroup.com/ProductDetail/?pid=000000000030322690	Pay	This European Standard provides guidelines for sustainably improving the energy performance of historic buildings, e.g. historically, architecturally or culturally valuable buildings, while respecting their heritage significance. The use of this standard is not limited to buildings with statutory heritage designation. It applies to historic buildings of all types and ages. This European Standard presents a normative

						working procedure for selecting measures to improve energy performance, based on an investigation, analysis and documentation of the building including its heritage significance. The procedure assesses the impact of those measures in relation to preserving the character-defining elements of the building.
BSI	2020	PAS 2035/2030: 2019 Retrofitting dwellings for improved energy efficiency. Specification and guidance	U, V	https://shop.bsigroup.com/ProductDetail?pid=00000000030400875	Pay	Sponsored by the UK Government's Department for Business, Energy and Industrial Strategy (BEIS), this PAS is a key document in a framework of new and existing standards on how to conduct effective energy retrofits of existing buildings. PAS 2035 covers how to assess dwellings for retrofit, identify improvement options, design and specify Energy Efficiency Measures (EEM) and monitor retrofit projects. Meanwhile PAS 2030, which was redeveloped in conjunction with PAS 2035, covers the installation, commissioning and handover of retrofit projects. Organisations which trade using the Trustmark Government endorsed Quality scheme are required to comply with PAS 2035. PAS 2035/2030:2019 is available as an online interactive product. This product also includes access to PAS 2030:2017.

Author(s)	Date	Title	GA Code	URL	Free/ pay	Abstract
Building Conservation	2017	Heritage Retrofit - The Building Conservation Directory Special Report	B, D, E, F, G, H, M, N, R, T, V	https://buildingconservation.com/books/retrofit2017	Free	A series of reports on heritage retrofit, including understanding the risks of retrofit, improving energy efficiency in traditional homes, and indoor air quality and ventilation.
CAR Ltd	2017	Solid Wall Insulation: Best Practice and Innovation Report for the Department of Business, Energy and Industrial Strategy	G, V	https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/658604/BEIS_-_SWI_Innovation_Final_Report_-_FINAL_Approved.pdf	Free	This report compares the features of eight materials for solid wall insulation that are currently available on the market, and considers new methods for insulating walls that could increase take-up of wall insulation in future.
Carbonara, G	2015	Energy efficiency as a protection tool, Energy and Buildings, Volume 95, 15 May 2015, Pages 9-12	D, H	https://www.sciencedirect.com/science/article/abs/pii/S0378778814011256	Pay	The relationship between renovation, system engineering and environmental physics is at present not as developed as the one between renovation and full accessibility needs, that is the elimination of architectural barriers, or better still between renovation and structural consolidation works. As a matter of fact, the latter, in the past 40 years, has been subject to deep changes which resulted in a new scientific approach and new methods which are translated in wide spread practices that are by far more respectful than was the case in the mid twentieth century. This progress has

						meant that technical operations have undergone a real “historicisation” to respond to a “critical” reason, more than to a technical one, in view of the issue at stake, renovation and cultural objects. It can be stated that these studies resulted in a less abstract, less mathematical approach, yet not less rational or scientific, to address the issue of ancient wall structures, which entailed a better and deeper insight into what they are like and what their function is, with an improved familiarity with these structures. This new approach allowed the development of innovative consolidation works able to preserve the well-rooted “historicity” of the structures, without prejudice to the safety requirements for the monuments and the people.

Author(s)	Date	Title	GA Code	URL	Free/ pay	Abstract
Chambers, J et al	2015	How solid is our knowledge of solid walls? - Comparing energy savings through three different methods	G, H	https://discovery.ucl.ac.uk/id/eprint/1496025/	Free	Recent UK-based studies have shown a performance gap between the energy performance of buildings calculated using tabulated thermophysical properties of solid walls and that estimated from in-situ measurements. Solid-walled buildings have been targeted by UK Government policies and incentive schemes to meet climate change mitigation targets and improve the efficiency of the building stock, as they are less efficient and more expensive to treat than cavity walls. Since it is common practice to estimate energy use and potential savings for buildings retrofit assuming standard values from the literature, the performance gap may have serious implications on the decision-making and the cost-effectiveness of energy-saving interventions. The aim of this paper is to compare and contrast the results obtained from three different methods for estimating normalised dwelling energy demand: a) the UK energy performance certificate (EPC) method, which uses the standard assessment procedure (SAP) with tabulated inputs (the business as usual case); b) the SAP calculated using empirical air change rates from pressure tests and U-values estimated analysing monitored data with a Bayesian-based dynamic method developed by the authors; c) a normalised annual consumption (NAC) method based on

						empirical energy consumption data from smart meter and weather data. The analysis is performed on a sample of dwellings from the Energy Saving Trust "Solid Wall Field Trials" dataset. Results show that EPC estimates are systematically higher (between 7.5 per cent and 22 per cent) than SAP. Conversely, the NAC displayed a large range of relative differences (between -77 per cent and +99 per cent) compared to the EPC. This raises questions about the relative merits and purpose of the EPC and SAP bottom up methods compared to the smart-meter data-driven NAC method. Further research is suggested using SAP 2009 to isolate the thermal component of energy demand and compare it directly with the NAC component.
Chatzivasileiadi, A, Ampatzi, E, and Knight, I P	2019	The impact of battery storage technologies in residential buildings with sub-daily autonomy and EV contribution	N	http://orca.cf.ac.uk/124162/1/CISBAT_AC_iv_rev_2.pdf	Free	This study has been undertaken to gain a better understanding regarding the choice and impact of battery storage technologies in a use case with contribution of an electric vehicle to the overall domestic consumption. The study assessed the storage requirements of nine battery technologies for different residential building scales at the distribution level considering sub-daily autonomy periods.

Author(s)	Date	Title	GA Code	URL	Free/ pay	Abstract
Chitnis, M, Fouquet, R, and Sorrell, S	2020	Rebound Effects for Household Energy Services in the UK	S	https://www.iaee.org/en/publications/ejarticle.aspx?id=3528&id=3528	Pay	This study estimates the combined direct and indirect rebound effects from energy efficiency improvements in the delivery of six energy services to UK households, namely: heating, lighting, cooking, refrigeration and clothes washing; entertainment and computing; and private vehicle travel. We use a unique database on the price and quantity demanded of these energy services over the past half century. We estimate a two-stage almost ideal demand system for household expenditure, using these energy services as expenditure categories. We estimate rebound effects in terms of carbon emissions and only include the 'direct' emissions associated with energy consumption. Our results suggest direct rebound effects of 70 per cent for heating, 54 per cent for private vehicle travel and ~90 per cent for the other energy services. However, these effects are offset by negative indirect rebound effects, that is, indirect rebounds contribute additional emission savings. As a result, our estimates of combined rebound effects are generally smaller, namely 54 per cent for lighting, 55 per cent for heating, 41 per cent for refrigeration and clothes washing, 12 per cent for entertainment and computing, 44 per cent for cooking and 69 per cent for vehicle travel. We also find

						some evidence that rebound effects have declined over time. We provide some important caveats to these results, and indicate priorities for future research.
Chitty, G and Smith, C L	2019	Principles into Policy: Assessing the Impact of Conservation Principles in Local Planning Policy	V	https://www.researchgate.net/publication/335127139_Principles_into_Policy_Assessing_the_Impact_of_Conservation_Principles_in_Local_Planning_Policy	Pay	This paper takes the instance of English Heritage (now Historic England)'s Conservation Principles, Policies and Guidance for the sustainable management of the historic environment (2008) and considers its international hinterland and legacy. While it has no formal status in the heritage protection or planning system in England, this research examines its sustained presence in local heritage planning policy. An examination of local heritage strategy documents shows that Conservation Principles, and the body of early 21st-century European and international thought that it reflects, are embedded in current practice in local authority policy-making. This impact is notable in the context of an English statutory planning and heritage protection system largely unchanged for 30 years, and attests to the agency of innovative international conservation principles despite the inertia of national heritage reform.
Constructing Excellence in Wales	2013	Post installation performance of cavity wall external wall insulation	G, H	http://www.cewales.org.uk/files/2414/7505/5257/Post_Installation_Performance_05_FINAL_ENG.pdf	Free	This report serves to scope the potential issues and unintended consequences regarding the retrofit of cavity wall and

						external wall insulation. Two case studies demonstrating best practice for CWI installation are presented from North and West Wales.
Cornwall Council Historic Environment Service	2016	Improving Energy Efficiency in Historic Cornish Buildings	B, D, E, F, G, H, K, N, Q, R, T, U, W	https://www.cornwall.gov.uk/environment-and-planning/strategic-historic-environment-service/guidance/technical-guidance/improving-energy-efficiency-in-historic-cornish-buildings/	Free	As part of the Heritage Led Regeneration Project 'Camborne, Roskear and Tuckingmill Townscape Heritage Initiatives', guidance has been produced on good practice in upgrading the energy efficiency of historic buildings. The guide provides local examples of good practice along with current costs and performance details of suitable products.

Author(s)	Date	Title	GA Code	URL	Free/ pay	Abstract
Crawley, J, Wingfield, J, and Elwell, C	2018	The relationship between airtightness and ventilation in new UK dwellings	B	https://journals.sagepub.com/doi/pdf/10.1177/0143624418822199	Free	Analysis of a large database of the airtightness of new UK dwellings found that ventilation strategy makes very little difference to airtightness design. For dwellings with MVHR, the results suggest that infiltration levels are too high to maximise the energy savings; for naturally ventilated homes, there may be air quality issues. Coupling airtightness design and ventilation strategy can reduce a dwelling's energy demand and can support achieving the required energy performance rating.
DCLG	2015	English housing survey 2013: energy efficiency of English housing report	G	https://www.gov.uk/government/statistics/english-housing-survey-2013-energy-efficiency-of-english-housing-report	Free	Annual report focusing on the energy efficiency of the English housing stock.

Author(s)	Date	Title	GA Code	URL	Free/ pay	Abstract
DCLG	2015	English Housing Survey - all versions and reports	A, C, E, F, G, P, T, U	https://www.gov.uk/government/collections/english-housing-survey	Free	Information and publications on the English Housing Survey.
De Simon, L	2017	New mathematical approaches to the quantification of uncertainty affecting the measurement of U-value	H	https://www.researchgate.net/publication/321378990_New_mathematical_approaches_to_the_quantification_of_uncertainty_affecting_the_measurement_of_U-value	Pay	This thesis describes the development and validation of a new computational procedure for the calculation of thermal transmittance (U-value) of existing building elements from the measurement of surface heat flux, and surface and nearby air temperatures.
DECC	2014	In-situ measurements of wall U-values in English housing	G, H, V	https://www.gov.uk/government/publications/in-situ-measurements-of-wall-u-values-in-english-housing	Free	On behalf of the Department of Energy and Climate Change, research consultancy BRE has carried out in-situ measurements of wall U-values in approximately 300 domestic dwellings in England, together with more detailed investigations in a subsample of those walls. In addition, laboratory tests have been carried out in order to validate the method of measuring U-values. The research is important in order to understand how the

						walls of homes in the UK are performing in-situ in order to provide realistic estimates of current energy consumption, and to quantify the potential for energy efficiency improvements such as wall insulation.
DECC (Palmer, J and Cooper, I)	2013	Great Britain's housing energy fact file	G, T	https://www.researchgate.net/publication/262493003_United_Kingdom_housing_energy_fact_file	Free	The Housing Energy Fact File aims to draw together most of the important data about energy use in homes in the United Kingdom since 1970. It is intended for policy-makers, researchers, and interested members of the public. Prepared under contract to DECC (now BEIS) by Cambridge Architectural Research, Eclipse Research Consultants and Cambridge Energy.

Author(s)	Date	Title	GA Code	URL	Free/ pay	Abstract
Dublin City Council	2004	Built to last: The Sustainable Reuse of Buildings	D, G, W	http://www.dublincity.ie/sites/default/files/content/Planning/HeritageConservation/Documents/sustainable_reuse_buildings_athusaid_inbhuanaithe_foirgneamh.pdf	Free	The retention, rehabilitation and reuse of older buildings can play a pivotal role in the sustainable development of the city. Dublin City contains many examples of buildings, which, though not protected, have artistic, architectural or historic merit. Many of these buildings are well designed, soundly constructed and fit for continuance of use. In many cases they make a positive contribution to both streetscape and sense of place. In some cases they also serve to protect underlying deposits of archaeology. Equally importantly, the retention and reuse of older buildings can benefit the environment through the reduction in waste generation.
El-Alwani, E M	2016	Modelling the embodied energy of the UK housing stock for shallow refurbishment	H, R, W	https://pdfs.semanticscholar.org/2b6e/1f299f809d6091f2f9c57f5a3defda87efbd.pdf	Free	Renovations must be considered in the light of embodied energy that will be consumed in their undertaking. In this case, embodied energy comprises all the energy inputs that are needed to manufacture the material elements of the building that are being renovated. Great care must be taken to ensure that embodied energy consumed is considered when planning renovations to existing housing stock. This thesis will document how the required reduction in the greenhouse gas emissions from the UK housing stock can be achieved and to outline ways of reducing the impact of

						domestic emissions on the environment, considering at all times, the embodied energy that is required to do so. Secondly, it aims to provide efficient homes with lower energy bills and to convince householders to implement appropriate retrofit solutions to improve the energy efficiency of their dwellings. To achieve this, the Cambridge Housing Model 2010 was used as a direct source of housing data in order to create an embodied energy model that allow a direct comparison of the embodied energy and the operational energy gains and various refurbishment strategies.
Element Energy	2017	Hybrid Heat Pumps Final Report for BEIS	G, M, N	https://www.gov.uk/government/publications/hybrid-heat-pumps-study	Free	Heating and cooling currently accounts for nearly half of UK energy consumption, and around 50 per cent of UK emissions from heating are associated with space heating and hot water in domestic buildings. As such, decarbonisation of domestic space heating and hot water will be vital for the reduction of UK carbon emissions by 80 per cent by 2050 relative to 1990 levels, as required under the Climate Change Act.

Author(s)	Date	Title	GA Code	URL	Free/ pay	Abstract
Eliopoulou, E and Mantziou, E	2017	Architectural Energy Retrofit (AER): An alternative building's deep energy retrofit strategy, Energy and Buildings, Volume 150, 1 September 2017, Pages 239-252	A, G	https://www.sciencedirect.com/science/article/abs/pii/S037877881731561X	Pay	The refinement of architectural space plays a catalytic role in the building's energy balance. A different configuration on the deep energy building retrofit is presented on this paper, by proposing mainly strategies that hierarchise in a high position the invigoration of the building's architectural design principals. These space qualities enable diversity of occupancy, environmental variability and facilitate the building envelope to operate efficiently as climate moderator. The main working hypothesis claims that bioclimatic trends, derived from primary architectural decisions of the early design phase, predispose the final energy performance of the existing building. Based on that, the alternative retrofit proposal called Architectural Energy Retrofit (AER) strategy focuses on the energy genetic code of these basic architectural features. It argues that their holistic revival and refinement, indoors and outdoors will pave the way for the building's energy retrofit and the space's regeneration. As a case study to test this theory, an old and energy-consuming school complex is selected. By applying solely architectural interventions, a reduction of 44 per cent energy demands was achieved. The results highlighted the

						challenges of “quantifying” the energy efficiency of architecture. However, by exploring and focusing on the non-energy, co-benefits, it also seeks to expand the perspective of energy efficiency beyond the traditional measures, by identifying and measuring its impacts across many different spheres. AER, as a counterproposal, wishes to add a new base of discussion on deep energy retrofit strategies as it follows a diametrically opposed direction than the typical practices. The building instead of being “sealed” and its environment kept strictly controlled, it “opens” and interacts with its surroundings.
Elwell, C A et al	2017	The thermal characteristics of roofs: policy, installation and performance	G, H	https://www.researchgate.net/publication/320477141_The_thermal_characteristics_of_roofs_policy_installation_and_performance	Free	This paper investigates the in-situ performance of UK cold pitched roof structures through a case study dwelling of typical construction using site survey, and estimation of U-values through simple calculation and from measured heat flow data. Significant increases of U-values resulted from under- and un-insulated areas due to installation issues, whilst a higher than expected estimated thermal resistance of the roof space and structure was also noted, potentially associated with heat gains. Both issues are expected to be observed more widely in the stock and contribute to a performance gap for roof insulation.

Author(s)	Date	Title	GA Code	URL	Free/ pay	Abstract
Energy Networks Association	2019	Pathways to Net-Zero: Decarbonising the Gas Networks in Great Britain	N	https://wwutilities.co.uk/media/3647/ena-pathways-to-net-zero-report-nov-19.pdf	Free	In this context, the Energy Networks Association (ENA) commissioned Navigant to explore the role that the gas sector can play in the decarbonisation of the Great Britain (GB) energy system. In this report, we demonstrate that low carbon and renewable gases can make a fundamental contribution to the decarbonisation pathway between now and 2050.
Energy Saving Trust	2016	Quantification of non-standard cavity walls and lofts in Great Britain: Understanding the number of dwellings with unfilled non-standard cavity walls and lofts in Great Britain, and information on how these might be insulated	H	https://www.gov.uk/government/publications/quantification-of-non-standard-cavity-walls-and-lofts-in-great-britain	Free	Understanding the number of dwellings with unfilled non-standard cavity walls and lofts in Great Britain, and information on how these might be insulated.

Author(s)	Date	Title	GA Code	URL	Free/ pay	Abstract
English Heritage (Creative and Cultural Skills)	2013	The Historic Environment and Cultural Heritage Skills Survey	V	https://historicengland.org.uk/content/heritage-counts/pub/2013/historic-environment-cultural-heritage-skills-survey-pdf/	Free	Across the historic environment and cultural heritage sector there are a vast number of professionals and volunteers who work tirelessly towards preserving and presenting our heritage assets. However, in recent years concerns have been raised about skills being lost and not replaced. 'The historic environment and cultural heritage skills survey', a major piece of research examining the skills of entrants entering the sector, the skills of current employees and the issues employers perceive to be key in the future.
English Heritage, Historic Scotland and CITB	2013	Skills Needs Analysis 2013 Repair, Maintenance and Energy Efficiency Retrofit of Traditional (pre-1919) Buildings in England and Scotland	V	https://historicengland.org.uk/content/heritage-counts/pub/2013/skills-needs-analysis-2013-repair-maintenance-energy-efficiency-retrofit/	Free	This research was commissioned by English Heritage, Historic Scotland and CITB to provide an update on the National Heritage Training Group (NHTG) Skills Needs Analysis of the built heritage sector reports for Scotland (2007) and England (2008). This new report provides up-to-date evidence and data sets on the demand for and supply of traditional building skills, materials and training related to the repair and maintenance of traditional (pre-1919) buildings in England and Scotland. The scope of this research was also extended to include the skills and training needs for energy efficiency retrofit of traditional (pre-1919) buildings.

Author(s)	Date	Title	GA Code	URL	Free/ pay	Abstract
Eriksson, P et al	2014	EFFESUS Methodology for Assessing the Impacts of Energy-Related Retrofit Measures on Heritage Significance, The Historic Environment: Policy and Practice, Volume 5, 2014 - Issue 2: Energy Efficiency and Heritage Values in Historic Buildings	D	https://www.tandfonline.com/doi/abs/10.1179/1756750514Z.00000000054	Pay	Improving the energy performance of historic districts and their buildings is a balancing act between retaining their heritage significance and allowing the installation of retrofit measures. This paper describes a heritage impact assessment methodology to enable such a balancing process in a well-structured and systematic way. The methodology, developed for the Energy Efficiency for EU Historic Districts' Sustainability (EFFESUS) research project, is one of six impact assessment modules for a decision-support system, a software tool under development as part of EFFESUS. In this paper, the three parts of the methodology - the heritage significance evaluation, heritage impact definitions and heritage balancing process - are discussed and their use illustrated in a case study.
Fabian, P, Adamkiewicz, G and Levy, J I	2012	Simulating indoor concentrations of NO2 and PM2.5 in multi-family housing for use in health-based intervention modeling	A	https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3248980	Free	Residents of low-income, multi-family housing can have elevated exposures to multiple environmental pollutants known to influence asthma. Simulation models can characterise the health implications of changing indoor concentrations, but quantifying the influence of interventions on concentrations is challenging given complex airflow and source

						characteristics. In this study, we simulated concentrations in a prototype multi-family building using CONTAM, a multi-zone airflow and contaminant transport program. Contaminants modeled included PM2.5 and NO2, and parameters included stove use, presence and operability of exhaust fans, smoking, unit level, and building leakiness. We developed regression models to explain variability in CONTAM outputs for individual sources, in a manner that could be utilised in simulation modeling of health outcomes. To evaluate our models, we generated a database of 1,000 simulated households with characteristics consistent with Boston public housing developments and residents, and compared the predicted levels of NO2 and PM2.5 and their correlates with the literature. Our analyses demonstrated that CONTAM outputs could be readily explained by available parameters (R2 between 0.89 and 0.98 across models), but that one-compartment box models would mischaracterise concentrations and source contributions. Our study quantifies the key drivers for indoor concentrations in multi-family housing and helps to identify opportunities for interventions.

Author(s)	Date	Title	GA Code	URL	Free/ pay	Abstract
Farmer, D et al	2017	Measuring thermal performance in steady-state conditions at each stage of a full fabric retrofit to a solid wall dwelling, Energy and Buildings, Volume 156, 1 December 2017, Pages 404-414	G, H	https://www.sciencedirect.com/science/article/abs/pii/S0378778817311581	Pay	The methodology used for measuring the thermal performance of fabric retrofit systems which were applied to a solid wall UK Victorian house situated within an environmental chamber is explored in detail. The work describes how steady-state boundary conditions were approximated, and then repeated at the Salford Energy House test facility. How established methods of measuring the fabric thermal performance of buildings in situ were adapted to test the effectiveness of retrofit measures within a steady-state environment. The results presented show that steady-state boundary conditions enable the change in fabric heat loss resulting from the retrofit of a whole house or individual element to be measured to a level of accuracy and precision that is unlikely to be achieved in the field. The test environment enabled identification of heat loss phenomena difficult to detect in the field. However, undertaking tests in an environment devoid of wind underestimates the potential reduction in ventilation heat loss resulting from an improvement in airtightness, and hides the susceptibility of retrofit measures to various heat loss mechanisms, such as wind washing. The strengths and weaknesses of the methods employed, the Energy House test facility,

						and a steady-state environment, for characterising retrofit building fabric thermal performance are demonstrated.
Fawcett, T and Killip, G	2014	Anatomy of low carbon retrofits: evidence from owner-occupied Superhomes; Volume 42, 2014 - Issue 4: Energy retrofits of owner-occupied homes	S	https://www.tandfonline.com/doi/full/10.1080/09613218.2014.893162	Pay	A small number of 'Superhome' owners in the UK have renovated their homes to reduce CO2 emissions by 60 per cent or more. Superhome owner-occupiers, their homes and various aspects of their retrofit are characterised including the timing, planning, motivation, costs and interactions with professionals, and lessons drawn from this specialised group for the wider population. Research is based on a survey of 57 Superhome owners and 14 more detailed interviews. Compared with typical owner-occupiers, Superhome owners are on average younger, better educated, living in larger household groups and larger homes, and have higher incomes. However, there is considerable variation between households. Two main routes to retrofit were identified: planned and emergent, with emergent retrofits taking longer to complete, stretching over many years in some cases. Householder levels of knowledge and involvement in planning and managing the retrofit were high. Most commonly, paid professionals did most or some of the retrofit work, but many projects included some DIY. Significantly, their decisions are not made

						as 'rational economic actors'; instead motivations were multiple and included environmental concern, desire for improved comfort and living standards, reducing waste and saving on energy costs. Questions for further research are identified, as are suggestions for policy development.
Ferdyn-Grygierek, J and Grygierek, K	2019	HVAC control methods for drastically improved hygrothermal museum microclimates in warm season, Building and Environment, Volume 149, February 2019, Pages 90-99	M, N	https://www.sciencedirect.com/science/article/abs/pii/S0360132318307546	Pay	Due to financial and construction limitations, existing museum buildings often do not allow the retrofit of complex HVAC systems. Thus, an attractive way to improve the quality of the microclimates in the museum rooms is to improve the control of systems that are already installed. This paper presents novel proven control strategies to drastically reduce the temperature and relative humidity fluctuations in the exhibitions halls of a Polish museum in a moderate climate. The methods comprise improved control of existing indoor temperature and ventilation airflow control systems, without humidification and dehumidification devices. Simulations were performed with EnergyPlus software; the multi-zone model of the building was calibrated and verified with existing measured data. A warm period of the year was simulated, and six weeks of it were experimentally validated. The existing heating and cooling systems comprised radiators and

						in some areas, fan-coils. Through improved control schemes and the addition of outdoor air fans, the period with the small relative humidity fluctuations (<±5 per cent) increased from 2 per cent to 88 per cent in the season.
Filippín, C, Flores Larsen, S and Ricard, F	2018	Improvement of energy performance metrics for the retrofit of the built environment. Adaptation to climate change and mitigation of energy poverty, Energy and Buildings, Volume 165, 15 April 2018, Pages 399-415	G	https://www.sciencedirect.com/science/article/abs/pii/S0378778817335089	Pay	Energy retrofit of existing buildings was highlighted as an efficient massive action to decrease energy consumption and emissions of greenhouse gases. But, detecting the optimal retrofit strategies for groups of buildings is nowadays a highly complex problem. Their energy consumptions are influenced by building-related factors (climate, building envelope, building services and systems) and by user-related ones (building operation and maintenance, occupant behavior, and indoor environmental quality). Detecting the contributions of each factor and grouping buildings with similarities - in order to establish similar retrofit strategies - are the main issues that can be faced by statistical multivariate methods. In this paper, we present a new and broader view to propose retrofit strategies adapted to a climate change scenario and analysed from the economic and energy-poverty points of view, by using multivariate and clustering techniques that include building-related and user-related metrics

						influencing the energy consumption of groups of buildings. A group of 10 single-family houses in Argentina were selected as a case-study. The contributions of eleven building-related driving metrics and four user-related ones to the energy consumption were analysed. Then, the more representative house of the cluster was selected for a retrofit analysis for current weather conditions and for future weather under a climate change scenario. The analysis also included an economic assessment in relation to the energy poverty. The higher CV values found in the user-related metrics highlight the influence of occupants in the energy consumption that can result in huge gaps between real and predicted energy performance of buildings. This holistic study contributes to reveal the internal structure of energy consumption and to generate useful knowledge about energy retrofit of the built environment in cities, particularly for those householders which are more susceptible to suffer the adverse effects of energy poverty and climate change.
Forest of Dean Council	2017	Building control guidance document for upgrading	D, F, G, H	http://www.superhomes.org.uk/wp-content/uploads/2017/02/Upgradi	Free	This document has been produced for home owners, occupiers, students, builders, designers and other property professionals who have a basic knowledge of building construction and requires easy

		traditional buildings using lime and modern applications		ng-traditional-stone-buildings-Nov-2016-FoDC.pdf		to understand guidance on the building regulations for building projects in England and Wales. The author's intentions is to ensure the highest standards of conservation practice, to support the effective protection and enhancement of the historic environment and to promote heritage led regeneration of the built heritage for the enjoyment of future generations.
Forster, A M et al	2019	Lime binders for the repair of historic buildings: Considerations for CO2 abatement	X	https://www.researchgate.net/publication/338098450_Lime_Binders_for_the_Repair_of_Historic_Buildings_Considerations_for_CO2_Abatement	Free	Lime binders are utilised worldwide and are associated with a considerable scale of production and corresponding CO2 emissions. The relevance of this review is therefore international in scope, with production transcending geographical boundaries and construction practices.
Fouseki, K and Cassar, M	2014	Energy Efficiency in Heritage Buildings — Future Challenges and Research Needs. The Historic Environment: Policy and Practice, 5, 95-100	S	https://www.tandfonline.com/doi/full/10.1179/1756750514Z.00000000058	Free	This special issue explores through interdisciplinary perspectives the growing theoretical discourses, policies, and practices related to the topical and often contentious issue of improving the energy performance of historic and traditional buildings. It does so by bringing together contributions from academics as well as practitioners of different disciplines with experience in relevant projects from the UK, Italy, and Sweden. This volume is timely. Current national and international imperatives to reduce greenhouse-gas

						emissions across Europe have triggered intensive efforts to refurbish 'old' buildings in order to render them energy efficient. Taking into consideration the general assumption that older buildings consume more energy than modern structures, the issue of how best to balance energy-efficiency measures with the values attached to heritage buildings becomes a critical one.
Francis, G et al	2014	Solid-wall *U*-values: heat flux measurements compared with standard assumptions, Building Research and Information 2015 Vol. 43, No. 2, 238–252	H	https://www.tandfonline.com/doi/full/10.1080/09613218.2014.967977	Free	The assumed *U*-values of solid walls represent a significant source of uncertainty when estimating the energy performance of dwellings. The typical *U*-value for UK solid walls used for stock-level energy demand estimates and energy certification is 2.1 Wm−2 K−1. A re-analysis (based on 40 brick solid walls and 18 stone walls) using a lumped thermal mass and inverse parameter estimation technique gives a mean value of 1.3 ± 0.4 Wm−2 K−1 for both solid wall types. Among the many implications for policy, this suggests that standard UK solid-wall *U*-values may be inappropriate for energy certification or for evaluating the investment economics of solid-wall insulation. For stock-level energy modelling, changing the assumed *U*-value for solid walls reduces the estimated mean annual space heating demand by 16 per cent, and causes a proportion of the stock to change Energy Performance

						Certification (EPC) band. The analysis shows that the diversity of energy use in domestic buildings may be as much influenced by heterogeneity in the physical characteristics of individual building components as it is by variation in occupant behaviour. Policy assessment and guidance material needs to acknowledge and account for this variation in physical building characteristics through regular grounding in empirical field data.
Frazer-Nash Consultancy	2018	Logistics of Domestic Hydrogen Conversion	N	https://www.gov.uk/government/publications/logistics-of-domestic-hydrogen-conversion	Free	This report presents an investigation of the logistical requirements associated with transitioning UK domestic properties from natural gas to 100 per cent hydrogen. It has sought to answer a series of questions raised by BEIS on the following topics; practical tasks required to transition homes from natural gas to hydrogen; how these tasks could be delivered and the associated risks, barriers and opportunities.

Author(s)	Date	Title	GA Code	URL	Free/ pay	Abstract
Frick, J et al	2019	Studies on Thermal Performance of Advanced Aerogel-Based Materials, Sustainability in Energy and Buildings pp 641-649	H	https://link.springer.com/chapter/10.1007/978-981-32-9868-2_54	Pay	The present work describes the development and assessment of aerogel-based brick fillings, as well as aerogel blow-in insulation with optimised thermal performance. The brick filling was developed within the EU Horizon 2020 project Wall-ACE. The focus of this work was the assessment of the brick filling developed by the industrial partners in the project to present a new class of bricks with outstanding thermal performance. Within the EU-project EFFESUS, an aerogel-based blow-in insulation was developed by an industrial partner and tested by several research partners. A feasibility study at a heritage building in Glasgow and large-scale laboratory tests were performed to assess the material with respect to thermal performance, applicability and removability.
Frick, J et al	2016	Moisture Monitoring during an Artificial Weathering Test of a Cultural Heritage Compatible Insulation Plaster	F, H	https://www.wcndt2016.com/portals/wcndt/bb/Mo2C3.pdf	Free	The majority of the building-stock from before 1900 has been erected with natural hydraulic lime-based mortars in massive masonry. Due to the low modulus of elasticity of lime-based mortars there has never been a need for dilation joints in old masonry structures. Changes in shape as a result of expansion and contraction, due to hot/cold cycles, could be “followed” by

						these masonry structures without damage. Moreover, lime-based mortars have a high vapour transmission rate, beneficial to the breathing capacity of monolithic historic masonry. These two most important characteristics have been taken into account when selecting natural hydraulic lime as binder for a Cultural Heritage compatible insulation plaster which was developed within the EU-Project EFFESUS (www.effesus.eu). The developed plaster was tested successfully in a so-called EOTA-wall test according to ETAG 004. Additional to the normal temperature and humidity monitoring within the test chamber, plaster and supporting wall were equipped with impedance sensors and other sensors to monitor material moisture behaviour. The results show moisture uptake and drying during the different test phases. Differences occurred depending on the material of the supporting wall.
Fylan, F et al	2016	Reflections on retrofits: Overcoming barriers to energy efficiency among the fuel poor	T	https://www.sciencedirect.com/science/article/abs/pii/S2214629616301852?via%3Dihub	Pay	To meet targets on fuel poverty, energy efficiency and carbon emissions existing homes need to be more energy efficient. We report the results of a participatory action research project to explore the challenges associated with energy efficiency retrofit programmes and ways to better implement future schemes.

		in the United Kingdom, Energy Research and Social Science, Volume 21, November 2016, Pages 190-198				Six focus groups were held with 48 participants from a range of energy efficiency roles. Data were analysed thematically using the research question "What are the challenges presented by implementing energy efficiency retrofit programmes". We identified four themes in the data: Funding mechanisms; Predicting performance; Installation; and People. Challenges include funding mechanisms for retrofit programmes resulting in insufficient time to plan, publicise, implement and evaluate a scheme and insufficient flexibility to specify the most appropriate intervention for individual homes. Site workers sometimes need to adapt retrofit designs because of insufficient detail from the designer and can equate quality of installation with quality of finish. Landlords and occupier behaviour can impact on the programme's success and there is a need for greater information on benefits for landlords and for energy behaviour change interventions run alongside retrofit programmes for occupiers. There is a need for outcome evaluations of retrofit schemes with the results shared with stakeholders.

Author(s)	Date	Title	GA Code	URL	Free/ pay	Abstract
Ganobjak, M	2019	Aerogel materials for heritage buildings: Materials, properties and case studies; Journal of Cultural Heritage Available online 9 November 2019	D, H	https://www.sciencedirect.com/science/article/pii/S1296207419302080	Free	Aerogels are open-porous, high-performance thermal insulation materials that can be used for very thin building insulation. So far, the application conditions of these materials and their potential in heritage buildings have not yet been described comprehensively. This review shows the technical properties of commercially available aerogel materials – such as blankets, boards and renders – and their use scenarios in heritage buildings, taking into account the heritage criteria of authenticity, integrity, reversibility and compatibility. Additionally, historic buildings that were refurbished using aerogels are presented. The study by theoretical evaluations and calculated U-values indicates that super-insulating aerogel materials have an exceptional potential in the refurbishment of heritage buildings. The presented examples show the feasibility of refurbishments with aerogel and the resulting improvements in terms of both comfort and thermal properties. Hence, aerogel materials are well suited to be used in preservation of heritage objects according to generally known rules and conditions of heritage preservation, thus contributing to the reduction of energy consumption in the building sector.

Author(s)	Date	Title	GA Code	URL	Free/ pay	Abstract
Gavin, K and Owen, A	2017	Seven Myths of Building Retrofit	T, V	https://www.researchgate.net/publication/319978432_Seven_Myths_of_Building_Retrofit	Free	This paper identifies seven widely-respected myths in the retrofit debate, which need to be debunked if retrofit is to have a chance of achieving its potential. Myth 1: Retrofit is a 'fit and forget', once-only intervention. Buildings need upkeep and they change over time in response to user needs. Energy retrofits need to be similarly maintainable and adaptable. Myth 2: Low-energy retrofit happens independently of repair and maintenance cycles. The service providers with the potential to deliver retrofit at scale are in construction, not energy. Myth 3: Off-site methods can industrialise all retrofit activity. The unpredictable nature of retrofit work means that it will always involve labour-intensive tasks and on-the-job problem-solving. Myth 4: The only useful innovations are in technology. The construction industry needs support to trial processes and practices which do not show up in conventional metrics of innovation (R and D spending; patents). Myth 5: Regulation is bad for business. Well-designed policy provides a level playing field for business activity. Businesses need policy support to prevent being undermined by poor-quality competitors. Myth 6: Retrofit policy should promote specific measures. Engineering and economic assessments of retrofit give insights into what needs to be done by when, but they are poor predictors of how

						the work is to be achieved and by whom. Myth 7: Real-life retrofit decisions are based on cost-benefit analysis. Buildings serve many more functions than providing energy services, so assessments of energy costs and savings are too narrow to drive investment decisions.
Gillard, R et al	2016	Transformational Responses to Climate Change: Beyond a Systems Perspective of Social Change in Mitigation and Adaptation; Wiley Interdisciplinary Reviews: Climate Change, 7 (2). pp. 251-265. ISSN 1757-7780	T	http://eprints.whiterose.ac.uk/92526/	Free	There is a growing imperative for responses to climate change to go beyond incremental adjustments, aiming instead for society-wide transformation. In this context, sociotechnical (ST) transitions and social–ecological (SE) resilience are two prominent normative agendas. Reviewing these literatures reveals how both share a complex-systems epistemology with inherent limitations, often producing managerial governance recommendations and foregrounding material over social drivers of change.

Author(s)	Date	Title	GA Code	URL	Free/ pay	Abstract
GLA	2016	London Energiesprong Transferability Assessment	W	https://carbonneutralcities.org/wp-content/uploads/2018/05/1-London-Energiesprong-Transferability-Assessment.pdf	Free	Energiesprong is a model developed in the Netherlands to provide state-of-the-art whole-house retrofits, initially in the social housing sector. These combine industrialised retrofit techniques, designed to obtain net zero energy consumption, with novel contractual structures for delivery and cost recovery. This model has been successfully implemented across 8,002 homes within The Netherlands but has not yet been undertaken at mass scale. The approach has not yet been tested within the UK, where the market environment may pose different challenges. The GLA therefore commissioned Frontier Economics, Savills and UCL to identify the main components of the Energiesprong model, and then consider whether it could be transferred to London. Our review finds that while there are a number of barriers that could reduce the effectiveness of the model in London, solutions are available in many cases.

Author(s)	Date	Title	GA Code	URL	Free/ pay	Abstract
Glew, D et al	2017	Assessing the quality of retrofits in solid wall dwellings, International Journal of Building Pathology and Adaptation	A, E, F	https://www.emerald.com/insight/content/doi/10.1108/IJBPA-05-2017-0022/full/html	Pay	The purpose of this paper is to provide a detailed appraisal of the quality of domestic retrofits. This paper presents the results of technical surveys on 51 retrofits undertaken before, during and after the retrofits. Failures are observed to be endemic and characterised into five themes: 72 per cent showed moisture issues pre-retrofit, 68 per cent had moisture risks post-retrofit, 62 per cent did not adopt a whole house approach, 16 per cent showed inadequate quality assurance protocols and 64 per cent showed evidence of insufficient design detailing. Each theme is further subcategorised with a view to identifying implications for future policy. The findings suggest the 10 per cent Ofgem retrofit failure rates predictions are an underestimate and so there may be a need for additional investigations to understand the trend across the UK. Recommendations to reduce the failure rates may include making changes to the current inspection regime, widening understanding among installers; providing standard repeatable designs for repeated features; and empowering occupants to trigger inspections.

						The sample is representative of a substantial proportion of the homes in the UK suggesting that retrofit quality may in many instances be below the required standards. Risks of moisture issues and underperformance in domestic retrofit are a concern for government industry and households. This research shows that many installation failures are the result of not implementing existing guidelines and a change to the enforcement of standards may be needed to enact a fundamental change in installer practice and process control.
Gori, V et al	2018	Inferring the thermal resistance and effective thermal mass distribution of a wall from in situ measurements to characterise heat transfer at both the interior and exterior surfaces	H	https://discovery.ucl.ac.uk/id/eprint/1529281/	Free	The estimation of the thermophysical characteristics of building elements based on in situ monitoring enables their performance to be assessed for quality assurance and successful decision making in policy making, building design, construction and refurbishment. Two physically-informed lumped thermal mass models, together with Bayesian statistical analysis of temperature and heat flow measurements, are presented to derive estimates of the thermophysical properties of a wall. The development of a two thermal mass, three thermal resistance model (2TM) enabled the thermal structure of the wall to be investigated and related to the known

						physical structure of two heavy-weight walls of different construction: a solid brick wall and an aerated clay, plaster, woodfibre insulation and gypsum fibreboard wall.
Gorse, C et al	2017	Core cities Green Deal monitoring project, for DECC	A, B, C, E, F, G, H, J, K, M	https://www.gov.uk/government/publications/core-cities-green-deal-monitoring-project-leeds	Pay	Energy savings were quantified in 65 dwellings that had measures installed with Green Deal Funding. Measures included internal and external wall, loft and party wall insulation. The report identifies how energy savings could have been further improved.
Green, E et al	2018	Homes of today for tomorrow: Decarbonising Welsh Housing between 2020 and 2050 Stage 1 Report	G, N, W	https://gov.wales/sites/default/files/publications/2019-07/decarbonising-welsh-homes-stage-1-report.pdf	Free	In March 2018, Cardiff University was commissioned by the Welsh Government's Homes and Places division to conduct Stage 1 of their Housing Decarbonisation programme, through the production of a scoping review. This piece of work was to identify 'what works' through a review of case studies (completed projects, mostly domestic retrofit but also new- build) and published literature (including industry publications, academic papers, advice for policy makers and other best practice).
Green, E et al	2019	Homes of today for tomorrow: Decarbonising Welsh Housing	G, N, W	https://gov.wales/sites/default/files/publications/2019-07/decarbonising	Free	The primary aim of this study was to understand the degree to which the nature of the existing Welsh housing stock could inform the development of a pathway to decarbonisation, while also giving due consideration to energy costs and

		between 2020 and 2050 Stage 2 Report		-welsh-homes-stage-2-report.pdf		affordable warmth. Fourteen recurrent dwelling 'types' were used to explore the effect of key retrofit actions upon the Welsh housing stock, by modelling each dwelling type in 1990, in 2018 and in 2050. The impact of key retrofit actions is explained in terms of capital cost, carbon emissions, ongoing energy costs and overheating. Capital costs are also compared with likely ongoing maintenance costs. Consideration was also given to changes in the energy supply network, because of the current uncertainty around decarbonisation of energy supply, and the impact this could have on decision making.
Griffiths, N et al	2015	Developing an approach to Domestic Energy Efficiency Retrofit in Jersey	G, H, V, W	https://www.gov.je/Government/Pages/StatesReports.aspx?ReportID=1755	Free	Ricardo-AEA was commissioned by the States of Jersey to develop an approach to retrofitting energy efficiency in the able-to-pay domestic sector in Jersey. This sector was identified as a priority in the Pathway 2050 report which sets out an energy plan for Jersey to meet the commitments to reducing carbon emissions made as a signatory to the Kyoto protocol. The Pathway 2050 report also includes plans for reducing fuel poverty through building retrofits. The report sets out the results of the research and makes recommendations on the options to address energy efficiency in the domestic sector in Jersey.

Author(s)	Date	Title	GA Code	URL	Free/ pay	Abstract
Groß, M et al	2020	A simplified calculation process of buildings' energy saving potential	G	https://iopscience.iop.org/article/10.1088/1755-1315/410/1/012020	Free	The real estate sector is responsible for 40 per cent of the energy consumption and one third of the CO2 emissions in Europe. Moreover one third of the European Union's buildings are in fact older than 50 years while only one per cent is being renovated each year. This paper provides a simplified analysis targets not only for 2020 but also long term. This method has been integrated into AiBATROS® software and can help to prioritise measures increasing energy efficiency. Verification and validation of the process are demonstrated comparing results with another method's energy calculations.
Grosvenor	2013	Sustainable Refurbishment: A Toolkit for Going Green	B, C, D, G, H, K, P, T	http://grosvenorlondon.com/GrosvenorLondon/media/GrosvenorLondon/SustainableRefurbishmentAToolkitForGoingGreen.pdf	Free	Refurbishments to properties present ideal opportunities to take advantage of sustainable technologies that not only improve the environmental performance of a building but also benefit the occupants in terms of thermal comfort, user control, lighting, acoustics, aesthetics, health considerations and financial value. The aim of this document is to inform residents of Grosvenor's London estate of the key sustainable measures to consider when undertaking residential refurbishments.

Author(s)	Date	Title	GA Code	URL	Free/ pay	Abstract
Grytli, E et al	2014	The Impact of Energy Improvement Measures on Heritage Buildings	D, R	https://www.tandfonline.com/doi/abs/10.1080/13556207.2012.10785120?src=recsys	Pay	Energy improvement measures can destroy the historical and architectural values of existing buildings. From a broader environmental perspective, extensive energy efficiency measures may even lead to increased greenhouse gas emissions from demolition, waste production and transportation of new materials. The complexity of the consequences of energy-saving measures on existing buildings calls for more holistic methods in discussing solutions. This paper presents an integrated analysis method developed by three masters' students at the Norwegian University of Science and Technology. The method examined different short- and long-term impacts from various energy efficiency measures on a model building by combining life cycle assessment, energy calculations and a self-developed heritage value assessment system. By combining the results from the different analyses in an integrated decision-making tool, it was possible to discuss optimal solutions for energy improvement, taking both environmental and heritage aspects into consideration.

Author(s)	Date	Title	GA Code	URL	Free/ pay	Abstract
Gupta, R and Gregg, M	2017	Mapping socio-economic barriers to the implementation of energy efficiency policies in the UK building sector	T	https://pdfs.semanticscholar.org/3d3e/9473190207f1ee8c507e48e63ff7d2ce6733.pdf	Free	Barriers to energy efficiency are vast and complex, and overcoming them is a key challenge for effective implementation of energy efficiency policies. This paper describes the findings from a review of literature and an expert survey to map and assess the key social, cultural, educational, economic and institutional barriers (in terms of small, medium and high impact) to implementing energy efficiency policies across the UK building sector.
Hanmer, C et al	2018	How household thermal routines shape UK home heating demand patterns	S	https://link.springer.com/article/10.1007/s12053-018-9632-x	Free	In homes in the UK, it is very common to operate space heating intermittently; the heating is usually switched off when the occupants are asleep at night and when they are out during the day. The strong association between heating operation and household routines leads to a morning peak in demand which, if it persists following electrification of heating, will require significant reinforcement of electricity supply networks. This paper examines factors that underpin how heating is used in the UK. A unique dataset of heating controller settings from 337 UK allows investigation of how patterns of heating operation in individual homes contribute to daily patterns of space heating energy consumption at the group level.

						A mixed method approach is followed, combining quantitative analysis of data with interviews with householders.
Hansen, T K et al	2016	A lime based mortar for thermal insulation of medieval church vaults	H, X	https://backend.orbit.dtu.dk/ws/portalfiles/portal/127943899/A_lime_based_mortar_for_thermal_insulation_of_medieval_church_vaults_Final_paper_HMC2016.pdf	Free	There are 1,700 medieval churches in Denmark, and many of these have brick vaults. The thickness is only 12–15cm, and the heat loss through this building component is large. Thermal insulation has not been permitted until now in respect for the antiquarian values and doubts about the effect on water vapour transport through the vault, and the risk of condensation inside the insulation. A new mortar was developed for thermal insulation of bricks vaults, consisting mainly of expanded perlite, mixed with slaked lime. These materials are compatible with the fired clay bricks and the lime mortar joints. The insulation mortar is applied to the top side of the vault in a thickness of 10cm, and covered by 10mm lime plaster, reinforced with cattle hair. This assembly is resistant to the weight of a person, working with maintenance of the roof. The thermal conductivity of the insulation mortar was measured to 0.08W/mK, which is twice the value for mineral wool. It has 1/3 of the resistance to water vapour diffusion as brick, and a high capacity for liquid water absorption. This is a benefit in the case of rain leaking from the roof, because the

						water does not penetrate further down into the bricks.
Hardy, A L R et al	2018	Validating Solid Wall Insulation Retrofits with In-Use Data, Energy and Buildings, Volume 165, 15 April 2018, Pages 200-205	C, G, S	https://www.sciencedirect.com/science/article/abs/pii/S0378778817328682?via%3Dihub	Pay	Improving the energy efficiency of the UK housing stock is important both to meet carbon emission reduction targets and to reduce fuel poverty. For this reason, domestic properties are frequently retrofitted with energy saving measures. This study looks at how the energy consumption, thermal properties and internal temperature of 14 dwellings change as a result of a solid wall insulation (SWI) retrofit. A decrease in heat transfer coefficient of per cent was calculated for two dwellings, which is slightly lower than the previously modelled value of 18 per cent. However, many houses displayed evidence that the full benefit of SWI was not being realised as, for example, energy savings were offset with increases in internal temperature. Future retrofit schemes should therefore consider supplementing the changes in fabric with increased guidance for the occupant.

Author(s)	Date	Title	GA Code	URL	Free/ pay	Abstract
Harrestrup, M and Svendsen, S	2015	Full-scale test of an old heritage multi-storey building undergoing energy retrofitting with focus on internal insulation and moisture; Building and Environment, Volume 85, February 2015, Pages 123-133	D, F, H, S	https://www.sciencedirect.com/science/article/abs/pii/S0360132314004168	Pay	The hypothesis investigated in this article is: it is possible to carry out moisture safe energy renovations in the old existing multi-storey buildings with heritage value and still save 50 per cent of the building's energy consumption by use of existing technologies. A holistic energy renovation on an old multi-storey building with heritage value was carried out. Focus was given to energy-saving measures that would preserve the original architectural expression of the building, such as internal insulation. Comprehensive measurements were performed on the energy consumption before and after the renovation to document the obtained savings. Numerical simulations were validated with the measurements in order to explain the savings and to carry out parameter variations on the energy saving measures. Since internal insulation was applied the durability and robustness were investigated and measurements of the temperature and relative humidity were performed in the wooden beams-ends embedded in the masonry brick wall. A solution where the insulation was stopped 200mm above the floor was investigated. This increased the heat flows through the wall compared to a fully insulated wall, and calculations showed that the difference in the space heating

						consumption was 3kWh/m2/yr. The measurements showed the proposed solution should have no risk of moisture problems. The measured energy consumption was reduced with 47 per cent whereas the theoretical reduction could be reduced with 39–61 per cent depending on the room set-point temperature (20–24°C). Highlights: • We energy renovated an old heritage multi-storey building with internal insulation. • We examined the moisture safety of a solution with 200mm gap in the insulation. • Full-scale tests and theoretical investigations are carried out. • Energy-savings of 39–61 per cent was obtained strongly influenced by occupant behaviour. • A 200mm gap in the insulation result in increased heating consumption of 3kWh/m2/yr.

Author(s)	Date	Title	GA Code	URL	Free/ pay	Abstract
Hashemi, A et al	2016	Performance gap? Energy, health and comfort needs in buildings	A, C, S	http://orca.cf.ac.uk/126758/1/Performance%20gap-%20energy%2C%20health%20and%20comfort%20needs%20in%20buildings2.pdf	Free	Research on performance gap suggests that the actual energy consumption in buildings can be twice as much as expected. Energy models rely on predictive indicators and assumptions that are usually done at design stage, without acknowledging behavioural patterns of actual users. Moreover, in the context of performance gap, it is evident that energy efficiency is over-emphasised while other key issues such as health and comfort of occupants, indoor air quality, noise levels, for example, have been less stressed and discussed. This paper discusses the performance gap using surveys and physical measurements in a case study building at the University of Cambridge and reports findings of a research workshop with graduate students working on environmental performances of the built environment.

Author(s)	Date	Title	GA Code	URL	Free/ pay	Abstract
Historic England	2018	Energy Efficiency and Historic Buildings: How to Improve Energy Efficiency	D, G	https://historicengland.org.uk/images-books/publications/eehb-how-to-improve-energy-efficiency/	Free	This guidance is for anyone who wishes to improve energy efficiency in an historic building. There are many reasons to do this. Improving energy efficiency will lower carbon emissions and fuel bills and often increase comfort. It also might be necessary to ensure that a building complies with legal requirements. More broadly, improving energy efficiency forms a part of the wider objective to achieve a sustainable environment.
Historic England	2017	Energy Efficiency and Historic Buildings Application of Part L of the Building Regulations to Historic and Traditionally Constructed Buildings	G, T, V	https://historicengland.org.uk/images-books/publications/energy-efficiency-historic-buildings-ptl/	Free	This guidance has been produced to help prevent conflicts between energy efficiency requirements in Part L of the Building Regulations and the conservation of historic and traditionally constructed buildings. It also provides strategic advice on implementing measures, highlighting the various stages and issues that need to be considered when reducing energy use and thermally upgrading existing buildings.

Author(s)	Date	Title	GA Code	URL	Free/ pay	Abstract
Historic England	2016	Correlating Maintenance, Energy Efficiency and Fuel Poverty for Traditional Buildings in the UK	D	https://research.historicengland.org.uk/Report.aspx?i=16029&ru=%2fResults.aspx%3fp%3d1%26n%3d10%26k%3dretrofit%26ns%3d1	Free	The scoping study here reviews potential for developing a research framework to address the feasibility for energy efficiency of historic buildings to be increased through better maintenance programmes. The new British Standard for conservation has already triggered recognition of the correlation of dampness to energy efficiency (BSI, 2013), here we aim to address further means to link building condition to building performance and to further substantiate that claim. More broadly the paper investigates the potential for recovering evidence in the interests of incentivising maintenance as a business case addressed to stakeholders and custodians, underwriters and legislators.
Historic England	2016	Energy Efficiency and Historic Buildings: Insulating solid walls	H	https://historicengland.org.uk/images-books/publications/eehb-insulating-solid-walls/	Free	This guidance note provides advice on the principles, risks, materials and methods for insulating solid masonry walls. Traditional solid wall construction is often the most difficult and in many cases the least cost effective part of a building to insulate. However, adding insulation to solid walls can lead to a significant reduction in heat loss but thought and care is needed to make sure the works are appropriate, effective and do not cause long-term problems.

Author(s)	Date	Title	GA Code	URL	Free/ pay	Abstract
Historic England	2017	Energy Efficiency in Historic Buildings - Heat Pumps	M, N	https://historicengland.org.uk/images-books/publications/eehb-heat-pumps/	Free	This guidance covers the issues associated with installing a heat pump in a historic building. It describes the different options available and how they work. Advice is also provided on how to minimise the potential damage to the fabric of the building in the design of the installation.
Historic England	2015	Energy Efficiency and Historic Buildings: Insulating pitched roofs at rafter level	H, J	https://historicengland.org.uk/images-books/publications/eehb-insulating-pitched-roofs-rafter-level-warm-roofs/	Free	This guidance note provides advice on the principles, risks, materials and methods for insulating pitched roofs at rafter level. When insulation is placed at this position the roof is often referred to as a 'warm roof'. The simplest and most common way to insulate a pitched roof is to add insulation above the horizontal ceiling of the top floor. However, if the top floor is open to the rafters and is used as habitable accommodation then insulation will need to be provided at rafter level. Insulation can be placed above, between or just below the rafters.
Historic England	2016	Energy Efficiency and Historic Buildings: Insulating pitched roofs at ceiling level-cold roofs	H, J	https://historicengland.org.uk/images-books/publications/eehb-insulating-pitched-roofs-ceiling-level-cold-roofs/	Free	This guidance note provides advice on the principles, risks, materials and methods for insulating pitched roofs at ceiling level. When insulation is placed in this position, the roof is often referred to as a 'cold roof'. Insulating above the top floor ceiling is one of the easiest and cheapest means of improving the energy efficiency of buildings and such work can be carried out successfully in older buildings if approached with some care. Even very thick layers of insulation will not cause problems if installed with materials that are compatible with the existing construction. However, the

						installation can be made much more difficult if part of the ceiling to the top floor rooms is within a pitched roof space.
Historic England	2016	Energy Efficiency and Historic Buildings: Insulating flat roofs	H, J	https://historicengland.org.uk/images-books/publications/eehb-insulating-flat-roofs/	Free	This guidance note provides advice on the principles, risks, materials and methods for improving the thermal performance of flat roofs by the addition or upgrading of insulation. Adding insulation to flat roofs can lead to a significant reduction in heat loss but thought and care is needed to make sure this is effective and does not cause problems.
Historic England	2016	Energy Efficiency and Historic Buildings: Insulating thatched roofs	H	https://historicengland.org.uk/images-books/publications/eehb-insulating-thatched-roofs/	Free	This guidance provides advice on the principles, risks, materials and methods for insulating thatched roofs. There are estimated to be about 50,000 thatched buildings in England today, some of which retain thatch which is over 600 years old. Thatching reflects strong vernacular traditions all over the country.
Historic England	2016	Energy Efficiency and Historic Buildings: Open fires, chimneys and flues	B, N	https://historicengland.org.uk/images-books/publications/eehb-open-fires-chimneys-flues/	Free	This guidance provides advice on how unused or intermittently used chimneys can be made more energy efficient by preventing draughts. Open chimneys and flues can be useful sources of ventilation but they can often let too much warm air out and cold air in. The resultant draughts can create uncomfortable conditions. Chimneys in older buildings can develop a wide range of defects. This guidance note also discusses how to avoid introducing further defects when measures are taken to improve energy efficiency but it does not cover the diagnosis or remedy of common defects.

Author(s)	Date	Title	GA Code	URL	Free/ pay	Abstract
Historic England	2015	Energy Efficiency and Historic Buildings: Insulating timber-framed walls	F, H	https://historicengland.org.uk/images-books/publications/eehb-insulating-timber-framed-walls/	Free	This guidance note provides advice on the methods, materials and risks involved with insulating the walls of timber-framed buildings. Making improvements can improve comfort for occupants as well as lowering fuel bills and carbon emissions. However, such improvements can raise significant technical and conservation issues.
Historic England	2016	Energy Efficiency and Historic Buildings: Insulating dormer windows	H	https://historicengland.org.uk/images-books/publications/eehb-insulating-dormer-windows/	Free	Advice on the principles, risks, materials and methods for insulating dormer windows. Dormers come in a large variety of shapes, sizes and materials and can be a particularly difficult element to insulate. However, if insulation is omitted or is poorly detailed then the energy performance of the whole roof can be compromised.
Historic England	2016	Energy Efficiency and Historic Buildings: Early cavity walls	H	https://historicengland.org.uk/images-books/publications/eehb-early-cavity-walls/	Free	This guidance note provides advice on the principles, risks, materials and methods for improving the thermal performance of buildings built with early forms of masonry cavity walls dating from before the Second World War.

Author(s)	Date	Title	GA Code	URL	Free/ pay	Abstract
Historic England	2016	Energy Efficiency and Historic Buildings: Insulation of suspended timber floors	F, H	https://historicengland.org.uk/images-books/publications/eehb-insulation-suspended-timber-floors/	Free	This guidance note provides advice on the methods, materials and risks involved with insulating suspended timber ground floors. The applications described are also appropriate for timber upper floors where there is an unheated space below, such as above a passageway. Advice is also provided on how suspended floors can be draught-proofed where the installation of insulation may be difficult or potentially damaging to the historic fabric of the building.
Historic England	2016	Energy Efficiency and Historic Buildings: Insulating solid ground floors	H	https://historicengland.org.uk/images-books/publications/eehb-insulating-solid-ground-floors/	Free	Advice on the methods, materials and risks involved with insulating solid ground floors. The energy savings resulting from insulating solid ground floors can in many cases be of marginal benefit when the cost and disruption to the building fabric are considered. Insulating other building elements is likely to produce greater benefits in energy efficiency for significantly less cost.
Historic England	2017	Survey of Listed Buildings Owners		https://historicengland.org.uk/content/docs/research/survey-listed-building-owners-2017-pdf/	Free	Property owners still report a strong sense of the national and local cultural significance of their listed buildings and properties in Conservation Areas. It is generally felt that listed building consent requirements and Conservation Area regulations are an appropriate and effective way of maintaining properties and safeguarding their cultural value. A large proportion of property owners regard builders or craftspeople as their first source of information for advice on repairs and

						maintenance. A significant proportion of owners don't know where to go for advice on other issues relating to repairs and maintenance. Property owners generally do not have difficulties in finding professionals to advise or undertake work or to find suitable building materials. A minority do find it difficult to find professional expertise and materials and this may indicate a supply problem locally or nationally. Listed Building owners do find it more difficult to find affordable building materials than Conservation Area property owners - most likely due to the specific needs of their property. Satisfaction with the planning process is generally high. However there is a significant level of dissatisfaction that is partially, but not entirely, due to outcome of the application. Listed building owners in particular appear to be undertaking a significant amount of commercial activity at their properties. Listed building and Conservation Area property owners both find it fairly easy to find appropriate building insurance. While listed building owners find it noticeably more difficult - due to the specialist requirements of their properties - most do manage to find insurance. Owners are aware of a large range of large and small providers. Listed building owners and owners of properties in Conservation Areas appear to use different insurance providers. This is likely to represent the specialist nature of listed building insurance. It is not clear whether historic property owners are seeking and receiving appropriate insurance advice. There is a risk that historic properties are not

						being adequately insured for repair or reinstatement. There is a significant amount of homeworking reported by respondents in listed buildings and Conservation Area properties. This dual residential-commercial use has implications for the type of insurance required and the level of maintenance necessary. Survey respondents to the listed building survey do not engage with Historic England's social media in large proportions but they do appear ready to engage with Historic England. Two-thirds of respondents were interested in participating in the 'Enrich the List' initiative.
Historic England	2017	The Engine House, Swindon, Wiltshire: Thermal Performance of Energy Efficiency Improvements to Timber Windows	H	https://research.historicengland.org.uk/redirect.aspx?id=6688|%20The%20Engine%20House,%20Swindon,%20Wiltshire:%20Thermal%20Performance%20of%20Energy%20Efficiency%20Improvements%20to%20Timber%20Windows	Free	This report describes tests carried out at the Engine House, Swindon to compare three proprietary retrofit systems for improving the thermal performance of traditional timber windows. To assess their performance U-values of glazing (centre of pane) were measured in situ before and after the systems were installed. The results showed that all three systems reduced heat loss by more than 50 per cent. The report also discusses impact of each system on heritage values, operation and maintenance of the windows.

Author(s)	Date	Title	GA Code	URL	Free/ pay	Abstract
Historic England	2019	Understanding Carbon in the Historic Environment	R,W	https://historicengland.org.uk/content/docs/research/understanding-carbon-in-historic-environment/	Free	To date, regulations and policymakers measure the carbon emissions of buildings based on operational energy use only, ignoring the embodied carbon benefits of reusing the existing structure.
Historic England (Baker, P)	2015	Shrewsbury, Shropshire: Hygrothermal Modelling of Shrewsbury Flaxmill Maltings	F, G, H, X	https://research.historicengland.org.uk/redirect.aspx?id=6662|Shrewsbury,%20Shropshire:%20Hygrothermal%20Modelling%20of%20Shrewsbury20Flax%20Mill%20Maltings	Free	The report describes hygrothermal simulations of the second floor of the South Engine House at Shrewsbury Flaxmill Maltings to predict the impact of a range of internal wall insulation systems over a period of 30 years. Simulation results using WUFI indicate that 1-D modelling is generally satisfactory for a range of scenarios. Uncertainty will result from using alternative material data from the WUFI database compared with the actual material in the Flaxmill case. Thirty year simulations indicate that insulation systems which are hygroscopic with some vapour resistance are possibly the best option to reduce risk of moisture problems in internal wall insulation, whereas materials unable to buffer moisture or having a high vapour resistance may, in the worst case, allow a long term build-up of moisture. WUFI is a useful tool which can be used to assess options for upgrading the thermal performance of traditional buildings,

						provided we know the material properties of our traditional materials. However, as the simulations results reported show, unknown boundary conditions such as absorption of driving rain may produce a high level of uncertainty.
Historic England (Newman, C)	2017	Reducing Energy Use in Traditional Dwellings: Analysis of Four Solid Wall Houses in Reading, Report number: 9/2017	H	https://research.historicengland.org.uk/Report.aspx?i=15562&ru=%2fResults.aspx%3fp%3d1%26n%3d10%26ry%3d2017%26t%3dReducing%2520Energy%26ns%3d1	Free	This report describes an in-depth 'whole building' analysis of energy use carried out in four traditionally built houses in Reading, Berks. The results were used to devise strategies to reduce energy use and carbon emissions for each household.
Historic England (CSE)	2017	The Sustainable Use of Energy in Traditional Dwellings: Using legislation and policy to guide decision-making	V	https://research.historicengland.org.uk/redirect.aspx?id=6809|%20The%20Sustainable%20Use%20of%20Energy%20in%20Traditional%20Dwellings:%20Using%20legislation%20and%20policy%20to%20guide%20decision-making	Free	Local authorities are responsible for implementing a diverse range of legislation, policies and guidance relating to sustainable development, fuel poverty, housing standards and carbon reduction. These all have impacts on the historic environment. But if there is not adequate inter-departmental understanding and coordination of the many overlapping (and sometimes conflicting) requirements, there is a risk that one agenda will be undermined by another. The consequences of this include harm to heritage assets and failure to meet legislative and policy objectives in full. This report presents the findings of a research project carried out to understand better the areas of convergence and conflict between current legislation,

						policy and guidance. A further aim of the project has been to suggest ways in which local authorities might increase understanding between departments and stakeholders, and develop more integrated and better-informed approaches to policy and decision-making. The suggestions set out in this report have been developed in consultation with Oxford City Council, and other local authorities in four regional, cross sector workshops.
Historic England (Curteis, T and Seliger, L)	2017	Conserving Stained Glass Using Environmental Protective Glazing	C, H, X	https://research.historicengland.org.uk/redirect.aspx?id=7555|Conserving%20Stained%20Glass%20Using%20Environmental%20Protective%20Glazing	Free	Because stained-glass windows form part of the building envelope - separating the internal and external environments - they are uniquely vulnerable to aggressive environmental deterioration. On the exterior, rainfall, wind and pollution can cause structural and chemical deterioration of the glass and the leading; on the interior, condensation can cause irreversible loss of paint and other applied decoration. Unfortunately, our ability to improve the environmental conditions to which historic glass is subjected is limited. Historic England's Building Conservation and Research Team initiated the research reported here, with a fundamental aim: to establish whether EPG is robust enough to allow flexibility in design choices that could to minimise harm. In other words, how might modifications of the basic design of EPG affect its effectiveness?

Author(s)	Date	Title	GA Code	URL	Free/ pay	Abstract
Historic England (NDM Heath Ltd)	2014	External Wall Insulation in Traditional Buildings: Case studies of three large-scale projects in the North of England: Research Report	B, C, D, E, F, G, H, J, K, S, T, U, V	https://research.historicengland.org.uk/Report.aspx?i=15747	Free	Given the technical risks associated with insulating walls internally, external insulation is often an option worth considering, where aesthetics allow. However there are various considerations that need to be addressed and further research is needed to gain a fuller understanding of these. This report provides an overview of three recently completed external wall insulation projects in three towns of Northern England: Liverpool, Blackpool and Stockton-on-Tees.
Historic England (McCaig, I)	2016	Measuring Moisture Content in Historic Building Materials	F	https://research.historicengland.org.uk/redirect.aspx?id=6713|Measuring%20Moisture%20Content%20in%20Historic%20Building%20Materials	Free	This report presents some preliminary results from an ongoing programme of research to gain a better practical understanding of the limitations of various techniques for assessing moisture in historic building materials. This task has become more urgent as a changing climate increases the risk from flooding. The topics considered include: • variation in moisture distribution within historic brick walls • how this variation may be overcome to provide a useful and repeatable moisture content approximation • unfamiliar limitations of resistance moisture meters for wood.

Author(s)	Date	Title	GA Code	URL	Free/ pay	Abstract
Historic England (Newman, C)	2017	Reducing Energy Use in Traditional Dwellings: Analysis of Four Solid Wall Houses in Reading	G, H, M, W	https://research.historicengland.org.uk/redirect.aspx?id=6799|%20Reducing%20Energy%20Use%20in%20Traditional%20Dwellings:%20Analysis%20of%20Four%20Solid%20Wall%20Houses%20in%20Reading	Free	This report describes an in-depth 'whole building' analysis of energy use carried out in four traditionally built houses in Reading, Berks. The results were used to devise strategies to reduce energy use and carbon emissions for each household. These were then assessed in terms of their effectiveness and cost-efficiency. An important aim of the project was to understand better the costs and benefits of solid wall insulation in relation to other energy and carbon saving measures. The project demonstrates the benefits of a 'whole building' approach, and shows how the economics of specific energy and carbon-saving improvements vary from one household to another.
Historic England (Baker, P)	2016	Improving the Thermal Performance of Traditional Windows: Metal-Framed Windows - report number 15/2017	H	https://research.historicengland.org.uk/Report.aspx?i=15568	Free	This report summarises the results of research to investigate the thermal performance of metal windows and methods of reducing heat loss. The project was carried out by the Centre for Research on Indoor Climate & Health, Glasgow Caledonian University (GCU) on behalf of Historic England.

Author(s)	Date	Title	GA Code	URL	Free/ pay	Abstract
Historic England (Rhee-Duverne, S and Baker, P)	2013	Research into the Thermal Performance of Traditional Brick Walls	H	https://research.historicengland.org.uk/redirect.aspx?id=6935|%20Research%20into%20the%20Thermal%20Performance%20of%20Traditional%20Brick%20Walls	Free	Global pressures to reduce energy use are on the increase. Traditional buildings are often seen as energy inefficient and there are pressures to adapt them to improve their thermal performance. To better understand the performance of traditional and historic buildings and elements and the need and scope for upgrading, English Heritage has been commissioning a series of research projects. This report presents the finds of two studies undertaken during 2010-12 by Glasgow Caledonian University and English Heritage, which focused on the thermal performance of brick walls, as this is the form of construction most commonly encountered in traditional buildings in England.
Historic England (Rhee-Duverne, S and Baker, P)	2015	A Retrofit of a Victorian Terrace House in New Bolsover: A Whole House Thermal Performance Assessment	F, G, H	https://research.historicengland.org.uk/redirect.aspx?id=6940|%20A%20Retrofit%20of%20a%20Victorian%20Terrace%20House%20in%20New%20Bolsover:%20A%20Whole%20House%20Thermal%20Performance%20Assessment	Free	This report presents the results and analysis of the thermal performance measurements made in a brick built end terrace house in New Bolsover, Derbyshire. The house constructed in 1891 has a total floor area of 88m2 and comprises a living room, kitchen/dining room and bathroom on the ground floor and three bedrooms on the first floor. The work was carried out by Historic England and Glasgow Caledonian University, before and after the installation in December 2011 of a package of interventions, including internal wall insulation, improved loft insulation, insulation of the suspended timber floor

						and reinstatement of single-glazed timber framed windows with high specification secondary glazing systems behind them. Before the intervention, the house had only loft insulation of varying thicknesses and a variety of single and double glazed replacement aluminum framed windows.
Historic England (Ridout, B)	2017	Ventilation and Conservation	B	https://research.historicengland.org.uk/redirect.aspx?id=6737|Ventilation%20and%20conservation	Free	This report discusses the relationships between timber decay and ventilation. Among architects and other building professionals, the accepted wisdom is that even a little air movement is better than none. Therefore, holes will be made into any kind of cavity with the intention of providing ventilation. The result can be very disfiguring and damaging and has prompted the questions: • Can air actually be made to flow in small cavities? • What would we expect small air movements to achieve? Many building professionals will be surprised that there is any need for further research on ventilation. Therefore, some historical information is presented to show how our faith in air movement has developed.

Author(s)	Date	Title	GA Code	URL	Free/ pay	Abstract
Historic England (Ridout, B)	2017	Does Wall Plaster Retard the Drying of Walls After Flooding?	F, X	https://research.historicengland.org.uk/redirect.aspx?id=7480|Does%20Wall%20Plaster%20Retard%20the%20Drying%20of%20Walls%20After%20Flooding?	Free	After fire or flood, wall plaster is usually removed from walls in an effort to speed drying. This report presents the results of some preliminary, small-scale experiments to find out whether the removal of lime plaster does in fact speed the drying of walls. The experimental procedure uses a simple and rapid methodology to compare the drying rates of samples of lime plaster and brick as a starting point for further research. The results suggest that a wet wall will not dry more quickly if lime plaster is removed.
Historic England (Willett, C and Wood, C)	2018	Finding stone	X	https://historicengland.org.uk/content/docs/research/ctx154-willett-wood-finding-stonepdf/	Free	Historic England's Strategic Stone Study's county-by-county, nationwide survey identifies building stones used, and maps their sources and representative buildings and structures.
Historic Environment Forum	2015	Case studies from Heritage Counts 2015	D,U	https://historicengland.org.uk/research/heritage-counts/2015-caring-for-the-local-historic-environment/	Free	Heritage Counts reported on the views and experiences of those responsible for looking after the local historic environment. Three pieces of research were commissioned which include case studies and profiles.

Author(s)	Date	Title	GA Code	URL	Free/ pay	Abstract
Historic Environment Forum	2015	Heritage Counts 2015: Caring for the Local Historic Environment	D, S, T	https://historicengland.org.uk/content/heritage-counts/pub/2015/heritage-counts-2015-caring-local-historic-environment-pdf	Free	Heritage Counts provides trends, insights and data about the heritage sector, highlighting changes and history in the making. This year, Heritage Counts research focuses on carbon in the built historic environment.
Historic Environment Forum	2019	Heritage Counts 2019: Carbon in the built historic environment	R	https://historicengland.org.uk/research/heritage-counts/2019-carbon-in-built-environment/	Free	Using actual data from two historic building case studies the consultants developed a life cycle assessment model to estimate the whole life carbon emissions before and after different energy efficient refurbishment scenarios. The research shows that carbon emissions are reduced by more than 60 per cent by 2050 as a result of the refurbishment and retrofit options.
Historic Environment Scotland	2018	Technical Paper 24: Historic Environment Scotland Refurbishment Case Studies: Review Of Energy Efficiency Project	B, F, G, H, J, K, T, U, W	https://www.historicenvironment.scot/archives-and-research/publications/publication/?publicationid=1b9092e3-4080-439e-be0a-a96600c2c1e4	Free	This reports on an independent review of 18 of Historic Environment Scotland's Refurbishment Case Studies which describe how traditional buildings have been improved, and what lessons can be learned about how best to upgrade Scotland's traditional building stock.

Author(s)	Date	Title	GA Code	URL	Free/ pay	Abstract
Historic Environment Scotland	2013	Fabric Improvements for Energy Efficiency in Traditional Buildings	D, G, H, J, K	https://www.historicenvironment.scot/archives-and-research/publications/publication/?publicationId=179c1909-3679-4486-9583-a59100fa98c1	Free	This guide presents a series of practical solutions to improving energy efficiency in traditional and historic buildings, through a range of fabric improvements measures to different elements of a structure. The methods outlined in this report will allow the building to continue to function in terms of ventilation and permeability whilst maintaining historic fabric and character and minimising the visual impact of the changes.
Historic Environment Scotland	2015	Technical Paper 15 Assessing risks in insulation retrofits using hygrothermal software tools: Heat and moisture transport in internally insulated stone walls	F	https://www.historicenvironment.scot/archives-and-research/publications/publication/?publicationId=8a2a7b9d-e3b2-4c7d-8c17-a59400a8387b	Free	This paper provides an introduction to the basics of hygrothermal building physics, and discusses assessment methodologies, including related methods, standards and software tools and illustrates these in a case study.
Historic Environment Scotland	2013	Technical Paper 17 Green Deal, Energy Company Obligation and traditional buildings	G	https://www.historicenvironment.scot/archives-and-research/publications/publication/?publicationId=d3cc13e0-f84a-4c39-bfb4-a59400a9952d	Free	The Green Deal is the UK government's flagship policy to drive an increased uptake in energy efficiency measures. Through the Green Deal, households and businesses can install energy efficiency measures at no upfront cost. Instead, they will pay for the installation costs through regular payments

						on their energy bills. The Green Deal's 'Golden Rule' aims to ensure that the repayments do not exceed savings on energy bills as a result of the energy efficiency improvements. Some measures, which do not meet the 'Golden Rule' without support, will still be eligible under the Green Deal. These are expected to receive funding through the Energy Company Obligations (ECO). This includes hard-to-treat housing, and places significant emphasis on solid wall insulation. Historic Scotland Technical Paper 17 analysed three traditional property types common across Scotland, modelling comprehensive upgrade packages and identifying opportunities for financial support through the Green Deal and ECO. The report revisits Technical Paper 16, which explored the Green Deal in relation to traditional buildings in early 2012. Significant changes to the Green Deal and ECO has been made since, and the likely funding arena is substantially different. Technical Paper 17 therefore provides an up-to-date analysis of the applicability and limitations of the Green Deal and ECO for traditional properties in Scotland.

Author(s)	Date	Title	GA Code	URL	Free/ pay	Abstract
Historic Environment Scotland	2013	Technical Paper 18 Evaluating Energy Modelling in Traditionally Constructed Dwellings	G	https://www.historicenvironment.scot/archives-and-research/publications/publication/?publicationId=1d90d4c3-f8ca-4468-8049-a59400b32e50	Free	With the use of building modelling now mandatory, there is a need to understand the requirement, the types of evaluation packages available and how the apply to certain house types. The use of modelling tools to assess performance and give recommendations for thermal upgrade is an area of growth and constant change. The scope of the Scottish building stock is extensive, with a wide variety of property types and differing dates of construction. Historic Scotland is taking special interest in older properties, mainly inter war housing and properties that date from pre 1919. Some of these dwellings are historic and many of which are not. However, they generally conform to standard construction techniques and the materials used, and as such the retrofit measures need to be configured with this fabric in mind. The Scottish House Condition Survey estimates that up to 20 per cent of Scotland's housing stock is in the pre-1919 category and therefore represents a significant proportion of the stock. As much of the basic thermal upgrades will be delivered by Green Deal or ECO processes, which uses the modelling tool RdSAP, it is important to understand how this process assesses older properties and what sort of

						recommendations it will give for refurbishment. No modelling system can cover all house types, and any system is a compromise of differing demands. This paper will seek to outline some of the characteristics of RdSAP and how it interprets this significant proportion of the pre-1919 stock. It will also consider areas where some improvement might assist in the modelling of older buildings and the consequent recommendations for improvement.
Historic Environment Scotland	2013	Technical Paper 19 Monitoring Thermal Upgrades to Ten Traditional Properties	F, H	https://www.historicenvironment.scot/archives-and-research/publications/publication/?publicationId=4d0a95cb-2a0c-484a-894d-a59400b3f69b	Free	This Technical Paper sets out the pre- and post-intervention monitoring work carried out by The Scottish Energy Centre (SEC) at Edinburgh Napier University for Historic Scotland as part of the energy efficiency refurbishment pilot programme on traditional and historic buildings. The measurements were concerned with quantifying the thermal improvements achieved by the upgrade measures, and as such follow a before and after sequence. While hygrothermal monitoring is ongoing in several of the Historic Scotland pilots (Wells O Wearie, Cumnock and Newtongrange) that aspect of the monitoring work is a longer-term process (over a 12 to 24 month timeframe) and will be a part of a separate study.

						Details of the site work at the locations discussed are discussed further in the Refurbishment Case Studies published by Historic Scotland. The results in this paper contribute to the increasing evidence available on the thermal performance of traditional building elements. This will be a useful contribution to a knowledge base, which can be used towards the development of suitable energy performance modelling tools for older buildings in the future.
Historic Environment Scotland	2013	Technical Paper 20 Slim-profile double-glazing in listed buildings: Re-measuring the thermal performance	D, H	https://www.historicenvironment.scot/archives-and-research/publications/publication/?publicationId=a4eee388-69ec-4da6-915f-a59400aa36d5	Free	Historic Scotland Technical Paper 20 presents the results from thermal in-situ testing of slim-profile double glazing. During the winter of 2009/2010, Changeworks led a pilot project, Double Glazing in Listed Buildings, installing a range of slim-profile double-glazing systems into category 'B' listed, Georgian tenement buildings in Edinburgh's Old Town. As part of that project, published as Historic Scotland Technical Paper 9, the thermal performance of all glazing units was measured and the embodied energy associated with them was investigated. That project answered most of the questions surrounding double-glazing in listed buildings, except for the longevity of the glazing units. In 2011, it was, therefore, decided to re-measure in situ the thermal performance of the units, which by then would have been in place for two years.

						This report presents, and draws conclusions from, the comparison of the U-value results measured in the winters of 2009/10 and 2011/12.
Historic Environment Scotland	2014	Technical Paper 22 Scotstarvit Tower Cottage	M, N	https://www.historicenvironment.scot/archives-and-research/publications/publication/?publicationId=7a69ec6b-1488-4a14-8560-a59400bbfc2a	Free	Electric radiant heating panels were installed at Scotstarvit Tower Cottage following extensive refurbishment to improve the building's energy efficiency and replace the existing oil fired wet-heating system. This report outlines the study that was carried out to assess the performance of the new heating system and considers the methods used, results obtained and the conclusions that can be drawn from the analysis.
Historic Environment Scotland	2014	Technical Paper 23 Thermal assessment of internal shutters and window film applied to traditional single glazed sash and case windows	D, H	https://www.historicenvironment.scot/archives-and-research/publications/publication/?publicationId=4a1a95dd-9e9f-4b9d-8381-a59400ac0be8	Free	This report examines two inexpensive methods for improving the thermal performance of single glazed sash and case windows; the use of insulated shutters, and a window film applied to the existing panes. Both techniques were trialed at Wee Causeway, a detached 18th century cottage in Culross, with the success of each approach analysed in relation to thermal transmittance measurements taken in-situ, together with those calculated using proprietary software programmes.

Author(s)	Date	Title	GA Code	URL	Free/ pay	Abstract
Historic Environment Scotland	2018	Technical Paper 27 Hot-mixed Lime Mortars: Microstructure and Functional Performance	D	https://www.historicenvironment.scot/archives-and-research/publications/publication/?publicationId=42b16bde-857d-400d-98b1-a89400ea3898	Free	This paper presents technical evidence for the use of hot-mixed lime mortars in the conservation of masonry structures. It examines how lime mortars function in practice, looks at historic lime mortars and highlights key characteristics of hot-mixed lime mortars.
Historic Environment Scotland	2019	36 refurbishment case studies	D, F, H	https://www.historicenvironment.scot/archives-and-research/publications/?publicationtype=31&q=&curPage=2	Free	Case studies on the refurbishment of buildings in Scotland.
Hossain, A and Mourshed, M	2018	Retrofitting buildings: Embodied and operational energy use in English housing stock	H, R	https://www.researchgate.net/publication/327188457_Retrofitting_Buildings_Embodied_Operational_Energy_Use_in_English_Housing_Stock	Free	This study is aimed at assessing the impact of the insulation refurbishment of the English housing stock on the embodied energy needed for the various refurbishment scenarios and their corresponding operational energy use reductions. An embodied energy model comprising 22 million homes has been constructed, enabling the assessment and comparison of operational and embodied energy use due to the insulation refurbishment of various applicable building elements. Results indicate that

						mineral wool, sheep wool and expanded polystyrene (EPS) are the optimum insulation materials for cavity walls, cold pitch roofs and warm pitched roofs, respectively.
Hu, D, Jones, P and Lannon, S	2016	Creating localised near future weather data for predicting the performance of buildings in the UK	V	http://orca.cf.ac.uk/88545/1/Dr.%20Hu%20Du%2C%20clima2016%20v31Jan.pdf	Free	Past research shows that the optimisation of energy management with weather forecasting can generate 15-30 per cent savings in most cases. Therefore, it is crucial to develop a method of gathering reliable weather forecast data and applying the forecast data into building performance simulation or building energy management system. Since 2011, the Meteorological Office (Met Office) in the United Kingdom released three-hourly site-specific forecast data feeds for nearly 6,000 locations in the UK through the Met Office DataPoint in a format that is suitable for web application developers. This provides a great opportunity for building performance simulation professionals to re-use Met Office data for predicting near future building performance.

Author(s)	Date	Title	GA Code	URL	Free/ pay	Abstract
IHBC	2013	Skills assessment of local authority conservation staff	V	https://historicengland.org.uk/content/heritage-counts/pub/2013/ihbc-skills-assessment-local-authority-conservation-staff-pdf	Free	This report represents an initial mapping of the skills available to England's local authority conservation services in delivering their statutory and non-statutory duties. The report, commissioned by English Heritage, is based on data collected and collated in 2013 by The Institute of Historic Building Conservation (IHBC). It uses two sets of data sources from two distinct research programmes: a desk top data gathering based on existing research into local authorities already carried out by the IHBC and other public sources; and a new open public web-based survey specifically developed in partnership with English Heritage to help evaluate current skills, skills development priorities and future support needs. This summary collates the conclusion to each strand of the project.

Author(s)	Date	Title	GA Code	URL	Free/ pay	Abstract
Innovate UK	2016	Innovative Refurbishment, Garth House, Bicester	D, G	https://connect.innovateuk.org/documents/3335695/30423546/972157%20-%20Internal%20insulation%20at%20the%20Garth?version=1.1	Free	These non-domestic, heritage buildings pose a twin challenge for refurbishment programmes, which have energy efficiency drivers at their heart. Firstly, retaining the essence of these existing buildings often prevents the environmental upgrade of the building fabric using external insulation or replacement windows as altering the external appearance is generally unacceptable. Secondly, insulating internally has significant challenges and can be highly disruptive for building users. The project tackled these challenges to achieve a step-change reduction in primary energy consumption and CO2 savings by employing an innovative application of internal insulation technology, in combination with secondary glazing and a ventilation strategy. In addition to the energy and carbon savings, the significant upgrade to the environmental comfort, and consequent increase in productivity, is an attractive option for organisations operating in historic buildings. Specifically, the project used the patented WHISCERS™ technology that had previously only been used in domestic dwellings in the UK. WHISCERS™ (Whole House In-situ Carbon and Energy Reduction System) uses a laser to survey each room of the building allowing off-site cutting of the insulated plasterboard.

Author(s)	Date	Title	GA Code	URL	Free/ pay	Abstract
Institute for Sustainability	2012	Key Findings report: retrofit project team perspectives	G, S	https://www.bere.co.uk/assets/NEW-r-and-d-attachments/Passfield-Drive-and-Grove-Road-Retrofit-for-the-Future-Retrofit-insights-perspectives-for-an-emerging-industry-2012.pdf	Free	Between May 2011 and July 2012, the UCL Energy Institute (UCL-Energy), working in partnership with the Institute for Sustainability, undertook a post-occupancy evaluation study on a sample of the projects funded by the Technology Strategy Board's Retrofit for the Future (Rt4F) programme in London. The core aim of the programme was to reduce the carbon emissions of existing homes by a minimum of 80 per cent (TSB 2009) while providing affordable warmth for the occupants.
Ireland, T, Brown, S and Schofield, J	2020	Situating (in)significance	D	https://pure.york.ac.uk/portal/en/publications/situating-insignificance(2b09db55-1c39-483e-9016-726215ec0083).html	Pay	In this paper we introduce the concept of '(in)significance' as a way to think about values in heritage, and in the attribution, recording, description, assessment and categorisation practices that characterise heritage processes. Our aim is to throw light on how this concept shapes, and is shaped by, contemporary heritage practices and outcomes. We consider the history of the idea of significance, particularly as it is defined in the Burra Charter, and trace its inheritance lines in settler nation states and capitalist economic structures, and highlight its retention of concepts of heritage value as both intrinsic and culturally attributed.

Author(s)	Date	Title	GA Code	URL	Free/ pay	Abstract
Ji, Y et al	2014	Assessing overheating of the UK existing dwellings – A case study of replica Victorian end terrace house, Building and Environment	P	http://dx.doi.org/10.1016/j.buildenv.2014.03.012	Pay	This paper aims to investigate the likely thermal performance of a unique pre-1919 Victorian case study property by using both current and future projected weather data after a deep retrofit. The property is a re-construction within an environmental chamber using reclaimed materials designed to test housing retrofit solutions. Climate projections for Manchester from both UKCIP02 and UKCP09 programmes were used to assess the likely overheating in summer for this 'Hard to Treat' property judging by both single and adaptive comfort criteria from CIBSE Guide A and BS EN 15251. In the bedroom, where occupants have less ability to adapt, overheating could occur as early as 2020s; while in the living room, using the annually adaptive approach, overheating may not happen until 2080s.
Jiang, S et al	2015	Winter Indoor Air Temperature and Relative Humidity in Hard-To-Heat, Hard-To-Treat Houses in Wales: Results from a Household Monitoring Study	A, C, E, G	https://www.cardiff.ac.uk/__data/assets/pdf_file/0013/1320331/WSA-Working-Paper-03-2015.pdf	Free	This working paper presents the descriptive results of the first phase of a household monitoring study that is part of a wider research project examining the health impacts of energy performance investments in Wales under the Arbed programme, which aims to improve energy efficiency of homes in low-income neighbourhoods. The study monitored the internal environmental conditions of 99 dwellings, of which 50 were located in five

						low income areas where Arbed domestic energy-performance investments were planned and 49 in matched control areas where no such investments were planned. The monitoring took place before the Arbed energy efficiency upgrades were made. The results described in this working paper therefore reflect the energy performance of typical 'hard-to-heat, hard-to-treat' houses in Wales.
John Gilbert Architects	2013	PassivTEN: Upgrading Glasgow's Tenements to Passivhaus Standard	D	http://www.cicstart.org/userfiles/file/FS-39-REPORT.PDF	Free	John Gilbert Architects, The Mackintosh Environmental Architecture Research Unit and Towler and Hyslop Ltd (Quantity Surveyors) were appointed by Milnbank Housing Association and CIC Start Online to explore the feasibility of upgrading tenements to reduce energy use, reduce energy bills and explore the possibility of meeting the internationally recognised Passivhaus standard. Traditional sandstone tenements make up over 35 per cent of Milnbank Housing Association's stock. They are not listed and do not fall into a conservation area. Whilst they have no historic designation, they are fundamentally sound, beautiful buildings that could have a number of adaptions made to ensure that residents can continue to live long lives in these homes without suffering fuel poverty.

Author(s)	Date	Title	GA Code	URL	Free/ pay	Abstract
Jones, P et al	2017	Five energy retrofit houses in South Wales, Energy and Buildings, Volume 154, 1 November 2017, Pages 335-342	G, H	http://orca.cf.ac.uk/104753/1/retrofit%20paper_27%20Jul17_3.pdf	Free	With around 1–2 per cent annual replacement of the UK's housing stock, housing retrofit must play a major role in reducing future energy use and CO2 emissions. This paper presents a whole-house approach for energy retrofit for five houses located in South Wales. This 'systems based' approach combines reduced energy demand, renewable energy supply and battery storage. The paper describes a combination of energy modelling, using the building energy model HTB2, and field measurements to analyse the performance of the houses before and after retrofit. The results indicate that significant reductions in energy use, CO2 emissions and energy costs can be achieved using a whole house approach, combining energy efficiency with building integrated renewable energy generation and energy storage. CO2 emission reductions are estimated to be in the range of 50–75 per cent, with cost savings of £402 to £621 per year. The cost of carrying out the retrofitting ranges from £23,852 to £30,510. Although retrofits are still relatively expensive in relation to their annual cost savings, there are multiple benefits relating to reducing fuel poverty, reducing electricity grid stress and contributing to national CO2 emission reduction targets. Also, as costs of

						measures are further reduced and energy prices likely to rise in future, the cost balance will change more in favour of whole house retrofit. The paper demonstrates the advantages in using a combination of energy simulation and field monitoring to investigate the performance of buildings in use, which in this case concerns the impact of carrying out energy retrofits in housing.
Jones, P, Lannon, S and Patterson, J	2013	Retrofitting Existing Housing: How Far, How Much	G, H, N, W	http://www.solcer.org/files/2014/01/Building-retrofit-paper-2013.pdf	Free	The significance of retrofitting the existing housing stock is considered for the policy commitment of delivering an 80 per cent CO2 emission reduction by 2050.
Jurošević, S and Grytli, E R	2016	Energy efficiency retrofit of historic buildings: concepts, approaches and interventions, Proceedings EECHB-2016 - Energy Efficiency and Comfort of Historic Buildings	D, H, V	https://www.researchgate.net/profile/Michael_Hunt3/publication/309358419_Cornwall_Council-Skills_Training_and_Energy_Saving_Initiatives/links/580b0c6a08ae74852b5309b6/Cornwall-Council-Skills-Training-and-Energy-Saving-Initiatives.pdf	Free	The concept of retrofitting existing buildings is getting more attention, primarily due to data indicating that the building sector is one of the key consumers of energy, and the targets for greenhouse gas emissions set by the legislative branch. However, in case of historic buildings there is a great concern regarding valuable architectural heritage that has to be considered prior to making any decisions that could permanently harm the heritage value in question. There have been many individual and joint research projects trying to examine the gap between energy efficiency legislation and

						heritage protection, consequences of use of different retrofit scenarios and technologies, and establishing a methodology of assessing possible strategies for the energy efficiency upgrade of historic buildings not officially heritage-designated. This paper aims to give a brief overview of the research conducted, with special emphasis on the complex issues regarding retrofitting historic buildings with regard to their sensitivity.
Kenny, P and Tatar, G	2015	Innovative strategies for the sustainable re-use of vacant Victorian terraced houses: Part 1: The causes and effects of large numbers of vacant traditional Victorian terraced houses AND Innovative strategies for the sustainable re-use of vacant Victorian terraced houses Part 2	D, F, S, T, U	https://www.researchgate.net/publication/284183550_Innovative_strategies_for_the_sustainable_re-use_of_vacant_Victorian_terraced_houses_Part_1	Free	This study is intended to be the first research paper in a series of studies dedicated to the re-use of vacant traditional Victorian terraced houses as an alternative to the many demolition schemes that have been carried out in recent years. This article attempts to explore the causes which have contributed to a large number of Victorian terraced houses becoming vacant leading to the possibility of large scale demolition. The empty home phenomenon is investigated by identifying and analysing the key issues that have led to this problem including dampness, poor design, overcrowding conditions, and high heating costs. The article also aims to bring attention to and explain the effects from a social, economic, environmental perspective. The conclusions will set up the next study topic in order to offer strategies and practical solutions for bringing

						traditional Victorian terraced houses back into use.
Latif, E et al	2018	An experimental investigation into the comparative hygrothermal performance of wall panels incorporating wood fibre, mineral wool and hemp-lime	F, H, X	http://orca.cf.ac.uk/108359/1/comparative%20hygrothermal%20performance%20of%20wall%20panels%20.pdf	Free	Three wall panels of identical calculated U-value were simultaneously assessed in a large dual environmental chamber under a number of steady state and dynamic hygrothermal boundary conditions. This study used large-scale wall elements under identical controlled conditions in order to eliminate uncontrollable variables normally encountered in full-scale studies. The following panels were tested: Mineral Wool Panel, Wood Fibre Panel and the Biond Panel (an assembly of wood fibre and hemplime). Within the limits of the error range of the calculation, the measured U-value was same for all test panels when assessed under steady state and dynamic hygrothermal boundary conditions. It was however observed that in a boundary condition simulating intermittent heating, the Biond panel showed the highest heat storing and releasing capability whereas the Mineral Wool Panel showed the lowest. In terms of moisture management, the Biond panel exhibited the highest moisture dampening ability within the panel structure. Higher thermal and hygric inertia of the Biond panel may be useful in mitigating overheating of dwellings and reducing interstitial condensation.

Author(s)	Date	Title	GA Code	URL	Free/ pay	Abstract
Latif, E et al	2015	Hygrothermal performance of wood-hemp insulation in timber frame wall panels with and without a vapour barrier	F	https://www.researchgate.net/publication/275697815_Hygrothermal_performance_of_wood-hemp_insulation_in_timber_frame_wall_panels_with_and_without_a_vapour_barrier	Pay	An in situ experiment on a full-scale timber frame test building was carried out to study the hygrothermal performance of wood-hemp composite insulation in timber frame wall panels with and without a vapour barrier. The heat transfer properties and the likelihood of mould growth and condensation in the panels were compared. Step changes in the internal relative humidity were performed to explore the effects of high, normal and low internal moisture loads on the wall panels. No significant difference in the average equivalent thermal transmittance (U-values) between the panels with and without a vapour barrier was observed. The average equivalent U-values of the panels were close to the U-values calculated from the manufacturers' declared thermal conductivity values of the insulation. The likelihood of condensation was higher at the interface of the wood-hemp insulation and the oriented strand board (OSB) in the panel without a vapour barrier. In terms of the parametric assessment of the mould germination potential, the relative humidity, the temperature and the exposure conditions in the insulation-OSB interfaces of the panel without a vapour barrier were found to be more favourable to the germination of mould spores.

Author(s)	Date	Title	GA Code	URL	Free/ pay	Abstract
Litti, G et al	2015	Hygrothermal performance evaluation of traditional brick masonry in historic buildings, Energy and Buildings Volume 105, 15 October 2015, Pages 393-411	H	https://www.sciencedirect.com/science/article/abs/pii/S0378778815301651	Pay	In this study, an indirect non-invasive envelope monitoring, for evaluating brick masonry hygrothermal behavior, has been proposed and applied in a heritage building in Antwerp (Belgium). The suggested method is aimed at onsite evaluating the thermal performance of buildings traditional masonry and at quantifying the extent of its alteration due to the moisture distribution variation.
Little, J and Arregi, B	2016	Managing moisture – the key to healthy internal wall insulation retrofits of solid walls	F	https://www.researchgate.net/publication/303458807_Managing_moisture_-_the_key_to_healthy_internal_wall_insulation_retrofits_of_solid_walls	Free	This study investigates the appropriateness of internally insulating solid walls to the Passivhaus standard. A number of variables are assessed using numerical hygrothermal simulation (under EN 15026) to check (1) associated risk of mould growth on original substrate and (2) if they result in a greater likelihood of timber decay at built-in joist ends. 1. Cellulose blown through a gauze, as representing a 'low- carbon' approach 2. Cellulose with an AVCL, as representing a 'best practice' approach 3. PIR with foil face taped, representing a 'commercial' approach

Author(s)	Date	Title	GA Code	URL	Free/ pay	Abstract
Littlewood, J et al	2017	Introduction to a Wales project for evaluating residential retrofit measures and impacts on energy performance, occupant fuel poverty, health and thermal comfort	A, C, E, G, S	https://www.sciencedirect.com/science/article/pii/S1876610217346672	Free	This paper discusses a Knowledge Economy Skills Scholarship two (KESS2) under the Low Carbon, which crosses the Energy and Environment and also the Lifesciences and health economic priority areas of the Welsh Government and is to be undertaken by the final author under the guidance of the other authors. The KESS2 project will evaluate retrofit measures on upgrades to dwelling from the Arbed 1, 2 and 3 programmes in Wales, and also assess impacts upon energy performance, and occupant fuel poverty, health and wellbeing and thermal comfort. The significance of the research is that there are no other studies that address all these parameters; indeed, much of the work to date in the UK is focused upon investigating impacts upon the dwellings. The KESS2 project led by Cardiff Metropolitan University is undertaken and co-funded in collaboration with Being Greener at Melin Homes and builds upon a successful KESS1 project that evaluated the construction quality of retrofitted exterior wall insulation (EWI) on dwellings where the occupants were in fuel poverty between 2010 and 2014. Context to the academic, scientific and industrial challenges are discussed, as is the programme of work and the expected outcomes. This paper will be useful for academics, landlords of housing

						stock undergoing retrofit measures and government agencies funding retrofit upgrades to dwellings.
Lomas, K and Porritt, S	2016	Overheating in buildings: lessons from research	C	https://www.tandfonline.com/doi/full/10.1080/09613218.2017.1256136	Free	There is growing evidence of an increased incidence of overheating during warm weather in buildings without air-conditioning, especially homes in temperate climates where the retention of winter heat has been the principal focus of thermal design. Overheating has been particularly notable in new homes and in existing stocks. Excess heat affects the health and wellbeing of occupants, especially if sleep is degraded. In extremis, the heat stress caused can lead to premature mortality, especially amongst more vulnerable members of society. The problem came vividly to the fore during the devastating 2003 pan-European heatwave which caused 15,000 premature deaths (PHE, 2015).
Lucchi, E et al	2017	Thermal performance evaluation and comfort assessment of advanced aerogel as blown-in insulation for historic buildings,	H	https://www.sciencedirect.com/science/article/abs/pii/S0360132317302536	Pay	Research and development of cost-effective, high-performance thermal insulation materials for the construction sector has to be focused on their final application. In particular, solutions for refurbishing historic buildings, which represent 40 per cent of the European building stock, have to offer a good

		Building and Environment, Volume 122, September 2017, Pages 258-268				compromise between environmental quality, energy efficiency and conservation aspects. In this paper, the experimental assessment of an insulation material based on aerogel technology, recently developed in the European project EFFESUS, is presented with regard to the material's thermal performance, compatibility with historic fabric and reversibility. The overall results obtained in laboratory testing on a real-size mock-up and in a real-world case application indicate that the new material is a promising solution for retrofitting historic buildings, thanks to its thermal properties, easy application, reversibility and material compatibility.

Author(s)	Date	Title	GA Code	URL	Free/ pay	Abstract
Lucchi, E, Roberti, F and Alexandra, T	2018	Definition of an experimental procedure with the hot box method for the thermal performance evaluation of inhomogeneous walls, Energy and Buildings, Volume 179, 15 November 2018, Pages 99-111	H	https://www.sciencedirect.com/science/article/abs/pii/S0378778818312313	Pay	Research and development of high thermal insulation materials for the construction sector requires an accurate characterisation of the wall's performance, since that is the main causes of thermal exchanges between the internal and external boundaries. This paper presents a test procedure developed within the EU Project EFFESUS for evaluating the steady-state thermal performance of a masonry wall. A large-scale mock-up of the inhomogeneous wall was tested in a guarded hot box (GHB) apparatus before and after the application of an aerogel-based material. The methodology proposed in this paper is structured in the following steps: (i) definition of the wall geometry and the percentage of stone and mortar, using walls' photographic records and geometrical surveys; (ii) precise thermal characterisation of the material used; (iii) hygrothermal assessment procedure based on infrared technology (IRT) survey, gravimetric test, and monitoring of the internal relative humidity (RH); (iv) steady-state and dynamic thermal simulation; and (v) detailed set-up of the test using the data retrieved from the thermal surveys and simulations. According to the results of IRT surveys

						and the dynamic simulations, the mock-up was divided into thermal homogeneous parts, verifying the uniformity of the surface temperature and the heat flux in an isothermal area. This approach was validated both for low and high energy performance walls. Results show that the thermal flux was reduced to one third after the application of the aerogel.
Mackintosh Environmental Architecture Research Unit	2012	7 -11 Gilmour's Close, Performance Evaluation – January 2012	B, G, M, N, S	http://www.cicstart.org/userfiles/file/AC-6-REPORT.PDF	Free	Gilmour's Close is a four storey, 19th century stone tenement, with commercial ground floor, located in the World Heritage site of Edinburgh's Grassmarket. Refurbishment of this building was completed by Assist Architects, in 2008, to provide social rented and supported housing for Hillcrest Housing Association. In the refurbishment process Assist sought not only to conserve the historic aspects of this category B listed structure but also to incorporate low energy principles to the design in the form of ground source heating, passive solar strategies, mechanical ventilation with heat recovery (MVHR) and upgrade of the fabric's thermal performance by internal lining. This project aims to assess the performance of this development in terms of energy use and user experience, through a three week monitoring process and subsequent analysis of the small office space within the

						development and five individual dwellings (two mainstream social rented and three supported).
Marincioni, V et al	2016	Estimating the impact of reveals on the transmission heat transfer coefficient of internally insulated solid wall dwellings; Energy and Buildings, Volume 128, 15 September 2016, Pages 405-412	J	https://www.sciencedirect.com/science/article/pii/S0378778816305564	Free	Internal wall insulation as a retrofit measure could help to reduce energy use and greenhouse gas emissions in many of the six million solid wall buildings in the UK. However during retrofit, junctions that are hard to deal with are often left uninsulated, increasing heat loss and surface mould growth risk at thermal bridges. Furthermore the effect of junctions, insulated or uninsulated is not properly taken into account in commonly used assessments of heat loss. This paper presents a study on the impact of the junctions around openings, also called reveals, on the transmission heat transfer coefficient of internally insulated dwellings and a discussion on potential areas of improvement of common assessment tools for retrofit. Findings showed that reveals account for the majority of the transmission heat transfer coefficient at junctions, that thicker wall insulation is not necessarily advantageous from a heat loss perspective, and that the transmission heat transfer coefficient at junctions per unit area of exposed elements was often higher than the reference value used in the UK.

Author(s)	Date	Title	GA Code	URL	Free/ pay	Abstract
Marincioni, V, Lorenzetti, F and Altamirano, H	2019	Parametric study on the hygrothermal performance of timber frame walls with external airtightness membranes in a temperate maritime climate	F	https://www.readcube.com/articles/10.1051%2Fmatecconf%2F201928202080	Free	In recent years, external airtightness membranes have become an option for timber frame wall systems, as they allow high levels of air- and wind-tightness with an easy installation and provide rainwater protection during construction. This opens up the option of removing the internal air and vapour control layer. However, the hygrothermal risks associated to this option could be higher than in conventional construction, because vapour transfer can occur from the indoor environment into the timber frame wall not just via diffusion but also advection. This can lead to moisture accumulation and mould growth risk within the wall structure. This paper presents a parametric study that aims at identifying the moisture risk when external airtightness membranes are installed on a timber frame wall in a temperate maritime climate.
Marincioni, V, Marra, G and Altamirano, H	2018	Development of predictive models for the probabilistic moisture risk assessment of internal wall insulation	F	https://discovery.ucl.ac.uk/id/eprint/10050920/	Free	Solid wall buildings account for a quarter of the UK building stock and need to be thermally upgraded to meet national greenhouse gas emission targets. Internal wall insulation (IWI) is often the only option for the retrofit of solid walls, especially when they are of architectural or historical interest. However, IWI can lead to moisture accumulation within the existing wall, affecting the structural integrity of the

						building and the health of occupants. To avoid these issues, a thorough risk assessment is necessary. This paper presents a method for developing predictive meta-models that can be used for a fast probabilistic moisture risk assessment of IWI, considering both the uncertainty and variability of input variables.
Marincioni, V, May, N and Altamirano-Medina, H	2015	Parametric Study on the Impact of Thermal Bridges on the Heat Loss of Internally Insulated Buildings, Energy Procedia, Volume 78, November 2015, Pages 889-894	J	https://www.sciencedirect.com/science/article/pii/S1876102150177452	Free	Internal wall insulation as energy efficiency retrofit measure could considerably help to reduce the greenhouse gas emissions of more than six million solid wall buildings in the UK. However during retrofit, junctions that are hard to reach are often left uninsulated, increasing heat loss and surface mould growth risk at thermal bridges. This paper presents a parametric study on the impact of thermal bridges on the total heat loss of an internally insulated mid-terrace house. Findings showed that heat flux through junctions occurred mainly at reveals and that the total heat flux at junctions per unit of exposed area was often higher than the default value used in the UK.

Author(s)	Date	Title	GA Code	URL	Free/ pay	Abstract
Marincioni, V, Sanders, C and May, N	2013	Heat loss from thermal bridging in internal wall insulation of solid buildings - DRAFT	G, H, J	http://files.site-fusion.co.uk/4f/04/4f042f22-9250-4782-8c08-84af00b2e0a3.pdf	Free	The contract states that the funding was "for the provision of the further development of the work summarised in the existing STBA report 'Internal insulation of solid masonry walls – practical limits due to thermal bridging and moisture performance'".
Marshall, A et al	2017	Domestic building fabric performance: Closing the gap between the in situ measured and modelled performance	G, H	https://www.researchgate.net/publication/317575657_Domestic_building_fabric_performance_Closing_the_gap_between_the_in_situ_measured_and_modelled_performance	Pay	To investigate this issue, a typical pre-1920s UK house is modelled in Designbuilder in order to recognise and reduce the gap between modelled and measured energy performance. A model was first built to the specifications of a measured survey of the Salford Energy House, a facility which is housed in a climate controlled chamber. Electric co-heating tests were performed to calculate the building's heat transfer coefficient; a difference of 18.5 per cent was demonstrated between the modelled and measured data, indicating a significant 'prediction gap'. Accurate measurements of air permeability and U-value were made in-situ; these were found to differ considerably from the standard values used in the initial model. The standard values in the model were modified to reflect these in-situ measurements, resulting in a reduction of the performance gap to 2.4 per cent.

Author(s)	Date	Title	GA Code	URL	Free/ pay	Abstract
May, N and Sanders, C	2017	White Paper Moisture in buildings: an integrated approach to risk assessment and guidance	E, F	https://shop.bsigroup.com/Browse-by-Sector/Building--Construction/Whitepaper-Moisture-in-buildings/	Free	There's a growing understanding that traditional moisture risk approaches are inadequate. This is because of changes to how buildings are constructed and used, and a greater understanding of why moisture causes buildings to fail. The White Paper: - describes why the approach to moisture in buildings needs to change - explains the limitations of current moisture risk assessment standards and regulations - proposes a way forward, using a new whole building approach - sets out the principles of the whole building approach - outlines how we should tackle moisture risk assessment and design in future. The content has been endorsed by academic experts and mainstream practitioners and is backed up by a considerable amount of research done in the UK and other parts of Europe.
May, N and Sanders, C	2012	A Short Paper on Internal Wall Insulation	H	http://stbauk.org/resources/index	Free	U value claims and targets for Internal Wall Insulation do not take sufficient account of: - The technical limitations to heat loss from IWI applications due to unavoidable thermal bridging - The increased risk to fabric and human health of reducing heat flow into walls beyond a certain

						limit and particularly in certain locations and orientations. This risk is particularly high in solid wall buildings There is a need to adjust or amend Building Regulations Approved Document part L1B and L2B and also the Scottish Technical Handbooks and Northern Irish Technical Booklets so that they reflect these facts. There is a need to ensure that certification and guidance reflect this fact. There is a need for further research to identify more clearly the limits and risks in different contexts.
May, N, Carmona, I and Leaman, A		Moisture guidance for existing homeowners	E, F, T	https://ukcmb.org/2019/10/23/moisture-guidance-for-existing-homeowners/	Free	This project aims to produce guidance to homeowners on how to avoid moisture problems in existing homes. A short video will be prepared that will provide an introduction to moisture in buildings, explaining in simple terms and images what damp means, where moisture in buildings comes from, as well as, introduce the notion of balance and how this can be achieved. Images of balance and interactions (inside/outside, fabric/people/services, for example) will be developed. An interactive web-based tool will be developed which shows how different measures or problems can push a building out of balance in a particular way and how we can start to restore balance.

Author(s)	Date	Title	GA Code	URL	Free/ pay	Abstract
May, N, Ucci, M and McGilligan, C	2017	Health and Moisture in Buildings	A, E, F	https://ukcmb.org/2019/10/27/health-and-moisture-in-buildings-report/	Free	Buildings which are too damp or too dry can be bad for occupants' health. This fact has been well established by many reports including those of the World Health Organisation and the Institute of Medicine. Yet precisely how bad such buildings are to what kinds of occupants at what level of dampness or dryness is much more difficult to define, as are the agents of illness, such as the many types of mould, bacteria, other irritants and toxins that can result from imbalances of moisture in buildings.
MHCLG	2019	Research into overheating in new homes - Phase 2 report	C	https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/845483/Research_into_overheating_in_new_homes_-_phase_2.pdf	Free	In response to the recommendations in the Committee on Climate Change (CCC) Progress Report to Parliament in 2015, the government has commissioned research to better understand the overheating risk in new dwellings in England and options to mitigate this risk. Phase 1 of the research was previously reported on. This report presents the results from Phase 2 which consists of a cost-benefit analysis of alternative risk mitigation strategies to reduce overheating risk to an acceptable level.

Author(s)	Date	Title	GA Code	URL	Free/ pay	Abstract
Murtagh, N, Gatersleben, B and Fife-Schaw, C	2017	Resilience to Overheating in Homes in Southern England: Householders Awareness and Preparedness, Conference Proceedings	C, M, P	https://www.researchgate.net/publication/334362043_Resilience_to_overheating_in_homes_in_southern_England_Householders'_awareness_and_preparedness	Free	In southern England, climate projections show increasing likelihood of the number and duration of heatwaves. With over 80 per cent of the 2050 UK housing stock already built, the householder is an important gatekeeper to making the built environment more resilient to overheating. The National House Building Council and others have issued recommendations for mitigating actions, including more insulation, better ventilation, shading and reflective external surfaces.
Murtagh, N, Gatersleben, B and Fife-Schaw, C	2019	Occupants' motivation to protect residential building stock from climate-related overheating: A study in southern England, Journal of Cleaner Production, volume 226, 20 July 2019, Pages 186-194	C, P, T	https://www.sciencedirect.com/science/article/pii/S0959652619311473?via%3Dihub	Free	Temperate zones including the UK and mainland Europe continue to be exposed to increasing temperatures and more frequent heatwaves as global warming continues. The built environment can mitigate the public health risk of overheating and recommendations for precautionary actions on homes have been published by government and industry. A key player in improving resilience is the householder, who can determine whether precautionary measures will be installed in their home. Previous research on flooding has applied Protection Motivation Theory to examine determinants of householder response to risk. However, flooding risks differ from those of overheating in several ways. The

						current study builds on this work to address the gap on understanding householder propensity to install precautionary measures against overheating. A large-scale survey (n = 1007) of householders was conducted in the south of England and regression analyses applied to the data. While threat appraisal (perception of threat risk and severity) had an influence on motivation to take action, coping appraisal (perception of ability to make changes, of the effectiveness of the changes and of convenience) was a stronger predictor, particularly for flat dwellers. Previous experience of overheating did not directly influence protection motivation. Age was negatively related to intentions to act but income was not a significant factor. Recommendations for policy and practice include focusing on enhancing coping appraisal, targeting older citizens, customising initiatives by type of property and occupancy, and framing mitigating actions in ways other than protection from overheating.

Author(s)	Date	Title	GA Code	URL	Free/ pay	Abstract
National Standards Authority of Ireland	2019	Code of practice for the energy efficient retrofit of dwellings	B, E, F, G, H, J, K, M, N, Q, V	https://shop.standards.ie/en-ie/Standards/S-R-54-2014-A1-2019-877610_SAIG_NSAI_NSAI_2749895/	Free	The scope of this Standard Recommendation addresses the energy retrofit of the building fabric and services of detached, semi-detached and terraced dwellings of not more than three stories.
NBT (Smith, M)	2017	Avoidance and Diagnosis of Problems Associated with Internal Wall Insulation	E, F, G, H, R	https://www.ingentaconnect.com/content/hsp/jbsav/2017/00000006/00000001/art00003?crawler=true#Data	Pay	Improving energy efficiency and comfort of traditional buildings affects how moisture moves through the building fabric. Internally insulating solid masonry walls can have a hugely positive impact on comfort, but doing so without regard for this relationship can lead to undesirable consequences, including trapped moisture and mould growth. A well-designed specification informed by a good understanding of the building and its context will preclude any unintended consequences.

Author(s)	Date	Title	GA Code	URL	Free/ pay	Abstract
Neroutsou, T I and Croxford, B	2016	Lifecycle costing of low energy housing refurbishment: A case study of a seven year retrofit in Chester Road, London; Energy and Buildings, Volume 128, 15 September 2016, Pages 178-189	R	https://www.sciencedirect.com/science/article/abs/pii/S0378778816305291	Pay	The low energy retrofit of the UK existing building stock is an urgent matter after the government's commitment to reduce carbon emissions by 80 per cent until 2050. This research addressed the question of whether it is preferable to refurbish in an extensive way or to choose a retrofit strategy with lower capital cost, embodied energy and CO2, tackling issues of cost- effectiveness, embodied and operational energy throughout the lifecycle of an existing Victorian house in London. The indicator Cost per Ton carbon Saved (CTS) was used, which resulted in higher values for the EnerPHit retrofit model, rendering it a less viable alternative. It was also concluded that retrofitting, in general and especially the application of EnerPHit, is an appealing option only with rising gas prices, low discount rates and long lifespans. Those results were even more amplified when climate change was taken into account, a conclusion very important for the application of future legislation and the possible transfer of this study to other climates. It was deduced that a house's remaining lifetime is a very significant factor to be taken into account, as investments of higher capital cost give higher benefit in long term.

Author(s)	Date	Title	GA Code	URL	Free/ pay	Abstract
Odgers, D	2018	Progress with stone consolidants	U, X	https://historicengland.org.uk/content/docs/research/ctx154-odgers-stone-consolidantspdf/	Free	For many centuries stone has been treated with a variety of materials, including limewash, oil, waterglass, copperas and wax. Some were applied to provide an aesthetic effect and some to provide protection. They should all be considered as surface treatments and not confused with consolidants, which are intended to restore cohesion and give mechanical strength to deteriorated stone without adversely affecting the behavior of the stone, depositing by-products that may harm it or affect its appearance. To achieve this, they need to penetrate through the full depth of the decayed zone but not fill the pores of the stone; and as though all of this were not difficult enough to achieve, the consolidant should not prejudice subsequent treatment or affect future maintenance of the stone. The search for a suitable consolidant has been going on for centuries.
Okutan, R S et al	2018	A socio-mathematical approach to exploring conflicts between energy retrofit and	D	https://purehost.bath.ac.uk/ws/portalfiles/portal/169823012/1_s2.0_S036013231830180X_main.pdf	Free	Retrofitting such buildings is controversial, as historic elements might be altered or covered up, thereby changing the character of the building. In this work, we introduce a novel socio-mathematical method to aid the resolution of this controversy. Firstly, we garner in a new way the views of 116 members of the public about the acceptability of 15

		perceived heritage character				common retrofit measures. Secondly, the public's ranking of the acceptability of the measures with respect to heritage impact is compared to a ranking of the energy saving given by the measures when analysed using a dynamic thermal simulation of the building. No simple correlation is found; hence it is concluded that measures that present greater energy savings are not de facto more intrusive, and that there is the potential for a constructive dialogue between those inspired by a conservation agenda and those targeting carbon savings. Finally, by using a Pareto front approach, a new theory is developed of how to identify measures that are sensible in the eyes of both parties. This new three-stage process will be of use to those in Government attempting to resolve such conflicts or set national guidance.
Oxford Brookes	2021	Angmering Community Centre - Non-domestic in-use building performance evaluation	M, P, Q, S	https://www.brookes.ac.uk/architecture/research/low-carbon-building-group/building-performance-evaluation/angmering/	n/a	The initial study of the centre has revealed complications with the handover process, issues with usability of controls especially for public use, external noise restrictions in the buildings location and lack of in-use energy data. The two year Building Performance Evaluation study intends to: • improve performance by providing feedback on how the multi-stakeholder public client manages the building to support each end users group's very distinctive needs. • investigate if there is a demand for a

						cooling system and whether it could be met by a reversal of the cooling system. • assess the feasibility of solving acoustic problems in the hall, installing daylight detectors, time controls, LED lighting and automatic blinds in the hall.
Oxford Brookes	2021	College Lake Wildlife Visitor Centre - Non-domestic in-use building performance evaluation	G, H	https://www.brookes.ac.uk/architecture/research/low-carbon-building-group/building-performance-evaluation/college-lake/	n/a	The scheme is designed to a high environmental agenda and far exceed the building regulations. The building has been designed to be low energy based on 'fabric first' approach, focusing on elements such as airtightness, earth-retaining structure, high insulation levels, innovative rammed chalk material for internal walls, solar shading, thermal mass, stack ventilation system combined with 'high level' glazing and low energy fittings. The annual CO2 emission rate from the EPC is 23.37kg CO2/m2/year which is 50 per cent less than the notional building of the same category. This BPE study will verify the extent to which the design aspirations are met in reality and the reasons for the gap.
Palumbo, M et al	2016	Determination of hygrothermal parameters of experimental and commercial bio-based insulation materials	X	https://www.researchgate.net/publication/305845454_Determination_of_hygrothermal_parameters_of_experim	Pay	The development and application of bio-based insulation materials can contribute to the minimisation of the environmental impacts of buildings through reduction of embodied and in-use energy demand, in addition to many other major impacts such as resource depletion and waste generation. The hygrothermal performance of natural building materials has direct and indirect

				ental_and_commercial_bio-based_insulation_materials		impacts on moderating indoor environmental conditions and can contribute to energy savings provided that such aspects are taken into account during the design and construction phases. This requires in-depth knowledge of the thermal and hygroscopic properties of the materials and their dependence on the moisture content. In this paper, the hygrothermal properties of six insulation materials is determined; four are commercially available materials while the other two are experimental materials based on crop by-products and natural binders.
PCA	2019	Investigation of Moisture and its Effects in Traditional Buildings	B, E, F, J, K, U, V	https://www.property-care.org/wp-content/uploads/2019/11/RICS-Historic-England-and-PCA-Joint-Methodology.pdf	Free	The document is intended to be a framework for moisture investigations in buildings of all types and ages. It is important to note that the term traditional refers to buildings with solid walls built from permeable materials such as brick, stone, earth, timber, and lime-based mortars, plasters and renders. Traditional construction absorbs moisture but readily allows it to evaporate when conditions become drier. This is in contrast to modern construction which relies on impermeable barriers to prevent moisture entering the fabric.

Author(s)	Date	Title	GA Code	URL	Free/ pay	Abstract
Pelsmakers, S	2016	Pre-1919 suspended timber ground floors in the UK: estimating in-situ U-values and heat loss reduction potential of interventions	B, C, F, G, H, J, K	https://www.researchgate.net/publication/311886972_Pre-1919_suspended_timber_ground_floors_in_the_UK_estimating_in-situ_U-values_and_heat_loss_reduction_potential_of_interventions	Free	Approximately 25 per cent of the UK's 26 million dwellings pre-date 1919 and are predominantly of suspended timber ground floor construction, the performance of which has not been extensively investigated at present. While under-floor insulation uptake may increase under future government policies, the actual thermal performance of suspended timber ground floors and the implications of insulating them are poorly characterised at present. This PhD research used in-situ heat-flow measuring techniques and the research improved and added knowledge and understanding to the methodological approaches of in-situ estimation of floor U-values, the in-situ estimated U-value of a small number of suspended timber ground floors and the effect of some insulation interventions. Findings highlighted a significant variation in 'point' U-values across the floor with increased thermal transmittance observed along the exposed perimeter and near airbrick locations. This additionally highlighted that obtaining 'whole' floor U-values from a limited number of measured point locations on a floor with large heat-flow variations is challenging.
Pelsmakers, S, Croxford, B and Elwell, C A	2017	Suspended timber ground floors: measured heat loss compared with models	G, H	http://eprints.whiterose.ac.uk/116433/14/Suspended%2	Free	There are approximately 6.6 million dwellings in the UK built before 1919, predominantly constructed with suspended timber ground floors whose thermal performance has not been extensively

				otimber%20ground%20floors%20measured%20heat%20loss%20compared%20with%20models.pdf		investigated. The results are presented from an in- situ heat-flow measuring campaign conducted at 27 locations on a suspended timber ground floor, and the estimated whole- floor U-value compared with modelled results. Findings highlight a significant variability in heat flow, with increased heat loss near the external perimeter. In-situ measured-point U-values ranged from 0.54 ± 0.09 Wm−2 K−1, when away from the external wall perimeter, to nearly four times as high (2.04 ±0.21 Wm−2 K−1) when near the perimeter. The results highlight the fact that observing only a few measurements is likely to bias any attempts to derive a whole-floor Uvalue, which was estimated to be 1.04 ± 0.12 Wm−2 K−1 and nearly twice that derived from current models. This raises questions about the validity of using such models in housing stock models to inform retrofit decision-making and space-heating-reduction interventions. If this disparity between models and measurements exists in the wider stock, a reappraisal of the performance of suspended timber ground floors and heat-loss- reduction potential through this element will be required to support the UK's carbon-emission-reduction targets.

Author(s)	Date	Title	GA Code	URL	Free/ pay	Abstract
Perisoglou, E et al	2019	Evaluation of building and systems performance for a deep domestic retrofit	G, N	https://iopscience.iop.org/article/10.1088/1742-6596/1343/1/012176/pdf	Free	Deep retrofitting by using innovative technologies with respect to aesthetics has considerable and measurable benefits, while it can be a costly and challenging process. This study examines a combination of measures undertaken in a pre-1919 dwelling in south Wales, including reduction of energy demand and the application of renewable energy supply and energy storage. A whole house performance and a systems breakdown evaluation is presented comparing the pre and post intervention status. Both monitoring and modelling tools where used, and the performance gap is also discussed. An annual reduction of 34 per cent in space heating and 78 per cent in electricity import was monitored with an additional electricity export of 3217kWh. This represents a total annual cost saving of £1115, at 2019 UK gas and electricity prices. The total cost of the retrofit was £55K.
Poortinga, W et al	2018	The health impacts of energy performance investments in low-income areas: a mixed-methods approach, Public Health Research, No. 6.5	A, C, E, S	https://www.ncbi.nlm.nih.gov/books/NBK488181/	Free	Background: Cold homes and fuel poverty contribute to health inequalities in ways that could be addressed through energy efficiency interventions. Objectives: To determine the health and psychosocial impacts of energy performance investments

						in low-income areas, particularly hospital admissions for cardiorespiratory conditions, prevalence of respiratory symptoms and mental health status, hydrothermal conditions and household energy use, psychosocial outcomes, cost consequences to the health system and the cost utility of these investments. Design: A mixed-methods study comprising data linkage (25,908 individuals living in 4,968 intervention homes), a field study with a controlled pre-/post-test design (intervention, n = 418; control, n = 418), a controlled multilevel interrupted time series analysis of internal hydrothermal conditions (intervention, n = 48; control, n = 40) and a health economic assessment.
Poortinga, W et al	2018	Impacts of energy-efficiency investments on internal conditions in low-income households	A, C, S	https://www.tandfonline.com/doi/full/10.1080/09613218.2017.1314641	Free	Living in cold conditions poses a risk to health, in particular to low-income, fuel-poor households. Improving the energy efficiency of the housing stock may bring multiple positive health gains through improved indoor temperatures and reduced fuel consumption. This study used a multilevel interrupted time-series approach to evaluate a policy-led energy-performance investment programme. Long-term monitoring data were collected for intervention and control households at baseline (n = 99) and follow-up (n = 88), creating a dataset with 15,771 data points for a series of daily-averaged hydrothermal outcome variables. The study found that the

						intervention raised indoor air temperature by on average 0.84K as compared with control households, thereby bringing the majority of indoor temperature measurements within the 'healthy' comfort zone of 18–24°C, while average daily gas usage dropped by 37 per cent. External wall insulation was the most effective measure to increase indoor air temperature. The greatest increases were found in the evening and at night, in the bedroom, and in British steel-framed buildings. No evidence was found that the intervention substantially increased indoor relative humidity levels when accompanied by mechanical ventilation. The study concludes that the multilevel interrupted time-series approach offers a useful model for evaluating housing improvement programmes.
Poortinga, W et al	2018	The health impacts of energy performance investments in low- income areas: a mixed-methods approach	A, G	http://orca.cf.ac.uk/110397/1/3013325.pdf	Free	Although there was no evidence that energy performance investments provide physical health benefits or reduce health service usage, there was evidence that they improve social and economic conditions that are conducive to better health and improved subjective well-being. The intervention has been successful in reducing energy use and improving the living conditions of households in low-income areas. The lack of association of emergency hospital admissions with energy performance investments means that we were unable to evidence cost saving to health-service providers.

Author(s)	Date	Title	GA Code	URL	Free/ pay	Abstract
Pradana, M, Gauthier, S and Bourikas, L	2017	Close the energy performance gap, a window at a time	S	https://eprints.soton.ac.uk/414907/1/MC2017_Pradana_Muhamad.pdf	Free	This research aims to quantify occupants' window behaviour impact to the energy performance gap. Occupants' window behaviour poses a real challenge to energy demand control in mixed-mode buildings. A window being left open, may compromise the efficiency of the ventilation system. Applying a mixed-method approach, this study was carried out over the summer of 2017, in a mixed mode office building at the University of Southampton. Dry bulb temperature, radiant temperature, relative humidity, CO2 and window movement were recorded. Concurrently a weekly questionnaire gathered environmental perception from 35 participants. Using TRNSYS, the results of the monitoring were compared to standard assumptions. Results indicate that windows activity plays a significant part in bridging the performance gap between design and actual energy consumption. Furthermore, the results of the questionnaires revealed participants' rationales for window opening and closing behaviours. Although this study comprises of a small sample in temperate climate, implications of this research addresses key issues for researchers investigating behaviour modelling and practitioners initiating building design.

Author(s)	Date	Title	GA Code	URL	Free/ pay	Abstract
Ravelo, B, Rajaoarisoa, L and Maurice, O	2020	Thermal modelling of multilayer walls for building retrofitting applications	G	https://www.researchgate.net/publication/337906447_Thermal_modelling_of_multilayer_walls_for_building_retrofitting_applications	Free	This paper introduces an original modelling of thermal dynamic in the building wall. The model will help us to understand the heat transfer mechanism of multilayer walls to better support building retrofits, in order to reduce energy consumption. The model is based on the Kron's method developed with the Tensorial Analysis of Networks (TAN).
RCP and RCPCH	2016	Every breath we take: the lifelong impact of air pollution	A	https://www.rcplondon.ac.uk/projects/outputs/every-breath-we-take-lifelong-impact-air-pollution	Free	The report starkly sets out the dangerous impact air pollution is currently having on our nation's health. Each year in the UK, around 40,000 deaths are attributable to exposure to outdoor air pollution which plays a role in many of the major health challenges of our day. It has been linked to cancer, asthma, stroke and heart disease, diabetes, obesity, and changes linked to dementia. The health problems resulting from exposure to air pollution have a high cost to people who suffer from illness and premature death, to our health services and to business. In the UK, these costs add up to more than £20 billion every year.

Author(s)	Date	Title	GA Code	URL	Free/ pay	Abstract
Rye, C	2012	A Short Paper on the Conventions and Standards that govern the understanding of heat loss in traditional buildings	H, K	http://stbauk.org/resources/index	Free	BR 443 sets out the calculations that should be used for the estimation of heat loss (U-value) in building elements in order to demonstrate compliance with the building regulations for the conservation of fuel and power.
Rye, C and May, N	2012	A Short Paper on the Conventions and Standards that govern the understanding of moisture risk in traditional buildings	E, F	http://stbauk.org/resources/index	Free	At present the Standard BS 5250:2011 is used almost exclusively as the sole test of moisture risk for buildings. This Standard is titled Code of Practice for the Control of Condensation and provides advice on the avoidance of internal surface and interstitial condensation caused by the movement of water vapour by diffusion through the building envelop from the interior to the exterior.
Sakkas, N	2015	Non-intrusive U value metering	H	https://www.researchgate.net/publication/277925492_Non_intrusive_U_value_metering	Free	Aim of this paper is to introduce an easily deployed, plug and play, contact less technology, able to provide a reasonable approximation of the building element U value and its variation with external air speed as well as an accurate estimation of the U value change in case of a shell (wall or window) retrofit.

Author(s)	Date	Title	GA Code	URL	Free/ pay	Abstract
Santarius, T	2012	Green Growth Unravelled: How rebound effects baffle sustainability targets when the economy keeps growing	C, S	https://www.greengrowthknowledge.org/resource/green-growth-unravelled-how-rebound-effects-baffle-sustainability-targets-when-economy	Free	The concept of green growth rests on the idea of an efficiency revolution: green and climate-friendly innovations, huge investments to restructure the industrial, building and transport sectors, and a boost for using resources and energy more productively and efficiently. This study explores a fatal fallacy of the notion of green growth: while vast productivity increases do indeed incentivise a more efficient use of energy (and resources), they also raise demand. This rebound effect nullifies a considerable proportion of the savings potential of efficiency technologies and measures. This paper explores a range of possible rebound effects, outlines their quantitative extent and describes the difficulties encountered by political efforts to contain them.

Author(s)	Date	Title	GA Code	URL	Free/ pay	Abstract
Scarpa, M et al	2017	New Measurement Procedure for U-value Assessment via Heat Flow Meter	H	https://www.researchgate.net/publication/317158960_New_Measurement_Procedure_for_U-value_Assessment_via_Heat_Flow_Meter	Free	The present paper deals with building envelope assessments performed via heat flux meters and reports the outcomes of a monitoring campaign verifying a measurement procedure proposed by the authors. Such a procedure is aimed at the improvement of the accuracy and reliability in the on-field measurement of the U-value of building constructions. In detail, the proposed method exploits an experimental device providing controlled local heating aimed at speeding up the measurement process and limiting temperature fluctuations, with possible improvements over the calculation of the final U- value. The advantages and limits of this measurement procedure are explained in this paper, together with possible future improvements.
Schibuola, L	2018	Innovative technologies for energy retrofit of historic buildings: An experimental validation; Journal of Cultural Heritage, Volume 30, March–April 2018, Pages 147-154	B, C, M, N, X	https://www.sciencedirect.com/science/article/abs/pii/S1296207417302753	Pay	Refurbished buildings should also increase their energy efficiency, according with current regulation; however, in case of historical buildings, preservation orders are so strict to hamper usual energy efficient interventions on the building envelope side. As a consequence, in historical buildings, HVAC (Heating, Ventilation and Air-Conditioning) systems and control strategies should be further improved, since they are the only true means for energy efficiency. This paper presents the set of technologies implemented in the frame of the refurbishment of an historical building in the very center of Venice, in order to lower energy

						consumption and increase occupants' comfort. The refurbishment consisted mainly in the application of the following technologies: Surface Water Heat Pump (SWHP), Demand Controlled Ventilation (DCV) and trigeneration. Furthermore, the paper proves the achieved energy savings by comparing the actual energy consumption against detailed building energy simulations for baseline HVAC system configurations. For such a purpose, the authors take advantage of the installed extensive building management system (BMS), which is able to record detailed data about flow rates (of air and water), temperature and humidity for all of the key devices of the HVAC system. The building used as a case study is very significant because of its energy intensive intended use as well as for the very strict preservation orders acting on it. In particular, global primary energy savings equal to 36 per cent have been calculated, if compared with a traditional baseline HVAC system.

Author(s)	Date	Title	GA Code	URL	Free/ pay	Abstract
Scuderi, G	2019	Retrofit of Residential Buildings in Europe	D, G, S	https://www.researchgate.net/publication/330580034_Retrofit_of_Residential_Buildings_in_Europe	Free	Recently, many cities in Europe are encouraging the recovery of the existing residential heritage. To maximise the benefits of these campaigns, a multipurpose campaign of architectural, functional, and structural retrofit is essential. This paper proposes a method of analysis for 49 residential retrofit projects, a range of 'best practices' presented through the definition of strategies, and actions and thematic packages, aiming at reassuming, in a systematic way, the complex panorama of the state of the art in Europe. The analysis of the state of the art showed that lightweight interventions achieved using dry stratified construction technologies of structure/cladding/finishing are a widespread approach to renovation and requalification both for superficial/two-dimensional actions and volumetric/spatial actions. The study also highlights the leading role of the envelope within retrofit interventions. The retrofit approaches appear to reach the greatest efficiency when reversible, because only in this way do they ensure environmentally friendly actions with the possibility of dismantling. The intervention should improve the flexibility of the existing construction with a correct balance between planning for the present and planning for the future.

Author(s)	Date	Title	GA Code	URL	Free/ pay	Abstract
SEAI	2015	Behavioural insights on energy efficiency in the residential sector	A	http://www.buildup.eu/sites/default/files/content/behavioural-insights-on-energy-efficiency-in-the-residential-sector.pdf	Free	This report brings together research findings and knowledge gathered by SEAI over the last six years on how to best stimulate home energy efficiency upgrades. The focus of the report centres on consumer behaviour and decision making in the context of energy efficiency in the home. Research is gathered from consumer surveys, focus groups, design thinking exercises, pilots and trials and data analysis. Much work has been done with consumers themselves, to ensure that we understand their motivations and barriers, and what their support needs are when seeking to upgrade the energy efficiency of their homes. We explore what we know about householders' attitudes to improving the energy efficiency of their homes, and how government and its agencies can best encourage and support more households to upgrade. Various models of financing and the design of support schemes are also examined so that we find out what is the most attractive design mix for consumers. We try to answer the big question of how do we encourage more people to deliver deeper energy retrofits, and in doing so, maximise comfort, energy savings and help provide health and wellbeing benefits?

Author(s)	Date	Title	GA Code	URL	Free/ pay	Abstract
SEDA	2018	Sustainable Renovation improving homes for energy, health and environment	A, B, C, D, E, F, G, H, J, K, M, N, P, Q, R, S, T, U, V, W	http://www.thepebbletrust.org/index.asp?pageid=706477	Free	This guide is especially encouraging and insightful in how it uniquely recognises how renovation works require careful workmanship, and much closer engagement with occupants. Installing insulation and double glazing, for example, without understanding and addressing their effects on the house as a whole, such as air flow, has the potential to cause unintended consequences. This can negatively impact residents' comfort or health, such as poor ventilation or moisture build-up resulting in mould.
Sharpe, T et al	2014	Research Project To Investigate Occupier Influence On Indoor Air Quality In Dwellings	B	https://www2.gov.scot/Resource/0046/00460968.pdf	Free	This report confirmed that dwellings built to the most recent Scottish Building Regulations for prescribing construction air tightness are suffering from poor indoor air quality. Trickle ventilators are not up to the task of providing sufficient air change rates even in the small percentage of dwellings where the occupier/s knows what they are and maintains them in the open position. The report concluded with a range of recommendations that have now been put out for consultation.

Author(s)	Date	Title	GA Code	URL	Free/ pay	Abstract
Sharpe, T and Shearer, D	2012	Post Occupancy Evaluation of adaptive restoration and performance enhancement of Gilmour's Close, Edinburgh	B, C, E	http://www.cicstart.org/userfiles/file/IR12_51-59.pdf	Free	This piece describes the building performance evaluation of a project which endeavoured to address these relevant and complex design challenges; an adaptive rehabilitation project of 7-11 Gilmour's Close - a stone tenement located within the World Heritage Site of Edinburgh's Grassmarket. Working within the constraints of its historical significance, a limited budget (a registered social landlord as Client) and end user group, this project sought to create an energy efficient solution for its sustainable rehabilitation. A full description of this project, its inception and design intent has previously been produced by Andy Jack of Assist Architects and can be found in CIC Start Innovation Review, Issue 1, December 2009 (pp. 48– 55).
Shikder, S, Mourshed, M and Price, A D F	2012	Summertime impact of climate change on multi-occupancy British dwellings	P	https://www.researchgate.net/publication/277055872_Summertime_impact_of_climate_change_on_multi-occupancy_British_dwellings	Free	Recent climate change projections estimate that the average summertime temperature in the southern part of Great Britain may increase by up to 5.4°C by the end of the century. The general consensus is that projected increases in temperature will render British dwellings vulnerable to summer overheating and by the middle of this century it may become difficult to maintain a comfortable indoor environment, if adaptation measures are not well integrated in the design and operation of new dwellings, which are likely to remain in use beyond the 2050s.

Author(s)	Date	Title	GA Code	URL	Free/ pay	Abstract
Shrubsole, C et al	2014	100 Unintended consequences of policies to improve the energy efficiency of the UK housing stock	A, B, C, D, E, F, G, H, J, K, L, P, Q	https://www.researchgate.net/publication/259931254_100_Unintended_consequences_of_policies_to_improve_the_energy_efficiency_of_the_UK_housing_stock	Free	Housing is an important focus of government policies to mitigate climate change. Current policy promotes the application of a variety of energy efficiency measures to a diverse building stock, which will likely lead to a wide range of unintended consequences. We have undertaken a scoping review identifying more than 100 unintended consequences impacting building fabric, population health and the environment, thus highlighting the urgent need for government and society to reconsider its approach. Many impacts are connected in complex relationships. Some are negative, others possibly co-benefits for other objectives.
Smith, O	2014	Balancing Heritage and Environmental Policies for Sustainable Refurbishment of Historic Buildings: The Case of New Court, Trinity College, Cambridge, The Historic Environment: Policy and Practice, Volume 5, 2014 - Issue 2: Energy Efficiency and Heritage Values in Historic Buildings	D	https://www.tandfonline.com/doi/full/10.1179/1756750514Z.00000000050?src=recsys&	Pay	This paper analyses the environmentally sustainable retrofit of the Grade I-listed buildings at New Court for Trinity College, Cambridge. The paper critically reviews existing heritage and environmental policies as these relate to practice. The project on which the paper is based has brought together architects, engineers, building physicists, building conditions surveyors, and industry experts. The role of building physics and design, the monitoring and modelling of existing and future fabric conditions and building character are defined as essential components of a strategy to resolve the critical gaps between — and oppositions in — the policies addressing heritage and environmental sustainability. The case study unveils the complexity of the issues involved in such projects and the difficult, nuanced judgments to be made at every level

						of building physics, design, and policy interpretation. Indeed, there is a critical need for the appropriate allocation of resources (time, money, and intellectual rigour) by all parties involved in such projects to ensure that all decisions are made in a fully-informed and, hopefully, collaborative manner.
Snell, C et al	2018	Policy Pathways to Justice in Energy Efficiency	S	http://eprints.whiterose.ac.uk/139942/1/UKERC_Working_Paper_Policy_pathways_to_justice_in_energy_efficiency.pdf	Pay	This project addresses two key gaps in knowledge regarding justice in energy efficiency policy in the UK. First, despite disabled people and low-income families with children being defined in policy as vulnerable to fuel poverty, there is very little evidence about how the needs of these groups are recognised or incorporated into policy decisions. Second, there is no clear evidence on how energy efficiency policies actually affect these groups, and whether policy outcomes are consistent across the UK. Drawing on concepts of justice, the overarching aim of this project is to investigate the implications of existing domestic energy efficiency policies across the four nations of the UK, and to use cross-national comparisons and lesson-drawing to identify sustainable future policy pathways.

Author(s)	Date	Title	GA Code	URL	Free/ pay	Abstract
Sorrell, S, Gatersleben, B and Druckman, A	2020	The limits of energy sufficiency: A review of the evidence for rebound effects and negative spillovers from behavioural change	S	https://www.sciencedirect.com/science/article/pii/S2214629620300165	Free	'Energy sufficiency' involves reducing consumption of energy services in order to minimise the associated environmental impacts. This may either be through individual actions, such as reducing car travel, or through reducing working time, income and aggregate consumption ('downshifting'). However, the environmental benefits of both strategies may be less than anticipated. First, people may save money that they can spend on other goods and services that require energy to provide (rebounds). Second, people may feel they have 'done her bit' for the environment and can spend time and money on more energy-intensive goods and activities (spillovers). Third, people may save time that they can spend on other activities that require energy to participate in (time-use rebounds). This paper reviews the current state of knowledge on rebounds and spillovers from sufficiency actions, and on time-use rebounds from downshifting. It concludes that: first, rebound effects can erode a significant proportion of the anticipated energy and emission savings from sufficiency actions; second, that such actions appear to have a very limited influence on aggregate energy use and emissions; and third, that downshifting should reduce energy use and emissions,

						but by proportionately less than the reduction in working hours and income.
SPAB	2018	Control of Dampness	D, E, F, U	https://www.spab.org.uk/sites/default/files/Control_of_Dampness_0.pdf	Free	This Technical Advice Note explains the nature and causes of dampness together with its diagnosis, control and prevention in buildings predating c1919. Despite dampness problems being commonplace, their cause is frequently misdiagnosed and ineffective remediation undertaken. Unnecessary treatments are often carried out, including the insertion of damp-proof membranes to create barriers to moisture. Action to address basic maintenance or lifestyle issues is usually more appropriate, as well as measures that respect the need for old buildings to 'breathe'.
SPAB	2014	SPAB Briefing: Energy efficiency in old buildings	B, D, H, M	https://www.spab.org.uk/sites/default/files/documents/MainSociety/SPAB%20Briefing_Energy%20efficiency.pdf	Free	Old buildings are sustainable, their very existence demonstrates this, but they can still frequently benefit from sensitive, well-informed energy efficiency measures. Early on, the SPAB recognised that such upgrading is important if our precious national asset of older buildings is not to be perceived as a liability or unaffordable luxury. Accurate information is a pre-requisite for good building conservation work so we had to ensure our advice to others on energy efficiency improvements came from a sound understanding of how old buildings perform in practice, not just theory.

Author(s)	Date	Title	GA Code	URL	Free/ pay	Abstract
STBA	2018	Sustainable Traditional Buildings Alliance - EPCs and the Whole House Approach: A Scoping Study	D	http://stbauk.org/stba-guidance-research-papers	Free	This report has been prepared by the Sustainable Traditional Buildings Alliance (STBA) on behalf of Historic England and the National Trust, in response to the growing use of Energy Performance Certificates (EPCs) in UK Energy Policy. It provides an overview of the key issues, constraints and opportunities surrounding EPCs, identifying ways in which they could be better aligned with the 'whole-house' approach to retrofit developed by the STBA and recommended in the Each Home Counts report.
STBA	2015	What is Whole House Retrofit	T, V	http://stbauk.org/stba-guidance-research-papers	Free	This short paper sets out the background to the development of the whole house approach, then examines the various levels of retrofit which are often described as whole house but in reality most fall far short.
STBA	2018	EPCs and Whole-House Approach - A Scoping Study	D, V	http://stbauk.org/stba-guidance-research-papers	Free	This report provides an overview of the key issues, constraints and opportunities surrounding EPCs, identifying ways in which they could be better aligned with the 'whole-house' approach to retrofit developed by the STBA and recommended in the Each Home Counts report.

Author(s)	Date	Title	GA Code	URL	Free/ pay	Abstract
Stevenson, V and McNaboe, B	2014	The importance of occupancy patterns on the analysis of heating energy relating to housing refurbishment	G, S	https://www.ingentaconnect.com/content/hsp/jbsav/2014/00000002/00000004/art00008	Free	Attempts to reduce household energy consumption for space heating are showing little progress. This paper explores the role of thermal mass in refurbishing an existing dwelling to reduce heating energy consumption. The investigation is based on three refurbishment strategies to achieve light, medium and heavy weight building structures in conjunction with a highly insulated and airtight structure (compatible with Code for Sustainable Homes Level 5).
Strandberg-de Bruijn, P B and Balksten, K	2019	Energy and moisture in historic masonry walls retrofitted with hemp-lime	D, F, H	https://www.researchgate.net/publication/337752457_Energy_and_moisture_in_historic_masonry_walls_retrofitted_with_hemp-lime	Free	Thermally insulating historic buildings is imperative in order to reduce energy demands of the existing building stock. Therefore an insulation material is needed that improves energy efficiency while being compatible with the existing structure from a hygrothermal, aesthetic and cultural heritage perspective. Hemp-lime is a building material that consists of a combination of hemp shiv, the woody core part of the hemp stem, and building limes. The aim of this study was to determine if hemp-lime could be a feasible option for thermally insulating historic masonry walls in Sweden. The objectives were to measure energy performance of full-scale masonry façades insulated with hemp-lime and to monitor moisture levels inside the masonry walls. Three small single leaf masonry façades were

						constructed. One façade was uninsulated, the other had internal hemp-lime insulation and a third had external hemp-lime insulation. Energy use for space heating as well as temperature and relative humidity in the walls and rooms were monitored. Results show that thermally insulating historic masonry walls with hemp-lime can lead to an improvement in energy performance of 44-53 per cent compared to uninsulated single-leaf masonry. However, moisture levels were higher in the masonry façades that were insulated with hemp-lime.
Sturgis Carbon Profiling et al	2013	Improving Historic Soho's Environmental Performance - Practical Retrofitting Guidance	B, D, G, H, K, M, N, Q, W	http://transact.westminster.gov.uk/docstores/publications_store/Improving_Historic_Sohos_Environmental_Performance_February_2013.pdf	Free	The aims of the guidance are twofold: to encourage the retrofitting of buildings in historic core city areas to improve their environmental performance, and to highlight the importance of preserving the heritage.

Author(s)	Date	Title	GA Code	URL	Free/ pay	Abstract
Summerfield, A et al	2019	What do empirical findings reveal about modelled energy demand and energy ratings? Comparisons of gas consumption across the English residential sector	G	https://www.sciencedirect.com/science/article/abs/pii/S0301421519301168?via%3Dihub	Pay	This study used data from a sample of over 2.5 million gas-heated dwellings in England from the National Energy Efficiency Data-Framework (NEED) to compare with estimates of 2012 gas consumption from the Cambridge Housing Model (CHM), a national energy stock model. The analysis quantified differences by dwelling type, size, and age band. It also compared variations in gas consumption from NEED dwellings with that expected from Energy Performance Certificate (EPC) bands. The findings show that the CHM overestimates average gas consumption from NEED for all dwelling types built before 1930, most notably for large detached dwellings. For other dwellings built since 1930, the model estimates were in relatively close agreement with NEED data. Furthermore, a simple comparison between estimated gas consumption and NEED data suggests savings from upgrading dwellings to at least EPC band C would be substantially lower than expected. Findings raise question regarding assumptions used in models and EPC ratings, including occupancy and space heating patterns, and have implications for development of energy models and policy regarding energy efficiency programmes.

Author(s)	Date	Title	GA Code	URL	Free/ pay	Abstract
Sweett	2014	Retrofit for the Future - Cost Data Analysis - Final Report 2014	W	https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/669109/Retrofit_for_the_Future_-_analysis_of_cost_data_report_2014.pdf	Free	Retrofit for the Future developed into one of the highlight achievements of the Technology Strategy Board. With the support of the Homes and Communities Agency and the Department for Communities and Local Government, the Technology Strategy Board was able to provide grants of up to £150,000 to demonstrate innovative whole-house retrofit. Retrofit for the Future enabled more than 500 organisations to take part in a whole-house retrofit project.
Symonds, P et al	2019	Home energy efficiency and radon: An observational study	A	https://onlinelibrary.wiley.com/doi/full/10.1111/ina.12575	Free	HEED database was used to analyse the association of housing and energy performance characteristics with indoor radon concentrations in the UK. The findings show that energy efficiency measures that increase the airtightness of properties are observed to have an adverse association with indoor radon levels. Homes with double glazing installed had radon measurements with a significantly higher geometric mean, 67 per cent (95 per cent CI: 44, 89) greater than those without a recorded fabric retrofit. Those with loft insulation (47 per cent, 95 per cent CI: 26, 69) and wall insulation (32 per cent, 95 per cent CI: 11, 53) were also found to have

						higher radon readings. Improving the energy performance of the UK's housing stock is vital in meeting carbon emission reduction targets. However, compromising indoor air quality must be avoided through careful assessment and implementation practices.
Teli, D et al	2016	Fuel poverty-induced 'prebound effect' in achieving the anticipated carbon savings from social housing retrofit	G, S	https://eprints.soton.ac.uk/385181/	Free	Social housing retrofit is often seen as a way to contribute to carbon reductions as it typically encompasses large-scale interventions managed by one landlord. This work investigates the carbon savings potential of a deep retrofit in a local authority owned 107-flat tower block, taking into account the tenants' pre-retrofit heating strategies. Prior to the retrofit, temperature and relative humidity monitoring were undertaken in 18 flats for 35 days. The measurements were then used to develop occupant heating profiles in the 18 homes. Dynamic thermal simulation of the flats pre- and post-retrofit using the identified user heating profiles highlights that for these fuel poverty-constrained flats, the estimated carbon savings of retrofit will be typically half those predicted using standard rules for temperatures in living spaces.

Author(s)	Date	Title	GA Code	URL	Free/ pay	Abstract
The Heritage Council	2018	Deep Energy Renovation of Traditional Building	A, B, C, D, E, F, G, H, J, K, M, N, P, Q, V	https://www.heritagecouncil.ie/content/files/Deep_Energy_Renovation_of_Traditional_Buildings.pdf	Free	The primary intent of this research project is to review the current state of knowledge and risks relating to the deep energy renovation of traditional buildings, which have different hygroscopic and thermal behaviours to buildings of modern construction, and which represent approximately 16 per cent of the total housing stock in Ireland. One of the key characteristics of traditional buildings is that they are constructed of solid masonry walls that are 'breathable', such as the building fabric allows moisture to be absorbed and released cyclically. This form of construction relies on vapour permeable materials and higher levels of ventilation to ensure the well-being of the building fabric and the internal environment. The term 'traditional building' is more comprehensively described in the DEHLG publication 'Energy Efficiency in Traditional Buildings'.
Topouzi, M, Fawcett, T and Killip, G	2019	Deep retrofit approaches: managing risks to minimise the energy performance gap	G	https://www.eceee.org/library/conference_proceedings/eceee_Summer_Studies/2019/7-make-buildings-policies-great-	Pay	The paper discusses the complexity of a deep renovation project in terms of planning and management and the ways current policies can lead to unintended consequences in the short and long term, as well in lock-in effects that contribute to energy performance, and to the gap between designed and actual energy performance. Using a typology of risks, the issues associated with renovation processes and technologies were explored in a sample of cases studies from deep retrofits

				again/deep-retrofit-approaches-managing-risks-to-minimise-the-energy-performance-gap		across the EU. The evidence from these shows that despite holistic planning for renovation, interventions tend to be carried out in phases. These contrasting time dimensions and the different retrofit approaches are discussed with risk profiles for each retrofit project, suggesting how risks emerge throughout a project. A series of risk mitigation strategies are suggested which, taken in combination to suit a specific project's risk profile, may serve to reduce and potentially eliminate the building renovation energy performance gap.
Topouzi, M, Killip, G, and Owen, A	2017	Learning from Horror Stories: A Plan of Work to Reduce the Performance Gap in Deep Retrofit	G, V	http://eprints.whiterose.ac.uk/117475/	Free	Over the past 20 years efforts have been made to bridge the performance gap by developing design guidance and reports to raise awareness and increase construction quality of the delivery and handover stages; as well as improving tools and prediction methods by validating them with real data comparing anticipated performance with achieved energy use. The complexity of the gap 'problem' increases in deep, low-carbon refurbishment processes. Both the scale and quality of construction work need to be increased if challenging emission reduction targets are to be met.

Author(s)	Date	Title	GA Code	URL	Free/ pay	Abstract
Topouzi, M, Owen, A and Killip, G	2017	Retrofit 'daemons' in the Process of Low Carbon Housing Stock Renovation; eceee 2017 Summer Study on energy efficiency: Consumption, efficiency and limits. eceee 2017 Summer Study, 29 May - 03 Jun 2017, Presqu'ile de Giens, France. eceee. ISBN 978-91-983878-0-3	G, V	http://eprints.whiterose.ac.uk/114101/	Free	The 'performance gap' between design and actual energy use is well recognised. Much of the debate on the performance gap focuses on the use and accuracy of building energy models or on the 'misbehaviour' of users and maloperation of measures. This paper focuses instead on the design and construction phases of retrofit projects. Pioneering case studies in deep low-carbon refurbishment in the UK show a lack of quality assurance and poor integration of the intermediate stages between design and implementation within retrofit process.
Tweed, C and Zapata-Lancaster, M	2016	Smart people in stupid homes: the skill in creating preferred thermal environments	G, S, T	http://orca.cf.ac.uk/95857/1/DEMAND2016_Full_paper_23-Tweed.pdf	Free	This paper suggests that some occupants have a deeper understanding of how their homes work thermally than is usually acknowledged in top-down imposed energy interventions that limit the occupants' control of their home environment. The authors will argue that users' intuitive understanding often exceeds the capabilities of automated or 'black box' heating control systems by embracing control mechanisms, such as windows and doors, that are not normally considered part of the whole environmental control system.

Author(s)	Date	Title	GA Code	URL	Free/ pay	Abstract
UCL (CAR Ltd)	2017	Understanding best practice in deploying external solid-wall insulation and internal wall insulation in the UK	G, H, W	https://www.gov.uk/government/publications/understanding-best-practice-in-deploying-external-solid-wall-insulation-and-internal-wall-insulation-in-the-uk	Free	These reports explore best-practice in deploying external solid-wall and internal wall insulation in the UK.
UKCMB		Moisture Balance Calculator	E, F	https://ukcmb.org/2020/03/05/moisture-balance-calculator/	Free	Online tool to help form a better understanding of the moisture balance in your home and the factors at play.

Author(s)	Date	Title	GA Code	URL	Free/ pay	Abstract
Underhill, L J et al	2018	Modeling the resiliency of energy efficient retrofits in low-income multifamily housing	A	https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6386461/	Free	Residential energy efficiency and ventilation retrofits (for example, building weatherisation, local exhaust ventilation, HVAC filtration) can influence indoor air quality (IAQ) and occupant health, but these measures' impact varies by occupant activity. In this study, we used the multi-zone airflow and IAQ analysis program CONTAM to simulate the impacts of energy retrofits on indoor concentrations of PM2.5 and NO2 in a low-income multifamily housing complex in Boston, Massachusetts (USA).
Varas-Muriel M J and Fort, R	2019	Microclimatic monitoring in an historic church fitted with modern heating: Implications for the preventive conservation of its cultural heritage	B, C, D, E	https://www.sciencedirect.com/science/article/abs/pii/S0360132318305365	Pay	Conservation of historic churches' interior artistic and architectural heritage may be severely compromised by heating systems that alter indoor microclimatic stability. The modern centralised heating systems installed over the last 20 years are claimed to guarantee comfort without jeopardising heritage assets by warming only the lower, occupied areas. Each building is a case unto itself, however, and even in recently installed facilities where it may still be too soon to determine possible harm to the cultural heritage, a plan to monitor the microclimate and its heating-induced fluctuations must be designed to guarantee the conservation of artworks. In this case study, the impact of heating was observed to vary due to architectural differences within the building, the type of facility and daily usage patterns.

						Within one hour, the church's latest generation heating system raises the air temperature in nearly the entire building, including the upper heights, to the programmed 18 ± 1 °C, while lowering the environmental relative humidity by up to 1/3. Although (Category II and III) thermal comfort is reached in one hour, daily heating of that duration is not recommended, for it would result in short-term relative humidity values below the target relative humidity range for preventive conservation of the church's indoor heritage. The mechanical damage (fissures and cracking) that may be inflicted on these assets is related to thermal contraction-expansion and hygroscopic contraction-swelling cycles.
Wade, F, Murtagh, N and Hitchings, R	2017	Managing Professional Jurisdiction and Domestic Energy Use, Building Research and Information, 46:1, 42-53	S	https://www.research.ed.ac.uk/portal/en/publications/managing-professional-jurisdiction-and-domestic-energy-use%280a76ea95-6f56-	Free	Professionals involved in organising and undertaking domestic works, such as extensions, maintenance and refurbishment, have an important role in influencing how homes are configured and how occupants live within them. Despite this, the professional identities of these actors, and their impact on domestic energy use, is often overlooked.

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Wales and West Utilities	2018	Freedom Project Final Report	G, N	https://www.wwutilities.co.uk/media/2829/freedom-project-final-report-october-2018.pdf	Free	The Freedom Project is a joint Western Power Distribution and Wales and West Utilities £5m innovation initiative in the Bridgend 'living heat laboratory' in South Wales. Using an air source heat pump and high-efficiency gas boiler hybrid system in 75 residential properties, the project has demonstrated the significant benefits that an integrated whole energy systems approach to deploying smart dual-fuel technologies can deliver.
Weeks, C, Ward, T and King, C (BRE)	2013	Reducing thermal bridging at junctions when designing and installing solid wall insulation	J	https://www.brebookshop.com/samples/327295.pdf	Free	This guide sets out clear principles and methods that should be considered and adopted during the design and installation of solid wall insulation in order to reduce thermal bridging effects, maximise carbon dioxide (CO2) emission reductions and minimise the risk of condensation. The effect of installing external and internal wall insulation in typical solid wall homes has been modelled for junctions with windows, eaves, floors and party walls. Potential problems are considered, taking examples from recent refurbishment projects in which BRE has been involved.

Author(s)	Date	Title	GA Code	URL	Free/ pay	Abstract
Weng, K	2016	Performance of UK dwellings in projected future climates	C, P	http://orca.cf.ac.uk/94054/1/Weng_ICAE_2016_manuscript.pdf	Free	Projected increases in temperature due to the changing climate are likely to exacerbate overheating in buildings, especially in UK domestic buildings that are designed for the existing temperate climate. Due to the long life span of buildings, over two-thirds of dwellings in 2050 are projected to be the buildings built before 2000. Adaptability of the existing buildings to future climates, therefore, needs to be assessed to see if they will remain comfortable without resorting to mechanical cooling. This research evaluated occupant thermal comfort in a semi-detached UK residential building with different strategies of window openings under weather scenarios at different time scales: present-day, 2030s, 2050s and 2080s, using dynamic thermal simulation in five UK cities: London, Birmingham, Manchester, Edinburgh and Belfast.

Author(s)	Date	Title	GA Code	URL	Free/ pay	Abstract
Wessberg, M, Vyhlídal, T and Broström, T	2019	A model-based method to control temperature and humidity in intermittently heated massive historic buildings, Building and Environment, Volume 159, 15 July 2019, 106026	B, C	https://www.sciencedirect.com/science/article/abs/pii/S0360132319301830	Pay	The indoor climate of historic buildings is governed not only by human comfort but also the desire to preserve these buildings and their interiors. For preservation, relative humidity is the most important parameter, including its amplitude and change rate. To control the change rate of relative humidity at a heat-up event for an intermittently heated massive historic building with heavy masonry walls, a simplified model for heat and moisture transfer at the heat-up time is presented. A method to derive the time constants and hygrothermal parameters of the building from measurements taken during a step response test is proposed and validated. The model with its parameters can be used to predict both heat-up time to reach the target temperature as well as the amount of moisture gained from the walls. These predictions are in turn used to calculate the decrease in relative humidity during the heat-up event. The indoor air relative humidity is predictable as it is determined by the air temperature and air mixing ratio. A control algorithm that uses the model for predicting and controlling the change rate of relative humidity by shaping the heating

						power is presented and validated using simulation results.
Whitman, C	2019	Evaluating incidental thermal performance improvements of a historic timber-framed building in central Hereford	H, X	https://www.researchgate.net/publication/336444177_Evaluating_Incidental_Thermal_Performance_Improvements_of_a_Historic_Timber-Framed_Building_in_Central_Hereford	Free	This paper presents the evaluation of the refurbishment of The Old Mayor's Parlour, Church Street, Hereford - a historic timber-framed building now used as a gallery and exhibition space. The conservation work was not specifically envisioned as an energy retrofit, however the necessary replacement of failing concrete block infill, the legacy of a 1970s renovation, allowed improvements to be made to the thermal performance of the external envelope. Environmental monitoring and digital simulation have been used to assess the impact of these interventions. In situ U-value measurements show the success of the replacement infill panels and associated internal lining, although digital energy simulations suggest a limited improvement to the building's overall energy efficiency. At the same time thermography suggests a potential threat of increased condensation risk to the uninsulated ornate 17th century plaster ceiling. The results of this paper show the risk of unintended consequences and the challenges faced by sustainable building conservation.

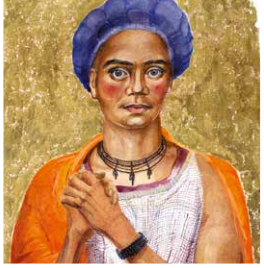
Author(s)	Date	Title	GA Code	URL	Free/ pay	Abstract
Whitman, C et al	2020	Heritage retrofit and cultural empathy; a discussion of challenges regarding the energy performance of historic UK timber-framed dwellings	D, T	http://orca.cf.ac.uk/125484/1/Building_Pathology_Adaptation_paper_Revised_B.pdf	Free	The results show that whilst the application of energy retrofit actions to this emblematic typology may have limited success, the emotional connection of the buildings occupants often results in the work resulting in higher user satisfaction than would otherwise be expected.
Whitman, C et al	2015	Interstitial hygrothermal conditions of low carbon retrofitting details for historic timber-framed buildings in UK	F, H, X	https://www.researchgate.net/publication/291980846_Interstitial_Hygrothermal_Conditions_of_Low_Carbon_Retrofitting_Details_for_Historic_Timber-Framed_Buildings_in_the_UK	Free	The hygrothermal behaviour of wall build-ups of traditional materials must also be fully understood in order to avoid problems of interstitial moisture, long term decay and overheating. Research in this area to date has focused on solid-walled masonry construction (Gandhi, Jiang and Tweed, 2012; Mohammadpourkarbasi and Sharples, 2013; Scott and Rye, 2014), however little work has been conducted on historic timber-framed construction, the subject of the research presented in this paper. Whilst representing only a small percentage of the UK pre-1919 housing stock (approximately 66,000 in England (Nicol, Beer, and Scott, 2014); 1,200 in Wales and almost non-existent in Scotland (Naismith, 1985) and

						Northern Ireland (Gailey, 1984)), many historic timber-framed buildings have stood for hundreds of years and form an important element of UK heritage. Inappropriate introduction of thermal insulation can cause unintentional negative impacts, including increased moisture content and interstitial condensation leading to the deterioration of the built fabric. Using WUFI P ro5 transient heat and moisture simulation software, the interstitial temperature, humidity and moisture conditions within traditional and retrofitted wall build-ups have been simulated.
Whitman, C et al	2020	Energy retrofit infill panels for historic timber-framed buildings in the UK: Physical test panel monitoring versus hygrothermal simulation	F, H, X	https://www.researchgate.net/publication/329737328_Physical_Monitoring_of_Replacement_Infill_Panels_for_Historic_Timber-Framed_Buildings_in_the_UK_Comparing_hygrothermal_simulation	Free	Work to date in the UK has focused on the retrofit of historic solid masonry construction, with little research into historic timber-framed buildings. With these buildings, where infill panels are beyond repair or have previously been substituted with inappropriate materials, there exists the potential to retrofit panels with a higher thermal performance. The research presented in this article compares the monitoring of three physical test panels mounted between climate-controlled chambers with digital hygrothermal simulations in order to investigate the risk

				s and dual climate chamber testing		of increased moisture which may threaten the surrounding historic fabric. Results of previously unpublished cyclical testing are is also included. Whilst all prediction methods successfully identified interstitial condensation where measured, major discrepancies existed between simulated and measured results, and between different simulation methods.
Willand, N, Ridley, I and Maller, C	2015	Towards Explaining the Health Impacts of Residential Energy Efficiency Interventions - A Realist Review - Part 1: Pathways	A	https://www.sciencedirect.com/science/article/abs/pii/S027795361500088X?via%3Dihub	Pay	This paper is Part 1 of a realist review that tries to explain the impacts of residential energy efficiency interventions (REEIs) on householder health. According to recent systematic reviews residential energy efficiency interventions may benefit health. It is argued that home energy improvements are complex interventions and that a better understanding of the latent mechanisms and contextual issues that may shape the outcome of interventions is needed for effective intervention design.
Xiaojun, L, Jones, P and Patterson. J	2017	Building and community energy retrofit housing in Wales	M, N	https://pdfs.semanticscholar.org/5237/d82d3e35a1834adb4c10e14a46	Free	This paper presents a modelling-led approach applied to low carbon innovative housing retrofit practice in Wales. The research has investigated the implementation of combinations of existing and emerging low carbon technologies

				4cc1ddac7c.pdf?_ga=2.190502637.757794919.1586707220-943583264.1586707220		through a systems based approach to optimise the use of energy at the point of generation at both building and community scales. A performance prediction model has been developed to examine the effectiveness of different strategies in relation to energy and carbon reduction. Simulation results of individual building have shown, the retrofits with a net carbon reduction by up to 110 per cent indicating a zero-energy or energy positive performance. Based on this, further investigation is carried out in retrofitting the whole community towards a 'zero-energy' or 'energy positive' community through a micro-grid connection and storage. The simulation results show an energy positive performance can be achieved for community one under the proposed retrofit scenarios.

Author(s)	Date	Title	GA Code	URL	Free/ pay	Abstract
Zhou, X, Carmeliet, J and Derome, D	2020	Assessment of risk of freeze-thaw damage in internally insulated masonry in a changing climate, Building and Environment Available online 29 February 2020, 106773	H	https://www.sciencedirect.com/science/article/abs/pii/S0360132320301311	Pay	In this study, the impact of climate change on the risk of freeze-thaw damage for internally insulated masonry wall in two regions in Switzerland (Zurich and Davos) for two future periods is investigated. The risk of freeze-thaw damage at Zurich is relatively high in the reference period. An increase in air temperature in the cold period that leads to less freeze-thaw cycles is the main reason for the lower risk of freeze-thaw damage in the future periods. By comparison, the risk of freeze-thaw damage at Davos is low in the reference period. An increase in temperature and precipitation in the cold period is the main reason for the higher risk of freeze-thaw damage in the future periods at Davos. In the face of climate change, the future requirement on frost resistance of building materials and components at Davos should take the future climate loading into account.



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