The
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SPECIAL
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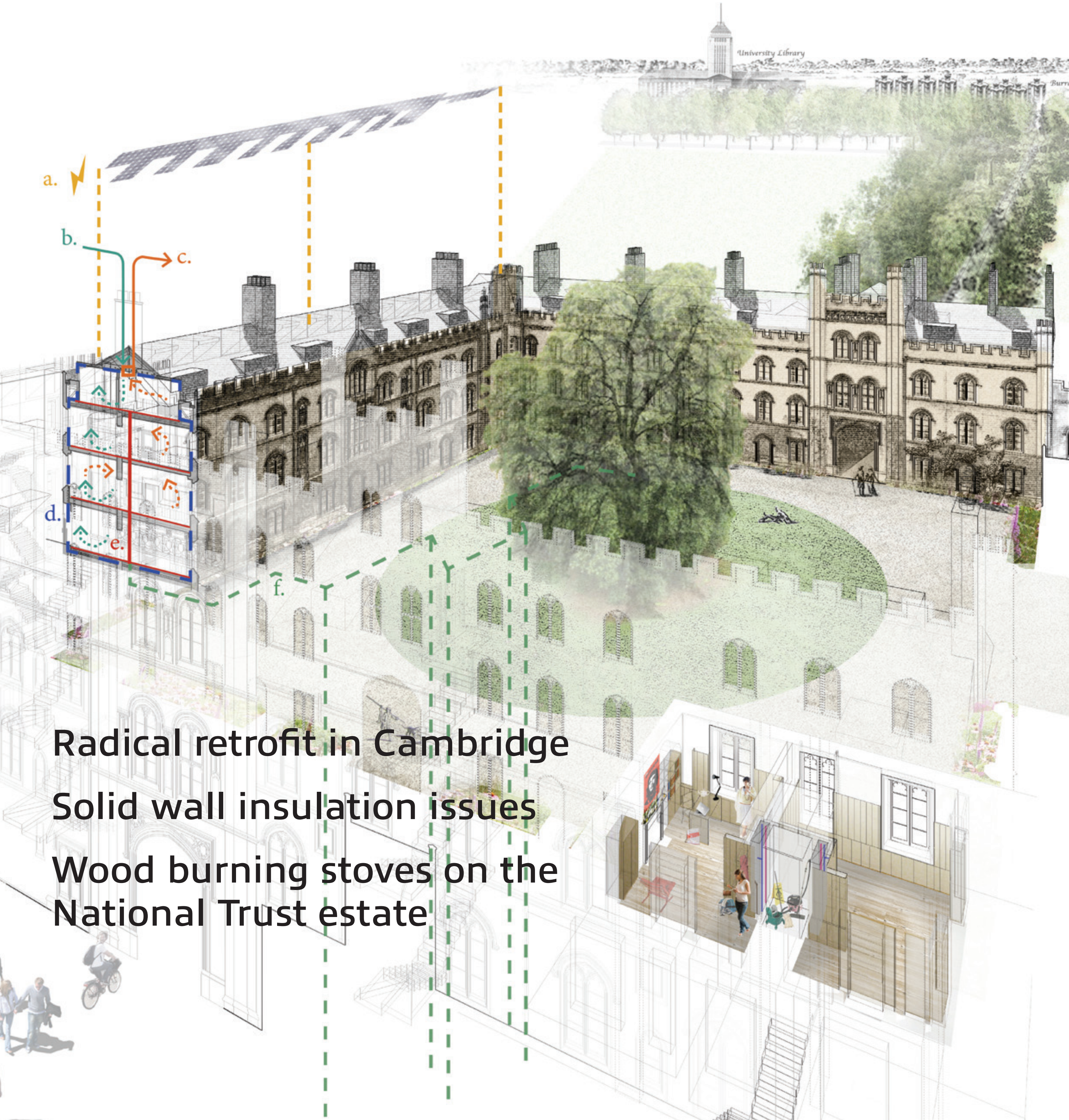
Magazine

HERITAGE RETROFIT

OLDER BUILDINGS AND SUSTAINABILITY



Radical retrofit in Cambridge

Solid wall insulation issues

Wood burning stoves on the National Trust estate

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5th Studio's proposals for renewable energy in the retrofit of New Court, Trinity College (Image: 5th Studio)

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FROM THE EDITORS

The contribution made by the UK's older buildings to climate change should not be ignored. Our country has the second highest level of greenhouse gas emissions in Europe, 557 million tonnes in 2014. Energy-use in buildings is responsible for a third of this, and almost a quarter of our homes are over a century old. If our grandchildren are to avoid catastrophe, the government's target of an 80 per cent reduction in greenhouse gas emissions by 2050 must be met, and all buildings must play their part.

Older buildings should, however, be treated carefully as modern retrofit technology can be highly damaging to older structures and counter-productive. In this rapidly developing field, new research is revealing how we can make best use of their strengths and resolve their weaknesses, and developments in both modern and traditional technologies are helping us to keep them warm and dry sustainably. The aim of this publication is to bring the latest information to those who need it most.

Welcome to the first edition of *Heritage Retrofit*.

HERITAGE AND SUSTAINABILITY

DENNIS RODWELL

TODAY, PAST the halfway mark in the first quarter of the 21st century, we are challenged by a number of coincidental global agendas: the exhaustion of the key non-renewable material and energy resources which industrialised and developing countries currently depend on; recognition of the relationship between the burning of fossil fuels, carbon dioxide emissions and global warming ('climate change'); and the agenda of sustainable development, articulated in the 1987 *Brundtland Report*, affirmed at the 1992 Rio de Janeiro Earth Summit, and reinforced in the *2015 United Nations Sustainable Development Goals*.

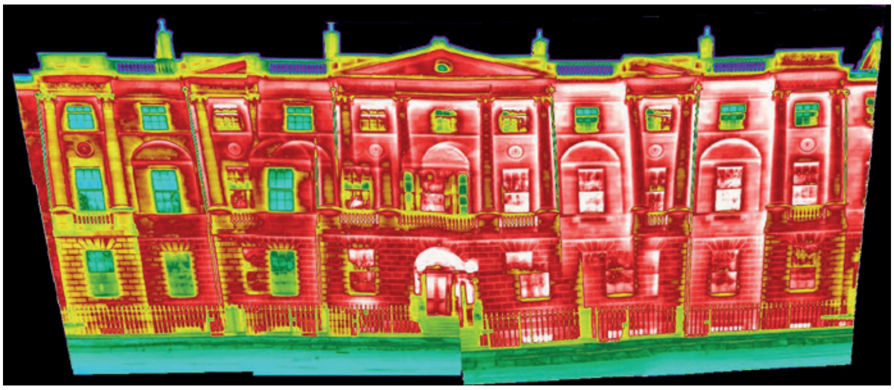
Sustainable development has many interpretations, but two will suffice in the context of this article.

First, the concept of sustainability is defined in ecology as the capacity of systems to endure and remain diverse and productive over time. It signifies durability, is dynamic and not static, and presupposes resilience and adaptability to change. Elaborating this, sustainable development is defined in the 1991 publication *Caring for the Earth* as development directed at 'improving the quality of human life while living within the carrying capacity of supporting ecosystems' (see Further Information for details of all cited publications). The 2010 European Union *Toledo Declaration on Urban Development* encapsulates the multiple dimensions of sustainability as 'economic, social, environmental, cultural and governance'. It stresses the importance of cultural heritage alongside building rehabilitation.

Second, whereas the 1987 *Brundtland Report* has been criticised in many quarters for its emphasis on economic growth, an oft-overlooked passage on the first page reads: 'We see the possibility for a new era of economic growth, one that *must* [author's italics] be based on policies that sustain and expand the environmental resource base'.

The Edinburgh Centre for Carbon Innovation, which opened in 2013, is a category A listed former school. Its refurbishment used low carbon materials including highly engineered timber and reclaimed steelwork. It is the first refurbished historic building in the UK to achieve a BREEAM 'Outstanding' rating. (Photo: Dave Morris)

The environmental resource base that concerns us here has two components, renewable and non-renewable. The latter divides into the unexploited, for which tables of reserves and projected expiration dates are regularly published, and the exploited. The environmental resources already exploited for the development of our existing buildings and urban infrastructure include both the materials themselves and the fuels used in their extraction, manufacture, transportation and construction – their 'embodied energy'. This investment provides the building conservation and retrofit sector with a vital role in today's global agendas which extends beyond a reductionist focus on 'architectural or historic interest' premised on selective survival. In a Europe-wide context the importance of conserving this embodied resource is underlined by the estimation that 80 per cent of the buildings that will exist in the year 2050 have already been built. This figure varies regionally, increasing to 87 per cent relative to the housing stock in Scotland for example.



Thermal image composition showing heat loss from Bute House, Edinburgh (Image: Kal Murray, Eco Surveys)

Analysis of the embodied energy and materials of historic buildings provides important indicators:

- it prioritises a holistic evaluation of the long-term energy investment as well as performance in use of all older buildings
- it broadens perception of the value of our built heritage beyond delimited cultural criteria to embrace environmental resource, societal factors and usefulness
- it highlights the potential for mainstreaming retrofit measures beyond a restricted heritage sector, up-scaling traditional methods in tandem with appropriate new technologies
- it facilitates the development of manifold options for balancing energy-related objectives with those of heritage significance, ones that are normal and affordable rather than specialist and expensive.

In short, understanding sustainability requirements provides a major opportunity for the heritage sector to expand its field of activity and influence in concert with the mainstream retrofit sector.

UNDERVALUED ENERGY PERFORMANCE

An important starting point is to address negative assumptions regarding the energy performance of our existing building stock, especially older buildings constructed using traditional materials and techniques.

The conventional criteria for identifying and calculating thermal performance across the built environment rely on simplistic thermal transmittance or U-values, ignore factors such as thermal inertia, and employ standardised and generally high assumptions concerning acceptable indoor temperature levels. The variation in performance as well as human comfort levels experienced between buildings of diverse constructional types is not taken into account, the behavioural patterns of building occupants as well as their tolerance of variabilities is ignored, and the results obtained from different energy certification systems – all of which are modelled theoretically – can vary significantly.

The current measurement criteria combine to undervalue the thermal performance of older buildings and create an expectation that intensive levels of intervention are required to make them energy efficient, ones that anticipate conflict with their heritage significance while proving less effective than assumed. Additionally, there is no industry-agreed methodology for calculating and comparing the embodied materials and energy of diverse typologies of buildings by age and construction or of interventions into them, and life-cycle parameters and analyses are either neglected or poor.

In 2007, based on research of energy consumption data across a broad cross-section of its building stock, the Ministry of Justice in England confounded preconceptions by demonstrating that its oldest, pre-1900 buildings use the least energy. The research also demonstrated that the performance of these older buildings was not approached in new construction until the 1990s and 2000s, decades during which energy use was still eight per cent higher per square metre than for the pre-1900 buildings. As the architect Jon Wallsgrove has written: 'This innovative research... has shown that the conservation of our architectural heritage is directly compatible with energy conservation, rather than being diametrically opposed, as some environmental fundamentalists believe.'

In the light of these and related findings both at home and abroad, priority has been attached by the historic environment agencies and others across the United Kingdom to the research and promotion of benign interventions and limiting detrimental impacts on the historic and traditional building stock. Notable in this regard is the ongoing applied research by Historic England (formerly English Heritage) and Historic Environment Scotland (formerly Historic Scotland), the Building Research Establishment, Changeworks, the Society for the Protection of Ancient Buildings (SPAB) and the Sustainable Traditional Buildings Alliance (STBA), and research conducted in historic cities including Bath, Bristol and Edinburgh.

Austwick, Lancashire: house conversion. Heritage significance subsumes appearance and material fabric. In this case, whereas the material fabric has been retained by overlaying solar panels, the building's appearance has been seriously compromised. Advances are being made in the production of solar roof tiles, also shingles and slates, which protect the overall as well as detailed appearance of historic buildings but require substitution of the fabric. The heritage impact methodology outlined in this article facilitates informed and transparent decision-making in situations where choices have to be made. (All photos: Dennis Rodwell)

CONSERVATION PRINCIPLES AND HERITAGE IMPACT METHODOLOGY

'Significance' is the collective term used by heritage professionals to encapsulate the diverse heritage values that can be ascribed to a building. These values may include artistic, symbolic, historical, social, economic, scientific and technological attributes.

Assessment is the key to articulating heritage values, whether for statutory designations or local recognition, and the preparation of statements of significance is generally a pre-requisite where interventions are proposed. Statements of significance aim to:

- identify the 'character defining elements' of a building and its curtilage
- describe the degrees of significance (typically, from high to none) that attach to setting, form and appearance, components (such as doors and windows) and material fabric
- facilitate accurate and transparent assessment of the overall and detailed impact of retrofit measures (from none to high).

A successful retrofit procedure additionally requires:

- detailed examination of existing needs for repair and conservation
- assessment of the thermal characteristics and performance of the building envelope, for which expertise in thermal imaging is a crucial advance on theoretical U-values
- analysis of heating and electrical systems
- understanding of moisture effects and humidity
- assured competences in the requisite disciplines.

A main objective of the 2012–16 European research project Energy Efficiency for EU Historic Districts' Sustainability (EFFESUS), was to develop a heritage impact assessment methodology for the selection and prioritisation of cost-effective life cycle energy efficiency improvements at the urban district scale. For this, given that listed buildings account for less than three per cent of the total, an inclusive definition of historic urban district was adopted. The definition covers almost a quarter of the building stock: 'a significant grouping of old buildings, built before 1945 and representative of the period of their construction or history, and comprising buildings which are not necessarily protected by heritage legislation.'

An essential premise was that building-scale approaches are inefficient and costly, and urban strategies which identify representative typologies of buildings will support the economies of scale associated with mainstreaming retrofit technologies, as well as achieve the reductions in greenhouse gas emissions anticipated in EU directives (targets which the UK is independently committed to achieving under the *Climate Change Act 2008*). Adopting the principle of holistic understanding of the suitability of specific retrofit measures in any given situation, heritage impact assessment is one of six complementary modules in the EFFESUS project. The other modules are operational energy, indoor environment (air quality and humidity), fabric compatibility, embodied energy (of retrofit measures) and economy.

A complementary component of the EFFESUS project has been the research and testing of fabric retrofits incorporating new technologies. These include high-performance insulating lime mortars for use externally as render and internally as plaster, silica aerogel fibre insulation as infill to cavities behind internal dry linings, and advanced window systems with integrated air supply valves and shading blinds connected to building management systems.

Essential to the overarching context is that heritage values are maintained and interventions and their consequences have minimal ecological impact. Minimum intervention is a core conservation principle and encapsulates both objectives. It is also essential that all actors are focussed on elaborating properly considered retrofit solutions that are long- rather than short-term and do not respond to individual concerns (such as simply reducing heating bills) while provoking others (such as moisture and health issues). Retrofit solutions should be communicated to building owners and occupants in ways that express what they can do rather than what they can't and, most importantly, *why* they have been chosen.

SAMPLE RETROFIT MEASURES

Retrofit measures fall into two main categories: those that improve the thermal and energy performance of buildings (fabric and services) and those that change the energy supply source from fossil fuels to renewables, whether at the individual building scale or at the urban district level.

If the reduction of carbon emissions is the sole or primary objective, then a balanced approach that converts the energy source to renewables can limit the need for fabric interventions, especially those which would impact prejudicially on a building's heritage significance. In this, rapid advances are being made across the multiple options for renewables – solar, wind, biomass, ground, air and water source heat exchangers, micro hydro-electric and others. Advances are also being made in defining methodologies for cradle-to-grave carbon emission audits to confirm whether or not certain technologies really are 'green' as opposed to just appearing to be so.

For fabric retrofits, the starting point is to fully understand what are the weakest areas and components of buildings (which are not necessarily those promoted in government programmes such as cavity-wall insulation and window replacement), and what are the most cost-effective and sustainable ways of dealing with them: from roofs to walls and floors, windows and doors, and involuntary leakage. New solutions such as those researched for the EFFESUS project need to be promoted in tandem with the recovery of traditional solutions.

The weakest links in buildings are often their roofs – frequently simple to remedy with ecologically-friendly insulation materials such as sheep's wool – and windows. From a heritage significance as well as an ecological perspective, however, windows can be the most challenging to retrofit. What merit is there in replacing a repairable 250-year-old timber window with one which may, in whole or part, only last

Lörrach, Baden-Württemberg, south-west Germany: biomass-fuelled urban-district heating plant. District energy systems, whether for heating/cooling or electricity, are more cost-effective and sustainable and avoid impacting on the heritage significance of individual buildings.

Sibiu, Romania: historic double windows, typical of those found throughout Central and Eastern Europe

Stirling Castle, Scotland: crafted secondary glazing and shutters have been installed as part of the restoration works in the royal apartments.

a maximum of 25 years? A particular problem arises with the glass, and this author has yet to be convinced that the building industry is able to resolve the inherently limited lifespan of sealed double- and triple-glazing.

Double windows and secondary glazing, which tests have demonstrated to have thermal characteristics at least as good as if not better than sealed glazing units, have been the norm across much of continental Europe for centuries. They often offer a viable alternative that accords with the heritage principle of minimum intervention, is not subject to failure of the glazing technology, and is highly durable.

COORDINATED, COST-EFFECTIVE ACTION

An increasingly invoked truism is that the most sustainable building is the one that has already been built. Lack of holistic understanding and simplistic energy certification systems serve to undervalue the energy performance of our existing building stock, especially older, traditionally constructed buildings.

The retrofitting of our built heritage requires a methodical approach to assessing and respecting its heritage significance in whole and in its discrete parts. Europe's building stock has a historical and projected longevity that constitutes a major contribution to the reduction of global carbon emissions: through the environmental capital that has already been invested in it; and through the potential for significantly reducing or eliminating the occupancy emissions by a combination of energy efficiency retrofitting and conversion to renewable energy sources.

To meet global emissions reduction targets, we need to mainstream retrofit measures and systems to satisfy complementary objectives. Central to this are principles that have hitherto been most closely associated with the heritage sector, including minimum intervention and minimal ecological impact. Common ownership of these across the whole retrofit sector will enable coordinated, cost-effective action at the scale that is required to counter the predicted impacts of anthropological global warming.

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DENNIS RODWELL, architect-planner, is an international consultant in cultural heritage and sustainable urban development (www.dennisrodwell.co.uk). Previously a principal in private practice and a heritage at risk developer, he has also served in local government posts as architect, conservation officer, urban designer, principal planner and project manager. He was a partner in the EFFESUS research project described in this article.

RETROFIT IN HERITAGE BUILDINGS

Understanding the risks

IAIN McCAIG

IT IS a widely held view that older buildings are not energy efficient and must be radically upgraded in order to improve their performance. In reality the situation is more complicated and assumptions about poor performance are not always justified. For example, as Dennis Rodwell points out in his article on heritage and sustainability (see page 3), when HM Courts Service analysed their records of energy use they found that '…buildings from the early part of the 20th century and before tend to use less energy than the equivalent more recent buildings'. Nevertheless, opportunities exist to improve the energy and carbon performance of many heritage buildings, thereby helping them to remain viable and useful now and in the future.

The challenges in striking the right balance between benefit and harm can, however, be considerable. The unintended consequences of getting energy efficiency measures wrong (or doing them badly) include:

- harm to heritage significance
    altered appearance
    loss of features
- harm to human health and building fabric
    poor indoor air quality
    condensation and mould growth
    decay of building fabric
- failure to achieve the predicted savings or reductions in environmental impact.

Getting the balance right is best achieved through a systematic 'whole building' approach. This is a logical process based on conservation planning principles that uses the understanding of a heritage asset, its context, significance and all the factors that affect energy use (not least, the people inhabiting it) as the starting point for devising strategies for energy efficiency.

Shrewsbury Flaxmill Maltings (Grade I, 1797), where Historic England is assessing the effects of internal wall insulation on the hygrothermal behaviour of brickwork (Photo: Jonathan Taylor, all other images: Iain McCaig/Historic England)

Strategies may vary depending on whether the main aim is to mitigate carbon emissions, cut fuel bills or comply with legislation such as the Building Regulations. Compromises are inevitable, but the whole building approach enables informed decisions to be taken and ensures that improvements are suitable, well-integrated, properly coordinated, effective, cost-efficient and sustainable. It also provides an effective framework for communication between all parties involved in the process, including assessors, designers, installers and the people who will use and manage the building.

A 'Mean, Lean, Green' philosophy has evolved for the design, construction and use of new buildings. This is based on a hierarchy that begins with the siting, orientation, form, materials and construction of the building to optimise the efficient use of energy and other resources ('Mean'). Next comes the design, management and control of engineering systems to ensure they can operate as efficiently as possible ('Lean'). The final consideration is supplying energy requirements from renewable sources to minimise greenhouse gas emissions ('Green').

Although this philosophy can be applied in principle to existing buildings, a more nuanced approach is needed and the priorities will differ. For example, while the 'fabric first' approach (which focusses on achieving a high performance building envelope) makes perfect sense for a new building, in a historic building this may be neither practicable nor desirable. Instead, effective, cost-efficient and less risky measures that have minimal impact on heritage significance might be identified. Such measures include improving building services and controls, changing the way a building is occupied, used and managed, and questioning current expectations and standards to find out what is really necessary. It is important to remember that success cannot be achieved by technical means alone – building owners, managers and occupiers play a crucial role and should be fully engaged in plans for saving energy at every stage.

Where building fabric improvements such as reducing uncontrolled air infiltration or adding insulation are considered desirable and feasible as part of a whole building energy strategy, careful consideration must be given to minimising the risks of unintended consequences. For example, if adequate provision is not made for ventilation, making a building more airtight can result in poor indoor air quality, with consequential health risks for the occupants. And the failure to remove excess moisture generated by activities within the building can lead to condensation and mould.

Similarly, the building may be harmed if added insulation adversely affects its benign 'hygric balance' (water in = water out) leading to a build-up of moisture within the fabric. Moisture problems caused by poorly designed and badly installed external wall insulation, or pre-existing building defects which allow rain to penetrate and become trapped are already becoming evident in some retrofitted buildings. In some of the worst cases buildings have been rendered uninhabitable.

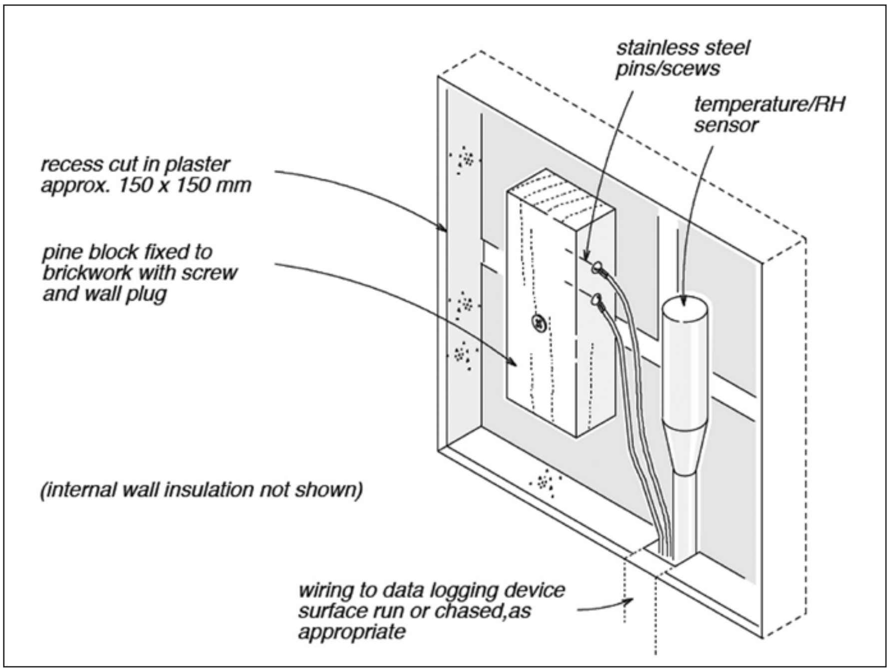
The interactions between a building and the internal and external environments are complex and dynamic. It can be difficult, therefore, to fully predict the effects of particular retrofit measures and to assess the technical risks with any degree of certainty. Although the risk of moisture accumulation can be assessed using numerical models – a range of software applications of varying degrees of sophistication exists for this purpose – there is very little empirical evidence to validate the models.

Concerns about the risk of moisture accumulation associated with retrofitted wall insulation have prompted Historic England and others to obtain data from systematic site- and laboratory-based observations conducted over extended periods. The aim is to better understand the hygrothermal behaviour (heat and moisture transfer) of building elements and the effects of energy efficiency retrofit measures.

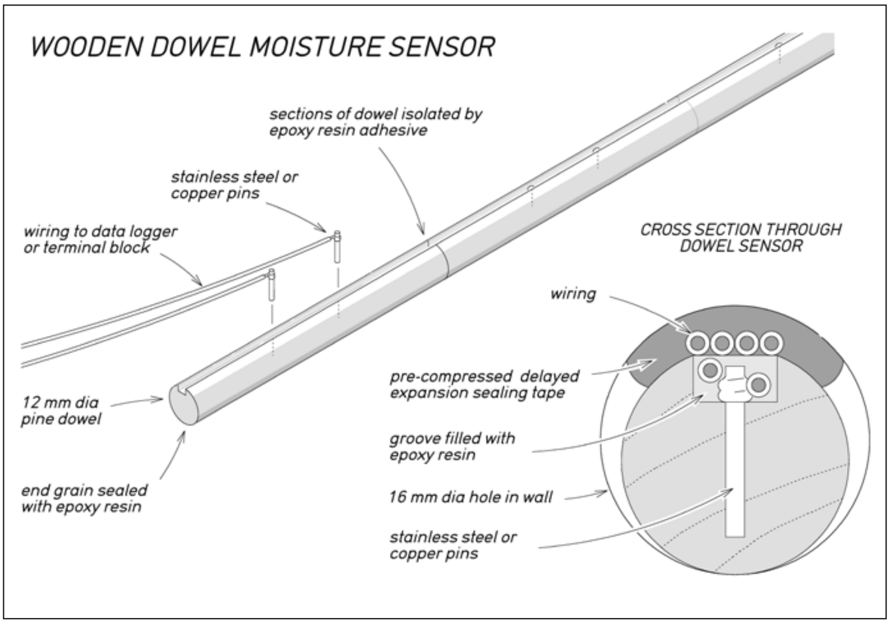
VICTORIAN END-OF-TERRACE, NEW BOLSOVER

New Bolsover is a model village built by the Bolsover Collier Company in 1891 on the outskirts of Bolsover, Derbyshire. It comprises 206 two- and three-storey brick houses (Grade II listed) arranged in double terraces on three sides of a square village green. In 2011 Historic England (then English Heritage) leased an end-of-terrace two-storey brick house and carried out a package of measures to improve the energy performance of the building envelope. This included loft insulation, secondary glazing, internal wall insulation and insulation of the suspended timber ground floor. Two types of wall insulation were used for comparison: a non-hygroscopic, vapour-closed system (polyisocyanurate or 'PIR'), and a hygroscopic, vapour-open system (wood fibre).

Victorian end-of-terrace in New Bolsover, Derbyshire before (above) and after (below) installation of loft insulation, secondary glazing, internal wall insulation and insulation of the suspended timber ground floor. These thermal improvement measures increased the building's SAP rating from E (46) to C (73).

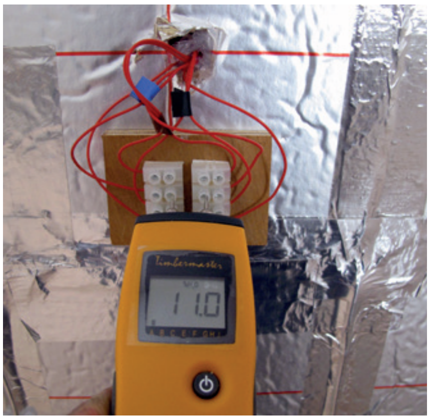


Hygrothermal monitoring set-up at New Bolsover. Wooden blocks (or dowels) are a convenient method for assessing moisture content in historic building materials. The moisture content of the timber equilibrates to the relative humidity of its surroundings and can be determined (within limits) from measurements of electrical resistance. The humidity of the surroundings can then be deduced.



Hygrothermal monitoring set-up at Shrewsbury Flaxmill Maltings: the dowels are cut into three sections isolated by epoxy resin. The ends of the dowels are also sealed with epoxy resin. In each section there is a pair of embedded electrodes which enable the electrical resistance to be measured remotely to provide a moisture profile through the thickness of the wall.

The interior of the flax mill: the line of short cast iron columns once held the drive shaft to power the looms.



Measuring the moisture content of the dowels manually, using a resistance moisture meter. The dowels are connected to terminal blocks located to suit the spacing of the pins on the moisture meter. This enables repeated measurements to be made quickly and easily.

The thermal performance of the building envelope was quantified before and after the improvements using in situ U-value measurements, co-heating and air pressurisation tests. The improvements were also modelled using the government Standard Assessment Procedure (SAP) for the energy rating of dwellings, and the outputs compared with the measured results (see Further Information for details of the research report).

In addition, sensors were installed behind the internal wall insulation in 16 locations to monitor heat and moisture at the interface with the wall. In a heated building the addition of internal wall insulation will make the existing wall colder because it gains less heat from the interior of the building. As the wall becomes colder, its humidity increases. This prompts two questions: does the wall remain sufficiently wet for long enough to harm building fabric? And does moisture tend to accumulate over time? The sensors installed measure temperature, relative humidity and the moisture content of a small block of wood (page 7).

Moisture monitoring at New Bolsover has been carried out continuously since 2011. During this period seasonal fluctuations have been observed, with walls becoming wetter in winter and drying out during the summer months. So far, no conclusive evidence of moisture accumulation behind either insulation system has been observed, but monitoring is continuing. (The results of the work to date will be published in an interim research report report which will be available for download from Historic England's website).

GEORGIAN FLAX MILL, SHREWSBURY

Historic England has also been monitoring site trials to assess the effects of internal wall insulation on the hygrothermal behaviour of brickwork at Shrewsbury Flaxmill Maltings, Shropshire, (also known as Ditherington Flax Mill). The internationally important historic site comprises seven listed buildings, including the main mill (Grade I listed), built in 1797 to the designs of Charles Bage. It is the world's first iron-framed building – a forerunner to the modern skyscraper.

The site ceased trading in 1987 and became derelict. English Heritage acquired it in 2005 and carried out emergency works to halt the decline of its buildings. Plans to bring the site back into sustainable beneficial use as a mixed-use commercial and residential development are in preparation. In this context questions have arisen about the extent to which wall insulation might form part of the energy strategy for the buildings, providing an ideal opportunity for further research into its effects.

Two systems of internal wall insulation, similar to those used at New Bolsover, have been installed in trial areas on three exterior walls in a room in the engine house adjoining the main mill. The 1½-brick thick walls face south, east and west respectively. The monitoring set-up is similar to that at New Bolsover, except that wooden dowel moisture sensors have been installed in holes drilled in the walls to within 50mm of the external faces. This allows moisture profiles through the thickness of the wall to be obtained, in addition to heat and moisture transfer data from the interface between the insulation and the wall.

During the winter months the room is heated and humidified to simulate occupation. Internal air temperature and relative humidity are monitored while a weather station records meteorological data. In addition, there are gauges to measure the amounts of wind-driven rain striking the elevations of the building. A little over a year’s worth of data has been gathered and is currently being analysed. However, differences in the hygrothermal behaviour of insulated and uninsulated walls, and variations resulting from the differing orientations of the walls are already apparent.

Interestingly, the largest differences between summer and winter temperature and humidity levels were observed in the exterior sections of the insulated walls. In contrast, the scale of the fluctuations in the exterior sections of the uninsulated walls was generally smaller. Further investigation will be needed to determine whether the magnitude of these fluctuations would be sufficient to increase the vulnerability of fragile brick surfaces to deterioration over time.

WUFI

Measured data obtained from New Bolsover and Shrewsbury Flaxmill Maltings is also being used to investigate factors affecting the accuracy of heat and moisture transfer simulations using WUFI software (*Wärme Und Feuchte Instationär* or ‘heat and moisture transiency’) in a project being carried out on behalf of Historic England by Dr Paul Baker at Glasgow Caledonian University. The ability to predict the hygrothermal behaviour of building components is important in assessing and managing moisture risks.

WUFI software has been developed by the Fraunhofer Institute for Building Physics, Germany. It complies with *BS EN 15026:2007* which sets out minimum requirements for simulation software use to predict one-dimensional transient heat and moisture transfer in multi-layer building components exposed on both sides to transient climate conditions.

In the first phase of the project, WUFI Pro 5 software was used to simulate the hygrothermal behaviour of brick walls, both insulated and uninsulated, at Shrewsbury Flaxmill Maltings over a period of 30 years (1960–1990) using historical meteorological data recorded at a nearby weather station. The simulations were carried out using the material properties of two bricks from the WUFI database (‘hand-formed brick’ and ‘historical brick’) plus the measured material properties of a third brick from the main mill building. Four types of insulation system were modelled:

- wood fibre
- mineral wool without an air and vapour control layer (AVCL)
- mineral wool with AVCL
- PIR.

Results of the various simulations were then compared.

There were significant differences between the results obtained when the measured properties of the Flaxmill brick were used instead of the WUFI database values. Clearly, it is better to use the measured properties of traditional building materials for hygrothermal simulations – there will always be uncertainties when using alternatives from the WUFI database. (This observation has also been made by other researchers.) It is a drawback of the application that the database contains no traditional UK building materials.

After comparing the simulation results obtained for the different types of insulation, wood fibre – which is hygroscopic and has some vapour diffusion resistance – appeared to be the best of the four systems. Mineral wool, although it has very low vapour resistance, is non-hygroscopic and therefore unable to buffer moisture. The insulation systems with higher vapour diffusion resistance – mineral wool with AVCL and PIR – appeared to cause moisture to accumulate within the walls in the long term.

Altering the rain adherence factor in the model had a significant effect on simulation results. The actual rain adherence factor at the Flaxmill is unknown, and may vary depending on the intensity of wind-driven rain. It may be possible to ‘calibrate’ the model by adjusting the rain adherence factor based on the site measurements of wind-driven rain. These, and other unknown boundary conditions led to a high level of uncertainty about the simulation results.

The next stages of the WUFI project will include sensitivity analysis of input parameters and the modelling of the walls at New Bolsover so that a direct comparison can be made between the simulation results and the measured data gathered over the past five years. In due course it will also be possible to compare the simulation results with measured data from Shrewsbury Flaxmill Maltings to provide further validation of the model. (A research report on the first phase of the hygrothermal modelling project can be downloaded from Historic England’s website, see Further Information.)

LOOKING AHEAD

In addition to the research described above, Historic England’s Building Conservation and Research Team is also investigating the effects of added insulation on the hygrothermal behaviour of roofs and suspended timber ground floors, including the role of ventilation in maintaining moisture at safe levels.

Building physics is complicated. Dr Paul Baker observed recently ‘It’s not rocket science – it’s harder!’ And there are still many gaps in our knowledge and understanding. Therefore, a very welcome and timely development has been the launch earlier this year of the UK Centre for Moisture in Buildings (UKCMB). This not-for-profit organisation will work with partners from academia, government, industry and the public to substantially improve the way moisture risk is understood and managed in the UK. Watch this space.

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Historic England Research Report, *External Wall Insulation in Traditional Buildings: Case studies of three large-scale project in the North of England*, 2014 (http://bc-url.com/ewi)

Historic England technical guides on energy efficiency and historic buildings are available at https://historicengland.org.uk/advice/technical-advice/energy-efficiency-and-historic-buildings

Historic Environment Scotland guidance on saving energy in traditional buildings is available at https://www.historicenvironment.scot/advice-and-support/your-property/saving-energy-in-traditional-buildings/saving-energy-guidance

Sustainable Traditional Buildings Alliance, *A Bristolian’s Guide to Solid Wall Insulation*, BCC, 2015 (http://bc-url.com/bristol)

Sustainable Traditional Buildings Alliance, *Planning for Responsible Retrofit of Traditional Buildings*, 2015 (http://bc-url.com/retrofit)

UK Centre for Moisture in Buildings ww.ukcmb.org

IAIN McCAIG is senior architectural conservator at Historic England. He studied architecture before specialising in building conservation and has many years of experience in both statutory conservation bodies and private practice.

THE EASY WINS

A strategic approach to improving energy efficiency in traditional homes

RACHEL COXCOON

THE PAST three years have seen an explosion in retrofit activity, not least because of the heavily promoted (but now defunct) Green Deal programme. External wall insulation in particular has been promoted heavily by government as the number of unfilled cavities and lofts has diminished and policymakers' attention has turned to the 'hard to treat' sector, which includes almost all buildings of traditional construction.[1] However, the list of approved measures under the Green Deal did not include some of the simplest available interventions. An unfortunate side-effect of this omission has been to focus public awareness on the more expensive, disruptive and (for traditional buildings) potentially damaging[2] measures at the expense of easier, cheaper and less disruptive ones.

Growth in demand for these more expensive measures has also created opportunities for less skilled operatives to move into this area of work. This has increased the risk of poorly applied external wall insulation systems being carried out by general building firms without the specialist knowledge needed to specify each system to the bespoke needs of the house in question. This is especially true of traditional buildings, which function differently to modern ones, particularly with regard to how air and moisture move around them. Modern buildings rely on a high level of air and moisture tightness, and the design aim is to create a sealed envelope that keeps most moisture out through the use of moisture-resistant materials and finishes. Excess moisture such as that generated in bathrooms and kitchens is typically expelled mechanically via extraction fans or, at the very least, trickle ventilation in windows.

Applying an external render that adds to the already impermeable design can significantly improve some more modern buildings in terms of thermal performance. By contrast, traditional homes (partly because they pre-date the technical ability to achieve moisture tightness) have tended to work with flows of moisture. Damp from the ground, driving rain and occupant use would have travelled through the walls and occupants principally relied on sunshine, wind, heating and ventilation through windows, chimneys and draughts in order to keep the building at an acceptable equilibrium.

Tightly packed Georgian housing in Bath: intrinsically sustainable design with a low ratio of external envelope to interior

Since many traditional homes were not originally constructed with an internal bathroom, plumbing or central heating, and because the idea of taking a daily bath or shower would have seemed like madness to many of our predecessors, the amount of moisture generated daily by a household would have been much lower. Most traditional homes now have these features, so the fabric of those buildings must deal with far higher levels of moisture than in the past. When coupled with the application of impermeable insulation materials and insufficient ventilation, this can have disastrous consequences. Moisture that would previously have travelled through the walls is now trapped inside. Mould and mildew can build up and eventually cause damage to the fabric. It is therefore vital that those living in traditionally constructed homes are asking potential contractors the right questions about the system that will be used and the way that excess moisture will be dealt with.

Less well documented, but perhaps of equal concern, is the effect that new external finishes can have on the historic significance of many traditional buildings. The Centre for Sustainable Energy (CSE)

LOVE YOUR OLD HOME

Making your traditional home warmer and cheaper to run

If your home was built before 1919, and has solid walls (i.e. there are no cavities to fill with insulation), then it's known as a 'traditional dwelling' in conservation terms.

Traditional dwellings contribute greatly to our understanding of the past; they tell us many things about the way people used to live. The 'clues' found in individual houses can combine to tell us a bigger story, like the rise and fall of a local industry, changes in religious practices, or the evolution of building techniques. The people who built your home and lived in it before you may have left a wealth of information that can help you understand its story.

Your chapter in the story

Improving your home to make it more energy efficient is just another chapter in that story. We live at a time when fuel prices are at a historic high and we now understand that our energy use is contributing to climate change. So reducing energy use in your home is likely to be more important to you than it was for its past inhabitants.

The changes you make now will contribute to the story of your home, telling those who come after how our generation adapted to these pressures.

But while there is almost certainly some opportunity to improve the energy efficiency of your home, it's important to bear in mind the impact that change could have, both on the historic significance of your home as it stands, and on the fabric of the building itself. Get it wrong, and you could undermine the historic value of your home, and also cause physical damage to it, both of which could cost you more in the long run.

Get the balance right, and you'll have a warmer, more comfortable home that can continue to help us understand our national story for decades, or even centuries, to come.

The Centre for Sustainable Energy's Love Your Old Home *booklet (2014)*

Damp and mould caused by poor external wall insulation (Photo: Centre for Sustainable Energy)

	LEAST INVASIVE	INVASIVE	MOST INVASIVE
WALLS	Gap filling	Internal solid wall insulation	External solid wall insulation
			Insulating within depth of timber frame
ROOFS	Loft hatch insulation	Rafter insulation (heated loft)	
	Loft insulation (unheated loft)	Flat roof insulation	
FLOORS	Gap filling and floor coverings	Under-floor insulation (suspended floor)	Under-floor insulation (solid floor)
			Under-floor heating
			Over-floor insulation
WINDOWS	Thermal curtains and blinds	Refurbishing and draught-proofing original windows	Replacing non-original or badly damaged original windows with timber double glazing or slim-line timber double glazing
	Refurbishing or reinstating shutters		
	Film secondary glazing	Framed secondary glazing	
DOORS	Door draught-proofing		New high-performance thermal doors
	Door refurbishment		
	Creating a draught lobby		
CHIMNEYS		Chimney blocking	

has run a local energy-efficiency advice service in the Bristol and Somerset area for more than 20 years, including home visits for complex cases. It is regularly called upon to advise householders in traditional homes on how to improve efficiency (mainly by reducing heat loss). Three things are becoming increasingly clear to CSE advisers as they deliver these services:

- Residents of traditional homes often have little knowledge of the construction techniques used in them, or the way in which moisture moves through the building. This is compounded by a tendency to believe (perhaps because of the marketing techniques of modern housebuilders) that moisture movement in or through walls should be resisted at all costs, and that it is a sign of an underlying problem with the house.
- Very few people understand the meaning of the term 'significance' when applied to historic properties. Householders typically fail to distinguish between impacts on historic significance and impacts on the physical fabric of the building when proposing change. They are not the same; one can be present without the other – for example poorly fitted insulation which increases condensation could lead to physical damage in the first instance by creating a build-up of damp between a stone wall and internal wood panelling. If the wood panelling then has to be removed as a result, then not only is there physical damage but ultimately loss of historic significance as well. However, it is also possible to damage only the historic significance of a building, for example by obscuring decorative brickwork with external wall insulation where this measure has no detrimental effect on the physical fabric of the building. Conservation officers may well object to proposed retrofit simply because it will damage historic significance, a concept that the householder often finds vague and elusive, without causing actual physical harm to the building.
- It is very common for householders to want to make changes based on a desire for a particular product or measure (such as double glazing), rather than a desire to see a particular outcome (such as reducing draughts), often because they have received some sort of marketing literature about the product in question.

Particularly where buildings are listed or in a conservation area, these three factors are the source of a great deal of conflict with local authority conservation and planning teams who expect greater justification for the installation of potentially damaging measures than many householders are prepared to give. More guidance is also becoming available to support local authorities in framing their decisions. The forthcoming Historic England conservation research report The Sustainable Use of Energy in Traditional Dwellings (authored by CSE, expected Spring 2017) is targeted at local authority planning and conservation officers and explores how to use legislation and policy to guide decision-making.

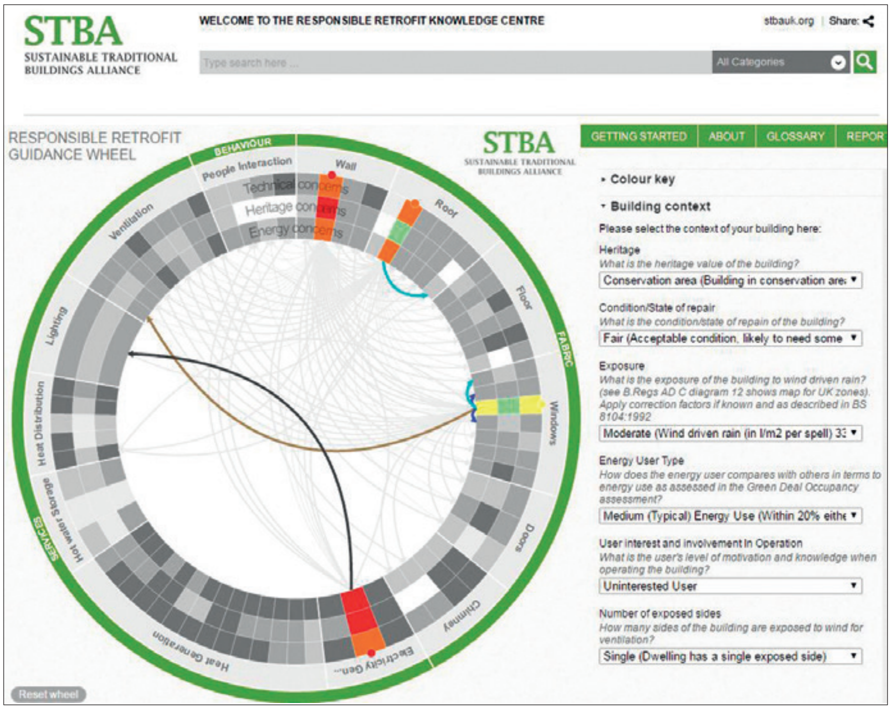
Where the building is neither listed nor in a conservation area, there is no such oversight from local authority experts, and these three factors (alone or in combination) mean that many householders are making changes to their properties that can be hugely damaging to their value, both from a heritage point of view and also in physical terms.

To try to cut through some of this potential for conflict, the Centre for Sustainable Energy produced a booklet titled *Love Your Old Home* in 2014. The booklet guides homeowners through a four-step process to evaluate what makes their home historically significant, and what that means for the types of energy efficiency improvements they could make. CSE is also working with the National Trust on guidance for applying for and securing consent for traditional home retrofit, which is primarily aimed at helping residents in protected buildings to understand how to apply for consent for appropriate measures, but will also be a useful resource for local authority officers. An accompanying online resource is also being developed to provide technical advice on a range of retrofit measures

THE ENERGY HIERARCHY

The energy hierarchy is an excellent framework for thinking through the range of possible changes:

- first reduce energy demand (for example by changing behaviour in the home)
- then ensure energy is used as efficiently as possible



Building context

Please select the context of your building here:

Heritage
What is the heritage value of the building?
Conservation area (Building in conservation are

Condition/State of repair
What is the condition/state of repain of the building?
Fair (Acceptable condition, likely to need some

Exposure
What is the exposure of the building to wind driven rain? (see B.Regs AD C diagram 12 shows map for UK zones). Apply correction factors if known and as described in BS 8104:1992
Moderate (Wind driven rain (in l/m2 per spell) 33

Energy User Type
How does the energy user compares with others in terms to energy use as assessed in the Green Deal Occupancy assessment?
Medium (Typical) Energy Use (Within 20% eithe

User interest and involvement in Operation
What is the user's level of motivation and knowledge when operating the building?
Uninterested User

Number of exposed sides
How many sides of the building are exposed to wind for ventilation?
Single (Dwelling has a single exposed side)

Produced by the Sustainable Traditional Buildings Alliance, the Responsible Retrofit Guidance Wheel helps users to evaluate how a range of measures might interact with each other and what risks they could pose to a given building's physical fabric and historic significance. (Image: STBA)

- then look at generating the remaining energy needs from renewable sources.

This approach ensures that the 'low-hanging fruit' are chosen first, which often yields comparable benefits to more complex, expensive, or harder-to-implement measures.

In a heritage dwelling, the energy hierarchy should be considered within a 'whole house' approach – that is, understanding the home as a system, and systematically thinking through whether changes made to some elements or functions will impact on others. For example, draught-proofing will decrease the movement of air in the home, so consider fitting controlled ventilation. Chapter 2 of *Warmer Bath* (see Further Information), 'Deciding what to do', explores how to reduce energy use and improve energy efficiency in a traditional dwelling, and compares measures to each other in terms of cost and carbon cost-effectiveness. Further guidance on the appropriate choice of measures will be available from a forthcoming Historic England advice note, which CSE has helped to develop and which will set out good practice on the sustainable energy retrofit of traditional dwellings.

EASY WINS

With reference to the above, it is crucial that retrofit plans start with the desired outcome, not with a specific measure. It can be useful to rank desired outcomes because this can also guide the best approach. Examples of desired outcomes are:

- a warmer home
- reduced running costs
- increased market value.

Thinking about a Georgian house with sizeable windows against this list of desired outcomes, the measure that might initially spring to mind could be double glazing. But the key question is always the same: 'Is there something simpler, less invasive, and more cost-effective that I can do first?'

In this case, there is almost certainly a cheaper, less invasive way to achieve all three outcomes. Replacing original Georgian windows with modern double glazing is unlikely to have a positive impact on the market value of the home in any case, since original features are so highly prized. It is also unlikely to be acceptable in heritage terms if the building is protected in any way. It may be that timber, slim-line double glazing units could be acceptable, but these are likely to be astronomically expensive. However, a combination of other measures might achieve the same desired outcomes with less harm (for example draught-proofing the original windows, in combination with fitting thermal blinds and curtains with the installation of secondary glazing and the renovation of existing internal shutters).

Ideally, energy-saving measures should also contribute to conserving the building's significance, including undertaking necessary remedial and maintenance work, and might even enhance it by emphasising historic features and the ways in which they illustrate the building's history and use.

CHOOSING APPROPRIATE MEASURES

Behaviour change is always the cheapest measure, and should always be considered first. Better control over heating and lighting systems can sometimes be expensive but can reap rewards in the long run (fitting more efficient boilers, heating controls and timing systems). The imminent roll-out of smart meters bridges the behaviour and control themes, and 'queue jumping' is sometimes possible so householders are encouraged to contact their utility provider to see whether they can have a smart meter installed. Daily interaction with the data from a smart meter has been shown to alter energy-use behaviour and cut energy costs without any other measures being implemented.

Beyond behaviour change and better controls, we move into the realms of physical changes to the home. Breaking down the home into its constituent elements, the types of interventions that can be deployed can be ranked from least to most invasive (green to red) which, in general terms, also means least to most expensive.

If all the measures coloured green in the table on page 11 were deployed (alongside behaviour change and better controls), the likely energy savings and comfort improvements would be significant. In terms of value for money they would be likely to cost less in total than a single red measure in the table.

Detailed guidance on how a range of measures can interact with each other can be found in the excellent *Responsible Retrofit Guidance Wheel*, produced by the Sustainable Traditional Buildings Alliance. This allows the user to select a range of measures and consider how they might interact with each other and what the risks to both the physical fabric and historic significance of the building might be.

Fuel poverty levels are higher in traditional homes than in the wider housing stock, the costs of energy are rising almost inexorably, national retrofit policy is seemingly in disarray following the collapse of the Green Deal, and huge cuts to local authority budgets mean that conservation specialists are thin on the ground. It has never been more important to ensure that householders have access to useful guidance on making the right choices on how to make traditional buildings more energy efficient.

The UK's heritage housing stock is an

Most of the heat loss through this Georgian sash window was eliminated simply by draught-stripping. The restored shutters and heavy curtains also enabled the window to be insulated after dark.

Draught-stripping on the meeting rail of the lower sash (shown open on the left and closed on the right), neatly eliminating a significant source of draughts (Photos: Centre for Sustainable Energy)

irreplaceable resource, the value of which is slowly and irrevocably being eroded through the application of badly planned retrofit projects. While it is clear that the joint challenges of climate change, fuel poverty and energy security must be tackled, it should not be at the expense of our national heritage. A range of useful and comprehensive guidance resources now exists, many of which are referenced below – getting the message out to those who live in traditional homes on how best to make them fit for the future is now the key challenge.

Further information

W Anderson and J Robinson, *Warmer Bath: A Guide to Improving the Energy Efficiency of Traditional Homes in the City of Bath*, Bath and Bristol: Bath Preservation Trust/Centre for Sustainable Energy, 2011 (www.cse.org.uk/downloads/file/warmer_bath_june2011.pdf)

Department of Energy & Climate Change, *Smart Meters: A Guide*, 2013 (www.gov.uk/guidance/smart-meters-how-they-work)

Oxford City Council, Heritage and Energy Efficiency Tool (http://bc-url.com/oxford-heet)

D Pickles et al *Energy Efficiency and Historic Buildings: Application of Part L of the Building Regulations to Historic and Traditionally Constructed Buildings.* Swindon: English Heritage, 2011 (http://bc-url.com/he-energy)

Smart Energy GB, *How can I get a smart meter?* (www.smartenergygb.org)

Sustainable Traditional Buildings Alliance, *Responsible Retrofit Guidance Wheel* (http://responsible-retrofit.org/wheel)

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Notes

[1] A 'traditional building' is defined as one built before 1919, with solid walled construction, single glazed windows and no damp proof course.

[2] Useful guidance on specifying external wall insulation systems can be found in 'The Bristolian's Guide to Solid Wall Insulation' (http://bc-url.com/bristol).

SUSTAINABILITY STANDARDS & REGULATIONS

JOHN EDWARDS

THE MENTION of the energy efficiency of buildings almost always brings up U-values, energy performance certificates, standard assessment procedures (SAP and RdSAP) and building regulations. Those who are a little more informed may also refer to terms like BREEAM, Passivhaus, BREDEM and possibly even EnerPhit. These are all to do with prescribed ways of dealing with energy efficiency of buildings and sometimes their wider sustainability. All have their place but will not necessarily be appropriate and reliable, particularly where historic or traditionally constructed buildings are concerned. However, they are often the means by which we have to assess such issues.

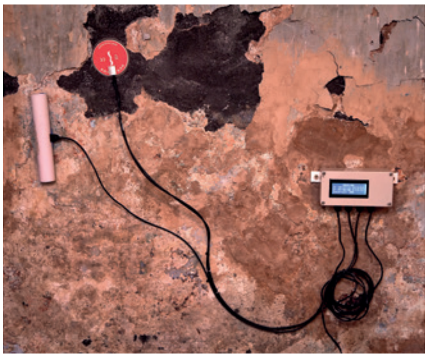
Many of the acronyms stand for things we don't necessarily have to adopt, but we do have to be mindful of them because of the potential benefits as well as the potential risks in adopting such schemes and processes.

A miner's cottage in David Street, Cwmdare: analysis of the building's pathology as required under BS 7913: 2013 provided information on the effects of damp on the in situ U-value, and demonstrated that the walls were more thermally efficient than predicted. (Photos: John Edwards)

One regulatory framework that applies to almost all development is the Building Regulations, and the part concerning the conservation of fuel and power is particularly important. Although there is some variation between those adopted by each of the UK home nations, all versions require what we call 'consequential improvements' when works to the thermal envelope are undertaken.

THE BUILDING REGULATIONS

In England and Wales, the Building Regulations are worded more emphatically than in Scotland and Northern Ireland. While there is an expectation that reasonable efforts will be made to improve energy efficiency, listed buildings, scheduled monuments and buildings in conservation areas do enjoy some degree of exemption depending on which UK home nation they are in. However, over 90 per cent of traditional buildings don't come under these categories even though from a technical perspective, most of the buildings are just the same as those which receive statutory protection. In England and Wales 'special consideration' can be given to buildings which have vapour permeable construction when the regulations would otherwise require work which may impede the movement of moisture. In Northern Ireland and Scotland it is less emphatic but, as in England and Wales, work must be 'technically feasible' and this is where the imposition of such works can be challenged. Here, British Standard 7913 can be used to support the case for not undertaking works which would adversely affect the building's performance. *BS 7913: 2013 Guide to the Conservation of Historic Buildings* (to give the standard its full name) emphasises that damp building fabric could be over a third less thermally efficient than dry building fabric, thus highlighting the importance of appropriate repair and maintenance measures as described in the document. In this respect, building maintenance is an energy conservation measure that should always come before the 'improvements' arising out of the Building Regulations, RdSAP and such like..



One very important issue that *BS 7913* raises is the need for proper condition surveys based on an understanding of the pathology of historic buildings and the materials used: this is especially essential when considering the impact of problems such as damp. Another important issue is the need to consider significance and the undertaking of heritage impact assessments. All traditional buildings have some significance and the impact of measures on that significance always needs to be understood.

Proposals are sometimes put forward for external wall insulation to be applied intermittently to the front elevation of individual houses in a terrace, despite there being features of architectural interest. A heritage impact assessment may prevent alterations like this from happening. Aesthetics are not the only consideration under the significance umbrella, but assessing significance will inevitably mean a greater likelihood of external wall insulation being applied to plain rendered elevations than to very ornate elevations with bay windows. This terrace is somewhere between the two, which is where the more difficult decisions lie. (Photo: Historic Environment Scotland)

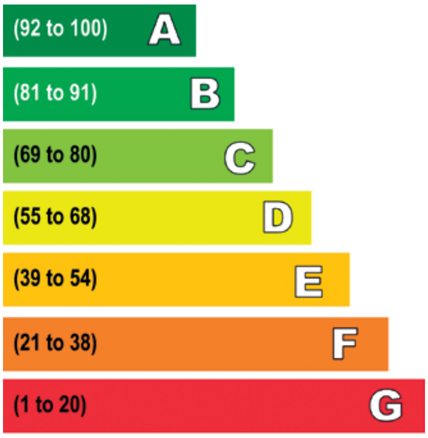
THE STANDARD ASSESSMENT PROCEDURE – RDSAP and SAP

The most common detrimental tool imposed on domestic traditional buildings is RdSAP – the reduced data standard assessment procedure – which was the basis for advice provided under the UK government's failed financial incentive scheme, the Green Deal. Today its most common use is in producing energy performance certificates (EPCs) when a dwelling is being let or sold, unless it is listed. RdSAP will almost always underestimate the current energy efficiency of a traditional building and therefore make recommendations for works which are not necessary and which may not make a building more energy efficient. There are a number of reasons why this is the case, but the main one concerns the standardisation of U-values which normally results in the thermal performance of traditional construction being underestimated. It becomes a serious concern when this results in inappropriate measures being deployed.

Despite these well-known flaws, the imposition of RdSAP is being taken a stage further. The *Private Rented Sector Energy Efficiency Regulations (Domestic)* dictate that by April 2018 residential properties cannot be let unless they reach energy performance rating band E. Property owners may have to undertake works which deliver SAP points determined by RdSAP. There is no reward, however, for maintaining buildings properly and appropriately and keeping building fabric dry, all of which help to make buildings far more energy efficient and sustainable.

BREEAM and BREDEM

The Building Research Establishment's environmental assessment method (BREEAM) for the refurbishment of domestic buildings contains some very good practice in considering a range of issues, but where energy is concerned it is flawed in using RdSAP for the reasons stated above. Another version of BREEAM has been developed for the refurbishment of non-domestic buildings where research by BRE has established that heritage buildings do relatively well. However, while RdSAP is not part of this process, the full version of SAP is, and again the standardisation of performance data (such as the U-values of existing walls) results in inevitable inaccuracy where energy performance is concerned.



An EPC gives a property an energy efficiency rating from A (most efficient) to G (least efficient). Figures on the left give the SAP points required for each rating band.

The BREDEM (BRE Domestic Energy Model) is also based on SAP, hence its potential unreliability in some areas, but it could nevertheless provide some good advice. Again, caution is needed and it would be sensible to refer to *BS 7913: 2013* in order to reduce risks and take a more robust approach.

PASSIVHAUS and ENERPHIT

Passivhaus is defined as: '… a building for which thermal comfort can be achieved solely by post-heating or post-cooling of the fresh air mass, which is required to achieve sufficient indoor air quality conditions – without the need for additional recirculation of air'. A version has also been developed for retrofit and refurbishment called EnerPHit which

Above, draught-stripping sash windows at Clovelly, Devon as part of the programme of EPC improvement measures and, top left, simple secondary glazing fitted to a casement window. (Photos: Jonathan Taylor)

has less challenging heat demand and airtightness requirements. There are many aspects of EnerPhit which are very good such as mechanical heat recovery, but the approach still relies on high levels of insulation and airtightness and will only work well if the relevant products have been installed properly. Although traditional buildings need to retain their vapour permeability characteristics, the high insulation levels which are required (to achieve the specified U-values) inevitably means solid wall insulation. The technical feasibility of installing solid wall insulation will depend on the construction of the building and its location, with due consideration paid to UK weather exposure zones. This might not be feasible in BRE zones three and four (which includes most of Scotland, Wales and Northern Ireland, and the more westerly areas of England). The impact on significance that such works would make also needs to be assessed.

HOLISTIC ALTERNATIVES

While all these official and credible energy and environmental assessment methods provide tangible outputs, they are all unreliable or potentially problematic when it comes to traditional buildings. The best way of achieving energy efficiency in a sustainable way is to take a holistic approach which considers all aspects of the building. This, however, doesn't deliver any SAP points which are of course needed for EPCs to improve the official energy performance rating.

The STBA retrofit guidance wheel (page 12) is an excellent tool for going through the process of choosing retrofit measures and there isn't anything better that does this. It takes one through all the options, steering away from those measures which are most risky and less likely to work, and towards those which are less risky and more likely to work. It also advises on how measures interact and therefore what they mean in combination with each other. But again, the wheel needs to be used with caution. It is essential to understand the make-up of the building and its condition, and there is no substitute for a thorough building survey which addresses the cause of problems from a building pathology perspective. In addition a heritage impact assessment may well be required to measure the impact of proposals on the historic significance of a building.

There is much concern from the well-informed about the approach we take towards the energy efficiency and sustainability of traditional buildings. One problem is that standards and guidance suitable for modern construction systems are often incorrectly applied to traditional structures, and there is clearly a lack of specialist expertise in this area. However, other forms of retrofit have had even greater detrimental impact on traditional buildings. For example, the retrofitting of damp-proof courses and the associated works (such as the use of impervious plasters and cement renders, and often the replacement of rotten timber floors with concrete) have, just like many forms of energy efficiency retrofit, resulted in changing the hygrothermal performance of traditional buildings. Dampness and mould are common symptoms and both suggest that any form of retrofit needs to be well informed.

Several new courses are beginning to address these problems. In particular the new Level 3 SQA Award in the 'energy efficiency and retrofit of traditional buildings' had trained 200 people by the end of 2016. However, there are some six million traditional buildings in the UK, and with an acknowledged deficiency in the knowledge and skills of both the professions and building contractors in this area, thousands need to be trained not hundreds.

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EPCs at CLOVELLY

JONATHAN TAYLOR

ENERGY PERFORMANCE Certificates (EPCs) are needed whenever a property is built, sold or rented. The EPC indicates the energy efficiency of the property as estimated by the standard assessment procedure (SAP). The higher the score the lower the running costs are likely to be, with 100 representing zero energy cost. EPC band A (most efficient) corresponds to a SAP score of 92–100, while band G (least efficient) corresponds to a score of less than 20 (see figure on page 15).

Listed buildings are generally exempt from the requirement, but often owners choose to have their properties assessed in any case. In Clovelly, a picturesque village on the North Devon coast, most of the buildings are rented to people who live and work in the region. John Rous, who owns and manages the estate, considers the EPC rating as a necessity in a competitive market for attracting tenants, whether or not the building is listed. With the help of Mukti Mitchell of the CosyHome Company, the estate has an ongoing retrofit programme to improve the EPC rating of their housing stock to at least band E, which is the minimum level set by the government for letting residential properties from April 2018. Measures are chosen to give the greatest economic return, taking into account not only improvements in EPC rating and fuel efficiency, but also any risk of damage to the fabric in the long term from the alterations.

There is growing recognition that some measures encouraged by the SAP system are inappropriate for traditional fabric, and the estate's consultant was particularly concerned by the risks posed by solid wall insulation. Key areas for improvements therefore include roof insulation, draught exclusion, secondary glazing and high-specification night storage heaters which store more heat and control its release more effectively. EPC point gains are carefully simulated by an experienced EPC assessor and used as a guide for the work to each property. The table opposite summarises the likely benefits from each measure.

The main street of Clovelly, Devon (Photo: Jonathan Taylor)

Loft spaces which were readily accessible already contain some insulation, but many of the houses have rooms within the roof space with sloping ceilings and dormer windows. These are more difficult to improve, requiring insulation between and below rafters and studs, before relining and re-plastering.

In terms of keeping the heat in, roof insulation and the draught-proofing of windows have the greatest impact, and for the attic bedrooms with uninsulated dormers, the cost per SAP is very good, despite its high cost. However, for gaining the most SAP points, the most cost-effective measure is the introduction of night storage heaters to replace a variety of older heating appliances. Although electricity generation and distribution has a relatively high carbon footprint, the SAP system encourages the use of modern night storage heaters because they use energy from the grid when demand is least.

THE AUTHOR This case study was prepared by editor **Jonathan Taylor** with the help of **Mukti Mitchell**, CosyHome Company (www.cosyhomecompany.co.uk) and **John Rous**, Clovelly Estate Company Ltd (www.clovelly.co.uk).

	Number of houses affected	Average per house		Cost per SAP point
		Cost of work	SAP point gains	
Night storage radiators	23	£4,174	23.0	£180
Room in roof insulation	29	£4,717	15.0	£318
Loft top-up insulation	15	£613	1.3	£460
Secondary glazing	39	£3,484	4.2	£829
Draft proofing doors & windows	29	£1,362	1.6	£859

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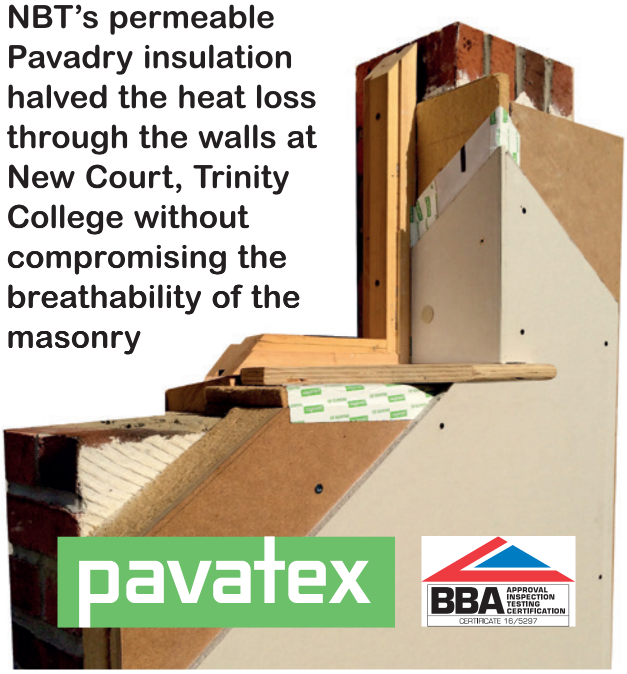
NBT's permeable Pavadry insulation halved the heat loss through the walls at New Court, Trinity College without compromising the breathability of the masonry



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RADICAL RETROFIT

at Trinity College, Cambridge

JONATHAN TAYLOR


Detail of the fine riverside elevation of New Court, Trinity College, completed in 1825 and now listed Grade I (Photo: Tim Soar)

THE COLLEGE estates of Cambridge University include a high proportion of nationally important listed buildings by leading architects from every period since the 15th century, and the colleges have a continuing interest in showcasing the achievements of the architectural avant-garde. So, it is not surprising to find they have taken an interest in the greatest architectural challenge of the modern era – sustainability. Nevertheless, the scope of the interventions at New Court at Trinity College is astonishing. Despite being Grade I listed (the grade includes the top two per cent of all listed buildings in England), its retrofit is expected to achieve an 88 per cent reduction in carbon emissions.

New Court was designed by William Wilkins to provide accommodation for students and has been in continuous use for this purpose since its completion in 1825. The building's construction around a central court is relatively conventional, with pitched roofs of slate with dormer windows behind parapets, solid masonry walls, and single-glazed casement windows. The façades facing onto the court are of brick, originally rendered with Roman cement incorporating fine mouldings, much of which had been repaired or replaced with a cementitious render. Others are of bare-faced brick and, facing the river Cam, ashlar limestone.

Refurbishment was required to meet fire officer requirements, to remove asbestos, to repair the fabric and to bring the existing accommodation up to a standard that would meet the needs of the college for the next 30 years. The accommodation includes 160 student rooms, some with en suite bathrooms, and a few teaching rooms and offices. Its listed status means that there was no requirement for an EPC, and that there was some flexibility under the requirements of the Building Regulations. But it was expensive to heat and its interior environment was poor. Penetrating damp meant that a high level of heating was required to keep the ground floor warm, while students on the floors above regularly had to keep their windows open to avoid over-heating. Fabric repairs and improvements were therefore essential, both for students' comfort and to reduce heating bills, but the desire to improve the thermal performance of the building went further than this, driven by an ethical interest in reducing carbon emissions.

As many buildings across the college's estate face similar conflicts between heritage requirements and economic/ethical requirements for conserving energy, the opportunity was taken to explore a radical approach which would challenge the flexibility of current heritage protection policy. This would provide a model for further improvements to buildings in other colleges.

The sustainability measures included:

- the repair and improvement of the external envelope to conserve historic fabric and to reduce uncontrolled heat loss through damp and drafts (windows, walls, doors and ceilings)
- the addition of 60mm vapour permeable insulation to the inner face of external walls, accepting some limited thermal bridging through cross walls
- reglazing the existing windows with 10mm thin double-glazed units
- the introduction of underfloor heating beneath the original Georgian floor boards, to be warmed by ground source heat pumps at 36°C, and controlled by occupancy sensors in each room
- mechanical ventilation using the existing chimney flues for air supply and venting stale air, with heat exchangers to pre-heat the intake
- the installation of PV solar cells on south-facing roofs, accepting that they will be visible from other buildings.

PRELIMINARY INVESTIGATION AND MONITORING

A thorough understanding of the construction of the buildings and its defects was necessary in order to deal with its principal problems appropriately – damp at ground floor level and uncontrolled heat loss. Additionally, retrofitting to insulate the fabric and to control the air permeability of the external envelope has implications for moisture levels. In particular, insulating the interior faces of external walls and the underside of roof spaces leads to parts of the structure becoming

Originally the façades facing the courtyard were all rendered with Roman cement, later repairs were executed in cement, and they have now been re-rendered using a more permeable hydraulic lime painted with limewash (above).

One of the windows facing the courtyard (left) at the start of the project, and (right), the same image modified to show the architect's proposals for re-colouring the walls and window frames, following surviving evidence of the original colour scheme (All photos: Tim Soar)

cooler, potentially inviting interstitial condensation. When combined with a decrease in air movement due to draft exclusion, there is a real risk that dry exterior walls above ground floor level could become damp. Proposals for the retrofit were therefore preceded by a three-year programme of investigation, monitoring and modelling to develop a clear picture of the hygrothermal performance of the spaces and fabric that could be most affected, and to provide a benchmark for assessing subsequent performance, from one season to another.

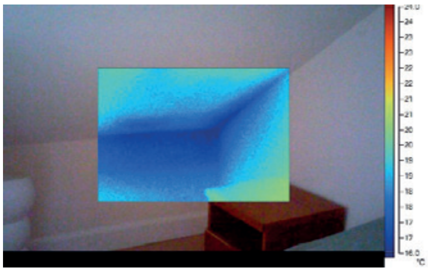
A modified form of WUFI software was used by building physics engineers Max Fordham to explore how the materials would be affected. WUFI (an acronym of *wärme und feuchte instationär* – heat and moisture transiency) tends to underestimate the thermal performance of traditional materials. Old bricks, for example, tend to be less well fired than modern ones and the clays are less uniform so they do not conduct heat as well. Nevertheless, WUFI provides a useful model for assessing the relative performance of insulation measures and the effects of cold bridging, particularly when combined with real data from monitoring the performance of the existing structures, and by material analysis. Samples of brick, stone and render were therefore sent for testing by Glasgow Caledonian University, and probes were installed by Archimetrics in 2011 to record real time variations in moisture and temperature at four depths through walls of different orientation and material. A weather station was also installed so the WUFI model could be calibrated according to the local environmental conditions and the U-values of the walls recorded by Archimetrics.

In addition to the technical impact on the performance of historic fabric, the insulation of walls and windows has a substantial design impact, and all aspects of the retrofit would affect the historic and architectural significance of the building. Before any proposals were put forward, the building was thoroughly surveyed by the architects and Beacon Planning to identify how the building had evolved, what alterations had been made in the past, and what fabric was original. At New Court, exterior insulation was clearly out of the question. Interiors, on the other hand, were generally quite plain and had been affected by alterations over the course of 185 years of student occupation, particularly in the 1970s when extensive repairs were required for dry rot.

From a design perspective, phenolic foam insulation offers the least intrusive solution as it gives the highest insulation levels for the least thickness, but the material is impermeable. The WUFI modelling indicated that this could cause problems on those elevations most exposed to driving rain, and a permeable solution which allowed evaporation from both interior and exterior surfaces would be necessary, particularly on north- and west-facing walls. The exception was in rooms where high levels of humidity would be expected, such as bathrooms. The solution was to locate en suite showers and bathrooms away from external walls and ventilate them thoroughly. Only two bathrooms could not easily be moved. In these cases the design of the ventilation was particularly important to ensure that the interior vapour pressure remains within acceptable levels, and moisture levels in these walls will be monitored carefully for years to come.

INTERIOR WALL INSULATION

Most rooms had been subjected to extensive repairs in the past, particularly the exterior walls, due to defective gutters and outbreaks of dry rot. Few retained original plasterwork. The exterior walls were stripped of their plaster finishes and refinished with a lime plaster base coat to ensure that all gaps were sealed, particularly where penetrated by structural timbers and joinery. As well as being essential for air-tightness, this would also help to draw moisture away from joist ends and other vulnerable timbers. The



Thermal image showing the cooling effect of condensation and poor insulation in one of the attic bedrooms: the ceilings (modern gypsum plaster on metal lath) were stripped out and replaced with insulation below and between the rafters to achieve a U-value of 0.15w/m²/°C and air-tightness of 3.0m³/h/m²@50Pa. (Image: ArchiMetrics)

walls were then lined using a vapour-permeable Pavatex fibreboard insulation system, 60 mm thick, and plastered to give a U-value of 0.25W/m²/°C.

WUFI and other static thermal modelling indicated that leaving the cross walls and even cornices exposed without insulation would have surprisingly little impact on heat loss, due to the relatively low thermal conductivity of the bricks. It was concluded that cold-bridging would be insufficient to allow condensation to reach a level where mould growth could occur.

Where rooms still retained original cornices, it was decided to terminate the insulation (and the replastering) just below the cornice. This would result in a rather curious detail, with the cornice running around three sides of a room as normal, before diving into a recess on the fourth side. However, the scheme developed by the architects, 5th Studio, demonstrated that the impact of this detail on the character of the interior would be significantly reduced when combined with modern furnishings and fittings, and it was seen as an 'honest' approach to the retrofit.

WINDOWS AND SHUTTERS

The original window shutters and their housing had to be removed for several reasons; first, repairs were best carried out in the workshop; second, it enabled their position to be modified so their relationship with the face of the wall, which was now insulated, could be maintained; and third, it allowed the insulation to be run behind them into the reveal. After conservation and repair, the joinery was reinstated in its new position. This created a slight gap between the shutters and the face of the windows, providing the opportunity to improve security with window locks.

Computer modelling indicated that the cooling effect of a 60mm-lining of vapour permeable insulation would not cause an unacceptable increase in moisture in the masonry, but long-term monitoring was essential. The diagram shows an external weather station and probes installed at different depths in the masonry to monitor changes in temperature and relative humidity. (Image: 5th Studio)

Although the original windows had been replaced in the late 19th century, upgrading the glazing remains a controversial decision. In listed building terms, all alterations are considered to be part of a building's history and the conservation authorities are rarely in favour of the replacement of single glazing with sealed units. However, many factors may be taken into consideration when assessing the significance of a later alteration, and in this case it was concluded that the replacement was acceptable in principle. The original glass was saved for use in the repair of windows on the estate, and modern sealed units with a thickness of just 10mm were chosen from the Holloseal range. For the outer pane machine-drawn cylinder glass was used to produce an uneven reflection similar to that of early glass.

The timber casements were also draft stripped, and contacts were added to the casements to detect when they were opened, automatically turning off the heating.

ROOF INSULATION

Rooms on the top floor were partially within the roof, with no insulation in the sections of the ceilings formed against the rafters, nor in the dormer windows. All the original lath and plaster had been replaced in the past with gypsum and metal lath, so from a listed building perspective these ceilings had little significance, allowing them to be remade with rigid insulation bats between the rafters and below, retaining a generous ventilation channel between the top and the underside of the roof covering.

The roof slates had been relayed in the past over an impervious roofing felt. A vapour permeable insulation system at ceiling level would allow moisture to enter a cooler space, increasing the risk of condensation on the underside of the felt. The usual solution to this problem is to introduce additional ventilators, but

Window shutters and architraves (left) were brought forward slightly to accommodate secondary glazing, security fixings and wall insulation. Bookcases and other fittings on either side were designed to accommodate services and (right) to hide an en suite shower. All showers were located away from exterior walls to avoid contributing to the moisture load. (All photos: Tim Soar)

this was considered too intrusive for most elevations. Increased ventilation can also increase fluctuations in humidity levels in unheated voids, by admitting warm, moist air. A modern closed-cell insulation system with vapour barrier on the warm side was therefore introduced as the most practical option. However, Historic England (then English Heritage) objected to the approach as it relies on the long-term integrity of the vapour barrier. Any defects which arise would leave timbers in the insulation layer vulnerable to condensation and decay. As many of the attic timbers are completely inaccessible, risk management relies on specialist monitoring technology.

GROUND FLOOR

In most areas the suspended timber floor had been replaced with concrete in the 1970s and walls had been replastered with a waterproof plaster. Externally, ground levels had risen and original lime based renders had been replaced with cement. As a result, there was evidence of rising damp from ground and surface water and from leaking drains, exacerbated by damp from wall surfaces and window sills above.

External ground levels were therefore reduced, drainage improved, and vapour permeability was restored to the walls and these were insulated. However, a non-traditional solution was adopted for the floor, with a conventional modern slab laid on rigid foam insulation, and isolated from the walls by perimeter insulation. This replaced both the existing slab and any surviving, but decayed timber floors.

HEATING AND VENTILATION

The carbon footprint of the building is being further reduced by the use of renewables, with photovoltaic panels to be installed on the south facing roof slopes over Garret Hostel Lane, where they are screened from street views by adjacent college buildings, and by using heat extracted from boreholes in the central court with ground source heat pumps. Underfloor heating was therefore used throughout, including beneath the floor boards of the upper floors, with sound insulation below.

Absence detectors are used to reduce the heating level if a room is unoccupied for more than 24 hours, and window detectors will turn down the heating if the window is open for more than 10 minutes during the colder months.

Chimney flues were used to provide controlled ventilation. Two ducts were installed, one supplying fresh air to the students' room, and the other extracting waste air from the shower rooms and loos. In the roof a heat exchanger was incorporated into the system to extract almost 80 per cent of the heat from the exhaust, which is used to preheat the incoming fresh air supply. The system can be reversed in the summer to provide cooled air.

LEGACY – A MODEL SCHEME?

The extent of the interventions made at New Court is extraordinary for a Grade I listed building. Key changes such as the stripping of plaster from interior wall faces, the replacement of single glazing, and the replacement of the remaining timber floors at ground level with insulated concrete slabs, are all irreversible. However, the level of alteration is the product of its own unique circumstances, which include cumulative alterations to the building over many decades, the damage caused by dry rot in the past, the simplicity of its interiors, and the necessity for change to meet the requirements of health, safety, preservation and use. Perhaps above all it was the scientific approach to the issues which enabled the college to gain listed building consent for the proposals, despite objections raised by the conservation authorities. The level of change may not, as a result, provide a model for other colleges to follow, but the level of investigation and analysis certainly does.

Beneath the romantic gothic embellishments, this is a common structure of bricks and mortar. Lessons learnt from monitoring its hygrothermal performance are equally applicable to countless solid wall buildings throughout the UK, from the retrofit of Victorian terraced housing to the conversion of industrial buildings for office, residential and other uses. While the project has been based on the very best available expertise, our understanding of the long-term effects of such changes remains incomplete. That is why the decision to monitor New Court for the next seven years is so important, and it also why the legacy of this project is so valuable.

THE AUTHOR: this article was prepared by editor **Jonathan Taylor** with the help of architect **Oliver Smith**, 5th Studio (oliver@5thstudio.co.uk).

INTERNALLY INSULATED SOLID WALLS

The SPAB building performance survey

CAROLINE RYE and CAMERON SCOTT

North-west facing granite wall in Drewsteignton, Devon: one of two internally insulated solid walls featured in the Building Performance Survey, this 600mm granite wall had been internally insulated with 100mm of polyisocyanurate board with an air gap and a plasterboard and gypsum skim finish.

THE SOCIETY for the Protection of Ancient Buildings Building Performance Survey (SPAB BPS) was first established in 2011 to address the dearth of information on energy efficiency and traditional buildings. In particular, there was an absence of measured evidence showing how traditional buildings performed before alteration, and a lack of understanding as to what constituted effective and risk-free energy saving interventions. Of specific concern was the potential for damage to fabric and occupants' wellbeing over the long-term as a result of the application of insulation and reductions in ventilation/air infiltration in older buildings.

The BPS measured various aspects of performance in solid-wall, traditionally constructed properties before and after energy efficiency retrofitting. The survey looked at fabric heat loss, air leakage, indoor air quality, wall moisture behaviour, room comfort and fabric risk conditions in seven houses.

A central part of the study looked at the impact of insulation on solid walls. Measurements of four of the buildings were made again after refurbishment, and the analyses of three are ongoing, with findings published annually online at www.spab.org.uk/advice/energy-efficiency. One wall in each of the three buildings chosen – two internally insulated and one an externally insulated cob wall – were subject to extended interstitial hygrothermal monitoring. In particular, the internal insulation of a wall is seen as a risk because fabric on the external side of the wall, outside the insulating layer, no longer benefits from the heat inside the building and in the winter months becomes cooler. The effect of this is to lower the dew point, meaning the air within the wall may more frequently reach saturation – 100% relative humidity (RH) – leading to condensation. High levels of fabric moisture could give rise to uncomfortable living conditions and increased heat loss. They could also have serious consequences in the form of mould growth and rot, which can be harmful both to human health and to the structural integrity of the building.

Over the past four years, as part of the BPS, moisture profiles (in the form of vapour, measured as RH) and temperature profiles have been monitored continuously at four points through and either side of insulated solid walls. (This element of the BPS work was extended in 2014 due to a grant provided by English Heritage.) This method of moisture monitoring, which relies on high quality instrumentation and careful installation, has been developed specifically for this purpose. The measurement of water vapour in

Annual Average Sat Margins	Sensor 1	Sensor 2	Sensor 3	Sensor 4
SHREWSBURY				
2011	6.46°C	6.41°C	5.12°C	3.96°C
2012–2013	6.34°C	5.08°C	4.30°C	3.08°C
2013–2014	6.33°C	5.00°C	4.08°C	3.45°C
2014–2015	6.85°C	5.16°C	4.20°C	4.24°C
DREWSTEIGNTON				
2011	5.30°C	4.82°C	3.53°C	2.38°C
2012–2013	5.60°C	2.23°C	1.53°C	0.57°C
2013–2014	6.90°C	1.97°C	1.14°C	0.49°C
2014–2015	7.09°C	1.58°C	0.67°C	0.59°C

Table 1 Annual average saturation margins for interstitial sensors 2011–2015. Orange shading indicates increased margins, blue indicates decreased margins

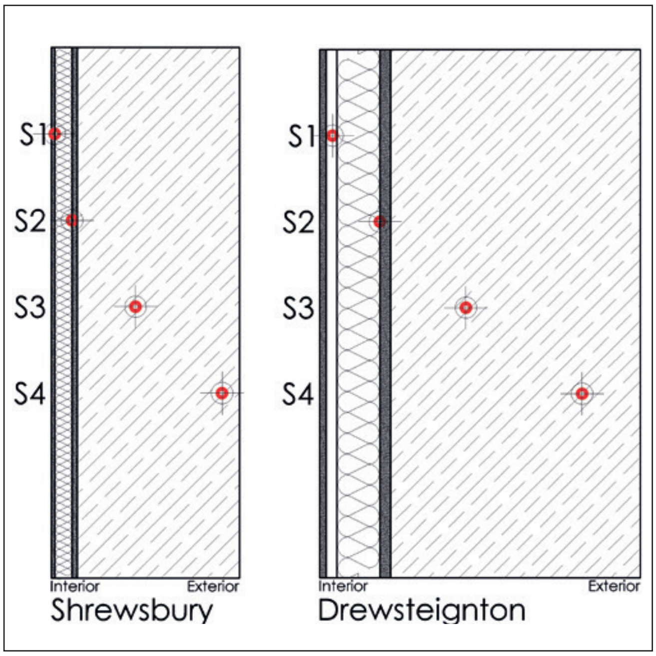


Figure 1 Wall sections showing build-ups and locations of sensors for walls at Shrewsbury and Drewsteignton

Monitoring equipment installed on the internally insulated granite wall at Drewsteignton

air is used to provide an indication of the moisture performance of the wall.

The use of air as a proxy medium for moisture measurements has a number of advantages. As a quantity it provides an indication of dew point conditions within the wall (100% RH) and %RH is commonly used within fabric risk indices, 80 per cent being the threshold value often quoted for the formation of mould growth (see Further Information: DCLG and Altamirano-Medina). Unlike measurements of moisture made via electrical resistivity, it is unaffected by salt contamination and does not rely on assumptions regarding resistivity and moisture content, which is material-dependent and can therefore be hugely variable.

In order to identify the fundamental drivers of hygrothermal performance within the walls, as opposed to just seasonal differences when the walls may become wet as a result of local weather conditions, long-term monitoring of fabric is necessary. By 2015 it was felt that sufficient evidence had been gathered to be able to describe, with some certainty, the reasons for the different performance of the walls in the BPS.

Of the two internally insulated solid walls featured in this study, the first was a 345mm brick wall at Shrewsbury which was insulated with 40mm of woodfibre board and finished with 20mm of lime plaster. This wall does not incorporate any formal vapour control layer (VCL). The addition of a VCL is standard practice when adding internal insulation to solid walls to limit the movement of internal room vapour into the wall where cold fabric beyond the insulation might cause vapour to condense, but the practice has been called into question by conservation specialists where traditional solid walls are concerned.

The other example chosen for the study was a 600mm granite wall at Drewsteignton in Devon. This wall had been internally insulated with 100mm of polyisocyanurate (PIR) board and, following manufacturers guidelines, an air gap, plasterboard and gypsum skim finish. In this construction the insulation is bound front and back with a metallised foil sheet which, being impermeable, performs the function of a VCL.

Findings from the interstitial hygrothermal monitoring are examined across a number of bases. Vapour behaviour is examined as both relative and absolute humidity as well as in the form of dew point gradients which extend through the wall section. Dew point gradients are compared against the actual temperature gradients measured through the wall, the difference between the two being the drop in temperature required to create saturation conditions. This difference, which is described as the 'saturation margin' and is measured in °C, provides another indicator of risk for the wall in terms of how close the air is to saturation, for what duration and at which times of year.

In 2012, following insulation, the saturation margins measured in both walls narrowed, something that might be expected for internally insulated walls as temperatures reduce on the cold side of the insulation. However, it is long-term trends that are most of interest and here we see a difference between the walls. Saturation margins continue to narrow year on year in the granite wall at Drewsteignton, indicating a wall moving closer to permanent saturation of the air within parts of its structure. The other internally insulated wall, at Shrewsbury, appears more stable with wider margins and little year on year change in these following insulation.

Another way to examine moisture behaviour in the walls is to study their RH profiles. In particular, RH behaviour in the central part of the

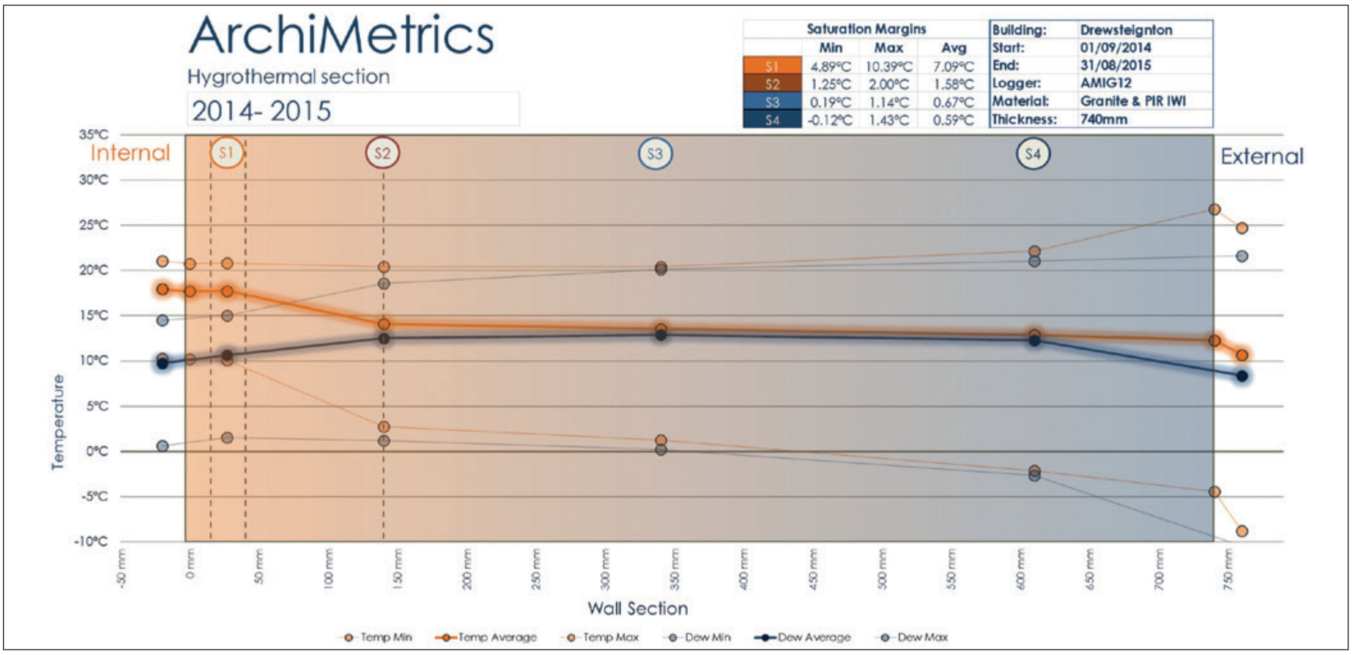


Figure 2 Hygrothermal section showing temperature and dew point gradients for the wall at Drewsteignton

walls, at sensors 2 and 3, is indicative of its underlying performance because this part of the wall is less influenced by both the wetting and drying influences of external and internal environments.

In Figure 3 it can be seen that since 2012 measurements of RH at sensors 2 and 3 within the wall at Drewsteignton rise immediately following the application of insulation and continue to rise over three years of measurements. There are periods of rising RH seen in the traces from sensors in the Shrewsbury wall but these are also seen to fall at certain times of the year indicating periods when the air in the wall is able to dry via evaporation. Importantly, at Shrewsbury, there are also times when RH quantities fall below those initially measured immediately after the wall was insulated, something not seen at Drewsteignton.

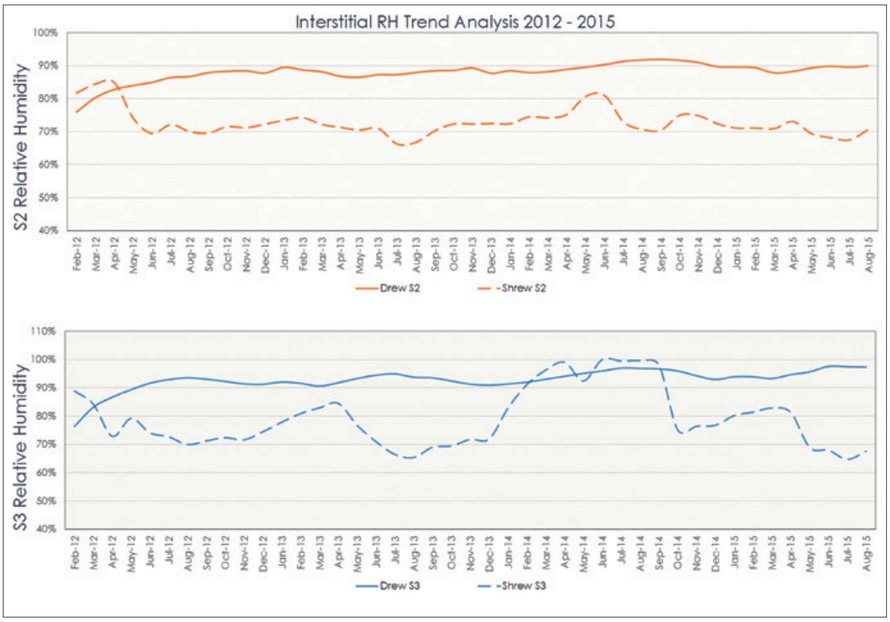


Figure 3 RH trends for the walls at Drewsteignton (solid) and Shrewsbury (dotted), 2011-2015

In terms of risk, the quantities of RH measured at Drewsteignton exceed 80% from March 2012 onwards and would suggest that the wall, or perhaps more accurately certain materials such as timbers which are embedded in the wall, may be at risk of mould growth. The majority of the measurements for the wall at Shrewsbury fall below 80%.

The reasons for the differences in moisture behaviour between the two walls originate in their very different constructions. It is possible, however, to extrapolate from this certain qualities that determine moisture behaviour and apply this learning to solid walls more generally.

The wall at Shrewsbury is south-facing and, compared to that at Drewsteignton, quite thin. The pointing is in poor condition and the brick is quite porous and permeable. It has also been insulated with a relatively small quantity of a vapour-open, capillary-active and hygroscopic material with no formal VCL. Of the walls under study, it is the driest in terms of both relative and absolute humidity (%RH and AH g/m³) and it has the widest saturation margins. Vapour responses in this wall are very dynamic and at times quite extreme. This is due to the nature and orientation of the construction. The external side of the wall quickly becomes wet during periods of driving rain and this moisture can easily penetrate towards the centre of the wall. However, the wall also dries out rapidly due to heat from direct (and diffuse) solar radiation and plentiful air exchange through the substrate.

It is noticeable that, despite this volatility, overall the wall operates below the 80% RH threshold for mould growth. It is also possible that the quantity of insulation installed (40mm), which reduced the measured in situ U-value from 1.48 W/m²K to 0.48 W/m²K, ensures that while the passage of heat through the wall is reduced, sufficient heat still travels from interior to exterior during colder winter periods to provide a safe margin between the measured air temperature and the dew point temperature. It is important to note that

Monitoring a south-facing brick wall at Shrewsbury

these U-values have been measured rather than derived from the standard calculating method, which has been shown to have limitations when used to estimate heat loss for solid walls (see Further Information: Baker and BRE).

The wall at Drewsteignton is quite different, being a north-west-facing, 600mm thick granite construction. In this wall we find higher moisture levels (in terms of both %RH and AH g/m^3) and narrower saturation margins. We also find, over the past three years, a trend of rising RH in the centre of the wall which, year on year, moves this part of the wall closer to saturation conditions. As this trend has continued over a number of years, we conclude that the high RH within the wall is not solely a response to atmospheric conditions but is also a function of certain qualities of the construction that might limit or inhibit drying.

This may be, in part, down to the heavyweight nature of the wall and its aspect, but vapour profiles have climbed since the wall was insulated and have not returned to pre-insulation levels. This suggests that the insulation itself may be having some impact on the wall's performance, although it is not clear whether this is primarily due to its thickness or its impermeability.

The wall at Drewsteignton has been insulated with a greater quantity of more thermally resistive insulation and this reduced the measured in situ U-value from 1.20 W/m2K to 0.16 W/m2K. This ensures that less heat passes into the cold side of the masonry during the winter period, thus saturation margins are lower and air is more likely to become saturated and remain saturated for longer periods, limiting the wall's ability to dry. Furthermore, the foil-facing of the PIR board acts as a barrier to the movement of moisture from the core of the wall, which can no longer access the potential evaporative surface of the interior wall face.

In conclusion, we find that the performance of these walls is in part conditioned by their individual material components, including changes made to the fabric to improve energy efficiency. Interstitial condensation has been a particular concern, yet the internally insulated brick wall at Shrewsbury, which uses a limited quantity of insulation and does not incorporate a VCL, has stable vapour responses that operate within safe limits. In contrast, at Drewsteignton, where insulation has reduced the U-value of the wall to a fraction of its previous heat loss and a VCL limits the movement of vapour towards the internal side of the wall, vapour conditions are deteriorating.

The measurements from the BPS tell us that, rather than internally generated moisture, the influence of the external environment in combination with the individual circumstances of the walls – their materials, aspect and condition – has the greatest impact on their moisture performance. These walls are solid, there is no capillary break in the form of a cavity or damp-proof course to prevent moisture, particularly wind-driven rain, penetrating deep into the core of the wall.

Many solid walls are thick, built with heavyweight materials and they can be shaded and/or sheltered. This means that the ability of heat and air movement to dry these walls may be limited. While this may not, prior to insulation, create a moisture problem in the wall, the method by which a wall is retrofitted must take into account all the factors which might impinge upon its performance.

The decision as to what type and what thickness of wall insulation might be suitable for a solid wall cannot be answered by looking at heat loss reduction alone. Those charged with improving the energy profiles of these buildings must view the building as a whole, looking at how it may perform in its specific context including individual wall aspects and what the effect of its constituent materials, condition and finishes may be.

The wall at Drewsteignton shows that the use of a relatively large quantity of higher performing close-cell insulation, incorporating an impermeable VCL, can result in a risky vapour profile. This is not to say that the application of similar material to the internal wall at Shrewsbury would have produced the same results. Indeed, at this location the wall's performance may have been more satisfactory as this wall is able to dry more readily. However, the BPS shows how complex and multifactorial the hygrothermal performance of walls can be. It is an interplay between materials, condition and context, and the exact effect of all these upon the long-term performance of the building may remain unknown or difficult to predict.

Given this uncertainty, we need to acknowledge the limits of our understanding and adopt a precautionary principle. This would ensure that elements are not deprived of all internally generated heat by excessive amounts of internal insulation because it may be that it is the contribution of this heat, in combination with external solar radiation, that allows the wall to moderate its moisture load over time. In addition, materials that are vapour-open and capillary-active and thus have some ability to move moisture through the structure to surfaces from which it can evaporate are also more likely to be a safer option for the insulation of a solid wall.

This study demonstrates that it is possible to make positive changes to the energy efficiency of solid walls through the application of insulation but that an approach that favours limited improvements to heat loss and materials that promote moisture movement may introduce less risk than alternative strategies.

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CAROLINE RYE and **CAMERON SCOTT** founded the research company ArchiMetrics Ltd in 2011, with the aim of increasing the understanding of building performance via the measurement of real buildings. ArchiMetrics carries out research using bespoke methods of measurement and analysis to ensure an integrated and thorough approach, and the partnership specialises in older or non-standard buildings throughout the UK.

INDOOR AIR QUALITY AND VENTILATION

in traditional building retrofit

NICHOLAS HEATH

WHEN PEOPLE think of retrofit, the first thing that springs to mind is often insulation. This is perhaps unsurprising, given the increasing and logical preference for a fabric-first approach to improving energy efficiency. However, for a retrofit to be thorough and low risk in the long term, insulation is just one part of the equation. To maintain the health of both buildings and occupants, insulation must be part of a wider, whole-building approach that also considers indoor air quality and ventilation, among other things.

Much has been written about the energy efficiency of traditional buildings and construction materials. Rather than focussing purely on thermal performance, this article is concerned with the movement of air and moisture both in and around building fabric. This issue can be split into two broad areas: first, the moisture characteristics of the fabric elements themselves; and second, the junctions and spaces between the various building fabric elements.

Solid brick walls, bay windows and tiled roofs in a typical Edwardian terrace. Venting top and bottom, the original vertical sliding sashes (right) offer controlled and highly efficient air circulation when retrofitted with draught seals.

BUILDING FABRIC AND MOISTURE

Many traditional building materials allow some degree of moisture movement within the fabric. Different terms are used to describe this, with ‘permeability’ or ‘breathability’ being among the most common, but these do not present the full picture. ‘Moisture open’ is a more holistic term, covering the following key areas:

- vapour permeability – a material’s ability to allow water vapour to pass through it
- capillarity – a material’s ability to draw up or transfer liquid water
- hygroscopicity – a material’s ability to absorb, temporarily ‘store’ and then release water molecules from the surrounding environment as relative humidity changes (often called moisture buffering).

When adding insulation to traditional building fabric, it is essential that these characteristics are considered and compatible systems are used in order to minimise the risk of excessive moisture building up in or on materials.

Insulation and airtightness systems then need to be applied coherently to avoid similar moisture build-up issues as a result of either a) cold bridges at uninsulated areas or b) moisture building up within or on fabric.

The unintended consequences of excess moisture build-up as a result of imperfect retrofit are becoming more and more widely recognised, and these include not only cosmetic and fabric damage but also decreased air quality and its potential negative health impacts. In extreme cases, the moisture balance between ingress (rainfall on the outer face of a wall, for example) and evaporation may be tipped, so a structure becomes progressively more cold and damp, which in turn attracts more condensation until saturation occurs.

VENTILATION AND AIRTIGHTNESS

Ventilation is defined in the current Building Regulations as ‘the removal of “stale” indoor air from a building and its replacement with fresh outside air’. It is needed not only to control internal moisture levels but also to get rid of pollutants and to maintain an indoor environment that is healthy for both the occupants and the fabric.

In uninsulated older buildings ventilation is often largely uncontrolled and relies on a combination of gaps in the building fabric, window and door opening and more deliberate measures like chimneys and other vents. In many cases this ventilation can be excessive, particularly at colder and windier times of year, resulting in substantial and unnecessary heat loss. However, it is essential to maintain controlled, intended ventilation paths.

When a building is insulated, it is likely to 'behave' differently as a result. In particular, its internal conditions are likely to change. Relative humidity may be more prone to increases, for example, particularly where occupants are unaware of the change in building conditions and do not adjust their ventilation or other habits accordingly. The more comprehensive the retrofit, the more likely it is that such changes will occur.

A common contributor to such changes is an increase in airtightness, often as an unintentional by-product of adding insulation which blocks up previous air leakage routes. Without adequate ventilation, moisture in the building is now less able to escape, and this can cause problems even where moisture-open insulation systems are used (although such systems should considerably ease the moisture transfer process). This is exacerbated where insulation is partial (leaving some cold surfaces) and where intended as well as unintended ventilation routes are blocked up, leading to problems such as moisture build-up in cold voids (roof spaces and cellars for example) or deterioration of air quality in the occupied spaces.

More holistic retrofit projects often deliberately target improved airtightness, with the aim of sealing up unintended ventilation routes and thereby reducing unwanted heat loss. This is a sensible strategy, but must include consequential measures such as additional controlled ventilation to ensure that indoor air quality remains good.

Deliberately making a building more airtight and then having to add more ventilation may seem like a paradox, but the key issue here is one of controllability. Uncontrolled ventilation can cause excessive heat loss, uncomfortable draughts and locally poor air quality; controlled ventilation keeps indoor air quality good while minimising heat loss and increasing comfort levels.

Shutters on the ground floor of a Georgian terrace in Spitalfields, London: commonly used on the continent to keep interiors shaded and ventilated during the day, here the focus was on privacy and security.

TABLE 1 Air permeability ratings for existing homes

Band	Air permeability (m^3/hr/m^2@50Pa)	Described condition
A	Less than 3	Very airtight
B	Between 3 and 5	Fairly airtight
C	Between 5 and 10	Acceptably airtight
D	Between 10 and 20	Not airtight – a leaky building
E	Above 20	Very leaky

(Source: *A Bristolian's Guide to Solid Wall Insulation*, see Further Information)

A COHERENT APPROACH

The aim, then, is to:

- reduce heat loss via insulation and airtightness
- retain a moisture balance in the building fabric via a coherent, thorough application of appropriate systems and through additional intentional ventilation where necessary
- retain good indoor air quality via an adequate, fool-proof ventilation strategy.

A successful retrofit considers insulation, airtightness and ventilation as integrated parts of a whole-building approach.

ASSESSING VENTILATION NEEDS

If considering a retrofit project on an older building, particularly a deep retrofit that aims to insulate all parts of the building and increase its airtightness, it is essential to consider the ventilation requirements at the outset. Perhaps the best piece of advice is to seek the services of a reputable, independent ventilation expert with experience of retrofitting traditional buildings and an understanding of the issues covered in this publication.

As part of the assessment process, it is helpful to establish current airtightness levels and ventilation provision in the building, as well as any residual moisture or likely future moisture load. Informal initial checks should include intended ventilation routes (such as gaps below doors, wall and window vents, chimneys, extractor fans, roof and sub-floor vents) and unintended ventilation routes (such as structural cracks, poorly-fitting windows and doors, gaps between floorboards and at floor perimeters), and can be simply and effectively informed by occupant experience. For a more formal measurement, airtightness may be measured by a fan pressurisation test, a fairly simple measurement of the building's air permeability (AP, measured in m^3/hr/m^2@50Pa).

It is then necessary to identify the airtightness level being targeted by the retrofit project. This is also commonly measured in terms of AP. For context, current Building Regulations require new-build homes to achieve an AP of 5, while the default assumption for an older home is likely to be much worse. The table above provides an example of different ratings and what they mean. (N.B. This table is taken from the recent retrofit publication *A Bristolian's Guide to Wall Insulation*, which provides detailed guidance on many of the principles outlined in this article.)

Identifying the baseline performance will help identify air leakage routes that should be targeted for improvement and intended ventilation paths that must be maintained, while identifying the target AP will help inform the amount and type of ventilation provision likely to be needed.

Once a retrofit project starts, repeat fan pressurisation tests can be very helpful, both during the retrofit (to check that planned airtightness works have been effective) and afterwards (to identify the actual airtightness of the retrofitted building).

As well as understanding baseline and post-retrofit airtightness and ventilation performance, there are a number of other issues which require consideration at the planning stage to ensure that a healthy indoor environment is maintained:

- **Moisture buffering** – the use of a fully moisture-open insulation system will support the performance of the ventilation system, providing a greater 'buffer' for moisture management when needed.
- **Airtightness method** – as well as coherent design, the manner in which airtightness is to be achieved merits consideration. The more complex the system (a moisture-closed insulation system, for example, or one that relies on extensive use of tapes and/or

membranes) the greater the potential for application errors or future failure, in contrast to a simpler system (a wet lime plaster finish and/or backing coat for a wood-fibre insulation system, for example) which could be more robust in the longer term.

- **End-use and end-users** – how is the building going to be used post-retrofit and who will be using it? How engaged are they? What, if any, behavioural changes may be needed? Are they tech-savvy or would a simple, passive ventilation system suit them better? All these questions need to be answered to inform the design of a suitable ventilation strategy.

Considering all these aspects before embarking on building work is more likely to result in a successful retrofit.

VENTILATION OPTIONS

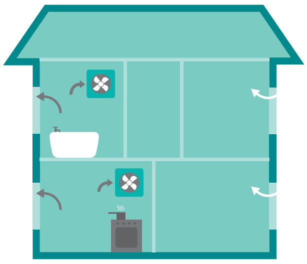
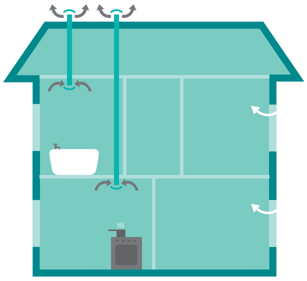
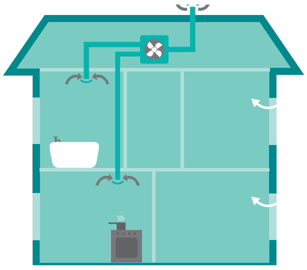
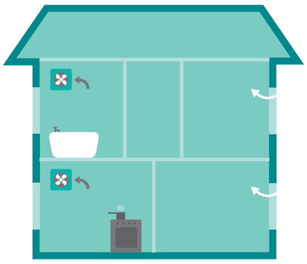
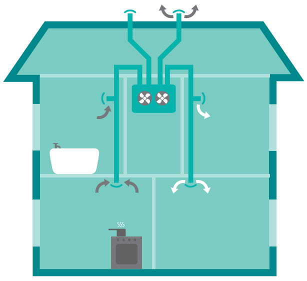
Once a thorough assessment of insulation, airtightness and ventilation has been made, an appropriate ventilation system needs to be identified. There are many different types of ventilation system, all with different pros and cons (see Table 2). Broadly these divide into passive and mechanical systems. Passive ventilation systems work on the basis that warm air rises and avoids the need for extractor fans. Ducts rise through the building to the roof, extracting moist air from bathrooms and kitchens. The extracted air is replaced by air drawn in from outside through adjacent rooms, so the whole house is naturally ventilated. These systems rely on changing air pressures and particularly on wind movement over roof vents, so the design of the system must be carefully considered and they are not always suitable or feasible.

The simplest mechanical ventilation systems use the same system of air displacement but use fans to extract moist air from those rooms with the highest moisture level. These may be intermittent (a simple extractor fan in a bathroom for example, activated by a humidistat) or constantly operating at a low speed (a 'decentralised mechanical extract ventilation system' or DMEV). More complex systems have centralised fans and can be either continuous or demand controlled. In theory this makes the systems more reliable and the fans can be less noisy as they are located in loft spaces or cupboards.

Mechanical ventilation and heat-recovery (MVHR) systems are the most complex mechanical systems, having a heat exchanger and two sets of ducts, one to extract moist air and the other to supply fresh air back to the adjacent rooms, preheated using the heat from the waste air. MVHR systems are generally best suited to comprehensive retrofits where a high level of airtightness is achieved.

The type of system suitable for a building depends largely on its post-retrofit airtightness and on the configuration of the building in question – not all older buildings can accommodate the ducting or fan units required for some ventilation systems. Other factors such as complexity and occupant type must also be considered, as they can be key determinants of success.

TABLE 2 A simple overview of each of the principal ventilation options, and their main pros and cons

INTERMITTENT EXTRACT (suitable band B–E)		
Pros	**Cons**	
▪ low cost ▪ easy to install ▪ easy to use	▪ fan noise ▪ user can choose not to use	
PASSIVE STACK VENTILATION (suitable band B–C)		
Pros	**Cons**	
▪ low cost ▪ easy to install (in top-floor wet rooms) ▪ silent ▪ continuous	▪ hard to accommodate vertical ducting (in ground-floor wet rooms) ▪ summer ventilation may be insufficient	
CENTRALISED MECHANICAL EXTRACT (suitable band A–C)		
Pros	**Cons**	
▪ medium cost ▪ potentially easy to install ▪ easy to use ▪ continuous ▪ maintains background ventilation	▪ requires ducting, which may be hard to accommodate ▪ uses electricity ▪ potential fan noise	
DECENTRALISED MECHANICAL EXTRACT (suitable band A–C)		
Pros	**Cons**	
▪ low cost ▪ easy to install ▪ easy to use ▪ continuous ▪ maintains background ventilation ▪ less ducting than centralised system	▪ uses electricity ▪ room-side fan: increased potential for fan noise	
WHOLE-HOUSE MECHANICAL HEAT RECOVERY (suitable band A–B)		
Pros	**Cons**	
▪ air quality: intake air is filtered ▪ comfort: air movement and exchange throughout home ▪ efficiency: heat recovery reduces heat demand and tempers incoming air	▪ most expensive system ▪ requires ducting to most rooms ▪ uses electricity ▪ potential fan noise ▪ correct commissioning can be complex	

The suitable band information refers to Table 1 (Source: *A Bristolian's Guide to Solid Wall Insulation*).

Condensation on a window pane is often a good indicator of inadequate ventilation.

A 1930s copper cupola providing passive stack ventilation on a former school building in Bath

UNHEATED AREAS

It is important that ventilation requirements are also assessed and addressed for unheated areas of a building such as roof and sub-floor spaces. Where insulation or airtightness are improved in a home, this can make unheated areas colder and less well ventilated, particularly if measures are applied incorrectly (sub-floor vents being blocked by insulation, for example, or loft hatches being left uninsulated).

For unused roof spaces, adding significant levels of ceiling-level insulation will make the roof space colder, increasing the likelihood of condensation and associated problems, and increasing the risk of water tanks and pipework freezing unless these are also adequately insulated. Moisture-related problems are exacerbated where gaps in the insulation and airtightness layer (such as loft hatches or spotlight openings) allow warm, moisture-laden air to enter the roof space, and where insulation blocks existing vents. While such problems may be minimised by good practice and attention to detail, additional ventilation may be needed in any case, typically in the form of eaves, ridge or slate vents, for example.

It should also be borne in mind that in the UK's temperate climate, external ventilation often admits warm moisture-laden air. As warm air can carry more moisture than cool air, condensation may occur in a void cooled by high levels of insulation. So, increasing ventilation levels can bring its own issues, and uncontrolled ventilation may simply add to the problem. Ventilation paths must be carefully thought through to ensure that the overall strategy is effective and appropriate, and avoids stagnant pockets of air.

Ventilation in sub-floor spaces can already be compromised by the build-up of debris in the floor void and/or in and around vents, which again presents risks of condensation and associated issues. Any such blockages should be removed as part of a retrofit project, and care must be taken to avoid blocking up ventilation routes with insulation, and to increase ventilation provision if necessary.

Where the building is in an area with high levels of radon, strategies for ventilation (both sub-floor and for the main building), airtightness and insulation will require particular consideration.

SAFEGUARDING PERFORMANCE

'Despite all efforts made in its provision, ventilation is still one of the most difficult aspects to safeguard in use.' (*Designing Out Unintended Consequences*, see Further Information)

Once a ventilation system has been chosen, the key question is: how can its operation and performance be maintained in the long term? Or, more simply, how much risk can be designed out? This is a vital question, and covers the following considerations:

- Design – is the designer experienced in traditional building retrofit and do they understand the systems under consideration?
- Installation and commissioning (particularly for higher-end ventilation systems) – is a specialist installer being used, or at the very least is the installer familiar with the selected system? Leading on from this, will the system be commissioned by an expert?
- Control and use – are the end-users engaged? How simple can the system and its controls be made? How foolproof is the system? How will users know if it fails? Are the maintenance needs clear? What are the consequences of failure?
- Supplementing ventilation provision (leading on from the previous question) – is supplementary ventilation available (use of windows, for example) in case of system failure?

To maximise chances of success, insulation must be considered alongside airtightness and ventilation, following a whole-building approach to retrofit. Worst-case scenarios must be anticipated and risk designed out accordingly – this will often lead to simpler, more foolproof solutions rather than overly-complicated designs. The building must be considered in the context of its users and their behaviours. Experienced designers, installers and commissioners must be used, and occupants must be involved from the outset and be made fully aware of any behavioural impacts and maintenance needs in the future.

At the heart of all this lies understanding: 'Regardless of your reasons for retrofitting, the key to success is understanding. Understand your home, your lifestyle, your environment, your priorities, the upgrade measures available, the importance of careful planning and detailing, and the whole-house approach and joined-up process.' (*A Bristolian's Guide to Solid Wall Insulation*)

Further Information

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HOME AND DRY

Developing a non-hydraulic setting air lime for the insulation and repair of traditional buildings

HARRY CURSHAM

ALMOST ONE in four buildings in the UK are traditionally constructed using lime rather than cement. If well maintained, solid walls of brick or stone set in a lime mortar work well, drying rapidly after a rain shower so damp never penetrates far into the wall. Condensation inside the building also dries quickly, so the walls act as a buffer for both humidity and heat, moderating extremes in the building.

By the end of the first world war lime technology had largely been abandoned in favour of faster-setting mortars. It was only in the late 20th century that conservationists began to realise that these cementitious mortars were actually damaging traditionally constructed buildings. Traditional mortars were softer and tolerated the natural expansion and contraction of solid masonry without failing. And they were highly permeable. It was discovered that problems occurred when old masonry was repointed, as this introduced just a thin layer of hard cement at the surface alone. As the core remained flexible, even modest thermal movement could cause the surface to spall, as pressure is exerted across the face of the wall. Being relatively impermeable, cement also prevented the mortar from wicking moisture to the surface. In particular, the cement renders used tended to trap moisture, and if cracked, more moisture is drawn in by capillarity, making the walls cold and damp.

Over the course of 60 years or so prior to the lime revival, traditional methods of making and using mortars were forgotten. Text book descriptions were often ambiguous, and a new generation of conservators had to rely on trial and error and on the analysis of old mortars. Today, new discoveries are still being made.

For the retrofit sector these developments are important because damp walls are known to leak up to 30 per cent more heat than dry walls, and in some cases the actual figure can be far higher. Simply by getting all our traditionally constructed buildings up to a sound condition would help reduce the UK's carbon emissions substantially.


A traditional roughcast lime render on a solid masonry wall

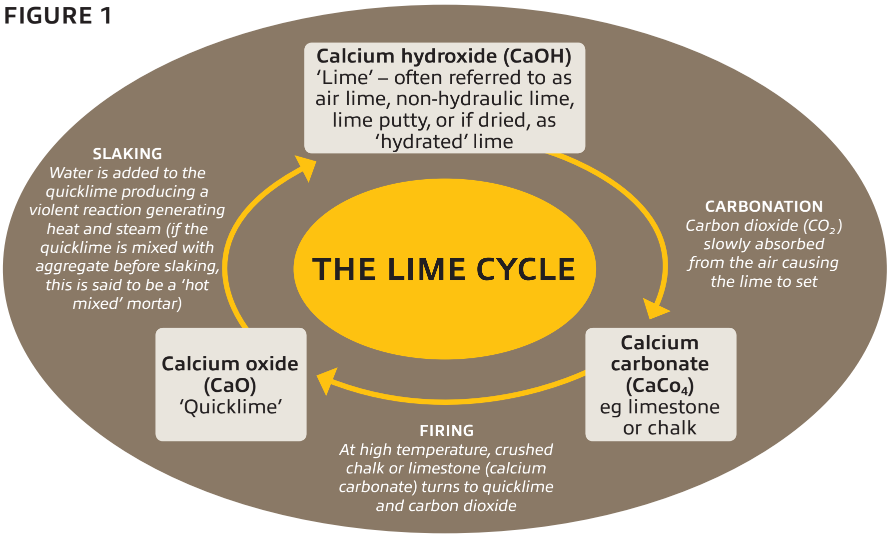
The types of lime used generally fall into two categories: non-hydraulic or 'air' limes which set very slowly by a chemical reaction with carbon dioxide alone; and hydraulic limes which stiffen more quickly due to a partial crystallisation set. One area of great interest is in the development of non-hydraulic hot-mixed mortars, because they seem to be producing mortars which are much closer in nature to those found historically and there is a growing consensus that these mortars can provide the best performance in use.

While their slow set means that air limes require more care and skill in use, they tend to be more permeable, and some hydraulic limes have been shown to become almost as hard and as impermeable as cementitious mortars when aged. Mortars made with air limes also offer lower conductivity and are therefore a good insulant, all of which make these mortars ideally suitable for older solid wall buildings. These properties are also significantly enhanced when used with appropriate aggregates, and the final result is akin to most pre-industrial mortars found in the UK and on the continent.

This article looks at one proprietary product which has recently been developed. Although a form of non-hydraulic calcium hydroxide, it is supplied as a dry powder and when water is added the mix stiffens to provide a preliminary set without any addition of setting agent or pozzolan. The set is referred to by its manufacturer as a 'Vivus' set, which results from the way that the quicklime is manufactured and slaked. There are no clay impurities in the limestone used to make it, and none are added, so in essence it remains a pure air-lime and within the normal 'lime cycle'. Carbonation is a secondary setting process in that it is unnecessary for construction work to proceed, but adds strength in the long term. Like a hydraulic lime, it will continue to carbonate over the following months and years, depending on the depth of material. In the process carbon dioxide is absorbed from the air, completing the lime cycle (see Figure 1).

This non-hydraulic setting mortar is able to perform in the application stage

FIGURE 1



One of the pre-production insulation panels tested, 62mm (2½") thick

as effectively as hydraulic lime but then delivers the flexibility that is essential for the conservation and repair of old buildings. In one experiment, a piece of carpet was skimmed with a plaster made from this lime and allowed to set. It did so overnight. It was possible to dent the plaster with a thumb without cracking it and even to bend the piece of carpet without damaging the plaster. The remaining mix from the experiment was left in a tub. This same batch is now a hard lump and the carpet plaster is still intact – 2½ years of poking and prodding, later.

DEVELOPING A LIME-BASED INSULATION PRODUCT

In 2014 development of an insulation system based on a non-hydraulic setting mortar was awarded funding under a Small Business Research Initiative (SBRI) established by The City of Cardiff Council, Cadw, Innovate UK (formerly Technology Strategy Board) and Low Carbon Trust with principal funding from the Welsh Government. The aim of the scheme was to assist the development of 'innovative measures that will improve the energy performance of traditional and historic buildings'.

The first step was to prepare sample insulation panels (left) with a thickness of 62mm (2½"). These contained Vivus lime, mineralised wood chips and various permeable aggregates selected to ensure a very high degree of vapour transfer, ideally suited to traditional solid wall construction. Independent testing confirmed thermal conductivity of 0.1 W/mK in the least efficient sample of Vivus render, in order to establish a base-line, compared to 0.5 W/mK typically found in conventional sand/cement renders. (Thermal conductivity is measured in watts per square metre of surface area for a temperature gradient of one kelvin for every metre thickness – W/mK.) The tester also confirmed that in his view even better results could be expected if different aggregate materials and thicknesses were used.

Currently the insulation systems in common use are all impermeable and are not readily compatible with older building walls. The research confirmed that a suitable insulation panel would be a useful tool in the retrofit armoury.

Testing and experimentation is on-going to determine exactly how thick the panel or how deep the insulation needs to be, to provide adequate insulation and to buffer humidity, but without being too deep to apply to older walls with existing architectural features. Findings are expected during the course of 2017.

Other materials such as plasters and renders were also developed using the same quick setting non-hydraulic lime and a similar range of aggregates. During workshop trials these were shown to be successful in their ability to set and, once dry, in their ability to absorb and readily release humidity. Conventional lime sand mortars tend to have a much higher degree of capillarity due to the impervious nature of the mineral aggregate, drawing moisture in and retaining it for longer, off-setting some of the benefits of the lime. The advantage of a premixed product using carefully selected aggregates is that the resulting render, plaster or insulation panel is able to work in a diffusive manner, without capillarity.

The plasters and renders also work in conjunction with the insulation material to create a holistic approach to insulating and finishing historic buildings. The materials are all compatible with those found in older buildings. The panels are best fitted to either internal or external faces of exterior walls by being solid bedded onto the surface using the non-hydraulic setting lime mortar. The reasoning is that the panel will then become an integral part of the wall, thus ensuring the original design is maintained, promoting seamless humidity extraction through the structure. This simple approach contrasts with many modern retrofit solutions which include air-gaps, capillarity and impervious layers.

MANUFACTURING AND TESTING

Following successful completion of the insulation tests, the product was approved for a second phase of SBRI funding. £142,000 was awarded for developing commercial production, for developing variations in the setting time, and for demonstrating the products in a 'whole house project'.

The facilities of a manufacturing company in Derbyshire were used to test production of the material in normal commercial mixing and blending apparatus, and to benchmark a manufacturing process and ability.

Due to the high temperature of the chemical reaction (approaching 200°C during slaking), it very quickly became obvious that specialist machinery would need to be developed in order to manufacture the binders if they were to ever reach the market. Nevertheless, enough materials were produced for demonstrating the product. The first successful prototype machine is now in operation, with basic materials being produced in autumn 2016.

The house chosen for the 'whole house' demonstration was Mill Cottage, in Pontcanna, Cardiff, which was saturated and rotting before the works began. The house is of 18th-century origin with 19th-century rebuilds. As with many

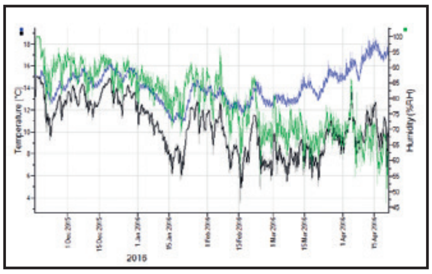
Mill Cottage on completion of repointing and lime-washing using Vivus materials

Fireplace and window details, with insulated walls, plastered and finished

FIGURE 2: Humidity readings – June 2015

AREA	POSITION	HUMIDITY(%RH)	
		Ground floor	First floor
Internal west wall	Low level	96.35%	88.50%
	High level	88.99%	88.50%
Internal north wall	Low level	94.89%	79.50%
	High level	78.56%	79.50%
Internal east wall	Low level	93.02%	89.99%
	High level	89.90%	89.55%
Internal south wall	Low level	89.95%	88.70%
	High level	87.05%	88.70%

FIGURE 3



Sample data recorded following the work at Mill Cottage showing a marked fall in dewpoint (black) and relative humidity (green) from December 2015 to April 2016, while temperatures (blue) rose. During this period the house was uninhabited and the weather in this exposed location was particularly cold and wet.

such vernacular and humble houses, some terrible 20th-century replastering, painting, patch rebuilds and hard cement pointing had been carried out. There were even areas of glistening moisture on interior wall surfaces and large areas were black with mould. Also, the ground floor skirting boards had rotted through. At this point, some basic humidity readings were taken in June 2015 (Figure 2).

The work began with internal faces of the exterior walls being stripped of their coatings and then relined with insulating and humidity-buffering mineralised woodchip panels created especially for the project, and then plaster finished with a Vivus plaster skim.

Outside, the walls were depointed of cement and repointed with Vivus mortar and lime-washed.

It was clearly demonstrated that the material can be applied quickly. Pure lime skims were applied and finished in the same day. The skims contained no aggregate of any kind nor any other additive – they were pure air lime. In some rooms, purely for the experiment, panels were fitted to the walls and then skimmed and finished on the same day without issue.

The north- and south-facing external walls were also finished in the same timescale, repointing and initial coat of limewash completed on day one and subsequent coats applied on day two, completing the work, front and back – sunshine with wind (south front) and cold damp shade (north rear). The two walls were completed in the same manner, clearly demonstrating the setting property of the materials used.

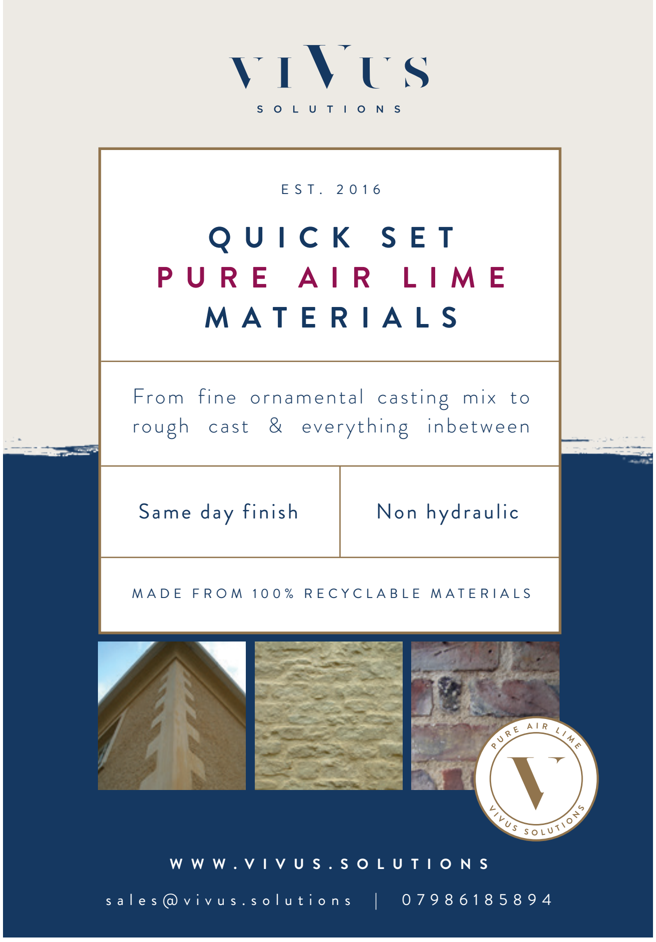
Inside, the walls were paper lined and then decorated with a modern 'fully breathable' soft paint. Although this will not affect the insulation per se, it will undoubtedly reduce the ability of the walls to absorb humidity. However, many owners and tenants will expect to be able to use these finishes, so this was added as part of the experiment. It is expected that the house will remain humidity free, even with the walls lined with paper.

A key element of the demonstration lay in showing the effect of humidity, contained within a structure, on the insulation performance. This moisture can reduce the effectiveness of any insulation by up to 30 per cent depending on the levels. Successfully dry out a building and maintain that humidity, then it will be warmer. Take an insulation that buffers humidity while also helping to equalise the humidity by being diffusive, and apply it to a wall that because of its manner of construction, acts in the same way, then we will have achieved many things simultaneously.

The insulation and humidity control abilities are now being monitored with sensors installed at the property. The data taken thus far has shown a very beneficial effect. The average humidity levels recorded in the building had dropped 24 per cent from June 2015 to April 2016, and it is estimated that the energy efficiency of the walls has increased by more than 30 per cent. Empirically, the house is now warm and dry, even though the building was not inhabited all winter following the works. The temperature remains fairly constant, feeling cool on hot summer days and warm and dry on damp cold days.

The monitoring will continue for another two years to show the long term effect over winters and summers with the building being regularly used and inhabited. Feedback from the occupants will also be sought.

HARRY CURSHAM (harry@vivus.solutions) has spent the past 27 years working with, experimenting with and learning about air lime materials. He is a director of Vivus Solutions Ltd (see page 34). The full Welsh Government SBRI report is available from the author on request.



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INSULATION IN TIMBER-FRAMED BUILDINGS

ROBERT DEMAUS

THERMALLY, TIMBER-FRAMED walls generally perform badly compared with other traditional construction, and struggle to meet modern expectations. This article addresses the problems and risks associated with retrofitting insulation to upgrade their thermal performance. It focusses on cases where the timbers are exposed externally, which are usually the most problematic, but also considers timber frames which are concealed behind cladding (either of the same period or later).

There are circumstances in which retrofitting insulation to a timber-framed wall is acceptable and beneficial, but other measures might prove more cost-effective and less damaging. To determine the best way forward, survey and analysis should be carried out by an independent consultant rather than by a materials supplier or contractor. As well as comfort, cost-saving and environmental gain, many other factors must also be considered, including:

- The historic significance of the building as a whole, as well as the relative significance of individual elements, and the degree to which retrofitted insulation will alter it
- The condition of the building fabric and the nature and extent of any interventions (other than thermal insulation) that might be necessary
- The causes of any existing degradation and how these might best be remedied
- The current hygrothermal performance of the timber-framed walls and the building as a whole
- The 'landscape value' of the building and the potential impact of any change to its external appearance
- The performance of heating and hot water systems and the cost benefit of upgrading
- The condition and efficiency of existing insulation, for example in roof spaces and floors, and the cost benefit of upgrading
- The potential for introducing cost-effective and reversible new elements such as secondary glazing that do not involve significant harm to historic fabric
- The building's current use and the occupants' expectations.

The absolute and relative importance of these and other factors will vary greatly, not just between buildings, but between areas of the same building.


The large original verge overhangs of this historic timber-framed house protect the wall below, while an angled 'pentice' board above the ground floor window sheds water away from the wall below. (All photos: Robert Demaus)

The thermal performance of a timber-framed wall is not only controlled by its component materials. Condition, orientation and exposure will have a far greater effect on a 100mm thick timber-framed wall than on a 225–350mm brick wall. Moisture retention within the wall is also critical to its thermal performance.

This timber-framed house has retained its original eaves and verges, both beautiful and practical. The house must always have been tiled.

The depth of thatch shelters the wall below. If the thatch were replaced with tile or slate (as so much was) the wall becomes very vulnerable.

Timber frames are full of joints and cracks through which air (and water) can penetrate. The most effective improvement that can be made to the overall hygrothermal performance is to fill these gaps. A sensitive thermographic camera is the best way of locating them, provided there is a reasonable temperature difference (5–10°C) between the inside and outside, and preferably when the wind is blowing. It is as important to survey the outside of the building to identify where heat is escaping, as it is internally to identify where cold air is entering. The survey should be repeated when the remedial work has been completed, but is almost meaningless unless carried out in the same weather conditions. Most timber-framed buildings are too air-porous for standard air pressure tests to be meaningful.

Optimum methods and materials for gap filling will vary depending on the size and location of the gaps, but should always be flexible and breathable: sheep's wool pushed into the gap with a thin blade and finished with haired lime plaster can be very effective. Proprietary sealants, mastics and cementitious mortars should not be used.

These rafters have been restored to their original overhang, greatly improving protection of the wall below.

There is a much greater variety of constructional materials and details in timber-framed walls than might be found in brick or stone walls, with correspondingly complex, variable and unpredictable physical properties and interactions. Moreover, the original wide palette of materials is often further complicated by subsequent alterations and additions, such as changes from wattle and daub to brick infill, from lime to cement render and from permeable to impermeable finishes. Many of these variations can occur within a single elevation. By comparison, brick and stone walls are relatively homogeneous and predictable. As a result, desktop heat-loss calculations using standard formulae and computer modelling are less reliable where walls are timber-framed. On-site detailed physical investigation is required. Sensitive infrared thermographic cameras may be used to locate concealed timbers, identify the make-up of infill panels and assess heat loss and damp penetration. Decay-detecting micro-drills are also very useful for these investigations.

For such assessments to be of value, the assessor must have a good working knowledge of how the building was constructed, what changes might have occurred since, and the causes and extent of any degradation.

Typically, timber-framed buildings were built using freshly felled timber that shrank and moved significantly, particularly over the first 30 years. The timbers were usually left exposed externally and internally and the spaces between the frame were filled with clay-based daub, often finished with limewash. Gaps that formed between the frame and infill as the materials settled and shrank were regularly filled and additional coats

Historically, many timber-framed buildings were rendered to improve their weather-tightness. Some of the visible render is lime-based and probably early 19th century, other sections have been replaced with a cementitious render in the 20th century.

of limewash applied. The entire fabric was therefore very breathable, allowing any moisture that entered to readily evaporate, and moisture levels in the wall generally remained below the point at which the various materials would degrade. The walls were protected by large roof overhangs and pentice boards (see title illustration), but over the following centuries, these were lost, causing the walls to be wetter more often and for longer periods. As a consequence, the wattle and daub began to degrade rapidly and the timber more slowly.

In the 18th and 19th centuries timber-frames were often concealed behind facades of weatherboard, brick, tile or lime render. Early renders were lime-based and breathable: later renders were often much less breathable, such as Parker's Roman cement which was patented in 1796.

Where frames remained exposed into the 19th century, the degraded wattle and daub was often replaced with brick, which tended to exacerbate degradation. Increasing use of cementitious renders, impermeable paints, damp-proof membranes and mastic sealants in the 20th century tended to reduce breathability and trap water, increasing degradation and heat loss.

More recently, economic and environmental pressures to improve thermal performance have become increasingly important, but often poor detailing and inappropriate materials have exacerbated decay.

In the 21st century there has been a growing understanding of the need for buildings to breathe and a consequent move to more permeable materials. The crucial point is that impermeable modern finishes and sealants not only cause significant and continuing damage to the timber frame and other historic fabric, they also greatly diminish the thermal performance of the wall.

The condition of the wall and its hygrothermal behaviour are intimately linked. Unless faults are remedied, the introduction of insulation may be of relatively little benefit and can greatly increase the risk of further deterioration. Only when the detailed survey has been completed can the advisability of retrofitting insulation be evaluated and the best method selected.

There are essentially three options for retrofitting insulation to an exposed timber-framed wall; externally, internally or within the depth of the frame.

WITHIN THE FRAME

Given that timber-framed walls are often less than 100mm thick, insulating within the depth of the frame almost inevitably involves loss of the existing infill material.

Original wattle and daub should be retained and repaired if possible, but where there is a later brick infill, its historic and aesthetic significance and its condition may affect the decision. Where there is evidence of significant degradation, a good case can be made for its replacement with a more sympathetic and better performing material. Where the timber frame requires repair that involves removal of the infill, there is an opportunity to introduce more sympathetic and better performing infill.

It is now generally accepted that infill panels should be breathable and vapour permeable throughout their thickness, but there are many theories about the best materials and techniques. Many recommended systems involve complex combinations of materials including synthetic edge seals, breather membranes and vapour barriers, stainless steel mesh, wood-wool substrates and softwood sub-frames. Systems such as these may work better in theory than in the variable conditions found on site, where quality control may be difficult, particularly when the timber frame is neither straight nor in perfect condition.

As a rule, the simpler the method and materials, the more likely they are to function predictably and reliably. There is great merit in using methods and materials as close to the original wattle and daub as possible. The theoretically poorer U-value may not be as bad in practice and the greatest reduction in heat-loss is often achieved simply by creating a dry, draught-free structure. A modern material similar in concept to daub, but with more durability and better U-value, is a hydraulic lime/hemp mix that can be cast in-situ to form a homogenous breathable infill.

If the frame and/or the panels are in poor condition and repairs would involve the loss of a high proportion of historically significant fabric, there would be a strong case for protecting the wall behind a shelter coat of lime render or other regionally appropriate material. This is usually preferable to creating a crude modern replica of the wall in band-sawn timber, and may provide the opportunity to insulate outside the wall line.

INSIDE THE WALL LINE

If the timber frame and infill are in sufficiently good condition, and are robust enough to cope with continuing exposure with limited interventions, insulation can be fitted to the inside face, either directly to the wall or with an air gap. However, this will have a serious impact on the appearance of the room, obscuring features such as window surrounds, skirtings and adjacent ceiling mouldings, and it will reduce the internal floor area. More significantly, there is an increased risk that moisture entering the wall will become trapped, even if all the materials used in the new lining (insulation, plaster and paint finish) are vapour permeable. If problems do occur, they are unlikely to become apparent until significant damage has occurred. The risk of driven rain penetration can be reduced by careful gap-stopping and the reinstatement of overhangs, but any intervention that restricts the passage of water vapour through the wall significantly increases the risk of condensation and/or water entrapment. For this reason, non-breathable rigid insulation such as PIR (polyisocyanurate) boards should not be used, even though they can achieve better U-values at relatively small thicknesses.

Wood-wool insulation boards ready for lime rendering

Insulating inside the wall line also greatly increases the risk of condensation due to cold-bridging in those areas which, for various reasons, cannot be insulated. In particular, the ends of floor beams and joists built into the external wall are at greater risk of increased degradation.

OUTSIDE THE WALL LINE

For many reasons, fitting insulation to the outside face of a timber-framed wall is often the best solution, both in terms of hygrothermal performance and building conservation.

- The wall is fully protected (assuming materials and detailing are correct)
- Necessary repairs can be kept to the minimum structurally required, and can usually take the form of additional surface-fixed straps, etc. These repairs are reversible and involve no loss of historic fabric.
- Air penetration through the wall can be fully controlled
- Insulation can be continuous with all original fabric on the warm side, reducing the risk of cold-bridging and condensation
- Keeping what thermal mass there is in the wall on the warm side also helps to balance diurnal variations
- The historic significance and appearance of the interior is not compromised
- The intervention is reversible.

External insulation will alter the external appearance: the additional thickness requires changes to window reveals and other features, and conceals the timber frame. This often meets with resistance, both professional and public. However, there is a strong historical precedent and the benefits are considerable.

Historically, render was usually applied direct to lath nailed to the frame, and it is widely held that this must offer good protection to the frame, simply because it is breathable. However, it is quite common to find widespread active Deathwatch beetle attack in timbers immediately behind lime renders, but rare to find it in exposed external timbers, suggesting that sometimes moisture content of a lime-rendered frame can be high enough to sustain fungal and beetle attack. When applying new or replacing old render, a vapour permeable membrane should be used and the lath set off the frame on counter-battens if possible.

The recent development of relatively high-performance breathable multi-layer insulation quilts, effectively insulated breather membranes, has great potential as they increase wall thickness far less than most other breathable insulation materials. Although designed for use in roofs, these quilts have been successfully used to insulate timber-framed walls behind render or weatherboard. New materials need to be used cautiously until their long-term performance is better understood, but equally, they should not be dismissed out of hand. Furthermore, imported materials that perform well in cold dry climates may not work in wetter UK conditions. Perhaps the best advice is to question everything.

In a surprising number of cases, what appears to be a timber frame is actually an agglomeration of paint, mastic and cementitious render repair concealing a severely degraded and structurally compromised frame. Sooner or later this will require such extensive repair/replacement that protection with a lime render or other cladding would almost certainly provide a more effective and conservative solution while avoiding further loss. If the appearance of a timber-framed building is deemed desirable, this can always be applied to the face of the new render – there is a long tradition of what many now consider 'fakery'. At least what remains of the frame and surrounding fabric is retained for future generations.

RELATED REPAIRS

If the timber frame is to remain exposed, the essential first step in improving the thermal performance is to ensure that the frame and surrounding fabric are in good condition, and consist of materials that allow the wall to breathe. A conflict arises where an alteration regarded as part of the building's history is demonstrably causing damage. Brick infill for example, does not always cause problems, but can significantly increase the rate of degradation of the frame, particularly when bedded in cementitious mortar, where frames are relatively light, poorly constructed or weakened by decay, or where the bricks project outside the face of the frame, creating ledges that trap water.

The use of inappropriate materials is not the only problem. The introduction of impermeable materials was usually prompted by the failure of earlier or original wattle and daub infill, which usually began to fail once the protection of big overhangs was lost. Although impermeable materials are generally damaging, if permeable materials are reintroduced without reinstating the original protection (such as overhangs), their exposure to extensive and persistent wetting will lead to fungal degradation, loss of cohesion and frost damage. Furthermore, heat loss through persistently wet daub, render or brick is much greater. Recent changes in weather patterns may also create greater problems for poorly protected buildings. It is therefore an essential element of any building upgrade (particularly for timber-framed buildings) that adequate overhangs and other protective measures are re-introduced, even where the evidence for them is inconclusive.

Another important issue is that moisture content is critical and often finely balanced. Typical ambient moisture content of timber in a well maintained building is around 16 per cent (lower if heated). This tends to rise to around 18–20 per cent in well-maintained external walls. Many fungi will germinate at around 27 per cent, but can survive down to 23–24 per cent. Deathwatch beetle thrive where there is or has been fungal activity and can survive in timber down to 16 per cent moisture content or lower. Controlling water penetration, condensation and evaporation are therefore critically important, and using the wrong materials or details might raise the moisture content by just a few per cent and risk starting or re-starting degradation. Equally, reintroducing the right materials and detailing should lower the moisture content by just a few per cent into the safe zone.

The severely degraded timber framed end wall has been strengthened and protected behind weatherboarding, with a layer of breathable multi-layer insulation included.

SUMMARY

1. The decision whether to retrofit insulation, and if so, which approach to adopt, cannot be taken in isolation. A detailed appraisal of the building, including the historic significance of the timber frame, infill panels and other features, as well as an accurate condition assessment, must be carried out.
2. Most traditional timber-framed buildings will be listed. There should be discussion at an early stage with the local conservation officer about the problems identified and proposed remedies.
3. Upgrading the hygrothermal performance of timber-framed walls by retrofitting insulation is very difficult and can rarely be achieved without significantly compromising the historic significance and/or appearance of the building. Any potential benefits in terms of cost saving, comfort and reduced carbon emissions need to be weighed against the initial cost, loss of historic fabric and potential for further degradation of historic fabric.
4. Where timber-framed walls retain a high proportion of original or historically significant fabric, retrofitting insulation should be considered a last resort and only used when other potential improvements have been explored.
5. Heat loss through the various materials that make up a relatively thin timber-framed wall is often compounded by air leakage around the edges of panels and through joints in the frame. Minimising uncontrolled air movement is critical and will often prove more effective and less damaging.
6. Alternative measures to upgrade the overall performance of the complete building should be considered. These might include reinstatement of roof overhangs and fitting of pentice boards, removal of impermeable materials and finishes, and measures to reduce wind exposure.
7. Timber-framed walls generally have low thermal mass and high uncontrolled air penetration. Heating systems that make use of large internal masonry stacks or stone floors as heat stores are often more effective than systems that heat the air via conventional radiators. Radiators should never be placed against external timber-framed walls.

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YAKISUGI CHARRED TIMBER

An ancient technique in new hands

DIANA ROWSELL

Yakisugi cladding on a house designed by Terunobu Fujimori in Utsunomiya, Tochigi Prefecture, Japan (Photo: Dana Buntrock, Flickr)

TIMBER CLADDING is a traditional feature of the historic environment, and today it is a popular finish for new developments and extensions. Although timbers such as oak and sweet chestnut might be used without any preservative, in many areas black-stained softwoods are a key element of the local vernacular due to the traditional use of coal- and pine-tar resins to preserve exterior cladding. In the southwest of Japan, however, the traditional preservative technique is wood charring, known as *Yakisugi*. A similar technique is used in the Swiss Alps where timber chalets last for generations, and charring is a well-known method of preserving wood in many countries and cultures around the world. It is sometimes used on the ends of fence posts to slow down rotting in the ground and on timbers that are joined together with metal elements.

Charring is arguably the oldest method of preserving timber known to man. Since it involves no chemicals, it also has minimal impact on the environment, making it highly sustainable.

YAKISUGI AT THE WEALD & DOWNLAND LIVING MUSEUM

In October 2015 Kingston University tutors Takeshi Hayatsu and Simon Jones visited the Weald & Downland Living Museum with 15 postgraduate architecture students to begin an investigation into architectural materials and building crafts. At the end of that month the students travelled to Japan to explore alternative approaches to building crafts by visiting a number of buildings designed by the contemporary Japanese architect and architectural historian Professor Terunobu Fujimori in his hometown of Nagano. This is a region surrounded by mountains and agricultural land, next to the ancient Shinto shrine complex Suwa Taisha. It is a highly charged place, because the Suwa Taisha shrine is one of Japan's oldest. In the mountains and in the fields sacred territories are marked by four standing wooden poles which symbolise the presence of gods.

CATHEDRAL COMMUNICATIONS

The influence of place is clearly evident in Fujimori's idiosyncratic work, in which timber plays a central role. In March 2016 Fujimori visited Kingston University as part of a week-long workshop project supported by the Daiwa Anglo-Japanese Foundation. He discussed his approach to design, explaining that he tried to avoid referencing traditional Japanese architecture in his work. Instead his work is often strangely reminiscent of prehistoric monuments and he favours materials that are treated primitively and sourced naturally to clad the exposed surfaces of his buildings.

Yakisugi cladding is one of Fujimori's trademark materials. The charring technique makes the cladding planks naturally resistant to damage from moisture, repels insects and prevents fungal decay.

In March 2016, the Kingston students visited the Weald & Downland Living Museum again, this time with Professor Fujimori as the special guest, for a day-long event exploring elements of traditional timber construction in the UK and Japan. The aim of the event was to exchange practical skills through demonstrations of *Yakisugi* timber treatment and sweet chestnut shingle making.

Shingle making was demonstrated by 81-year-old Peter Harknett, who is the oldest working steeplejack in the UK. It is a simple method to understand, but much harder to master. The log splits where it wants to split, following the direction of its grain. With experience it becomes easier to predict how the material will behave and a few of the students achieved an acceptable shingle or two.

Yakisugi making was demonstrated by 71-year-old Professor Fujimori. Three-metre long Douglas fir planks were bound together with wire to create triangular chimneys and a ball of newspaper was lit at the base and pushed up inside. As the fire caught the inside faces of the triangulated planks, the intense flames produced a thick layer of charcoal. Fujimori opened up the corners of the bundles, carefully controlling the flames and ensuring even charring of the plank surfaces. The professor listened to the fire, placing his ear against the back of the burning timber. When he decided they were ready, he wrapped his arms around the burning bundles and lifted them up off their bases, laid them on the ground and then opened them up to extinguish the flames.

Describing the traditional timber construction day, Kingston University course leader Takeshi Hayatsu said 'These two cladding materials are defined by their creators – both men demonstrated skills learned over years of experience and reminded us of the wisdom of old age and the importance of learning from history, the passing down of craft knowledge from generation to generation.'

Professor Fujimori oversees the charring process

A bundle of burning planks is tipped over to be extinguished. Another triangular bundle can be seen in the background ready for charring.

The Douglas fir planks after charring

Yakisugi has a powerful resonance in the context of modern conservation philosophy and practice. Recent building conservation research, much of it archival, has not only increased our understanding of building materials, how they work, and their efficiency and durability, but has also led to the rediscovery of some traditional materials and methods.

Seeing young students taking part in such an old method was exciting and refreshing. The 30 *Yakisugi* planks made at the museum have since been used to clad a pavilion which the Kingston University students built as their final course project. Sourcing the timber for the *Yakisugi* planks locally to the museum also reduced the project's carbon footprint, helping to meet the project's objective of minimising environmental impact. The completed pavilion was displayed in the garden of Dorich House Museum in South West London in June and July 2016 as part of the London Festival of Architecture.

DIANA ROWSELL is the former head of learning at the Weald and Downland Living Museum, West Sussex (see page 42).


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HEATING NATIONAL TRUST PROPERTIES

EMMA GRIFFITHS

Blickling Hall in Norfolk, where the National Trust recently installed a 200kW lake source heat pump to heat the main hall

AS THE UK's largest private landowner and custodian of many of Britain's most treasured historic buildings, the National Trust (NT) has a varied range of properties in its care. These include 300 major historic houses, office buildings, visitor centres, 360 holiday cottages and around 5,000 tenanted farmhouses and cottages on NT estates.

Climate change now poses the single biggest threat to the places the trust looks after bringing new, damaging threats to a natural environment already under pressure. It also poses a growing conservation challenge for the houses and gardens in the NT's care, not least as a result of the increasing frequency of extreme weather events.

The trust currently spends nearly £6 million a year on electricity, oil and gas, offering a clear business incentive to use energy more efficiently and, where possible, to produce its own. Aside from the economic benefits of moving towards a renewable future, playing its part in mitigating climate change is an organisational priority for the trust as a conservation charity. The National Trust aims to cut energy usage by 20 per cent from 2008 levels by 2020 and to generate 50 per cent of that from renewable sources on its own land.

In the summer of 2015 the trust made its biggest ever investment in renewable energy to heat and power more of the historic places it looks after. The Renewable Energy Investment (REI) programme followed the successful completion of five renewable energy projects at NT properties, part of a £3.5 million pilot launched in 2013.

In one example, a 5,000-litre oil tank in the grounds of Ickworth, Suffolk was removed following the installation of a biomass boiler, removing the risk of contamination from oil leaks. Using wood fuel sourced directly from the estate created an even bigger

Used to heat the property and for cooking, the wood pellet range cooker trialled at Hafod y Llan in Snowdonia reduced fuel costs considerably and demonstrated that wood pellet ranges are a viable alternative to the oil-fired models used in many similar properties.

conservation dividend. As well as the mansion becoming self-sufficient in heat, the new woodland being planted to secure future fuel helped reinstate lost design features from the Grade II listed park and gardens. The more actively managed woodlands are also helping to create larger, better habitats and improve nature conservation.

Following the success of these schemes and the experience gained, the ten-year REI programme was launched with the expectation that it would enable the trust save up to £4 million on its energy costs each year. Electricity generated from some of the projects will be sold to the grid providing a new source of income.

The trust is investing in more than 40 further projects which include:

- a 200kW lake source heating project on the Blickling Estate in Norfolk, which will remove two oil tanks and 25,572 litres a year of oil consumption with an estimated saving of 68 tonnes of CO_2 per year
- two biomass boilers at Upton House in Warwickshire to heat the mansion and other areas, saving an estimated 55 tonnes of CO_2 per year
- a 250kW hydro scheme at Hayeswater in Cumbria where there is a legacy of hydropower from historic corn mills and water wheels – this project will provide an income stream to support conservation work on land the trust cares for.

As well as generating and using renewable energy, the trust has set about implementing high energy efficiency standards in all buildings and operations. This is being achieved by increasing standards of insulation and draught proofing, using water-saving devices and smart meters, fitting double or secondary glazing, using thermostatic heating controls, and installing energy-efficient equipment and lighting.

Many of the properties in the trust's care are energy intensive and in remote areas without access to mains gas. So far, the trust has fitted over 60 of its properties with renewable heating systems tailored to the needs of each property. Ultimately, the overriding goal is to switch to sustainable forms of energy to reduce reliance on fossil fuels.

HEAT PUMPS

The REI Programme has achieved results by fitting both biomass appliances and heat pumps, depending on which technology suits the individual site. At Plas Newydd, on the Menai Strait in North Wales, a 300kW marine source heat pump fitted the conservation heating needs of the property. And at Blickling Hall in Norfolk, the trust has nearly finished installing a 200kW lake source heat pump to heat the main hall.

At more isolated, rural properties such as Blickling, getting the right electrical load on site can prove challenging. Prior to installation of the heat pump, the system was already operating at the capacity of its electrical load so a system upgrade was required. This can be challenging, particularly if the electricity distribution network operator (DNO) needs to upgrade the invertors, cabling and/or transformers required to power the heat pump. The DNO often has its own operational constraints and challenges. It is also expensive because the technology and materials are complex and use a significant amount of copper, and the costs incurred by the DNO must be met by the developer.

When considering whether a lake is suitable for a water source heat pump, distance from the property is important both in terms of cost for civil engineering and pipework, and for heat losses in pumping a longer distance. The relative elevation of the property and the water will be relevant too because more energy is required to pump uphill.

The volume of water in the lake, its depth and the flow rate of water refreshing it impact on how much heat can be generated without significantly altering the overall temperature. How much energy the heat pump needs to take out will depend on the size and heating requirements of the building it is being used to heat. Crucially, the sensitivity of the ecology in the lake or river to temperature change and to disturbance caused by the installation of collectors has to be taken into consideration.

The trust has to select lake sites for extracting heat carefully to ensure that the area, depth and flow rate can be maintained over the course of the year. Many trust lakes are spring-fed, ensuring that the 'fuel source' is replenished constantly.

Independent studies by SEACAMS, a marine science research scheme, have shown that disruption to biodiversity can also occur during construction. Mitigation measures need to be carefully considered and incorporated in a method statement agreed with the Environment Agency and other statutory bodies as necessary (such as planning and heritage authorities where archaeological sites are involved). It is important to keep these bodies fully engaged during the design stage of the project.

Sometimes the trust also faces challenges around the sensitive archaeological nature of its sites. It is often necessary to seek specialist guidance and take precautions to avoid affecting significant archaeological finds, which can include whole Saxon villages. This can make it problematic to excavate large areas of a site to develop schemes such as ground source heat pumps.

Choosing the most appropriate type of energy for some National Trust properties can be a difficult challenge. For example, the trust's historic art and house collections at Beningborough Hall in North Yorkshire require lower heat levels and would only need a 90kW biomass boiler, but this option may not be financially viable, especially following substantial reductions in payments made under the Renewable Heat Incentive in 2015/16 for biomass heating installations of less than 200kW. On the other hand, a heat pump might not provide the right solution either, because the heat emitters are too small. Ground-source heat pumps work most efficiently with underfloor heating systems due to the lower temperature requirements of a large emitter, but installation is rarely possible due to both conservation issues and financial constraints.

WOOD FUEL

Log heating systems such as stoves and boilers are ideal for houses but in larger properties they require more frequent refilling so in these environments other types of wood fuel such as wood chips and pellets are mostly used in automated systems.

Wood chips can be made from virtually any kind of woody biomass, including whole trees, by a chipping machine. This makes it possible for the trust to supply fuel from its own estates. Wood chips are typically used in automated systems making them a clean and convenient heating option for the trust.

Pellets are relatively new in the UK but they have been used in central Europe for some time. They are produced from wood by-products such as sawdust and have a better calorific value which means the energy to weight ratio is very favourable, so they are more appropriate for smaller spaces.

The visitor building at Penrhyn Castle in Wales has a new wood pellet space heater with a hot-air convector built in, which heats the whole building.

In simple carbon dioxide emission terms the log stove at another trust property, Llanerchaeron tea room, emits considerably less carbon dioxide per kWh than the new high-tech pellet stove at Penrhyn. Research has shown that log stoves emit around 4g of carbon dioxide per kWh compared to 34g per kWh for a wood pellet system (and around 500g per kWh for an electric heater using power from the grid).

Deciding whether a pellet stove or a log stove is more suitable for a particular site can come down to the ability to manage the stoves. Cutting, hauling, drying and splitting logs, or just supplying them, as well as loading and cleaning the stove are all time-consuming and members of staff have other tasks to carry out. It can come down to the simple question: 'Do you have the space to store the fuel and the time to manage the fire?'

Expense can also be a consideration. The Tigchelaar wood-fired storage heater or 'masonry stove' at Llanerchaeron is over 90 per cent efficient and a very good space heater but it is also twice the price of some stoves. On the other hand, there is a simple Clearview stove space heater in Colby Woodland Garden which is significantly cheaper than the masonry stove, and far cheaper than any pellet system.

Fuel is important and the trust ensures that its wood fuels are produced in the UK from FSC timber and from as local a supplier as possible, if not from its own estates. Wood chip and pellets must also conform to the relevant standards (including DIN 66 165).

In some cases, using the natural resources that properties and estates have access to creates additional conservation wins. The biomass system at Croft Castle in Herefordshire uses wood from conifer trees on the estate to heat the property. Removing the conifers has exposed ancient wood pasture and led to an increase in biodiversity.

CASE STUDY 1:
A wood pellet range cooker in a farmhouse in Snowdonia

At Hafod y Llan in Snowdonia, the trust experimented with a Klover 120 wood pellet range cooker. The requirement was for a viable, economic, manageable biomass cooker and central heating appliance which could simply replace the host of oil-fired range cookers (Aga, Stanley, Rayburn, Esse, etc) used in many similar farmhouses and cottages.

The building is a fairly typical three-bedroom farm-house with moderate levels of insulation, draught-proofing and retrofitted windows. The appliance had no problem at all heating it. When used all day, two 20kg bags of pellets were consumed and this fell to one bag a day if the property was heated only in the morning and evening. In the summer months just half a bag a day was used for hot water. A fossil-fuel boiler was retained as a backup, but it has never been needed.

Wood-fired storage heater or 'masonry stove' at Llanerchaeron, Ceredigion

In winter-heating mode the fuel was burning much more cleanly and only leaving a very fine ash. In summer there was some partially burnt pellet but this was not an issue. The daily and weekly controls were not very intuitive at first but are adequate once members of staff get used to them.

As a cooker it performed well overall, if a little less refined than an Aga. The oven could be a tad hot (200°C+ top and 180°C bottom of the oven), and it was a matter of trial and error at the start. Using the hob plate also took some practice, with a range of temperatures across the surface.

A simple slot-in electric plate cooker was also provided for minor cooking requirements (boiling an egg for example), to avoid having to crank up the oven unnecessarily.

Overall the trial was a success. An estimated saving of about £400 per annum was achieved with the Klover, and the house is also much warmer. The conclusion is that this is a suitable option for replacing oil range cookers.

CASE STUDY 2: Wood pellet boilers at Upton House

Towards the end of 2015 the first completed Renewable Energy Investment Programme project, Upton House, Warwickshire made the switch from oil to a renewable energy heating system.

Former Shell chairman Lord Bearsted gifted the estate and its extensive art and porcelain collections to the National Trust in 1948. It was using 25,000 litres of oil each year to heat the various buildings (which equate to around 11 average houses). Today, the heating is powered by two new wood pellet boilers, saving £6,000 a year on energy bills and 55 tonnes of CO_2 emissions.

Four oil boilers were removed and the new biomass system now heats the house, site offices, squash court gallery, restaurant and a cottage.

According to Ed Wood, the renewables project manager at Upton: 'The irony that the estate was owned by a family whose fortune was built on oil was not lost on us when we started our project to take Upton off fossil fuel. In the past, oil was the most effective way to heat the estate. Times have changed and to lower our carbon emissions and meet our target, to generate 50 per cent of all energy we use from renewable sources by 2020, we felt it was important to change our energy source here.'

This is a great example of what support from the Renewable Heat Incentive scheme is enabling the trust to do.

Schemes like these cut carbon emissions, promote local sustainable wood management and work in harmony with the natural and built environment. They work for the local environment and economy and support national energy and climate change reduction initiatives.

FUNDING

Recent changes to government incentives (the Renewable Heat Incentive and the Feed in Tariff or 'FIT' scheme) have seen a shift in support for certain renewable energy technologies and system sizes.

The FIT rates for smaller hydro-electric installations are lower than the trust had hoped. However, the government has reinstated pre-accreditation, reducing the risk of the longer lead-in times associated with hydro projects. The trust has been working hard not only on financial modelling of its hydro potential but also revisiting its approach to construction methodologies and procurement approaches before making any final decisions.

Upton House, Warwickshire was using 25,000 litres of oil each year before the installation of two wood pellet boilers, which are now saving £6,000 a year on energy bills and 55 tonnes of CO_2 emissions.

The RHI consultation led to the introduction of an annual budget cap based on deployment of technologies which means that once a certain threshold is reached the RHI is no longer available for that technology/size. However, the good news is that a tariff guarantee will be introduced for heat pumps over 100kW and for large scale biomass. In addition, tariffs for heat pumps are predicted to rise as the technology has not been developed at the same rate as other technologies, which presents a fantastic opportunity for the trust.

SHARING EXPERIENCE

Collaboration has been a key part of the trust's renewable energy work. Its energy partner, Good Energy, has worked alongside the trust to help develop its renewable strategy and inspire others to think about their energy use. Lessons learned help inform future projects including those of other bodies. With the sustainable energy charity Ashden, the trust helped launch the Fit for the Future Network to share their experience with others who are looking for a greener energy supply. Now more than 80 groups including The Crown Estate, Historic Environment Scotland, Oxfam GB and the RSPB are part of the network.

In one example, following advice from the trust, Chatsworth installed 15 biomass systems into tenanted properties. These boilers have produced over 1 million kWh and the estate hopes to eventually power these using woodchip from the estate which is a by-product of sustainable woodland management.

In the view of the trust, collaboration is one of the best tools it has to mitigate the threat of climate change. A February 2016 report revealed that the Fit for the Future Network collectively saved nearly 15,000 tonnes of CO_2 over the past year. This is equivalent to making 1,766 trips around the world in an average petrol car.

EMMA GRIFFITHS is project manager for the National Trust's Renewable Energy Investment Programme.

The Alliance for Sustainable Building Products
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www.asbp.org.uk

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Council for British Archaeology
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new.archaeologyuk.org

Department for Business, Energy & Industrial Strategy
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Energy Saving Trust
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English Heritage
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www.english-heritage.org.uk

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www.englishstone.org.uk

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Heat Pump Association
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REGEN 2017

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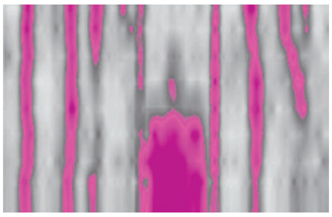

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Mar 2	**Glorious Mud!: Building with Earth** Lecture by earth builder Alex Gibbons **Venue:** St Botolph's Church Hall, London **Contact:** SPAB Tel 020 7377 1644 education@spab.org.uk
Mar 2	**Heritage and Sustainability** Lecture by Ana Pereira-Roders, Eindhoven University of Technology **Venue:** 3 Chambers Street, Edinburgh **Contact:** Edinburgh College of Art mstalker@exseed.ed.ac.uk
Mar 7–9	**Ecobuild 2017** International trade show and conference showcasing sustainable design, construction, energy and the built environment **Venue:** ExCel, London **Contact:** Ecobuild
Mar 9	**Building Services Retrofit** Ventilation, heating, hot water, lighting and appliances, and their controls **Venue:** FMB, London **Contact:** The Retrofit Academy Tel 01785 711574 info@retrofitacademy.org
Mar 15	**Ventilation and Air Tightness for Retrofit** Ventilation strategies and system options for domestic retrofit **Venue:** FMB, London **Contact:** The Retrofit Academy Tel 01785 711574 info@retrofitacademy.org
Mar 18	**Lime Pointing** Practical repointing of traditional masonry structures **Venue:** Merryhill Training Centre, Fife **Contact:** Scottish Lime Centre Trust Tel 01383 872722 admin@scotlime.org
Mar 21	**Retrofit Building Physics** Understanding building physics for retrofit with an emphasis on energy use **Venue:** FMB, London **Contact:** The Retrofit Academy Tel 01785 711574 info@retrofitacademy.org
Mar 22–23	**Regen 2017** The latest issues in urban and rural regeneration, policy and implementation **Venue:** St George's Hall, Liverpool **Contact:** Tel 0845 467 3303 info@regen2017.co.uk
Mar 28	**Retrofit Coordination and Risk Management** Mitigating risks on retrofit projects through good project management **Venue:** FMB, London **Contact:** The Retrofit Academy Tel 01785 711574 info@retrofitacademy.org
Mar 30–31	**Lime Plaster for Plasterers** Hands-on course aimed at both working plasterers and amateurs with some plastering skills **Venue:** Cressing Temple Barns, Essex **Contact:** Gemma Clayton, Essex County Council Tel 03330 132738 traditional.buildingskills@essex.gov.uk
APR 3	**Retrofit for Older Buildings** Informed retrofitting of traditionally constructed buildings **Venue:** FMB, London **Contact:** Environment Study Centre for Sustainable Buildings Tel 020 7193 9926 info@environmentstudycentre.org
Apr 7-8	**The Use of Lime in Historic Buildings** Essential skills for specifying mixes and applying mortars **Venue:** Llanymynech Limeworks Shropshire **Contact:** Harriet Devlin harriet.devlin@bcu.ac.uk
Apr 27	**Retrofit for Older Buildings** Informed retrofitting of traditionally constructed buildings **Venue:** Glasgow, tba **Contact:** Environment Study Centre for Sustainable Buildings Tel 020 7193 9926 info@environmentstudycentre.org
MAY 2	**Introduction to Domestic Retrofit** Context, policy, principles and practice of domestic retrofit **Venue:** FMB, London **Contact:** The Retrofit Academy Tel 01785 711574 info@retrofitacademy.org
May 6–7	**Old Houses for the Future** How to make older homes comfortable and sustainable without harming fabric or character **Venue:** King's Manor, York **Contact:** SPAB Tel 020 7377 1644 education@spab.org.uk
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May 23	**Building Fabric Retrofit and Solid Wall Insulation** Insulation/ airtightness, thermal bridging and moisture migration **Venue:** FMB, London **Contact:** The Retrofit Academy Tel 01785 711574 info@retrofitacademy.org
May 30	**Building Services Retrofit** Ventilation, heating, hot water, lighting and appliances, and their controls **Venue:** FMB, London **Contact:** The Retrofit Academy Tel 01785 711574 info@retrofitacademy.org
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Jun 15	**Retrofit for Older Buildings** Informed retrofitting of traditionally constructed buildings **Venue:** FMB, London **Contact:** Environment Study Centre for Sustainable Buildings Tel 020 7193 9926 info@environmentstudycentre.org
Jun 20	**Retrofit Coordination and Risk Management** Mitigating risks on retrofit projects through good project management **Venue:** FMB, London **Contact:** The Retrofit Academy Tel 01785 711574 info@retrofitacademy.org
Jun 27–28	**Historic Lime Plasters and Renders** Fundamentals of lime plastering from simple renders to fine ornamental work **Venue:** Weald & Downland Living Museum, West Sussex **Contact:** Tel 01243 811021 courses@wealddown.co.uk
JUL 5	**Damp and Historic Buildings** Achieving breathability in historic buildings **Venue:** Weald & Downland Living Museum, West Sussex **Contact:** Tel 01243 811021 courses@wealddown.co.uk
SEP 12	**Retrofit for Older Buildings** Informed retrofitting of traditionally constructed buildings **Venue:** FMB, London **Contact:** Environment Study Centre for Sustainable Buildings Tel 020 7193 9926 info@environmentstudycentre.org


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