STBA

Sustainable Traditional Buildings Alliance

ENGLISH HERITAGE

Performance and Energy Efficiency of Traditional Buildings

Gap Analysis Study

2012




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CONTENTS

1. Introduction

1.1 Background Context

CITB-ConstructionSkills and English Heritage are actively involved in various aspects concerning the understanding and practices involved in the use of the correct methods and materials in the sympathetic repair, maintenance and retrofit of traditional (pre-1919) buildings.[1] For this reason, both organisations played a key role in establishing and launching the Sustainable Traditional Buildings Alliance (STBA) on 29th November 2012 at Somerset House, London.

While much work is being undertaken to understand the performance of traditional buildings and the health of occupants, this is disparate, uncoordinated and remains largely unknown by those within mainstream sustainability and construction. CITB-ConstructionSkills and English Heritage funded and commissioned this Gap Analysis Study in partnership with the STBA as a starting point to identify the current state of knowledge and examine and synthesise existing relevant research and information regarding the thermal performance and energy efficiency of traditional buildings and to collate the various strands of this into a published format.

This study is intended to act as a reference source and by identifying gaps in the research field, to stimulate debate and further investigation needed to expand upon important themes and aspects explored in recent research projects. This is also intended to shape current and future thinking on new areas requiring further research and inform other relevant related activities including training and skills development and promoting best practice.

This Gap Analysis Study research, and the collective knowledge and expertise of the respective organisations within the STBA, are part of a process to help disseminate information as widely as possible and to increase understanding of the particular needs of traditional buildings within mainstream thinking. With large-scale government initiatives, such as, the Green Deal, it is critical to have as complete a picture as possible of what is known and not know about performance and energy efficiency and the risks posed to traditional buildings.

It is hoped that this study will inform this debate and influence thinking regarding the measures being undertaken to reduce carbon in relation to traditional buildings - but at the same time respecting the nature and integrity of these buildings and retaining as much as possible of the original fabric.

1.2 Scope of the Research

The purpose of this study was to understand where the greatest effort must be expended to gain meaningful information on the use and consequences of the practices and interactions with traditional buildings to embody and deliver energy efficiency and contribute to their sustainability by:

- Identifying the research field including contributors, institutions, references; a literature review of the pertinent research material, papers, articles, reports etc.(section 2.2, page 5); creating a bibliography of publically available research covered by this study (section 5, page 31)
- Producing a summary of each of the most relevant individual research papers related to this study covering their subject area and breadth of coverage and with comment on the strengths and weaknesses of the work (section 2.2, page 5) and identifying significant 'gaps' in understanding

1 A traditional building is defined as of solid wall construction built before 1919 constructed of moisture permeable materials with no formal damp-proof course (DPC). This definition broadly follows that for a traditional building found in Section 3.8 of Building Regulation Approved Documents L1B & L2B in *Energy Efficiency and Historic Buildings: Application of Part L of the Building Regulations to historic and traditionally constructed buildings*, English Heritage http://www.english-heritage.org.uk/publications/energy-efficiency-historic-buildings-ptl/eehb-partl.pdf

identified in the study (section 3, page 27) and recommendations for further work (section 4, page 30)

- Making the Gap Analysis Study widely available to help stimulate discussion and influence opinion and actions, inform future research projects and where possible, help support funding bids for further research within this field.

2. Review of Existing Relevant Research and Information

2.1 Methodology

The Gap Analysis Study consisted of a literature search and a call for evidence from a wide range of organisations and individuals within the traditional buildings/built heritage sector. The call for evidence was through an e-mail request to interested parties who had attended the launch of the STBA at Somerset House in November 2011 and specific individuals known to be active in this field.

Searches were undertaken of recognised relevant academic and specialist building conservation literature databases and used a variety of search fields including the terms; buildings, historic, heritage, traditional, old, conservation, energy, efficiency, performance, behaviour, thermal, moisture, ventilation, Indoor Air Quality. A number of journals were established as principle sources of evidence including: the Association for Preservation Technology (APT); Building & Environment; Energy & Buildings; and Energy Policy.

Websites of the statutory bodies responsible for the protection of the UK historic environment were also searched; Cadw, English Heritage and Historic Scotland, as well as other building conservation interest groups, such as, the Institute for Historic Building Conservation (IHBC) and the Society for the Protection of Ancient Buildings (SPAB).

The searches uncovered a range of documents, some of which had more direct relevance to the research question than others. Those judged to be of some relevance were collected into a spread-sheet of relevant references. Decisions on this were based on degree of relevance to the research question; if a paper was concerned specifically with the performance of traditional buildings via an analysis based on measured or theoretical data it was deemed highly relevant.

Literature concerning the retrofit of traditional buildings was excluded, unless it contained information about the performance of buildings prior to refurbishment or revealed information of wider consequence to the understanding of the performance of pre-1919 buildings. As there is also research work on the performance of buildings in general, it was necessary to ascertain those of particular relevance to traditional buildings, for example, papers on condensation and moisture or indoor air quality. Some research focussed on existing buildings, or particular types of building forms and in such cases, it was necessary to try to extrapolate elements of the research pertaining specifically to pre-1919 buildings.

The choice of the papers reviewed in-depth and discussed in section 2.2 below was based upon their degree of relevance to the specific question of performance and energy efficiency of traditional buildings. Priority was given to papers which included data derived from the buildings themselves, that is, from measurements or observations made in-situ. The reason for prioritising in-situ monitoring and its resultant data is made clear in the summaries and comment in section 2.2 below.

An analysis of the selected documents to identify gaps in the research and evidence base pertaining to the performance and energy efficiency of traditional buildings is located in Section 3, with a brief summary of recommendations for further work to address issues of risk as well as improvements to the knowledge of traditional buildings in general in Section 4.

2.2 Literature Review

This section contains a precise of the selected papers from an initial literature search, which are considered important in relation to the specific question of performance and energy efficiency of traditional buildings. This is presented as brief abstracts/descriptions of the contents of each paper and accompanied where appropriate, by relevant comments by the researcher to highlight key aspects, findings or areas for further exploration. If the findings of the individual papers are self-explanatory or there is no suggested comment then none has been provided.

1. Thermal Performance of Traditional Windows and Low-Cost Energy-Saving Retrofits

Baker P, Curtis R, Kennedy C, Wood C (2010)

Abstract/Description

Good thermal performance of traditional windows can be achieved using low cost methods. The work quantifies the effectiveness of relatively simple measures to improve the thermal performance of traditional windows by draft-proofing and using blinds, curtains, shutters, and secondary glazing.

Two typical traditional sash-and-casement windows with single glazing were provided for testing by Historic Scotland and English Heritage. The windows were mounted in an insulated panel between the two independently controlled rooms of an environmental chamber. Under a 68˚F (20˚C) temperature gradient, the heat flow through the glazing was measured using heat-flux sensors both for the glazing only and with the various improvement options. The reductions in heat loss and U-values were estimated. The improvements in the airtightness were assessed after the refurbishment of the joinery of the English Heritage window and draft proofing of both windows. In addition, in-situ measurements of secondary glazing and shutters were performed in an early nineteenth-century building in Edinburgh.

Comment

This paper is based on research work by Historic Scotland and English Heritage and commented can be found in Number 3 below.

2. Research into the Thermal Performance of Traditional Windows: Timber Sash Windows, English Heritage

Wood C, Bordass B, Baker P (2009)

Abstract/Description

This work also quantifies the effectiveness of relatively simple measures to improve the thermal performance of traditional windows by draught-proofing and using blinds, curtains, shutters and secondary glazing. A traditional Victorian sash window with single glazing was provided for testing. The window was mounted in an insulated panel between the two independently controlled rooms of an environmental chamber at GCU. Under a 20°C temperature gradient, the conductive heat flow through the glazing was measured using heat-flux sensors for the glazing only and with the various improvement options. The reduction in conductive heat loss and U-values were estimated. Improvements in the air-tightness were assessed after refurbishing the joinery, and again after draught-proofing. Condensation tests were also carried out on the window before and after installation of secondary glazing, as the assessment of condensation risk should be considered as part of the overall evaluation of improvements made to the window.

Comment

The English Heritage and Historic Scotland reports (see Number 2 above) summarise a joint research project. The windows used in the laboratory tests had been rescued from skips and were in poor condition therefore their performance prior to refurbishment may not be wholly indicative for windows found in-situ within traditional buildings, particularly regarding air leakage. Significant benefits to performance were found through draught-proofing which reduced air leakage by 86% and meant the window was tighter than the recommended 4000mm^2 trickle vent for new domestic windows. A range of measures applied to the window improved heat loss including the deployment of traditional shutters. A combination of measures involving secondary glazing improved the performance beyond that required for windows of new buildings.

The English Heritage work looked specifically at questions of condensation and found that "the tests at the upper end of the range of domestic humidity conditions (22°C, 60% RH) showed that the risk of condensation on the original window was high. Once the well-sealed secondary glazing system was added, there was never any condensation on the secondary glazing itself".

This research work could be seen as demonstrating a productive synergy between broader concerns of energy and building conservation as it provides solutions to questions of the energy efficiency of traditional buildings by retaining and supplementing traditional building fabric. The research work also allows for the formation of high quality guidance based on rigorous experimental research.

3. Climate Change and Traditional Buildings: The Approach Taken by Historic Scotland

Curtis R, Historic Scotland (2010)

Abstract/Description

The reduction of carbon dioxide and equivalent emissions in Europe and other developed countries is now part of the mainstream political and social agenda, with particular focus on the performance of the built environment. Traditional and historic buildings are under significant pressure to reduce the carbon emissions associated with their operation, and Historic Scotland is taking a lead in the provision of guidance and advice for traditionally built structures of all types. Its programme of research has looked at the thermal performance of the traditional building envelope and how it can be improved by sensitive and appropriate intervention. Other related factors such as embodied energy, passive benefits and sustainability issues are presented with an outline of their future research programme.

Comment

This paper provides an introduction to Historic Scotland's extensive research work into the subject of the performance of traditional buildings as well as energy saving techniques and methods that may be applied to them. The research is largely presented as Technical Papers, some of which are detailed below.

4. Historic Scotland: Technical Paper 1. Thermal Performance of Traditional Windows - Revision 2010

Baker P (2010)

Abstract/Description

The Scottish Government has set a target of reducing Scotland's carbon emissions by 80% by the year 2050. This is an ambitious target that requires a series of energy saving measured to be implemented across the country. Just under one fifth of Scotland's dwellings is traditionally constructed, and has significant value to Scotland's built heritage. The key issue for these buildings is how to make them energy efficient, in a way that does not detract from their character or damage the building fabric.

To tackle this question, Historic Scotland's Technical Conservation Group commissioned the Centre for Research on Indoor Climate & Health at Glasgow Caledonian University to carry out a series of tests on traditional window performance. Windows are the most targeted building element for replacement to reduce heat loss in dwellings. The window that was tested and provided by Historic Scotland was a typical timber single paned sash and casement window. The thermal performance of the window was tested at the National Physical Laboratory using a guarded hot box system, in order to get an industry-standard measurement of the window's properties. The thermal transmittance of the window (known as the U value) was measured as being 4.5 W/m2K.

Draught proofing is a common practice to prevent wind from blowing in through traditional windows. The test window was draught proofed, and although the U value of the window was not improved, the airtightness of the window was improved considerably, reducing the air leakage by 86%. The window is tighter than the recommended 4,000 mm^2 trickle vent for domestic new build.

A series of widely available heat loss reduction measures were tested (including the use of curtains, shutters, blinds, and secondary glazing) were tested on the window in the Environmental Chamber at Glasgow Caledonian University and shown to reduce the heat loss through the glazing to varying degrees. Secondary glazing was the most effective overall option, as it reduced heat loss through the window by 63%. Timber shutters are the most effective option of the traditional methods, reducing heat loss by 51%; curtains reduced heat loss by 14%; a Victorian roller blind reduced heat loss by 28%; a modern roller blind reduced heat loss by 22%.

The greatest reductions in heat loss came from combining these measures (i.e. blinds, shutters and curtains all closed) and by adding extra insulation to these options. Using secondary glazing, or combinations of blind and shutters, reduced the U value of the window to below 2 W/m2K, which is the maximum U value allowed by Scottish Building Standards for timber or uPVC windows in new dwellings with an energy efficient boiler.

Comment

See Number 9 below.

5. Historic Scotland: Technical Paper 3. - Energy Modelling Analysis of a Scottish Tenement Flat

Barnham B, Heath N, Pearson (2008)

Abstract/Description

Changeworks tested four different energy-modelling methodologies in relation to a traditionally built Georgian tenement flat in central Edinburgh. The results demonstrated that each software model will generate a different result, depending on the content and amount of the data sets.

As a general rule, the more detailed the data sets, the more accurate the energy model. In terms of construction dates, most energy modelling software systems group construction dates into bands that broadly correspond with changes in Building Standards, allowing a reasonable degree of accuracy. However, everything built before 1919 (or 1900 depending upon the software model) is grouped into a single category ('Pre-1919' or 'Pre-1900'). This makes inaccuracies more likely when modelling the energy efficiency of older housing, due to the wide range of building types, local construction methods, materials, built forms, etc. This is an important point, showing an in-built generic approach to most energy modelling of older housing. Some software models assume incorrect building sizes, not taking into account the larger room sizes common in older housing. This immediately weakens the subsequent energy rating assigned to the property.

In addition, built forms such as tenement flats have a relatively low ‘floor/external wall area’ ratio. Some software packages were not sufficiently sensitive to adapt to this scenario, and thus generated a higher-than- expected energy efficiency rating.

Similarly, some software packages take no account of local climate data, which again can lead to unrealistic energy ratings (regardless of the age of the property) depending on the geographic location of the property. Within these software models, some data sets are more flexible than others, allowing pre-set values to be over-written. The user can thereby manually ‘construct’ the build type (for example) in order to create a more accurate energy model. Other models, however, contain only fixed values, which may sometimes be inaccurate, particularly in relation to older traditionally built housing.

Such generic treatments and in-built inflexibilities of these software models predispose older housing to less accurate energy efficiency ratings (both up and down) than what their actual efficiency might be for older housing. The property surveyed for this research achieved reasonably high energy ratings. However as shown by the subsequent analysis, the property’s true energy efficiency and the software accuracy are far from clear-cut.

Looking to the future, with the emergence of Energy Performance Certificates (EPCs), it seems likely the software package for these (Reduced data Standard Assessment Procedure or RdSAP) will become the main model by which the energy efficiency of domestic properties is rated. Other programmes, such as, the National Home Energy Rating (NHER) may become less common. Furthermore, as concluded by this research, there is a case for the development of a new software package to provide an accurate energy efficiency model for older, traditionally built, Scottish housing.

Comment

See Number 9 below.

6. Historic Scotland: Technical Paper 4. - Energy Modelling in Traditional Scottish Houses

Jenkins D (2008)

Abstract/Description

When applying energy saving measures to solid wall houses, typical in many parts of Scotland, it is important to recognise that a subtly different approach might be required than that used for other sections of the housing stock. Thermal transmittances of solid sandstone, granite and similar materials are, compared to modern buildings, generally poor (depending on wall thickness) and the lack of a cavity results in cavity- wall insulation not being an option. When such buildings also have an aesthetic or historical value, any visible building fabric measure (such as external insulation, many glazing options and rooftop alterations) becomes problematic. The result is, when compared to very modern dwellings, a relatively inefficient building with potentially fewer energy-saving refurbishment options.

Comment

See Number 9 below. Technical papers 4 and 5 should be read in conjunction with the findings in Technical Papers 3 & 8. These are circumspect about the efficacy of building models to provide good quality data on the performance of traditional building, either before or after refurbishment.

7. Historic Scotland: Technical Paper 5. - Energy Modelling of a Mid-19th Century Villa

Integrated Environmental Solutions (2009)

Abstract/Description

Integrated Environmental Solutions were commissioned by Historic Scotland to assess a traditional, two-storey sandstone villa in terms of its energy performance and internal comfort conditions. Dynamic thermal modelling is being used rather than Steady State calculation methods in an attempt to record results from an alternative software testing technique.

Comment

See Number 9 below. Technical papers 4 and 5 should be read in conjunction with the findings in Technical Papers 3 & 8 and which are circumspect regarding the efficacy of building models to provide good quality data on the performance of traditional building either before or after refurbishment.

8. Historic Scotland: Technical Paper 6. - Indoor Air Quality and Energy Efficiency in Traditional Buildings

Halliday S (2009)

Abstract/Description

This short report is the result of a scoping study undertaken for Historic Scotland, which comprises a brief overview using desk research of existing publications, web based information and on-going research on indoor air quality and energy efficiency issues in traditional buildings of relevance to Historic Scotland.

Comment

Indoor Air Quality is determined by a number of factors which include, amongst others, air permeability, ventilation and humidity. Halliday's report, (as with Gentry et al in *English Heritage Hearth and Home Scoping Study Final Report*, see section 2.3 below) is a scoping study of particular relevance to the question of the performance of traditional buildings as the study of Indoor Air Quality, might reveal aspects on the performance of traditional buildings.

This report also overlaps with another Historic Scotland report Technical Paper 12 Indoor Environmental Quality in Refurbishment by Richard Hobday and the two reports should be read in conjunction.

Halliday says: "There is a widely held belief that traditional buildings have better indoor air quality than more recently constructed ones due to higher ventilation rates. The study found little evidence of comparisons of indoor air quality in buildings of different ages, hence this could not be substantiated........We have concluded that there is a dearth of research in this area".

Hubbard's and Stephen's work (see Number 18 above) suggest that there is a misunderstanding concerning rates of ventilation (air permeability) for older buildings and associated questions of Indoor Air Quality. Halliday also found "very little published research into chemical loads in buildings and

[also] found that issues associated with maintaining a healthy indoor environment are barely touched upon. It identified no studies on the effect on human health of making changes to traditional buildings to meet energy efficiency targets". Hobday makes a similar point: "There is also a notable lack of published data on indoor environmental quality in highly energy-efficient buildings (including both indoor air quality and other health factors, such as heating, lighting and ventilation".

9. Historic Scotland: Technical Paper 8. - Energy Modelling of the Garden Bothy, Dumfries House

Heath N, Pearson G, Barnham B, Atkins R (2010)

Abstract/Description

This report presents pre- and post-improvement energy performance data and analysis for the Dumfries House Garden Bothy, an unoccupied 19th-century stone building in Ayrshire. The baseline data was gathered from a site survey in January 2010, and calculated using a range of energy modelling software packages. Improvement measures and specifications were provided by Historic Scotland and measured subsequently.

Comment

The work presented in Technical Paper 8 builds on the findings and recommendations of Technical Paper 3 and although neither is based on direct measurements of the energy performance and behaviour of traditional buildings both papers offer important comment regarding the understanding on this subject.

Technical Paper 3 reports the findings of a study which compared assessments made by four different energy modelling software programmes for an 1820's tenement building located in the city of Edinburgh. The different methodologies used (NHER, SAP, RdSAP and EPC) generated widely varying results and underlining assumptions within the programmes were found to be problematic specifically regarding predictions for older buildings as "generic treatments and in-built inflexibilities of these software models predispose older housing to less accurate energy efficiency ratings (both up and down) than their actual efficiency might be."

Technical Paper 8 pursued a similar methodology but was concerned with energy assessments of a stone built cottage in rural Ayrshire before and after an energy efficiency refurbishment programme. Results were generated using the models SAP, RdSAP, NHER, SBEM and a dynamic building simulation software tool based on ESP-r.

As with Technical Paper 3, these results were very diverse and lacking in consistency and it was not clear which model provided results that were 'closest' to 'reality'. The models were found to be very sensitive to operator inputs just as building energy consumption is also very sensitive to user behavior. Both factors can add uncertainty into modelled predictions. It seemed that with an increasing number of assumptions the accuracy of the model was reduced and that this generic approach is particularly unsuitable when applied to the reality of the extremely diverse range of buildings that make up the UK traditional building stock.

Of most concern is that the Energy Performance Certificates (EPC) used most widely as the basis for assessments of buildings are particularly poor regarding older properties and that generally some improvement measures deployed in the buildings were not recognised or did not register as significant in some energy assessments.

The report recommends that "the actual energy consumption, CO2 emissions and running costs should be monitored once the Bothy is improved and occupied. This will allow the accuracy of the software predictions, and the gap between predicted and actual performance, to be fully assessed" and that "more widely, considerable further *in-situ* monitoring would seem to be required to test the calibration of each of the programmes". It concludes by calling for the development of a building energy model specifically for traditional building stock.

10. Historic Scotland Technical Paper 10: U-values and Traditional Buildings

Baker P (2011)

Abstract/Description

U-values are normally calculated with computer programs developed to be used on present-day non-traditional construction. Historic Scotland felt that the suitability of such programs when used to assess traditional buildings needed investigation, and therefore appointed Glasgow Caledonian University to carry out this study. The results will help construction professionals and assessors of energy building performance to make better informed and more balanced decisions when assessing and improving the energy performance of traditional buildings.

For the study, 67 *in situ* U-value measurements were carried out, mostly of un-insulated solid walls but, for comparison, some cavity walls, and building elements retrofitted with insulation, were also measured. The non-invasive measurements were generally taken of building elements with their internal and external finishes intact. The study then compared the U-values measured *in-situ* with their calculated equivalents, with a particular focus on the comparison of the impact of the lime-and-stone core of a traditional solid stone wall.

The study found that software programs for U-value calculations tend to over-estimate U-values of traditional building elements as traditional building elements tend to perform better thermally than would be expected from the U-value calculations. The study suggests that the *in-situ* measurement of U-values is a useful tool, which can aid assessment of the thermal performance of traditional building elements.

The study recommends further research on the thermal properties of traditional building materials and construction components, improvement to U-value calculations and a standardised methodology for *in-situ* measurements of U-values

Comment

Baker's work focused largely around solid stone walls as this is the predominant material in traditional buildings in Scotland and revealed similar findings to Rye's work for the SPAB (see Number 13 below). Baker developed the study further by attempting to establish a mortar ratio which could be included in the calculation of U-values for solid stone walls. He found that by adapting the model built by the U-value calculating software (BuildDesk) to include a 40:60 ratio of stone to mortar, it was possible to provide better correlation between the calculated and measured U-values for stone walls. However as this practice is not required by any regulations, guidance or standard it remains to be seen whether it becomes widely adopted with the building construction industry in general.

11. Scotland: Assessing U-values of Existing Housing

Energy Saving Trust (2004)

Abstract/Description

This document offers guidance to designers and energy auditors on how to assess the U-values of existing dwellings. This publication gives details of typical, as-built, U-values for Scottish housing prior to the retrofitting of any insulation materials. These are ‘typical’ or default values for different types of dwelling: if more accurate information on a specific building is available, this should be used in preference. Unless otherwise stated, they have been calculated using BS EN ISO 6946 with the exception of floors where BS EN ISO 13370 has been used. Pre-1919 Traditional sandstone (or granite) dwellings with solid walls: stone thickness typically 600mm with internal lath and plaster finish = 1.7 W/m^{2}K. Roofs - no insulation and unventilated = 1.6 W/m^{2}K, ventilated = 2.3 W/m^{2}K.Floors (until 1991) 0.60 W/m^{2}K. Windows (until 1991) = 4.8 W/m^{2}K.

Comment

For combined comments see Number 12 below.

12. Northern Ireland: Assessing U-values of Existing Housing

Energy Saving Trust (2005)

Abstract/Description

This publication deals with the assessment of U-values in existing dwellings in Northern Ireland and is intended to help designers and energy auditors. This publication gives typical, as-built U-values for existing housing in Northern Ireland, prior to any retrofit of insulation materials. The U-value depends upon the precise details of a construction, including the thicknesses and properties of the materials. The usual method of calculating a U-value is by using the combined method, described in BS EN ISO 6946 and BS EN ISO 13370.

If more accurate information on thermal performance is available at the time of the assessment, it should be used in preference to the default U-values given here. When the age of construction is unknown the following apply; solid brick walls = 2.0 W/m^{2}K, Cavity Walls = 1.7 W/m^{2}K, Timber frame walls = 1.7 W/m^{2}K. Pre 1919 - 9" solid (single) brick = 2.0 W/m^{2}K, 13.5" solid brick (brick and a half) = 1.6 W/m^{2}K, early cavities = 1.7 W/m^{2}K. Roofs with no insulation and no sarking felt = 3.85 W/m^{2}K, with sarking felt = 2.5 W/m^{2}K. Floors = 0.60 W/m^{2}K, windows = 4.8 W/m^{2}K.

Comment

Beyond the default U-value tables found in Appendix S of the Standard Assessment Procedure (SAP) documents, both the above publications are rare examples of attempts to estimate fabric heat losses for existing building stocks including pre-1919 traditional buildings.

These estimates however, suffer from a number of limitations, the stock age bands follow either changes in construction patterns or when, relevant changes, in buildings regulations and assume that buildings from certain periods will have conformed to the threshold limits set for the time. As pre-1919 buildings were not subject to building codes to limit heat losses the estimates for this age bracket rely on calculated losses.

The predominant calculation standard used, BS EN ISO 6946 has been criticised elsewhere as inappropriate to calculate fabric heat loss for solid stone walls based on work which compared calculated and measured U-values for these elements (Rye, 2010, 2011, Baker, 2011). This standard is structured around a modern conception of building forms made up of discretely layered materials consisting of known thermal properties (e.g. modern cavity walls) this is a problematic model for the more inhomogeneous forms of some existing solid walls whose materials and properties are difficult to define.

Notwithstanding the difficulties of providing a calculated U-value for a solid wall in general, the amalgamation of all pre-1919 buildings into a single category ignores a defining feature of traditional buildings, which is their diversity (partly a feature of age but also of highly localised construction patterns and material use). The notion that all buildings built before 1919 could all share approximately the same U-value for a particular element is barely credible.

The document for Northern Ireland attempts to address this by providing a number of different heat loss estimates for different pre-1919 wall types. It also recognises the difficulty of identifying an age bracket for a property and provides figures for walls of 'unknown' construction age. However, these figures again seem strange as U-values tend to decrease with wall thickness (Baker 2011) whereas timber frame walls in this document provide a lower U-value (1.7 W/m^2K) than a solid brick wall (2.0 W/m^2K). Timber frame walls are often quite thin (being the width of intermitted studwork) and therefore in measured studies are found to have higher U-vales than solid walls (Rye, 2010, 2011).

It should be noted that these documents state that if more accurate U-value data is available then this should be used for assessment, but make no suggestions as to how such data could be sourced. Other work (see below) suggests that for certain traditional constructions or buildings only a measured in situ U-value is likely to be accurate, however the reality of such measurements means this remains a specialist exercise.

The U-values provided in these documents may be misleading, for a more complete understanding of the U-values of traditional buildings please consult the papers by Rye (number 13 below) and Baker (number 10 above).

13. SPAB Research Report 1: The U-value Report 2010 (revised 2011) & The Energy Profiles of Historic Buildings: A Comparison of the In-situ and Calculated U-values of Traditionally Built Walls, 2011.

Rye C (2010 & 2011)

Abstract/Description

The energy performance of traditional buildings is poorly understood and yet it is of critical importance to current debates concerning climate change and the sustainability of the built environment. The predominant view, promoted by standard methods of assessment, is that older buildings are the least energy efficient of all existing UK housing stock. This research looks at the subject of energy performance in traditional buildings through a study of heat loss and investigates the U-values (thermal transmissivity) of traditionally built walls. It compares the U-values generated for a variety of old walls using two different quantification methods: *in-situ* method which measures a U-value from the wall itself; a U-value produced by a standard method of calculation. The investigation discovers a discrepancy between the two sets of U-values, with the conventional U-value calculation underestimating the thermal performance of the walls in 75% of cases.

The consequences of this performance gap are debated regarding the limitations of conventional methods of energy assessments for older buildings. In light of the findings, the research calls for improved understanding of the energy profiles of traditional buildings and asks that attitudes regarding older buildings, based on inaccurate assumptions, be re-evaluated to take account of the contribution that traditional buildings can make to a sustainable future.

Comment

Both the above papers record the results of in situ U-value measurements of 28 traditionally built walls and compare these with U-values calculated for the same walls using the standard calculation methodology, BS EN ISO 6946. This is the standard referred to in the document BR 443 Conventions for U-value Calculations which in turn is reference in Approved Documents Part L of the building regulations.

A significant discrepancy was found between the measured and calculated U-values which underestimated the thermal performance of the traditionally built walls. In light of these findings a similar comparison was carried out by Dr Paul Baker of measurements of solid walls that he had undertaken on behalf of Historic Scotland (see Number 10 above regarding Historic Scotland, Technical Paper 10, U-values and Traditional Buildings) and a similar discrepancy was found. These papers discuss the reasons for the failure of current calculation methods to provide accurate U-values for these walls as steady-state measurement calculations do not evaluate the contribution made to thermal performance by thermal mass (inertia) which is a prime factor in most traditionally constructed walls.

There is also the difficulty of providing a complete definition of an existing wall, of not knowing the exact types and quantities of materials within the wall build-up, the limited range of base thermal conductivity values for historic building materials and the rationale of the simplified calculating procedure itself which uses discrete forms of construction to model heat loss that are unrepresentative of traditional conglomerate forms.

The software calculator BuildDesk (based on BS EN ISO 6946 and guidance found in BR 443) further simplified the calculation process by not requiring a mortar fraction to be included in the calculation of a wall built of stone, thereby allowing unwitting operators to calculate a U-value as if the wall were made of solid stone. This is possible because there is no guidance which requires a technically more realistic approach.

The papers recommend that, in circumstances where accurate U-values are required for an existing building of traditional construction, *in-situ* measurements would be a more appropriate method. This quasi-dynamic method is able to take into account the complete thermal performance of the element without the need for total definition. It can account for the complexity of the structure without the need to describe it for calculation purposes. In situations where large-scale refurbishment work is planned or work is being undertaken on buildings of particular significance, an *in-situ* method should be preferred for U-value assessment to generate a more inclusive picture of thermal performance.

The *Energy Profiles of Historic Buildings* paper also demonstrates that there is a need for good quality energy performance data measured from actual buildings to inform debate and practices concerning energy reduction measures in both new and existing buildings. (The findings were further strengthened by a continuation of *in-situ* monitoring of a variety of walls through the winter of 2010-2011 by the SPAB. The results from two winters of research work show the same discrepancy, that U-value calculation over-estimate the degree of heat lost through traditional walls in 73% of the 58 samples walls.)

14. SPAB Research Report 2: The SPAB Building Performance Survey 2011 Interim Report

Rye C, Hubbard D, Scott C (2011)

Abstract/Description

This is an attempt to provide an assessment in order to engage more comprehensively with debates concerning energy efficiency and older buildings, by looking at a range of factors that may affect the energy performance and environmental behaviour of traditionally built dwellings. This was supported in part by a grant from the Dartmoor National Park Sustainable Development Fund.

Seven different properties, four of which are located in and around the Dartmoor area, were identified as being of traditional construction and scheduled for various forms of energy improvement interventions in 2011-12. During a two week period between January and April 2011, whilst in an 'unimproved' condition, various aspects of the energy performance and environmental behaviour in these seven properties were monitored and recorded. It is expected, once refurbishment work has been completed, that these same buildings will once again be measured during the 2011-12 winter season.

The survey looks specifically at fabric heat loss through the U-value measurement of wall elements both in the form of *in- situ* and calculated U-values, air infiltration through air permeability testing and thermography, moisture (room and wall moisture including wall surface and interstitial moisture) behaviour, indoor air conditions and comfort levels via the measurement of CO2, interior temperature and relative humidity.

When complete this study will present an analysis of the various parameters relating to fabric performance and the environment within the individual properties before and after refurbishment.

Comment

The findings from this interim study are also reported in a conference paper *The Performance of Traditional Buildings: the SPAB Building Performance Survey 2011 Interim Findings*. With regards to fabric heat loss the results confirm earlier findings by Rye 2010 & 2011 and Baker concerning lower than anticipated U-values measured *in-situ* for the traditionally built walls in the study and hence the overestimation of U-values for these walls by standard calculation processes.

Moisture measurements showed that wall surfaces were not affected by damp but the sub-surface of walls showed raised levels of moisture up to a nominal 'rising damp' height of 1.2m above finished floor level in ground floor rooms. Moisture ingress into the body of the walls was also noted in some cases at cill or lintel heights. Interstitial moisture was monitored and this showed no incidence of any condensation risk through the wall sections during the two week monitoring period and relatively safe dew point margins for all, but one of the walls.

Air permeability results were in line with previous studies for pre-1919 buildings (see Hubbard in sub-section 2.20) and modern extensions were found to be leakier than earlier parts of the constructions. Comfort levels were plotted against temperature and relative humidity indices and found to be below ideal and in some cases even acceptable levels. This is not perhaps surprising as all these dwelling were awaiting refurbishment in part motivated by the need to improve their comfort levels.

15. Her Majesty’s Courts Service: Justice Estate's Energy Use

Wallsgrove J (2008)

Abstract/Description

The Ministry of Justice has an annual £60 million energy bill. As with any other major property holder of public buildings, the continuing energy consumption of the law court estate is significant for Her Majesty’s Courts Service (HMCS). The assumption among most estates staff in HMCS, as in most businesses, was that older buildings, particularly those before 1900, were very energy inefficient. This was also felt to be the perception of most supporters of sustainability and energy efficiency. This is reflected in government policy, which was derived from theoretical research for housing. However, HMCS research using the unique and detailed data held on the unusually broad HMCS estate has proved this perception to be completely false for public buildings.

This established that the oldest buildings use the least energy and established a clear pattern of energy use per square metre related to age of the building. For public buildings, the oldest buildings (pre-1900) use the lowest energy (197kW/h per sq. m).

The pre-war buildings between 1900 and 1939 use 24 per cent more energy. The immediately post-war buildings from 1940 to 1959 use 45 per cent more energy and are by far the worst. The buildings of the 1960s use 36 per cent more energy than the pre-1900 buildings, whilst those of the 1970s and 1980s improve on this (average 21 per cent more energy use than Victorian buildings), and are therefore similar to the pre-war buildings. The court buildings of the 1990s and 2000s have managed to almost equal the energy efficiency of the pre-1900 buildings, and only exceed them by eight per cent.

This innovative research, using real data rather than theoretical calculations, has shown that the conservation of our architectural heritage historic is directly compatible with energy conservation, rather than being diametrically opposed, as some environmental fundamentalists believe.

Comment

Wallsgrove's findings, importantly based on measured data, are in clear contradiction to the findings previously cited in the DCLG Review of the Sustainability of Existing Buildings. Wallsgrove finds that there is a relationship between building age and energy efficiency, but it is in exactly the opposite direction to that found via the theoretical SAP method used in the DCLG report where "For public buildings, the oldest buildings (pre-1900) use the lowest energy (197kW/h per sq. m)".

Wallsgrove's age bands are idiosyncratic and do not provide a clear division for pre-1919 buildings and are from pre-1900 and then 1900-39. He finds that the worst performing buildings are found immediately after the 2nd World War (1945-1959).

Wallsgrove's study relates to public, court buildings and not to domestic dwellings used in the SAP assessment. A direct comparison cannot therefore, be supported but it serves to emphasis the uncertainty around the understanding of energy profiles and performance of pre-1919 traditional building stock.

16. Developing a Database of Energy Use of Historic Dwellings in Bath, UK

Moran F, Nikolopoulo M, Natarajan S (2012)

Abstract/Description

Historic dwellings in the UK make up 20% of all homes. In the Georgian city of Bath this rises to 30%. These buildings are amongst the most poorly performing part of the English housing stock in energy use terms, with the lowest SAP rating and highest average annual CO2 emissions.

The UK legal aim to reduce CO2 emissions by 80% by 2050 will involve all existing dwellings, including historic buildings. The degree to which proposals to retrofit the UK housing stock can reduce emissions therefore depends upon how much energy they currently use, what it is used for and how much CO2 they emit.

This paper establishes a benchmark of gas and electricity energy use and CO2 emissions for 102 pre 1919 (historic) dwellings in Bath, permitting comparison of their energy performance against other parts of the housing stock. The level of energy use found was less than expected using SAP values; it was also less than national, regional and local authority averages. The benchmark established allows a base line from which to monitor future performance and to gauge the direct benefits of retrofit adaptations.

Comment

This paper uses the term historic to describe what would more commonly be referred to as traditional buildings (as defined and used in this Gap Analysis study, that is, solid permeable constructed walls of pre-1919 date and with no DPC). Moran notes the lack of bench-mark data for the energy performance of pre-1919 buildings and this research sets out to address this gap and importantly once again finds an over-estimate of energy use by the SAP for traditional buildings in the study.

17. Review of the Sustainability of Existing Buildings: The Energy Efficiency of Dwellings - Initial Analysis

Department for Communities and Local Government (2006)

Abstract/Description

The analysis from this review so far shows that a substantial reduction in carbon emissions can be made by introducing cost effective technology, which can make substantial savings on fuel bills for consumers. This shows that there are still barriers to up-take of this, including information and up-front costs, which many of our developing policies are designed to address and in the longer term, new, emerging technologies and a wider range of measures must be considered to meet the 2050 timetable.

It also cites however, that there remains a close correlation between the age of a property and its energy efficiency, with the factors that have the greatest correlation with energy performance of the existing stock being age and dwelling type/size.

Comment

This analysis of the energy performance of existing UK building stock is made using the Standard Assessment Procedure (SAP) model; it finds a correlation between building age and poor energy performance with pre-1919 being shown to be the worst performing age bracket all the building stock. SAP has been shown not to provide an accurate assessment of the energy performance of traditional buildings (Heath et al 2010, Rye 2011, Moran 2012); therefore the findings of this study should be treated with some caution.

18. What is the Relationship Between Built Form and Energy Use in Dwellings?

Wright A (2008)

Abstract/Description

Energy is used in dwellings to provide four services: space heating, hot water, lighting and to power appliances. This paper describes how the usage of energy in a UK home results from a complex interaction between built form, location, energy-using equipment, occupants and the affordability of fuel. Current models with standard occupancy predict that energy use will be strongly related to size and built form, but surveys of real homes show only weak correlations, across all types of dwelling.

Recent research has provided insights into occupancy factors including preferred comfort, ‘take-back’ from thermal efficiency improvements, and patterns of electricity use. Space heating is on a downward trend and is low in new dwellings. Energy use for lights and appliances, which is weakly related to built form, is increasing. Strong legislation, combined with low-carbon technologies, will be needed to counteract this trend. Future challenges discussed include increases in real energy prices and climate change mitigation efforts, which are likely to improve the existing stock.

Challenging targets are now in place for new housing to move towards low or zero energy and carbon standards. In the longer term, dwellings will demand less energy. Alternatives to gas for space heating will be increasingly common, including ground source heat and local combined heat and power (CHP) from biomass, while electricity could come from a more de-carbonised electricity system. However, these improvements must be set alongside a demand for many new homes, demographic trends towards smaller households, and a more holistic approach to overall carbon use including personal transport.

Comment

Although Wrights study is couched in terms of built form, rather than building age, he makes the point that form is often related to building age. However, this paper once again provides a complication to the assertion in the DCLG paper that there is a strong correlation between building age and energy use. Wright explains " The actual energy usage of a home results from a complex interaction between its built form, its location, the energy-using equipment it contains, its occupants and the affordability of fuel.....Households have a stronger influence on energy use than does built form."

Building energy models such as SAP as Wright demonstrates are unable to take account of the multiplicity of factors that determine overall energy use in a building, including traditional ones.

19. Can we Improve the Identification of Cold Homes for Targeted Home Energy Efficiency Improvements?

Hutchinson E.J, Wilkinson P, Hong S.H, Oreszczyn T, Warm Front Study Group (2006)

Abstract/Description

Property and household characteristics provide only limited potential for identifying dwellings where winter indoor temperatures are likely to be low, presumably because of the multiple influences on home heating, including personal choice and behaviour. This suggests that the highly selective targeting of energy-efficiency programmes is difficult to achieve if the primary aim is to identify dwellings with cold-indoor-temperatures.

Comment

This study found that "Property and household characteristics provide only limited potential for identifying dwellings where winter indoor temperatures are likely to be low, presumably because of the multiple influences on home heating, including personal choice and behaviour".

Once again, although this does not provide any direct evidence for the energy efficiency and performance of 'unimproved' pre-1919 buildings, it does suggest that there is not a simple relationship between low indoor temperatures and fabric performance and cold buildings may not be a direct result of building age as if often assumed.

20. Air Tightness in UK Dwellings

Stephens R (2000)

Abstract/Description

Adequate ventilation is essential for the health and comfort of building occupants, but excessive ventilation leads to energy waste and sometimes discomfort. Often, the planned ventilation is augmented by unwanted infiltration through air leakage paths in the building envelope which leads to the concept of build tight – ventilate right. Attention has focused on reducing unwanted infiltration by the review of Part L of the Building Regulations, which will lead to reduced energy consumption in buildings to help meet Government targets for CO2 emissions. Published at the request of the Department of the Environment, Transport and the Regions, this Information Paper draws on BRE’s experience. Intended for a wide audience, it will be of interest particularly to those involved in the design, specification and supervision of the construction of new dwellings.

Comment

See Number 21 below for combined comments.

21. Ventilation, Infiltration and Air Permeability of Traditional UK Dwellings

Hubbard D (2011)

Abstract/Description

The focus of this paper is ventilation in traditional dwellings, specifically with reference to the English Heritage 'rule of thumb' for historic buildings, which is that it should be 'twice the normal level of ventilation'. Examination of the subject has occurred through a literature review and the empirical case studies of two groups of un-improved dwellings. The paper considers the ventilation of traditional buildings using the breakdown on the subject offered by the Building Regulations document for new build dwellings in England and Wales – Approved Document F.

Where occupancy patterns are available, for example, the case study on Fitz Steps, Cumbria, validity of the rule of thumb is questioned. The paper also shows that, for the dwellings studied as a whole, lower air permeability results, rather than orthodoxy would suggest, were recorded with common infiltration points between properties. There was also some evidence of modern extensions being less air-tight than the original dwelling.

A wide variation in measured air flow relating to chimneys was noted, raising questions over the air flow figures for this type of dwelling used in SAP (Standard Assessment Procedure) for the energy assessment of buildings.

Comment

This paper is largely based on Hubbard's CAT/UEL's MSc Thesis entitled *Ventilation and condensation in traditional Lakeland dwellings: controlling moisture and maintaining building performance* which featured a case study of 6 terraced houses in Cumbria monitored for internal temperature and relative humidity as well as air pressure tested. The research found lower than expected rates of ventilation for these properties, a finding which Hubbard has gone on to confirm through research on behalf of the SPAB (see Number 14 above).

The SPAB study generated findings regarding more modern additions to traditional buildings, which were found to be 'leakier' than the earlier parts of the building when tested. Hubbard's findings of "lower air permeability results than orthodoxy would suggest" correlates with Stephen's work on behalf of the BRE where data from 15 years of measurements from buildings across the full range of building stocks was examined.

Stephen's in *Air Tightness in UK Dwellings* (Number 20 above) finds that there is "A widely held belief in the UK is that older dwellings are more draughty, and therefore less airtight, than modern dwellings........there is no evidence to support such a trend in the BRE database....In fact, the oldest dwellings tend to be more airtight: the average air leakage rate rose in the 1920s." Although as Stephen's himself notes "most of the measurements were taken with chimneys sealed and no allowances were made in the results for them as per standard practice.

Hubbard is at present conducting research on the effect of chimneys on air permeability rates for traditional buildings.

22. Blickling Hall Basement Case Study, Environmental Monitoring of Brodick Castle and Investigation of Wetting and Drying Behaviour of Replica Historic Wall Constructions

Baker P, Sanders C, Galbraith G.H, McLean C (2007)

(This section combines three related case studies and reported in *Engineering Historic Futures* UCL Centre for Sustainable Heritage, 2007 see bibliography, references 2, 3 and 4)

Blickling Hall Basement Case Study

Abstract/Description

Blickling Hall, Norfolk, was selected as a suitable case study for field monitoring as part of the Engineering Historic Futures project, with the objective of collecting data for the validation of a hygrothermal model. The basement area, which was chosen for monitoring, has a history of flooding and suffers from severe algae problems and salt damage. The construction of the basement walls consists of approximately 700mm thick clay brick and lime mortar walls, lined partly with cement based tanking from floor level and lime plaster higher up the wall.

The south-west facing wall, which has a window with the sill just above ground level, was chosen for monitoring moisture contents using wooden dowels. Wall surface and room temperatures and relative humidities were measured. Climate data was collected using a weather station in the grounds of the Hall. Soil moisture contents were also measured in the area outside the basement for part of the monitoring period.

Whilst the basement has its own particular moisture problems resulting from a constant moisture supply, the monitoring results indicate that shifting the room conditions (e.g. reducing ventilation, introducing de-humidification) had a significant impact on the wall conditions. The intervention with de-humidification had the greatest impact, but partitioning demonstrated the importance of ventilation in ameliorating the wall conditions.

Comment

Monitoring carried out on basement wall of Blickling Hall "with the objective of collecting data for the validation of a hygrothermal model." Report concludes that "Whilst the intervention with de-humidification had the greatest impact, partitioning demonstrated the importance of ventilation in ameliorating the wall conditions." It makes no statement concerning the validation of a hygrothermal model.

Environmental Monitoring of Brodick Castle

Abstract/Description

Wall moisture content (using wooden dowels) and external weather conditions were monitored at Brodick Castle, Arran. The monitoring can be divided into two phases: before and after the installation of an air barrier in April 2005 to reduce air exchange within the room, including sealing off the roof space. The Tower (a Victorian addition to the building constructed from porous red sandstone, which laboratory measurements indicate has a high rate of moisture uptake) chosen for monitoring, suffers from water ingress problems, possibly as a consequence of driving rain.

Whilst evidence of fine lime putty joints in the external masonry was apparent, there had also been some use of cement mortar for repair work. The wall and ceiling plasterwork had been removed due to water damage and remedial work had been carried out on the roof timbers The Tower is unheated and draughty due to the exposed roof space, leaky windows and fireplace.

This report summarises the results of the monitoring period from July 2004 to February 2006. The environmental conditions within the unheated Tower respond to changes in the external climate, however, following partitioning the response of the Tower conditions are less dependent. This evidence suggests that the higher air exchange rates prior to partitioning tend to reduce the effects of moisture ingress through the Tower walls.

The wall conditions, e.g. the high surface humidities and dowel moisture contents and algae growth on the west wall, indicate that the Tower is still subject to moisture ingress problems. A cause of the continuing problems may be the result of the deterioration of the guttering around the parapet of the Tower. There is also evidence from the dowel moisture contents that the wall conditions depend on the degree of exposure to rainfall: the west wall receives about twice the rainfall of the east wall. Additional factors, which may exacerbate the problems, are the general level of maintenance of the mortar joints of the walls and the porous nature of the sandstone.

The results from the Tower suggest that it is important to improve maintenance regimes to mitigate the effects of climate change, particularly increased precipitation and vapour pressure.

Comment

Both this and the Blicking Hall case study used a resistivity method to monitor wall moisture content using wooden dowels. However, in an additional piece of research conducted as part of the *Engineering Historic Futures Project* the researchers, Baker, et al concluded that there were limitations to this method of moisture monitoring:

"The use of dowels is unsatisfactory for dynamic measurements of the moisture content of brick and sandstone in so far as the response lags behind that of the masonry materials, particularly during drying. This may give rise to a pessimistic assessment of the drying stage. However, the dowel measurements may be considered as a reasonable indicator of the state of the masonry over the longer term".

Investigation of Wetting and Drying Behaviour of Replica Historic Wall Constructions

Abstract/Description

This involved the construction of two replica historic walls in summer 2004 within the Glasgow Caledonian Laboratories as a means to test, under less restricted and more controlled conditions, aspects of both brick and sandstone masonry wetting and drying behaviour. Instrumentation was installed and monitoring of the walls commenced in December 2004, but due to the long curing of the lime mortars used, the first tests were carried out in October 2005 after the walls were considered to have reached a stable condition.

The tests involved flooding the base of the brick wall and spraying the stone walls followed by a period of unassisted drying. A second flooding test was performed in December 2005, with subsequent forced drying using a dehumidifier. Further spraying of the stone wall was also carried out.

Flooding Tests

Whilst it is evident that the drying process requires several months, even using a de-humidifier, time constraints did not allow a proper comparison with natural drying. The 50 day period allowed for the natural drying of the wall was insufficient, except for locations near to the cold side of the wall, where the drying time was similar to the de-humidification test.

Spraying Test

The sandstone wall was sprayed regularly with water to simulate driving rain. The results indicate that whilst the relative humidity near to the cold surface rises in response to the spraying, the conditions within the core of the wall and near to the warm side of the wall appear to be largely unaffected. In comparison, the monitoring results from Brodick Castle indicate that moisture ingress in a wall of similar construction and material properties is largely the result of the deterioration of the sealing of guttering chased into the stonework.

The implication is that a sound constructed and well maintained wall should perform to keep moisture out of a building under current climatic conditions with the relatively high levels of precipitation experienced at Brodick Castle, and with increased rainfall in the future climate scenario.

23. Understanding and Controlling the Movement of Moisture through Solid Stone Masonry Caused by Driving Rain

Wood C (2010)

Abstract/Description

Wind driven rain (WDR) affects a significant number of historic buildings constructed of solid masonry walls comprising two leaves of facing stones and a rubble and mortar core. Those of greatest value tend to be tall, exposed structures situated in areas of high rainfall. Church towers in the south west of England are especially affected and this can result in damage to historically important fabric and finishes and an uncomfortable and unhealthy environment for worshippers. The biggest problem is often diagnosing the condition of the wall and determining where the ingress is occurring and which remedial treatment is most appropriate. A failure to get this right has resulted in repairs making the problem worse.

This research employs a combination of small and large scale laboratory tests with monitoring on sites and investigations of case histories to provide information on the diagnosis of problems and effectiveness of remedial treatments, concentrating on pointing and grouting and the importance of workmanship.

The results indicate that rendering and grouting are the most effective treatments as is re-pointing, providing that voids in the core were also filled. A significant amount of data was produced on the differing performance of mortar mixes bound with hydraulic and non-hydraulic limes and the effect of additives, which allowed tentative conclusions to be drawn on their performance.

Workmanship also proved to be a significant factor particularly for re-pointing and grouting. Monitoring with timber dowels was successful, but finding an effective method which responds more quickly would benefit future research.

24. Refurbishing Victorian Housing IP 9/06

Yates T, BRE (2006)

Abstract/Description

This paper outlines a method of assessing the refurbishment of traditionally built houses dating from the period 1840–1919 similar to that used in BREEAM (BRE Environmental Assessment Method) EcoHomes. It looks at competing requirements for modern energy and acoustic standards, whole building performance and the effects of durability, reliability and maintainability of the building fabric. It is of interest to construction professionals responsible for refurbishment of Victorian housing.

The paper summarises the economic, environmental and social costs and benefits of retaining this part of the building stock and sets out a methodology that can be used in the assessment process. It is based on a recent BRE Trust Report Sustainable Refurbishment of Victorian housing (FB14), which deals with the topic in much greater detail and includes several case studies.

Comment

This paper is concerned with the cost benefit analysis of refurbishing Victorian and Edwardian Houses. It acts as an introduction to the methodology used by the BRE assessment tool 'EcoHomes XBC' which can identify the limits of improvement, which allow the important aspects of the built heritage to be retained whilst maximising the improvements in environmental performance. The development of the tool was informed by practical refurbishment projects including one in Nelson, East Lancashire.

This paper however, makes little reference to practical refurbishment measures or measured performance data of pre-1919 housing stock and is more concerned with sustainability in its broadest sense both cultural, economic and social

25. Building Conservation and Sustainability in the United Kingdom

Godwin P.J (2010)

Abstract/Description

This paper seeks to examine the extent to which the principles of sustainability are applied in the conservation, restoration and adaptation of historic buildings in the United Kingdom. It will also outline how traditional buildings are already examples of sustainability and how they can be made to be more sustainable without doing harm to their character. It also explores the ways in which tried and tested building techniques, craftsmanship and the use of traditional materials can still be used to meet emerging standards for sustainability and energy conservation. Whilst concentrating on historic properties the use of traditional materials and building techniques in respect of new-build is outlined, particularly in the context of retaining local distinctiveness and identity.

Comment

In essence, this paper is an examination of conservation principles and aesthetic concerns in relation to traditional and historic buildings and issues of energy efficiency. It provides a list of elements that prove problematic regarding energy efficiency upgrades for older buildings and a discussion about vernacular materials in relation to broader issues of sustainability.

There is little technical information in the paper and some assertions concerning building performance are unsubstantiated. Ultimately it is an argument that social/cultural factors need to be taken into account within arguments of sustainability in order to protect historic buildings.

26. Sustainable Heritage: Challenges and Strategies for the Twenty-First Century

Cassar M (2009)

Abstract/Description

This article looks at the intersection of heritage conservation and sustainability and how these two disciplines will together address the challenges of this century.

Comment

A broad based discussion on the principles of historic building conservation and sustainability; "so the next step for heritage conservation is an obvious one, to align the principles and practices of conservation in the twenty first century fully with sustainability principles".

27. Energy Analysis Focus Report: A study of Hard to Treat Homes Using the English House Condition Survey - Part 1

Building Research Establishment, Department for Environment Food and Rural Affairs, Energy Saving Trust (2008)

Abstract/Description

This report provides a detailed analysis of the numbers and characteristics of the 'Hard to Treat' (HTT) building stock in England using data from the English House Condition Survey (EHCS). A 'Hard to Treat' dwelling is defined as one that, for whatever reason, cannot accommodate 'staple' or cost-effective fabric energy efficiency measures. Four categories of dwellings have been considered as Hard to Treat in this work; dwellings with solid walls, dwellings off the gas network, dwellings with no loft and high-rise flats.

The dwelling, heating and household characteristics of the HTT stock have been investigated and detailed tables are presented. In England, 9.2 million dwellings can be considered Hard to Treat, accounting for 43% of the total stock.

Solid wall and off-gas network dwellings make up the largest component. Nearly 84% of this Hard to Treat stock is in the private sector with the private rented tenure comprising the greatest proportion of Hard to Treat dwellings at more than 50% of this sector. London has the highest percentage of Hard to Treat dwellings, due mainly to the large number of solid wall dwellings.

The second section of this report presents the results of a preliminary exploration of the Hard to Treat stock in relation to the potential for staple energy efficiency measures. Currently, 81% of the Hard to Treat stock has the potential to have some energy efficiency measures installed leaving 1.7 million dwellings which are not able to be cost-effectively addressed with staple energy efficiency measures.

Data collected from the interview survey of the EHCS provides a unique opportunity to assess householders' attitudes to various aspects of their homes, including how effective their heating is and their ability to keep warm. Those living in a Hard to Treat home are much less likely to find their heating and insulation systems 'very effective' compared to those living in a non-Hard to Treat home. A relatively large number of residents in high-rise flats find it hard to keep warm in their living rooms in winter.

Comment

Just below half (45%) of the Hard to Treat building stock identified in this report dates from pre-1919.

28. Resilience of 'Nightingale' Hospital Wards in a Changing Climate

Lomas K.J, Giridharan R, Short C.A, Fair A.J (2012)

Abstract/Description

The National Health Service (NHS) Estate in England comprises more than 30 Mm2 with 18.83Mm2 of acute hospital accommodation on 330 sites. There is concern about the resilience of these buildings in a changing climate, informed by the experience of recent heat waves. However, the widespread installation of air conditioning would disrupt the achievement of ambitious energy reduction targets.

The research project 'Design and Delivery of Robust Hospital Environments in a Changing Climate' is attempting to estimate the resilience of the NHS Estate on the basis of current and projected performance, using an adaptive comfort model. This paper presents results relating to a 1920s traditionally built block with open 'Nightingale' wards, being a representative type. The paper demonstrates the relative resilience of the type, and illustrates a series of light-touch measures that may increase resilience while saving energy.

The results presented in this paper will be of value to NHS Trusts Estates staff charged with operating buildings as well as Boards and others involved in decision-making and policymakers in central government and the Department of Health, as well as those who own, operate or are tasked with working on non-domestic buildings with heavy traditional construction.

Comment

Lomas' paper (2012) on the 'resilience of "Nightingale' hospital wards' to climate change identifies a number of features common to many traditional buildings, that is, narrow sections, high floor to ceiling heights and high mass walls which provide excellent potential for cooling.

29. Investigating the Thermal Characteristics of English Dwellings: Summer Temperatures

Firth K.S, Wright A.J (2008)

Abstract/Description

This paper describes a nationally representative study of summer temperatures in English dwellings. Living room and bedroom temperatures were recorded at 45 minutely intervals for 224 dwellings from 22nd July to 31st August 2007.

Overall, living rooms had an average temperature of 21.4°C and bedrooms 21.5°C. Average daily maximum temperatures in living rooms were 25.9°C and in bedrooms 26.6°C. The average external air temperature over the period was 15.3°C. The variation in summer temperatures for different dwelling built form types and age bands is investigated.

Of built form types in this study, purpose-built flats and end terraces demonstrated the highest average summer temperatures and the greatest potential for over-heating. For age bands, post-1990 dwellings showed the highest average temperatures and are most likely to over-heat. Average summer temperatures in dwellings are highest in the evenings (17:15 to 23:15) and lowest in the morning (06:45 to 09:00).

The benefits of further study analysing the relationships between internal and external temperatures is also discussed.

Comment

Firth and Wright find that inversely "Pre-1919 dwellings are the least likely to overheat, possibly due to their high thermal mass". However, the contribution of thermal mass (a feature of many traditional buildings) makes to cooling is not discussed and appears to be unclear.

30. Dwelling Temperatures and Comfort during the August 2003 Heat Wave

Wright A, Young A.N, Natarajan S (2005)

Abstract/Description

More frequent hot summers in the UK under climate change could lead to increased discomfort in dwellings, but there is little published field data on internal summer temperatures.

Temperatures were measured in four dwellings around south Manchester and five dwellings in London during the August 2003 heat wave. Resultant statistics and various comfort metrics indicated a high level of discomfort in most dwellings, particularly in London. Daily internal temperatures were shown to correlate strongly with a time-decaying function of daily outside temperatures. Day and night temperatures were shown to relate to the type of structure.

It is concluded that if heat waves become more common, this would lead to increased discomfort, with implications for health, mortality and housing design. The results presented in this paper show what actually happens to a sample of dwelling temperatures during a severe UK heat wave, and the consequences for comfort. Little has been published on this previously.

The correlations between time-averaged outside temperatures, and internal temperatures, provide a method for predicting dwelling temperatures in the future in a warming climate, without the need for detailed simulation and including real occupancy effects such as window opening, which are difficult to simulate reliably. Since there were many excess deaths during the August 2003 heat wave, health is an important concern.

Work by others on this issue has shown that mortality rate is correlated with a three-day moving average of outside temperature above a threshold. This moving average correlates closely with the type of time-averaged outside temperature used in the paper. It seems quite possible that a 3-day moving average is a good predictor of excess mortality because it is also a good predictor of internal building temperatures, due to the mediation of thermal mass. This provides an alternative, or additional, explanation to that which explains the mortality as the cumulative result of high external temperatures acting on the human body over a few days, without considering the effects of buildings.

Comment

Some findings in this paper appear to contradict the assumption that thermal mass can have a beneficial cooling effect during a heat wave, particularly within bedroom constructions. The authors state "Clearly further work needs to be done on the benefits and disadvantages of thermal mass and night ventilation in bedrooms during hot summer weather."

Thermal mass is often cited as one of the advantages provided by traditional building construction both for heat retention and cooling potential. In this paper the contribution made to cooling by thermal mass is emphasised as needing further study and is particularly pertinent as part of adaptation strategies in response to climate change.

3. Gap Analysis Summary

Examination of the documents reviewed during this study revealed a number of significant 'gaps' in understanding regarding the performance and energy efficiency of traditional buildings and these are summarised in the following categories:.

3.1 Evidence on Performance in Relation to Energy Efficiency of Traditional Buildings

In general, there is very little work which describes or quantifies the performance of traditional buildings in relation to energy efficiency. There is, on the other hand, a body of work which attempts to provide evidence of *changes* to the performance of existing buildings, including traditional buildings, as a result of retrofit or refurbishment interventions. An evaluation of this is contained in the *Responsible Retrofit' – A Green Deal Research Project for the Department of Energy and Climate Change DECC* Gap Analysis report (still to be published). Evidence from these descriptions is often flawed because it is not based on any direct measurements or observations of buildings prior to retrofit work and frequently relies on modelled assessments to prove assertions of improvement.

3.2 Modelling Techniques

This study demonstrates that the current models used to make assessments of the energy performance of building fabric; buildings and whole building stock are particularly problematic when applied to traditional buildings.

Papers by Barnham and Heath for Historic Scotland which review a number of building energy assessment models provide significant evidence to support this view. The problem with models also forms a major part of Gentry's *Hearth and Home Scoping Study* for English Heritage (see section 2.3 above) where the BREDEM model (the basis of SAP assessments) is found to have an uncertainty ratio of up to 50% when applied to traditional building stock.

Rye (2010, 2011a) and Baker (2011) both provide evidence for the short comings of heat loss models for traditionally built walls which leads to a misunderstanding regarding the thermal performance of these elements (and thus contributes to the degree of error embedded in whole building energy models).

There are numerous other reasons for this modelling gap: a lack of accurate base case data about, and understanding of, the construction forms of traditional buildings and traditional building materials: grouping all buildings built before 1919 under a single set of performance assumptions is not appropriate for what is in reality a diverse range of buildings: misunderstanding and lack of knowledge of both fabric and ventilation heat losses for these types of buildings.

3.3 Reverse Performance

The uncertainty surrounding modelling processes is, in some cases, realised by the misalignment of modelled building performance and actual performance (Moran, 2012, Rye 2010, 2011a, Baker 2011).

The discrepancy between modelled and measured performance has been described elsewhere as a performance gap. This concept is better known in relation to studies that have analysed the performance of new buildings, where it is found, that modelling over-estimates the energy efficiency of a building in comparison with measured energy consumption[2].

In the case of traditional buildings there is some evidence that the performance gap is in a reverse direction, that is to say that models *under-estimate* the energy efficiency of either elements of traditional building performance, such as fabric or ventilation heat losses, or whole performance energy use.

3.4 Perception Regarding Traditional Buildings

Older, traditional buildings are frequently positioned as the poorest performers of all existing building stocks regarding energy consumption, a view which originates in part from modelled predictions.

An examination of the limited evidence base of measured data from pre-1919 buildings does not support this perception. Heat loss through solid walls is found to be no different to post-1919 unfilled cavity walls. Air permeability and ventilation rates for pre-1919 buildings are actually better than buildings built between1945-59.

A shift in attitude regarding traditional building performance is therefore, required to correctly judge the energy saving potential offered by these buildings and accordingly inform any required work. For this to occur there however, needs to be a robust and comprehensive evidence base to underpin assertions of traditional building performance. Only then can prevailing attitudes be wholly challenged, informed and changed.

3.5 Uncertainty Regarding Changes to Traditional Buildings

One consequence of the paucity of evidence surrounding traditional buildings is the many unknowns regarding the performance of these structures. This is particularly the case regarding moisture behaviour, air permeability, ventilation and the role of thermal mass.

The lack of understanding of 'base case' performance leads to increased uncertainty regarding changes to these buildings, particularly alterations to attain energy improvement. Traditional buildings are constructed of moisture permeable fabric and rely on a balance between ventilation and fabric moisture buffering to maintain a healthy environment, both for human health and fabric longevity. Mould growth and indoor air quality is a factor of both ventilation and moisture balances within a building (amongst other things) and refurbishment work which alters the air and moisture permeability of a property may alter these moisture balances.

Refurbishment strategies quite correctly identify improvements to air tightness as one way to reduce energy consumption within a building, yet there is currently no data available on recommended minimum ventilation rates for traditional buildings.

3.6 User Behaviour

Human behaviour has a significant effect on building energy consumption, for all buildings, not just traditional buildings, however, determining and accounting for the effect of this is problematic. No current work specifically looks at the effect of human behaviour on the performance of traditional buildings. Just as these constructions are different in terms of fabric and building methods, how we live in them may have a strong effect on energy efficiency. For example, are ubiquitous heating

2 See work by Leeds Metropolitan University, by Wingfield, J., Bell, M., Miles-Shenton, D., & Seavers, J. (2011). Elm Tree Mews field trial – evaluation and monitoring of dwellings performance: final technical report. and the BRE, Doran, S., Kosima, L. (1999). Examples of U-value calculations using BS EN ISO 6946: 1997. East Kilbride: Building Research Establishment.

systems appropriate for buildings of traditional construction, which is, with high ceilings and thermally massive walls? A greater understanding of the interactions between users and traditional buildings is required to inform debates and strategies on the efficiency of these buildings.

3.7 Monitoring

Due to the limitations of model derived descriptions of traditional building performance there is a considerable need for performance data measured from the actual buildings themselves.

Monitoring is perceived as difficult and expensive and there are at present technical limitations to some forms of measurement particularly in the field of moisture monitoring, and few protocols to govern monitoring practices. Nevertheless, due to the present uncertainty embedded within modelled data, precedence should be given to measured data over and above modelled information.

Measured data gathering methods should be improved and be used to inform understanding of traditional building performance as well as calibrating modelling tools and thus improve modelling outcomes.

Building performance monitoring programmes should include feedback mechanisms which allow findings in the field to inform building energy assessment models. There are at present a small number of on-going studies, which combine monitoring and modelling to develop understanding of the consequences of refurbishment for traditional building. Great attention should be paid to these results when published and the work thoroughly interrogated and an iterative relationship between modelling and monitoring encouraged.

4. Recommendations for Further Work

The following are the key recommendations arising from this Gap Analysis Study:

1. A radical expansion of research endeavours is urgently required to establish a substantial and robust evidence base for the performance of traditional buildings.

2. Evidence should primarily be gathered directly from traditional buildings themselves via *in-situ* monitoring, field measurements and on site observation.

3. More work is urgently required in relation to specific questions surrounding the energy efficient refurbishment of traditional buildings, particularly in the areas of moisture behaviour, ventilation, thermal behaviour and cooling, indoor air quality, fabric degradation and effects on human health.

4. Research evidence should not be restricted to the technical performance of whole buildings and building elements. This should also include all aspects of human behaviour that impinge upon building energy consumption, such as, occupant behaviour, but also refurbishment design, installation and maintenance practices including construction site practices.

5. More appropriate building energy models for traditional constructions need to be developed, which are informed by measured data and accurately defined material properties for the traditional materials found within older buildings in the United Kingdom.

6. Those involved in the practices of design, specification and modelling for traditional buildings, including refurbishment strategies, need to be aware of the limitations of the current evidence base and the consequences that this on their decision making regarding the mitigation of risk.

7. A more nuanced understanding of the 'performance' of traditional buildings in general is required, based upon a credible account of the technical performance of these buildings, including both their embodied and potential contributions to carbon reduction targets. This would recognise the real value of traditional buildings within energy efficiency debates and sustainability more generally.

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6. Partners in this Gap Analysis Study

About CITB-ConstructionSkills

ConstructionSkills is the Sector Skills Council (SSC) for the construction industry. It is a partnership between CITB-ConstructionSkills, CIC and CITB-ConstructionSkills Northern Ireland. It is UK-wide and represents the whole industry from professional consultancies to major contractors and SMEs.

Established as an SSC in 2003, ConstructionSkills works to deliver a safe, professional and fully qualified construction workforce. All three partners are committed to working together to deliver industry-led skills and training solutions through the Sector Skills Agreement for construction. This includes negotiating the best partnership and funding deals for the construction industry to help raise standards, increase diversity and develop the skills products and services employers need.

For more information visit www.cskills.org

About English Heritage

English Heritage is the Government's statutory adviser on the historic environment, with responsibility for protecting and promoting all aspects of the historic environment and works in partnership with central government departments, local authorities, voluntary bodies and the private sector to conserve and enhance the historic environment, broaden public access to heritage, and increase people's understanding of the past.

In November 2004, English Heritage and ConstructionSkills signed the first ever Sector Skills Agreement for the historic environment sector co-ordinate the development of traditional building craft skills in England and continue working together under this agreement to address the skills needs of the sector.

For more information visit www.english-heritage.org.uk

About the Sustainable Traditional Buildings Alliance

The Sustainable Traditional Buildings Alliance (STBA) is an umbrella group of organisations working in the built environment, seeking to improve understanding of traditional buildings, their impact on environment and society and the construction industry's impact on buildings. It is inclusive and not aligned to any particular organisation and promotes the need to learn more about the actual performance of traditional buildings and for training and funding to be based upon this and inform the risks and benefits associated with upgrading traditionally constructed buildings and structures.

The STBA, which was formally launched at Somerset House, London on 29th November 2011 currently includes organisations such as, Cadw, CITB-ConstructionSkills, English Heritage, Historic Scotland, CIOB, RIBA, RICS, National Trust, SPAB, Good Homes Alliance, UCL Energy Institute, Parity Projects. Other organisations and individuals with an interest in the aims and objectives of the STBA are encouraged to join. www.stbauk.org