Improving Energy Efficiency in Traditional Structures: Work by Historic Scotland

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ABSTRACT

The reduction of carbon dioxide (CO_2) 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 type in Scotland. Following the established principles of traditional construction, 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; key processes and initial findings are presented and the savings achieved in certain site projects. Other related factors such as passive benefits and sustainability issues are presented together with an outline of the future research programme.

Keywords: Energy efficiency, traditional buildings, refurbishment.

INTRODUCTION

As a result of the potential impacts of climate change, significant attention is being placed on older buildings. Legislation passed by The Scottish Government (The Climate Change (Scotland) Act 2008) has set the most demanding reductions and the built environment (especially housing) has some challenging targets to reach. In all sectors, an 80% reduction by 2050, with an intermediate target of a 40% reduction by 2020, is now set in law. This article introduces the challenges and opportunities facing typical existing buildings and a description of key areas of intervention and initial results. Most work described will be in process across a number of trial sites, although the measures used will be also be described in the context of a single project and the saving achieved there. Future research and other emerging themes will also be considered.

IMPROVING THE ENERGY EFFICIENCY OF TRADITIONAL BUILDINGS

Historic Scotland refer to traditional buildings generally, but not exclusively, as those structures in Scotland built before 1919. Such structures are normally constructed with double pitched roofs and solid masonry load-bearing walls, built from a limited palette of largely natural materials thought of in general as being vapour permeable. These structures, comprising an estimated 19% of Scotland's housing stock, include tenements, terraces, semi-detached houses, detached villas and cottages (Figure 1). Many of these buildings have no statutory protection and are vulnerable to interventions as a result of thermal upgrading especially with regard to wall insulation and other changes where large amounts of historic material are at risk of removal.

Figure 1. Late nineteenth century tenements in Edinburgh. (Historic Scotland.)

As attention focussed on upgrade options of traditional stock, it became apparent that there was little accurate data on the actual thermal performance of traditional building elements. This resulted in a research schedule for testing of building fabric that has allowed better baseline performance information to be obtained. This work was carried out in partnership with Glasgow Caledonian University [1] and Napier University in Edinburgh. Generally these results indicate that calculated performance values gave a poorer performance that what was actually measured. This data allows a more modest improvement to bring the fabric performance within required tolerances. In addition the measured values obtained can now be used as input into assessment methodologies in the building assessment processes. How older structures are assessed is a developing area of which the Energy Performance Certificate (EPC) is possibly the best known method to date and required under European Legislation since 2009. Work commissioned by Historic Scotland on assessment methodologies has outlined the respective attributes of the different systems used in the UK and how they assess traditionally built structures. It is clear that further work is required in this area to allow certain benefits of older structures to be realised.

To summarise these research strands, and to prove on site the interventions being considered, a set of pilot refurbishments were set up by Historic Scotland and other stakeholders in the Summer of 2010. Such pilot projects included work on tenement flats, detached rural cottages and other buildings described as “hard to treat”. To summarise the techniques and approaches used in the pilots a small detached rural property, the former Gardner’s Bothy at Dumfries House was extensively refurbished and will form the vehicle for the dissemination of best practice refurbishment of older structures. For ease of reference this building is called the “test cottage” in this text.

Figure 2. The Historic Scotland Test Cottage. (Historic Scotland)

RESEARCH AND IMPROVEMENTS TO TRADITIONAL FABRIC

Windows

Windows, a long standing and high profile area of sensitivity, were the natural starting point for the research. In Scotland the dominant window type, the vertical sliding sash in a timber case, is proven and durable, and was the focus of testing. In a programme run with English Heritage, two windows were tested at Glasgow Caledonian University in an ‘as received condition’ and subsequently with a range of interventions. Heat flux metres measured heat transfer through the glazing and allowed the actual U-value of the interventions to be calculated. The interventions ranged from draught stripping, fitting of roller blinds, shutters and curtains, continuing on to secondary glazing and more invasive options with double glazed units. A full report [2] is available from the Historic Scotland website.

What the tests showed clearly is that there is a scale of interventions to suit a range of conservation situations. The use of new roller blinds improved the U value by 28%, use of shutters gave an improvement of 51%, which when used combined with a blind gave an improvement of 58% - down to an opening value of 1.8 W/m^2K . Other measures were tested, including secondary glazing, lined curtains and retrofitting double glazed units within the existing timber sashes. While use of double glazed units is considered controversial, it is considered better to have manufacturers repairing or making timber windows in a form with which conservation bodies are comfortable than have industry develop less satisfactory options on their own.

In a separate project, a trial run by Changeworks for the City of Edinburgh Council and supported by The Edinburgh World Heritage Trust, a more detailed study of advanced glazing systems was undertaken. This project evaluated a range of slim profile double glazed units in the windows of a B listed property in use as social housing. This range of glazing products was trialled for cost, thermal performance, ease of installation, appearance and embodied energy. The windows being tested were modern and all dated from a refurbishment in the 1980s. Historic Scotland funded the testing of the thermal performance and the embodied energy of the products and their installation. The results were encouraging in terms of both thermal performance and appearance, although cost remains an issue and is considered in the final report [3]. The intention is to monitor the windows over a two-year period to fully assess durability and long-term thermal performance.

Figure 3 Original windows in the test cottage. (Historic Scotland)

The existing windows in the test cottage will be removed, re-glazed, fitted with draught strips and re-fitted. With windows and door improvements a calculated improvement of 5% in the energy running costs, equating to 0.8 tons of CO_2 per annum is achieved with this intervention.

Mass walls

The performance of mass masonry walls, common in Scotland and other parts of the United Kingdom, seemed especially unclear, with a lack of measured data and a lot of assumptions among designers and regulatory bodies as to the actual thermal properties of traditional masonry.

Historic Scotland therefore commissioned a programme of basic research that measured a wide range of walls across Scotland and how they performed thermally. This used *in situ* heat flux metres in a similar manner to the method used for the glazing tests. The results gave a generally better performance than expected (calculated U-values for a typical mass wall of 600 mm in thickness range from 1.5 to 2.5 W/m^{2}K) and certain broad conclusions were drawn, i.e. a dry mass wall of around 600 mm in thickness (very common in Scotland in buildings of all types) generally had a U-value of 1.0–0.9 W/m^{2}K . The full report with these results [4] including comparison with the calculated values is available from the Historic

Scotland website. Knowing the real U-value of a mass wall and accepting that its performance falls short of modern requirements (a U-value of 0.28 Wm^2K for current UK regulations), what are the insulation options: internal or external insulation; strip out and re-line; or upgrade the linings *in situ*? From a building and materials conservation point of view, removal of traditional linings such as lath and plaster should not be considered. However, in many cases such finishes may have been removed in the past and replaced by modern materials, thus allowing greater intervention.

An opportunity arose to test a range of internal insulation products in six social housing units in Glasgow dating from *c*. 1900. The existing walls were tested for thermal performance before removal of the modern plasterboard and the rear rooms of the flats were then retrofitted with a range of six different insulation materials. Some materials were applied directly onto the inside masonry face while others were fitted on new timber strapping. The insulation materials, ranging from a silica-based insulant to a wood fibre board, achieved the designed U-value of 0.33 W/m^2K with minor variation between products. In terms of moisture and potential condensation in the former space, initial results from Jan 2011 are that moisture levels are within tolerance in the masonry core and in the former void space. Full results of this trial will be available following the project evaluation in spring 2011.

In order to retain original and historic linings, the current focus by Historic Scotland on internal wall insulation is intervention in the void behind the lath and plaster (the traditional internal lining technique used since the 17^{th} C). Site trials over the winter of 2010/2011 involved the insertion of various form of blown materials into the cavity space in a range of structures. This will reduce volume advection of air, but not compromise the ability of water vapour to disperse through the structure – which ideally remains vapour permeable both inside and out. Insulation material has now been blown into cavities in a range of properties, including the test cottage. Long-term in situ monitoring will assess the humidity levels at the internal masonry and in the now partially filled void

Figure 4. Application of blown cellulose insulation (Historic Scotland).

These blown insulation techniques have also been used in the upstairs rooms of the test cottage. In the down stairs rooms, where no original plaster remained, hemp board, finished with a lime plaster, was installed. This internal insulation as a modelled energy improvement of 25% or 3.9 tons of CO_2. Full on site evaluation is presently being conducted to test the calculated savings with those achieved.

Roofs and attics

There are a range of standard roof insulation options, and as part of the test cottage programme sheep's wool insulation has been laid between and above the joists to a thickness of 250mm. Some building types present difficulties, especially when installing insulation in what are known as combed ceilings (the sloping part of a ceiling on a top floor) and often such areas are left unimproved. As a consequence, a significant proportion of the roof area is not covered (Figure 5); effective insulation of coombs will be tested over the winter of 2010.

Figure 5. Poor insulation of coombs revealed by snow melt. (Historic Scotland.)

Roof insulation was installed in the test cottage as part of the works. This consisted of 250mm of sheep's wool insulation, laid between and above the joists. This material is now proving to be an effective insulator, capable of handling moisture and water vapour in traditional structures. As is well know, roof and loft insulation is by far the most cost effective intervention on any building, and in this case there is a modelled saving of 15% in energy consumption or 2.3 tons of CO_2.

Floors

Heat losses through floors are significant in thermal terms and also in human comfort terms where low radiant temperatures from the heat sink of an un-insulated floor can significantly affect perceptions of warmth. Timber floors at ground level can be insulated by adding material underneath the floor (Figure 6), although unless there is crawl space, it will be necessary to lift the boards. Parquet and hardwood floors are especially problematic and intervention might not be cost-effective.

Fig 6. A timber floor being re-laid following addition of insulation board. (Historic Scotland).

Some solid floors have considerable potential for upgrade. Un-insulated concrete floors are common in Scotland on ground floors in a range of properties, especially traditional buildings that were modernized prior to the 1980's. Such concrete floors can be improved by the addition of a thin insulated floor layer (35 mm) on top of the concrete. Tests with Changeworks at Lauriston Place in Edinburgh)with proprietary insulation gave a six-fold improvement in U-value, down to 0.35 W/m^2K. Some trimming of the bottom of doors was required but skirtings were able to be left *in situ*. The proportions of the rooms were not adversely affected by such a thin layer, and as vapour movement through concrete is minimal, the addition of a further layer was not thought to be damaging. Where original material survives, traditional or historic stone floors can be lifted and re-laid on an insulated lime hemp concrete base layer or other lime-based material, without need for a damp-proof course, thus maintaining vapour movement through the floor. Relaying a floor in this fashion was done in a recent conservation project at Blackburn House (Figure 7), and also at our test cottage, where a new lime concrete floor was laid. Upgrade of the floors at the test cottage gave a reduction of 4% in energy costs or 0.6 tons of CO_2. This modest saving should be considered in the light of the additional thermal comfort factor, and that the assessment tools give low weighting to floors at present.

Figure 7 Laying insulating lime hemp floor. (Simpson and Brown Architects.)

Air tightness and air quality

In refurbishment achieving a good balance of natural ventilation and air tightness is important, for the benefit of the occupants and the fabric. Many commentators have raised concerns about ventilation rates in housing of all types and ages, and Historic Scotland funded a scoping study by GAIA Research to look at some of the issues [5]. Others have commented on the health effects of low air change rates; for example, Howieson [6] considers why asthma rates in Scotland are now many times higher than they were in 1960 and suggests that reduced ventilation rates in the UK housing stock may have been responsible for this trend.

However, an increase in the air tightness of the test cottage was necessary and was achieved by draft proofing of the windows, the new door and new laid floors in the ground floor. The existing chimneys and flues were retained as a key part of the ventilation strategy and later work in 2011 will examine the effectiveness of heat recovery from air extracted via the upstairs bedroom chimney flues. On the ground floor one flue was used for a wood pellet burning boiler, the second was fitted with a small log burning stove. Traditional construction practice can offer many benefits in air quality management, especially that of humidity control - traditional finishes such as limewash and distemper offer many benefits in being able to absorb excess water vapour in times of high humidity load – the principle of humidity buffering. Traditional materials used for linings and finishes are known to have this property, and modern materials such as clay paint and modern distemper used in refurbishment are equally effective. Some of these finishes and materials will also be tested by Historic Scotland in the test cottage over the next eighteen months and their effects on internal humidity regulation assessed.

Energy and Carbon Savings for the Test Cottage

The fabric interventions and their effects were modelled using RDSAP and NHER (UK domestic stock assessment tools) and an Energy Performance Certificate was produced for the as found state and the post interventions state. Modelling the works described gave an energy saving of 63% or 14.8 tons of CO_2. Running costs we reduced by 47%, showing clearly that even in rural areas traditional properties can be upgraded at realistic cost.

FUTURE WORK

Site Trials

Historic Scotland, as part of the Scottish Government, is actively involved with other government departments in developing a range of improvement options for variety of indigenous housing stock in Scotland. Historic Scotland will continue its work on energy efficiency in the non-domestic and domestic sector through a second phase of site interventions and evaluation. Trials will be conducted in a range of traditionally built properties to further develop simple and cost-effective interventions that are replicable across housing and other built stock in Scotland. Such site projects will be a small house on the Island of Uist in the Hebrides, further work at the test cottage, and small house upgrades with The National Trust for Scotland. The results will be published as case studies and will seek to guide best practice in the refurbishment sector.

Dissemination and Training

In addition to site trials, dialogue is being developed with a range of stakeholders involved in the delivery of training and the provision of advice to the business and residential sectors. Technical solutions will only be effective if there are the professional skills to properly specify and direct the work, and the trade skills to carry out this work to a proper standard. This also means that there needs to be educational materials with which to deliver training. Historic Scotland is developing an interactive CD of the test cottage, showcasing the various upgrades options for the fabric. This will be used at trade and professional level training, to ensure that Architects, specificers and those who will do the work have the knowledge and understanding to work with existing fabric on appropriate energy improvements.

Embodied Energy

The wider sustainability arguments of new materials, their origin, make-up, toxicity and disposal costs are being increasingly considered during procurement and in addition to developing practical measures for intervention, Historic Scotland will seek understand better the arguments regarding embodied energy and how they should influence not only argue for the retention of existing structures (historic or otherwise), but how they are repaired and upgraded.

CONCLUSION

Work by Historic Scotland in quantifying the thermal properties of the traditional building envelope has allowed a better assessment of what is required instead of a default to a worst case application of upgrade solutions. Through its on-site and laboratory-based research programme, Historic Scotland has identified a range of ways by which traditional fabric can be upgraded to nearly modern standards while retaining original fabric and without compromising the essential vapour dynamic that characterizes traditional construction.

References

1. Baker, P., Historic Scotland Technical Paper 2. In situ U-value Measurements in Traditional Building (Interim Report), Historic Scotland, Edinburgh (2008).
2. Baker, P., Historic Scotland Technical Paper 1. Thermal Performance of Traditional Windows, Historic Scotland, Edinburgh (2008).
3. Heath, N., Baker, P. and Menzies, G., Historic Scotland Technical Paper 9. Slim Profile Double Glazing, Thermal Performance and embodied energy, Historic Scotland Edinburgh (2010).
4. Baker, P., Historic Scotland Technical Paper 10, U-Values and Traditional Buildings, Historic Scotland Edinburgh (2011).

5. Halliday, S., Historic Scotland Technical Paper 6. Indoor Air Quality and Energy Efficiency in Traditional Buildings, Historic Scotland, Edinburgh (2008).
6. Howieson, S., Housing and Asthma, Spon, London (2005).

All Technical reports are available free as PDF's from the Historic Scotland Website:
http://www.historic-scotland.gov.uk/index/conservation-research.htm