Assessing the execution of retrofitted external wall insulation for pre-1919 dwellings in Swansea (UK)

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Abstract:
The purpose of this paper is to evaluate the execution of retrofitted external wall insulation as a method of improving the thermal performance of pre-1919 dwellings with solid exterior walls. Public and private case study dwellings in Swansea, UK, have been monitored before, during and after installation of external wall insulation, which have been funded by the Welsh Government's Arbed I scheme. The installations have been procured by a principal contractor through a 'Design and Build' contract with Coastal Housing Group and Family Housing Association, based in Swansea. The methodology for the research includes field observations, to record technical solutions implemented on site, and pre-retrofit and post-retrofit thermographic surveys, to assess heat loss through the dwelling fabric. The findings include photographic, technical and thermographic evidence of potential thermal bridges, resulting from an incomplete covering of insulation. Whilst some thermal bridging is unavoidable, some could have been avoided with systematic preliminary surveys and technical detailing at the design stage and improved execution of quality on site. Furthermore, external wall insulation manufacturers are recommended to explore the development of additional products and methods to enable thermal bridging to be avoided at critical junctions encountered at pre-1919 dwellings. This paper will be of interest to stakeholders involved in improving the thermal performance of existing dwellings in the UK.

Keywords:
External wall insulation, Evaluation, Pre-1919 dwellings, Thermal bridging, Wales

1 Introduction

Within the UK, Wales has some of the oldest and poorest quality housing stock. Approximately 30% of dwellings in Wales were built prior to 1919 and of these 90%

have solid exterior walls, which mean they lose around 45% of their heat through this one thermal element (Energy Saving Trust (EST), 2011a; EST, 2011b). In 2009, the Welsh Government implemented the Arbed scheme in recognition of the requirement to make mass thermal improvements to the poorest quality dwellings in Wales (Welsh Assembly Government (WAG), 2010a). Arbed is the Welsh word for 'Save'. The scheme is a Strategic Energy Performance Funding Programme, which is being run over two phases. The aim is to improve the most deprived 15% of publically and privately owned dwellings in Wales. The first phase of Arbed (Arbed I hereafter) has been delivered by housing associations and local authorities across Wales (ibid). One of the funding requirements was that monitoring and evaluation should be undertaken to assess the effectiveness of the improvement measures (WAG, 2010b). However, the methodology had very limited funding allocated for these assessments across Wales.

A three year doctoral research project was instigated in response to the requirement for these assessments to be undertaken, which commenced in August 2010. The research is being undertaken within the Ecological Built Environment Research and Enterprise group at the University of Wales Institute Cardiff (UWIC). Working in collaboration with Coastal Housing Group (CHG), based in Swansea, one of the objectives of the research includes collecting and analysing data before, during and after retrofitted thermal improvements through the Arbed I scheme in Swansea. The main improvement measure undertaken and thus the main focus of the research is that of retrofitted external wall insulation to pre-1919 dwellings with solid exterior walls.

The aim of this paper is to appraise the execution of retrofitted external wall insulation applied to pre-1919 dwellings through the Arbed I scheme in Swansea. Retrofitting insulation to improve the thermal performance of pre-1919 dwellings is relatively uncommon in the UK. As a result, there is limited experience and guidance available, particularly to older existing dwellings where typical construction details cannot be applied. The potential outcome is for the possibility of avoidable thermal bridging and consequent condensation. It is proposed that evaluating the installation of retrofitted insulation through the Arbed I scheme in Wales offers an opportunity to analyse the issues encountered at pre-1919 dwellings. To explore this proposal, field observations to record technical solutions on site and pre-retrofit (pre-R:T) and post-retrofit (post-R:T) thermographic surveys have been undertaken at a sample of pre-1919 dwellings in Swansea. These methods are to be followed by trade, building owner and occupant satisfaction surveys. The retrofitted insulation was initiated by CHG and Family Housing Association (FHA), who are both housing associations based in Swansea. The installations were implemented using a design and build contract with a principal contractor, who employed sub-contractors to undertake the work. The site operatives also had access to technical assistance from the manufacturers of the insulation systems.

The research is limited to the case studies in Swansea and thus not a reflection of installations generally across the UK. Nevertheless, the findings could be applied to other locations in the UK where there are pre-1919 dwellings. The key findings are that: the occurrence of thermal bridging is either avoidable and unavoidable at different junctions within the exterior walls; greater attention is required before and during the design stage and during installation to ensure avoidable thermal bridges do not occur; and the suppliers of the systems are recommended to explore the possibilities for additional products and methods to minimise instances of avoidable thermal bridging further. The findings are expected to be of benefit to stakeholders involved in implementing thermal improvements to pre-1919 dwellings. This paper commences by reviewing literature to discuss the advantages and challenges for using external wall insulation and methods of evaluating installations. This is followed by the research methodology, findings and discussion and conclusions drawn from the research.

2 Retrofitting external wall insulation to solid exterior walls

2.1 External wall insulation

Whilst external wall insulation is not suitable for all dwellings with solid exterior walls, for example where the external facade has a particular aesthetic value, it has many advantages over the alternative of using internal wall insulation to improve thermal performance (Immendorfer *et al,* 2008a; Immendorfer *et al,* 2008b). The main advantages include: increased opportunities to achieve a complete covering and thus remove risks posed by unavoidable thermal bridging, for example at partition wall and floor junctions; improved air-tightness; thermal mass exposed to the internal space to control overheating risk is retained; less disruption to occupants; no loss of internal floor area; and internal fixtures and fittings do not have to be relocated or restricted to predetermined locations (English Heritage, 2010; King and Weeks, 2010; Immendorfer *et al,* 2008a; Immendorfer *et al,* 2008b; Construction Products Association, 2010).

Where a complete covering of insulation is not achieved, the cold un-insulated areas (thermal bridges) will entice a concentration of condensation to these locations as the load will no longer be shared by the other warmer surfaces (English Heritage, 2010). Thermal bridging between thermal elements and around openings can be responsible for approximately 30% of heat loss from a building (King and Weeks, 2010). Heat loss is also reduced as a result of improving air-tightness. External wall insulation systems seal gaps and cracks in the building fabric, which cause draughts as a result of warm air being replaced by cold air. This cold air then requires heating, thus using more energy (EST, 2010). The use of external wall insulation can further reduce energy use as it allows the thermal mass of solid walls to be retained for use within the dwelling, which aids the maintenance of indoor comfort levels (Immendorfer *et al*, 2008b).

Nevertheless, retrofitting external wall insulation can pose significant technical challenges. Whilst challenges can be experienced in terms of repositioning rainwater downpipes, external lights and satellite dishes for example, the main challenge is that of avoidable thermal bridging. As with all domestic renovations involving existing thermal elements, Approved Document L1B of the UK Building Regulations recommends that thermal bridging is avoided wherever possible (H.M. Government, 2010). Minimising instances of thermal bridging is critical to avoid internal and interstitial condensation and reduce heat loss (King and Weeks, 2010). Whilst internal wall insulation poses a risk of thermal bridging at partition wall and floor junctions, which are unavoidable, external wall insulation presents challenges in other locations. To avert avoidable thermal bridging, the design of retrofitted external wall insulation requires particular attention when detailing: around window and door openings; wall to roof junctions; window sills; and at any projections, such as porches or conservatories (CPA, 2010; English Heritage, 2010; EST, 2006; Immendorfer *et al,* 2008a). Appropriate preliminary surveys are required to achieve design details to prevent avoidable thermal bridging

(Energy Solutions, n.d). These surveys are also a technical requirement stipulated under the installation guidance for external wall insulation systems accredited by the British Board of Agrément (BBA), for example certificate number: 03/4058, issued for one of Wetherby Building Systems Limited's external wall insulation systems (BBA, 2011).

In some circumstances it may not be possible to achieve the necessary level of detailing required to avoid thermal bridging (English Heritage, 2010). Subsequently, English Heritage (2010) argues that, if the consequences of the thermal bridges are likely to be severe, it may be better not to insulate at all. When other building work is being undertaken, this could offer the ideal opportunity to install external wall insulation without creating any thermal bridges. For example, where a new roof covering is being applied to a dwelling with flush eaves, the roof could be extended to provide an overhang to cover the top of the external wall insulation (CPA, 2010). The alternative is that the top of the insulation is protected by a capping. Nonetheless, it is inevitable that with this approach there will be a thermal bridge created at the eaves (ibid). The next issue to overcome is one of execution. Once appropriate detailing at the design stage has been achieved, this then needs to be coupled with delivery on site. Poor workmanship can undermine design intentions, resulting in the occurrence of avoidable thermal bridging and thus a reduced thermal performance (Immendorfer *et al,* 2008a). In order to develop knowledge of the issues surrounding thermal bridging, related to retrofitting external wall insulation, undertaking an evaluation of installations could provide valuable feedback, based on empirical evidence.

2.2 Evaluating retrofitted external wall insulation

The assessment of thermal performance of buildings is often referred to as Post-occupancy Evaluation (POE) (Zimring, 2010; Leaman *et al,* 2010). Established methods of data collection include: questionnaires; interviews; site visits/field observations; and recording of technical solutions and performance of the building fabric, services and systems (ibid). In order to gain maximum cooperation from occupants and building owners, where they differ, the choice of methods should be determined to limit intrusiveness, duration and costs, as much as possible (Leaman *et al,* 2010). Traditionally, POE is undertaken for new buildings. However, there is an emerging field of POE for existing dwellings that have received thermal improvements (ibid).

The most documented strategy in the UK is that which has been developed by the EST and Technology Strategy Board (TSB) for the TSB's 'Retrofit for the Future' programme (TSB and EST, 2009). Drawing on methods used to assess new dwellings, data collection and analysis techniques include: air-leakage pressurisation tests; thermal imaging; co-heating tests; walk-through inspections; dwelling performance monitoring of temperature, relative humidity and carbon dioxide (CO_2); outputs from renewable energy sources; occupant interview surveys; and trade and building owner satisfaction surveys (ibid). Thomsen and Rose (2009) advocate the use of infrared thermography to identify thermal bridging, relating to execution on site. This claim is also supported by Pearson and Seaman (2003), who argue that thermal imaging provides an efficient way of determining the effectiveness of insulation applied to the fabric of buildings.

3 Research Methodology

The focus of this research is to evaluate the execution of retrofitted external wall insulation installed to pre-1919 dwellings in Swansea, UK, through the Arbed I scheme. The literature review in Section 2.1 above, highlighted that the main challenge when retrofitting external wall insulation is that of avoidable thermal bridging, resulting from either inadequate preliminary surveys or design details, poor execution or a combination of all three. In terms of evaluating retrofitted external wall insulation, Section 2.2 above listed a number of data collection methods and analysis techniques that could be used. In deciding upon a methodology for this research, the following factors were considered: appropriateness; intrusiveness; duration; and costs. Co-heating tests, dwelling performance monitoring and outputs from renewable energy sources are not considered appropriate for evaluating the execution of external wall insulation systems. Air-leakage pressurisation tests, in combination with thermal imaging, were considered inappropriate because they are intrusive and disruptive from an occupant's perspective.

Therefore, the methodological approach decided upon are: field observations to record technical solutions on site, using photography and production of technical details; pre-retrofit (pre-R:T) and post-retrofit (post-R:T) thermography surveys; and trade, building owner and occupant satisfaction surveys. The lead and second authors of this paper are Level One certified thermographers and have access to a thermal camera for use on the project. The lead author is a qualified Architectural Technologist and therefore trained to analyse technical details. In addition, approval has been granted by the appropriate UWIC ethical committee for the questionnaires, developed to undertake the trade, building owner and occupant satisfaction surveys. Collectively these methods of data collection could provide sufficient information to effectively evaluate the execution of retrofitted external wall insulation at pre-1919 dwellings. To date (October 2011), field observations and pre-R:T and post-R:T surveys have been undertaken; these results are summarised in Section 4 below. Trade, building owner and occupant satisfaction surveys are ongoing; these results will be documented in a future publication.

3.1 Field observations

Field observations were undertaken before, during and after retrofitted external wall insulation at the pre-1919 dwellings, which were part of the Arbed I scheme in Swansea. In addition to the lead author taking photographs, CHG provided photographs from their records for their Arbed I dwellings. Technical details were produced using a combination of the photographs and observations made during site visits. Annotations have been added to the details using information obtained from the manufacturer's specifications. In addition, the details produced from the field observations have been compared to the external wall insulation manufacturer's generic details.

3.2 Thermography surveys

The pre-R:T and post-R:T surveys were used to qualitatively assess retrofitted external wall insulation at four pre-1919 dwellings. The thermal images produced from qualitative surveys provide thermal patterns that indicate possible locations of increased heat loss. The process for implementing the thermography surveys involved contacting each occupant to: explain the purpose of the survey; advise them of the date, time and names of the thermographers; and to request that they activate their heating prior to the survey, to ensure there was a sufficient temperature difference between the outside and inside of the dwelling. The environmental criteria for undertaking a thermographic survey includes a minimum temperature difference of 10°, along with no solar radiation and precipitation for the preceding hour and 24 hours, respectively and a maximum wind speed of 10 meters per second. In addition to the thermal images, photographs were taken to aid visual interpretation when analysing the results.

4 Findings and Discussion

This section of the paper provides an overview of findings from field observations and the pre-R:T and post-R:T surveys undertaken at a sample of Arbed I pre-1919 dwellings in Swansea (A to D). The results from field observations include photographs taken before, during and after installations of retrofitted external wall insulation and technical details produced using a combination of photographs, observations and manufacturer's specifications. The thermal images were taken before and after retrofitted insulation.

4.1 Field observations

The photograph in Figure 1 was taken during the installation of the insulation at sample dwelling A. The grey area in the centre of the image has not been insulated for the reason that if it had been then the occupant would not be able to open the window. The result is a potentially large thermal bridge. This issue could have been identified in a preliminary survey and a more acceptable solution to the problem determined. Figure 1 also shows a potential thermal bridge at the eaves of the extension, which can be seen in the top left of the image, due to a capping having been installed, below the fascia board, to cover the top of the insulation. However, without extending the roof overhang, this approach to protecting the top of the insulation appears to be the only solution offered by the manufacturer.

The photograph in Figure 2 was taken during the installation of the insulation at the plinth of the external wall, which joins the pavement in front of dwelling sample B. There are gaps between the insulation boards and between the insulation and the rail supporting the insulation that is covering the remainder of the wall above. These gaps appear to be due to poor workmanship on site and could lead to condensation as a result of thermal bridging. In addition, it would appear that there is sufficient door frame depth to accommodate a reduced thickness of insulation at the door reveal. However, no insulation was installed on the door reveal.

The photograph in Figure 3 was taken after the installation of insulation at dwelling sample C and shows the eaves and gable wall junction of an end-terrace dwelling. The new fascia board stops short of the end of the external wall. As a result, a small area of insulation, which had not been covered by the fascia board, had to be rendered and a dash finish applied. In addition, the overhang of the capping had to be cut away to allow the new rainwater downpipe to be fitted and thus poses a risk of insufficient protection to the top of the insulation. Had an adequate preliminary survey been undertaken, there could have been appropriate detailing at the design stage and then this could have been executed on site.

Figure 4 shows the generic detail for one of the external wall insulation systems used in Swansea, produced by one of the Arbed I approved suppliers, as published in BBA certificate number: 03/4058 (BBA, 2011). Figure 5 shows the reproduction of a construction detail, as observed on site by the lead author, at dwelling samples A, C and D, which is different to the manufacturer's recommendations. It would appear from the observed detail that an attempt has been made to retain the feature of the window sill for aesthetic purposes and to also reduce heat loss further than that recommended by the manufacturer. Whilst aesthetically this approach appears to be more acceptable, without completely covering the sill (above and below) with insulation, the attempt to reduce heat loss is likely to be in vain as there are still paths for potential thermal bridging (as shown in Figure 5). A possible solution would be to use a reduced thickness of insulation on top of the window sill and to return the insulation underneath.

Figure 1: Example of thermal bridging resulting from an inadequate preliminary survey

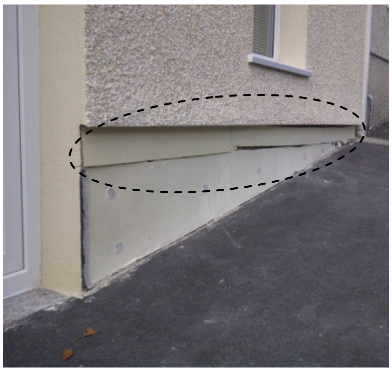

Figure 2: Example of poor execution, which could lead to thermal bridging

Figure 3: Example of poor detailing and execution resulting from an inadequate preliminary survey

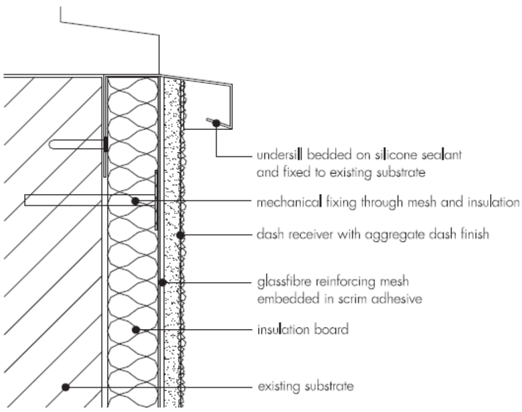

Figure 4: Window sill detail by one of the approved Arbed I suppliers (BBA, 2011)

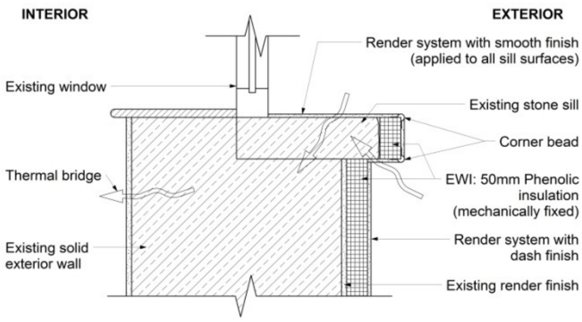

Figure 5: Window sill detail as observed on site

4.2 Thermographic surveys

Within the thermal images, the lighter shades represent the greatest amount of heat loss and the darker shades, the least. *Please note: the temperature scale on the thermal images is not representative of actual temperature readings as these are qualitative survey images.* Figures 6 and 7 show dwelling sample D before the external wall insulation system was installed.

Figure 6: Photograph of dwelling before installation of insulation

Figure 7: Pre-R:T survey image of dwelling, as shown in Figure 6

The apparent increased heat loss from the ground floor external wall to that for the first floor could be a result of the first floor rooms being cooler due to the window being open. Figures 8 to 10 show the same dwelling sample D, after the insulation was installed. Figure 10 does not illustrate the whole dwelling; it is just a focus on the bottom of the external wall. There appears to be evidence of thermal bridging: at the step below the external door; at window and door reveals; under the window sill; and where the insulation used at the base of the wall joins that used for the remainder of the wall above. Overcoming the potential thermal bridge at the step and below the exterior door is a junction where a solution does not appear to have been explored; this is evidenced by the lack of information available within the manufacturer's documentation, for example BBA certificate number: 03/4058 (BBA, 2011).

Insulation was not installed at the window and door reveals due to the frame thickness not being of an adequate size, despite a new door having been fitted as part of the works. However, without adjustments to the width of the opening, which could have been considered as part of a preliminary survey, a thicker door frame may have resulted in the access being below the recommended minimum width. As demonstrated in Figure 5; insulation was not installed above and below window sills. Whilst the thermal image does not show the top of the window sill, due to the angle that it was taken, there is evidence of heat escaping below the sill as a result of insulation having not been installed in this location. The heat loss between the insulation at the base of wall to that above is likely to be due to gaps created by poor execution, as demonstrated in Figure 2 above. However, it should be noted that Figures 2 and 9 are different dwellings. Whilst overall heat loss appears to have been reduced, there is evidence of thermal bridging due to an incomplete covering of insulation and poor execution on site. Together, Figures 2, 3 and 10 could be used as part of training material for external wall insulation installers to provide a visual method of illustrating the consequences of poor execution on site.

Figure 8: Photograph of dwelling shown in Figure 6, after installation of insulation

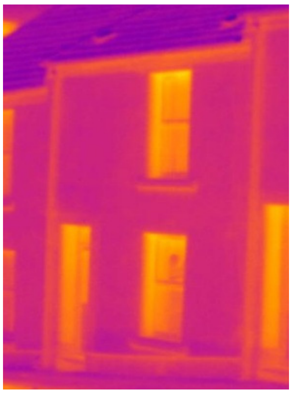

Figure 9: Post-R:T survey image of dwellings, as shown in Figure 8

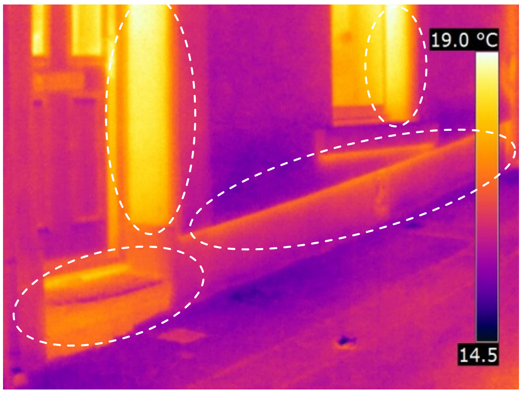

Figure 10: Post-R:T survey image showing focus of lower section of facade for dwelling shown in Figure 8

5 Conclusion and Further Research

This paper has presented the methodology and key findings from part of an evaluation for the execution of retrofitted external wall insulation at pre-1919 dwellings with solid exterior walls, through the Arbed I scheme in Swansea, UK. The paper began by reviewing literature, which discussed the advantages and challenges posed by retrofitting external wall insulation to existing dwellings and established methods of evaluating building work. The main advantages of installing external wall insulation, over the alternative of internal wall insulation, were identified as: reduced instances of unavoidable thermal bridging, for example at partition wall and floor junctions; increased air-tightness; and retained use of thermal mass. However, the main challenge for retrofitting external wall insulation is that of eliminating avoidable thermal bridging in locations such as: window and door openings; wall to roof junctions; and window sills. To overcome these challenges, it is desirable to undertake thorough preliminary surveys, which should be followed by suitable technical details at the design stage and then quality execution on site.

Based on established techniques of data collection, the methodological approach taken for this research involves: field observations to record technical solutions implemented on site, using photography and technical detailing; pre-retrofit (pre-R:T) and post-retrofit (post-R:T) thermography surveys; and trade, building owner and occupant satisfaction surveys. The findings presented in this paper are from data collected to date (December 2011) and include an overview from field observations and pre-R:T and post-R:T surveys. The data confirms that pre-1919 dwellings present many technical challenges for retrofitting external wall insulation, particularly when adequate preliminary surveys and technical details are not undertaken. As a result there is photographic, technical and thermographic evidence of thermal bridging due to an incomplete covering of insulation and poor execution. Furthermore, manufacturers of these systems appear to offer a limited range of products and methods for overcoming critical junctions within pre-1919 solid exterior walls. It is therefore recommended that further technical solutions are explored by all stakeholders involved in retrofitting external wall insulation to pre-1919 dwellings. As a method of improving standards of installation for retrofitting external wall insulation, it is recommended that photographs and thermal images from this type of research, for example Figures 2, 3 and 10, are used for training purposes to illustrate the consequences of poor execution.

The next stage of the research is to complete the trade, building owner and occupant satisfaction surveys. These surveys will provide valuable feedback from all stakeholders involved in the Arbed I scheme in Swansea and further extend the knowledge gained from the experience. Further research is recommended to assess the implications of the potential thermal bridges identified in this paper by monitoring and measuring condensation risks to both the dwellings and occupants. The aim of these assessments should be to determine if it is acceptable to insulate as much as possible, knowing that some thermal bridging will occur, or if it is absolutely critical to achieve a complete covering. In addition, technical details for retrofitting external wall insulation should be developed and disseminated to overcome some of the non-standard junctions encountered at pre-1919 dwellings, preferably using ecological materials.

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7 References

British Board of Agrément. (2011), *Certificate number: 03/4058 - Epsicon External Wall Insulation Systems,* British Board of Agrément, Watford, UK.

Construction Products Association. (2010), *An introduction to low carbon domestic refurbishment,* CPA, London.

Energy Saving Trust. (2006), *CE184 – Practical refurbishment of solid-walled houses*, EST, London.

EST. (2010), *CE309 – Sustainable Refurbishment*, EST, London.

EST. (2011a), ‘Pre-1919 homes in Wales’, presented at Existing Homes Alliance, Cymru, April 2011, *EST*, Cardiff, UK.

EST. (2011b), ‘Solid wall insulation’, *EST,* http://www.energysavingtrust.org.uk/Home-improvements-and-products/Home-insulation-glazing/Solid-wall-insulation, viewed: 20 April 2011.

Energy Solutions. (n.d.), *Cost Effective Retrofit Solutions for Solid Wall Properties,* Energy Solutions, London.

English Heritage. (2010), *Energy Efficiency in Historic Buildings – Insulating Solid Walls*, English Heritage, London.

H.M. Government. (2010), *Approved Document L1B-The Building Regulations 2000',* HMSO, London.

Immendoerfer, A., Hough, C., Andrews, A. and Mathias, A. (2008a), *Fit for the Future – The Green Homes Retrofit Manual, Technical Supplement,* Housing Corporation, London.

Immendoerfer, A., Hough, C., Andrews, A. and Mathias, A. (2008b), *Fit for the Future – The Green Homes Retrofit Manual,* Housing Corporation, London.

King, C. and Weeks, C. (2010), *IP 3/10 - Sustainable refurbishment of non-traditional housing and pre-1920's solid wall housing*, BRE Press, Watford, UK.

Leaman, A., Stevenson, F. and Boardass, B. (2010), 'Building evaluation: practice and principles', *Building Research and Information,* **38 (**5), pp 564-577.

Pearson, C. and Seaman, A. (2003), *Condition-based maintenance using non-destructive testing,* BSRIA, Berkshire, UK.

Technology Strategy Board and EST. (2009), *Evaluating energy and carbon performance in the 'Retrofit for the Future' demonstrator projects – Version 2,* EST, London.

Thomsen, K. E. and Rose, J. (2009), *Analysis of Execution Quality Related to Thermal Bridges,* Danish Building Research Institute, Denmark.

Welsh Assembly Government. (2010a), "Arbed – Strategic energy performance investment programme", http://wales.gov.uk/topics/environmentcountryside/energy/efficiency/arbed/?lang=en, viewed: 20 August 2010.

Welsh Assembly Government. (2010b), "Phase 1 Projects", http://wales.gov.uk/topics/environmentcountryside/energy/efficiency/arbed/phase1projects/?lang=en, viewed 20 August 2010.

Zimring, C. (2010), 'Facility Performance Evaluation (FPE)', *National Institute of Building Services,* http://www.wbdg.org/resources/fpe.php, viewed: 27/04/2011.