



Structural Survey

Emerald Article: Assessing retrofitted external wall insulation using infrared thermography

Joanne Hopper, John R. Littlewood, Tim Taylor, John A.M. Counsell, Andrew Michael Thomas, George Karani, Andrew Geens, Nick I. Evans

Article information:

To cite this document: Joanne Hopper, John R. Littlewood, Tim Taylor, John A.M. Counsell, Andrew Michael Thomas, George Karani, Andrew Geens, Nick I. Evans, (2012), "Assessing retrofitted external wall insulation using infrared thermography", Structural Survey, Vol. 30 Iss: 3 pp. 245 - 266

Permanent link to this document:

<http://dx.doi.org/10.1108/02630801211241810>

Downloaded on: 21-11-2012

References: This document contains references to 32 other documents

To copy this document: permissions@emeraldinsight.com

Access to this document was granted through an Emerald subscription provided by CARDIFF METROPOLITAN UNIVERSITY

For Authors:

If you would like to write for this, or any other Emerald publication, then please use our Emerald for Authors service. Information about how to choose which publication to write for and submission guidelines are available for all. Please visit www.emeraldinsight.com/authors for more information.

About Emerald www.emeraldinsight.com

With over forty years' experience, Emerald Group Publishing is a leading independent publisher of global research with impact in business, society, public policy and education. In total, Emerald publishes over 275 journals and more than 130 book series, as well as an extensive range of online products and services. Emerald is both COUNTER 3 and TRANSFER compliant. The organization is a partner of the Committee on Publication Ethics (COPE) and also works with Portico and the LOCKSS initiative for digital archive preservation.

*Related content and download information correct at time of download.



Assessing retrofitted external wall insulation using infrared thermography

Retrofitted
external wall
insulation

245

Joanne Hopper, John R. Littlewood, Tim Taylor and
John A.M. Counsell

Cardiff Metropolitan University, Cardiff, UK

Andrew Michael Thomas

Coastal Housing Group, Swansea, UK

George Karani

Cardiff Metropolitan University, Cardiff, UK

Andrew Geens

*Chartered Institution of Building Services Engineers (CIBSE),
London, UK, and*

Nick I. Evans

Cardiff Metropolitan University, Cardiff, UK

Abstract

Purpose – The purpose of this paper is to discuss the methodology and results of using thermography for pre-retrofit (pre-R:T) and post-retrofit (post-R:T) surveys undertaken to qualitatively assess retrofitted external wall insulation (EWI) on pre-1919 existing dwellings with solid exterior walls.

Design/methodology/approach – This study involved undertaking qualitative thermography surveys before and after installation of EWI at two mid-terrace dwellings in Swansea (UK). One dwelling was part of a whole-street approach and the other was an isolated installation.

Findings – The two case studies have provided evidence of potential thermal bridges created as a result of an incomplete covering of EWI. Whilst overall heat loss appears to have been reduced, further evidence is required to establish the extent to which these thermal bridges reduce overall thermal performance.

Research limitations/implications – Only two schemes undertaken in Swansea (UK) are represented in this study and are therefore not a reflection of EWI installations generally. Nevertheless, the study suggests more general concerns with the installation of EWI where a continuous covering of insulation cannot be achieved. Further research is required to assess the long-term implications of thermal bridges on the condition of the dwelling and the health of occupants.

Originality/value – This paper has introduced and tested a pre-R:T and post-R:T methodology for assessing the thermal performance of deprived dwellings, which have had EWI retrofitted to solid exterior walls. By using the pre-R:T and post-R:T methodology the paper has demonstrated a visual method for illustrating problems in retrofitting EWI and highlighted improvements in thermal performance, which can be used by stakeholders involved in the maintenance and improvement of existing dwellings.

Keywords United Kingdom, Housing, Thermal insulation, Walls, Existing dwellings, External wall insulation, Infrared thermography, Thermal performance, Retrofit

Paper type Research paper

1. Introduction

The aim of this paper is to discuss the use of infrared thermography, as a qualitative test method, for assessing the installation of retrofitted external wall insulation (EWI)



to pre-1919 dwellings with solid exterior walls (SEWs). (Note: this is not about quantifying heat loss.) Installation of EWI to dwellings on a mass scale is uncommon in the UK and therefore there is limited experience on: the effectiveness of these measures; the implications of not providing a continuous covering; and how to overcome many of the non-standard junction details present in older existing dwellings. It is proposed that using thermography qualitatively is one method that can be used to overcome these issues by demonstrating to those responsible for implementation and installation of EWI systems, what the consequences are of poor execution and where to focus attention during future installations to prevent potential problems occurring.

To explore this proposal, qualitative thermography surveys have been undertaken at the same sample of pre-1919 deprived dwellings with SEWs in Swansea (UK), both before and after installation of retrofitted EWI. The two samples presented in this paper are terraced dwellings, with one being part of a whole-street approach and the other being an isolated installation. The EWI has been installed as part of a Welsh Government-funded thermal improvement scheme, entitled Arbed I, aimed at the most deprived dwellings in Wales. This study forms part of a three-year doctorate research project being undertaken by the lead author within the Ecological Built Environment Research and Enterprise (EBERE) group at Cardiff Metropolitan University, which commenced in August 2010. Primarily working in collaboration with Coastal Housing Group, the aim of the research is to investigate, develop and test a best practice ecological retrofit methodology for technical and social improvements to deprived existing dwellings in Wales, to reduce energy use, carbon emissions and fuel poverty and thereby increase occupant quality of life.

The paper commences by reviewing literature to: set out the rationale for improving the thermal performance of deprived existing dwellings in the UK and Wales; provide a brief overview of the issues surrounding the use of EWI; introduce the Welsh Government's Arbed I scheme; and present infrared thermography as a method of monitoring and evaluating the effectiveness of EWI. This is then followed by a description of the study in Swansea and the methodology used to undertake the infrared thermography surveys, along with the results, discussion and conclusions drawn from the study.

2. Background and context

2.1 Rationale for improving existing deprived dwellings

The UK Climate Change Act 2008 sets out a legally binding target for an 80 per cent reduction in greenhouse gas emissions by 2050, based on the 1990 baseline (H.M. Government, 2008). The main greenhouse gas contributing to climate change is carbon dioxide (Department for Environment, Food and Rural Affairs (DEFRA), 2007). Housing accounts for over 25 per cent of UK carbon emissions resulting from domestic energy use, with over 75 per cent of this energy used for space and water heating purposes (Department of Energy and Climate Change, 2010; Department for Trade and Industry, 2008). In addition, over two-thirds of the UK existing housing stock is predicted to still be in use in 2050 (Department for Communities and Local Government, 2008).

It is anticipated that reducing domestic energy use and subsequent costs will also contribute to a decrease in the number of households in fuel poverty. The factors

associated with fuel poverty are: high energy costs, low income and poor quality dwellings (Kemp and Wexler, 2010). Dwellings that are classified as being of poor quality are more likely to be older (typically pre-1919) and have a low energy efficiency rating (Howarth, 2010). Those dwellings with the lowest energy efficiency ratings (Standard Assessment Procedure (SAP) rating of 30 or below), qualify as a Category One hazard for excess cold under the Housing, Health and Safety Rating System and pose a significant risk to the health of occupants (Boardman, 2007).

Within the UK, 40 per cent of all dwellings with a SAP rating of 40 or below are in Wales (Energy Saving Trust (EST), 2011a). Wales has some of the oldest dwellings in the UK, with over 30 per cent having been built before 1919 and of these 90 per cent have SEWs, making it more challenging to improve their thermal performance (EST, 2011a; Howarth, 2011). Dwellings with SEWs lose approximately 45 per cent of their heat through this element alone (EST, 2011b). Therefore, improving the thermal performance of SEWs offers the greatest opportunity for reducing energy consumption for the purposes of heating these types of dwellings.

2.2 Upgrading SEWs

As documented in Hopper *et al.* (2011), EWI, rather than internal wall insulation, is considered the preferred method of insulating existing SEWs. The main reasons are: there are reduced instances of thermal bridging, for example, at floor and wall junctions; thermal mass is maintained, which aids regulation of internal environmental conditions; it improves air-tightness; and there is a reduced risk of interstitial condensation (Hopper *et al.*, 2011). EWI offers the greatest potential to achieve a complete covering of SEWs, to allow these benefits to be realised (Immendoerfer *et al.*, 2008a). Nevertheless, retrofitting EWI is not without its challenges, for example, adaptation is likely to be required at roof verges and eaves, services inlets and outlets, and window and door reveals (English Heritage, 2010; EST, 2010). The most significant risk posed by these challenges, is that of thermal bridging (English Heritage, 2010; EST, 2010).

According to English Heritage (2010), Immendoerfer *et al.* (2008a,b) and the EST (2006), thermal bridging can lead to condensation, which in turn could result in damp and mould growth internally in these locations and subsequently pose a health risk to occupants. In addition, English Heritage (2010) argues that if thermal bridges cannot be avoided and the consequences are likely to be severe, then it could be better not to insulate at all. However, the authors are unable to find any literature that documents the results of any long-term monitoring of post-retrofit dwellings and therefore the effects of remaining thermal bridging on the health of the occupants.

2.3 Arbed: improving Wales' most deprived existing dwellings

In recognition of the requirement to make mass improvements to deprived existing dwellings in Wales, the Welsh Government instigated the "Arbed" scheme in 2009 (WAG, 2010a). Arbed is the Welsh word for "save". The scheme is a Strategic Energy Performance Funding Programme aimed at improving the most deprived 15 per cent of dwellings in Wales, across both public and private ownership. Arbed I is being implemented by housing associations and local authorities across Wales to deliver localised economic, social and environmental benefits (WAG, 2010a). The types of measures being installed as part of the Arbed I scheme are: EWI; connection to the main gas network; solar thermal panels; solar photovoltaic panels; and heat pumps (WAG, 2010b).

One of the requirements of the Arbed I scheme is for monitoring and evaluation to be undertaken to determine how effective the improvement measures are at reducing energy use, carbon emissions and fuel poverty (WAG, 2010c). However, there was no methodology and very limited funding provided for these assessments. In Swansea, the main improvement measure being implemented is EWI to dwellings with SEWs that were built prior to 1919. According to Pearson and Seaman (2003), an efficient way of determining the effectiveness of insulation applied to the fabric of buildings is through the use of infrared thermography. This claim is also supported by Thomsen and Rose (2009), who have undertaken a study across Europe to analyse the occurrences of thermal bridges relating to execution quality on site, for both new build and retrofit building work.

3. Infrared thermography

All objects with a temperature above -273°C (absolute zero) emit radiant heat (Pearson, 2002). Thermography is a technique for producing a visible image of this invisible heat energy (infrared radiation) emitted from the surface of an object, through a non-contact thermal imaging device (Hart, 1991; Pearson, 2002; Snell and Spring, 2002; Infrared Training Center, 2010). A thermogram is the visible image produced through the use of an infrared camera (Hart, 1991; Infrared Training Center, 2010). The thermogram is a map of the temperature difference across the surface of objects being viewed, which are displayed as different colours or shades of grey (Snell and Spring, 2002; Pearson and Seaman, 2003; Lo and Choi, 2004). When interpreting thermograms, it is necessary to understand the surface characteristics of the materials being viewed, in terms of their emissivity and reflectivity. Materials with high-emissivity values have a low reflectivity and vice versa (Lo and Choi, 2004). Only materials with a high emissivity provide a reliable reading as materials with a low emissivity will tend to reflect the temperature of surrounding objects and thus could produce misleading results, particularly where they are being interpreted by someone who has not undertaken appropriate thermography training (Snell and Spring, 2002; Lo and Choi, 2004; Infrared Training Center, 2010).

Whilst infrared thermography can be employed for undertaking both qualitative and quantitative surveys of buildings, Pearson (2002) argues that other methods should be adopted to quantify heat loss from a building. This is due to the precise thermal and environmental conditions required to obtain accurate results, which rarely occur. In most instances qualitative thermographic building surveys provide sufficient information, for example, to identify: continuity of insulation; occurrences of thermal bridges; sources of air-leakage, particularly at critical junctions; moisture and damp within an element; hidden components, such as pipes and wall ties; and electrical faults (Hart, 1991; Pearson, 2002; Thomsen and Rose, 2009; Littlewood *et al.*, 2011; Taylor *et al.*, 2011).

When undertaking thermographic surveys of buildings, there are a number of criteria for the environmental conditions required to maximise the accuracy of the data being collected (Hart, 1991; Pearson, 2002; APT, n.d.). However, there are discrepancies between some of the recommendations made. Hart (1991) recommends that the facade of the building should not be exposed to sufficient solar radiation that would affect the results, during and for at least 12 hours prior to the survey. Hart (1991) continues by stating that cold and overcast days are the most suitable environmental conditions for undertaking thermography surveys. Whereas, Pearson (2002) suggests at least one hour should elapse following exposure to direct solar radiation, before a survey is

undertaken. Pearson (2002) also recommends that surveys are undertaken in darkness to minimise effects from solar radiation. Both Hart (1991) and Pearson (2002) recommend a temperature difference of at least 10°C between the inside and outside of the building for the preceding 24 hours and during the survey being undertaken. However, APT (n.d.) recommend a 5°C temperature difference during and for the four hours prior to the survey. Pearson (2002) recommends that the building should not be exposed to precipitation for the preceding 24 hours of a survey. All recommendations are for surfaces to be dry at the time of the survey (Hart, 1991; Pearson, 2002; APT, n.d.). The final criterion is for wind speeds not exceeding six metres per second, according to APT (n.d.) and ten metres per second, according to Pearson (2002).

4. Methodology for assessing retrofitted EWI in Swansea (UK)

This study is limited to qualitative thermographic surveys to assess the continuity of retrofitted EWI and thus potential thermal bridging. Qualitative surveys are considered the most appropriate method for these assessments, as discussed in Section 3. Therefore, attempts have not been made to quantify heat loss as this did not form part of the study. Furthermore, data are not available for the precise construction of the existing exterior walls. As a result, assumptions have been made, which are presented in the results (Section 5), to allow the reader greater understanding of the methods implemented. Data are also not available for the costs associated for an individual dwelling that had EWI as the work formed part of a large scheme involving multiple interventions and these varied across dwellings.

The study presented in this paper involved using qualitative techniques to undertake thermographic surveys at two pre-1919 dwellings with SEWs that received EWI through the Arbed scheme in Swansea. The surveys were undertaken before and after installation of the EWI to allow an overall comparison to be made. Both dwellings are mid-terrace. One is part of a whole-street approach to the EWI (Case study A hereafter) and the other is an example of an isolated installation, where the neighbours either side were not insulated (Case study B hereafter). The infrared camera used for all thermographic surveys was a FLIR B365. The tasks undertaken in preparation for each of the surveys are set out in the list below:

- (1) Weather forecast was checked and a suitable day was chosen to undertake survey.
- (2) Each occupant was contacted, either by telephone or in person, to:
 - Provide an explanation of:
 - the purpose of the survey;
 - why it had to undertaken during the hours of darkness; and
 - possible reasons for a likely change in arrangements (for example, precipitation in the preceding 24 hours).
 - Advise them of the:
 - date;
 - time; and
 - names of the thermographers.
 - Request that they activate their heating at least four hours before the time of the survey (to ensure there was an adequate temperature difference between the inside and outside of the dwelling).

All preparations for the pre-retrofit (pre-R:T) surveys were repeated for the post-retrofit (post-R:T) surveys for each dwelling; this was due to the length of time between the pre-R:T and post-R:T surveys

- (3) Batteries for the camera were checked prior to each survey and charged if necessary.
- (4) Digital photographs were taken during the day prior to each survey. These aid visual interpretation of the thermograms.

Undertaking the thermographic surveys required precautions to be taken. First, due to the surveys being undertaken in the dark and the requirement to enter dwellings where occupants were unknown by the thermographers, it was not considered safe for any lone working. At least two thermographers were present on all surveys; this meant that one person could focus on capturing the images, whilst the other person recorded the environmental data and details about each thermogram. Second, due to the location of the dwellings adjacent to highways, caution had to be taken by the thermographers when choosing the ideal location for capturing images, as these were often in the middle of a road. This limited the possibilities for capturing some images.

4.1 Pre-retrofit thermography (pre-R:T) surveys

The pre-R:T survey for Case study A was undertaken on 27 January 2011 and Case study B was on 7 April 2011. Meteorological data, recorded by the nearest weather station, for during and the preceding 24 hours to each survey, obtained from City and County of Swansea (2011), is as shown in Table I. To verify the recommended environmental conditions had been achieved for the pre-R:T surveys, details were recorded at the time of each survey; these are presented in Table II, along with the time for each survey;

Table I.
Meteorological data recorded for pre-R:T surveys at Cwm Level Park 30m mast

	Case study	
	A	B
Average external air temperature during survey (°C)	3.1	15.1
Average external relative humidity during survey (%)	58.6	73.8
Maximum (hourly average) temperature in 24 h preceding survey (°C)	6.2	17.6
Minimum (hourly average) temperature in 24 h preceding survey (°C)	1.5	8.4
Precipitation in 24 h preceding survey (mm)	0.0	0.0
Average wind speed during survey (m/s)	3.6	0.8

Source: City and County of Swansea (2011)

Table II.
Details and environmental data for pre-R:T surveys

	Case study	
	A	B
Time of sunset (Time and Date AS, 2011)	16:53	19:55
Time of survey	19:00	21:50
Orientation (front/back)	N/S	NW/SE
Internal temperature (°C)	21.5	25.5
Internal relative humidity (%)	44.8	50.2
External temperature (°C)	4	15.2
External relative humidity (%)	54.5	68.3
Wind speed (m/s)	1.8	0.4

time of sunset; and orientation of the dwellings. Temperature, relative humidity and wind speed readings were obtained using a Kestrel 3000 handheld weather meter. In discussion with the occupants, as part of the preparations, it was requested that the thermographers enter the dwelling to take the internal temperature and relative humidity readings. Due to changes in the weather forecast the survey undertaken to Case study A had to be rearranged once and for Case study B, the date had to be changed twice.

4.2 Post-retrofit thermography (post-R:T) surveys

Both post-R:T surveys were undertaken on 27 June 2011. Meteorological data, from the same nearest weather station, for during and the preceding 24 hours to the survey, obtained from City and County of Swansea (2011), is as shown in Table III. The sun set at 21:34 on 26 June 2011 and the sun rose at 04:57 on 27 June 2011 (Time and Date AS, 2011). Due to the time of year, the post-R:T surveys commenced two hours before sunrise. Unfortunately, 26 June 2011 was the warmest day of the year to date and was not ideal for undertaking thermographic surveys. However, the occupants were very cooperative and agreed to activate their heating at 21:00 on 26 June 2011 and leave it on overnight. They also agreed to keep their windows shut.

The timing of the surveys were planned so as to allow any solar radiation, absorbed by building elements during the day, to be dispersed as much as possible. As with the pre-R:T surveys, to verify that recommended environmental conditions had been achieved, these details were recorded at the time of the post-R:T surveys and are presented in Table IV. Whilst external temperature, relative humidity and wind speed readings were obtainable at the time of the survey using the Kestrel 3000, internal readings were not. The solution decided upon, to overcome the issue of not being able to enter the dwellings at the time of the surveys, was to install “Signatrol” data loggers to record internal temperature and relative humidity readings at ten-minute intervals. Each dwelling had two data loggers installed (one in the ground floor and one in the first floor) within rooms located at the front of the dwelling, prior to the survey. The data loggers were then collected following the surveys. Data were retrieved from the loggers by connecting them to a computer and downloaded using the accompanying “TempIT-Pro” software.

Average external air temperature during survey (°C)	16.6
Average external relative humidity during survey (%)	94.0
Maximum (hourly average) temperature in 24 h preceding survey (°C)	27.4
Minimum (hourly average) temperature in 24 h preceding survey (°C)	14.5
Precipitation in 24 h preceding survey (mm)	0.0
Average wind speed during survey (m/s)	0.6

Source: City and County of Swansea (2011)

Table III.
Meteorological data
recorded for post-R:T
surveys at Cwm Level
Park 30 m mast

	Case study	
	A	B
Time of survey	02:00	03:10
Internal temperature (°C)	26.5	25.8
Internal relative humidity (%)	54.5	62.5
External temperature (°C)	19.5	19.5
External relative humidity (%)	77.5	73.9
Wind speed (m/s)	0.4	2.6

Table IV.
Details and environmental
data for post-R:T
thermography surveys

5. Results

To aid understanding of the thermographic results, this section of the paper commences with simple technical details (produced by the lead author) illustrating how the EWI was installed at the following critical junctions: pavement to external wall (Figure 1); window reveals (Figure 2); window sills (Figures 3 and 4); and eaves (Figure 5). Despite client expectations, observation at different stages on some of the properties showed that the specified detail was not fully applied. Further investigation would be needed to establish whether this was because adaptation was required on site to address an unanticipated obstacle, i.e. non-standard junction details or lack of supervision, inadequate training or other reason (Plate 1 and Figure 6).

The results for each case study are presented as thermograms with corresponding photographs. Each of the thermograms have been “thermally tuned” in the accompanying software for the thermal camera, to enhance the clarity of the images. Please note that the temperature scale on the thermograms is not representative of actual temperature readings as these are qualitative survey images. Lighter shading towards orange and yellow shows greater heat loss and darker shading towards blue shows lower heat loss. Figures 6-13 illustrate the qualitative thermographic results.

5.1 Case study A

Pre-retrofitted EWI. At the time of the survey the temperature difference between the inside and outside of the dwelling was between 17.5 and 18.4°C (Kestrel 3000 reading and Meteorological data, respectively). The main observations from the thermogram include the following:

- Apparent overall increased heat loss through the exterior wall when compared to the dwelling next door (to the left).

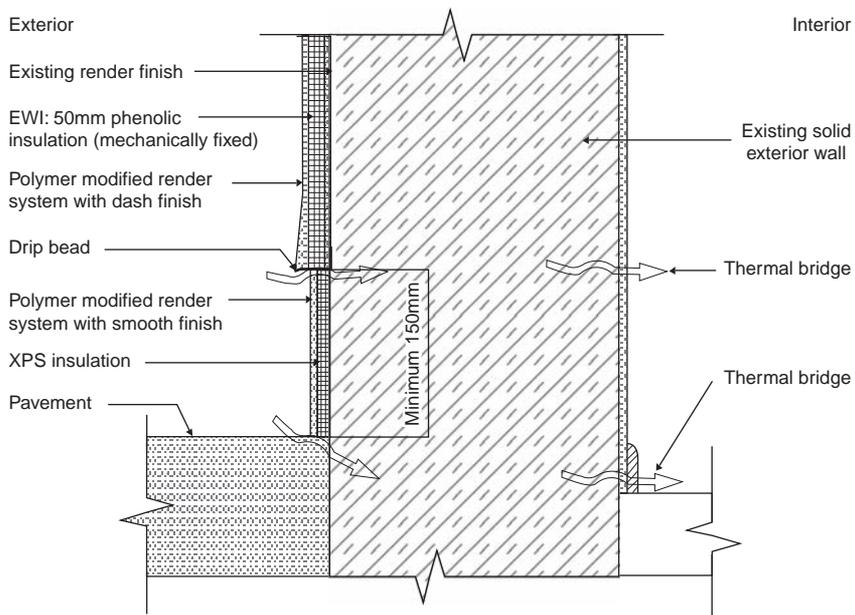


Figure 1.
Section detail – pavement
to external wall junction

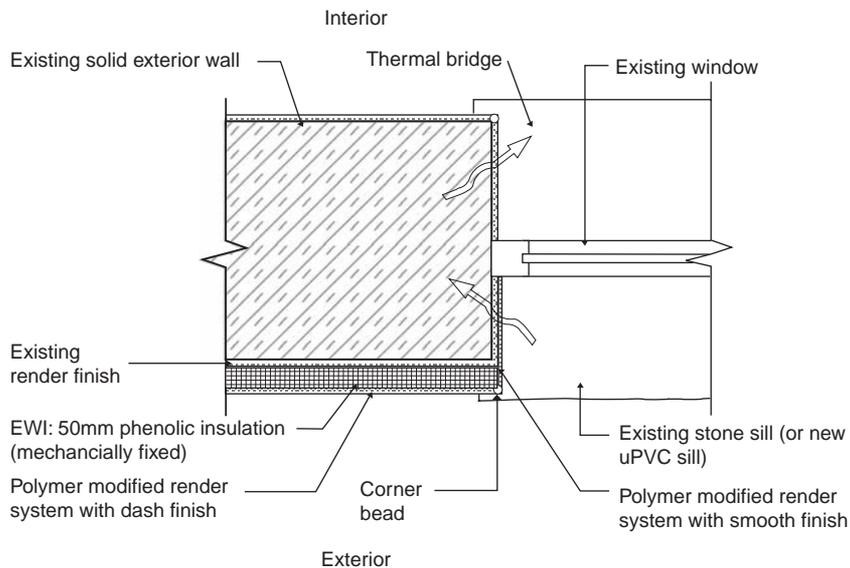


Figure 2.
Plan detail – window
reveal

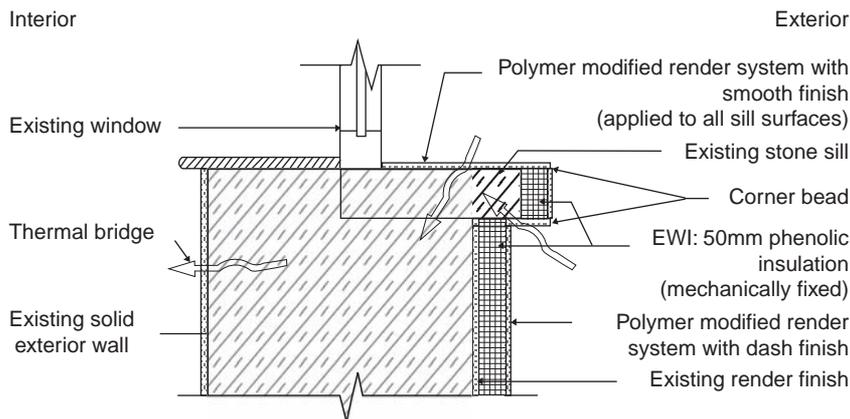


Figure 3.
Section detail – stone
window sill (method used
for Case study A)

- Apparent increased heat loss through the exterior wall surrounding the ground floor window, particularly where the wall meets the pavement and just below the eaves. However, it is likely that the internal space on the first floor is somewhat cooler than the ground floor due to the first floor window being open. This also explains the extended area of heat escaping from the upper portion of the first floor window.
- All window and door frames appear to be losing a significant amount of heat.
- Visibility of the brickwork that frames the windows, which has since been covered in render; this is due to the higher thermal resistance of bricks compared to the rest of the wall, which is thought to be constructed of different material, for example stone.

Figure 4.
Section detail – stone
window sill (method used
for Case study B)

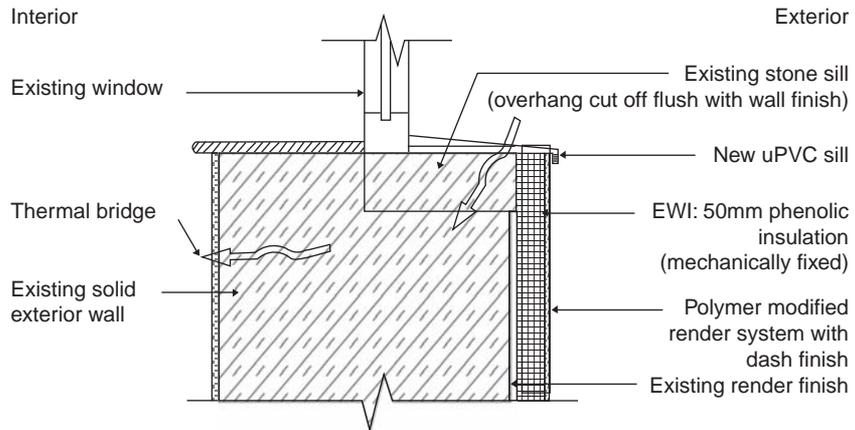
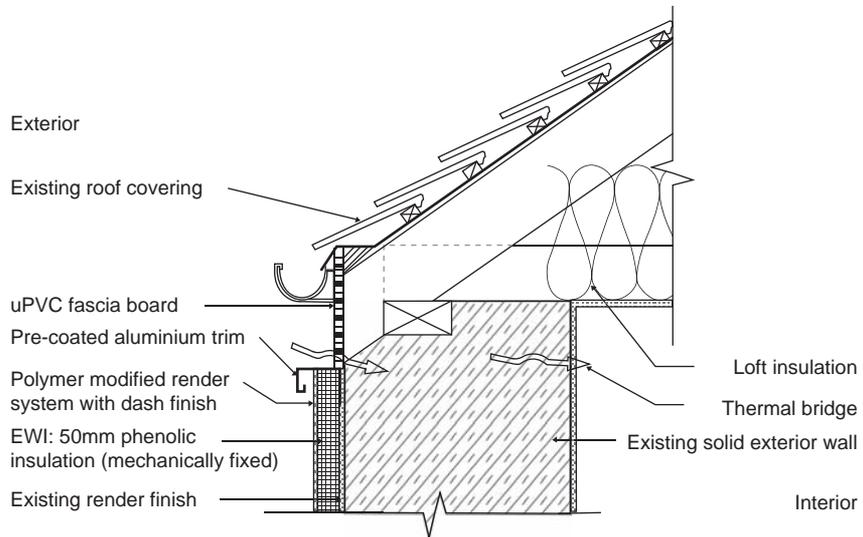


Figure 5.
Section detail – eaves



Post-retrofitted EWI. There was a 7-10.3°C (Kestrel 3000 reading and Meteorological data, respectively) temperature difference between the inside and outside of the dwelling at the time of the survey. The main observations from the thermograms are as follows:

- The EWI appears to have made an overall improvement on the heat loss through the exterior wall as the pattern variations and brickwork framing the windows observed in the pre-R:T survey is no longer visible (Plate 2 and Figures 7-9).
- Apparent thermal bridges: at the window and door reveals; under the window sills; at the eaves; and at the junction between the different insulation materials used at the plinth of the wall and that for the remainder of the wall above. However, particular caution should be taken in respect of the window and door



Plate 1.
Photograph of Case
study A before
installation of EWI

reveals and the eaves due to the higher thermal resistance of the brickwork that surrounds the openings and the highly reflective material of the fascia boards, respectively. Nevertheless, there is the possibility that there is a thermal bridge at both of these locations due to the reveals having not been insulated and the EWI ceasing just below the fascia (as shown in Figures 2 and 5).

5.2 Case study B

Pre-retrofitted EWI. There was a temperature difference of 10.3-10.4°C (Kestrel 3000 reading and Meteorological data, respectively) between the inside and outside of the dwelling at the time of the survey. The main observations from the thermogram include:

- apparent uneven distribution of heat loss across the exterior wall;
- apparent increased heat loss around windows and door;
- as with Case study A, the brickwork that frames the windows is visible despite it previously having been covered with render; and
- the cooler area over the door is likely to be where the metal flashing is reflecting the cold sky.

SS
30,3

256

Figure 6.
Thermogram of Case
study A before installation
of EWI



Plate 2.
Photograph of Case study
A after installation of EWI



Figure 7.
Thermogram of
Case study A after
installation of EWI

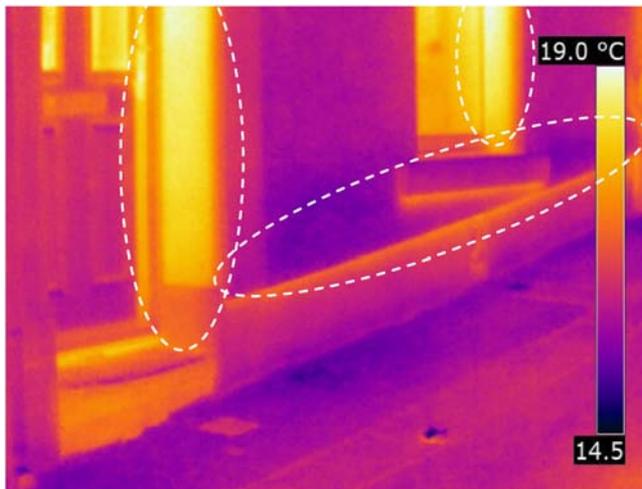


Figure 8.
Thermogram of bottom of
door and ground floor
window and wall to
pavement junction for
Case study A after
installation of EWI

Post-retrofitted EWI. There was a 6.3-9.5°C (Kestrel 3000 reading and Meteorological data, respectively) temperature difference between the inside and outside of the dwelling at the time of the survey. The main observations from the thermograms are as follows:

- Apparent overall improvement on heat loss demonstrated by the stark difference between the dwelling that received the EWI to those either side, which have not.
- As with Case study A, the pattern variations and brickwork framing the windows is no longer visible (Plate 3 and Figure 10).
- Apparent thermal bridges: at the window and door reveals; under the window sills (despite original stone sills having been cut off flush with the existing wall, as shown in Figure 4); at the eaves (where the insulation ceases below the fascia

SS
30,3

258

Figure 9.
Thermogram of first floor
window and eaves for
Case study A after
installation of EWI

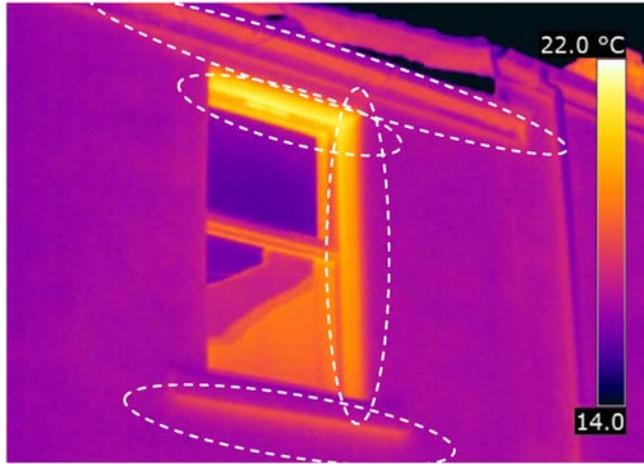


Plate 3.
Photograph of Case
study B before installation
of EWI



Figure 10.
Thermogram of Case
study B before
installation of EWI

board); where the insulation has been cut around the service pipes entering the dwelling; and around the vent cover. Note: as with Case study A, caution needs to be taken in respect of the window and door reveals and eaves due to the higher thermal resistance of the brickwork and highly reflective fascia material, respectively (Plate 4 and Figures 11-13).

6. Discussion

First and foremost the main observation from the results presented in this paper, which corresponds with literature by Pearson and Seaman (2003) and Thomsen and Rose (2009), is that qualitative thermography is an effective tool for project managers and maintenance managers, as a pre-retrofit and post-retrofit survey method, to assess the before and after affects on thermal performance of retrofitting EWI to existing dwellings. Furthermore, pre-R:T surveys can be utilised to identify where to focus thermal improvements and post-R:T surveys to illustrate where there are problems in quality control of the EWI retrofit, at site level. Using pre-R:T and post-R:T survey methods, the thermal patterns that have been identified could indicate potential thermal bridges, and thus an increased rate of heat loss: at the reveals for windows and

SS
30,3

260



Plate 4.
Photograph of Case study B after installation of EWI



Figure 11.
Thermogram of Case study B after installation of EWI

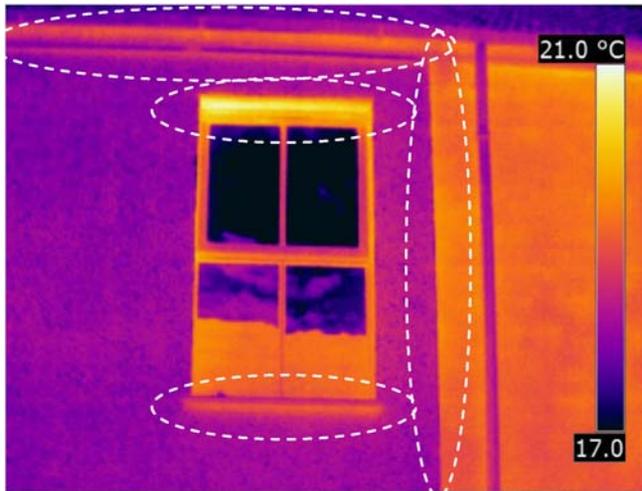


Figure 12.
Thermogram of first floor
window and at party wall
junction

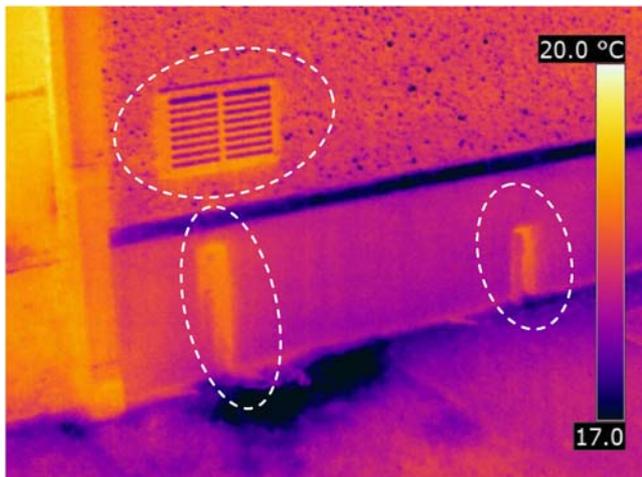


Figure 13.
Thermogram of exterior
wall to pavement junction
indicating EWI at plinth
level that has been cut
around service pipes
entering the dwelling and
external vent

doors; under the window sills; and at the eaves, as a result of the EWI not being installed in these locations. According to authors such as English Heritage (2010) and the EST (2006), potentially, these thermal bridges could lead to condensation and thus incidences of internal damp and mould growth at the locations not insulated. There is also the possibility of thermal bridging occurring in neighbouring dwellings, which have not had EWI installed, as the party wall provides an avenue for heat loss. Taking a whole-street approach to the installation of EWI removes the likelihood of these thermal bridges occurring at party walls. Where there are thermal bridges between the junctions of two insulation materials (at the top of the plinth of the wall; as shown in Figure 8), this is an execution issue that could be addressed in future installations. However, to establish the extent to which there is a risk factor resulting from the potential thermal bridges identified, due to the level of uncertainty surrounding the effects on the health of occupants, as documented by English Heritage (2010), it is desirable that further monitoring, along

with measurements or modelling be undertaken and results documented to fill this gap in knowledge. An additional means of measurement may be to conduct internal post-R:T surveys focused on areas of the SEWs identified as posing potential thermal bridges, benchmarked against neighbouring or similar dwellings that did not receive EWI.

In terms of undertaking thermographic surveys at occupied existing dwellings, there are four main issues that have been identified in this paper, as shown in the list below, which should be given forethought in future surveys:

- (1) Arranging thermographic surveys at occupied dwellings requires striking a balance between giving occupants plenty of notice and obtaining weather forecasts with a greater degree of accuracy.
- (2) When undertaking thermographic surveys to dwellings that front onto a highway, there is a possibility that there will be parked cars causing an obstruction to the visibility.
- (3) When a survey is to be undertaken at a dwelling that is located on a busy highway; it is not always possible to take images at the required distance to achieve maximum quality. Should a thermographer wish to increase the quality of the image by moving closer to the dwelling, this then poses a significant risk from moving vehicles.
- (4) Even when specific instructions are given to occupants in preparation for a survey, these may not necessarily be followed. It is therefore difficult to rely on occupants to undertake some of the preparation tasks required. For example, requesting that heating is turned up to its maximum and windows to be kept shut.

Following identification of the issues in the list, it is recommended that a pre-R:T and post-R:T protocol is developed within the EBERE group at Cardiff Metropolitan University to ensure that all factors are taken into consideration for future surveys at existing dwellings. The protocol should be published on the EBERE web site to allow others, who are proposing to undertake thermographic surveys at existing dwellings, to consider the experiences gained from this and future studies. Further to issue three in the list, it is recommended that thermographers take personal protective equipment, such as a high-visibility jacket, to all surveys where they are located near highways.

7. Conclusions

The literature review has presented evidence by Boardman (2007), the Energy Saving Trust (2011a) and Howarth (2011) for the importance of improving deprived dwellings in the UK and, in particular, in Wales. Improving the thermal performance of pre-1919 dwellings with SEWs can be achieved with the application of EWI. A complete covering is desirable to fully avoid thermal bridging and the subsequent potential risk of damp and mould growth, which, according to English Heritage (2010) could have health implications for occupants. However, further investigation and evidence is required to establish the extent of these risks. Improving existing dwellings was recognised as necessary by the Welsh Government in 2009 (WAG, 2010a), who instigated the Arbed I scheme to fund measures that would increase the thermal performance of the most deprived 15 per cent of dwellings in Wales. The Arbed I scheme has been delivered by housing associations and local authorities across Wales. The dominant method of improvement undertaken in Swansea, was the installation of EWI.

One of the criteria, set out by the then WAG (2010c), for the Arbed I funding was that monitoring and evaluation had to be undertaken to assess the effectiveness of the

improvements made. However, there was no methodology and very limited funding provided for these assessments. This paper has presented the methodology and results for undertaking qualitative infrared pre-R:T and post-R:T surveys, before and after the installation of EWI, at two dwellings in Swansea, UK; funded as part of the Arbed I scheme. One of the dwellings is part of a whole-street approach and one is where the neighbouring dwellings have not received EWI. The thermal images have identified temperature differences that could indicate potential thermal bridges present: at the reveals for windows and doors; under window sills; where two insulation materials have been joined; at the eaves; and at party walls, in the case study where a whole-street approach has not been taken. This study should be followed by further investigation to determine how best to measure the implications of such potential thermal bridges. One approach is long-term monitoring of the dwellings for possible mould growth at such junctions. In addition, it should be determined whether the EWI has improved overall comfort levels for occupants and reduced their energy use and costs and minimised carbon emissions.

The results of the qualitative thermographic surveys presented in this paper, particularly for the post-retrofit of Case study B, provide an opportunity to promote the installation of EWI. The thermal images appear to substantially endorse the benefits of EWI with the contrast between the dwelling that received EWI and those which have not being clearly visible. However, given the extent of the potential thermal bridges that have been identified, it is recommended that when the application of EWI is at the design stage, particular attention is given to ensuring that a complete covering is achieved by focusing on how to overcome non-standard and critical junctions. Furthermore, this attention to detail should then be ensured when execution is undertaken on site. In addition, where EWI is to be installed, thermograms from this study, particularly for the post-retrofit of Case study A, could be used as part of the skills training undertaken by installers to demonstrate the effects of poor execution on site. Furthermore, the use of pre-R:T surveys could inform the types of retrofit works that could be deployed by stakeholders responsible for improving existing dwellings.

7.1 Further research

The authors suggest that further research is needed to assess the long-term implications of the potential thermal bridges identified in this study, as some issues may take time to appear. This research will commence as part of the lead authors doctorate project and includes: further thermography surveys; longitudinal studies of internal environmental conditions, such as temperature, relative humidity and particulates to discover the potential for mould growth; and occupant interviews. In addition, assessing improvements in air-tightness would complement thermography surveys to provide a comprehensive appraisal of the benefits of EWI. However, whilst it is known that air-leakage is a source of heat loss, there could also be implications in terms of condensation, air-quality and humidity levels resulting from making pre-1919 dwellings with SEWs significantly more air-tight. The dwellings would need to be monitored to determine the effects; these should be studied as part of the assessments stated above. The results of this work are to be published in future papers.

References

- APT (n.d.), "Checklist of items/conditions prior to our arrival on site to undertake a thermographic test", available at: www.airpressuretesting.net/thermographic_checklist.php (accessed 22 June 2011).

- Boardman, B. (2007), *Home Truths: A Low Carbon Strategy to Reduce UK Housing Emissions by 80% by 2050*, Environmental Change Institute, Oxford.
- City and County of Swansea (2011), "Online air quality & meteorological readings in Swansea", available at: www.swansea.airqualitydata.com/cgi-bin/reporting.cgi (accessed 11 July 2011).
- Department for Communities and Local Government (2008), *Existing Housing and Climate Change*, The Stationary Office, London.
- Department for Environment, Food and Rural Affairs (DEFRA) (2007), *UK Energy Efficiency Action Plan 2007*, DEFRA, London.
- Department of Energy and Climate Change (2010), *Digest of UK Energy Statistics 2010*, The Stationary Office, London.
- Department of Trade and Industry (2008), *Energy Consumption in the UK*, Department of Trade and Industry, London.
- Energy Saving Trust (EST) (2006), *CE184 – Practical Refurbishment of Solid-Walled Houses*, EST, London.
- Energy Saving Trust (EST) (2010), *CE309 – Sustainable Refurbishment*, EST, London.
- Energy Saving Trust (EST) (2011a), "Pre-1919 homes in Wales", EST, Cardiff, presented at Existing Homes Alliance, Cymru, 24 March.
- Energy Saving Trust (EST) (2011b), "Solid wall insulation", available at: www.energysavingtrust.org.uk/Home-improvements-and-products/Home-insulation-glazing/Solid-wall-insulation (accessed 20 April 2011).
- English Heritage (2010), *Energy Efficiency in Historic Buildings – Insulating Solid Walls*, English Heritage, London.
- H.M. Government (2008), *Climate Change Act 2008*, Offices of Public Sector Information, London.
- Hart, J.M. (1991), *A Practical Guide to Infra-Red Thermography for Building Surveys*, BRE Press, Watford.
- Hopper, J.L., Littlewood, J.R., Geens, A., Karani, G., Counsell, J. and Thomas, A. (2011), "Improving existing deprived dwellings in Wales: monitoring and evaluating thermal performance", paper presented and published in 10th International Post Graduate Research Conference, Salford University, Salford, 14-15 September, pp. 162-73.
- Howarth, S. (2010), *Living in Wales 2008: Fuel Poverty*, Welsh Assembly Government, Cardiff.
- Howarth, S. (2011), *Dwelling Stock Estimates, 2009-10*, Welsh Assembly Government, Cardiff.
- Immendoerfer, A., Hough, C., Andrews, A. and Mathias, A. (2008a), *Fit for the Future – The Green Homes Retrofit Manual*, Housing Corporation, London.
- Immendoerfer, A., Hough, C., Andrews, A. and Mathias, A. (2008b), *Fit for the Future – The Green Homes Retrofit Manual*, Technical Supplement, Housing Corporation, London.
- Infrared Training Center (2010), *Thermography Level 1 Course Manual*, Infrared Training Center, Danderyd.
- Kemp, M. and Wexler, J. (2010), *Zero Carbon Britain 2030*, Centre for Alternative Technology, Machynlleth.
- Littlewood, J.R., Taylor, T.J., Goodhew, S., Evans, N., Counsell, J.A.M., Wilgeroth, P., Geens, A.J. and Griffiths, S. (2011), "Development of a thermography protocol for the in-construction testing of the thermal performance of low carbon dwellings", paper presented and published in The 2011 Chartered Institute of Building Services Engineers Technical Symposium, Demontford University, Leicester, 6-7 September.
- Lo, T.Y. and Choi, K.T.W. (2004), "Building defects diagnosis by infrared thermography", *Structural Survey*, Vol. 22 No. 5, pp. 259-63.

-
- Pearson, C. (2002), *Thermal Imaging of Building Fabric – A Best Practice Guide for Continuous Insulation*, BSRIA, Berkshire.
- Pearson, C. and Seaman, A. (2003), *Condition-Based Maintenance Using Non-Destructive Testing*, BSRIA, Berkshire.
- Snell, J. and Spring, R. (2002), *Nondestructive Testing of Building Envelope Systems Using Infrared Thermography*, Inframation, Montpelier, VT.
- Taylor, T., Littlewood, J.R., Goodhew, S., Hopper, J., Geens, A.J., Counsell, A.J., Blanch, T. and Sharp, D. (2011), “In-construction testing of the thermal performance of dwellings using thermography”, in Msirdi, N.K., Namaane, A. and Howlett, R.J. (Eds), *Sustainability in Energy and Buildings, SEB11, Proceedings of Third Annual Conference, 1-3 June*, Springer, Marseilles, pp. 307-18.
- Thomsen, K.E. and Rose, J. (2009), *Analysis of Execution Quality Related to Thermal Bridges*, Danish Building Research Institute, Fraunhofer.
- Time and Date AS (2011), “Sunrise and sunset in Cardiff”, available at: www.timeanddate.com/worldclock/astronomy.html?n=298&month=1&year=2011&obj=sun&af1=11&day=1 (accessed 8 July 2011).
- Welsh Assembly Government (WAG) (2010a), “Arbed – strategic energy performance investment programme”, available at: wales.gov.uk/topics/environmentcountryside/energy/efficiency/arbed/?lang=en (accessed 20 August 2010).
- Welsh Assembly Government (WAG) (2010b), “Phase 1 projects”, available at: wales.gov.uk/topics/environmentcountryside/energy/efficiency/arbed/phase1projects/?lang=en (accessed 20 August 2010).
- Welsh Assembly Government (WAG) (2010c), *Fuel Poverty Strategy 2010*, Welsh Assembly Government, Cardiff.

About the authors

Joanne Hopper BSc (Hons) graduated with first class honours in Architectural Design and Technology (2010) from the University of Wales Institute Cardiff, UK and was the winner of the Chartered Institute of Architectural Technologists' Student Award for Technical Excellence in Architectural Technology (2010). She is a Doctoral student within the Ecological Built Environment Research and Enterprise group at Cardiff Metropolitan University, UK. Commencing in August 2010, the research is being undertaken in collaboration with Coastal Housing Group, the industrial partner for the project, based in Swansea (UK), who are retrofitting energy efficiency improvements to deprived existing dwellings. To date (February 2012), three conference papers have been presented and published, one at the International Post-graduate Research Conference at Salford University, UK (September, 2011), the second at the 2011 World Sustainable Building Conference in Helsinki, Finland (October, 2011), and the third at the Retrofit 2012 Conference at Salford Quays, UK (January, 2012). Joanne Hopper is the corresponding author and can be contacted at: johopper@cardiffmet.ac.uk

John R. Littlewood graduated in Building Surveying in 1996 and obtained a PhD in the Design and Thermal Performance Modelling of Two-Storey Earth Sheltered Houses in 2001, from the University of Glamorgan, Faculty of Applied Technology, UK. Since 2007 he has been Senior Lecturer in the Architectural Design & Technology subject of the Cardiff School of Art & Design, University of Wales Institute Cardiff. He has been Director of the Ecological Built Environment group (EBERE) at UWIC, since its formation in 2009. He is Joint Pathway-Director of the Professional Doctorate Ecological Building Practices (DEBP) programme and Joint Pathway-Director of the MSc Environmental Change & Practice: Buildings programme. He is also Coordinator of the Assessment & Monitoring of the Environmental Performance of

Buildings for the Sustainability & Energy in Buildings Conference series. His main research fields are: the design of ecological dwellings and communities, monitoring the performance and occupant behaviour towards ecological and existing dwellings, biodiversity in the built environment, and building information modelling. He has supervised two PhDs to completion; is supervising five PhDs and five DEBP students, and has published over 40 international book, conference and journal papers.

Tim Taylor graduated from the University of Cambridge with a Master's degree in Civil, Structural and Environmental Engineering (MEng) in 2006. Currently he is a Doctoral student in the Ecological Built Environment Research & Enterprise Group at Cardiff Metropolitan University.

John A.M. Counsell, Architect RIBA, graduated in Architecture (1973) from the Welsh School of Architecture, University of Wales, Cardiff, UK and he holds a Master of Building Science (1985) from the School of Architecture, University of Strathclyde, Glasgow, UK. Currently he is Principal Lecturer in Architectural Studies in the Cardiff School of Art and Design, University of Wales Institute, Cardiff, UK. He is engaged in general architectural practice with a focus on conservation and refurbishment, and also specialist CAD and BIM consultancy, in the UK and abroad from 1973 to 1997. He moved into teaching and research from 1997 onwards, which led to a number of journal and conference papers, including the 1999 paper in *Structural Survey* on computer-based recording of heritage sites that was identified as "outstanding".

Andrew Michael Thomas, ICIQB, BSc (Hons) Project & Construction Management, has been employed as Maintenance Manager of Coastal Housing Group, Swansea, with responsibility for overseeing all aspects of property maintenance for *Circa* 5,000 properties since 2003. Previously he was Planned Maintenance Co-ordinator with Swansea Housing Association for five years. Prior to these positions he worked in various roles within housing development and building surveying.

Professor George Karani, BSc (Hons) (1980), MSc (1984) (Nairobi university), PhD (1991) (Leeds University) has been Professor of Environmental Health at Cardiff School of Health Sciences, UWIC, since 2007 and Chair, Africa Partnership Initiative, API. His main research fields are pollution and health. He is currently supervising seven PhD students and one DProf student and has published papers in international refereed journals and conferences.

Professor Andrew Geens graduated in Environmental Engineering from London South Bank University in 1989 and obtained a PhD in Environmental Engineering (2000) from the University of Glamorgan. He has been Professor of Building Services Engineering at the University of Glamorgan since 2008, is a Chartered Engineer and Fellow of the Chartered Institution of Building Services Engineers. He is Head of CIBSE (Energy) Certification and his main research fields are: energy performance of buildings and indoor air quality. He is supervisor of seven PhD theses, with over 50 papers published in international and national refereed journals and conferences.

Nick I. Evans, MRICS, graduated in Computer Systems (1996) from the Open University, Faculty of Technology, UK and is a Member of the Royal Institution of Chartered Surveyors, UK. Currently he is Senior Lecturer in the Architectural Design & Technology subject of the Cardiff School of Art & Design, University of Wales Institute Cardiff. He was Head of the Architectural Design & Technology subject field at UWIC, 2007-2009 and since 2011. His main research fields are: building regulations, sustainable design. An emerging researcher, he has published two conference papers.