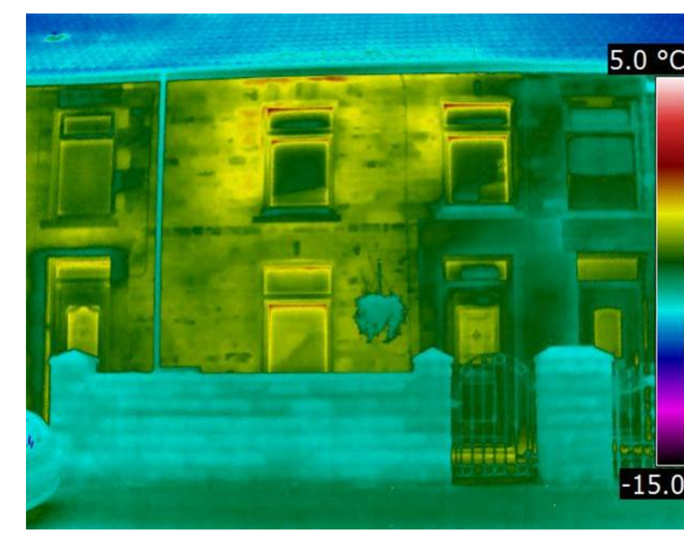
Assessment of the performance of cavity and solid wall dwellings

A shared learning resource from the EVALOC project

EVALOC
EVALUATING LOW CARBON COMMUNITIES



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ASSESSMENT OF THE PERFORMANCE OF CAVITY AND SOLID WALL DWELLINGS I A shared learning resource from the EVALOC project

OXFORD BROOKES UNIVERSITY

Research Councils UK Energy For a Low Carbon Future

Environmental Change Institute eci University of Oxford

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For more information on EVALOC project, please visit: **www.evaloc.org.uk** or contact Professor Rajat Gupta, rgupta@brookes.ac.uk

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Executive summary

The domestic sector in the UK accounts for 26% of the national carbon emissions. By 2050, carbon targets of an 80% reduction (from 1990 levels) are to be achieved. As such, retrofit measures to increase the energy efficiency of existing dwellings are seen as one way in which reductions can be made. This report uses thermographic surveys, undertaken as part of the RCUK funded EVALOC research project to assess and evaluate the performance of retrofit measures (including wall and loft insulation, and improved glazing) in 88 dwellings across the UK, in the context of community energy action. These dwellings include both cavity and solid wall construction and are typical of the UK's building stock.

The findings suggest that there are significant issues with retrofitted cavity wall insulation, particular in terms of consistency, and even in installations undertaken through Government schemes, with required quality assurance procedures. The surveys highlight 'difficulty' areas in practical terms such as under cills, around structural openings, bay windows and other junctions at which the potential for an incomplete thermal layer is increased. Recommendations are made in terms of using thermal imaging as a non-intrusive survey technique to assess and monitor retrofit measures, thus providing the opportunity for rectifying issues as well as an awareness-raising tool within community retrofit activities.

Acknowledgements

Particular thanks to the EVALOC participants for allowing us to survey their homes and use the images as reference. Also thanks to the other members of the EVALOC research team and the community groups involved.

Note: This Thermal Imaging survey was prepared by the Low Carbon Building Group, Oxford Brookes University as part of the EVALOC project. Please be advised that whilst every effort has been made to ensure their accuracy, these thermograms should be interpreted within the context of the constraints of the survey, including access, weather conditions and physical context. Oxford Brookes University accepts no responsibility for any works arising as a result of these findings and strongly recommends further investigation of the thermal performance of these properties before any such works are undertaken.

Summary of findings and recommendations

- The thermographic surveys of existing dwellings have highlighted a number of issues with retrofitting dwellings in terms of fabric efficiency improvements. Perhaps most significant are the findings in terms of retrofitted cavity wall insulation; the difficulties in installing it and the need for high quality workmanship and care required when installing insulation in and around critical details such as windows and other structural openings.

- In the dwellings that were retrofitted under a Government Scheme, the installers will have had to follow at least one set of quality assurance procedures. Yet 13 out of these 17 dwellings appear to have a patchy wall finish. This raises concern in terms of expected improved performance due to CWI and the quality of such work. A BRE report (Doran & Carr, 2008) on a study into pre- and post-cavity wall insulation application suggests that many of the difficulties encountered by the CWI installers are due to the condition of the cavity, and practical and technical issues related to retrofitting insulation, even when correct procedures are followed.

- Whilst the survey suggests that, overall, the more recent installations of CWI appear to be more consistent than those installed pre-2008, this may be in part due to 'settling' of the insulation and other factors over time. This is an area that is currently under researched and worthy of further more exploratory investigation.

- Although the number of retrofitted solid wall dwellings is few, a number of important issues have been highlighted; whilst external wall insulation appears to enable a smooth and consistent finish, internal wall insulation does not. This suggests that internal wall insulation may not offer the same performance as external wall insulation. In addition, it highlights the difficulties in ensuring a complete thermal barrier when using internal wall insulation due to the complex nature of junctions and details in corners and around structural openings such as windows and doors. However, this is not an issue that can be fully rectified by external wall insulation; there are indications of higher temperatures in and around both the door and window openings.

- A high majority of both cavity and solid wall dwellings show areas of higher temperatures below windows. Due to the difficulties in interpreting thermographic images, the exact causes of this cannot be confirmed and may not be due wholly to heat loss issues with the fabric itself. However, it does highlight the need to concentrate on aspects such as the installation of new window units, draughtproofing and sealing around doors and windows and even the effectiveness of low cost measures such as radiator reflector panels.

- The relatively high number of dwellings with apparent higher temperatures around the eaves (despite having loft insulation installed) also suggests difficulties with the installation of this relatively 'easy-to-install' measure, particularly in pitched roofs where the angles between the wall and roof are difficult to access.

- There are innate issues with external thermal imaging due to the need for specific conditions, the potential for incorrect interpretation of anomalies, and the complexities in explicitly quantifying the level of heat loss. It is also difficult to make comparisons between images, and even the different dwellings within the same image (due to the potential for different internal temperatures etc). Despite this, they play an important role in highlighting key areas of potential heat loss and through cross-analysis with occupant interviews and physical surveys of the building can suggest potential improvements that can be made. As such, it is an important communication as well as a possible diagnostic tool.

Recommendations

Findings relevant to a number of different stakeholders have been uncovered through the thermographic surveys. The following section outlines the principle recommendations and comments relevant to the key stakeholders.

Householders

- Simple low-cost measures such as radiator reflector panels, thick curtains and draughtproofing strips can make significant improvements in terms of reducing heat loss through walls.
- Bay windows are often of different construction (and quality) to main building and require particular care and detailing when upgrading their thermal performance.
- The performance of loft insulation can be significantly reduced if not installed fully (including up to eaves) but any existing ventilation gaps should be retained to mitigate unintended consequences such as interstitial condensation and subsequent damage to structural issues.
- Awareness of rights and compliancy procedures in relation to wall insulation installations is critical to achieving maximum benefits from improvements.

- When undertaking significant retrofitting such as solid wall insulation, care should be taken in finding, commissioning and installation of the works.

Community Organisations

- Thermographic surveys can be used to:
    - Provide feedback on projects involving energy efficiency measures and provide advice and support to residents to ensure issues are rectified where possible.
    - Raise awareness in occupants of key heat loss areas and provide advice, support (where funding and human resources allow).
    - Assess existing situation in order to co-ordinate future activities.
- Be aware of the difficulties in the interpretation of the thermal images; and ensure no further works are undertaken without further investigation.
- Undertake non-intrusive pre- and post-retrofitting monitoring such as thermal imaging (and follow-up rectifications, if applicable) to ensure performance of insulation is acceptable.
- Partnerships with intermediary organisations (including academic institutions, community networks and local authorities) at both national and local levels can bring expertise and resources otherwise lacking.
- Ensure advice to residents includes:
    - Information on compliancy certification and guarantees.
    - Knowledge and awareness to wide variety of measures, from low to high cost.
- In dwellings where uneven cavity wall insulation appears, ensure discussions with the occupants are held and potential follow-up action is undertaken including contacting the installers etc.

Installers

- Ensure full survey is undertaken of existing building prior to retrofit works to provide clarity on a) applicability of proposed improvements, b) existing conditions and quality, and c) correct materials to be used.
- Work with community and/or intermediary organisations to provide post-retrofit evidence of improvements.

Policy advisors

- Review self-certification process for installation of cavity wall insulation and other such minor works improvements currently not fully covered under building regulations.
- Include post-retrofit monitoring and evaluation techniques, particularly non-intrusive measures such as thermal imaging in policy and regulation implementation.
- Assess current standards of compliancy in relation to cavity wall insulation.

Contents

Chapter 1
Introduction

As part of the RCUK funded EVALOC research project, which seeks to understand and assess the impacts and effectiveness of community-led energy initiatives on individual household energy use and behaviours, the actual performance of dwellings with a varying range of physical fabric improvements was assessed. To achieve this, a thermographic survey of 88 dwellings was undertaken between February and March 2013. The 88 dwellings are situated in six communities across the UK; South East England, South Wales, North West England, North East England and Yorkshire & the Humber.

This report outlines the methodology and key findings of that survey.

1.1 Context

It is well known that the UK has been set the challenge of reducing carbon emissions by 80% (from the 1990 baseline figure) by 2050 (HMSO, 2008). The domestic energy sector accounts for around a quarter of these emissions (DECC, 2012), and with approximately 75% of the dwellings currently in existence likely to still be in use in 2050, there is a great need to concentrate efforts on increasing the energy efficiency of existing dwellings, and reducing the demand of this sector.

Whilst the energy performance of domestic dwellings is reliant on several factors (Gupta and Gregg, 2012), and the complex relationships between these (the physical, technical and behavioural environments), a key area is the improvement of the physical fabric of the buildings. The UK Government has recognised this, and sought to instigate retrofit measures such as wall and loft insulation through Government schemes since April 2008 (such as the Carbon Emissions Reduction Target (CERT), the Community Energy Saving Programme (CESP), Warm Front, and the current Green Deal and Energy Company Obligation (ECO)). As shown in Table 1, 70% of cavity wall dwellings have been insulated as of 2013. A similar figure is shown in the number of dwellings with loft insulation in Table 2. However, Table 3 shows that only 3% of solid wall dwellings have been insulated by April 2013. This highlights the emphasis placed on cavity wall and loft insulation measures since 2008; there has been a 15-24% increase in cavity wall and loft insulation from 2008 to 2013 but only a 2% increase in solid wall insulation.

Whilst the increase in insulated dwellings is a positive step forward, research has shown that such retrofit measures do not always result in the expected carbon and energy savings (EMC, 2008, Capel & Wilczek, 2004) and as such it is desirable to measure and understand their actual performance in terms of increasing thermal insulation and reducing heat loss.

Table 1. Number of UK dwellings with cavity walls, and those that have insulation from 2008 to 2013 (DECC, 2013).

Date	Total no. dwellings in UK	Dwellings with cavity walls		Dwellings with cavity wall insulation	
		No. (thousands)	Percentage (%)	No. (thousands)	Percentage (%)
Apr-08	27,050	18,840	70	10,310	55
Apr-09	27,270	19,060	70	11,060	58
Apr-10	27,450	19,240	70	11,820	61
Apr-11	27,610	19,400	70	12,430	64
Apr-12	27,750	19,540	70	13,110	67
Apr-13	27,890	19,670	71	13,740	70

Table 2. Number of UK dwellings with lofts, and those that have insulation greater than 125mm installed from 2008 to 2013 (DECC, 2013).

Date	Total no. dwellings in UK	Dwellings with lofts		Dwellings with loft insulation	
		No. (thousands)	Percentage (%)	No. (thousands)	Percentage (%)
Apr-08	27,050	23,700	88	10,430	44
Apr-09	27,270	23,870	88	11,230	47
Apr-10	27,450	24,010	87	12,810	53
Apr-11	27,610	24,140	87	13,920	58
Apr-12	27,750	24,250	87	15,190	63
Apr-13	27,890	24,360	87	16,620	68

Table 3. Number of UK dwellings with solid/undefined walls, and those that have insulation (DECC, 2013).

Date	Total no. dwellings in UK	Dwellings with solid/undefined walls		Dwellings with solid/undefined wall insulation	
		No. (thousands)	Percentage (%)	No. (thousands)	Percentage (%)
Apr-08	27,050	8,210	30	67	1
Apr-09	27,270	8,210	30	76	1
Apr-10	27,450	8,210	30	97	1
Apr-11	27,610	8,210	30	105	1
Apr-12	27,750	8,210	30	136	2
Apr-13	27,890	8,220	29	211	3

1.2 Factors affecting the performance of thermal insulation

The performance of a dwelling in terms of increasing overall efficiency is dependent upon the effectiveness of its physical elements (walls, floor, roof, windows and doors) in reducing heat escaping from the indoor environment to outside. The effectiveness of these elements is measured in terms of their thermal transmittance or U-Value (eg. A wall with a low U-Value are better insulated than those with a high U-Value) and is dependent on a number of factors surrounding the insulative properties and airtightness of the thermal elements. Issues mainly stem from the detailed design (including specification of materials and construction details) and workmanship of the overall installation. Typical issues (CLG, 2008 and Doran & Carr, 2008) include:

- Difficult joint and interface details creating thermal bridging and air leakage.
- Use of incorrect materials leading to poor thermal performance and possible damage to building structure.
- Poorly or incorrectly fitting insulation can enable air to circulate around the insulation and air gaps and voids.
- Cold bridging can be caused by poorly packed insulation.
- Lack of sealing and/or poorly constructed walls can result in poor airtightness.
- Inadequate construction process and sequencing of works can lead to difficult areas being left uninsulated.

Increasing the performance of existing dwellings is particularly tricky due to the unknown quantities involved in retrofitting existing elements; for example the condition, cleanliness and thickness of a cavity wall (Doran & Carr, 2008) as well as the practical limitations of working within existing physical confines.

1.3 Assessing the performance of thermal elements

Despite the difficulties in undertaking retrofitting of existing thermal elements there is currently no formal legal or statutory requirement for assessing the actual performance of the retrofitted elements to be undertaken. Whilst improvements to thermal elements in existing dwellings are notifiable under current UK building regulations, certain work such as cavity wall insulation, is generally carried out under a self-certification scheme (Schedule 3, Building Regulations, 2010). Whilst this does aim to provide quality assurance, examples such as the Temple Avenue Project by Leeds Metropolitan University (Miles-Shenton et al., 2011) for Joseph Rowntree Housing Trust indicate that some measured wall U-Values hardly changed, even when the fill process was felt to be in accordance with BBA (British Board of Agrement) and CIGA (Cavity Insulation Guarantee Agency) recommended procedures.

The Zero Carbon Hub (2014), through its research into the performance gap between expected and actual energy efficiency recommends the introduction of 'inspection and testing' programmes to ensure construction quality as much as possible. There are a number of techniques that can be used to measure and monitor the performance of thermal elements such as walls, roofs, floors, windows and doors:

1. In-situ U-Value measurements using heat flux meters
2. Boroscope investigations
3. Co-heating tests
4. Thermographic surveys

Whilst the most robust approach would be to use a number of such techniques in order to cross-tabulate findings, it was felt that in this research project most were not appropriate mainly due to the intrusive nature of the works involved. As such, only a thermographic survey of the external façade/s of the case study dwellings was undertaken. However, the research team has not ruled out future further investigation with appropriate and interested parties.

1.4 What is a thermographic survey?

A thermographic survey uses a thermal imaging camera (Figure 1) to create a thermal image, or thermogram, which is a visual display of the amount of infrared energy emitted, transmitted, and reflected by an object. It enables objects to be seen in terms of their thermal properties, and highlights parts of objects invisible to the human eye. A thermogram shows different colours to represent different temperatures measured across the surface (white/red for highest temperatures to blue for lowest temperatures).

A thermographic survey is particularly useful in terms of buildings as it provides a quick non-intrusive assessment of issues that involve heat generation and/or transfer. When a building is heated, a temperature difference between inside and outside is created, so that heat flows through the walls,

Figure 1. Thermal imaging camera similar to that used in the study (Image: http://thuongtin.co/extech-flir-t640-camera-nhiet-do-extech-flir-t640.html).

windows, doors, roof and even the floor. A thermographic survey can identify anomalies in the building fabric (Hopper et al., 2012) such as:

- Thermal bridges
- Discontinuity of insulation
- Air leakage paths (cracks and voids)
- Delamination or debonding of external wall finishes (for example tiling)
- Moisture and damp
- Hidden components within the building fabric

Thermography is fast becoming an awareness-raising tool within low carbon community groups in terms of areas of heat loss in homes and this aspect of the survey is particularly valuable to the overall EVALOC research project.

There are two types of thermographic survey; external and internal. The survey undertaken within this study was external and provides a useful overview of the dwellings. Whilst it is possible to quantify heat loss through thermographic surveys (Pearson, 2011), most surveys are qualitative and simply aim to show the locations of anomalies as the temperatures shown are not often the actual surface temperatures. This is due to the need for very specific survey conditions (particularly solar radiation and clear skies), which if not achieved can make the interpretation of the images very difficult.

For best results, the weather conditions for an external survey require:

- Substantial difference between indoor and outdoor temperatures (at least 10°C)
- Low wind speeds near surface (less than 5m/s)
- No precipitation (including mist) during and 24hrs prior to survey
- No 'hot' objects (eg. The sun)
- No 'cold' objects (eg. Clear sky)

Therefore, the best conditions for an external survey are a cold, cloudy, dry and still winter night.

Due to the difficulties in achieving these conditions, the interpretation of the images is fraught with issues. In addition, a number of physical aspects can distort the apparent temperatures if near to the building fabric including cars, vegetation and street lamps. An example of this is areas under eaves and cills, which in the presence of street lamps, can appear to be warm relative to the rest of the façade. This may be the result of light reflection distorting the apparent reflected temperature of other areas of the façade. In addition, the area under the cill/eaves may appear warm due to sheltering from night sky radiation.

Similarly, images taken at an angle further than perpendicular can reduce the amount of radiation, and as such reduce the apparent temperature reading. Therefore care must be taken when looking at pitched roofs and corners of walls; outside corners that get exposure will appear cooler whilst inside corners are more sheltered and will appear warmer (Figure 2).

In addition, different materials have different emissivity and thermal properties and as such require different thermographic settings. This is not always possible to achieve in one thermogram and care should be taken when interpreting images where mixed material finishes are present, eg. render and brick wall finishes with wooden door frames. Infrared, like light, can be reflected and as such the apparent temperature may not be the true temperature. Glazing is particularly tricky to interpret due to the reflective nature of glass.

Another difficulty in external thermographic surveys is that the internal temperatures within the properties may vary (the living room likely to be warmer than the bedroom etc) and as such may show a greater heat loss through the walls that is an inaccurate picture of the performance of the wall.

This survey is a qualitative study only of the 88 case study dwellings to locate anomalies in the building fabric for further investigation.

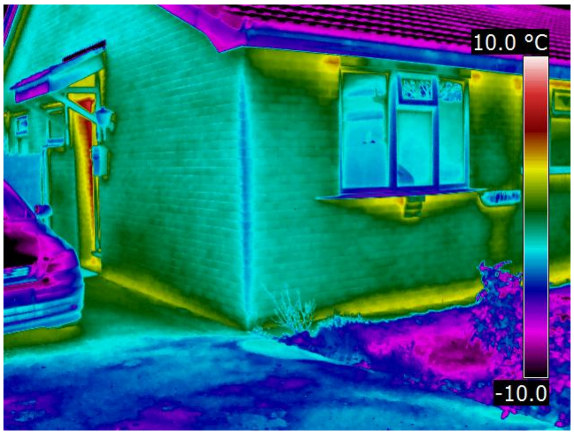

Figure 2. Thermal image showing outside corner which appears cooler than rest of building (likely effect of exposure to wind) and inside corners (below cills and eaves) that appear warmer (possible effect of sheltering).

Chapter 2

EVALOC research study: case study characteristics

The EVALOC project seeks to assess, explain and communicate the changes in household energy use due to community activities within six selected case study projects under the Department of Energy and Climate Change's (DECC) Low Carbon Communities Challenge (LCCC) initiative (from 2010 – 2012). The LCCC was a government-supported initiative to transform the way communities use and produce energy, and build new ways of supporting more sustainable living. The majority of the community-led projects followed a holistic approach and included both technical and behavioural aspects (Table 4).

The behavioural activities included behaviour and awareness programmes and energy display monitors, whilst the technical aspects included both physical and technical retrofits (from wall insulation and draught-proofing to low carbon technologies such as air source heat pumps and solar PVs). The Low Carbon Communities (LCCs) are spread across the UK; with one in South Wales, two in the South East, one in the North West, one in the North East and one in Yorkshire & Humber.

To investigate the long-term impacts, 88 households (in 88 dwellings) within the six low carbon communities were recruited to participate in the study. Whilst the focus was on ensuring participation from households that were involved in their local LCC and/or benefitted from the LCCC, the dwellings show a wide range in built form and age to provide representation, as far as possible, of the UK housing stock (Figure 3).

Table 4. Approaches taken in the six case study low carbon communities.

Community	Approach
A	Community scale technical
B	Household scale physical and behavioural
C	Community and household scale technical, physical and behavioural
D	Household scale technical, physical and behavioural
E	Community and household scale technical and behavioural
F	Community and household scale technical and behavioural

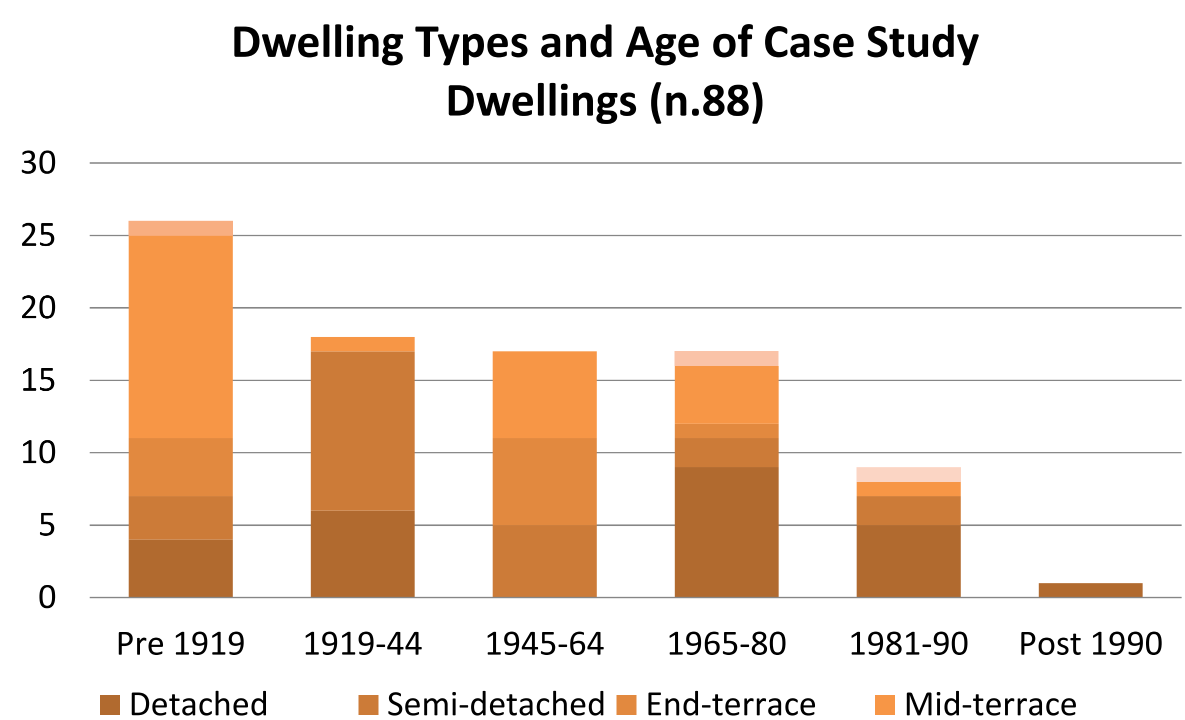

Figure 3. Dwelling types and ages of 88 case study dwellings in EVALOC study.

2.1 Improvements to the physical fabric

Whilst not all of the six case study community-led initiatives included physical retrofits of dwellings as part of their primary activities (Table 4), all of the 88 case study dwellings have had some physical improvement to the original building (from draughtproofing windows and doors and double glazing to external wall insulation), and 61 have undertaken improvements since 2008 (taken as the baseline year due to the majority of community activity happening from 2009 onwards).

Table 5 shows the type and number of improvements made whilst Figure 4 shows the type of improvements made in relation to the age of the dwellings. It must be noted that at least 19 of the solid wall dwellings (total 34) have had extensions to the original building that are known to be cavity wall construction. In at least two of these dwellings, due to the fact that they are mid-terrace, it is estimated that the cavity wall construction will equate to approximately 50% of the external wall. However, these instances are not included in the table, which is based on the predominant wall type and insulation present of the front external façade (ie the façade that has been surveyed).

17 of the 52 dwellings that have had some form of improved wall insulation received either full or partial funding from Government Schemes; all of which are cavity wall insulation top-ups.

Four dwellings have undergone solid wall insulation. However, one is split over two separate buildings and the researchers were unable to access the retrofitted building to assess its performance during the thermographic survey.

Table 5. Total numbers of dwellings with improvements made to physical fabric (total number of dwellings in study was 88).

	Total dwellings with improvements	Pre-2008	Post-2008
Improved cavity wall insulation	47[a]	26	11
Improved solid wall insulation	4	0	4
Improved roof/loft insulation	88[b]	38	45
Improved glazing	84[c]	64	20
Improved draughtproofing	28	1	27

Notes:-

[a] includes 6 dwellings that have cavity wall 'as built' but have not been improved further; and four dwellings where the installation date is unknown.

[b] includes 1 dwelling that only has loft insulation 'as built' and 4 unknown installation dates.

[c] includes 4 properties that have partial single glazing, but with improved glazing to some windows/doors.

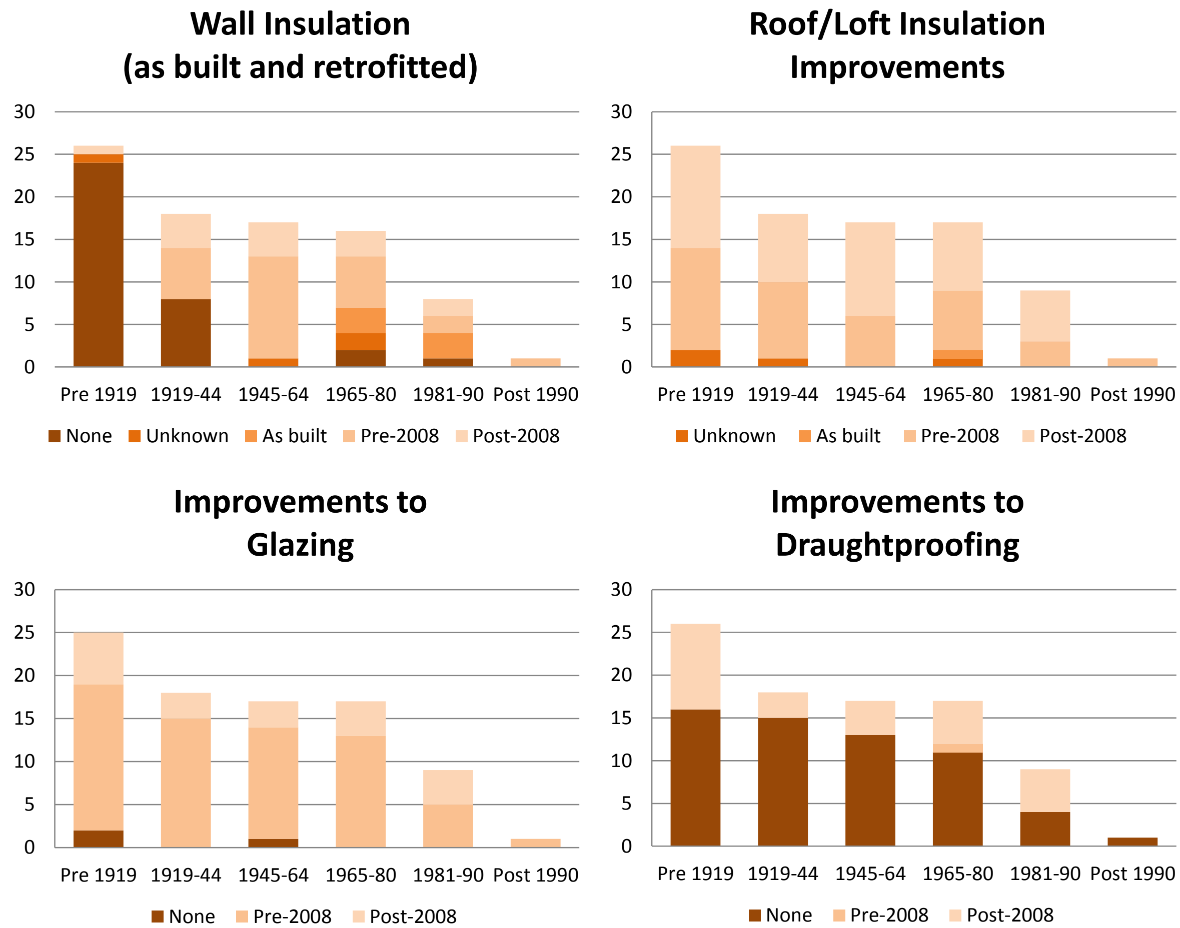

Figure 4. Improvements made to the 88 case study dwellings by age of property.

Chapter 3
Survey methodology

The survey was undertaken over six nights during February and March 2013 (one community per night) and took between 30minutes and 3 hours depending on the community. Letters were sent to occupants two weeks in advance advising that the researchers would be undertaking the survey within a two week period. It was felt that due to the location of some of the communities and the need for specific conditions it was not possible to organise exact dates in advance. The local police were informed at least 24 hours prior to the survey taking place to ensure they were aware of the proposed activities.

Each survey was undertaken approximately three hours after sunset to allow any residual heat from the sun to disperse. Despite this, it is thought that there were still signs of residual heat during the survey, particularly with the solid stone wall buildings. Thermograms were taken of the external elevations accessible from public land only. Whilst ideally all elevations would have been surveyed, due to the times at which the surveys were being conducted, it was felt inappropriate to seek entry into occupant's homes and closed gardens.

During the survey, notes were taken of potential contextual issues for each dwelling to ensure aspects that could influence the interpretation of the images were recorded. At least three images were taken of each dwelling. The files were downloaded and processed using Flir Tools+ (FLIR, 2011) to ensure each image had the correct temperature, relative humidity, distance and emissivity settings (Table 6). In addition, the scale was changed to signal linear colour distribution to provide consistency to the scale across all images in each community. All thermal images are presented in the rainbow-hi palette for increased thermal definition.

No further analysis of any abnormalities in the construction elements was undertaken as part of this thermographic survey, and it is recommended that where there are anomalies, further investigation is undertaken.

Table 6. Emissivity settings used for different material finishes to external façade taken from Table 3.8 of CIBSE Guide C, 2007.

	Brick	Stone	Render
Emissivity setting used	0.90	0.92	0.91
Recommended range (CIBSE Guide C, 2007)	0.85 – 0.95	0.90 – 0.93	0.91

3.1 Test Equipment Information

Table 7 outlines the test equipment used during the survey.

3.2 Environmental Conditions

The temperature, relative humidity and wind speed were measured at the beginning and end of each survey and the environmental conditions noted (eg. Cloudy/clear, cold, moist etc) to a) ensure images could be accurately processed and b) assess if there were significant changes in environmental conditions during the survey period. Table 8 outlines the measurements for each community (significant changes are recorded in final column).

3.3 Limitations of Surveys

3.3.1 External environmental conditions

Whilst every effort was made to ensure the surveys took place in optimum conditions, in some communities this was not possible due to changing weather conditions or availability of personnel and equipment. As such, the images from Communities D, E and F (E in particular) were taken when the sky was very clear and will be affected by the sky radiation. Whilst this still allows locations of possible defects/issues to be seen, it makes the interpretation of the images more difficult due to the temperatures recorded in the image not being an accurate representation of the actual surface temperatures. As such, the images contained with this report should not be compared to one another.

Table 7. Test equipment used in survey.

Manufacturer	Model	Description	Calibration Expiry
FLIR	T620bx	640x480 pixel, infrared camera set on rainbow colour palette	August 2013
Vaisala	Humicap HM40	Humidity and temperature meter	February 2013
ATP	DT-8880	Anemometer	October 2013

Table 8. Environmental conditions during surveys.

Community	Date of Survey	Temperature (°C)	Relative Humidity (%)	Wind Speed (m/s)	General weather description
A	22/02/13	0.2	62.5	0.08 – 0.57	Dry, cold and cloudy
B	01/03/13	5.7 *(dropped to 1.0)*	62.6 *(increased to 82.7)*	0.00 – 1.26	Dry, cold and cloudy *(significant reduction in cloud coverage during survey)*
C	03/03/13	7.0	73.1	0.01 – 1.99	Dry, mild and cloudy
D	13/03/13	-2.2	96.4	0.01 – 0.18	Dry, cold and clear
E	02/03/13	2.8	80.1	0.03 – 1.44	Dry, cold and clear
F	18/02/13	2.2	91.7	0.03	Dry, cold and clear

3.3.2 Indoor temperature variations

62 out the 88 dwellings are being monitored in terms of their indoor temperature and it is known that not all keep each room at the same temperature. This means that areas of higher temperatures (and therefore potential heat loss) may be indicative of differing indoor temperatures between rooms rather than actual heat loss as shown in Figure 5.

Figure 5. Higher temperatures at ground floor level to left; this room is heated to higher temperatures than rest of building, creating an anomaly in the consistency of the façade,

3.3.3 Changes in materials

A number of dwellings have more than one finishing material used upon the external façade, which can give misleading results in terms of potential areas of heat loss.

3.3.4 Orientation of dwellings

The orientation of the dwellings also appears to have affected the images and therefore the ability to interpret the images accurately; on a number of dwellings the south-facing façade appears to have significantly higher temperatures than the other facades (despite being part of the same room etc.). Whilst there may be issues with the construction of the walls, without further investigation it is difficult to interpret such results and the researchers express caution in the reading of such images.

Chapter 4
Findings

The thermograms were analysed in relation with physical characteristics data gathered during interviews with occupants of the homes in Summer 2012. Common issues relating to the external façade were identified, and further explanation is given in the following sections.

4.1 Solid Wall Dwellings

The case study solid wall dwellings are spread across the six communities, and include solid stone (both exposed and rendered) and solid brick buildings. All were built pre-1944 and include semi-detached and detached but with the majority being terraced dwellings (19 out of 34).

Overall it was difficult to assess the solid stone dwellings in terms of consistency of heat loss across the wall as in some cases each individual stone is clearly defined (Figure 6). This could be due to a number of specific influencing external factors including;

- Different stone types used within same façade (different emissivity).
- Orientation of surveyed facades and implications of the thermal storage properties of the solid stone.

Despite this, across both solid brick and stone facades, focused areas of higher temperatures are clearly visible and are further discussed in the following sections (Figures 6 - 14). There are a number of likely reasons for this including:

- Localised heating such as a radiator on the external (uninsulated) wall.
- Cracks in mortar/stonework.
- Chimneys (heat lost through draughts up chimney from open fireplace even when not in use).
- Poorly sealed windows and doors.
- Air gaps/thermal bridging at junction detailing.

Figure 7 shows a rare anomaly in the case study solid wall dwellings; and is worthy of a further visual inspection to rule out hairline cracks and/or issues with the mortar, creating air gaps within the external wall.

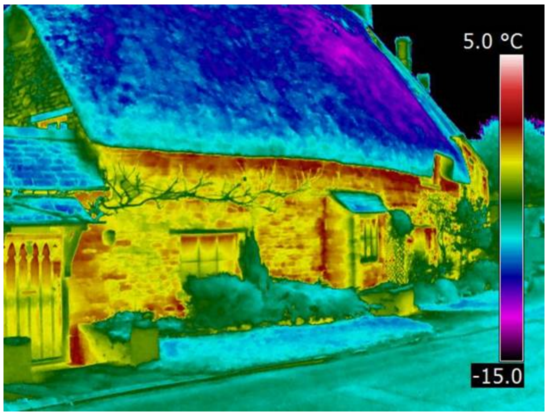

Figure 6. Solid stone wall dwelling, patchy wall finish indicative of different stone types being used (with different emissivities).

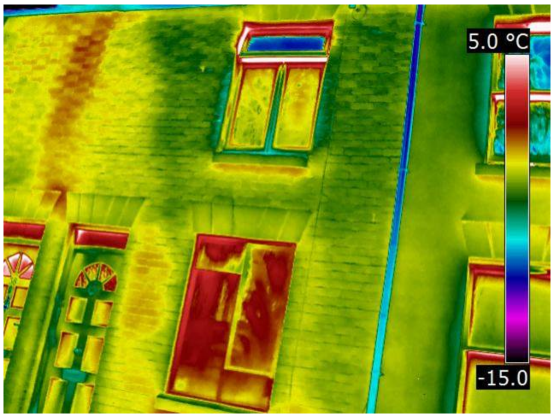

Figure 7. Solid brick wall dwelling (painted) with vertical strip of higher temperatures (possible heat loss through cracks in mortar).

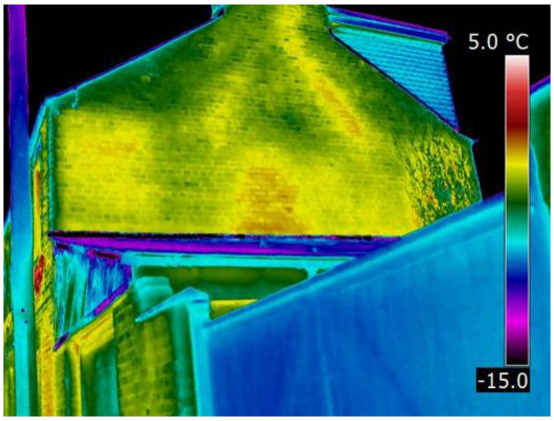

Figure 8. Solid brick wall dwelling with chimney stacks visible, and line of loft insulation present.

4.1.1 Roofs and Eaves

Although there were relatively few opportunities within the survey to thermograph the gable walls in order to assess the impacts of loft insulation, access to the gable walls of four of the solid wall case study buildings was possible. Three showed the relative success of the loft insulation installation as the line at ceiling level is clearly visible in Figure 8, with lower temperatures indicated above (except where the chimney stack penetrates the loft line). Interestingly however, as Figure 9 shows, in one dwelling (where the loft has been converted into a heated room and the insulation is between the rafters), the loft area generally appears at higher temperatures than the floors below. This suggests that this room is being overheated.

In 19 of the 34 dwellings, higher temperatures can be found along the eaves line (Figure 1), or a smooth line (along the loft level) was not apparent on the gable end, suggesting gaps in the loft insulation allowing heat to escape into the unheated loft space. When viewing the eaves line, the apparent increase in temperature could be due to sheltering from night sky radiation; warm air rising from windows or an existing ventilation gap into the loft space. However, it also could be indicative of the loft insulation not being installed correctly and not reaching the wall heads completely or thermal bridging near the wall heads.

4.1.2 Projecting window design

The survey also suggests that 17 out of the 34 dwellings have issues with potential heat loss at wall junctions, particularly around bay windows with all of the 14 dwellings with bay windows showing significantly higher temperatures at the junctions between the bays and the main building. Generally, the bay windows are of a different construction and material but even in buildings where they are of the same material, higher temperatures are present (Figure 10). Whilst the higher temperatures could be due to the sheltered nature of these areas, it is also potentially indicative of cracks along the junctions, poor workmanship in these areas and/or degradation of the materials and mortar joints.

4.1.3 Areas surrounding structural openings

A number of further issues relating to windows and doors in solid wall buildings were raised from the survey. The higher temperatures were again found above and around windows and doors in 20 of the 34 buildings. It suggests a lack of draughtproofing and/or sealing of the window units, although the angles and different materiality of these elements need to be taken into consideration when interpreting images of these areas.

4.1.4 Cills and area below windows

A number of dwellings also show higher temperatures below window cills. This may be due to cracked mortar joints in the stone/brick work below the cills, or in the case of Figures 11 and 12 it is likely that there is localised heating from radiators due to the lack of insulative material on the external walls. This issue appears more prevalent in solid brick dwellings than solid stone dwellings.

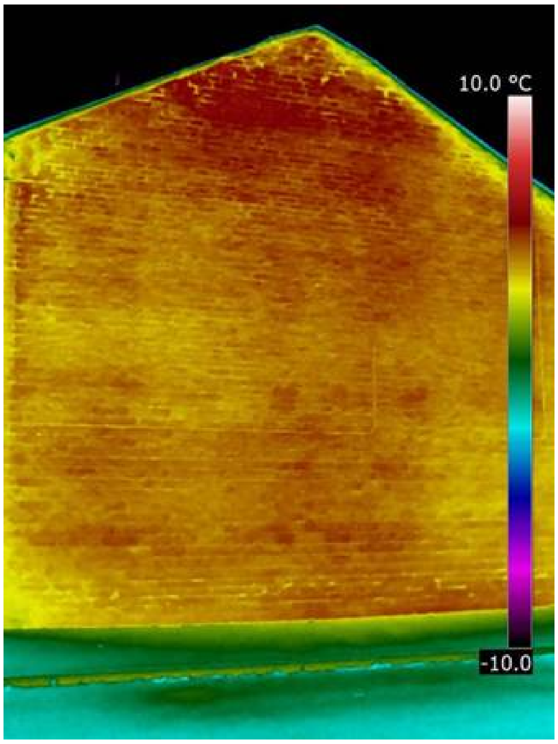

Figure 9. Solid stone wall dwelling with room in roof (insulation at eaves level). Higher temperatures apparent in room in roof.

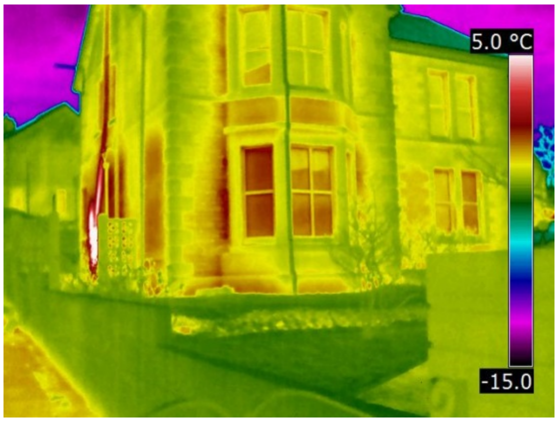

Figure 11. Solid stone wall dwelling, higher temperatures at bay window junctions.

Figure 10. Solid brick wall showing significant heat loss beneath window (location of radiator).

4.1.5 Inset entrance porches

Inset entrance porches also appear to be a source of heat loss; with all 12 of the dwellings with them showing higher temperatures around the frames. The images (Figure 13) corroborate the findings from the semi-structured interviews that most of the dwellings with this feature, although having improved their window glazing have not upgraded their doors and subsequently the fixed single glazing and frames adjacent. In addition, the wall adjacent to the heated space may also have been built as a single leaf (particularly in solid brick buildings) to increase internal floor area thus reducing its thermal properties. Despite this, due to the sheltered nature of these areas, it is likely that the apparent increase in temperatures may be due, in part, to thermal storage and/or shelter from night sky radiation.

An interesting case was found where an original doorway has been infilled. The higher temperatures in this area suggests that the construction (likely to be cavity wall) may not be insulated fully and that the detailing of the junctions between the original walls and the infill has not adequately dealt with in terms of thermal bridging and air gap issues.

4.1.6 Ground Level

Five dwellings showed signs of higher temperatures at ground level (Figure 14); although due to obstructions it is possible that more buildings may also suffer from this. Whilst this can be indicative of damp, it can also point to heat loss due to lack of sealing of suspended floors.

Higher temperatures at ground level were also found in dwellings with basements. This suggests that these areas, although not being living areas are still heated. It is also worth noting that in the majority of such buildings, the windows in the basement are single glazed, there is little to no insulation at ground floor level and the doors into the basement area are of indoor specification only.

Figure 12. Solid brick wall dwelling, localised elevated temperatures below windows (upper level).

Figure 13. Render and exposed solid brick wall dwelling, high temperatures apparent in inset entrance porch (single glazed, and no draughtproofing).

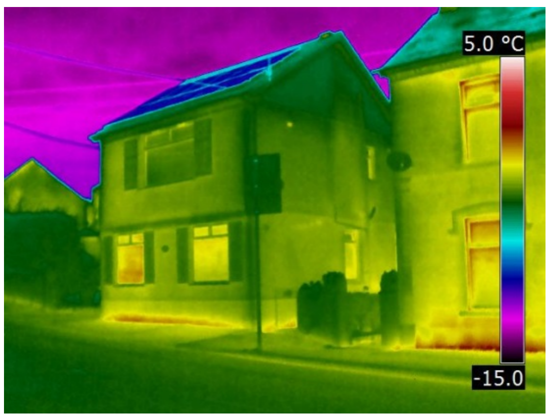

Figure 14. Rendered solid wall dwelling, higher temperatures visible at ground level (possible heat loss through floor).

4.1.7 Solid Wall Insulation

Whilst there were only three dwellings with retrofitted solid wall insulation (that were included in the survey), the images provide interesting results; Figure 15 shows a render finish wall (solid brick construction) with internal wall insulation. As can be seen there appears to be issues with the continuity of the insulation, particularly around the junctions with the bay windows and up within the eaves. Figure 16 also shows a rendered brick façade with internal wall insulation around the bay window. In comparison to the adjacent building, the insulation does appear to have improved the performance of the bay window but the overall surface is still uneven suggesting air gaps or voids within the insulation. In contrast Figure 17 shows external wall insulation with render finish (solid stone construction) that appears to have been installed well; with continuity in surface finish across the façade. Although unable to survey the other dwelling with external wall insulation adequately, it too appears to provide an even finish; much more so than that achieved by internal wall insulation, even though it is on the same building.

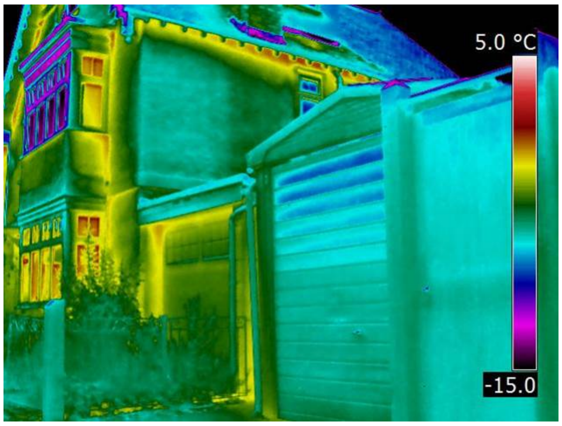

Figure 15. Solid wall dwelling, possible heat loss to eaves and corner junctions. Line of internal wall insulation visible at upper level.

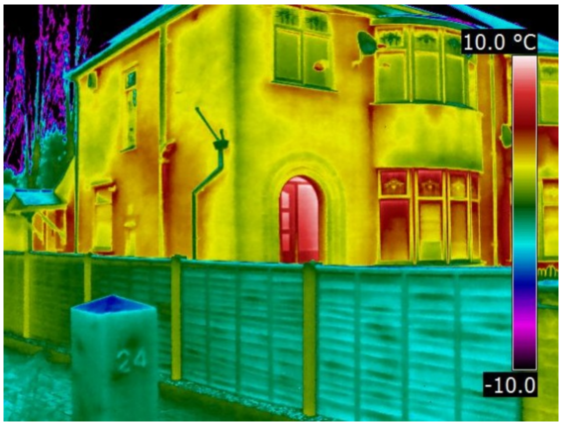

Figure 16. Rendered solid wall dwelling, with internal insulation installed in bay window. Bay window appears patchy suggesting loss of performance in the internal wall insulation.

Figure 17. Solid stone wall dwelling with rendered external insulation, continuous finish visible but areas of higher temperatures around windows and doors.

4.2 Cavity Wall Dwellings

54 out of the 88 dwellings are of cavity wall construction. The majority were built in the post-war era; between 1945 and 1980 (34 in total). The predominant dwelling types are detached and semi-detached. The majority have a mixed material finish to the front façade.

Six built post-1965 were constructed with cavity wall insulation and the occupants either know or are unaware of additional insulation being retrofitted. Although the number in the study is too small to make general assumptions, the overall appearance of these buildings is fairly continuous (with a few exceptions such as below windows and at ground level, which are discussed in further sections) suggesting that the initial workmanship and construction was of good quality (Figure 18). Despite this, there are issues around lintels, window and door frames, and at ground level that are consistent with other cavity wall dwellings and these are discussed in later sections.

4.2.1 Retrofitted cavity wall insulation

42 of the dwellings are known to have had cavity wall insulation (CWI) retrofitted, with most undertaking it prior to 2008 funded through a variety of sources including Government schemes such as Warm Front, the current residents themselves, and social landlords.

The thermographic images highlight inconsistencies in the appearance of the walls in 34 of the 42 dwellings (Figures 19 - 26). This is potentially indicative of issues relating to missing or defective retrofitted insulation. Previous research (Miles-Shenton et al., 2011; Doran & Carr, 2008) suggests that there a number of reasons for this, even if the insulation has been installed to industry standards including:

- Low compactness of insulation
- Mortar snots and other blockages/debris within the cavity
- Small cavity width
- Inaccurate estimated amount of insulation required
- Incorrect settings of the machinery leading to lack of insulation
- Too wide spacing of drill holes leading to possible voids in insulation layer
- CWI not spreading into cavity but gathering around injection hole

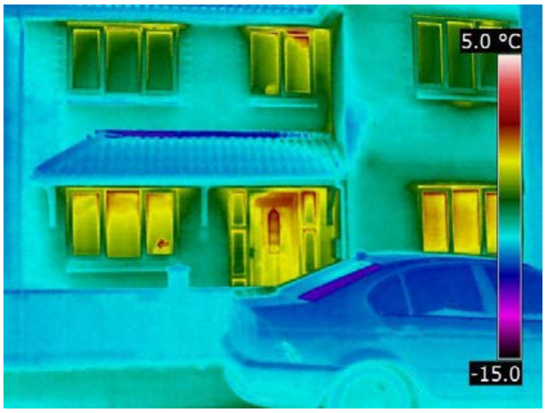

Figure 18. Brick cavity wall dwelling (built post-1990), showing relatively continuous temperatures across façade.

Figure 19. Rendered cavity wall dwelling with retrofitted insulation, showing lack of consistency across facade.

- \- Poor quality of inner leaf leading to crumbling brickwork

The majority of the cavity wall dwellings with retrofitted insulation are within three communities. Whilst the issues do not appear to be confined to one community, with similar results found across the three communities, there is a higher percentage of the dwellings with cavity wall insulation retrofitted prior to 2008 having issues than those with insulation installed post-2008 (88% to 64%).

This could indicate improvements in the industry since 2008 (in terms of equipment, knowledge and technique, and quality assurance procedures), but it may also indicate the lowering of performance of the retrofitted insulation over time. Further research and investigation into the long-term performance of retrofitted cavity wall insulation appears to be critical in this instance.

4.2.2 Roofs and Eaves

Due to a number of the cavity wall dwellings having exposed gable walls, images showing the roof and loft lines are available. In most (Figure 20), there is a clear line between the heated rooms and the unheated loft above. This suggests that the loft insulation in these dwellings is working. However, there are other examples, which suggest that there are possible gaps in the insulation, allowing heat to escape from the heated living areas into the roof space. The actual installation of loft insulation along the eaves line is particularly difficult due to the angles of the rafters, as well as practical issues such as items stored in the roof creating difficulties in accessibility.

Furthermore, 36 out of the 54 cavity wall dwellings are experiencing higher temperatures at the eaves line (Figures 21 – 22) and/or show a lack of a solid line at the loft level. This could be due to a number of reasons; including sheltering from night sky radiation, and warm air rising from windows or an existing ventilation gap into the loft space. However, it also could be indicative of the loft insulation not being installed correctly and not reaching the wall heads completely or thermal bridging near the wall heads.

In addition, there also appears to be issues with the junctions between the roof and chimney in some buildings. Although elevated temperatures can be expected on and around chimneys, the extended area of higher temperatures suggests that there could be local issues with either the roof tiling and/or the flashing details. Whilst it is worth highlighting, this issue does not appear to be common.

4.2.3 Lintels

In a number of cavity wall dwellings (39), lintels appear at higher temperatures than the rest of the elevation. Whilst particularly obvious in exposed brick dwellings (Figure 22), which could be due to the different material used (generally concrete), it does suggest that this is an area of significant heat transfer.

4.2.4 Areas surrounding structural openings

The issues with cavity wall dwellings appear to continue, particularly around structural openings such as windows. As shown in Figure 21 & 22, areas of higher temperatures appear around all sides of the window unit. This could indicate poor installation and sealing of the window unit itself but also a lack of insulation (especially relevant to retrofitted CWI dwellings) being packed tight up to the window opening.

4.2.5 Cills and below windows

42 out of the 54 dwellings have areas of higher temperatures below the cills. Whilst the usual problems with interpreting features that protrude from the main wall structure in terms of sheltering etc. apply, the inconsistent pattern of most suggests that there are gaps in the insulation and/or localised areas of heat loss due to the location of radiators on the external wall (Figures 22 & 23). Although

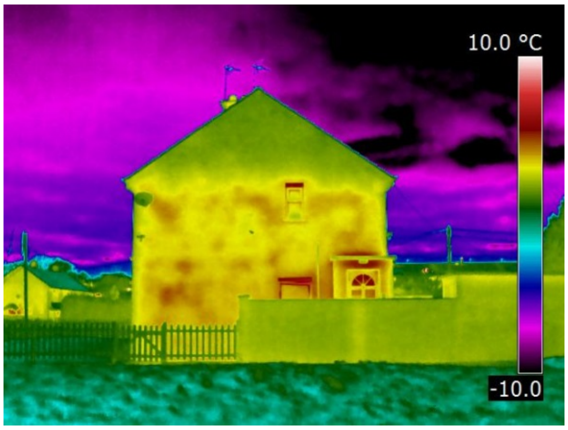

Figure 20. Brick cavity wall dwelling with both loft and cavity wall insulation (CWI), visibly patchy temperatures across façade suggesting voids in insulation; clear line along loft insulation level showing effectiveness of loft insulation.

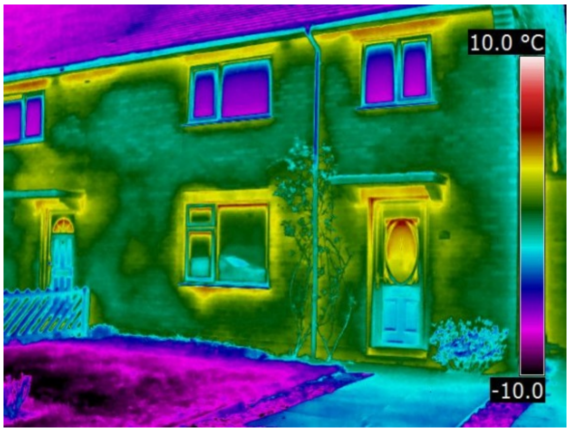

Figure 22. Brick cavity wall dwelling with insulation, apparent lack of draughtproofing/insulation around windows and doors.

Figure 21. Brick cavity wall dwelling with insulation, patchy finish across façade and apparent heat loss beneath windows, particularly middle ground floor window.

possibly not expected to be as obvious in cavity wall dwellings as it is in solid wall dwellings, due to the pattern and location of the higher temperatures in Figure 23 in the dwelling to the right in comparison to the dwelling on the left, it appears that localised heat loss from radiators is as relevant to cavity wall properties. Interestingly, it is known that the dwelling to the left was given radiator reflector panels by the local community group. It appears that this is a successful action in terms of reducing heat loss.

4.2.6 Projecting window design

13 out of 14 dwellings with either bay windows or other projecting window designs have significant areas of higher temperatures, suggesting potential locations of heat loss around these features (Figure 24). On the whole, bay windows appear to be at higher temperatures than the rest of the façade. Whilst this may be due to a number of factors including the different materials and sheltered nature of the feature, they do appear to be significant areas of heat loss due to the difficult detailing and construction of the junctions, and increased likelihood for poor workmanship.

4.2.7 Infill Panels and Cladding

In community C, one of the predominant housing styles included an area of tile cladding at first floor level and infill panels below a large room-length ground floor window. The thermal images indicate inconsistencies across these areas in particular (Figure 25). Whilst the different materials (and therefore emissivity) may have implications on this, the unevenness of the façade suggests that areas are suffering from insulation issues; either missing or incomplete installation, or the delamination (Lo and Choi, 2004) of the wall cladding from the main wall structure.

Also highlighted were issues around junctions between infill panels of door/window panel systems and the main built structure. Following discussions with the occupants of one dwelling, it was established that they had noticed the degradation of the infill panel through increased draughts in the lobby area, and have since replaced it.

4.2.8 Extensions

Whilst examples of extensions were few, of those that were able to be surveyed all showed unusual areas of higher temperatures around the junctions between the walls and roofs of the existing building and the extension. Whilst this may indicate thermal bridging and gaps at the junctions, it may also signify a lack of retrofitted insulation in and around the corner details.

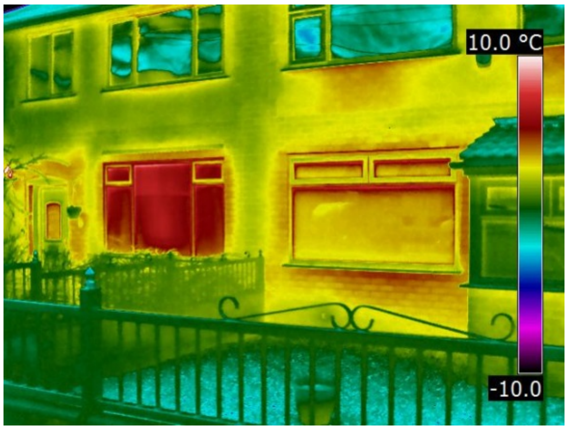

Figure 23. Brick cavity wall dwelling with insulation, apparent localised heat loss beneath windows (location of radiator). Dwelling to left has radiator reflector panels.

Figure 24. Rendered cavity wall dwelling with insulation, projecting window design creating higher temperatures around junction with main wall.

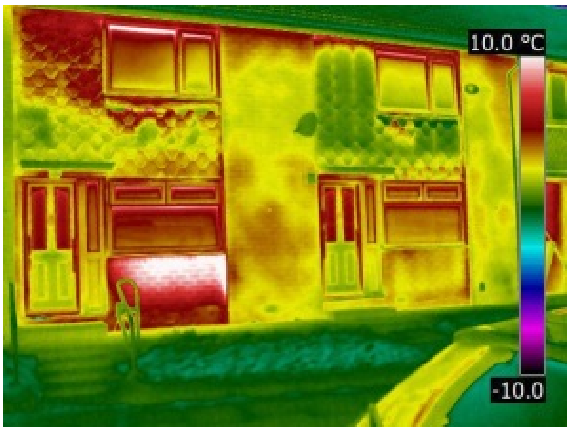

Figure 25. Brick and tile cladding finish cavity wall dwelling (assumed uninsulated), showing fluctuations across façade, particularly below window cill and at high level beneath cladding.

4.2.9 Unheated Adjoined Spaces

Figure 26 shows an unheated garage, yet the difference in temperatures between the garage wall and the external parapet wall above suggests that there is heat loss from the garage. This may be due to a lack of insulation between the heated dwelling spaces and the adjoining unheated garage area.

4.2.10 Ground Level

Although not possible to survey all dwellings at ground level, 18 of 27 dwellings (where images of the external wall at ground level were taken) show elevated temperatures at ground level (Figures 24 & 27).

Whilst further investigation was not undertaken as part of this study, evidence from other research (Miles-Shenton et al., 2011) suggests that this is potentially indicative of cavity wall insulation not extending below the DPC line. As such, particularly in suspended floor buildings, this could create air passages from the internal heated spaces to outside at ground level.

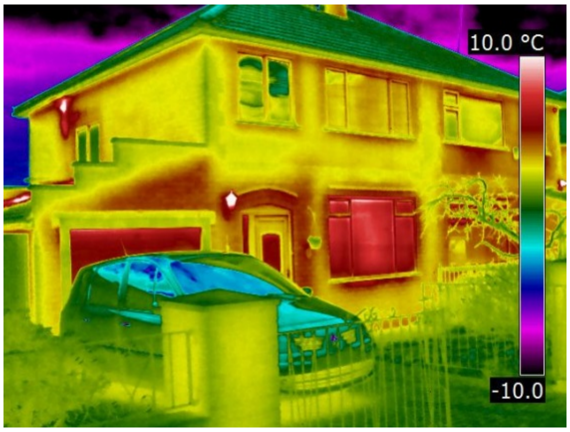

Figure 26. Brick cavity wall dwelling with insulation showing higher temperatures in unheated but adjoined garage space.

Figure 27. Brick cavity wall dwelling (insulation as built) with apparent heat loss at ground level.

Chapter 5

Discussion of key findings

The thermal imagingc surveys of existing dwellings have highlighted a number of issues with retrofitting dwellings in terms of fabric efficiency improvements. Perhaps most significant are the findings in terms of retrofitted cavity wall insulation; the difficulties in installing it and the need for high quality workmanship and care required when installing insulation in and around critical details such as windows and other structural openings.

In the dwellings that were retrofitted under a Government Scheme, the installers will have had to follow at least one set of quality assurance procedures. Yet 13 out of these 17 dwellings appear to have a patchy wall finish. This raises concern in terms of expected improved performance due to CWI and the quality of such work. A BRE report (Doran & Carr, 2008) on a study into pre- and post-cavity wall insulation application suggests that many of the difficulties encountered by the CWI installers are due to the condition of the cavity, and practical and technical issues related to retrofitting insulation, even when correct procedures are followed.

Whilst the survey suggests that, overall, the more recent installations of CWI appear to be more consistent than those installed pre-2008, this may be in part due to 'settling' of the insulation and other factors over time. This is an area that is currently under researched and worthy of further more exploratory investigation.

Although the number of retrofitted solid wall dwellings is few, a number of important issues have been highlighted; whilst external wall insulation appears to enable a smooth and consistent finish, internal wall insulation does not. This suggests that internal wall insulation may not offer the same performance as external wall insulation. In addition, it highlights the difficulties in ensuring a complete thermal barrier when using internal wall insulation due to the complex nature of junctions and details in corners and around structural openings such as windows and doors. However, Figure XX also suggests that this is not an issue that can be fully rectified by external wall insulation; there are indications of higher temperatures in and around both the door and window openings.

A high majority of both cavity and solid wall dwellings show areas of higher temperatures below windows. Due to the difficulties in interpreting thermographic images, the exact causes of this cannot be confirmed and may not be due wholly to heat loss issues with the fabric itself. However, it does highlight the need to concentrate on aspects such as the installation of new window units, draughtproofing and sealing around doors and windows and even the effectiveness of low cost measures such as radiator reflector panels.

The relatively high number of dwellings with apparent higher temperatures around the eaves (despite having loft insulation installed) also suggests difficulties with the installation of this relatively 'easy-to-install' measure, particularly in pitched roofs where the angles between the wall and roof are difficult to access.

There are innate issues with external thermal imaging due to the need for specific conditions, the potential for incorrect interpretation of anomalies, and the complexities in explicitly quantifying the level of heat loss. It is also difficult to make comparisons between images, and even the different dwellings within the same image (due to the potential for different internal temperatures etc). Despite this, they play an important role in highlighting key areas of potential heat loss and through cross-analysis with occupant interviews and physical surveys of the building can suggest potential improvements that can be made. As such, it is an important communication as well as a possible diagnostic tool.

Chapter 6
Conclusions and recommendations

Although it was not possible to undertake all the surveys under perfect conditions, the images produced provide invaluable insights into the current performance of the building fabric of the 88 case study dwellings. Although it is not possible to use thermal imaging as a diagnostic tool without full training, it can quickly and unobtrusively identify areas where there may be issues; and subsequently allow further investigation and action to take place. Findings relating to the likely under-performance of cavity and internal wall insulation suggest the need for performance checking both immediately after installation has been completed, and over the long-term to assess any changes in performance.

The fact that similar issues were found across a large number of the surveyed buildings suggests that there are typical locations where heat loss is likely to be increased and/or improving the performance of these elements is difficult. This emphasises the importance of increasing knowledge and skills in relation to the detailing of building fabric improvements and installation. It also adds to the body of existing evidence to help improve workmanship in this area.

In relation to community organisations, particularly those who are involved in energy efficiency and retrofit projects within their local community (including working with the ECO Community fund), thermographic surveys can be both a useful motivating and awareness tool for future action, but also a retrospective check on installations that have been undertaken. This could mitigate future issues, as well as ensure the improvements are completed to a high level of quality and competence. As an independent and trusted organisation, they could even provide advice on how individual households in the area can improve and/or rectify their dwellings energy efficiency.

In terms of Government policy, the findings suggest that lessons can and should be learnt in terms of 'simple' retrofit measures, as well as the deeper retrofit measures such as solid wall insulation. This is particularly important with respect to achieving carbon reduction targets through ECO and Green Deal (amongst other funding avenues) on two levels; the actual performance (and thus actual savings) from such measures not being as expected/desired, and the motivations to undertake deep retrofits such as external wall insulation (currently seen as costly and difficult) which appears to show marked improvements to the building fabric performance, when done well.

6.1 Key Recommendations

Findings relevant to a number of different stakeholders have been uncovered through the thermographic surveys. The following section outlines the principle recommendations and comments relevant to the key stakeholders.

6.1.1 Householders

- Simple low-cost measures such as radiator reflector panels, thick curtains and draughtproofing strips can make significant improvements in terms of reducing heat loss through walls.

- Bay windows are often of different construction (and quality) to main building and require particular care and detailing when upgrading their thermal performance.

- The performance of loft insulation can be significantly reduced if not installed fully (including up to eaves) but any existing ventilation gaps should be retained to mitigate unintended consequences such as interstitial condensation and subsequent damage to structural issues.

- Awareness of rights and compliancy procedures in relation to wall insulation installations is critical to achieving maximum benefits from improvements.

- When undertaking significant retrofitting such as solid wall insulation, care should be taken in finding, commissioning and installation of the works.

6.1.2 Community Organisations

- Thermographic surveys can be used to:

    - Provide feedback on projects involving energy efficiency measures and provide advice and support to residents to ensure issues are rectified where possible.

    - Raise awareness in occupants of key heat loss areas and provide advice, support (where funding and human resources allow).

    - Assess existing situation in order to co-ordinate future activities.

- Be aware of the difficulties in the interpretation of the thermal images; and ensure no further works are undertaken without further investigation.

- Undertake non-intrusive pre- and post-retrofitting monitoring such as thermal imaging (and follow-up rectifications, if applicable) to ensure performance of insulation is acceptable.

- Partnerships with intermediary organisations (including academic institutions, community networks and local authorities) at both national and local levels can bring expertise and resources otherwise lacking.

- Ensure advice to residents includes:

    - Information on compliancy certification and guarantees.

    - Knowledge and awareness to wide variety of measures, from low to high cost.

- In dwellings where uneven cavity wall insulation appears, ensure discussions with the occupants are held and potential follow-up action is undertaken including contacting the installers etc.

6.1.3 Installers

- Ensure full survey is undertaken of existing building prior to retrofit works to provide clarity on a) applicability of proposed improvements, b) existing conditions and quality, and c) correct materials to be used.

- Work with community and/or intermediary organisations to provide post-retrofit evidence of improvements.

6.1.4 Policy advisors

- Review self-certification process for installation of cavity wall insulation and other such minor works improvements currently not fully covered under building regulations.

- Include post-retrofit monitoring and evaluation techniques, particularly non-intrusive measures such as thermal imaging in policy and regulation implementation.

- Assess current standards of compliancy in relation to cavity wall insulation.

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Appendices

Appendix A: Case study dwelling characteristics and main identified issues

SortNo	DwellingType	DwellingAge	Predominant wall type	Predominant wall insulation	Wall Insulation	Predominant glazing type	Orientation	Improved Glazing	Improved loft insulation	Improved Draught-proofing	Eaves	Cladding/infill panels	Patchy wall finish	Cills & below windows	Lintels	Structural openings	Projecting window design	Junctions & extensions	Inset entrance porch	Chimney	Ground level	Unheated spaces (adjoining)
H1	F	<1919	SW (s)	x	x	DG	SW	<2008	<2008	x	✓	-	✓	x	x	✓	-	?	✓	?	?	-
H2	MT	1919-44	SW (s)	x	x	DG	NW	<2008	<2008	x	✓	-	✓	x	x	✓	-	-	-	?	?	-
H3	D	<1919	SW (s)	SWI	>2008	DG	S	>2008	>2008	>2008	✓	-	✓	x	x	✓	✓	x	✓	✓	?	-
H4	MT	<1919	SW (s)	x	x	SeG	S	>2008	>2008	>2008	x	-	✓	x	x	x	-	?	-	?	?	-
H5	ET	<1919	SW (s)	x	x	SeG	W	>2008	>2008	>2008	x	-	✓	x	x	✓	-	?	-	?	x	-
H6	ET	<1919	SW (s)	x	x	DG	SW	<2008	<2008	x	x	-	✓	✓	x	✓	-	?	-	✓	x	-
H7	SD	<1919	SW (s)	x	x	SeG	W	<2008	<2008	>2008	✓	-	✓	x	x	✓	y	x	-	x	?	-
H8	SD	<1919	SW (s)	x	x	DG	W	<2008	>2008	x	✓	-	✓	✓	x	x	-	-	✓	?	?	-
H9	MT	<1919	SW (s)	x	x	SeG	NW	<2008	<2008	>2008	x	-	✓	✓	x	✓	-	-	-	✓	x	-
H10	MT	<1919	SW (s)	x	x	DG	NE	>2008	>2008	>2008	x	-	x	✓	✓	x	-	-	-	?	?	-
H11	MT	<1919	SW (s)	x	x	DG	SW	>2008	>2008	x	?	-	✓	✓	✓	✓	-	-	-	?	✓	-
H12	MT	<1919	SW (s)	x	x	DG	NE	<2008	>2008	>2008	✓	-	✓	✓	✓	✓	-	✓	-	?	?	-
H13	ET	<1919	SW (s)	x	x	DG	SW	<2008	>2008	x	x	-	✓	✓	✓	x	-	✓	-	?	?	-
H14	MT	<1919	SW (s)	x	x	DG	NE	>2008	<2008	x	?	-	✓	✓	✓	✓	-	x	-	?	?	-

SortNo	DwellingType	DwellingAge	Predominant wall type	Predominant wall insulation	Wall Insulation	Predominant glazing type	Orientation	Improved Glazing	Improved loft insulation	Improved Draught-proofing	Eaves	Cladding/infill panels	Patchy wall finish	Cills & below windows	Lintels	Structural openings	Projecting window design	Junctions & extensions	Inset entrance porch	Chimney	Ground level	Unheated spaces (adjoining)
H15	MT	<1919	SW (s)	x	x	DG	E	<2008	<2008	x	✓	-	✓	✓	✓	x	✓	✓	-	✓	x	-
H16	SD	<1919	SW (r)	x	x	DG	N	<2008	>2008	x	x	-	✓	x	x	x	-	-	-	-	?	-
H17	D	1919-44	SW (r)	x	x	DG	S	<2008	<2008	x	x	-	x	✓	x	x	-	-	-	-	✓	-
H18	D	<1919	SW (r)	x	x	DG	E	<2008	<2008	x	x	-	x	x	x	x	-	✓	-	?	?	-
H19	D	1919-44	SW (r)	x	x	DG	NE	<2008	?	x	x	-	x	✓	x	✓	✓	✓	-	✓	✓	-
H20	D	1919-44	SW (r)	x	x	DG	NE	<2008	>2008	>2008	✓	-	x	✓	x	✓	✓	✓	✓	?	x	-
H21	D	1919-44	SW (r)	x	x	DG	N	<2008	<2008	x	✓	-	✓	?	x	✓	✓	?	✓	?	?	-
H22	SD	1919-44	SW (r)	SWI	>2008	DG	S	<2008	>2008	x	✓	-	✓	✓	x	✓	✓	✓	✓	?	?	-
H23	SD	1919-44	SW (b)	x	x	DG	SE	<2008	<2008	x	✓	-	x	x	x	x	✓	?	-	✓	?	-
H24	MT	<1919	SW (b)	x	x	DG	SW	<2008	<2008	>2008	✓	-	x	✓	x	x	✓	x	✓	?	?	-
H25	MT	<1919	SW (b)	x	x	SG	E	<2008	>2008	x	✓	-	✓	✓	✓	✓	-	-	-	?	?	-
H26	D	1919-44	SW (b)	SWI	>2008	DG	E	>2008	>2008	>2008	✓	-	✓	✓	x	✓	✓	-	-	x	?	-
H27	MT	<1919	SW (b)	x	x	SG	E	x	<2008	>2008	✓	-	x	✓	x	x	✓	-	✓	?	?	-
H28	MT	<1919	SW (b)	x	x	SG	W	<2008	>2008	>2008	x	-	✓	✓	x	x	-	-	-	?	✓	-
H29	MT	<1919	SW (b)	x	x	DG	W	<2008	>2008	x	✓	-	✓	✓	✓	✓	✓	-	✓	?	?	-
H30	D	<1919	SW (b)	x	x	SG	S	<2008	<2008	x	✓	-	✓	✓	x	x	-	-	-	?	✓	-
H31	MT	<1919	SW (b)	x	x	SG	E	x	<2008	x	x	-	✓	✓	✓	x	✓	-	✓	✓	?	-
H32	MT	<1919	SW (b)	x	x	DG	E	<2008	<2008	x	✓	-	✓	✓	x	✓	-	-	✓	?	x	-

SortNo	DwellingType	DwellingAge	Predominant wall type	Predominant wall insulation	Wall Insulation	Predominant glazing type	Orientation	Improved Glazing	Improved loft insulation	Improved Draught-proofing	Eaves	Cladding/infill panels	Patchy wall finish	Cills & below windows	Lintels	Structural openings	Projecting window design	Junctions & extensions	Inset entrance porch	Chimney	Ground level	Unheated spaces (adjoining)
H33	SD	1919-44	SW (b)	x	x	DG	S	<2008	<2008	x	✓	-	x	✓	x	✓	✓	-	✓	✓	?	?
H34	ET	<1919	SW (b)	x	x	SG	S		?	x	x	-	✓	✓	x	✓	-	-	-	✓	?	✓
H35	D	1965-80	CW (s)	CWI	<2008	DG	NE	<2008	<2008	<2008	✓	-	✓	x	x	x	-	✓	-	✓	x	x
H36	D	1965-80	CW (s)	x	x	DG	E	<2008	<2008	x	x	-	✓	✓	?	✓	-	?	-	✓	?	-
H37	D	1965-80	CW (s)	x	x	DG	SE	<2008	>2008	>2008	x	-	x	✓	?	✓	✓	✓	-	✓	?	-
H38	D	1965-80	CW (s)	CWI	As built	DG	NE	<2008	>2008	>2008	✓	-	x	✓	x	x	-	-	-	?	✓	-
H39	SD	1919-44	CW (r)	x	x	DG	S	<2008	>2008	x	✓	-	✓	✓	✓	✓	-	-	-	✓	?	-
H40	SD	1919-44	CW (r)	CWI	<2008	DG	E	<2008	>2008	x	✓	-	✓	✓	✓	✓	✓	✓	-	-	✓	-
H41	D	1965-80	CW (r)	CWI	<2008	DG	SE	<2008	<2008	x	✓	-	✓	✓	✓	✓	-	✓	-	?	✓	-
H42	D	1965-80	CW (r)	CWI	<2008	DG	S	<2008	<2008	x	x	-	✓	✓	✓	✓	-	✓	-	✓	?	-
H43	D	1981-90	CW (r)	CWI	>2008	DG	NW	>2008	>2008	x	x	-	x	x	✓	✓	-	x	✓	?	✓	-
H44	SD	1919-44	CW (r)	CWI	<2008	DG	W	<2008	<2008	x	✓	-	✓	✓	x	✓	-	?	✓	x	?	-
H45	D	<1919	CW (r)	CWI	?	DG	S	<2008	?	x	x	-	✓	✓	✓	✓	-	?	-	✓	✓	-
H46	SD	1919-44	CW (r)	CWI	<2008	DG	NE	<2008	<2008	x	✓	-	✓	✓	x	✓	✓	-	-	-	✓	-
H47	SD	1945-64	CW (r)	CWI	?	SG	SW	x	<2008	>2008	✓	-	✓	✓	✓	✓	-	✓	-	✓	✓	✓
H48	MT	1965-80	CW (r)	CWI	<2008	DG	SW	<2008	>2008	x	✓	-	✓	✓	✓	✓	-	✓	-	-	?	-
H49	D	1981-90	CW (r)	CWI	>2008	DG	NW	>2008	>2008	>2008	x	-	✓	x	✓	x	-	✓	-	?	x	x

SortNo	DwellingType	DwellingAge	Predominant wall type	Predominant wall insulation	Wall Insulation	Predominant glazing type	Orientation	Improved Glazing	Improved loft insulation	Improved Draught-proofing	Eaves	Cladding/infill panels	Patchy wall finish	Cills & below windows	Lintels	Structural openings	Projecting window design	Junctions & extensions	Inset entrance porch	Chimney	Ground level	Unheated spaces (adjoining)
H50	D	>1990	CW (r)	CWI	As built	DG	SE	<2008	<2008	x	✓	-	✓	✓	✓	x	-	x	-	x	?	-
H51	D	1965-80	CW (r)	CWI	>2008	DG	SE	<2008	>2008	x	✓	-	✓	?	✓	✓	-	✓	-	-	✓	-
H52	SD	1919-44	CW (r)	CWI	>2008	DG	NE	>2008	>2008	>2008	✓	-	x	✓	?	✓	✓	-	✓	?	x	-
H53	MT	1945-64	CW (r)	CWI	<2008	DG	SE	<2008	>2008	x	✓	-	✓	✓	✓	✓	-	-	-	-	✓	-
H54	SD	1981-90	CW (r)	CWI	<2008	DG	NE	<2008	>2008	>2008	x	-	x	x	✓	x	✓	x	✓	-	?	-
H55	SD	1965-80	CW (r)	CWI	As built	DG	SW	<2008	>2008	>2008	✓	-	x	✓	✓	x	✓	-	✓	-	✓	-
H56	D	1919-44	CW (r)	CWI	<2008	DG	S	>2008	>2008	x	✓	-	x	?	?	x	✓	✓	✓	x	x	-
H57	MT	1945-64	CW (r)	CWI	>2008	DG	NE	>2008	<2008	>2008	x	-	x	x	✓	x	-	✓	✓	-	x	-
H58	SD	1945-64	CW (r)	CWI	<2008	DG	NE	>2008	>2008	>2008	✓	-	✓	✓	✓	✓	-	✓	-	✓	?	✓
H59	F	1965-80	CW (r)	CWI	<2008	DG	SW	<2008	>2008	x	✓	-	✓	✓	✓	✓	-	✓	-	✓	x	-
H60	MT	1945-64	CW (r)	CWI	<2008	DG	NW	<2008	>2008	x	✓	-	✓	✓	✓	✓	-	-	-	x	?	-
H61	SD	1965-80	CW (r)	CWI	<2008	DG	NE	>2008	<2008	x	✓	-	✓	✓	✓	✓	-	-	-	x	?	-
H62	MT	1965-80	CW (r)	CWI	?	DG	NW	<2008	>2008	x	✓	-	✓	✓	✓	✓	-	✓	-	?	?	-
H63	ET	1945-64	CW (r)	CWI	<2008	DG	NW	<2008	>2008	x	✓	-	✓	✓	✓	✓	-	-	-	?	x	-
H64	MT	1945-64	CW (r)	CWI	<2008	DG	NW	<2008	<2008	x	✓	-	✓	✓	✓	✓	-	-	✓	x	?	-
H65	ET	1945-64	CW (r)	CWI	<2008	DG	N	<2008	>2008	x	✓	-	✓	✓	x	✓	-	-	-	-	?	-
H66	SD	1919-44	CW (r)	CWI	>2008	DG	SE	<2008	<2008	x	✓	✓	✓	✓	✓	✓	✓	-	✓	?	?	-

SortNo	DwellingType	DwellingAge	Predominant wall type	Predominant wall insulation	Wall Insulation	Predominant glazing type	Orientation	Improved Glazing	Improved loft insulation	Improved Draught-proofing	Eaves	Cladding/infill panels	Patchy wall finish	Cills & below windows	Lintels	Structural openings	Projecting window design	Junctions & extensions	Inset entrance porch	Chimney	Ground level	Unheated spaces (adjoining)
H67	SD	1919-44	CW (r)	CWI	<2008	DG	SW	<2008	>2008	x	✓	✓	✓	✓	✓	✓	✓	?	-	✓	?	-
H68	ET	1945-64	CW (r)	CWI	<2008	DG	NE	<2008	>2008	x	✓	✓	✓	✓	✓	✓	-	-	-	?	?	-
H69	ET	1945-64	CW (r)	CWI	<2008	DG	SW	<2008	>2008	x	✓	-	✓	✓	✓	✓	-	-	-	?	?	-
H70	SD	1945-64	CW (r)	CWI	<2008	DG	SE	<2008	>2008	x	✓	x	✓	✓	✓	✓	✓	x	-	✓	?	x
H71	MT	1965-80	CW (r)	CWI	>2008	DG	SE	<2008	<2008	x	x	✓	✓	✓	✓	✓	-	-	-	-	✓	?
H72	MT	1945-64	CW (r)	CWI	>2008	DG	SW	<2008	>2008	x	✓	✓	✓	✓	✓	✓	-	-	-	-	?	-
H73	SD	1945-64	CW (r)	CWI	<2008	DG	SW	<2008	<2008	x	x	x	x	x	✓	✓	-	x	-	?	?	-
H74	ET	1965-80	CW (r)	?		DG	NW	>2008	?	x	✓	✓	✓	✓	?	✓	-	-	-	-	?	-
H75	ET	1945-64	CW (r)	CWI	>2008	DG	NE	<2008	>2008	x	x	x	✓	✓	✓	✓	-	-	-	?	x	-
H76	SD	1919-44	CW (r)	CWI	<2008	DG	NE	<2008	<2008	x	x	-	✓	✓	✓	✓	✓	?	-	x	?	-
H77	MT	1945-64	CW (r)	CWI	<2008	DG	NE	<2008	>2008	>2008	x	✓	✓	✓	✓	✓	✓	-	-	?	?	✓
H78	SD	1945-64	CW (r)	CWI	<2008	DG	SE	>2008	<2008	x	✓	✓	✓	✓	?	✓	-	✓	-	✓	✓	✓
H79	ET	1945-64	CW (r)	CWI	>2008	DG	SW	<2008	<2008	x	✓	-	✓	✓	✓	✓	-	-	-	?	?	-
H80	SD	1981-90	CW (r)	CWI	As built	DG	NW	>2008	>2008	>2008	✓	-	✓	x	x	✓	-	✓	-	?	✓	x
H81	D	1981-90	CW (r)	CWI	As built	DG	E	<2008	>2008	>2008	x	-	x	x	✓	✓	-	✓	-	?	✓	-
H82	D	1965-80	CW (r)	CWI	?	DG	S	<2008	<2008	x	x	-	✓	✓	✓	✓	-	-	-	?	✓	-
H83	D	1981-90	CW (r)	CWI	<2008	DG	W	<2008	<2008	x	✓	-	✓	✓	x	x	-	✓	-	x	✓	-

SortNo	DwellingType	DwellingAge	Predominant wall type	Predominant wall insulation	Wall Insulation	Predominant glazing type	Orientation	Improved Glazing	Improved loft insulation	Improved Draught-proofing	Eaves	Cladding/infill panels	Patchy wall finish	Cills & below windows	Lintels	Structural openings	Projecting window design	Junctions & extensions	Inset entrance porch	Chimney	Ground level	Unheated spaces (adjoining)
H84	D	1965-80	CW (r)	CWI	>2008	DG	NW	>2008	>2008	>2008	x	-	x	✓	✓	x	-	✓	-	x	✓	x
H85	MT	1965-80	CW (r)	x	x	SeG	W	>2008	As built	>2008	✓	-	✓	?	?	✓	-	-	-	-	x	x
H86	MT	1981-90	CW (r)	CWI	As built	SG	W	<2008	>2008	x	✓	-	x	✓	✓	✓	x	-	✓	?	?	✓
H87	F	1981-90	CW (r)	x	x	DG	W	<2008	<2008	x	x	-	✓	✓	✓	x	-	✓	-	?	-	?
H88	D	1981-90		?		DG	S	>2008	<2008	>2008	x	-	x	x	?	✓	✓	?	-	-	✓	-