A BSRIA Guide

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Thermal Imaging of Building Fabric

By Colin Pearson

BG 39/2011

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1 Introduction – what is thermal imaging?

Thermal Imaging has many applications in the construction industry from heat loss and moisture detection to electrical inspection. It provides a quick assessment method for problems that involve heat generation and transfer. It generates images that clearly locate hot and cold areas.

This Guide concentrates on thermal imaging for building fabric insulation. It aims to help people involved in constructing, owning and operating buildings to obtain the thermal imaging they need when they need it and to have a basic understanding of the information that can be obtained from thermal images.

Infrared (meaning below red) is the name given to the part of the electromagnetic spectrum just beyond the red end of the visible spectrum. Infrared (IR) radiation is emitted by all objects proportional to the fourth power of absolute temperature. It travels through space in similar fashion to visible light but at longer wavelengths, approximately 0.7 microns to 1000 microns (μm). The two wavelength bands used for thermal imaging, shortwave (SW) and longwave (LW) are shown in Figure 1 in relation to other electromagnetic wavelengths in common use. The amount and wavelength of infrared emitted by an object generally varies with its surface temperature. The efficiency of the surface in radiating infrared (the emissivity) also affects the amount of IR radiation emitted. The transmissivity of the air or other material between the source and the observer affects how much infrared radiation is received by the observer or a surface exposed to the radiation.

Thermal imaging produces a picture that maps the intensity of IR radiation across the field of view. Because of the relationship between intensity of radiation and temperature this can be converted to a map of apparent temperature based on a number of assumptions that are explained later in this Guide. The use of temperature calibrated thermal images is generally referred to as 'thermography' a person who performs the task as a 'thermographer' and the images are often referred to as 'thermograms'.

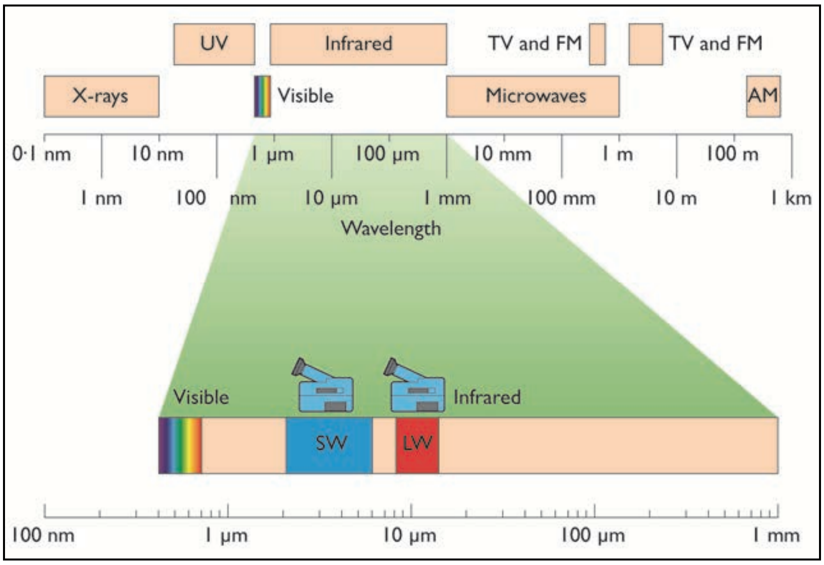

Figure 1: The electromagnetic spectrum

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2 The need for thermal imaging

Thermal imaging is the best way to assess continuity of insulation once the building fabric is complete. It is also a very effective method of locating air leakage paths in a completed building. This section discusses the legal requirements in Building Regulations and also the availability of BREEAM credits.

Regulations

The focus here is on the *2010 England & Wales Building Regulations* and supporting guidance, specifically *Part L (Conservation of Fuel and Power)*. Similar regulations and supporting guidance exist in *Scotland (Section 6)* and *Northern Ireland (Part F)*. It should be noted that Wales will have separate *Building Regulations* from England from the end of 2011, and that separate supporting guidance is expected to be published in 2013. At the time of writing this publication, it was not known what form these would take.

Building Regulations for England and Wales require that reasonable provision shall be made for the conservation of fuel and power in buildings by… limiting heat gains and losses… through thermal elements and other parts of the building fabric.

This requirement is supported by guidance in four Approved Documents:

- *Approved Document L1A - New Dwellings*
- *Approved Document L1B – Work in Existing Dwellings*
- *Approved Document L2A - New Non-Dwellings*
- *Approved Document L2B – Work in Existing Non-Dwellings*

All four Approved Documents provide the following guidance:

"The building fabric should be constructed so that there are no reasonably avoidable thermal bridges in the insulation layers caused by gaps within the various elements, at the joints between elements, and at the edges of elements such as those around window and door openings".

In the case of new buildings, linear transmittance values for the specific construction details used are fed into the CO_2 emissions calculations required by *Building Regulations*. Preference is given to accredited construction details by imposing a penalty in the CO_2 emissions calculations for non-accredited details. Also in the case of new buildings, it is a requirement to carry out airtightness testing, and the measured air permeability is fed into the CO_2 emissions calculations.

In the case of existing buildings, the guidance on continuity of insulation only applies where new thermal elements (for example walls, floors, and roofs.) are provided, for example when an extension is built. There are no requirements for CO_2 emissions calculations or airtightness testing on existing buildings.

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Regulation 43 of the *Building Regulations* for England and Wales requires that pressure testing is carried out on new buildings, in order to be satisfied that provision has been made to limit heat gains and losses through the building fabric. This includes heat transfer by air leakage. For new dwellings, *Building Regulations Approved Document L1A* [1] requires pressure tests to be carried out on a representative sample of dwellings. *Approved Document L2A* relating to new buildings other than dwellings requires an air leakage test to be carried out on all buildings subject to the regulations in accordance with the standard test method [2]. More details can be found in the BSRIA airtightness testing guides [3].

Thermal imaging is the only practical way of checking that thermal insulation hidden in the structure meets the requirements for continuity of insulation (see box).

Building Regulations Part L* and *Approved Documents

Continuity of insulation

5.3 The building fabric should be constructed so that there are no reasonably avoidable thermal bridges in the insulation layers caused by gaps within the various elements, at the joints between elements and at the edges of elements such as those around window and door openings.

5.5 Where calculated in support of the approaches set out in paragraph 5.7a and 5.7b, linear transmittance and temperature factors should be calculated following the guidance set out in BRE 497 [4]. Reasonable provision would be to demonstrate that the specified details achieve a **temperature factor** that is no worse than the performance set out in BRE 1/06 [5]

Specifications

Building specifications often include a clause specifying thermal imaging as a means of quality assurance.

The BRE Environmental Assessment Method, BREEAM, in its 2011 edition [6], gives credit for thermal imaging of new buildings provided that remedial action is taken for any serious defects found in the survey. There is no equivalent credit for new dwellings in the *Code for Sustainable Homes Technical Guide*, November 2010 [7].

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3 Thermal performance of buildings

When a building is heated (or cooled) there is a temperature difference between inside and outside so that the heat flows through the walls, windows, doors, roof and floor as well as by leakage of air through gaps in the structure. The resistance to heat flow varies with the properties of the materials and their thicknesses. Most building materials, such as brick and concrete, have a relatively poor resistance to heat flow so insulation is required to impede the flow of heat out of (or into) the building. Mineral fibre and foams of plastics are good insulators; their resistance to heat flow actually depends on the pockets of air trapped within. Other materials and components are continually being developed as insulators that trap pockets of air, inert gas or even a partial vacuum.

The relatively high thermal resistance of thin layers of air also results in differences between the surface temperature of a building material and the ambient air temperature. When there is little or no air movement, there is a layer of still air adjacent to the structure, the boundary layer, which acts as an insulator. When there is rapid air movement, in windy conditions, the boundary layer is diminished and the surface uniformly tends towards the ambient temperature. Differences in heat flow through the boundary layer cause the differences in surface temperature that are observed in thermal imaging.

Thermal conductance is the inverse of resistance and the term U value is used for the inverse of the sum of thermal resistances over an area of a fabric element.

Many factors affect the U value, of building fabric elements: presence, position, thickness and condition of insulation, moisture content and component material properties. Where thermal resistance is low there is increased flow of heat through the structure, an increased temperature on the cold side and a decreased temperature on the warm side. Where the thermal conductance falls outside the acceptable range, there may be a defect in the construction that should be highlighted. Thermal imaging of the structure can detect these variations in conductivity by finding differences in the surface temperature, but skill is required to differentiate variations in emissivity, reflections, evaporation or air leakage that can look similar.

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4 What to expect from a thermographic survey

Thermographers use their skill and experience to interpret thermal images and diagnose any anomalies in the construction. They work to European or International Standards such as BS-EN 13187 [8]. This makes recommendations on suitable conditions for a thermographic survey and what to expect in a report of the survey.

A well conducted thermographic survey should show whether there are any variations in the thermal performance of similar parts of a building. It should show with images and any necessary text:

- a summary of conditions at the time of the survey – see section 9
- the method used to analyse and draw conclusions from the images – see section 6
- any conditions that might compromise the results
- differences between superficially similar parts of the fabric
- variations in emissivity across the image
- the location of air leakage – dependent on wind speed, direction or artificial pressurisation.

If the thermographer has been asked to do so there should also be:

- an indication of likely causes of anomalies found
- an indication of what apparent anomalies should be ignored because they are caused by extraneous causes, such as concealed pipes or electrical equipment
- the presence and operational status of heat emitters such as radiators and underfloor heating or cooling systems
- an assessment of the effectiveness of the thermal insulation.

If the thermographer has additional suitable qualifications, such as a qualification in building science or surveying, you may also expect additional information from the survey:

- recommendations for remedial action
- quantitative estimates of thermal insulation effectiveness
- estimates of annual heating or cooling energy requirements.

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5 How to choose a thermographer

5.1 Qualifications

To be sure of a reliable result from a thermographic survey it is important to ensure that the thermographer is suitably qualified. Certification to an appropriate standard by an accredited body provides assurance that the thermographer has the necessary skill, knowledge and experience to perform a specific job. The International Standard, ISO 18436 part 7 [9] sets out requirements for certification of thermographers at three levels, referred to as Categories in the Standard:

- **Category I:** qualified for obtaining good images and reporting under the guidance of a more experienced and better qualified thermographer
- **Category II:** qualified for conducting thermographic surveys and producing reports
- **Category III:** qualified to set up and supervise monitoring programs, train and develop methods.

In the UK Certification of thermographers is managed by PCN, part of the British Institute of Non-Destructive Testing, (BINDT). The UK Thermography Association (UKTA) is also part of this Institute and provides a list of its members with a map of their locations on its website at www.ukta.org.

Experience

It is always advisable to ask for and look at examples of similar work done by the same thermographer and consult previous clients.

5.2 Equipment used

There is a wide range of infrared cameras on the market that have application in the building industry. The cameras differ in thermal sensitivity, image resolution, usability features and at the time of writing are priced from about one thousand to thirty thousand pounds but prices are falling and the features are continually improving. They fall into three groups:

1. low cost cameras
2. mid- range cameras
3. high-end cameras.

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Low-cost cameras

Typically <30,000 pixels, for example 160 x 120 pixel image size, 100 (millikelvin) mK sensitivity and £1k-5k.

These cameras are useful on small buildings for anyone such as an airtightness tester who wants a quick look at possible thermal problems such as air leakage locations. They typically have fixed lenses, can only be used at short range because of their low resolution, and the images are not suitable for reporting purposes.

Image supplied by Flir Systems

Figure 2: Example of a low-cost camera

Mid-range cameras

Typically 30-100,000 pixels, for example 320 x 240 pixel image size, 50 mK sensitivity and £5k-12k.

These cameras are most often used by thermographers offering professional thermography services as the images are suitable for reproduction in reports. They can typically resolve anomalies 10 mm wide at 5 m distance and have the capability of fitting interchangeable lenses such as wide angle versions that are often more suitable for work within building structures. Products also include visible light cameras ideal for simultaneously recording the object or building element under investigation.

Image supplied by Flir Systems

Figure 3: Example of a mid-range camera

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High-end cameras
Typically >100,000 pixels, for example 640 x 480 pixel image size, 30 mK sensitivity and £12k-30k.

These cameras are useful for external and large building surveys because they can resolve anomalies of 10 mm width at 10 m or more. Features on these cameras are extensive which can include video and GPS location, useful during large site surveys.


Image supplied by Flir Systems

Figure 4: Example of a high-end camera

Table 1: Specifications for infrared cameras

Camera	Typical specifications			Typical usage		
	Image pixels	Sensitivity	Cost	Building	Person	Features
Low-cost	160 x 120	100 mK	£1k-5k	Small	Airtightness tester	• fixed lenses • short range • low resolution
Mid-range	320 x 240	50 mK	£5k-12k	Medium	Thermographers	• resolves anomalies 10 mm wide at 5 m distance • interchangeable lenses • visible light cameras
High-end	640 x 480	30 mK	£12k-30k	External and large	Professional thermographers	• resolves anomalies 10 mm wide at 10 m distance • can include video and GPS location

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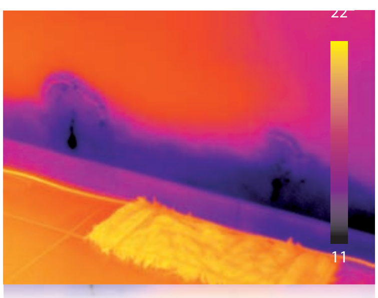

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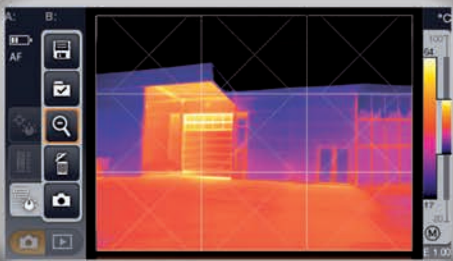

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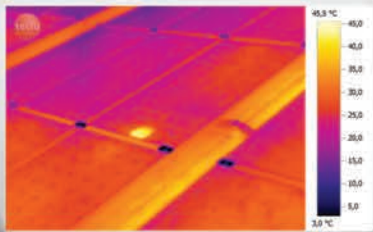

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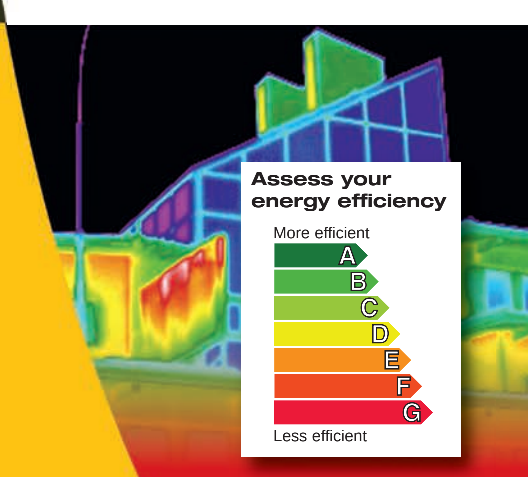

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6 Different approaches to the survey

The method used for a thermographic survey will depend on the objective of the survey and the features of the building. Experienced thermographers will choose the most appropriate method for each survey depending on site conditions and requirements of the specification or Regulations.

6.1 Qualitative or quantitative

Most thermographic surveys are qualitative, they show locations of anomalies that are abnormal thermal features, and do not attempt to quantify the heat loss from the anomaly or building as a whole. It is possible to quantify some aspects of the survey, such as condensation risk or surface areas of defects and to make approximate estimates of heat loss, but these methods are less often used.

6.2 External surveys

External surveys give a useful overview of a building and if they include a large enough area they can be useful for comparing one part of a building with another. If the internal temperature is known in each part of the building this can allow useful comparison of thermal performance between new and old parts of the structure. In the UK it is unusual to find suitable conditions in the summer months of May to September.

Greater temperature differences across the fabric and lower outside wind speeds next to the surface give best results for thermal imaging. For practical purposes the temperature difference should be at least 10°C, there should be no precipitation or mist and the wind speed for external imaging must be no more than 5 m/s. There should also be no very hot objects, like the sun, and no very cold objects, like a clear sky, which can be as cold as -50°C in the hemisphere facing the surface being imaged because these may be reflected by the surface, affecting the apparent temperature. They also affect the real temperature of surfaces by radiative heat transfer. Best results are usually obtained on cold, cloudy, dry still winter nights.

Since wind speeds exceed 5m/s and rain or mist occur for much of the winter when temperature differences are adequate, internal surveys are often more effective than external surveys in identifying anomalies. External surveys can be spoiled by solar radiation and clear skies. At night there may be a drop in the apparent surface temperature due to radiation to the sky. External thermography is fraught with problems that can make the results difficult to interpret. Figure 5 shows differences between two semi-detached houses, but it is difficult to tell whether the differences are caused by different internal temperatures, loft conversions, air leakage, double glazing or reflections.

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Figure 5: External thermal image of two semi-detached houses

Thermal imaging relies on the resistance to heat flow provided by the thin layer of air in contact with the surface, the boundary layer. This surface resistance provides a temperature difference between the surface and the general mass of air. The value of this surface resistance depends on how much the air at the surface is moving so it depends strongly on wind speed.

Table 2: Values of surface resistance (R_s) at various wind speeds

Wind speed m/s	R_s m²K/W	Wind condition
0.13	0.13	**Calm**: the assumed indoor condition in calculation of U values
1	0.08	**Light air**
2	0.06	**Light breeze**: assumed sheltered outdoor condition in U values
5	0.04	**Gentle breeze**: assumed normal outdoor condition in U values
7	0.03	**Moderate breeze**
10	0.02	**Fresh breeze**: assumed exposed outdoor condition in U values

Table 2 shows how the surface resistance varies with air movement. The air speed of 0.13m/s corresponds to the almost still air that is found inside buildings. Other speeds are related to descriptions in the Beaufort Scale used for wind speed. In very high wind speeds there is no surface resistance and therefore very little difference between air temperature and surface temperature. There will still be a difference due to radiant heat transfer when there is a cold clear sky for instance.

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6.3 Internal surveys

Internal surveys avoid most of the problems associated with external surveys, although hot objects such as radiators and electrical equipment can still cause anomalies. The low air speed next to the walls leads to a high boundary layer or surface resistance, R_s and a significant temperature difference between ambient and surface temperatures to give good thermal images. A defect that can be seen from inside and outside the building will nearly always show up better in the internal image.

This method clearly identifies anomalies in the fabric. In Figure 6 the regular dark lines show the low surface temperature characteristic of lower thermal resistance of the mortar joints in a wall built of lightweight concrete blocks. The dark continuous vertical line is characteristic of an internal corner, where the surface temperature is lower than on a flat wall because of the greater boundary layer resistance in corners. The short dark vertical lines at the top of the wall are indicative of air leakage where joints have not been fully filled with mortar.

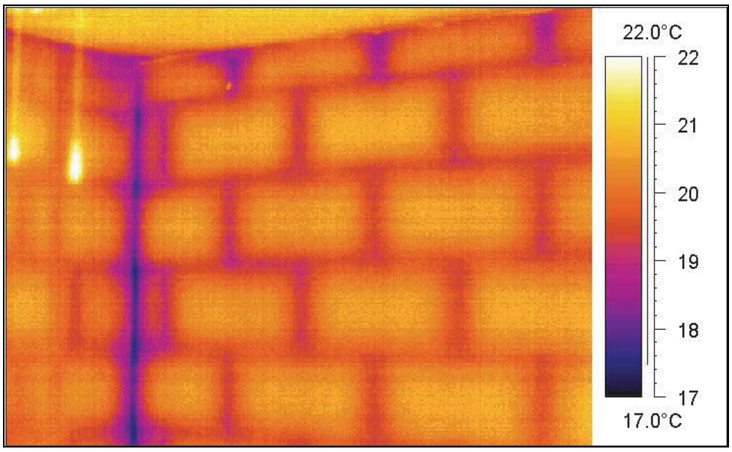

Figure 6: Thermal image of internal wall surface showing mortar joints

Predicting condensation risk

Properly adjusted thermal images from good quality cameras show surface temperatures accurately to within ± 0.1°C. When a surface is colder than the dewpoint of the surrounding air condensation will occur. There are published tables (such as CIBSE Guide C1) of dewpoint temperatures at different air temperatures and humidities. Thermal imaging can find these areas and some infrared cameras have built-in analysis features to detect areas of condensation risk as seen in Figure 7. But the temperature at the time of the survey may not be the design conditions so surface temperature could be lower at other times. The thermographer can use methods of predicting surface temperatures in other conditions.

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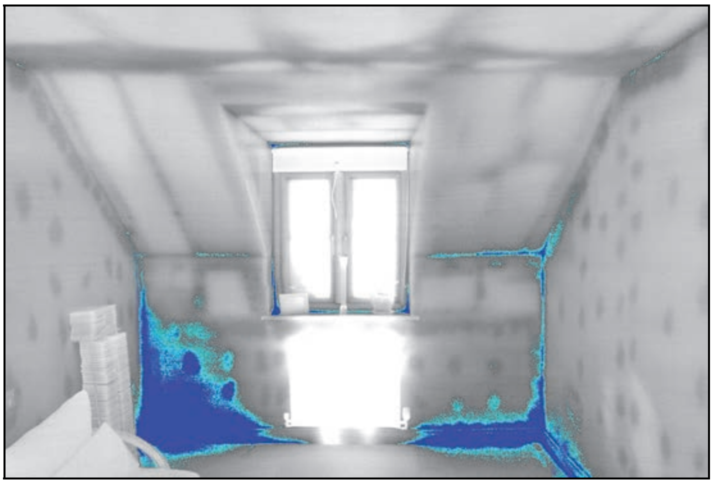

Figure 7: Thermal image with isotherms to show areas of condensation risk

Thermal index

Thermal index, TI, is a dimensionless parameter that describes the thermal performance of an area of building fabric. TI can be calculated for an area on a thermal image. It has been used as an indicator of the likelihood of condensation as described in BRE Information Paper IP 1/06 (although it is called temperature factor f_{Rsi}). IP 1/06 states that for dwellings the value of TI should not be less than 0.75. In buildings likely to be more humid, such as swimming pools the recommended minimum TI is 0.9 and in less humid buildings such as shops and offices it should not be below 0.5.

$$\text{Thermal index } \frac{(T_{si} - T_o)}{(T_i - T_o)}$$

Where

T_{si} = Internal surface temperature
T_i = Internal ambient temperature
T_o = External ambient temperature

The TI value of 0.75 corresponds to an internal surface temperature of 13.8 °C under commonly used design conditions of 20 °C inside and –5 °C outside. This is the dewpoint of air at 20°C and 67% saturation. Condensation would occur on these surfaces if the air was more saturated with water vapour or the outside temperature was below –5 °C. It also approximates to a localised U value of 1.9 W/m²K. Current Building Regulations require a U value to be no more than 0.2 or 0.3 W/m²K except for small areas that contribute less than 10% to the total heat loss.

Thermal imaging is not an accurate method of measuring U value because:

- it relies on assessing the small temperature difference across the thin boundary layer of air on the inside of the wall and the assumption of a constant thermal resistance for this boundary layer, usually 0.13 m²K/W.

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- this may be reasonable for controlled conditions in a laboratory, but not in the real conditions found in buildings
- accuracy is typically ± 25%, but worse for well-insulated walls with low U values
- it does not take into account the fact that heat is stored and transferred slowly through heavyweight structures such as brick and concrete so the heat transfer is affected by the past temperature difference. A snapshot is not representative of the average in dynamic conditions.

U value can be assessed by heat flux measurement (direct measurement of heat transfer using a special sensor) but thermal imaging can cover a much wider area to assess the extent of any problems identified. As TI and U value are both measures of thermal transmittance it is useful to know the approximate relationship between them.

Under typical survey conditions (Internal temperature, 20 °C, external temperature, 1 °C, Internal surface resistance, R_{si} = 0.13 m²K/W) the range of TI found would give a surface temperature of 15.3 to 19.6 °C as shown in Table 3.

Table 3: Approximate equivalence of TI, surface temperature and U Value To=1 °C, Ti=20 °C

Thermal Index, TI	0.75	0.8	0.85	0.9	0.95	0.97	0.98	
U Value	1.92	1.54	1.15	0.77	0.38	0.23	0.15	W/m²K
Internal surface temperature, T_{si}	15.3	16.2	17.2	18.1	19.1	19.4	19.6	°C
Total Thermal Resistance, R_t	0.52	0.65	0.87	1.30	2.60	4.33	6.50	m²K/W

Reflected apparent temperature

Thermographers often use a small area in some of the thermal images to estimate the ambient temperature in the vicinity. A reflective insulated pad may be temporarily fixed to the wall to reflect the temperature of the surroundings in a non-directional manner (for this reason the surface should have a crinkled metallic finish). The temperature of this is used to calibrate the image in which it appeared and other images of the same surface.

In Figure 8 the reflective area (in the blue square AR02*) shows a Reflected Apparent Temperature of 21 °C. This has been used in the analysis parameters for the image to show that the Thermal Index in the blue box AR01 area is 0.90.

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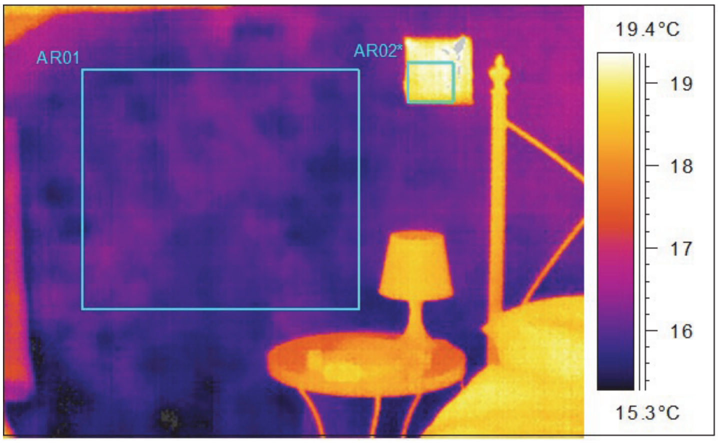

Figure 8: Thermal image including reflective surface for estimating ambient temperature

6.4 Estimating areas

Once thermal anomalies have been identified their severity may be assessed by their area. It is possible to use geometry and lens properties to estimate areas of anomalies. This requires accurate measurement of the distance between the infrared camera and the anomaly. Many thermographers use laser distance meters.

Thermographers and building owners may make an agreement on maximum acceptable defect area before the survey. At the time of writing there are no universal standards of continuity of insulation in *Building Regulations Approved Documents L1* and *L2*. The requirement is for 'no reasonably avoidable thermal bridges'. Acceptance criteria should be agreed before the survey and will depend on at least two factors:

- The seriousness of any defect
- The proportion of the fabric element affected by this defect

Some thermographers use a method of differentiating serious from non-serious defects. Serious defects can be defined as having a Thermal Index below a certain value such as 0.75. As explained on page 17 under thermal index, other values may be used where appropriate for different levels of internal humidity. This method can be used for checking compliance with the limits on alpha values in the *Building Regulations Approved Documents L1* and *L2*.

The alpha (α) value is defined as the ratio of the sum of the rate of heat loss through thermal bridges at junctions, psi (Ψ) values, to the sum of the rate of heat loss through the plane areas of the building (U values), and the value is limited to a maximum of 0.1.

That is:

$$\alpha = \frac{\Sigma L\Psi}{\Sigma AU} \leq 0.1$$

Where:

L is the length of thermal bridge, and A is the area of plane element.

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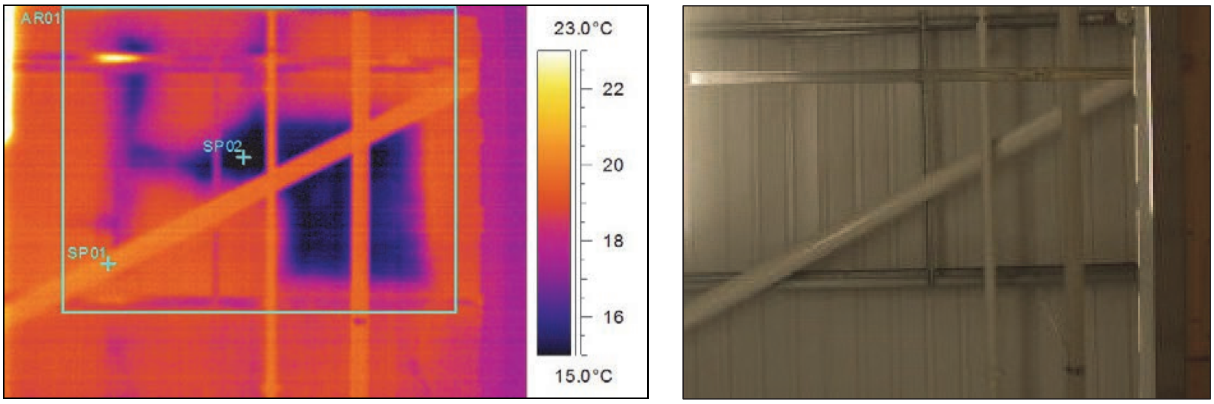
The critical temperature depends on location within the building and in some cases orientation if there are surrounding buildings at other temperatures. The maximum allowable area is often agreed between the thermographer and the client and a typical limit is not more than one square metre in every thousand should be affected by serious defects, that is 0.1%.

Figure 9: Cold area on underside of roof analysed for area below critical temperature



In Figure 9, the area below the critical temperature, 17.5 °C, within the blue square was estimated by the thermographic analysis software to be 0.93 m². The temperature at spot SP01 was 20.1 °C and that at SP02 was 14.6 °C with an external temperature of 7 °C. In this survey the areas below critical temperature were added for all the images to give a total area of anomalies in the building. This was then compared with the total internal surface area to give a percentage defect area. Small areas of defects may be acceptable, but large areas significantly affect the thermal performance of the building. The critical temperature and acceptable total areas of defects need to be agreed between the client and the thermographer before the survey. The thermographer may refer to recommendations for Thermal Index and prevailing temperatures to recommend a suitable critical temperature or use alpha values from the *Building Regulations*.

6.5 Air leakage surveys

Air infiltration contributes about 10% of the heat loss in a typical house built in the late 20th Century. Recent editions of building Regulations have aimed to reduce this by limiting the allowable infiltration and specifying airtightness testing. Unfortunately airtightness testing does not identify the location of the air leaks that are limiting the airtightness. Thermal imaging can clearly show these leaks in a depressurisation test provided that there is a temperature difference of at least 5 °C at the time of the test.

Thermal imaging is therefore a useful diagnostic tool in tests on new buildings, but it can also be used to detect air leakage that is causing heat loss from older buildings. Although a blower door is typically used to provide the pressurisation it is possible to use the effects of wind, which typically pressurises one side of a building or 'stack effect' that leads to air entry at low levels and exit at high levels in tall buildings.

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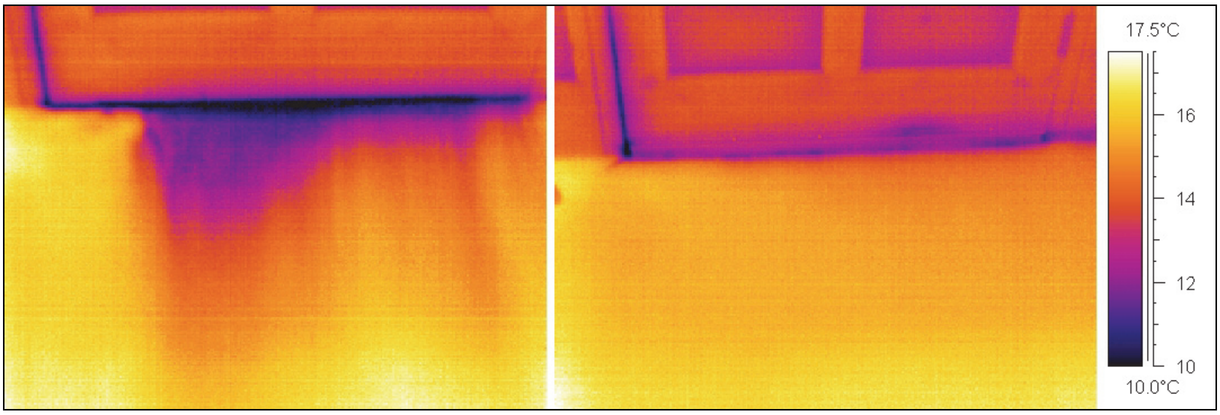
Figure 10: Thermal images of air leakage under door before and after draught strip installation



6.6 Roof surveys

There are health and safety issues for all surveys, but if roof surveys are to be undertaken the consequences of an accident are considerably greater than for wall inspections. In buildings where the underside of the roof insulation is near the exposed surface an internal survey will produce good results. This applies to many traditional dwellings where the roof insulation is at upper floor ceiling level, cold roof construction. It also applies to many industrial and commercial buildings where the underside of the roof cladding is visible.

Surveys from the upper surface of the roof can sometimes be undertaken from surrounding, taller buildings or by using a camera on a telescopic mast. If it is necessary to walk on the roof to do the survey the risk assessment should include, but not be limited to:

- bearing capacity of the roof
- slippery surfaces
- edge protection such as parapet or railing
- appropriate training of the thermographer
- harness and fall arrest systems
- availability of others to rescue a fallen worker.

As well as detecting missing insulation and cold bridges, a roof survey is often used to detect areas of thermal insulation that have been affected by water ingress from a damaged roof membrane. This is a very effective method of diagnosing damaged roof membranes, but there are limits on when it can be done. There should have been rain within the last week, but the roof should have a dry surface with no puddles, debris or stone chippings. The roof must have been allowed to warm during a sunny day. After sunset the roof will cool down but the areas that have absorbed water will remain warm for longer as seen in Figure 11.

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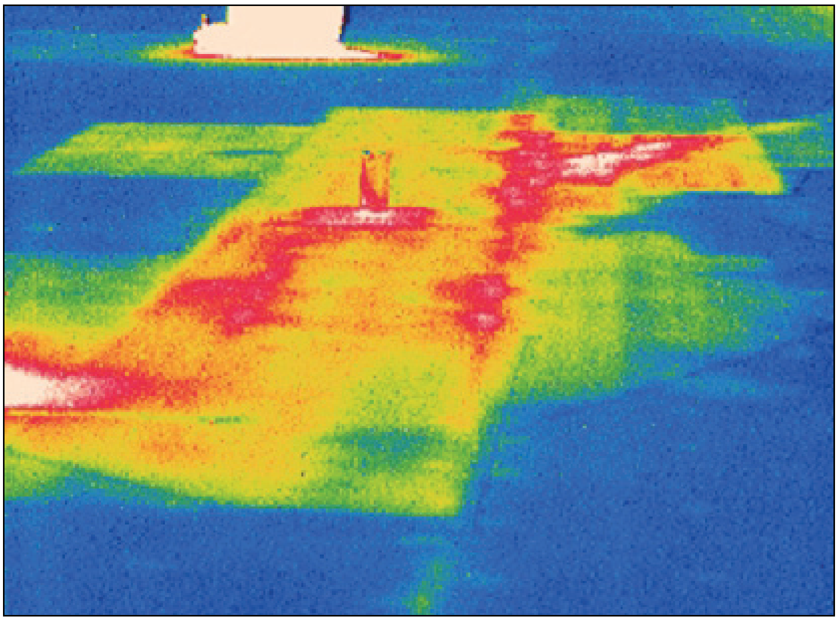

Figure 11: Flat roof with patch of damp insulation

Figure 12: Thermal imaging camera in use

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7 How to interpret the results

An infrared camera can detect the various levels of infrared emission from the surface of an object. It produces a visual 'thermal' image of the object viewed by mapping the intensity of infrared radiation from each point in the field of view. When thermal images are reproduced with a temperature scale the apparent temperature can also be seen at each point.

Most thermal imaging cameras also produce a digital photograph in addition to the thermal image. The purpose of the photograph (which usually covers a wider angle than the image) is to aid the location of the image in relation to the building.

7.1 Reading the temperature

Thermal images or thermograms as they are sometimes known are usually reproduced with a colour scale beside the image itself. This scale shows the relative temperature indicated by the colour in the image. To the right of this scale, numerical values are given. There are several sets of colours or palettes that are commonly used to show the differences in temperature. The colours in the image are related to the temperature scale by the colour bar beside the image. Most of the images in this document are reproduced in the 'ironbow' palette. This has two advantages: when reproduced in black and white it still allows interpretation of the temperatures and the scale is related to the colours of a real object heated to glowing temperatures.

The image reproduced below uses the rainbow palette. This has the advantage of exaggerating small temperature differences, but it is more difficult to compare temperatures that are more widely spaced. This image also shows how multiple images taken from a great distance can be stitched together to make an overall image of a large building.

Figure 13: Thermal image using the rainbow palette

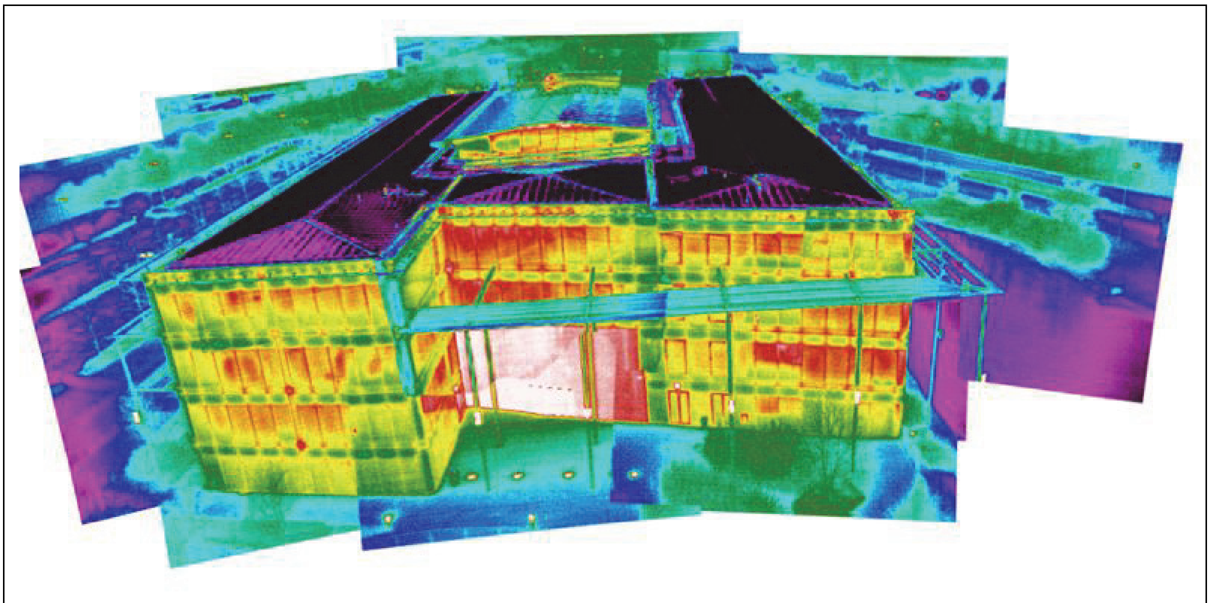

Image supplied by iRed Ltd

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The lowermost value on the temperature scale usually indicates the minimum temperature in the image. In most images, areas that are black in the image are colder than this value. The uppermost value indicates the maximum temperature in the image. Anything that is white in the image is warmer than this value. The difference between these two values is called the temperature span, for example an image with values of 18.2 °C and 32.5 °C has a temperature span of 14.3 °C. The lower the temperature span, the more sensitive the infrared camera is to changes in surface temperature.

7.2 Emissivity

Materials with a high emissivity show their true temperature better than those with low emissivity. Common building materials such as brick, concrete and paint have a high emissivity of around 0.9. For opaque materials emissivity plus reflectance = 1. Other materials such as clean copper, steel and zinc have a low emissivity of about 0.1 so they reflect the surrounding temperature. Plain glass has a relatively high emissivity at longwave infrared wavelengths of about 0.85. This means that reflections are visible but not dominant. However, most glass now used in buildings has some kind of coating to control solar gain or reduce heat loss so the emissivity and infrared reflectance cannot be assumed.

7.3 Reflections

The apparent temperature of part of an image may not be the true temperature. Infrared is reflected in the same way as light. Objects that are particularly reflective for infrared include polished metals, water and glass. These materials tend to reflect the temperature of the environment facing them. Corrections can be made to the indicated temperature by making the correct adjustment to the values of emissivity and reflected apparent temperature when processing the image.

7.4 Wind speed

The temperature of a surface can be changed significantly if there is a significant flow of air across the surface as explained in Section 6.2. In windy conditions the temperature of the outside of a building could be uniformly the same as the air temperature.

7.5 Angle of view

Most materials radiate infrared reasonably uniformly at angles up to 45º from perpendicular. But if the thermal image is generated further from the perpendicular the amount of radiation is reduced and the temperature can be underestimated. In Figure 14 the area labelled AR02 has an apparent average temperature of 8.7 ºC but the equivalent area AR03 nearer the camera shows that the true temperature is 9.2 ºC. The metal clad part of the wall also shows the effect of reflection as the average temperature of AR01 is 1.7 ºC and the upper part that is more exposed to the sky has a temperature of -1.0 ºC.

This effect can be seen more clearly in Figure 15 using a calibration hot plate in a laboratory. The images of the circular hot plate were taken at 0º, 57º and 71º from perpendicular. They show temperatures of 50 ºC, 48.9 ºC and 47.3 ºC respectively.

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Figure 14: Temperature can be underestimated because of camera angle

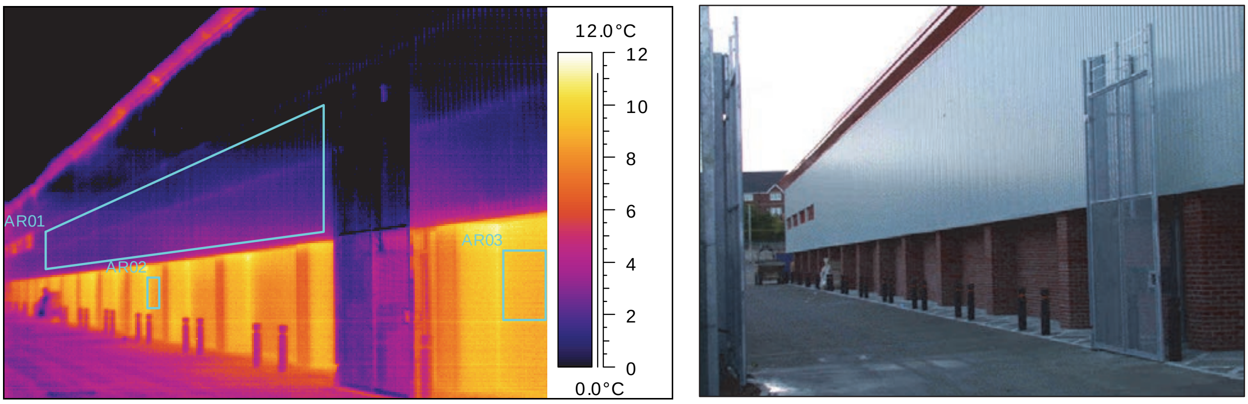
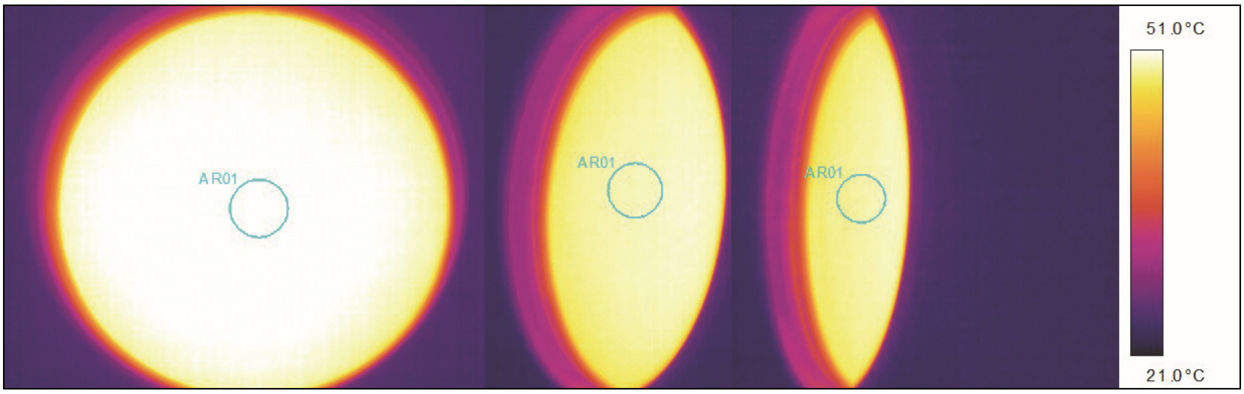


Figure 15: Different temperatures shown for a calibration plate at acute angles



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8 Supplementary testing

Thermography is often used in conjunction with other tests to demonstrate additional properties of the structure and confirm the cause of anomalies that have been identified.

8.1 Heat flux

Estimation of thermal conductance, U value, by infrared thermography alone is only practical when precise environmental conditions are known and wind speed is minimal. More accurate results can be obtained by using a heat flux measurement device in at least one location. Thermography can then be used to compare other areas with this known thermal performance.

Most heat flux sensors comprise a disc of a material with a small thermal resistance about 5mm thick and very accurate temperature sensors to measure the temperature difference across it. The result can be converted into heat flow in W/m^2 because the resistance of the pad is accurately known. Temperature inside and outside the building have to be measured accurately and the measurements usually continued for ten days so that an average can be obtained to take account of variations in temperature and thermal storage.

8.2 Cavity inspection

Endoscopes (or borescopes) allow visual inspection, through a small hole, of gaps in insulation and air leakage pathways. As this method usually involves drilling holes in the fabric it has limited application in new buildings, but is often used to check where remedial work is suggested.

8.3 Moisture content

A hand-held moisture meter can be very useful in diagnosing thermal anomalies. Masonry walls are often found to have variable moisture contents leading to thermal patterns not directly related to insulation placement. Wet thermal insulation will also give thermal anomalies and can be confirmed with a moisture meter if the insulation is accessible.

8.4 Airtightness

Airtightness testing is a requirement of Part L of the Building Regulations. It gives a measurement of the air leakage at a pressure difference of 50 Pa and there are limits of acceptability in the Approved Documents. It accurately quantifies, but gives no location of air leakage. Thermography can locate the air leakage, but not quantify it so the two are complementary. Air pressurisation using the same blower door can be useful even if the building passes the airtightness test.

8.5 Coheating

The concept of coheating has been introduced to testing of dwellings because it allows a holistic approach to measuring the complete heating energy use. It usually involves heating a completed but unoccupied dwelling to a fixed temperature, at least 10 °C above the ambient temperature and measuring how much energy is required to maintain this temperature for an extended period, typically a week. Weather conditions are also measured so that corrections can be made to the heat input to predict how much heat would be required in standard conditions. Thermal imaging is used to show areas of heat loss and to demonstrate that a constant temperature is maintained across the whole house.

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9 Expected report contents

The British standard for thermal imaging of buildings, *BS-EN 13187*, gives a list of information to be reported in a survey.

A full written report should be submitted presenting the survey data and the interpretation made. Submission of this report may be in printed form or in electronic format. Video of an infrared survey may be submitted as additional material to the written report. The written report should contain:

- a statement of the survey objective
- the date and time of survey
- environmental conditions prevailing at the time of the survey, such as wind speed/direction, internal and external temperature
- the infrared technology used
- the site-specific survey methodology
- infrared thermograms with temperature calibration
- photographs of thermogram locations
- an interpretation of the thermograms
- the conclusions/recommendations drawn from the survey.

Additional requirements may be imposed by the builder or developer in their contract. Some contracts require images of every part of the structure for record purposes, but it is normal to only record anomalies.

Where remedial work is recommended it is important to conduct a repeat survey of that part of the building. Since the weather conditions may be different at the time of the retest it may be useful to use a quantifying measure such as Thermal Index to compare the images before and after remedial work.

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References

1 Approved Document L2A: *Conservation of Fuel and Power (New buildings other than Dwellings)* (2010 edition) May 2010

2 Technical standard 1, *Measuring Air Permeability of Building Envelopes,* The Air Tightness Testing and Measurement Association (ATTMA), Issue 2, 2007

3 *Airtightness Testing for New Dwellings - A Practical Guide for Builders, 2007* and *Airtightness Testing- The Essential Guide to Part L2 of the2006 Building Regulations*, BSRIA Guide BG 4/2006 ISBN 0 86022 662 X

4 *Conventions for Calculating Linear Thermal Transmittance and Temperature Factors,* BRE 497, Tim Ward and Chris Sanders, BRE, 2007, ISBN 978-1-86081-986-5

5 IP 1/06, *Assessing the Effects of Thermal Bridging at Junctions and Around Openings*, BRE, February 2006, ISBN 1 86081 904 4

6 BREEAM 2011 *New Construction Technical Guide*, SD5073, ISSUE 2, BRE, July 2011

7 *Code for Sustainable Homes Technical Guide*, November 2010. ISBN 978 140982 123 6

8 BS-EN 13187. *Thermal Performance of Buildings- Qualitative Detection of Thermal Irregularities in Building Envelopes- Infrared Method* (Based on ISO 6781:1983 which is currently under review in 7 parts)

9 ISO 18436-7:2008, *Condition Monitoring and Diagnostics of Machines -- Requirements for Qualification and Assessment of Personnel – Part 7: Thermography*

Websites

ATTMA: www.attma.org/

BRE Bookshop: www.brebookshop.com/

BREEAM: www.breeam.org

British Standards: shop.bsigroup.com/

Building Regulations Part L:
www.planningportal.gov.uk/buildingregulations/approveddocuments/partl/

CIBSE: www.cibse.org

PCN: www.bindt.org/Certification

UK Thermography Association: www.ukta.org

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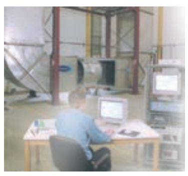

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