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Short Guide

THERMAL IMAGING IN THE HISTORIC ENVIRONMENT

Historic Environment Scotland
Àrainneachd Eachdraidheil Alba

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1. Introduction

Thermal imaging, also known as *infrared thermography*, is a type of non-destructive investigation that enables rapid imaging of temperature variations across large surface areas. Thermal imaging has become popular in recent years as the equipment is relatively easy to use and can appear to provide a quick and easy way of identifying problems in buildings. It allows the user to obtain data and analyse an object without the need for a sample to be removed and without damage to the object. However, the images produced with a thermal camera can easily be misinterpreted or manipulated and can sometimes be misleading.

There is a wide range of circumstances where thermography may be useful for the survey and investigation of traditional buildings. Useful applications include assessing heat loss, investigating the causes of dampness and locating voids. This Short Guide explains what thermography is, where it can be usefully applied, the conditions under which it is appropriate, and some of the pitfalls of using it inappropriately.

2. Infrared thermal imaging

2.1 What is a thermal image?

Thermal cameras are similar to digital photographic cameras, but they detect *infrared radiation* (IR) rather than visible light. Infrared radiation is related to the temperature of an object and a thermal camera converts the intensity of radiation to a visible image or *thermogram* in which every pixel records a temperature.

Infrared radiation is invisible to the human eye as it occurs beyond the red end of the visible light spectrum (Fig. 1). Visible light wavelengths lie between about 0.4-0.8 µm[1]. Thermal cameras work with wavelengths between 2-14 µm. No single camera covers this entire range; different wavelength ranges are appropriate to specific applications. Shortwave cameras which detect wavelengths around 2-8 µm are used in specialist applications, often for hot processes, such as inspection of furnaces and for the detection of gas leaks. Building thermography uses longwave cameras (8-14 µm).

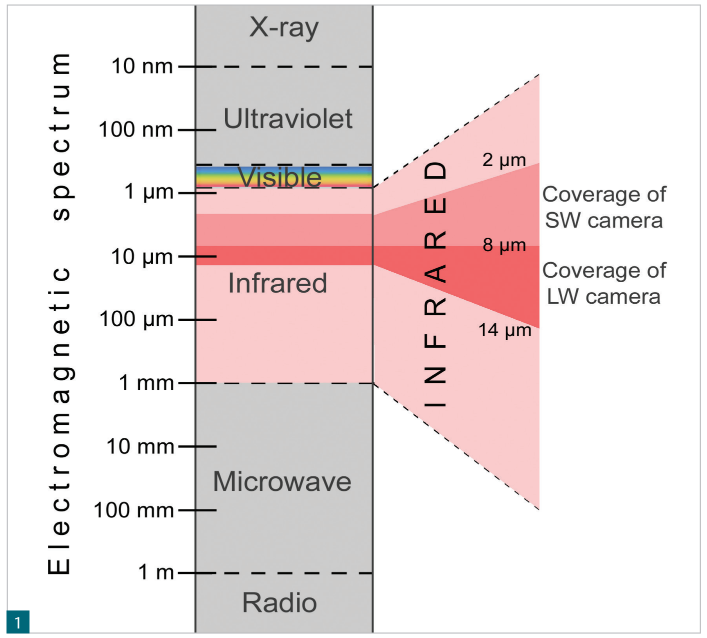

Fig. 1 Infrared radiation is part of the electromagnetic spectrum, with a longer wavelength than visible light. Long wave (LW) thermal cameras are described in this publication; short wave (SW) thermal cameras image different parts of the IR spectrum.

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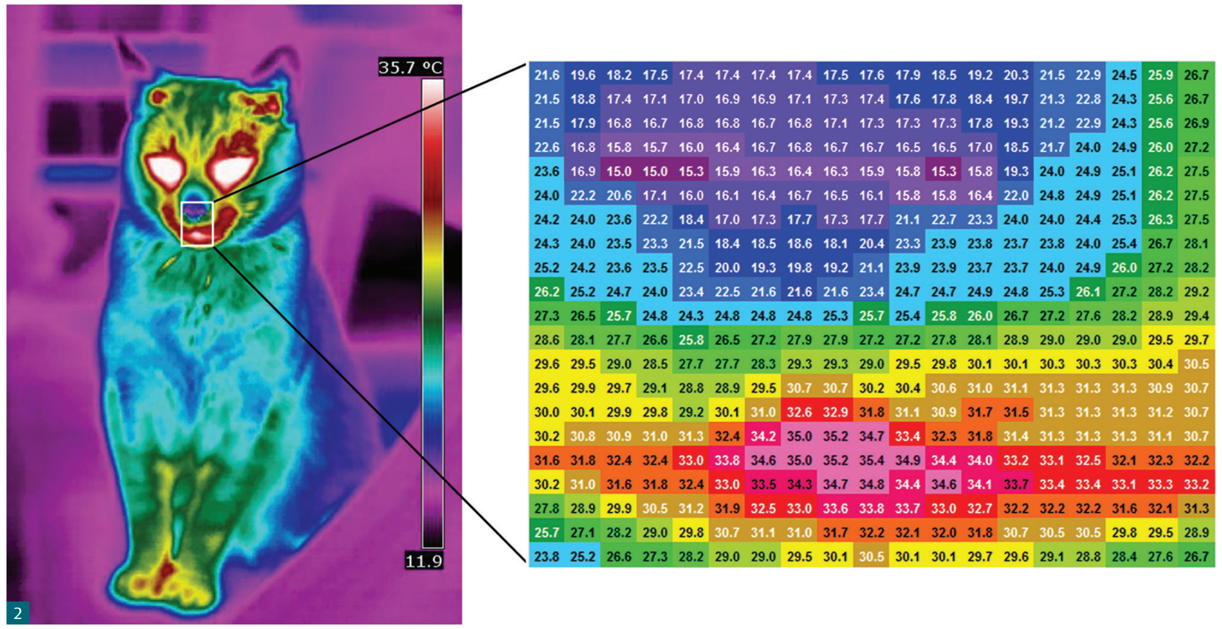
[1] µm = Micron or micrometre; a unit of length equivalent to 0.001 mm.

The thermal camera is ‘seeing’ heat emitted by an object, but it is not only objects that we think of as warm that emit infrared (IR) radiation. All objects with a temperature above absolute zero (-273 °C) emit infrared, and the intensity of infrared emitted increases exponentially with temperature. The warmer the object, the more infrared radiation it emits. Essentially, the warmer a surface is, the brighter it appears in infrared. The camera converts this infrared brightness to a temperature so that in a thermal image each pixel shows a colour, which is assigned to a precise temperature (Fig. 2). It is good practice to show a temperature scale on the image to aid interpretation.



21.6	19.6	18.2	17.5	17.4	17.4	17.4	17.4	17.5	17.6	17.9	18.5	19.2	20.3	21.5	22.9	24.5	25.9	26.7
21.5	18.8	17.4	17.1	17.0	16.9	16.9	17.1	17.3	17.4	17.6	17.8	18.4	19.7	21.3	22.8	24.3	25.6	26.7
21.5	17.9	16.8	16.7	16.8	16.8	16.7	16.8	17.1	17.3	17.3	17.3	17.8	19.3	21.2	22.9	24.3	25.6	26.9
22.6	16.8	15.8	15.7	16.0	16.4	16.7	16.8	16.7	16.7	16.5	16.5	17.0	18.5	21.7	24.0	24.9	26.0	27.2
23.6	16.9	15.0	15.0	15.3	15.9	16.3	16.4	16.3	15.9	15.8	15.3	15.8	19.3	24.0	24.9	25.1	26.2	27.5
24.0	22.2	20.6	17.1	16.0	16.1	16.4	16.7	16.5	16.1	15.8	15.8	16.4	22.0	24.8	24.9	25.1	26.2	27.5
24.2	24.0	23.6	22.2	18.4	17.0	17.3	17.7	17.3	17.7	21.1	22.7	23.3	24.0	24.0	24.4	25.3	26.3	27.5
24.3	24.0	23.5	23.3	21.5	18.4	18.5	18.6	18.1	20.4	23.3	23.9	23.8	23.7	23.8	24.0	25.4	26.7	28.1
25.2	24.2	23.6	23.5	22.5	20.0	19.3	19.8	19.2	21.1	23.9	23.9	23.7	23.7	24.0	24.9	26.0	27.2	28.2
26.2	25.2	24.7	24.0	23.4	22.5	21.6	21.6	21.6	23.4	24.7	24.7	24.9	24.8	25.3	26.1	27.2	28.2	29.2
27.3	26.5	25.7	24.8	24.3	24.8	24.8	24.8	25.3	25.7	25.4	25.8	26.0	26.7	27.2	27.6	28.2	28.9	29.4
28.6	28.1	27.7	26.6	25.8	26.5	27.2	27.9	27.9	27.2	27.2	27.8	28.1	28.9	29.0	29.0	29.0	29.5	29.7
29.6	29.5	29.0	28.5	27.7	27.7	28.3	29.3	29.3	29.0	29.5	29.8	30.1	30.1	30.3	30.3	30.3	30.4	30.5
29.6	29.9	29.7	29.1	28.8	28.9	29.5	30.7	30.7	30.2	30.4	30.6	31.0	31.1	31.3	31.3	31.3	30.9	30.7
30.0	30.1	29.9	29.8	29.2	30.1	31.0	32.6	32.9	31.8	31.1	30.9	31.7	31.5	31.3	31.3	31.3	31.2	30.7
30.2	30.8	30.9	31.0	31.3	32.4	34.2	35.0	35.2	34.7	33.4	32.3	31.8	31.4	31.3	31.3	31.3	31.1	30.7
31.6	31.8	32.4	32.4	33.0	33.8	34.6	35.0	35.2	35.4	34.9	34.4	34.0	33.2	33.1	32.5	32.1	32.3	32.2
30.2	31.0	31.6	31.8	32.4	33.0	33.5	34.3	34.7	34.8	34.4	34.6	34.1	33.7	33.4	33.4	33.1	33.3	33.2
27.8	28.9	29.9	30.5	31.2	31.9	32.5	33.0	33.6	33.8	33.7	33.0	32.7	32.2	32.2	32.2	31.6	32.1	31.3
25.7	27.1	28.2	29.0	29.8	30.7	31.1	31.0	31.7	32.2	32.1	32.0	31.8	30.7	30.5	30.5	29.8	29.5	28.9
23.8	25.2	26.6	27.3	28.2	29.0	29.0	29.5	30.1	30.5	30.1	30.1	29.7	29.6	29.1	28.8	28.4	27.6	26.7

Fig. 2 A thermal image is a radiometric image – every pixel in a thermal image records the mean surface temperature at that spot.

The thermal image is more than a simple picture of surface temperature. It is a *radiometric* image; that is, each pixel is a data point recording a temperature. Quantitative data can be obtained from the image by exporting the data to a spreadsheet for further analysis or to produce a graphic representation of a temperature profile. The resolution of most thermal cameras is not as high as photographic cameras. In the low cost range of thermal cameras you might expect to achieve a resolution of about 60 x 60 pixels. Higher specification IR cameras can have a resolution of 640 x 480 pixels.

The precision with which the camera can record a temperature is defined by its thermal sensitivity – the smallest difference in temperature that can be picked up. The more sensitive the detector within the camera, the more detail will be visible in a thermal image, especially when temperature differences are relatively small. Thermal sensitivity is usually described in millikelvin (mK) (or °C). An advanced thermal camera might have a thermal sensitivity of 30 mK (0.03 °C); a low cost camera perhaps 150 mK (0.15 °C). The temperatures recorded by the camera are normally accurate to within 1-2°C, provided conditions have been set correctly.

2.2 Enhancing thermal images

Most thermal cameras incorporate a digital camera to capture a visual image at the same time as the thermal image, ensuring that both illustrate the same area in the same orientation. This can be extremely useful as it is not always easy to determine where a thermal image was taken without a visual reference. It can, for instance, be difficult to locate a thermal anomaly on an area of wall which is visually uniform without an accompanying visual image. The camera may also incorporate a laser pointer which can be used to pick out a feature observed during thermal imaging. It should be noted that, if present, the digital camera is likely to capture an image automatically; requiring the operator to control the settings of both thermal and visual cameras at the same time would substantially slow down and complicate the process. Automatically recorded visual images may therefore be of relatively poor quality. If imaging is done at night or under poor lighting conditions the visual image is likely to be unusable. Some thermal cameras incorporate a light source to improve images from the visual light camera. If good quality visual images are required then a separate camera should be used to record these.

Recording both visual and thermal images at the same time has the further advantage that proprietary software allows the user to process both images together. The thermal image can be placed within the visual context and enhanced using partial transparency, or by picking out and enhancing edges from the visual image. Image enhancement techniques provided with proprietary software can significantly improve the resolution of raw thermal images and aid their interpretation (Fig. 3).

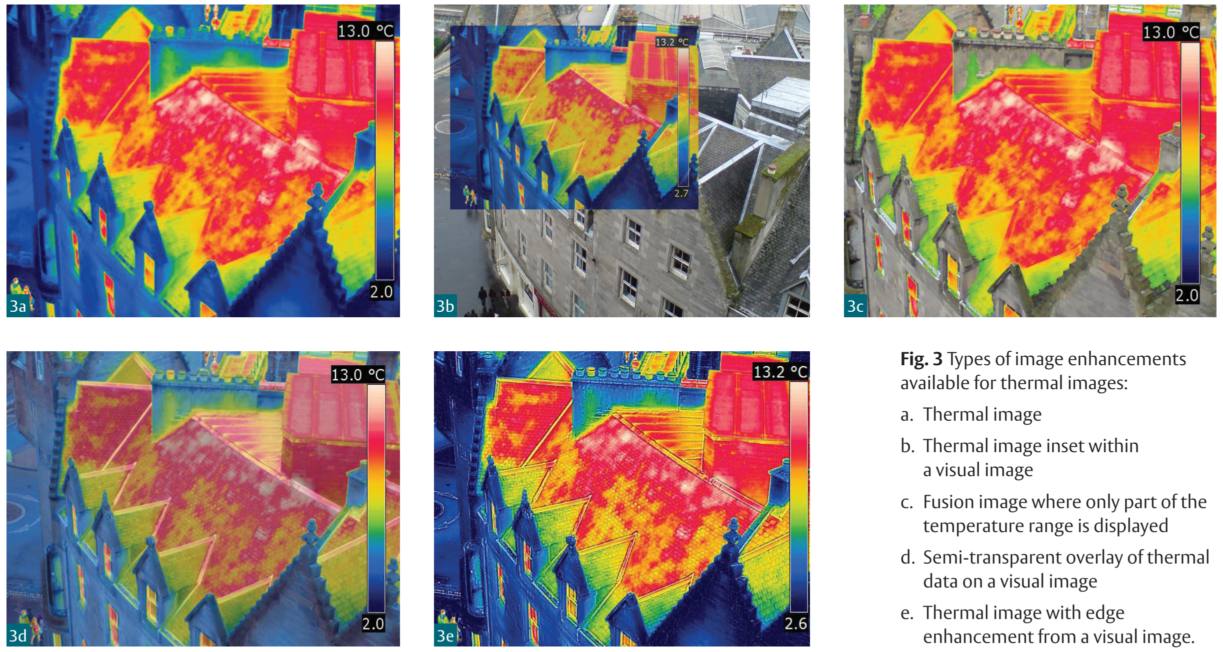


Fig. 3 Types of image enhancements available for thermal images:

a. Thermal image
b. Thermal image inset within a visual image
c. Fusion image where only part of the temperature range is displayed
d. Semi-transparent overlay of thermal data on a visual image
e. Thermal image with edge enhancement from a visual image.

In building thermography it is usually sufficient to take single images or multiple images which can be joined together to map larger areas. Should it be necessary to monitor changes in temperature, some cameras allow the user to take images in time lapse or video format. Specialist lenses allowing telephoto, wide angle or microscopic imaging are also available. Wide angle lenses can be particularly useful in building thermography when working indoors in small spaces or externally to capture an entire façade in a single image.

2.3 Colour schemes

A variety of colour schemes is available for thermal imaging. The choice depends on what is being illustrated. Images of heat loss are often illustrated with the iron colour scheme (Fig. 4a) as it emphasises the importance of hot spots, highlighting them in white and yellow. This colour scheme also reproduces well in black and white. The rainbow colour scheme (Fig. 4b) is useful for illustrating dampness or draughts, emphasising warmer areas with red, and colder areas in blues and purples. Where colour is not helpful, thermal images can be displayed in black and white (Fig. 4c). Generally, complex images work better with simpler colour schemes.

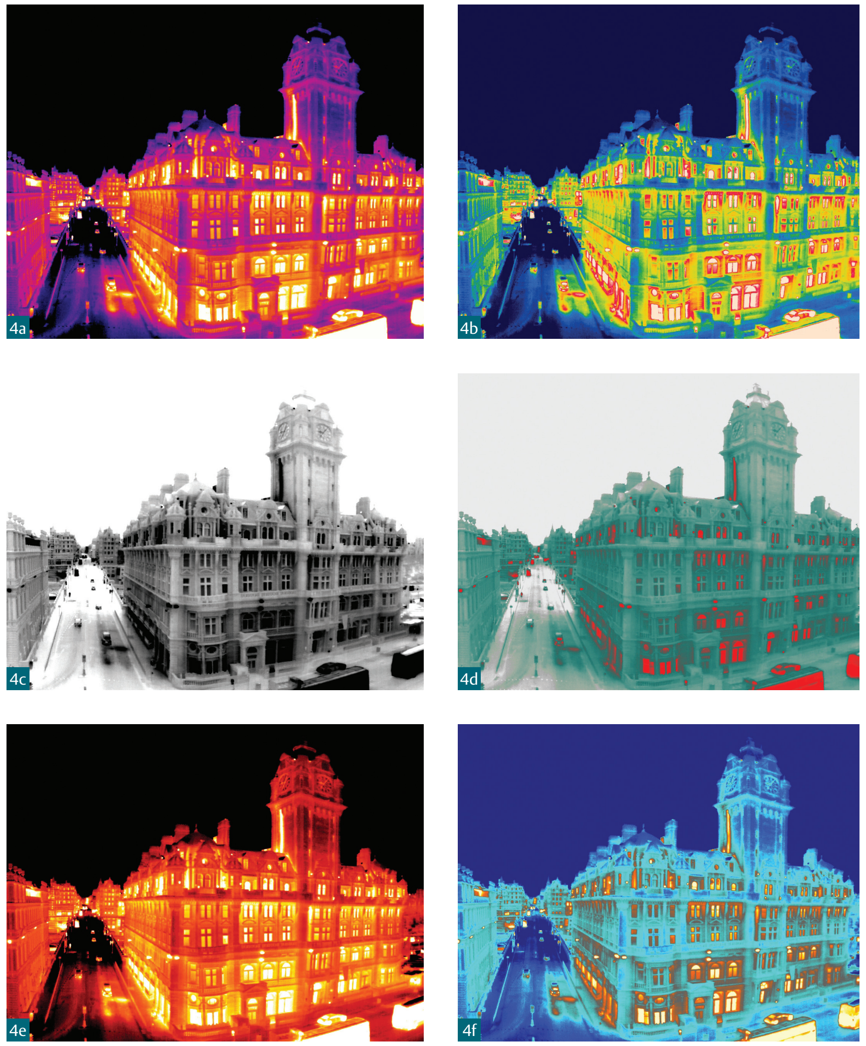


Fig. 4 Variety of colour schemes used to display thermal images. The choice is influenced by which aspect of the image the user wants to emphasise.

a. 'Iron'
b. 'Rainbow'
c. 'Black and white'
d. 'Greyred'
e. 'Fire'
f. 'Midgrey'

The operator can change camera settings to best illustrate particular features. The temperature scale should be adjusted to an appropriate range. Spot temperatures can be overlaid on the image to show surface temperature at particular points. Some cameras allow particular temperature ranges to be highlighted. For example, it is possible to highlight areas at risk of condensation by having the software pick out areas of the image where surface temperature is below the dew point. These, and other manipulations of the thermal data can also be carried out after the images have been downloaded using proprietary software.

2.4 Setting the correct parameters

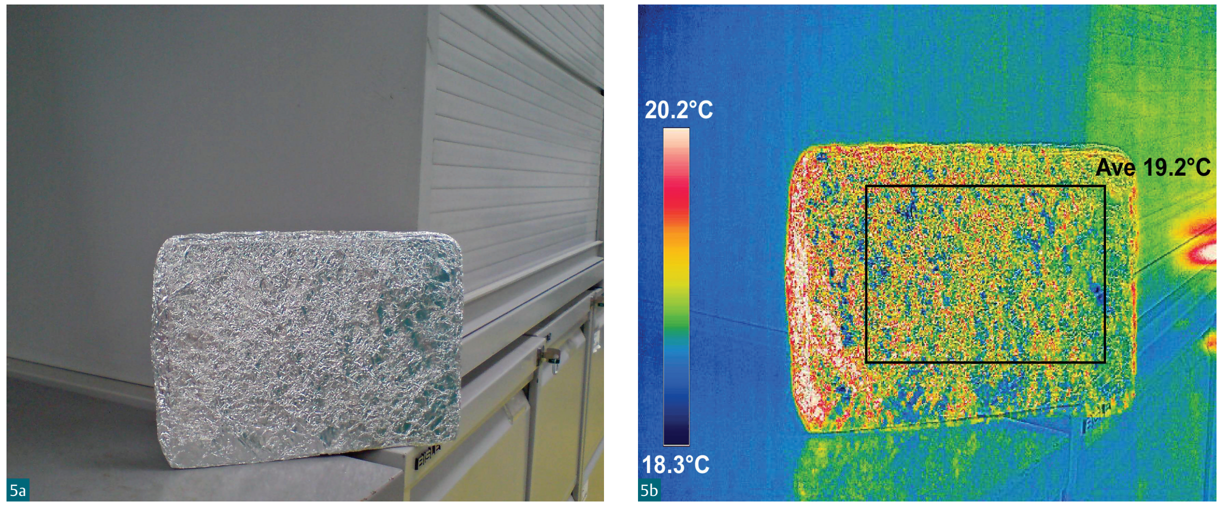
Before the operator begins to record thermal images it is necessary to manually set several basic parameters to allow the camera to make appropriate corrections and ensure that temperatures are accurately recorded. Air temperature, relative humidity and distance to the object are used to make corrections for infrared absorption by the atmosphere. By pointing the camera into the distance it will seem possible to read the temperature of objects, e.g. hills over long distances. However, the accuracy of the camera at long distances is affected by infrared absorption in the atmosphere and there is a limit to how well the camera can make corrections for this. On the scale of a building it is reasonable to assume that readings will be fairly accurate up to 30 metres, but this might not be true if, for example, it is a foggy day.

The accuracy of temperature readings over long distances is also affected by the pixel size of the detector. If the object being imaged is smaller than the coverage of a single pixel then temperature readings will be affected by the temperature of the background. A small hot spot caused by a hot air vent or an overheating electrical component, for instance, may be too small to resolve correctly at long distance.

The camera also requires a value for *reflected apparent temperature* often shown as T_{ref} or T_{amb}. This is not the air temperature – it is, in effect, a measure of the mean apparent temperature of all objects in the vicinity which could contribute to infrared reflections from the surface you are imaging. This is a necessary and potentially very important correction as the infrared emissions that the camera sees from a surface will contain components other than those relating to the temperature of the object. In fact, infrared emissions observed by the camera are the sum of infrared from three sources – infrared emitted due to the temperature of the object, infrared reflections from nearby objects and (if the object is partially transparent at IR wavelengths) infrared transmitted through the object. The important part is infrared emitted due to the temperature of the object. Estimating reflected apparent temperature allows the camera to make an appropriate correction for the reflected infrared component and provide an accurate temperature reading (assuming there is no infrared transmitted through the object, which is normally the case).

T_{ref} is commonly estimated by using a crumpled and re-flattened piece of aluminium foil which is assumed to have an emissivity of zero (Fig. 5). With the IR camera set to make no corrections for distance (i.e. set minimum distance) and zero emissivity (set emissivity value to 1), it is assumed that the mean temperature measured on a representative area of the foil represents the mean infrared temperature of the environment. It is important to avoid taking T_{ref} with the camera perpendicular to the foil as the heat of the thermographer's body could influence the reading. The foil should be orientated to encompass reflections that are representative of the area being imaged. Outdoors, the effect of having approximately half the T_{ref} contributed by the sky can be significant; outdoors the reflected apparent temperature can be very low on a clear day or at night time, i.e. the thermal camera may well record it at the lowest end of its calibrated range, e.g. -40 °C. Cloud cover will give a higher T_{ref} of around 0 °C. Indoors T_{ref} is likely to be similar to the ambient air temperature unless there are particularly hot or cold objects in the vicinity.

Fig. 5 Use of a crumpled and reflattened piece of aluminium foil (5a) to obtain a value for *reflected apparent temperature* (T_{ref}) (5b).



2.5 Emissivity

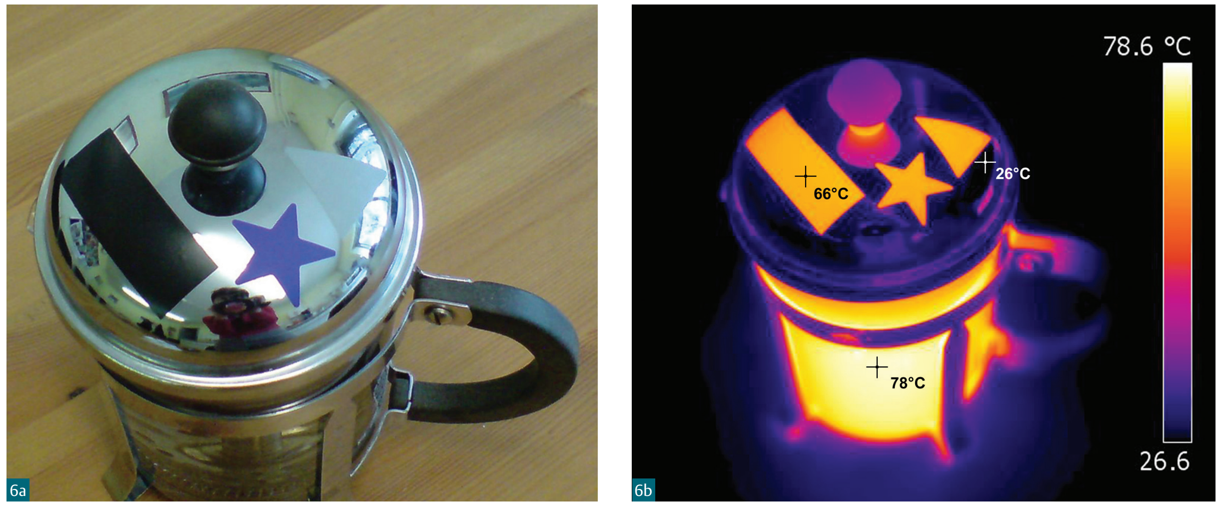
The thermal camera needs to calculate what proportion of the thermal data can be attributed to surface temperature and what proportion to reflected infrared radiation. Materials have significant variations in how reflective they are to infrared; this characteristic is called *emissivity* (ε-value), measured on a scale of 0-1. For most building materials the reflected part is small and affects results only slightly, but for some materials, especially metals, the reflected part is most of what the camera detects, and obtaining a true temperature reading is more problematic. If emissivity is set incorrectly, the thermal camera may give temperature readings which are wildly inaccurate.

Emissivity values lie between 0 and 1. A perfect mirror has an ε-value of 0. A so-called *blackbody* (a body in perfect thermal equilibrium – all incident radiation is absorbed and emitted with 100% efficiency) has an ε-value of 1. Real world objects are *greybodies*, having an emissivity between 0 and 1. A thermal camera will observe the temperature of a blackbody accurately with no need for correction for reflected infrared. But the lower the ε-value, the more infrared reflections will be observed, obscuring infrared emissions due to the object's temperature. To measure the temperature of surfaces we want to read the emission, not the reflection. Thermal cameras allow you to set a value for emissivity and will use this value (and T_{ref}) to make a correction and accurately report the temperature of a surface.

Tables of emissivity values can be consulted to find the most appropriate value for different substrates. Many building materials including stone, plaster and wood have a high emissivity, around 0.9 to 0.95, so provided the thermal camera is set at this value, accurate results for most building materials should be achieved. It is worth noting that the value set for emissivity, is applied to all objects in the image. If any objects have a different emissivity their temperature reading will be wrong and the error is greater at higher temperatures. This is not a big problem for many materials but it is an issue for metals whose emissivity values can vary widely and are often very low. Polished, un-oxidised metals commonly have an emissivity below 0.3, whilst oxidised metals will have a higher value. Note that emissivity can vary with different wavelengths, and this is commonly the case for glass (see Section 3.4).

If necessary, emissivity values can be measured, but there is a simpler method to get an accurate temperature reading on a metal or other reflective surface of unknown emissivity. Some brands of electrical tape have a known emissivity of 0.95, and special stickers with known emissivity are available. Depending on the nature and conservation requirements of the object it may be possible to stick these onto the problematic surface. After a few minutes the sticker will equilibrate to the temperature of the surface. With the emissivity set at 0.95 a spot temperature reading will provide an accurate temperature (Fig. 6).

Fig. 6 Coffee pot full of hot water (6a). The thermal image suggests the glass is about 78 °C and the metal parts about 26 °C. The temperature reading on the metal is incorrect because it has a much lower emissivity than the glass. Temperature readings on the emissivity stickers and electrical tape on the metal lid show its temperature more accurately (6b).



3. Appropriate conditions for thermal imaging of buildings

Section 2 described some of the parameters that are necessary to consider when setting up the thermal camera, but careful consideration needs to be given to several other aspects of the conditions in which imaging is carried out.

3.1 Temperature contrast

Just as you need light to get a good visual image, a good thermal image is dependent on heat. For useful thermal images to be recorded there needs to be temperature contrast. Passive thermography involves using the temperature contrasts inherent in the subject. In active thermography, surfaces are heated up or cooled down to provoke a useful temperature contrast.

Generally, thermographers will be looking to diagnose problems by picking up these temperature contrasts. Where the objects in question are not a source of heat in themselves, it is necessary to carry out thermal imaging while the area is heating up or cooling down. During these times, when surfaces are out of equilibrium with ambient temperatures, it may be possible to observe problematic differences in the behaviour of materials.

Typical examples of the use of thermal imaging during heating or cooling include:

- Locating damp problems by heating surfaces to drive evaporation of moisture causing a cold patch.
- Diagnosing detachment of harling on a sun-heated wall, where voids reduce heat flow into the wall resulting in warm patches appearing when the wall is cooling down.
- Locating failure of a flat roof by observing heat retained in trapped water below the coating after being heated by the sun.

All these examples need heat to be added into a system. The temperature contrast can be captured while the system is out of equilibrium with the ambient air temperature. The bigger the temperature contrast, the better the thermal images.

3.2 Imaging building exteriors

In an unheated building, especially one that is roofless, all surfaces are likely to be at a similar temperature. In these circumstances thermal imaging is unlikely to be useful. The heat input that provides temperature contrast is likely to come from solar and/or internal space heating. Sometimes solar heating provides the necessary temperature contrast, e.g. when looking for detachment of harling. This is only possible on unshaded areas. When looking for information about the thermal efficiency of heated buildings, the thermographer would hope to observe temperature contrasts that are solely caused by internal heat loss through the building envelope. Walls exposed to direct sunlight can retain heat for several hours after solar heating has ended, which can confuse the interpretation of thermal images. Therefore such work should normally be carried out at night before sunrise.

Relevant environmental conditions leading up to and during the survey should always be recorded as they are vital to the correct interpretation of images.

These may include:

- internal and external air temperature
- relative humidity
- wind speed
- distance from object
- orientation of elevations
- weather conditions such as current or recent rainfall
- overcast or clear sky
- mist or fog
- recent substantial changes in air temperature
- parameters set in the camera (e.g. emissivity).

Environmental conditions

The environmental conditions in which thermal imaging is carried out strongly affect the outcome. If environmental conditions are adverse it may not be possible to observe some problems, especially when the expected temperature anomalies would be relatively small.

Ideally the thermographer wants to control the environment so that problems show up clearly. This may be possible indoors, but outdoors the weather and exposure of elevations cannot be controlled. At best, the timing of the thermal survey can be chosen to optimise conditions.

Wind speed

It is very important to work during calm periods. High winds chill surfaces, effectively 'blowing away' any thermal anomalies, reducing the temperature contrast between hot and cold areas. Results of thermal imaging outdoors will be poor if wind speed is gusting over 20 mph (approximately 10 m/s). Ideally wind speed should be less than 10 mph (approximately 5 m/s).

Solar gain

Although solar gain can often confound imaging, in some instances it can be very useful. On sunlit walls, heat will flow most readily into a structure with no thermal barriers. If a wall is affected by voids, blistering or detached coatings, e.g. harling, heat will tend to be trapped on the outer surface of the wall as these cavities tend to give some extra thermal resistance (Fig. 7). Heat flow through the wall in such areas is reduced in comparison to adjacent solid areas. This effect can be used to detect detachments on sunlit walls. Thermography should be carried out after the sun has passed off the wall, during the cooling down phase. Near surface voids will retain heat for longer, showing up as hot spots in the image. Solar heating is dependent on the orientation of an elevation and therefore, in the UK, the best results are obtained on south-facing walls. On walls that are not heated by the sun, thermography is unlikely to provide any useful information on harling or render detachments.

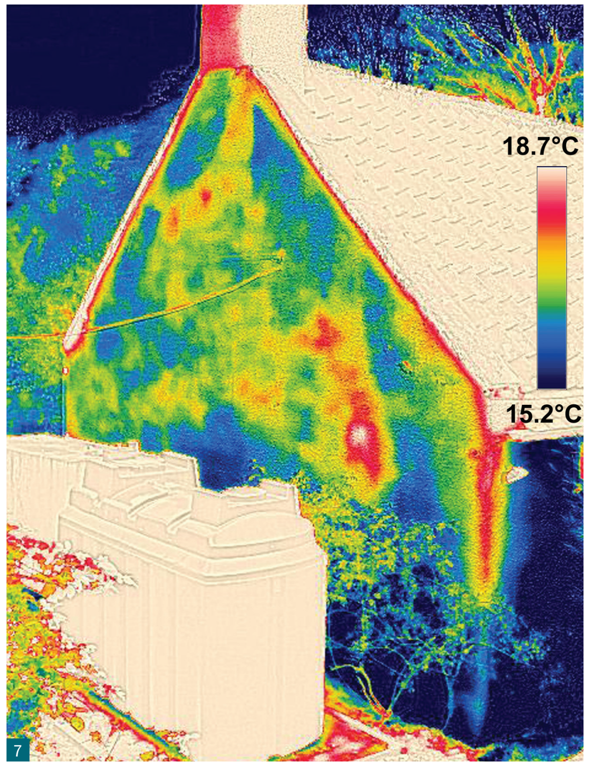


Fig. 7 The sun has warmed this harled gable wall for several hours. Hot spots show the location of detached areas of harling where air gaps reduce the rate of heat flow into the wall.

Heat retention by water

Solar heating can be utilised to highlight areas of moisture retention below surface coatings. Water has a higher thermal capacity than dry stone, so damp masonry takes up and retains more heat than dry masonry. During the cooling down period following exposure to the sun, sub-surface damp areas will remain warmer for longer than dry areas. This effect is particularly useful when looking for failures of coatings on flat roofs. A dark, bitumen coated surface is readily warmed by the sun and with only a thin surface cover the temperature contrast between water saturated and dry areas below the bitumen shows up clearly. The thermographer must however always be aware that dampness at the surface will create cooler areas due to evaporative cooling.

Infrared radiation

The very low temperature of ambient radiation from a clear sky can be problematic when working outdoors. Infrared radiation from the ground, sky, surrounding buildings and other objects affects the apparent temperature of objects because part of the infrared radiation from surfaces is reflected rather than being related solely to the temperature of the object. On an overcast day, cloud cover will have a radiant temperature of about 0 °C, but on a clear day or night the temperature of the sky will be very low, perhaps -40 to -60 °C. The contrast between sky and buildings can be a significant source of error where accurate temperature measurements are required (Fig. 8). Corrections can be made for this, but they are necessarily only approximations when the surrounding objects cover a wide temperature range. Carrying out thermography on an overcast day may give more accurate results.

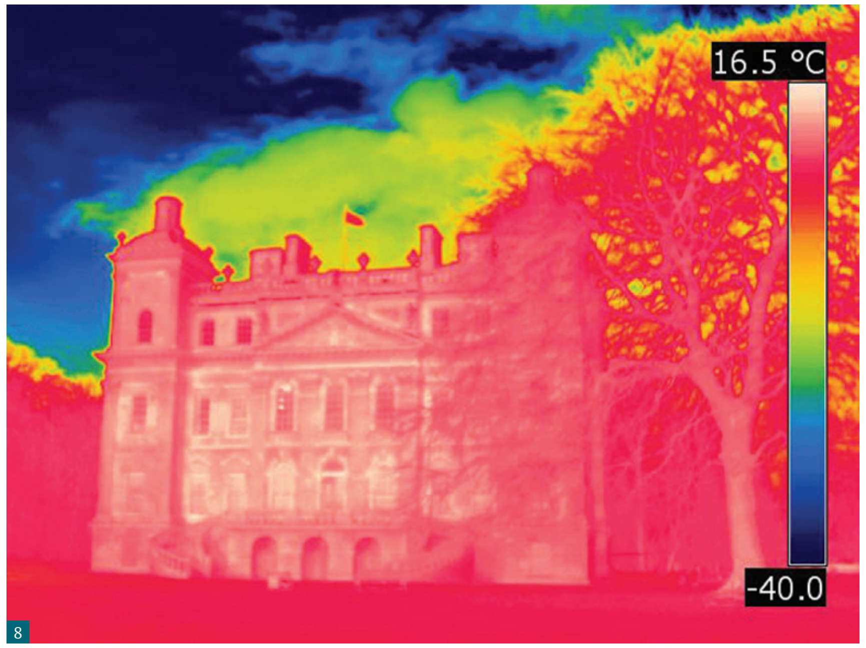


Fig. 8 The cloud cover has a radiant temperature of about 0 °C, but the temperature of the cloudless sky is approximately -40 °C. Extreme temperature variations are a source of inaccuracy when making corrections for reflected temperature.

3.3 Imaging building interiors

Thermal imaging indoors is not subject to the vagaries of climate that complicate work outdoors, though solar heating can still affect internal wall temperatures.

It is important to remember that the air temperature inside a room is unlikely to be uniform. Corners and areas where air circulation is restricted by furniture are often cold. Air does not circulate well into corners and the air trapped there forms a stable boundary layer which resists heat flow from the air in the room into the wall. Corners have a relatively higher surface area where heat can be radiated from the wall, especially on external corners (Fig. 9). Without significant air movement, stratification can cause air temperature to be higher towards the ceiling (Fig. 10). These natural temperature anomalies must not be mistaken for defects in a structure.

Fig. 9 The cold (blue) area in the corner of this room appears to suggest the location of dampness. In fact the wall is not damp. It is colder because warm air has not circulated effectively into the restricted space in the corner.

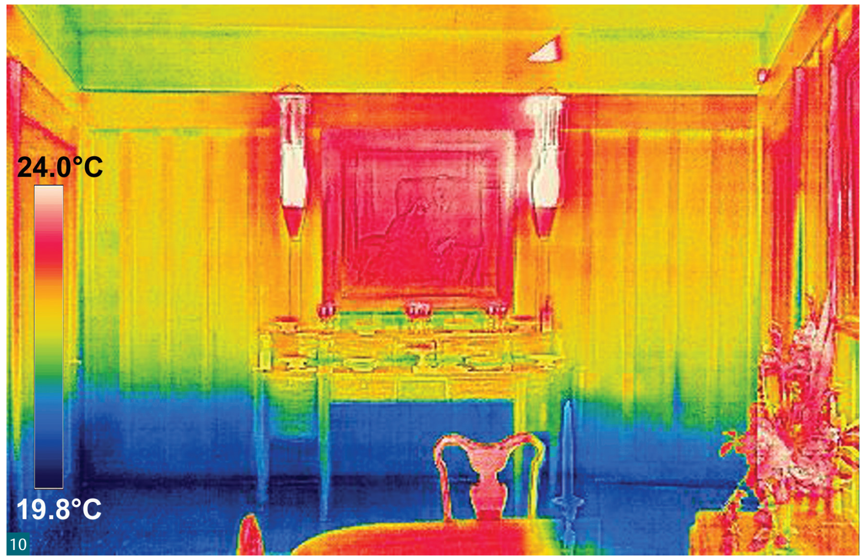


Fig. 10 Air temperature inside a room is unlikely to be uniform but this should not be mistaken for a defect. Without significant air movement, still air inside the room has caused stratification of the temperatures, with cold air sitting near the floor.

Using artificial heating

Larger temperature contrasts provide better resolution in thermal images, but it is best not to attempt to raise internal temperatures excessively. This is not only because of the potential damage to the building fabric, but because heat may be unevenly distributed, giving a misleadingly high temperature on surfaces close to the heat source.

Best results are obtained where a building can be heated to a minimum of 10°C above ambient outdoor air temperature. With a more sensitive thermal camera it may be possible to get useful results with smaller temperature differences. Artificial heating needs to be supplied for long enough to achieve an (approximate) equilibrium with the building structure, at least for long enough to warm the surfaces to a sufficient depth to reveal any subsurface anomalies. On a solid masonry wall this could take a long time. The daily average heat loss may be strongly influenced by the conditions over the previous days, particularly if the building contains thermal mass which can absorb and release heat from solar gain. It is usual to request that heating is maintained for 24 hours, or at least overnight, prior to a thermal survey. If furniture, paintings, wall coverings, etc. have to be moved to allow thermography, then it is advisable to do this at least six hours prior to the survey to allow time for the temperature to equilibrate.

When working in a historic building, or where there are potentially heat sensitive materials, it may not be possible to achieve the ideal level of heating. For example, a painted timber ceiling may be damaged if air temperature is too high or relative humidity too low. Gas heaters produce a lot of water vapour which can substantially raise the relative humidity and may damage materials such as textiles or unfired clay-based building materials that are sensitive to increased moisture levels. In this case the thermographer will have to make do with the level of heating that can be reasonably achieved.

3.4 Additional factors for thermal imaging

Angle of view

When taking a thermal image, the angle of view can strongly affect apparent surface temperature. At angles over 45° the temperature of a thermal anomaly may be substantially underestimated. At an angle of less than 5° the image is likely to contain reflections from the camera lens or the thermographer.

Reflections

Beware of reflections. Metals, especially polished metals, are an obvious source of infrared reflections. However, reflections can be a problem on more surfaces than might be expected. Many hard surfaces are more reflective of infrared than they are of visible light. To diagnose whether a hot spot is a reflection, the thermal camera should be moved slightly to the side. If the hot spot moves, then it is a reflection. In some cases the reflection can be that of the thermographer (Fig. 11). Outdoors, low temperature reflections can come from the sky. This is very common on glass windows, particularly where low emissivity glass has been used.

Fig. 11 As expected, there are infrared reflections from the mirror – but there are also infrared reflections from the adjacent hard wall surface. Care must be taken not to mistake a reflection for a thermal anomaly.

Glass

Infrared light of the relevant wavelength does not pass through glass, so objects cannot be seen behind windows[2]. This does not mean that room temperature has no impact on thermal images of windows; heat loss will still be observed as it affects the surface temperature of glass. However, accurate temperature readings on glass can be extremely challenging. Different types of glass vary in their emissivity and the emissivity of glass may vary significantly with wavelength.

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[2] Infrared 'windows' have nothing to do with normal glass windows encountered in buildings. They are used to aid electrical or kiln inspections. These windows are inspection ports that allow the thermographer to see into, for example, an electrical cabinet without opening it. They may be made of a range of materials which are transparent to IR, commonly including germanium and zinc selenide. They are not transparent to visual light wavelengths.

The emissivity of glass is usually relatively high (about 0.8 to 0.85) which one might expect to produce a good thermal result, but it produces very sharp, mirror-like reflections which can interfere with temperature measurements. Sharp, well defined reflections like those from glass are described as *specular*. Most surfaces are *diffuse* reflectors and produce blurred reflections (Fig. 12).

12a

12b

Fig. 12 Infrared reflections from glass (12a) are described as *specular* – the reflection is sharp and well defined rather than the blurred or diffused infrared reflection from many other surfaces (12b).

4. Practical building applications of thermal imaging

4.1 Revealing anomalies

Thermal imaging can be a very useful technique for examining the condition and diagnosing problems with buildings. As it is non-destructive and non-contact it allows diagnosis of problems at a distance and improves safety in some potentially hazardous situations, e.g. electrical inspections.

Anything that causes a significant temperature variation can be usefully imaged by thermography. The images can therefore be used to observe and diagnose potential building defects, visually revealing structural deficiencies. Inconsistencies or unusual temperature contrasts in thermal images are called *anomalies* and may sometimes indicate a problem with the building fabric.

Potential applications in the built environment include:

- locating voids, cracks or delamination
- identifying thermal bridges and areas at risk of condensation
- assessing heat loss or draughts
- assessing the performance of insulation
- detection of damp and water ingress
- remote identification of electrical faults.

A *qualitative* thermographic survey can easily pick up variations in temperature across an entire façade. With appropriate equipment, accurate recording of environmental data during the survey enables a *quantitative* analysis to be carried out, aiding diagnosis of conditions such as condensation risk, electrical faults and heat loss.

Thermal images should never be taken at face value. Imaging can easily locate thermal anomalies but the cause is not always obvious and it is all too easy to misinterpret or mistake their cause. Correct interpretation requires the input of a building professional who understands buildings and their problems. Thorough diagnosis of a problem cannot be achieved by the use of thermography in isolation, especially on complex structures.

4.2 Thermal imaging of hidden physical features

To identify structures or voids below the immediate surface, a relatively long period of heating would be required to allow sufficient time for heat to penetrate to the depth the thermographer wants to observe. In traditional massed stone structures, wall thicknesses may be substantially greater than in more modern constructions; consequently, heating times and intensity may need to be increased.

Blockage of cavities

In walls with voids behind the internal finish, such as those with lath and plaster or plasterboard finishes, thermography can locate areas where debris has fallen into and blocked up the cavity (Fig. 13). Blocked cavities are at risk from dampness as they can allow penetrating damp to pass through from the external wall. They are also at risk of condensation due to heat loss through the solid fill in the cavity forming a thermal bridge (see also Section 4.4).

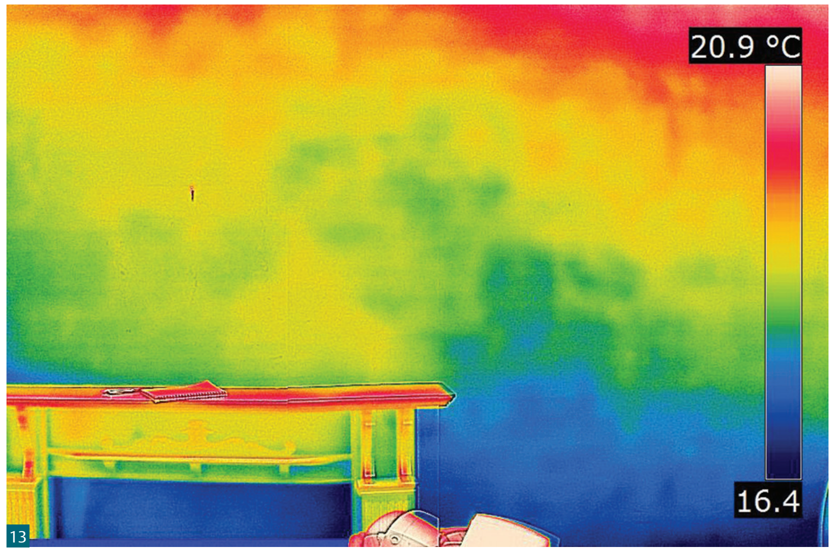


Fig. 13 The lower right part of the void behind this lath and plaster wall has become blocked by debris. Its uneven distribution is reflected in the uneven distribution of temperature. Higher heat flow and conduction of damp through the wall has caused the low temperature in the debris blocked area.

Location of cracks

Thermography can identify structural cracks which may not be visible at the surface. If a crack penetrates through to the exterior then it will show up internally as a cold line due to heat loss to the outside. Conversely, an internal crack may show up as a warm line on a building exterior (Fig. 14).

Joints with significant amounts of missing mortar or masonry junctions where stonework is not properly tied in provide routes where heat loss can be observed externally.

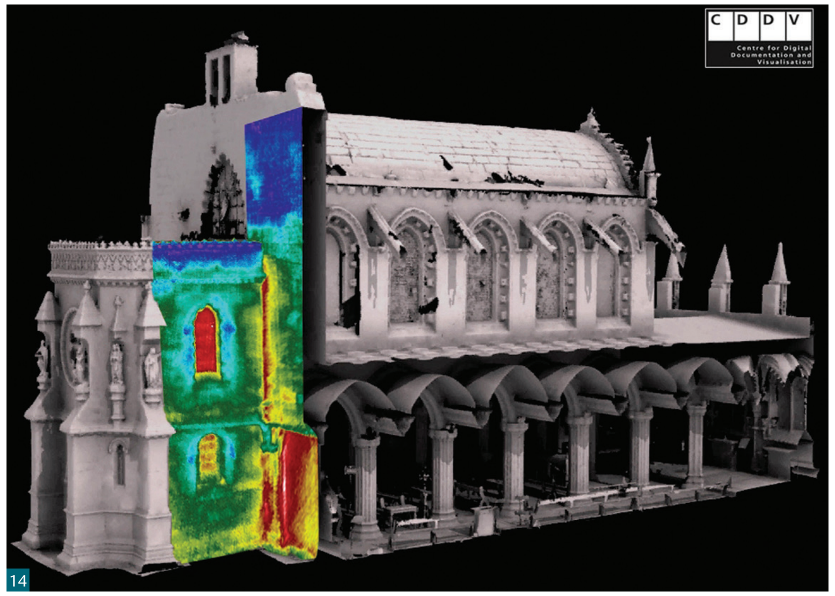


Fig. 14 The thermal image has been draped onto a 3D model to provide a clear representation of the data. The warm line along the junction between walls in this image shows the location of an air gap, allowing heat to escape the building.

Active infrared thermography (IRT)

The specialist technique of active infrared thermography (so-called *active IRT* or *pulsed IRT*) can be used to provide detailed analysis of cracks and other defects. It requires specialist technical equipment, data processing and expertise. Intense artificial heating is applied to the surface for a very short time interval. A series of thermal images are taken and processed to highlight the propagation of heat across the surface, showing up any anomalies through non-uniform temperature distribution. A related technique, *lock-in thermography*, utilises periodic heating to generate and analyse oscillations in temperature. These techniques have been used to locate cracks, adhesion detachments and other defects on a range of substrates including frescos, parchment and metals.

Localising sub-surface sources of heat

Although the thermal camera cannot see below a surface, sources of heat within or behind a structure can be located indirectly by their effect on local surface temperature. For example, thermography can be used to locate the path of warm flues in gable walls (Fig. 15). It can also be used to visualise the performance of underfloor heating and to locate hot water and heating pipes (Fig. 16).

Misinterpretation alert

Thermal imaging gives information about the temperature of surfaces. It cannot see below the surface, although deeper features may influence surface temperature, in which case they may be diagnosed under appropriate conditions.

Temperature variations on building surfaces can have a multitude of underlying causes. A thorough understanding of building structures is required to interpret thermal anomalies in areas where the sub-surface structure cannot be directly examined.

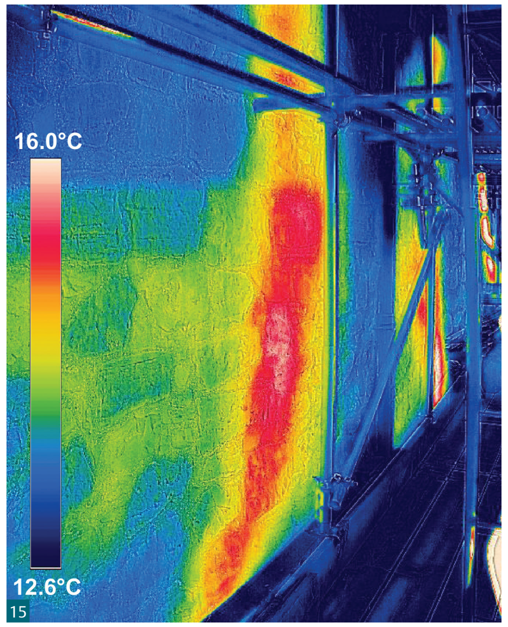


Fig. 15 Warm air blown up inside these disused flues reveals both their pathway within the gable and the location of air leaks from damaged flues (the warm patch centre left of the main flue).

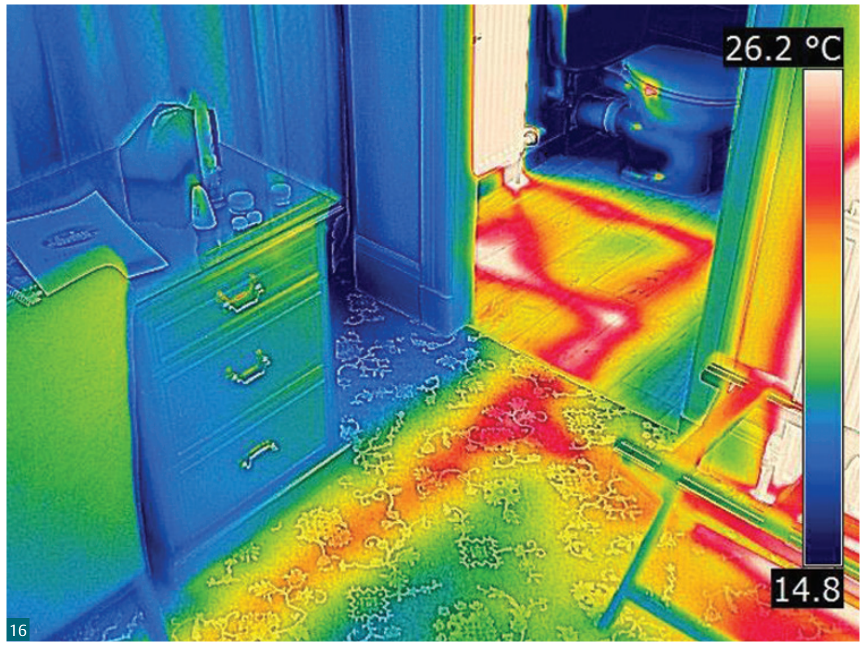


Fig. 16 The path of central heating pipes below this floor can be clearly observed in the thermal image because the floor is warmed by the pipes.

4.3 Identifying air leakage

Air leaks (draughts) are a problem where they lead to discomfort or poor energy efficiency. Typical locations for air leaks include the edges around windows or doors, around skirting boards and between floorboards.

It is important to remember that a healthy building needs adequate ventilation. Ventilation prevents damaging build-up of moisture in the building fabric or condensation on surfaces which can lead to mould growth and deterioration, as well as health problems for occupants. Traditional buildings are designed to allow circulation of fresh air in and around the fabric. Sealing up this ventilation is likely to cause potentially serious problems. However, excessive air leakage at windows, doors and skirting boards is undesirable.

Fig. 17 The blue areas on the floor reveal a cold draught at the gap between skirting and floor. The *wispy* appearance of the chilled area is typical of the appearance of draughts on surfaces. The thermal camera cannot observe the cold draught itself, only its chilling effect on adjacent surfaces.

Thermal cameras can be a useful way of detecting air leaks (Fig. 17). The camera does not see the leak itself, it sees the cooling effect of moving air on adjacent surfaces. The thermal image typically has a streaky or *wispy* appearance caused by the speed of air flow.

Blower door tests

The thermal camera’s usefulness in detecting air leakage is greatly enhanced when used in combination with a *blower door*. In this system a fan sealed into a doorway is used to suck air out or blow air into a structure, causing a pressure difference. Normally the blower door is used to reduce the air pressure inside a building (but be aware that in buildings which may contain asbestos dust in roof spaces or cavities, reducing air pressure could draw substantial quantities of asbestos dust into rooms). The thermal camera is used on the lower pressure side, i.e. indoors, and air infiltration will be observed due to the chilling effect on surfaces as external air is drawn into the structure or, potentially, as warmer surfaces if air is drawn from a warmer into a colder area.

Misinterpretation alert

To obtain useful images there needs to be a significant temperature difference between the outside and the inside of the building. A temperature difference of at least 5 °C is recommended.

Chilling by draughts can be mistaken for dampness. The presence or absence of damp must be confirmed by using an appropriate moisture sensor.

4.4 Identifying thermal bridges and condensation risk

Identifying thermal bridges

It is often possible to see wall studs, nail and screw heads and other structural features due to their influence on the temperature at the wall surface. These structural elements are observed where they conduct heat into the wall more rapidly than adjacent areas. Where this heat flow is significant it is called *thermal bridging* and it can be an important contributor to heat loss where thermal bridges cover a significant area of external surfaces. When observed internally, a thermal bridge will show up as an unusually cold area – signifying that heat flow to the outside is unusually high (Fig. 18). Conversely, observation of the outside of the building will show a thermal bridge as a warm patch. Where the camera is set up correctly and environmental conditions are recorded it is possible to calculate an approximate heat flow and determine whether this exceeds the acceptable level for heat flow through a structure.

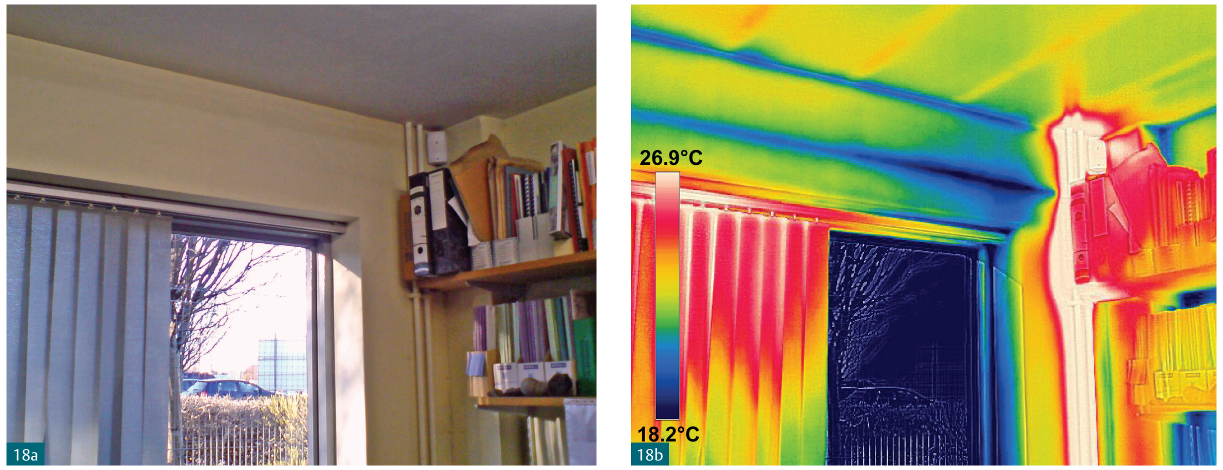


Fig. 18 Comparison of photographic image (18a) and thermal image (18b). The cold (blue) horizontal line above the window is a thermal bridge. Heat is being conducted rapidly from the interior to the external wall. The most probable cause is a metal component of the lintel.

Thermal bridges can attract staining to internal wall surfaces due to the tendency of particulate soiling to settle on cooler surfaces. This effect is known as *thermophoresis* (Fig. 19). Thermal bridging can result in surfaces being chilled to the extent that they fall below the dew point, allowing condensation of moisture to occur.

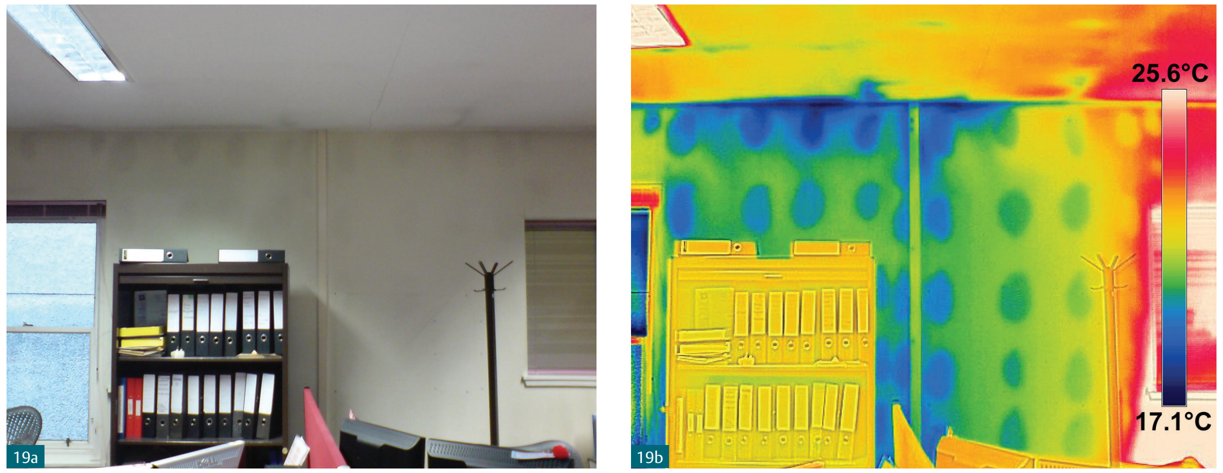


Fig. 19 Comparison of photographic image (19a) and thermal image (19b). Thermal bridging is responsible for the cold spots on this wall. The dark stained patches along the top of the wall, in the visual image, are caused by particulate soiling which preferentially settles onto cold surfaces.

Identifying condensation

Not all damp problems are caused by rainwater ingress or leaking pipes; they may be a result of condensation. Condensation happens when the temperature of a surface falls below the *dew point* (the point at which water vapour turns to liquid). The temperature at which this occurs depends on the moisture content of the atmosphere, but where the surface temperature is at or below the dew point, relative humidity reaches 100% and liquid water forms on the substrate.

Thermography can locate areas at risk of condensation. When setting initial conditions in the camera, the thermographer should record the air temperature and relative humidity (RH). Thermal cameras which have the capability to perform appropriate calculations can determine the dew point and highlight areas where surface temperature indicates a risk of condensation. Many thermal cameras can be programmed to do this. Alternatively, the calculation may be performed during image processing, and will display condensation risk as a differently coloured overlay on the thermal image (Fig. 20).

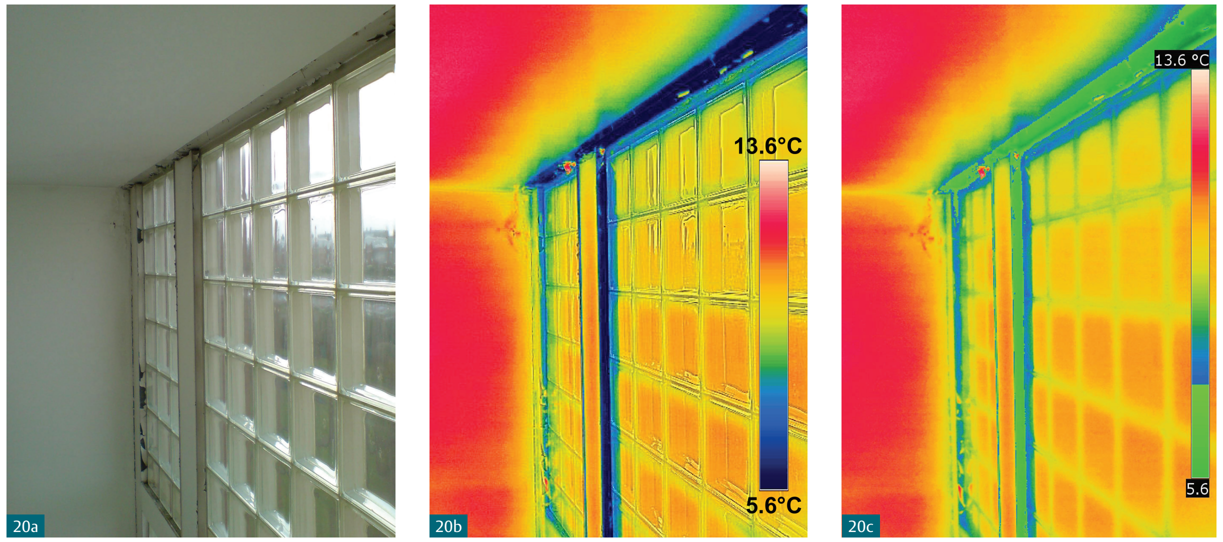


Fig. 20 The thermal image in the centre (20b) shows that the metal window frames (20a) are relatively cold. Where air temperature and relative humidity are known, software in the thermal camera can highlight areas where condensation will occur; the bright green areas in the right hand image (20c) are below the dewpoint and at risk from condensation.

Cold spots on walls are at risk of condensation and mould growth. They can indicate the presence of a thermal bridge where a structural element is responsible for heat loss through the building fabric. Some thermal cameras will allow the user to set an alarm which will highlight areas where relative humidity on surfaces reaches a potentially problematic level. The alarm can be set at whatever threshold is deemed appropriate. This might, for example, be used to indicate surfaces where mould growth could occur, e.g. where RH will be above 70-80%.

Misinterpretation alert

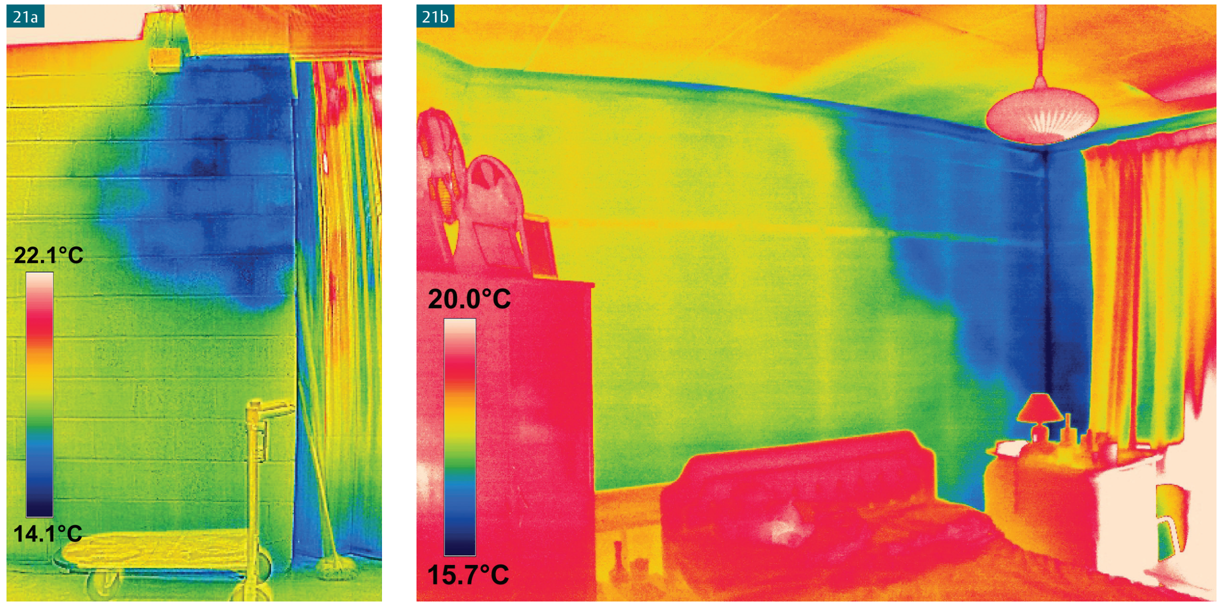
A cold area caused by moisture ingress can look very similar to one with a structural cause. Confirm the presence of dampness using appropriate moisture sensors.

A thorough knowledge of building structures will likely be necessary to diagnose the cause of thermal bridging.

4.5 Thermal imaging of moisture

Thermography is potentially useful in the detection of dampness, as wet materials behave differently to dry materials. Wet materials transfer heat more readily and wet surfaces can be cooled by evaporation so that they are visible in a thermal image as a cooler patch.

It is particularly challenging to use thermography to detect moisture at depth in a wall. Moisture will only be visible when the trapped water produces significant temperature changes at the surface (Fig. 21). When water is trapped below the surface and heating has been of sufficient intensity and duration, trapped water may show up as a hot spot; a confusing effect caused by differences in the thermal capacity of water and wall. Water has a higher heat capacity than most building materials, it is slower to warm up and slower to cool down. Therefore during cooling, a mass of water inside a wall may be warmer than surrounding materials.



In the hands of a skilled surveyor, thermography can be a useful tool to help trace the source of a moisture problem. Water can take devious routes through the building fabric and it may be necessary to examine adjacent rooms and other levels. In a building with a complex internal geometry it may be useful to combine thermal and 3D imaging to view thermal images in three dimensions.

Fig. 21 The cold (blue) patch in the thermal image on the left (21a) shows a wall affected by a water leak. The cold patch in the right image (21b) is located where the dormer window protrudes beyond the roof and is related to heat loss rather than moisture.

Misinterpretation alert

Sometimes thermography cannot detect dampness (Fig. 21). When relative humidity is high and air temperatures are low, evaporative cooling is inhibited and temperature variations are rarely visible.

While dampness at a surface will often be cooler than adjacent areas, moisture held at depth can, under the right conditions, produce a patch which is warmer than adjacent areas.

While thermography can often determine whether a wall is wet, the image alone cannot distinguish the cause/s, e.g. rainwater ingress, a leaking pipe or condensation. Further investigation will usually be necessary to determine the source of the problem, for instance using moisture sensors, examining plans or simply observing the other side of a wall.

4.6 Measuring heat loss

Thermal imaging of building exteriors for quantifying heat loss is more sensitive to environmental conditions than thermography for other purposes. Large errors can be expected if surfaces are damp, if wind speeds are high or if environmental conditions are rapidly changing or not accurately known.

To get a reasonably accurate assessment of heat flow through a wall, conditions around the time of imaging need to be stable so that the system is observed in equilibrium. If there have been major temperature fluctuations in the hours preceding the thermal survey this will influence results. A rapid fall in external air temperature will give the impression that heat flow is higher than its true value as air temperature will fall more rapidly than the temperature of the external wall. Conversely, a rapid rise in external air temperature will give the impression that heat loss through the wall is lower than its true value. A sufficiently large increase in air temperature, such as might easily occur in the morning, could give the profoundly mistaken impression that heat flow is reversed, with heat flowing into the building rather than out (Fig. 22). During a clear night, high heat loss by radiation to the cold sky can cause a drop in surface temperature greater than would be expected relative to the air temperature, giving the impression that heat flow is higher than its true value.

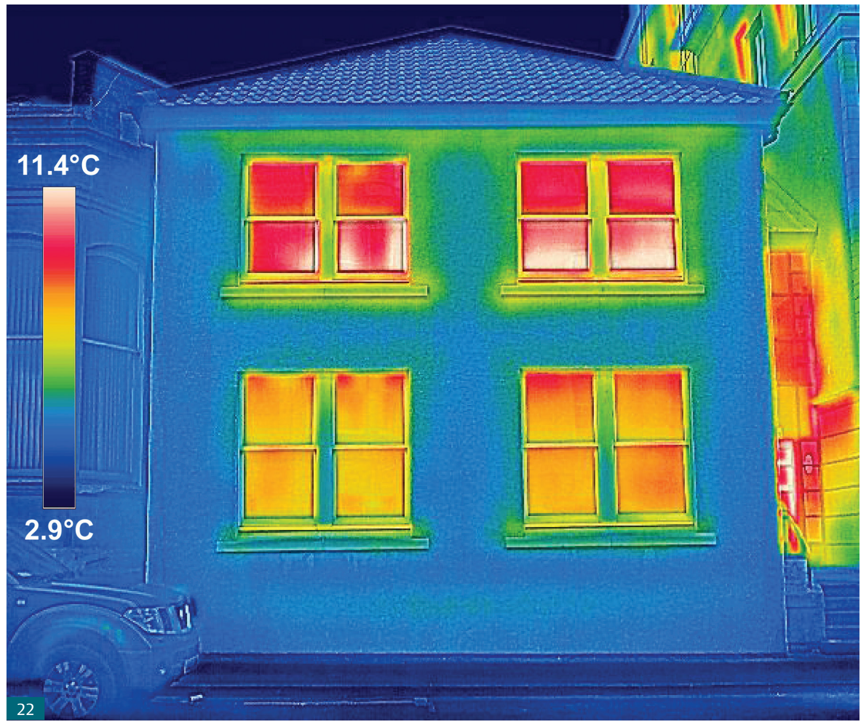


Fig. 22 After a cold night, air temperature has risen faster than wall temperature. Although air temperature is about 7 °C, the wall temperature is only 2-3 °C. Calculating a U-value in these circumstances would give the mistaken impression that heat is flowing into the building rather than out.

Heat flow through building materials is quantified as a U-value, a measure of thermal conductivity. The U-value is the inverse of the R-value, the thermal resistance. R-value is the sum of the thermal resistances of each of the components of the structure and also incorporates internal and external surface resistances. U-value is a measure of the thermal transmittance of a material or structure; the lower the U-value, the better the insulation value of the material or structure.

It is possible to derive U-values from thermal images, though results are affected by local environmental conditions and are therefore much less reliable than data from heat flux sensors which directly measure heat flow. Thermal images record only a single point in time; *in situ* heat flux sensors monitor heat flow over a long period allowing U-value calculations to be made during stable periods of heat flow. However, thermal imaging has the advantage that heat losses over the entire building surface can be imaged and, if the data is available, compared to areas where the heat flux has been more accurately measured.

Heat flow through a wall and at the surface occurs by a combination of conduction, convection and radiation. Estimation of U-value from thermal images uses data on internal and external air and surface temperatures along with estimates of reflected apparent temperature and emissivity. The calculated U-value includes components of heat loss at the surface, which occur by convection and radiation. Convective heat losses are strongly affected by air movement. Heat losses by radiation are strongly affected by the reflected apparent temperature. These confounding effects are particularly influential outdoors; consequently calculating U-values from external thermography can be problematic.

On external surfaces under a clear sky it is not possible to obtain an accurate value for reflected apparent temperature, as the temperature of the sky will be substantially lower than that of the building and surrounding surfaces. As building surfaces are more efficient emitters of infrared radiation than air, heat losses by radiation to a clear night sky can result in a wall temperature which is lower than the air temperature, thus creating a situation in which heat would (incorrectly) appear to be flowing into rather than out from the building.

The effects of air movement at the wall surface can affect temperature readings. In calm conditions a layer of still air at the wall surface allows a relatively accurate measurement of surface temperature, but any wind will tend to chill the surface. A variety of correction factors (formulae involving the *convective coefficient*) exist in the literature to take account of the effects of wind speed on heat loss by convection. Corrections for the windward and leeward sides of a structure can be made.

More reliable results will generally be obtained by calculating U-values under controlled conditions inside a building, provided data can be gathered well away from any localised heat sources such as radiators. Low speeds of air flow over internal walls allow a stable boundary layer to form which permits reliable measurements of temperature of surfaces. Again, correction factors for convective heat losses are required, but these are simpler for the low rates of air movement on internal walls, depending only on wall height.

U-value calculations made from internal observations are dependent on accurately knowing the internal and external air temperature, but it should be noted that a single measurement of internal air temperature is unlikely to be representative of the air temperature adjacent to the whole wall. A single measurement of air temperature can provide enough data to roughly estimate U-value but more accurate data requires a series of air temperature measurements close to the wall surface at points where U-values will be calculated. Accuracy is also affected by internal structures, e.g. voids and support structures and by any factors that could influence air movement, e.g. draughts from windows, air conditioning or heating. Surfaces may also be affected by residual heat on walls which are externally sunlit.

An accurate U-value cannot be obtained unless conditions are stable and the system is at equilibrium. As many building materials can store heat, dissipating it slowly over a long period of time, it can be difficult to ensure that the thermal survey is carried out during a period of stable heat flow. Inaccurate data will also be obtained where air temperature on either side of the wall is rising or falling, or if air flow, such as wind or draughts, unaccounted for in the calculation, disperses heat from the surface. U-values are also affected by the moisture content of materials. U-values obtained from thermal imaging should be taken as only generally indicative of relative heat loss. The sensitivity of the calculation means that U-values will be progressively less accurate for walls with better insulation. Where an accurate U-value is required it will generally be better to set up *in situ* heat flux sensors to measure heat flow over a representative period of time. Two weeks are generally considered sufficient.

4.7 Energy efficiency

The ability to visualise heat makes thermography a powerful tool for studying energy efficiency. It is possible to image large areas rapidly and highlight areas of concern. Under appropriate conditions it is possible to quantify heat loss by estimating U-values (see Section 4.6) though the quality of the data produced by thermography is highly variable and much less reliable that from direct measurement of heat flow.

It is common to image building exteriors for heat loss and this is appropriate for otherwise inaccessible areas like roofs (Fig. 23). It also allows rapid assessment of elevations. However, better quality data will usually be obtained by imaging building interiors where environmental conditions are better controlled, more easily recorded and temperature contrasts will normally be higher.

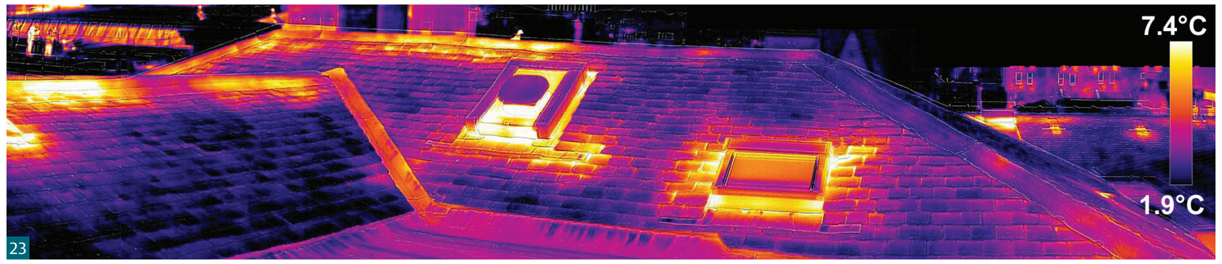


Fig. 23 High heat losses can be seen in several locations on this un-insulated roof; mainly along the ridges, but also around a vent and skylight.

Conduction of heat through walls, or any other material, is driven by the temperature difference between the two sides. Where there is little or no temperature difference, heat flow will be negligible. The higher the temperature difference the greater the heat flow. If thermal imaging is to give useful data then buildings should be surveyed when the temperature difference between inside and outside is as large as possible. Imaging the energy efficiency of buildings requires that they are internally heated. As a rough rule of thumb, a building should be heated to at least 10 °C above ambient temperature for at least 24 hours before thermal imaging commences. In the UK thermal imaging for heat loss through the building envelope is almost exclusively carried out in the winter months when the temperature contrast between the interior and exterior of buildings is greatest and solar gain is minimised.

The length of time over which heating is required depends on how deeply heat has to penetrate into the substrates; walls, windows, roofs, etc. To see heat loss through a wall, heating needs to be applied for sufficient time to warm the wall through to the exterior and establish a stable temperature on the outside. The quality of data obtained by imaging a building from the outside is highly dependent on weather conditions. Ideal weather conditions are cold, dry, overcast, windless and stable. In reality these conditions are rarely encountered.

To observe heat loss through a structure, thermal imaging has to be carried out during the hours of darkness, when solar heating will not confuse the issue. Solar heating can affect the temperature of a building several hours after sunlight has passed off the surface. The ideal time to conduct a survey to localise heat losses is in the early morning before sunrise. This allows time for any solar heating of the building on the previous day to dissipate.

4.8 Thermal index and surface temperature factor

Thermal Index (TI) is used to indicate the thermal performance of a component of the building fabric (see box for calculation). As it is a calculation based on temperature differences on either side of a wall it is only relevant where there is a continuous conductive path; the calculation will not be valid where there is an air gap in the structure.

Some thermal cameras allow the user to set an *insulation alarm* to highlight areas where heat leakage through a wall exceeds a predefined level. In new buildings typical acceptable values for this Thermal Index are >0.6-0.8.

In a related calculation method specified by BRE (Ward, 2006) relevant to thermal bridging, the *surface temperature factor* (f_{Rsi}) should be greater than or equal to a critical level to limit the risk of surface condensation or mould growth (see box for calculation). It is calculated in a similar manner to the Thermal Index. It is recommended that $f_{Rsi} \geq 0.75$ in dwelling houses. Different critical values for f_{Rsi} may be recommended for other situations, e.g. 0.5 for shops and offices and 0.9 for swimming pools and similar humid situations. Thermal images can be used to highlight areas where the surface temperature is below the critical temperature. Small defects of this type may be acceptable, but if large areas are affected this will negatively affect the performance of the building.

Thermal Index (TI) is the ratio of temperature drop across the building envelope, to the air temperature drop between inside and outside. It can be calculated from internal thermal imaging data and has a value between 0-1:

$$TI = \frac{\text{Internal surface temperature – external air temperature}}{\text{Internal air temperature – external air temperature}}$$

Surface temperature factor (f_{Rsi}) is related to TI and is used to quantify heat loss in relation to thermal bridging:

$$f_{Rsi} = \frac{\text{Minimum internal surface temperature – external air temperature}}{\text{Internal air temperature – external air temperature}}$$

Misinterpretation alert

There is a multitude of confounding factors which affect heat loss calculations based on thermal data including: wind speed, solar gain, moisture levels, unstable air temperature, local heat sources, thermal bridging and air movement in wall cavities.

U-values derived from thermography of building exteriors are particularly unreliable. Amongst other problems, they are particularly affected by air movement and by radiative heat losses which cannot be accurately quantified.

U-values derived from thermal data are affected by environmental conditions and are highly unreliable in comparison to data from heat flux sensors which directly measure heat flow.

A thermal image records only a single moment in time. There will be no certainty that the structure is in thermal equilibrium. Reliable heat flow data measured *in situ* require monitoring over at least two weeks.

5. Limitations of thermal imaging

5.1 Small temperature ranges

Thermography is all about imaging temperature contrasts. It will not be useful where everything is roughly at the same temperature, e.g. in unheated buildings.

5.2 Normal temperature variations

A thermographer must ensure that they are observing an anomaly and not a normal temperature variation. As previously stated, the corners of rooms are normally colder and this does not indicate a problem. It is also normal to see the location of wall studs and other structural features as cold areas on the wall surface when viewing internally; this is not a problem unless the heat loss is significant, i.e. indicating a thermal bridge (see Section 4.4).

5.3 Correctly setting emissivity

If emissivity is set incorrectly, temperature readings may be inaccurate. Emissivity values for materials can be obtained from data tables. Although many building materials have a high emissivity (around 0.9 to 0.95), difficulties with setting a correct emissivity value mean that temperature readings on metals are likely to be wrong (see Section 2). With a low emissivity, most of the infrared the camera picks up from a metal surface is the reflected temperature from the surroundings rather than an indication of the metal's actual temperature.

5.4 Time dependent processes

Thermal imaging only records the conditions at the time. If information is required on a process which varies over time, e.g. a U-value for a wall, it will be better to use a technique which monitors a surface over a long period. Some cameras allow time lapse and video thermography.

If thermography is to be useful, the defect or problem has to be present at the time of survey. For example, salt efflorescences and discolouration may suggest a damp problem, but thermography will not help unless the affected area is damp at the time of examination.

5.5 Sub-surface effects

Thermal imaging only provides information on the surface temperature. It cannot see below a surface. Thermal images do often reveal information about sub-surface structures, but only where these affect surface temperature, e.g. thermal bridging. To reveal information from depth requires a sufficient period of heating (or cooling) to significantly affect the material at that depth.

5.6 Deceptive temperature scales

Thermal images should include a scale to ensure accurate analysis of the results. Beware of interpretations of thermal images that do not include a temperature scale. Thermal images can be processed to show data on any temperature range and colour scale. If a temperature scale is compressed it can exaggerate an insignificant temperature variation so that it looks like a major problem.

5.7 Sky temperature

When imaging buildings several storeys high the upper storeys are more exposed to the sky. Under a clear sky they will lose relatively more heat by radiation than lower storeys. The lower surface temperature of the upper storeys does not indicate a difference in thermal performance.

When thermal imaging outdoors, the quality of the data can be affected by extremely low temperature reflections of the sky (a clear sky may register at or below -40 °C). Measurements of reflected infrared temperature (T_{ref}) allow firmware in the camera to make corrections for this, but with large variations in temperature between the sky and other nearby objects this correction is unlikely to be accurate.

5.8 Direct sunlight

Direct sunlight can cause problems. It is obviously a problem on a building exterior if it obscures other effects, such as heat loss. It can also be a problem inside a building as it may mask thermal differences on a sunlit internal wall.

5.9 Further investigations will be necessary

The area in question should be compared to other similar areas to investigate potential causes of the temperature anomaly (Fig. 24). Previous thermal imaging of the same area may indicate whether anything has changed. Often confirmation by further inspection will be required. This may involve looking at building plans and the use of other equipment such as moisture sensors or endoscopes.

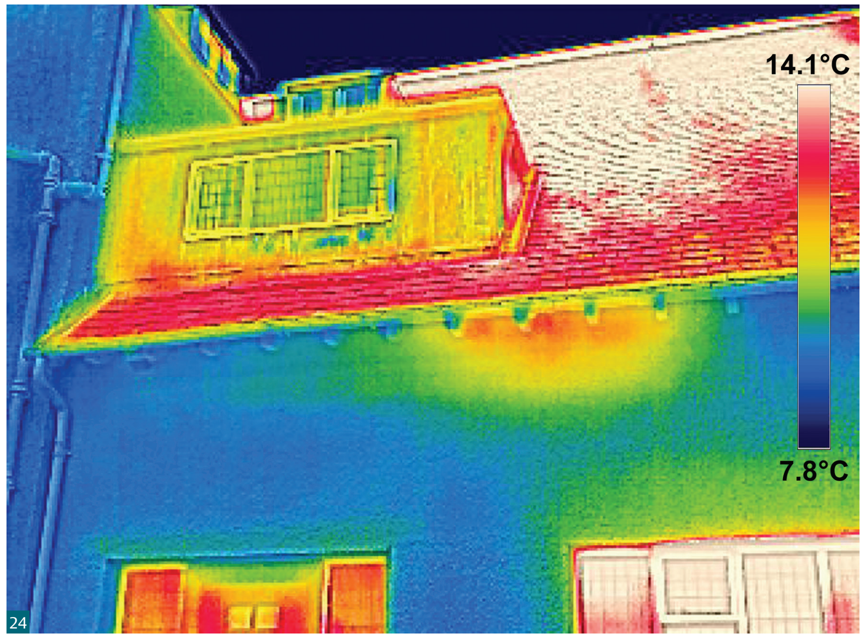


Fig. 24 Further investigation of the cause of thermal anomalies is often necessary. The hot patch on the wall below the roof is caused by a hot water boiler.

6. Conclusion

Infrared thermal imaging is a very useful tool for investigating and imaging a wide range of potential problems in the built environment. However, the immediate impact of a colourful thermal image can easily distract attention from accurate interpretation of the causes of temperature anomalies. A thermal image will always require analysis and interpretation with supporting information in order to be reliably used in defect analysis. Environmental conditions leading up to, and during, imaging will strongly influence the imaging process. Correct interpretation requires careful consideration of the conditions under which thermal imaging has been carried out and an understanding of the multitude of conditions that control surface temperature. Diagnosis of the cause of a thermal anomaly should always be confirmed by further inspection on site. Providing the necessary preparation and analysis takes place, its use can avoid the need for destructive or invasive survey techniques which may otherwise be required.

7. Contacts

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8. Further reading

British Standard: BS EN ISO 6946:2007. Building components and building elements. Thermal resistance and thermal transmittance: Calculation method.

British Standard: BS EN 13187: 1999. Thermal performance of buildings. Qualitative detection of thermal irregularities in building envelopes. Infrared method.

FLIR. *Thermal Imaging Guidebook for Building and Renewable Energy Applications.* FLIR, 2011. *www1.flir.com/thermal-imaging-building-guidebook-au*

FLIR. *Infrared guidebook for Building Applications*. FLIR, 2009. *www.flir.co.uk/home/*

ISO 6781:1983. Thermal insulation. Qualitative detection of thermal irregularities in building envelopes. Infrared method.

Lanzoni, D. *Building Thermography (including blower door and heat flux meter).* Iltuoebook.it, 2014. *www.saige.it/e-book*

Nowicki, A.N. *BINDT Guides to Thermal Imaging: Infrared Thermography Handbook. Volume 2. Applications*. Northampton: The British Institute of Non-Destructive Testing, 2004.

Pearson, C. *A BSRIA Guide: Thermal Imaging of the Building Fabric*. Berkshire: BSRIA, 2011.

Vollmer, M. and K.P. Möllmann. *Infrared Thermal Imaging: Fundamental, Research and Applications.* Weinheim: Wiley-VCH, 2010.

Walker, N.J. *BINDT Guides to Thermal Imaging: Infrared Thermography Handbook. Volume 1. Principles and Practice.* Northampton: The British Institute of Non-Destructive Testing, 2004.

Ward, T.I. *Assessing the Effects of Thermal Bridging at Junctions and around Openings*. Watford: Bre Press, 2006.

9. Historic Environment Scotland technical conservation publication series

The following publications are all free to download and are available from the publications page on our website: www.historic-scotland.gov.uk/conservation

Technical Papers

Our Technical Papers series disseminates the results of research carried out or commissioned by Historic Environment Scotland, mostly related to improving energy efficiency in traditional buildings. This series covers topics such as thermal performance of traditional windows, U-values and traditional buildings, keeping warm in a cool house, and slim-profile double-glazing.

Refurbishment Case Studies

This series details practical applications concerning the repair and upgrade of traditional structures to improve thermal performance. The Refurbishment Case Studies are projects sponsored by Historic Environment Scotland and the results are part of the evidence base that informs our technical guidance. This series covers measures such as upgrades to windows, walls and roof spaces in a range of traditional building types such as tenements, cottages and public buildings.

INFORM Guides

Our INFORM Guides provide short introductions to a range of topics relating to traditional skills and materials, building defects and the conservation and repair of traditional buildings. This series covers topics such as: ventilation in traditional houses, maintaining sash and case windows, domestic chimneys and flues, damp causes and solutions improving energy efficiency in traditional buildings, and biological growth on masonry.

Short Guides

Our Short Guides are more in-depth guides, aimed at practitioners and professionals, but may also be of interest to contractors, home owners and students. The series provides advice on a range of topics relating to traditional buildings and skills.

10. Glossary

Blackbody	A theoretical object which is in perfect thermal equilibrium – all incident radiation is absorbed and emitted with 100% efficiency. As a perfect radiator it neither reflects, nor transmits, radiation.
Conduction	The mechanism of heat transfer through a solid by vibrational activity of molecules from regions of high temperature to regions of low temperature.
Convection	A form of heat transfer where a temperature difference (or other external force) brings fluid (liquid or gas) into motion. The heated fluid becomes less dense and rises under the influence of gravity transferring heat away from the surface.
Dew point	The temperature at which air becomes saturated with water vapour. Condensation of water will occur on surfaces with a temperature below the dew point.
Emissivity	The ratio of radiation observed at an object's surface to that of a blackbody under the same conditions.
Infrared	Electromagnetic radiation with a wavelength of about 2-13µm.
Radiation	The mechanism of heat transfer which is the basis of thermography. Heat is lost by electromagnetic radiation from the object.
Reflected apparent temperature (T_{ref} or T_{amb})	The mean apparent infrared temperature in the vicinity of an object resulting from infrared emissions from nearby objects and from the sky. Used to make corrections for infrared reflections.
R-Value	The resistance to heat flow of a building element.
Solar gain	The increase in temperature of an object due to incident solar radiation.
Thermal bridge	A part of a structure which conducts heat at a rate higher than the acceptable threshold value.
Thermal capacity	The measure of the amount of heat required to change the temperature of a material by a certain amount. In relation to the built environment the term thermal mass is often used to convey the concept of a material's ability to store heat and even out temperature changes.
Thermal conductivity	Materials differ in their ability to take up and lose heat. Thermal conductivity is a measure of a material's ability to conduct heat. Materials like metals have a high thermal conductivity, taking up and losing heat quickly. By contrast, materials used for building insulation have a low conductivity, heating up and cooling down more slowly.
Thermography	Also known as thermal imaging. The production of images to visualise radiant emissions from surfaces.
U-value	A measure of the thermal transmittance of a material or structure. The lower the U-value, the better the insulation value.

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