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MARK THROWER MANAGING EDITOR
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Take a thermal image

Catherine Simpson, principal director, Building Simulation Ltd

Engineering and construction professionals are familiar with 'thermography' as a means of non-destructive and non-contact assessment, within the building, mechanical and electrical sectors. Though thermography is also used widely in clinical fields for humans and animals and the screening of airline passengers in 2003 in response to the outbreak of severe acute respiratory syndrome (SARS), also known as avian flu, is one example that gained media attention. There is immense potential for thermography because whenever a temperature difference is an indicator of some factor, then thermography may have a role to play. However, while many professionals may respond intuitively to the colour palettes used for visualisation of 'hot' and 'cold' areas, it could be without much knowledge of the physics and technology behind the infrared thermal image.

The discipline of infrared thermography as we know it today is less than 100 years old. Like many discoveries by notable scientists in the last few hundred years, the benefits are firmly embedded within modern practices while the personal determination which led to these discoveries is widely unacknowledged. Like most inventions, it was the culmination of a series of separate scientific discoveries which led to the invention of thermographic cameras.

Refract white light with prism

In 1665, the English mathematician, Sir Isaac Newton was the first to understand the rainbow by refracting white light with a prism, resolving it into its component colours: red, orange, yellow, green, blue and violet. An Italian scientist, Landriani, took Newton's work further by measuring the energy in the different colours of the light spectrum. However, it was in 1800 that the British-German scientist, William Herschel, when repeating Newton's and Landriani's experiments, accidentally discovered that the highest temperature was beyond the visible red light – Herschel referred to this as 'infrared'. Subsequently, William Herschel's son, John, produced the first infrared image in 1840 and coined the term 'thermograph'.

It was not until 1900, when scientists discovered the relationship between temperature and infrared, that for first-time the temperature of an object could be measured without direct contact. The invention of a night vision camera for the British military in 1929 by Hungarian physicist Kálmán Tihanyi and the development of the Aga-Bofor system in 1969 for aerial geophysical exploration were significant contributions to modern infrared thermography.

Electromagnetic spectrum

Landriani, Newton and Herschel had all discovered regions of the electromagnetic spectrum (EMS), and it was Herschel's discovery of infrared that led Johann Ritter to discover its book-end 'ultraviolet' a year later. The EMS comprises regions of radiation beginning with the lower energy, lower frequency, long wave-lengths of radio waves, television, microwaves, radar waves which are below infrared and visible light and ending with the high energy, higher frequencies of X-rays and gamma rays which are above visible light and ultraviolet. The spectrum is incomprehensibly vast and covers wavelengths between 0.3 m (radio waves) to the minute gamma rays with wavelengths of 6 x 10-12 m. The human eye can only detect the visible range, which is a tiny region of visible light with a wavelength between 380 nanometres (nm) and 760 nanometres (nm). Infrared is a larger region lying below visible light with wavelengths between 760 nm and 1400 (nm). As visible light is the only region we encounter in our daily lives, our knowledge of visible light is pervasive and therefore, when using thermal imaging, it is critically important that the different characteristics between the visible light region and the infrared region of the EMS are fully understood.

The theoretical concepts of emissivity and a blackbody, originated by Kirchoff in 1860, are important to understanding infrared thermography. Kirchoff discovered that at equilibrium a body absorbs 100 per cent of incident radiation, while simultaneously emitting 100 per cent of its own energy as radiation – an object that does this is termed a blackbody. However, real bodies are not perfect emitters and only a fraction of incident radiant energy is re-radiated. This fraction of surface reradiation is known as emissivity. Therefore, a blackbody has a reference emissivity of 1 and, relative to this, human skin has near perfect emissivity of 0.98 while at the other end of the emissivity spectrum, aluminium foil has an extremely low emissivity of 0.03. In 1884, the work of Josef Stefan and Ludwig Boltzmann culminated in the understanding that the total radiant energy emitted from a surface is proportional to its absolute temperature. This is known today as the Stefan-Boltzmann law.

Completed scientific journey

However, it was the work of Max Planck in 1900 that discovered that radiation had a spectral energy distribution (later corroborated later by Albert Einstein in 1905) that took scientists a step nearer to being able to determine the temperature of an object. Wien's laws, discovered around the same time, completed the scientific journey from theoretical concepts of

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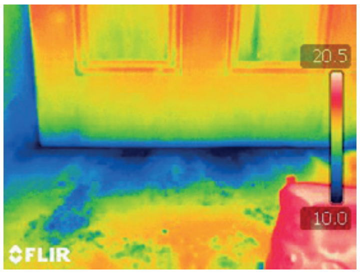

Figure 1

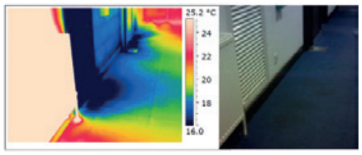
Figure 2

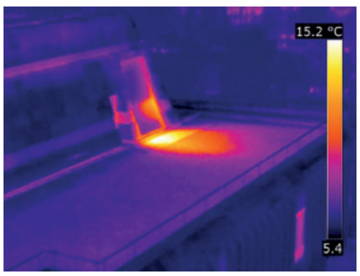

Figure 3

Figure 4

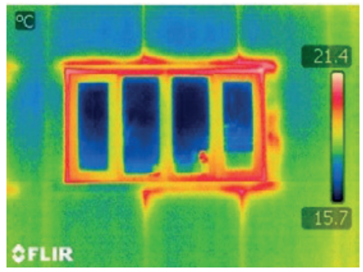

Figure 5

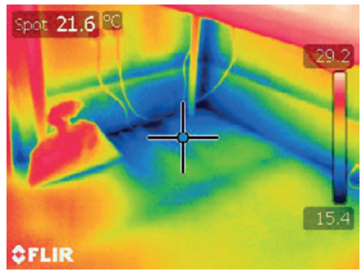

Figure 6

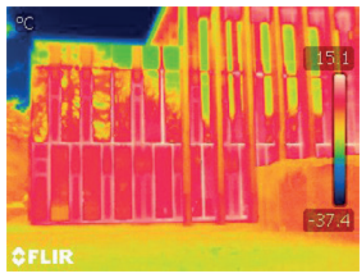

Figure 7

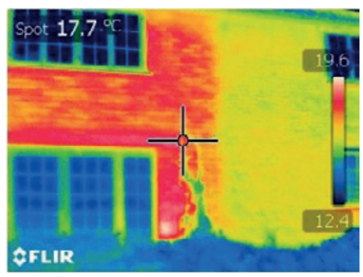

Figure 8

blackbodies and emissivity radiation to the identification of a specific temperature of an object. This journey of scientific discovery led to today's infrared thermography.

However, the real world comprises many materials with differing surface emissivities. Therefore, if the surface emissivity of an object determines how its temperature is calculated, how can a single thermal image correctly identify temperatures of different materials within the camera's viewfinder? This is where real-life makes the application of theory a little trickier and calls upon the skills of a trained thermographer. Human skin, water, snow, ice, uncoated glass, concrete, plaster, brick, stone, carbon, timber, paint and some metal alloys have high surface emissivities. On the other hand, metals generally have low emissivities with aluminium foil and polished brass being examples of materials with the lowest emissivities. However, it is important to remember that it is the surface condition of the material that determines its emissivity which is why for example, weathered stainless steel has a high emissivity (0.85) whereas polished stainless steel has a low emissivity (0.07) and 'low-e glass' which is generally glass with a low-e coating within the cavity, remains a high emissivity material. The reason a thermographer needs to know how to accurately assess and measure the emissivity of an object is because the thermographic calculations for low emissivity materials are very sensitive to error. Furthermore, emissivity can be affected by the surface roughness, the angle of view and the geometry of an object.

Reflection of radiated heat

Radiated heat from surrounding sources is also reflected from an object. Reflection of radiated heat can affect the calculation of the temperature of an object, even when the correct emissivity has been measured or estimated. Sometimes, the radiated reflection may be visible when viewed through an infrared camera; a common example is glass which while a poor reflector, has mirror like reflections of radiative energy because it is a specular reflector. This is why thermal images of glass often show the surroundings including sometimes a reflection of the camera operator! However, in general a good emitter (like a brick wall) is a poor and diffuse reflector whereas a poor emitter like aluminium foil is a good reflector. But, even when reflected radiation may not be visually obvious, it is still there and needs to be measured by the camera operator and must be taken into account in the camera settings to ensure accurate temperature calculations. However, reflected radiation, even after compensation within the temperature calculations, may still lead to false diagnoses, particularly when high and low emissivity materials are combined. This challenge is particularly prevalent when undertaking infrared thermal imaging of industrial plant, mechanical and electrical installations and highly glazed buildings. However, knowledge of the application combined with training will minimise the risk of misdiagnosis due to radiated heat reflections.

Modern infrared thermal imaging cameras combine all these scientific discoveries into easy to use software giving thermographers a safe and effective way to undertake non-destructive and non-contact assessments. The lens material for the front optic of an infrared camera is not glass but a material which has an ability to transmit infrared radiation combined with other attributes such as low refraction and durability. Germanium (Ge) is a common lens material with filters for specific applications made from Calcium Fluoride (CAF2), fused silica (FS), Sapphire, Silicon (Si), Sodium Chloride (NaCl), Zinc Selenide (ZnSe) and Zinc Sulfide (ZnS), for example. Once the infrared radiation has passed through the front optic lens it comes into contact with an array of detector pixels which transform the infrared radiation into an electrical impulse. Behind the array of sensors is a processor which receives the electrical impulse from each detector pixel and, using mathematical algorithms combined with the data input by the camera operator, creates the familiar thermal image to visualise the apparent temperature of the object. With use the detector pixels can become misaligned and not read in a uniform way which is why cameras should be recalibrated regularly. Modern infrared cameras combine many state-of-the-art features such as GPS tagging of images, visualisation tools as well as voice recording for site surveys.

Detection of moisture

Thermal imaging in buildings is frequently undertaken to improve energy efficiency and detect moisture. It is no coincidence that thermographers tend to specialise in a particular application of thermography, whether that be in buildings, medical or preventative maintenance of mechanical and electrical equipment. The reason for specialisation is that thermography requires an in-depth knowledge of the application under investigation in order to accurately interpret the thermal images and correctly diagnose potential issues. Rarely, do thermographers rely solely upon a thermal image for diagnosis, particularly within buildings which combine a wide range of construction materials (including lots of highly reflective glazing), an immense variety of construction methods,

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concealed building services and, in some cases, unwanted wildlife such as wasp nests and squirrel dreys! Correct diagnosis of an image relies upon a thermographer spotting something 'out of the ordinary' and then making further investigations. For this reason, many professional thermographers build a library of what 'normal' should look like as a source of reference. A good example of this is medical thermography where the assessment of potential issues in a patient is obtained by reference to a 'healthy' thermal image. Therefore, while there could be a range of causes for the heat contrast in an infrared thermal image, the correct diagnosis of will depend upon knowing and understanding the context of the image.

Buildings can lack energy efficiency for a variety of reasons and air leakage and infiltration can be primary factors. In older buildings, sources of infiltration may be easy to identify by draughts and complaints while, in modern, highly serviced environments, a building can appear airtight when it is not. Air leakage into a building is relatively easy to detect, as colder air entering a warm, internal space frequently leaves a distinct heat transfer 'foot print' on the interior fabric. For example, in Figure 1 air enters around a poorly draught-sealed door while in Figure 2 air enters via a poorly sealed smoke riser - in both cases the cooling effect on the interior fabric is clearly visible.

Air leakage from buildings

However, air leakage from a building is not so easy to detect because warm air exiting a building may disperse over a large area and mix quickly with outdoor air thus giving little opportunity for heat to transfer into the surface of the exterior fabric. However, there are circumstances when this can occur. Figure 3 records a thermal 'footprint' on an exterior flat roof due to prolonged air exfiltration and Figure 4 shows a more common scenario of air leakage from a poorly draught-sealed, sash window. While thermographic energy surveys tend to take place in winter, it should be borne in mind that if buildings are air conditioned, then air-leakage and

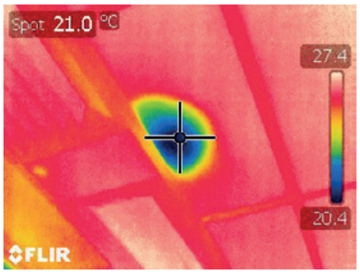

Figure 9a

Figure 9b

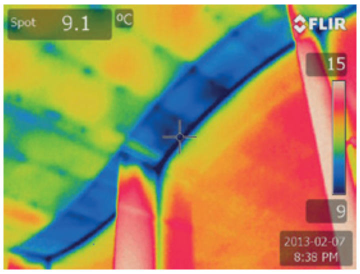

Figure 10a

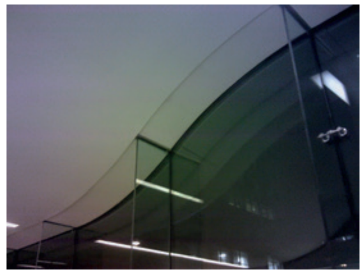

Figure 10b

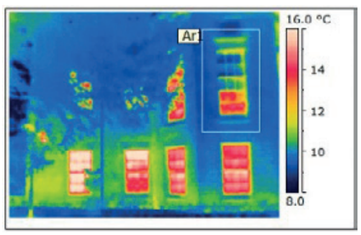

Figure 11

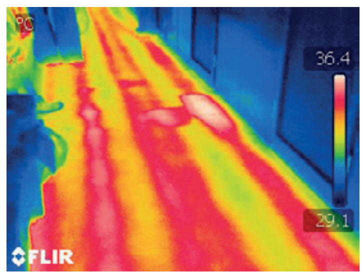

Figure 12

infiltration in summer can also reduce the energy efficiency of cooling systems.

The most easily visualised form of heat loss is conduction through the fabric although this can be equally challenging to interpret, particularly for highly glazed buildings and buildings with different materials and methods of construction.

Energy surveys begin frequently with the expectation of finding missing insulation in walls and roofs and cold bridging, and whist this does occur, there are many other areas where heat loss can originate; a common weakness is the interface between building elements. Unless care is taken with design detailing and construction, these interfaces allow heat to escape as shown in Figure 5 or cold air to ingress as shown in Figure 6. While a skirting board visually 'connects' the wall and floor, an open joint behind it can permit air ingress. However, notwithstanding that highly glazed buildings are spectral emitters, Figure 7 shows it is still possible to clearly identify excessive heat loss from areas of sub-standard construction in this case, the joints between the structural glazing, floor and mullions.

The effect of moisture, construction materials and thermal mass need to be borne in mind because infrared images can give surprising results as shown by the image in Figure 8; the exterior wall on the left-hand side of the image is a painted cavity wall and yet it has a warmer surface temperature indicating more heat loss than the wall on the left-hand side which is a lime-washed solid brick wall. In this case, the limewash has a high moisture content after a period of rain hence the lower surface temperature at the time of the survey. This demonstrates the awareness required of wider issues such as thermal mass, materials and construction methods in addition to any calculated U-values when diagnosing infrared thermal images.

Thermal imaging can also give insight to the performance of construction elements and building services concealed within the building fabric. While the brown staining in Figures 9a and 9b looks unsightly, and there were many such stains, the thermal image revealed that only this particular stain was a current issue and was a result of a light leak from a condensate located above the suspended ceiling

However, a far bigger issue, of which there was no indication until detected by a thermographic survey, was a water saturated roof to a newly constructed glazed entrance - Figure 10a and 10b. Thermographic surveys can also detect hidden leaks such as defective pipes embedded in screed as shown in Figure 11 where the white patch indicates a leak. While all the above is very useful and informative, illustrations of the importance of occupiers in the quest for energy savings are poignant. Figure 12 shows that closing a blind across a single glazed window significantly reduces heat loss which saves energy.

Minimum standard required

The minimum standard for building infrared thermography reports is BS EN 13187 (Thermal Performance of Buildings – Qualitative detection of thermal irregularities in building envelopes – Infrared Method). The BREEAM scheme awards a credit when a thermal imaging survey of the building fabric is undertaken to this standard by a UKTA Approved Level 2 thermographic surveyor. The training to achieve this standard is intense and involves in-depth knowledge and application of the physics relating to heat transfer and infrared radiation as well as the completion of practical laboratory sessions and hands-on experience required to progress from Level 1 to Level 2. This level of training ensures that a thermographer understands the physics and technology behind a thermographic image which combined with their application experience gives valuable insight. Level 3 is the ultimate achievement, although few acquire the training and application hours to deserve this accolade.

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CPD SERIES **16** | MODULE **07** | JANUARY **2019**

ENTRY FORM

THERMAL IMAGING

Please mark your answers on the sheet below by placing a cross in the box next to the correct answer. Only mark one box for each question. You may find it helpful to mark the answers in pencil first before filling in the final answers in ink. Once you have completed the answer sheet in ink, return it to the address below. Photocopies are acceptable.

QUESTIONS

1 What is necessary for infrared thermal imaging to be possible?
- ☐ One of the surfaces must be hot
- ☐ One surface must be hot and one must be cold
- ☐ There must be a temperature difference
- ☐ There must be a temperature difference of at least 10ºC.

2 What instrument did William Herschel use to discover what he called 'infrared'?
- ☐ Thermal imaging camera
- ☐ Infrared heater
- ☐ Thermometer
- ☐ A rainbow

3 Which is the correct range of regions within the electromagnetic spectrum?
- ☐ Radio, television, microwave, radar, infrared, visible light, ultraviolet, x-rays, gamma rays
- ☐ Radio, television, microwave, radar, ultraviolet, visible light, infrared, x-rays, gamma rays
- ☐ Radio, television, radar, infrared, visible light, ultraviolet, microwave, x-rays, gamma rays
- ☐ Radio, television, radar, infrared, visible light, ultraviolet, microwave, x-rays, gamma rays

4 Which scientists are most linked to discoveries leading to the development of infrared thermography?
- ☐ Herschel, Einstein, Planck, Wein, Stefan, Boltzmann
- ☐ Newton, Landriani, Herschel, Kirchoff, Stefan, Boltzmann, Wein, Planck
- ☐ Newton, Landriani, Herschel, Stefan, Boltzmann, Wein, Planck,
- ☐ Herschel, Einstein, Planck, Wein, Stefan, Boltzmann

5 What is Kirchoff's concept of a blackbody?
- ☐ When there is a temperature difference, a body absorbs 100 per cent of incident radiation while simultaneously emitting 100 per cent of its own energy as radiation
- ☐ at equilibrium a body absorbs 100 per cent of incident radiation while simultaneously reflecting 100 per cent of its own energy as radiation
- ☐ at equilibrium a body absorbs 100 per cent of incident radiation, while simultaneously emitting a proportion of its own energy as radiation
- ☐ at equilibrium a body absorbs 100 per cent of incident radiation while simultaneously emitting 100 per cent of its own energy as radiation

6 Which statement is true?
- ☐ Glass has a high emissivity and is opaque to infrared light
- ☐ Glass is low emissivity and is transparent to infrared light
- ☐ Glass can be high or low emissivity and is opaque to infrared light
- ☐ Glass is low emissivity and is opaque to infrared light

7 Which statement is most accurate?
- ☐ The emissivity of a material is a fixed value
- ☐ The emissivity of a material changes with time
- ☐ The emissivity of a material depends on a number of factors
- ☐ The emissivity of a material is dependent upon reflected radiation

8 Which statement is true?
- ☐ The most accurate thermal infrared cameras have Germanium lenses
- ☐ Many thermal infrared cameras have Germanium lenses
- ☐ The Germanium lens needs to be protected with a glass lens
- ☐ A Germanium lens processes the infrared radiation which passes through it

9 Which of these groups are all low emissivity materials?
- ☐ Human skin, oak, glass
- ☐ Polished stainless steel, aluminium foil, low-e glass
- ☐ Brick, concrete, copper
- ☐ Aluminium foil, polished brass, polished stainless steel

10 The materials that are most susceptible to inaccurate temperature calculations as a result of an incorrect emissivity assessment are those which:
- ☐ Have a high emissivity volume
- ☐ Have a low emissivity volume
- ☐ Have a low surface emissivity
- ☐ Have a high surface emissivity

Please complete your details below in block capitals

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