The structures we live and work in are susceptible to quality and performance problems during construction and maintenance that can impact performance and may, in some cases, render them dangerous. Regardless of the building type involved, infrared thermography can provide remarkable, nondestructive information about construction details and building performance.

This article discusses the numerous applications for the technology currently being used to inspect building envelopes. These include validation of structural details, verification of energy performance (conduction and air leakage), location of moisture intrusion, and the identification of structural and system degradation of roofs and facades. Examples will be given for each application and the basic conditions required will be discussed.

Buildings of all sorts, from homes to factories to high rises, can be troubled by problems related to design, construction and maintenance that can be difficult to diagnose and resolve. The major problems found in buildings include:

- Excessive energy use due to missing or damaged insulation, insulation that is performing inadequately, and excessive air leakage across the thermal perimeter
- Moisture damage due to leaks or condensation, especially in the walls or roofs
- Ice damage to sloped roofs
- Poor HVAC distribution or performance
- Inadequate verification of construction details or structural performance delaminations of façade materials
- “Sick building syndrome,” mould growth and other health related issues.

Often the problems – as well as their causes and consequences – simply cannot be seen until after costly damage has been done. At that point the only recourse may be extensive, costly reconstruction. The commercial building in Fig. 1, a nursing home, had extensive problems resulting from a poorly designed roof/ceiling insulation system; these included excessive heat loss during the winter months and, as a result, extensive ice damage due to snow melt. Hundreds of thousand so dollars were spent in various, poorly planned attempts to correct the underlying causes. In the end the owners simply lived with the continued problem because corrective actions were deemed too expensive. Despite this unfortunate resolution, the thermograms helped the owners negotiate a financial settlement with the architects and contractors.

A great value of infrared thermography is that it provides a means of seeing the invisible thermal signatures related to many of these problems in building. When properly used, thermography enables building owners, architects, contractors and inspectors to locate problems, verify building performance, and validate solutions. When people act on this information, significant savings result and buildings are more comfortable!

All surfaces radiate invisible heat energy. You’ve felt this energy emitted by the sun or a stove burner. Infrared cameras are specially-designed electronic devices that detect thermal radiation. They convert this radiation into thermal images, or thermograms, which visually portray temperature differences as small as 0.05°C. These portable, battery-operated instruments record the thermal data either as still, digital images or on conventional videotape or digital video. The image is displayed live in a viewfinder or on an LCD view screen.

Different radiant temperatures are shown as different colours or shades of grey. Although it may sometimes be useful to display temperature values, this is often not required in building work. Rather the differences are what is usually of interest.

Given the right conditions most buildings exhibit characteristic thermal patterns that can be interpreted by a qualified person. The infrared systems themselves are quite easy to operate and, thus, a number of thermographers conduct building inspections. The tasks of interpreting the imagery, understanding the root cause problems, and finding solutions are all more difficult. Because of this, thermographers often work closely with a team consisting of building specialists, architects, and contractors.

![Fig. 1: Excessive heat loss and poor ventilation resulted in costly ice damage to this large roof.](image1.png)

![Fig. 2: When conditions are right, it is possible to locate missing or poorly performing insulation, such as this urethane spray foam, that appears to have separated from the wood framing, creating a vertical cool insulation void in this residential home.](image2.png)

![Fig. 3: The insulation voids between the ceiling joists are clearly seen here in warm-weather conditions where there are missing fiberglass bats.](image3.png)
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[Image 41x278 to 204x384]
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The key to using thermography successfully is understanding what thermal patterns are associated with the problems being studied and knowing when those patterns will become visible in the infrared image.

**Building applications for thermography**

Thermography has been used since the mid-60s to solve building problems. During the late 70s and early 80s, a time when fuel prices rose dramatically, thermography was embraced widely as a tool to help determine building performance. Since then other applications have been developed and refined, especially related to verification of structural performance. The major building-related applications for the technology are detailed below.

**Insulation checks**

Missing, damaged or non-performing insulation will stand out clearly in a thermal image when there is at least a 10°C stable temperature difference between the conditioned space and the outside air. It is often possible to do work with less of a temperature spread due to differences in the thermal capacitance of the building materials. The inspection is typically done from both inside and outside. Often the best results are gained from inside because of fewer influences, but a better overall understanding of the building can often be gained from larger views of the outside elevations.

It is essential to know the type of insulation in the building and construction details, including how the insulation was installed. Insulation may be in place but not performing; often a destructive evaluation is warranted to establish baseline conditions or understand the exact construction detail.

Each type of insulation has a characteristic thermal pattern. Fig. 2 shows a classic pattern associated with injected foam insulation in a wood-framed wall. This type of insulation, a soft foam, is susceptible to shrinkage and cracking when poorly installed.

Many factors impact the image you will see. When work is done in the daytime or early evening, the impact of solar loading must be considered. The effects of the sun can easily last 6-8 hours on both the inside and outside after a wall has been exposed. This often results in the direction of heat flow being reversed, making for confusing images and misdiagnosis. Wind must also be reckoned with, as it can both quickly eliminate the thermal difference on a surface as well as enhance others. If building problems are wind-related, i.e. “we are cold on windy days,” then it is wise to conduct the inspection with a wind load.

The costs of poor performance of insulation are huge. In addition to excessive energy consumption, there may be costly freeze-ups of water pipes or fire sprinkler systems; health issues associated with mould growth in cold spots; damage to roofs and interiors caused by ice dams, condensation, and water intrusion.

**Air leakage location**

Excessive air leakage can account for up to half of the energy consumed to condition buildings. Of course adequate air exchange is essential for the occupants’ health and safety, but most buildings have a far higher rate of air exchange than is necessary. The root cause is often poor design and/or construction which allows air to move across the thermal perimeter. The problems can be as straightforward as a failed door weather seal or as complex as an air pathway through a plumbing chase in an interior wall or ceiling plenum. The leakage pathway is often complex and, without infrared, extremely difficult to visualise.

Air leakage inspections are best conducted when air flow is directed and controlled. This can be accomplished with exhaust fans, a specialised blower fan door, or, in larger buildings, by temporarily altering the HVAC system, to create a negative pressure inside. During the heating season the resulting sites of air infiltration appear cooler. The work can be done any time of year the indoor/outdoor temperature difference is greater than a few degrees. Blower door fans can also be used to quantify air leakage rates. This technique is invaluable in predicting building performance and monitoring air sealing work. Most types of insulation are not effective at reducing air movement through the thermal perimeter. Good construction practice includes interior air sealing; if this is not in place effectively, air can move through the interior and exterior surfaces and through the insulation. Unfortunately, fibreglass is particularly susceptible to this problem. Thus, while the insulation may be present, it does not perform as expected when the building is under a pressure gradient.

**Moisture intrusion or condensation**

As building designs and techniques produce tighter thermal envelopes, moisture (from leaks or condensation) has created more and more problems. The water can intrude through a small crack but it is then trapped between the relatively impermeable building materials. Good building techniques typically must deal with both air sealing and moisture retarders to keep moisture from accumulating inside the wall sections. Locating moisture with thermography can be challenging as the thermal patterns associated with water can be both warm or cool, depending on the conditions and location of the problem. These patterns can also look similar to missing
insulation or air leakage issues in some instances.

The fact that water has both a high thermal conductivity and a high thermal capacitance can help us in our search for moisture, however, a moisture meter is necessary to confirm its presence. Thermal imaging alone is not a primary tool for detecting moisture issues in buildings, but can be used to find surface thermal patterns that may be associated with sub-surface moisture content. Thermography also does not find mould, but can be used to locate thermal patterns possibly associated with moisture; a location favourable to mould growth should the conditions be conducive for its development.

**EIFS construction**

The use of exterior insulation and finish systems (EIFS) on buildings has been accompanied by numerous cases of moisture-related structural damage. Although often attributed to leaking windows, water typically intrudes where sealing or flashing systems were inadequate or have begun to fail. Moisture is then trapped under the relatively impervious foam. In warm climates the decay of structural wooden elements, which can occur very rapidly, is a major problem. Mould growth also often accompanies the moisture resulting in health concerns.

Thermography is an invaluable tool to locate moisture in EIFS systems. Inspections are best conducted in the early evening from the outside after a sunny day with little or no wind. It may also be possible to locate moisture from inside during cooling or heating conditions. The expanded foam insulation boards tend to become more absorbent to water over time.

**HVAC performance**

HVAC systems can be plagued by design and installation problems resulting in excessive energy use and/or uncomfortable buildings. Thermography helps building specialists visualise the otherwise invisible impact of this poor performance as indicated by excessively hot or cold areas. Once these have been located, the root causes can be determined; these may include reversed or misdirected airflow or poorly placed supply ducts, leading to shortcircuiting of air directly to the return ducts.

Unfortunately many of these problems result from poor design; by the time the thermographers spots them, it may be too late to correct some of them. On the other hand, some, such as reversed diffusers, are very easy to correct.

It is also possible to visualise air flow itself. Several thermography studies have been conducted by hanging layers of plastic netting in a room. As the air flows through it, the temperature of the netting can be imaged. In most comfort-related cases it is probably as useful to simply image the walls and objects in the room a technique that is much easier.

**Sub-surface heat sources**

Heating coils are being used more and more either to keep outside walkways or entrance ramps snow free or to provide heat to areas and rooms via hot water or electric cables. Thermography provides a quick way to verify location and performance of these subsurface devices. Typically the thermal pattern shows up very clearly even when the heat source is embedded in several inches of concrete. Similarly, water pipes in wall sections can usually be located quite readily. Water leaks from pipes, whether in a wall section or under a slab, may also be located using infrared (IR), although airborne ultrasonics may be a simpler method. To use IR a temperature difference must be induced generally by simply running hot water through the pipe. Leaks under concrete slabs may not express themselves because the water if the water is drained away in the sand/gravel base layer.

As a side note, thermographers are often asked to locate reinforcing steel in buildings. This is much more difficult. Heating the steel is not a simple task, usually accomplished with an inductive coil or direct DC powered heating. Secondly, the heat is often insufficient to express itself on the surface. Other methods, based on sending and receiving radio signals, are probably more useful.

**Verification of construction detail**

No area of application is more important these days, particularly in commercial buildings, than the verification of construction details and performance. Thermography is being used with great success to verify bond beams and placement of reinforcing in concrete masonry unit walls as well as structural elements of pre-cast, tip-up walls. How? The solid portions of the wall change temperature more slowly than the rest. The inspection can be conducted anytime the wall is in a thermally transient condition – typically in the early evening as it cools down. Because the inspection is conducted during construction, deficiencies can be corrected prior to occupation with relatively minor inconvenience.

Verification of placement of insulation in masonry unit walls is also more important than in the past due to high energy costs and health concern regarding mould growth.

**Sick-building syndrome**

When buildings are too tight or too moist, health-related problems quickly come to the forefront. Grouped together as “sick building syndrome,” these can stem from inadequate
HVAC performance, moisture trapped in walls, mould growth on cold, damp surfaces and inadequate air change rates. Many of these can be visualised and diagnosed, at least in part, with thermography to help solve these very serious – and common – problems. Diagnosing these problems is often a very complex process and, given the fact that litigation may be involved, it is not something to be entered into lightly.

Facade delaminations

A great deal of work has been done in SE Asia on inspecting the facades of large buildings for delaminations. Failures of these materials can result in serious personnel injury. The masonry tiles used to face the buildings tend to change temperature rather quickly when they begin to delaminate compared to the underlying structure to which they were affixed. The diurnal cycle is typically the driving heat source, and inspections are best done in the early evening hours after a warm sunny day.

Roof moisture inspections

The inspection of flat roofs, especially built-up roofs has been proven for a number of years. The technique allows for the detection of moisture trapped in a roof system; over time this moisture leads to the premature degradation of the roof. The moisture appears warmer at night after a sunny day due to its greater thermal capacitance.

The roof surface must be dry and the technique works best on roofs with absorbent insulation. Inspection work can be accomplished either in a roof-top survey or an aerial survey conducted from a helicopter or fixed-wing craft.

Conclusion

When properly used by qualified individuals, this remarkable technology can play a powerful role in visualising otherwise invisible building problems and conditions. Contractors and architects alike are both using thermography to assure the performance of their buildings. Building specialists count on thermography to help them diagnose tough problems that, left unsolved, are costly or dangerous.

Owners rely on thermography as a tool for commissioning a new building. While a foundation of expertise must underlie the successful use of thermography for building diagnostics, getting started with most of the applications is often not difficult. An appropriate infrared system is required, with proper training and expertise for the operator as well. Having supplementary knowledge of building sciences or access to that information is also vital. The primary return on an investment in building thermography is gaining a higher level of assurance that buildings will perform as intended and occupants will be more comfortable, often at a lower cost.

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