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Practical Identification of Moisture Sources in Building Assemblies using Infrared Thermography

If thermography is to have credibility as a reliable moisture detection and root cause investigative tool, then investigators will have to employ the proper scientific methodology for detection.

Thermography is limited to detecting moisture and moisture related issues only when these anomalies affect the surface temperature patterns. It therefore requires suitable thermodynamics and/or environmental conditions which are often unique to the building materials, assembly, or operation of the building in order to discover an anomaly related to a moisture deficiency. This creates limitations on the time, location, camera detection capabilities, and operator expertise required for suitable, ***reliable and repeatable*** detection of moisture.

While there are a number of published standards and guidelines related to the use of thermography for detection of heat and air related anomalies, there is very little contained in the standards and guidelines with respect to moisture detection. (the notable exception being moisture detection in built up low slope roofs) Yet in many cases, moisture intrusion or accumulation is often both the single most important and common problem in building investigative work.

Thermal cameras are often employed for moisture detection without scientific method, or regard for the variables which affect detection. It is very hit or miss, and often an experienced building investigator will, through visual examination of drawings, details and actual construction detect a moisture related deficiency and then simply use infrared as a dramatic illustration of its presence. Without the use of sound scientific investigative methodology and techniques thermography will produce either an overabundance of false positives requiring time wasting validation, or even worse false-negatives when the presence of water goes undetected. Unfortunately the dramatic nature of free air evaporative cooling leads to an over-confidence that if water is present it will be detected (and it will show up as cool).

Thermographic cameras are extremely sensitive, often able to detect differences less than 0.05°C (50mK). But while this may create a clearer, more defined pattern when the thermal conditions are right, it is not a viable substitute for moisture detection under poor thermodynamic conditions, and/or when moisture is buried deep within an enclosure especially with a low (vapor) permeance surface(s). High sensitivity cameras used under less than ideal conditions can lead to a large number of false positives, and/or lengthy field time for verification using other methods. False negatives lead to credibility issues of both the inspector and the thermographic industry as well as the possibilities of litigation, particularly when mold or other damage associated with moisture is present but not detected.

If thermography is to have credibility as a reliable moisture detection and root cause investigative tool, then investigators will have to employ the proper scientific methodology for detection. These methodologies should be established within industry accepted standards and guidelines.

Many thermographers believe that the only mechanism for detection of moisture is evaporation.

Detecting thermal anomalies related to moisture

Water, may be detected thermodynamically for three reasons: when a material contains water it can affect the thermal conductivity (k); when a material contains water it can alter the volumetric heat capacity (α·cp); or when water changes state latent heat is absorbed (evaporation, melting) or released (condensation, freezing). As can be seen in Figure 1 the reliability of detection, from the interior or exterior will be dependent on 1) whether the heat transfer rate is steady state or changing, 2) whether a phase change is occurring, 3) whether a temperature and/or pressure difference is present, 4) whether the inspection is being done from the inside or outside. The wall construction and the properties of materials within the wall along with the environmental conditions present on both sides of the assembly being inspected will have an impact on inspection results.

Moisture detection through evaporative phase change

Passive or Active Inspection Methodology can be utilized in both steady state and transient temperature conditions but it requires transient conditions for humidity and moisture within assembly materials and adjacent environments. It does not need a temperature differential across a building assembly.

Many thermographers believe that the only mechanism for detection of moisture is evaporation. Under the right conditions, free air evaporative cooling on a surface can indeed be very thermodynamic, and easily detected with a modern infrared camera: 1 droplet of water (e.g. of a mass of 0.45gms (0.001 lbs) can theoretically extract approximately 1.05kJ (1 Btu) from the surroundings in order to provide the latent heat required for evaporation. After a flood in a building, the restoration industry will usually attempt to dry the interior by significantly lowering the vapor pressure (relative humidity) and using IR has brought with it the concept of water 'always appearing cool'. The dramatic surface temperature depression, easily detectable during high vapour pressure difference has, however, led a very wrong general assumption by building investigators for passive moisture detection. Relying on water detection through the natural drying process only, will result both in false negatives (non-detection of moisture) and false positives (the thermal anomaly is not moisture). Even near-surface moisture can go undetected if the vapor pressure (RH) is too high in the free air condition adjacent to the

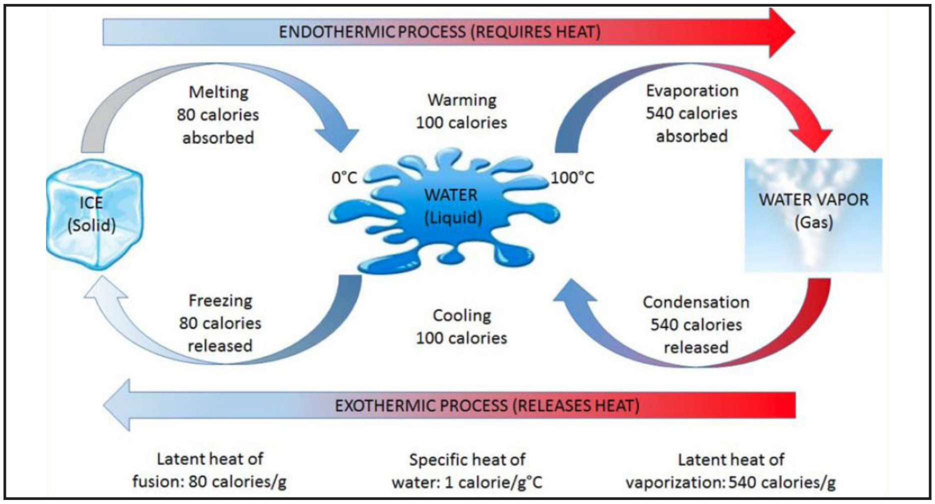


Figure 1. Energy values and process associated with the phase change of water

Just as the evaporative phase change from a liquid to a vapour can be a very dramatic endothermic process, the condensation of water vapour back to water can be just as dramatic exothermic process.

surface or if a non-permeable material is present. An infrared camera does not directly detect evaporation: rather it may detect a surface temperature depression due to the rate of evaporation. This is determined by two factors: the vapor pressure difference between the saturated condition of the material and the free air space adjacent to it; and the efficacy of the vapor retarders, if present, in between the saturated material and the free air. If the free air condition is warm and dry (low RH) it may create a high rate of cooling. Conversely, if the free air condition is cool and/or humid (high RH) it could easily go undetected because the evaporative cooling rate will be very low. The vapor permeance of the surface coating or materials on visible surfaces will have a significant effect on the rate of evaporation.

Moisture detection through condensing phase change

Passive or Active Inspection Methodology can be utilized in both steady state and transient temperature conditions but it requires transient conditions for humidity and moisture within assembly materials and adjacent environments and it does require a temperature differential across a building assembly.

Just as the evaporative phase change from a liquid to a vapour can be a very dramatic endothermic process, the condensation of water vapour back to water can be just as dramatic exothermic process. If condensation is occurring within a wall behind a vapour barrier then latent heat will be released and surface warming may occur. Particularly in cold climates, this warming pattern is often ignored or misinterpreted as a non-moisture condition (conductive heat loss) by an unsuspecting and untrained inspector who thinks that all that should be identified are "cool areas". If warm moist air is present either through vapour diffusion or air leakage and migrates to an area below the dew point, then water vapor will start condensing. This will often produces the so-called "mottled pattern" of interstitial trapped moisture identified by Public Works on the Saskatchewan low energy demonstration houses more than 35 years ago.

Moisture detection through freezing phase change

Passive or Active Inspection Methodology can be utilized in both steady state and transient temperature conditions but it requires transient conditions for humidity and moisture within assembly materials and adjacent environments) and does require a temperature differential across a building assembly.

The energy released through freezing phase change is only about 15% of the energy released through condensation phase change (80 cal/g°C vs. 540 cal/g°C). But the significant factor is that this freezing generally occurs at or immediately behind the exterior surfaces that are being viewed. Thus the full impact of the freezing phase change heat release is visible. This will occur only when exterior temperatures drop to or below 0ºC. In the case of interstitial freezing or condensation phase change, the energy of the heat release needs to travel through various materials and air spaces to impact either surface being inspected. There could be a time delay as well as a thermal dampening due to the thermal resistance encountered for this energy to affect either adjacent interior or exterior surfaces. Condensation can occur within the building assembly at temperatures above freezing depending on the RH levels found both in the building interior as well as within the building enclosure. But the heat patterns associated with freezing phase change will only be present at or below the freezing point.

Moisture detection through thawing phase change

Passive or Active Inspection Methodology can be utilized in both steady state and transient temperature conditions but it requires transient conditions for humidity and moisture within assembly materials and adjacent environments) and does require a temperature differential across a building assembly.

Identical in value (80 cal/g°C) but opposite to freezing the energy absorbed through thawing phase change is only about 15% of the energy absorbed through evaporative phase change. Thawing phase change occurs on exterior surfaces when exterior temperatures rise above freezing (or effect of solar heat gain on exterior surfaces) or the cumulative heat transfer from the building assembly increases the material temperatures above 0°C. The dark thermal patterns associated with melting frozen water within building cladding materials will not be as pronounced as those associated with evaporative cooling found on interior surfaces. There could be a time delay as well as a thermal dampening due to the thermal resistance encountered for this absorbed energy to affect either adjacent interior or exterior surfaces especially in situation where there is no evaporative cooling occurring to the interior. If evaporative cooling is occurring, then this phase change causal mechanism will over power the effect of melting phase change within the building assembly.

Moisture detection through increased capacitance

Active Inspection Methodology (Transient Conditions) can be utilized in only transient temperature conditions but it does not require transient conditions for humidity and moisture within assembly materials and adjacent environments and it does not require a temperature differential across a building assembly.

Detection of interstitial water within a wall or roof assembly is much more complex than the process of water evaporating from an exterior or interior surface exposed to free air. Many wall and roof systems have un-intentionally created two or more vapour retardant barriers which inhibits the drying process. This raises the vapor pressure within the assembly, and inhibits evaporative cooling as a means of detection. Ironically this situation creates enclosure issues which the investigator is often tasked with finding. In this case, the thermographer can use both active or passive methodologies and each is mutually exclusive of the other in terms of timing and environmental conditions required at time of inspection.

The active inspection methodology relies exclusively on the heat capacity change between wet and dry materials or the special thermal and moisture conditions required for one of the four phase changes (under transient state).

Moisture detection through increased conductivity

Passive Inspection Methodology can be utilized in only near steady state temperature conditions but it does not require transient conditions for humidity and moisture within assembly materials and adjacent environments. It does require a temperature differential across a building assembly.

The passive inspection methodology relies exclusively on the steady state conductivity change between wet and dry materials. Achieving these conditions could mean carrying

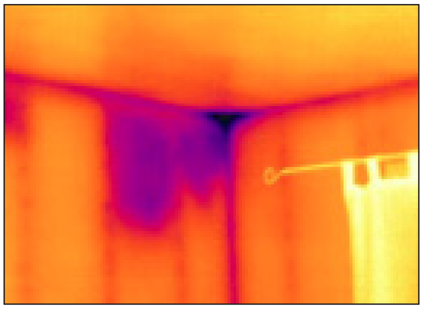


Figure 2A

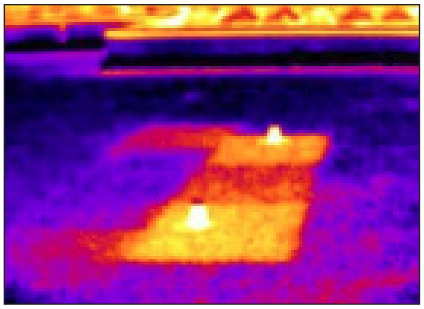
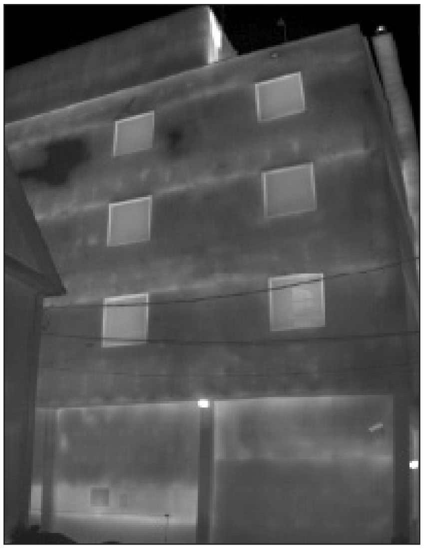


Figure 2B

Figure 2C

Moisture may be detected by: increased conductivity in steady state heat transfer (2a); increased thermal capacitance when undergoing transient heat transfer (2b); and through release or absorption of latent heat once undergoing a phase change. In this case (2c) evaporative cooling when relative humidity is low. (McIntosh, 2002-2007) out pre-dawn inspections to improve chances of achieving near steady state conditions. These types of inspections may eliminate thermal patterns associated with capacitance effects of residual moisture but under certain temperature conditions (at or below freezing) they may not eliminate the causal effects of some the phase change mechanisms.

Since moisture detection is not covered in much detail by any standard, a general assumption could be that the requirements for camera performance are at least equal to those for detection of conductive anomalies. The current consensus in the industry however, is that moisture detection necessitates a higher level of thermal sensitivity. Most manufacturers have accommodated this by producing "building" model of IR cameras with an NETD of at least 0.08°C (80mK) or better. It is likely that any future standards developed for moisture detection will require at least this level of sensitivity. Spatial requirements are likely to remain the same as for conductive anomaly detection. The NMS sections on thermographic assessments of building enclosures is the only specification which itemize certain conditions for the detection of moisture. The requires a minimum 20°C (temperature) and 25Pa (pressure) difference from the inside to the outside and 30°C difference when the pressure difference is less than 10Pa. The rationale for this requirement was for detection of residual moisture due to mass transport of air into the assembly during cold winter months.



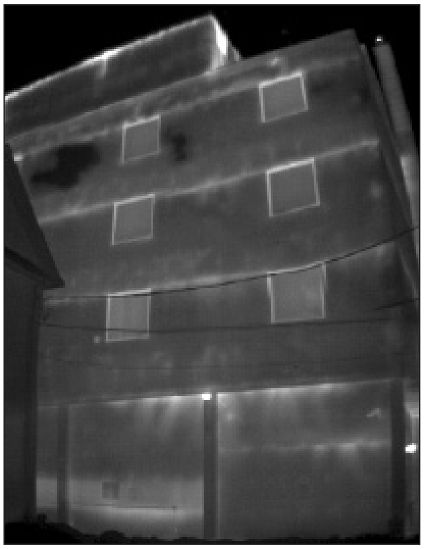


Figure 3a.(top) Negative Building Pressure (-140 Pa), To = 0°C Figure 3b. (bottom) Positive Building Pressure (+40 Pa), To = 0°C Both images taken during same evening, 4-hour time span between the two images. (Colantonio, Desroches 2005)

Simultaneous Multiple Phase Change Occurances

Steady state thermodynamic conditions rarely occur within exterior building assemblies but they can occur within interior or below grade exterior assemblies. When steady state conditions occur it would be difficult to find situations were there could be multiple phase change occurrences such as evaporative or condensation phase change or freezing or thawing phase changes occurring simultaneously in adjacent areas of the building assembly. In non-steady state conditions, however, the likely hood of simultaneous multiple phase changes occurring are a real possibility and make the use of infrared thermography much more challenging to verify the specific causal mechanisms for the thermal patterns detected.

An example of this would be a masonry wood stud wall assembly with an ineffective air and vapor barrier in a sub zero exterior climate. During cold night time conditions we could see moisture within the brick cladding freezing at the same time as we can see evaporation of wet insulation and gypsum board into the interior. During daytime conditions, we could see frozen moisture with the masonry cladding melting at the same time we experience condensation from interior moisture sources within the building assembly. These thermal patterns could be in parallel through the assembly or adjacent to each other so as to create a patchwork effect with complex thermodynamic interplay.

Appropriate Specific Applications for Moisture Detection

Moisture remediation: Detection through evaporative phase change

In cases of flood or water intrusion the use of thermography for detection of remaining moisture is essential for proper remediation efforts. Once mop-up is complete and the dehumidification equipment operating the very nature of this type of remediation process means evaporation must be taking place somewhere. Essential to this application is by-passing the presence of any low permeance surfaces (paint, vinyl wallpaper etc.)

by the introduction of holes or the partial removal of wall materials. Thermography, in conjunction with a sub-surface moisture probe is particularly appropriate for detection of water rising (through capillary action) up the absorbent backside paper in drywall, wood studs or absorbent insulation. This is one of the best and most appropriate applications for thermography because of the intentional drying which must be taking place. Unfortunately no universal standards exist for the use of thermography which has led to its unintentional misuse by some remediation companies because of the lack of a procedure, and understanding of the nature of evaporative cooling and its impact on surface temperature. This problem can be alleviated through adoption of a remediation standard, the use of adequate IR cameras, and directed formal certification training.

Figure 4A

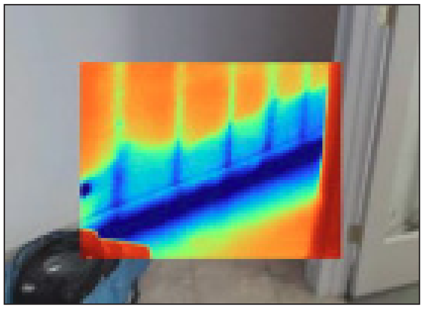


Figure 4B

Figure 4C

Figure 4a: Detection of hidden moisture absorbed by the paper the backside of the drywall and rising through capillary action. Figure 4b: Moisture present in wet insulation behind a wall that was tested dry on the surface. Figure 4c: Visual of center image after drywall was removed.

Low Slope Roof Moisture Detection:
Detection through increased capacitance or conductance

Both ASTM C1153-10 and NMS 02 27 16 standards detail the conditions necessary for detection of moisture trapped in conventional low slope built-up roofing systems. Interstitial moisture is detected using the capacitive method of detection by observing the outside roof surface under transient conditions. Ideal conditions are a warm sunny day with low wind, and no moisture on the roof surface. Inspection takes place 1 to 2 hours after the direct sunlight has left the roof surface and is conducted into the night. Potential wet areas are identified as warm areas that have retained the solar heat gained during the day. Both standards also permit investigations to be performed using the conductive method of inspection under steady state heat loss conditions with a minimum differential of 10°C (ASTM) or 15°C (NMS) across the enclosure. In all cases, and with both standards, the thermographer must be aware of inside conditions, fixtures and appliances and no standing water, ice or snow should be present on the roof surface.

Building Science Investigations:
Water detection through increased capacitance

While detecting moisture in walls through the capacitance method seem like the same application as detecting moisture in low slope roofs there are some important differences which make it both more difficult and less predictable. These are: 1) The insulation (and consequent moisture) in a flat roof is adjacent to the exterior membrane, meaning the solar gain is directly transferred into the wet (and dry) insulation; 2) the solar irradiation on a flat upward facing surface is more consistent, predictable than that of an east, south, or west facing vertical wall; and 3) gravity has less of an influence on the water movement once it has entered a roof rather than a wall. While this method will typically detect less amounts of water trapped within an enclosure over the conductive method it can be less predictable. It typically does not work on walls with little or no solar irradiance. This investigation would be more appropriate for investigations when the moisture is suspected to be closer to the outside surface on an east, south, or west facing elevations which have been subject to significant solar irradiance.

Building Science Investigations:
Wet insulation detection through increased conductance

When the presence of water is suspected to be present in absorbent type insulation then it may be detected if the concentration of water is high enough to increase the thermal conductivity. Understanding the type of material within the wall and how its thermal

Since condensation is highly probably on areas of thermal bridging with air barrier penetration, particular attention should be paid to thermal patterns in masonry and cladding systems around anchors and ties.

conductivity is affected by moisture absorption is critical to making this investigation work. Although modern cameras have a sensitivity of better than 0.05°C it in unrealistic to assume that a thermographer would pay attention to any anomaly of that level. A realistic assumption would be that using a tight span of approximately 4°C a thermographer would pay attention to something with a unusual pattern represented by a 10% screen contrast or 0.4°C. Figure 5 shows the relationship between the increase in thermal conductivity required (to produce a 0.4°C surface temperature difference) versus the temperature difference across the wall for two different thicknesses of insulation. A surface temperature difference 0.4°C would require a 15% increase in conductivity (R10 vs R12) and at least 35°C delta T across the wall. As this chart illustrates the conductive method for moisture detection should only be used when 1) a lot of water is suspected to be present in absorbent insulation and there is at least 15°C delta T across the wall or 2) there is a significant (e.g. 30°C plus difference across the wall. This investigation would also be most appropriate for investigations for moisture saturated in insulation closer to the inside surface and the investigation conducted from the inside.

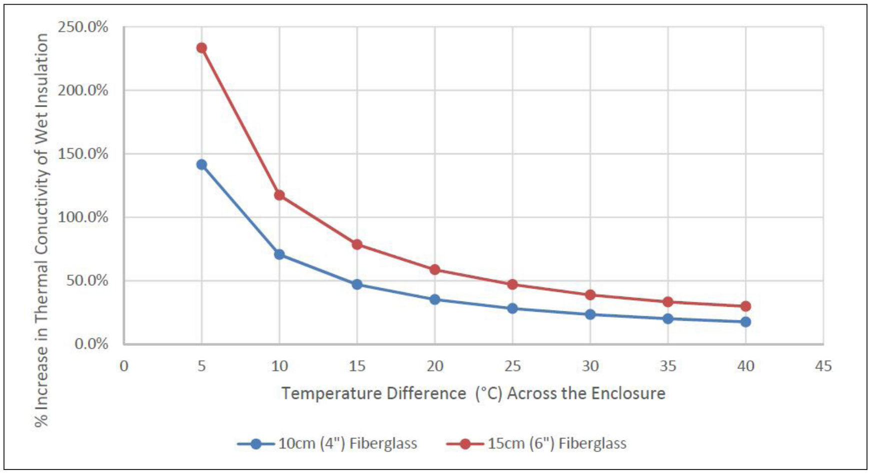


Figure 5. Percentage change in thermal conductivity associated with wet insulation versus delta T across the enclosure (assuming a nominal 0.4°C surface difference).

Building Science Investigations: Air leakage related water deposition through phase change

Testing for water deposition due to air leakage is typically conducted in conjunction with a controlled air leakage investigation where the pressure difference across the enclosure is controlled by either a blower door or manipulation of a commercial building's supply and exhaust fans. It is particularly appropriate when there is a large vapour pressure difference and moisture accumulation is suspected due to mass transport of water vapour via air leakage and consequent condensation when the dew point is reached within the wall. In addition to the air leakage thermal pattern, the latent heat exotherm from the condensation can often be observed from the negative pressure side of the wall. This implies an exterior inspection with positive pressure conducted in the heating seasons or an interior inspection with negative pressure conducted during the cooling season. Since condensation is highly probably on areas of thermal bridging with air barrier penetration, particular attention should be paid to thermal patterns in masonry and cladding systems around anchors and ties. Condensation in these areas could ultimately lead to failure of these essential structural components.

Thermography can play a significant role as a non destructive and rapid screening tool to identify potential moisture related anomalies in large and small buildings, but *only if the thermodynamic conditions are right.*

Building Science Investigations:
Moisture in masonry detection through phase change

Excessive moisture typically affects the durability and life of the masonry structures particularly in winter climates when sub-zero temperatures can cause freeze-thaw cycling and surface spalling. This inspection is best conducted from the exterior in the evening after the façade being investigated has been above zero in the day and well below zero at night. Ideally a clear sunny day followed by a clear cold windless night. As the water changes phase a dramatic transient thermal (warm) pattern can present itself against the cooler drier brick. This can often be validated again in the late morning when the masonry goes above zero and the ice changes phase to water creating an identical pattern in the same location but of reverse (cold) polarity.

Home inspection:
Plumbing/HVAC water leak detection through phase change

The use of infrared for pre-sale home inspection is much different than a building science investigation for two important reasons: 1) the home inspector does not know if a moisture problem exists versus a building science investigation which assumes or knows that one does exist. 2) the home inspector pre-arranges the inspection time and is under a time constraint whereas the building science investigator can often schedule the inspection for optimum conditions. The one application that can be carried out by a home inspector irrespective of the exterior environmental conditions is the potential identification of moisture sources from plumbing and HVAC equipment. This only requires that the water be present in the system, that the leak be occurring into a free air space (such as the interior ceiling joist space above the drywall, within interior uninsulated partition walls, or the flooring around showers, toilets and sinks or appliances such washing machines, dishwashers and fridges). Special attention is required around low permeance surface coatings or finish materials and info may need to be discounted at these areas.

Conclusions

Thermography can play a significant role as a non destructive and rapid screening tool to identify potential moisture related anomalies in large and small buildings, but ***only if the thermodynamic conditions are right***. Thermographic results alone cannot quantify moisture content. The primary use for thermography should be as a qualitative investigative tool, identifying potential areas for further investigation and determination of the potential root cause. Validation and quantification should be by other means and testing procedures. Thermographic investigations should be limited to those environmental conditions, procedures, and methods specified and recommended by various standards established by recognized independent bodies. Because of a lack of current standards for moisture detection, it should be done carefully and with a specific methodology for detection (conduction, capacitance or phase change) appropriate for the materials, assembly and environmental conditions. This is summarized in Table 1. Home inspectors, for example, could apply a thermal camera in a limited scope for free-air detection of water related anomalies, so long as they have a specific Standard of Practice detailing the method and conditions necessary for doing so and a means (e.g. a moisture detector) for immediate field confirmation of the suspected anomaly.

IR cameras suitable for building investigations are now inexpensive, lightweight and easy to use. There are, however, cameras available which do not even come close to meeting the requirements for detection of moisture anomalies. One should ensure that before a camera is purchased, or a contract for services engaged, that a camera and thermographer suitably meet the minimum requirements of the appropriate standard for the task. All standards emphasize the importance of training and certification related to not just the camera and infrared detection principles, but more importantly knowledge of building construction, performance, and sound building science principles. The proliferation of readily available low cost cameras used by unqualified persons unaware of the underlying thermodynamic principles, appropriate methods, and limitations however could jeopardize the legitimate value of thermography as a valuable tool for the building diagnostic industry.

	Conductive Method	Capacitive Method	Phase Change Method			
			Evaporation	Condensation	Freezing	Thawing
Temperature Difference	10°C (min) across wall	Yes (Varies)	No	No	Yes and sub-zero	Yes
Wind Dependent	Yes for exterior	Yes for exterior	Yes for exterior	Yes for exterior	Yes for exterior	Yes for exterior
Steady State/ Transient Heat	Steady State	Transient	Varies	Varies	Transient	Transient
Time and duration dependent	No	Yes	Varies	Varies	Yes	Yes
Vapour Pressure dependent	No	No	Yes	Yes	No	No*
Moisture content dependent	Yes	Yes	No	No	No	No
Interior/Exterior	Both	Both	Both	Both	Exterior	Exterior
Depth dependent	No	Varies	Yes	Yes	Yes	Yes
Thermal polarity	Warm or Cool	Warm or Cool	Cool	Warm	Warm	Cool
Specific temperature dependence	No	No	Yes, as it affects RH	At or below dew-point	Above then below 0°C	Varies with solar gain

Table 1. Summary of conditions for various moisture detection investigative methods utilizing thermography

For additional information about thermography, building inspections, and infrared training, visit www.thesnellgroup.com or contact The Snell Group at 1-800-636-9820.

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