Technical Building Services International

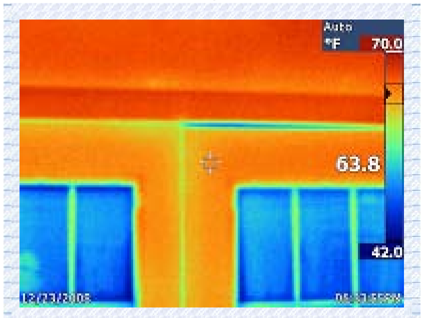
TBSI

Commercial Thermal Imaging

INTRODUCTION

Increased interest and the growing need for energy efficiency of buildings has led to building techniques which have altered the way moisture-laden air enters and exits the building envelope. Thermal imaging provides evidentiary documentation that can only be provided through thermograms that see building conditions beyond the realm of cursory visual inspections.

In the structural engineering capacity, thermography is used to study temperature variations over the surfaces of a structure. Variations in the structures thermal resistance can, under certain conditions, produce temperature variations on surfaces.



Revealing the unseen!!

Leakage of cold or warm air through the building envelope affects the temperature variations on the surfaces. Typical interior and exterior building envelope audits can locate;

- insulation defects, thermal bridges and air leaks in the building envelope components.
- When quantification of thermal resistance or air tightness is required, additional measurements also have to be taken.

Every structure is different when it comes to design, air leakage paths, insulating properties and causes of moisture problems and the control of these distinct problems. Solutions are not always expensive, and when incorporated into the design and construction phases are very cost effective in the life of the structure.

Well maintained, turn of the century buildings are still performing well, the same, probably cannot be said for current construction.

To document as-built conditions and provide useful feedback to the designers and builders, infrared auditing provides visual verification of as-built conditions. It is achieved by conducting thermal imaging along with placing the building envelope under positive and/or negative pressurization. This allows one to discover major air leaks, thermal bridging, missing or improperly installed insulation, and moisture intrusion.

These discoveries facilitate the repair process, reduce the number of call-backs and help avoid costly litigation. By testing the level of air-tightness of the building envelope, owners get an extra measure of comfort; they can expect lower utility expenses, improved thermal comfort, improved indoor air quality while lowering operating

and maintenance costs.
The ideal time to do an infrared audit is when new buildings envelopes are being constructed or renovated and prior to the final commissioning of the structure to insure quality and function of design and construction.
A proactive approach includes planning for thermal analysis during the construction or re-modeling of new or renovated space. Aside from new construction, a well conceived infrared audit management plan, concurrent with building maintenance schedules, will catch small problems that may arise, before they become difficult to manage or expensive to solve.
Since the oil embargo of the late 1970's, energy conservation initiatives spurred the development of energy audits.
The first and second gulf wars along with increased global demand have increased fossil fuel prices.
These events combined with the emergence of the global economy, most notably the industrialization of China and India, as well as the unrest in the oil producing regions of the world, seems to loom overhead.
There are efforts to develop alternative energy sources; solar, wind and geothermal. Efforts to extract energy from oil shale, oil sands, ethanol, drilling in less than desirable locations are less efficient, less environmentally friendly, and will prove to increase consumer prices.
The end result is that it is paramount that we build and /or retrofit energy efficiency and sustainability into our structures.

INDOOR AIR QUALITY

The installation of continuous high air infiltration resistant barriers to stop air leakage in new construction means that building air does not change as often as a result of air leakage into and out of buildings.
Therefore, it is important to provide adequate controlled ventilation. This may seem inherently contradictory, but the purpose of most buildings is to provide people with a Controlled environmental enclosure. Good design of the building provides; low air infiltration construction, controlled ventilation and air change to control air quality.

The HVAC system is equally important, good design as well as the construction, installation, test and balance can have a big effect on the sustainability of the structure. Explicit guidelines such as those developed by ASHRAE for mechanical ventilation requirements for buildings should be followed.

Design of controlled air in/exfiltration and ventilation is a critical priority in the construction process. Roof and wall assemblies along with roof and wall intersections are major sources of air leaks. Properly installed vapor and high air infiltration resistant barriers; properly designed wall and roof joint construction; and appropriate ventilation are critical to the prevention of air and moisture infiltration.

Most indoor air quality issues concerning the exterior building envelope are ultimately derived from water penetration, condensation or thermal bridging. Performing infrared audits and air leakage testing of the building envelope can help alleviate the concerns of architects, contractors, owners, occupants, and tenants with regard to indoor air quality, excess energy consumption and building sustainability.
Any water entering a building causes problems due to biological growth, affecting the indoor air quality. A tighter building, properly designed, will help prevent moisture intrusion. If a failure occurs in the building envelope allowing moisture to enter into a sealed system, the water cannot get out and actually does more damage than if the system were breathable.

* A note of caution with respect to indoor air quality. Most indoor air problems occur because the building is too tight, not allowing the building to breathe, and insufficient controlled ventilation. Soil gases are of concern to a majority of structures whether they are slab on grade or below ground level. Testing should be performed and proper systems should be installed to deal with them effectively.

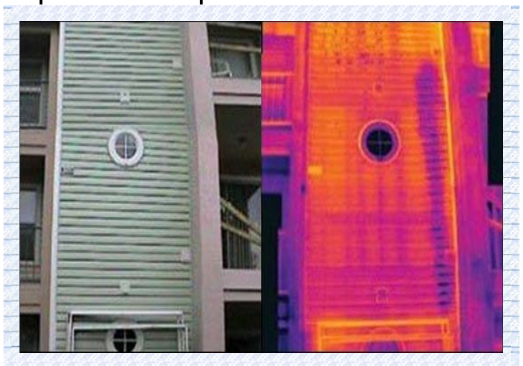
AIR-BARRIER CONTINUITY OF BUILDING ENVELOPES

The role of the building enclosure has evolved from providing basic protection from the elements to maintaining a well-conditioned interior space. Managing the thermal demands of mass and energy flow within building enclosures has become more complex, with many products and components contributing to their overall performance.

The air barrier is one such critical component: Unplanned air leakage has many consequences, ranging from increased energy consumption to moisture problems. Universal building physics must be applied to building design and construction practices. Infrared audits utilized under static, positive and negative air pressure are valuable in helping to determine any potential problems with the air barrier/building enclosure.

AIR, VAPOR AND WATER BARRIERS

Air, water and vapor barriers are important components of the building assembly and have a significant impact on building performance, durability and indoor environmental air quality. Unfortunately, there is still confusion, and there are general misconceptions surrounding the fundamentals of air and moisture movement through building enclosures and the functionality associated with barrier membranes. The confusion grows when membranes “supposedly” perform multiple functions (e.g. air AND vapor barriers, water AND air barriers, etc.). Air, water, and vapor barriers are normally separate components.

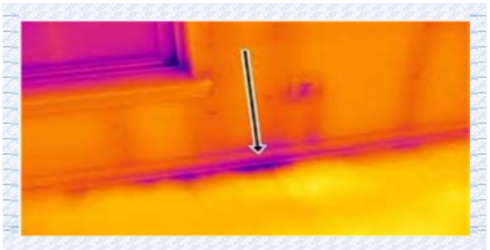


Thermal images show moisture intrusion behind the siding.

There is disagreement between the trades and professions that vapor barriers are needed or even necessary.
The prevention of vapor diffusion is what is causing many of the problems with new home and building construction. The improper use and installation of vapor impermeable materials trap moisture and do not allow it to move out of the building envelope.
As an example, OSB shear panels will allow vapor to be driven into, or out of, the building envelope at the joints, and to a lesser extent, through the panels themselves. This problem is created due to the inherent low perm rating (there are also different perm ratings among various OSB).
Most building scientists are not confused, a lot of architects, contractors, and other professionals are confused from the marketing strategies of the manufacturers and the lack of understanding of vapor movement, and the need to allow it. Information supplied by the manufacturers is based on verification that individual materials and building components have the promised properties.

This information is derived from testing performed under controlled conditions. How materials and components actually operate and perform in the built environment can be drastically different due to variations in construction practices, unique environmental conditions, etc.
We all know different building configurations leak, windows leak or will leak, the cable installer will punch holes, these and other imperfections may all lead to water intrusion that needs to get out. We cannot construct a building that is water-tight, therefore, we

cannot construct a building that is airtight. We must allow any moisture that enters to escape as vapor.
The simple act of painting the interior creates a semi-vapor
permeable barrier High air infiltration resistant barriers must retard airflow, which results from air pressure differences. Vapor barriers must retard water vapor diffusion which results from differences in vapor pressure. While air barriers are needed in just about every type of building, vapor barriers are only needed in certain climates. Furthermore, while air barriers could (should) be installed at pre-determined locations in the building enclosure, vapor barrier location within the building enclosure is climate specific.
Building codes generalize climates by region, however, there are micro-climates within climatic regions that will require even more planning and care in determining an appropriate building envelope. Vapor must be allowed to move in all structures and must be taken into consideration in all locales. Membranes with supposed dual functions (air and vapor barriers) must generally follow the more restrictive installation guidelines for vapor barriers.



AIR BARRIER

Air-barrier and high air infiltration resistant systems are required to be continuous, be durable through mechanical support, and conform to stipulated air leakage rates. This should be achieved through good engineering design and construction practices through the use of high air infiltration resistant materials, sealed joints, transitions, and penetrations.
Primary envelope tightness benefits are considered to be a stable interior air-shed created by effective control of air infiltration and exfiltration. Uncontrolled air in/exfiltration can cause condensation problems, increase energy consumption and adversely affect occupant comfort and health.
Retarding and minimizing air leakage is an important factor in the construction of buildings for the following reasons:

- Air leakage can be a high proportion of the total heating and cooling losses from a building.
- Careful sealing of structures with high air infiltration resistant design and components contributes to building comfort by reducing drafts (in some instances and conditions, convection air currents not related to air infiltration are the causes of discomfort, and all the efforts to seal a structure will not stop it).
- Air leakage through wall and roof joints transport moisture vapor on air currents causing condensation on framing members and cool surfaces, possibly in sufficient amounts to cause mold growth or other problems.

- Air leakage in buildings occurs wherever there is an unmanaged opening, joint, hole, or puncture in the building envelope. The frequency and quantity of air coming through these openings will depend on these, or a combination of these factors:
- Stack effect; the action of warm air rising in a building and causing positive (outward) air pressure in the upper stories and negative (inward) air pressure at the base of the building. (convection is sometimes assumed to be air infiltration by occupants)
- Ventilation effects; caused by negative or positive air pressure in a building caused by unbalanced HVAC or natural ventilation systems lacking a controlled supply of replacement air (ventilation / exhaust fans are a common source of this problem as well).
- Wind effect; wind creates positive pressure on the windward side of a building and negative pressure on the leeward side of a building. Wind forces on buildings of more than one story can be dramatically different at various elevations. This creates pressure differentials that drive air and moisture into the building system.

* These factors must be taken into account when performing infrared audits.
Although air tightness requirements are often specified in terms of maximum air flow rates per unit area of wall at a given pressure difference, conducting qualitative testing is seldom practiced in the field to verify where air leakage actually occurs.

INSULATION OF BUILDING ENVELOPES

Historically, moisture which escaped through building assemblies was not as likely to condense in building assemblies because the thermal gradient and absence of conditioned air in building assemblies caused less condensation.

Missing attic / ceiling insulation - visual image (left) and infrared image (right)

With older building methods (prior to the 1970's), there were more structures that had little or no insulation.
With the lack of insulation, the thermal gradient within the building envelope was not as severe as it is in new construction. Building structural components were less likely to have condensation with the movement of moisture laden air into (or out of) the building.

As intended, insulation prevents the movement of heat, but in turn, it can create problems due to the sharp jump in the thermal gradient within the building envelope. A major problem with this is vapor diffusion. Furthermore, thermal bridging and improperly conditioned air within the building envelope is more likely to cause condensation within the wall cavities. These conditions can lead to deterioration on inside surfaces, within the walls, and on the outside surfaces as well. A buildings' degree of insulation is often stated in the form of thermal resistance or a coefficient of thermal transmittance (U value) for various parts and components in a building. In spite of this, stated thermal resistance values rarely provide a measure of the actual energy losses in a building. Air and moisture infiltration from joints and connections that do not restrict air and moisture movement, along with areas that have insufficient or improperly installed insulation, cause considerable deviations from designed and expected values.
As the prices of fuel, electricity, and construction increase, infrared audits, performed under positive and negative pressurization, are becoming increasingly more important and beneficial in identifying air leaks, thermal bridging and proper installation of insulation. Defective insulation and tightness in highly insulated and airtight structures can have a great impact on energy losses. Defects in a building's thermal insulation and air tightness does not simply pose a risk of excessive heating and maintenance costs; they also create favorable conditions for poor indoor air quality.

Another effect of high insulation requirements and the infiltration or exfiltration of moisture-laden air is the reduction of insulating values.
The presence of moisture in insulation will change the thermal conductivity and the thermal mass, affecting the insulating properties of insulation and wall components. Thermal mass is a materials ability to store heat, while thermal conductivity is a materials ability to transfer heat.
Moisture intrusion in insulation can be detected during the infrared audit due to the surface temperature of building materials being changed by evaporative cooling and variations in thermal mass and conductivity.
Moisture meters should be utilized to confirm whether anomalies are actually derived from moisture.
Completed buildings have to be checked and audited in order to ensure that their intended levels of insulation and airtightness are achieved.

WIND AND ITS EFFECTS ON AIR BARRIERS/BUILDING ENVELOPES

Wind speed – the greater the speed, the greater the force on the building envelope. This creates positive pressure on the windward side and negative pressure on the leeward side.
Some factors include:

- Building elevations – the higher the elevation of the structure, the greater effect wind has on the envelope. This is also accentuated due to the stack effect.
- Exposure to or protection from wind by other surrounding structures and natural and manmade barriers.

- Building geometry – not just the size of the structure, but the geometric complexities of building design, will either break or facilitate wind flow.

Pressure differentials due to the Bernoulli principle and other flow factors may actually cause a negative pressure on some portions (based on geometric complexities) of the windward side
The perimeter or outside edges of a structure meet the full force of the wind, and thus wind forces are most severe in these locations. The ridges, eaves, roof and wall corners of the structure, initially break, channel, and sometimes trap the forces of the wind. These areas must be designed and constructed with greater high air infiltration resistance to air leaks than central portions (central fields). These areas must be capable of withstanding more pressure than the central fields or perimeters since they are simultaneously subjected to force from two sides.
The shear force of the wind is somewhat broken by the buildings corners and perimeters. The central fields of walls and roof structures bear less wind forces, as forces are somewhat dissipated by the time they reach these areas.

MOISTURE MOVEMENT

A building envelope requires structural strength, thermal insulation, and a fire resistance rating. And it needs to prevent the movement of moisture in both directions - into and out of the structure.

Moisture enters or leaves a building through three basic mechanisms:

- Diffusion: This occurs as moisture moves from an area of high humidity to an area of lower humidity through porous materials, this process occurs over large areas. Materials with high air and moisture infiltration resistance must be provided in the building envelope to control air and moisture movement by diffusion.
- Air movement: This is the movement of air (and moisture, high or low or levels of moisture), and heat transfer. Moisture movement (high levels of humidity), due to moisture laden air leaking through the building envelope. Air leakage takes places through gaps and discontinuities in the envelope and has the potential to deposit a large volume of moisture in wall and roof cavities. An effective high air infiltration resistant barrier is required in the building envelope to prevent moisture movement by means of air leakage.
- Liquid moisture penetration: This is the entry of precipitation, to include; precipitation, HVAC condensate lines, or water runoff into the building envelope. Proper grading, site drainage, and a weather barrier (ideally a rain-screen or redundant barrier system), and other techniques are used to prevent moisture infiltration.

Moisture laden air moving through the envelope and building materials may cause accumulation at any semi permeable vapor barrier.

Openings of any type allow air and moisture to infiltrate or exfiltrate the building envelope, and must be properly sealed to help reduce: drafts; airborne moisture movement; heating, cooling and climate conditioning costs; and help mitigate call-backs after construction has been completed.

AIRBORNE MOISTURE MOVEMENT

Air moisture levels are defined by relative humidity. A relative humidity of 100% indicates that the air is holding as much water vapor as possible for a given temperature.
Warm air is capable of transporting more moisture than cold air. Moisture diffuses from the warm, moist side of building components to the cooler side where the air retains less moisture. For a given dew-point and its corresponding absolute humidity, the relative humidity will change inversely with the temperature. Two laws of physics; hot seeks cold and wet seeks dry.
Fluctuating temperature and humidity levels, along with solar gain, are the major causes of vapor pressure differentials between the inside and outside of structures. As warm air is cooled, the air retains less moisture and also has a lower vapor pressure. When air reaches the dew point temperature, vapor suspended in the air changes to liquid form, depositing on cooler surfaces. This is another aspect that makes a properly designed and constructed building envelope important. In cold climates during the cooler times of the year, condensation from diffusion usually originates on the inside of structures. In the hot and humid summer months, an interior moisture barrier can cause condensation within the walls of an air conditioned building, and is most often caused by air leaks and a lack of insulation, or improperly installed insulation.

In colder regions these effects can destroy structures in the summer as easily as during the winter and sometime more depending on the moisture load of the environment. Moisture transport occurs as a result of a vapor pressure differential between the building environment and the outside. Moisture may be carried through the envelope in either direction depending on whether a positive or negative pressure occurs in a building at any given time.
An important factor is that cladding and other weather-shielding materials do not admit water, but at the same time have the permeability to allow the escape of moisture which has bypassed the high air and vapor resistant barriers. Vapor control is the solution.

SOLAR GAIN

Solar gain is more of an issue than most people realize. Buildings aren't inherently designed for the temperatures that are actually reached. Shingles, roofing materials, brick and other low emissivity materials are superheated, conducting heat into the interstitial wall cavities and ultimately the building envelope.

Solar gain causes movement of the building and building components, changing dew points, caulking deterioration, as well as accelerating the wear and premature deterioration of building materials.
Building design temperatures are stipulated for local regions, they are the annual range including the expected high and low temperatures. Solar gain is an important area of design that is often-times overlooked. I have seen instances of brick fascia with inadequate drainage plane, lack of rain screen / redundant barriers, lower grade vapor barriers, and lack of flashing. In these instances, the solar gain accentuated the vapor diffusion (and liquid moisture movement), causing moisture incursion resulting in structural component rot along with mold contamination of the structure. To observe solar gain, start prior to sun-up following a cool, clear night; image the building on the morning solar exposed side, taking a new set of images every 30 minutes. To see the effects on the interior of a structure, immediately image the inside corresponding wall, there will be some lag time for the heat to migrate, but it will show. When investigating for moisture intrusion, solar gain is sometimes the only way to see anomalies caused by moisture and water intrusion in the building envelope. Anomalies may only show up when heat is applied to the surfaces.
By designing buildings that are more resistant to solar gain, utility expenses could be reduced as well as providing longer service life for building materials and components. The area of solar gain, and its effects, deserves much more attention than it’s currently getting in the total design of buildings and systems.

INFRARED THERMOGRAPHY – GENERAL CONCEPTS

Infrared thermography has been used to identify building envelope deficiencies for over thirty-five years. Thermography relies on the physics principle; in that, objects emit a frequency of electromagnetic radiation in proportion to their absolute temperature. Emission effects of infrared wavelengths change in relation to emissivity of surfaces. In the case of objects which are at terrestrial temperatures, this radiation is beyond the visible spectrum, and is called infrared i.e. “below” red in the visible spectrum. Thermographic cameras use sensors to measure (detect) the infrared light and convert it to a visible image based on an electronic mapping of the infrared light to the visible spectrum. Modern thermographic cameras can convert and display the infrared images in a variety of chromatic schemes. Besides producing a visible image, the apparent temperature at any point in the image can be determined. Absolute temperature of the “spot” is dependent on many factors including emissivity, distance and the material the radiation component travels through. It is not a given that the spot is a true representation of the indicated “spot” temperature (some cameras do not have cross hair / spot temperature features).

One important feature of thermography is that large areas of a building can be audited in a relatively short period of time. Usually one session under optimal conditions (the

absence of solar spectral radiation, the absence of excessive exterior winds, and no measurable precipitation within the preceding 48 hours) is sufficient to complete the entire audit and identify locations where the usual temperature of the surface is substantially varied. These variations are typically referred to as thermal anomalies, and are caused by the effects of conductive or convective heat movement through the building materials that comprise the building envelope.
* Certain surfaces, glass, polished aluminum, or stainless and materials with high emissivity (reflectivity), prevent the thermographer from “seeing” anything.
Since infrared images are the apparent surface temperatures of the object, deficiencies other than air leakage can also be identified through qualitative comparisons. These thermal anomalies include missing or improperly installed insulation, moisture intrusion, and low thermal resistance pathways through the envelope, usually called thermal bridges. By locating and measuring thermal anomalies, thermal imaging along with positive and negative pressurization can be used to help deduce the cause of a particular thermal anomaly in
a wall or roof assembly. It may be necessary to confirm the anomaly by; physical verification involving a
review of the construction detail, smoke flow testing to locate air leakage paths through the assembly, and on occasion, opening up the assembly to precisely locate the failed component or building defect. Infrared audits should never be used as a single source of information in drawing conclusions with building defects. Verification should always be performed by utilizing temperature, humidity and moisture meters, as well as tracer gas (smoke flow) testing, construction drawings, etc.
Air and moisture infiltration in buildings is a complicated issue. In order to properly diagnose and correct building problems, the individuals assessing them should have a thorough knowledge of how and why moisture problems occur in buildings, and know how different construction designs and practices affect structures differently. There many causes or sources of moisture in the built environment.
In-depth analyses and interpretation of thermograms requires a thorough knowledge of material and structural properties, effects of environmental conditions and the latest auditing techniques. There are special requirements for taking and assessing measurements, this should be reflected through the assessment of skills, knowledge and experience by authorization of a national or regional standardization body.

NECESSARY TOOLS / EQUIPMENT

The following is a basic list tools/instruments that would be employed on project analisys:

- Anemometer
- Blower Door(s)
- Digital Camera
- Digital Camera
- Hygrometer
- Infrared Camera
- Manometer
- Moisture Meters (penetrating & non-penetrating)

- Smoke Generator
- Smoke Pencil
- Step / Extension Ladder
- Voice Data Recorder

INITIAL INFRARED AUDIT

It is very beneficial to review the as built drawings in advance of visiting the test site. Just the same, it is also a good idea to do a walkthrough of the structure, taking care to note and complex designs or unique features.
Prior to carrying out the audit, a proposed set of procedures and conditions would be circulated for comment among the stakeholders. A meeting is then held at the site with representatives of the owner, general contractor, building envelope consultant and thermographer to confirm the audit procedure. Basic features and areas that can be audited in various types of construction, depending on conditions include:

Applicable Type of Construction Components That Can Reasonably be Measured
Wood
Frame
Construction
Precast
Walls to
Include:
Precast
Concrete,
Cast in
Place
Concrete,
Insulating
Concrete
Forms
Construction
SIPS (structural insulated panels)
CMU Fill & Void Detection
Continuity of air barrier
Door / window penetrations
EIFS installation
Insulation installation - Ceiling
Insulation installation - Walls
Low Slope / Built up roofing
Mortar Joints on CMU
Other building envelope penetrations & thermal anomalies
Panel-to-panel joints
Parapet flashing seal

Pilaster and Bond Beam Fill & Placement
Rain Screen Barrier / Drainage System
Roof leaks (membrane)
Roof membrane to parapet to flashing seal
Roof structure to wall seal
Seals at the base of the walls
Thermal Bridging
Voids in concrete
Wall penetrations
Wall-to-base support junctions
Wall-to-roof junctions

Pertinent information to gather prior to audit
Background Information
Age of Structure
Soil Types
Building materials on exterior
Building materials on roof
Building materials in foundation/below grade
Copy of detail prints
Site drainage system
Building use - (moisture sources)
General condition of building materials
Absorption rates of building materials
Vapor barrier placement
Permeability of building materials
Type and operation of HVAC, humidification/dehumidification systems
Plumbing systems
Expected ambient conditions indoors
Climatic region (high & low temps, wind, rainfall, RH, solar exposure)
Unusual landscape characteristics
Complexity of building design & construction (wind loads, stack effect, conduction-design, solar loading, etc.)
Insulation types, levels and placement
Vapor barrier location and type
Wall surface coverings
Wall cavity and surface conditions, (temp, RH, DP)
Air in/exfiltration rates
Building pressure (zone to zone, total building)
Local exhaust, make-up air, HRV or ERV equipment and operation
Normal expected positive / negative pressures of structure

Pertinent information to be gathered and considered prior to infrared audit.
The building must be diagnosed as a whole, including; building pressures, materials, methods, soil characteristics, HVAC components, etc. before theories lead to solutions.

Optimal conditions for performing infrared audits will have the structure under the following environmental conditions;

- Outside temperature and inside temperature should optimally be at a difference of ≥20° F,
- No precipitation in the preceding 48 hours
- Calm winds (less than 5 mph), and
- Lack of solar spectral radiation.

These conditions are considered suitable for producing good thermal images. The building should be pressurized (see ASTM standards for pressure differentials, but the designs of a blower door uses 50Pa), to a target pressure of approximately 50 Pa using a blower door or mechanical systems. A static temperature difference between the interior and exterior of the structure is important. The greater the difference in temperature, the more pronounced the thermograms will be in realizing and documenting heat movement through the materials. Audits can be performed at lower temperature differentials, but analysis of the thermograms will be more difficult. Contrasts in the thermal image can vary significantly with changes in any of the optimum environmental parameters. In order to confirm that thermal anomalies are caused by air leakage, the air pressure in the building is reversed using a blower and/or mechanical system, so that air is infiltrating into the building rather than exfiltrating. The reversal of air pressure across the building envelope confirms that thermal anomalies are either air leakage vs. conduction (thermal bridging) or moisture intrusion.

The initial infrared audit should be carried out as soon as practicable after various areas of the building are closed in, preferably before the installation of interior wall and ceiling coverings.

The following are among the more important points that should be discussed:

- The infrared audit is carefully documented in terms of; environmental conditions, viewing angles and anomaly locations. This establishes benchmarks, or points of reference for future infrared audits as required by the owner.
- The audit is recorded on templates with thermographic images (‘thermograms’) and corresponding daylight (visual) images.
- Thermograms are taken of apparent thermal anomalies that may be warmer or cooler than the surrounding building materials; these are then used to indicate significant anomalies. These anomalies are interpreted for the client.
- The identification of anomalies and deficiencies will likely require some physical investigation after the audit is completed.

* True temperatures of a building will vary throughout the day as well as the year. Due to solar loading, it is advisable when checking for building envelope leaks and thermal bridging, that performing an infrared audit under static conditions is best (the absence of solar spectral radiation).

All efforts should be made to have representatives of all interested parties present during the testing. This includes representatives of the owner, project manager, sub-contractors, design consultant and building envelope consultants.

REMEDIAL REPAIRS

At the conclusion of the audit, a comprehensive report is compiled and distributed to various stakeholders. Presentation of unambiguous visual information (thermograms), clearly showing the air leakage locations and thermal anomalies, are instrumental and allow for a precise remediation work plan to be developed.

1. Documentation sheets of the audit are reviewed and physical investigation of
2. The as-built construction is carried out.
3. Copies of the report are distributed to the sub-trades to clearly identify the locations or remedial repairs.
4. An action plan is prepared, identifying repair locations referenced in the thermographic report.
5. After review of the first infrared audit report, the general contractor and the sub-trades begin a program of remediation.
6. Repairs proceed on the basis that; anomalies showing temperature differences greater than the established criteria be repaired.

FOLLOW-UP INFRARED AUDIT

After completion of noted repairs, follow-up infrared auditing is performed to verify whether the remedial repairs completed have been effective, blower doors are again used to create an interior negative and/or positive pressure. The building mechanical system, if operational, should be monitored to ensure that it does not affect the building pressurization process. Other environmental factors such as interior air temperature, wind speed and building air pressurization should be as similar to the first audit conditions as possible.

The procedures and sequences for follow-up audits should also be similar to the first audit; wherever possible the same vantage points should be utilized. The results of the follow-up audit will provide evidence that significant unplanned air-leakage and the most problematic locations have been mitigated. It provides visual documentation as to whether anomalies have been adequately addressed.

Although remedial repairs will significantly reduce the number and magnitude of anomalies due to air leakage, thermal bridging and insulating qualities, the follow-up infrared audit will likely show that the building is still not perfect. It is suggested that once the anomalies are repaired to the satisfaction of all parties, the building will have achieved an agreed upon, “workable level of performance”, and that further efforts of remedial efforts may not be cost effective.

It is important to remember that any moisture that enters the wall cavities / building envelope must be able to get out.

It is recommended that the exterior walls of the building be monitored periodically for signs of air leakage including but not limited to; deterioration of caulking, exposed joints, separation of building components, condensation, evidence of moisture staining, mold growth, icicles or frost formation. Interior walls and finishes should also be monitored for condensation, mold growth and any other exhibited characteristics that are different from normally expected conditions.

It is also recommended that building temperature, relative humidity and pressure be recorded as practicable, by the building mechanical control system so that environmental loads are known, should air leakage problems arise in the future.

Finally, it is recommended that another infrared audit be conducted within five years to determine if the airtightness of the building envelope changes over time with settlement, seal degradation, and structural movement/settlement.

BENEFITS AND EFFECTS OF TESTING AND ASSESSING

It can be difficult to anticipate how well a completed structure will operate in relation to the intended design in respect to the intended performance of thermal insulation and air tightness of the building envelope. There are certain factors involved in assembling the various components and building elements that can have a considerable impact of the final result. To ensure that the intended function is actually achieved, verification by testing and checking the completed building is required.

Modern insulation technologies and practices have reduced the theoretical heat requirement. This means that defects that are relatively minor, but at important locations, e.g. leaking joints or incorrectly installed insulation, can have considerable consequences in terms of heat, comfort, utility expenses, building sustainability and indoor air quality. Verification tests by means of thermography have proven invaluable to the designers/architects, contractors, developers, property managers and the user. “You can’t expect what you don’t inspect”

BENEFITS TO THE CONTRACTOR

The contractors benefits from effective infrared auditing, ensuring that structures are built to the expected function, corresponding with established requirements in the regulations issued by authorities and in contractual documents. The contractor needs to know at the early stages of construction about any changes that may be necessary so that systematic defects can be prevented. During construction, an audit should be carried out during the first phase of construction. Similar checking then follows as construction proceeds. In this way systematic defects can be prevented and unnecessary costs and future problems can be avoided.
Infrared auditing is a benefit to the designer, builder and end users.

BENEFITS TO THE DEVELOPER AND PROPERTY MANAGER

It is essential that buildings are checked with reference to energy efficiency standards, maintenance expense (damage from moisture, moisture infiltration, degradation from effects of solar loading), and comfort for the occupants.

BENEFITS TO THE OWNER AND OCCUPANTS

For the individual owner, a structure involves a considerable financial commitment so it is important to know that any design or construction defects will not result in major financial expenses or indoor air quality problems.
The total costs of building a structure and the perceived market value often dictate the building design and building methods. With building material costs and energy costs becoming more critical, attention to building sustainability and energy efficiency are becoming more important factors.
It is important that the finished structure fulfills the promised requirements in terms of the building’s thermal insulation, air tightness, and overall building envelope performance.
The results of proper design, construction, performance, and maintenance of building envelopes and systems have ecological, physiological and financial benefits.

SUMMARY AND CONCLUSIONS

Buildings used to be designed and built by master builders. Through “advances” in the construction processes, we have come to an era where we have specialized areas in design, as well as construction. This has led to buildings being designed by several different engineers/architects, with each placing special emphasis on their area of expertise and sometimes neglecting other design factors that heavily affect their systems. The reliance on computer models has also had a negative impact. Due to the fact that computers can not possible demonstrate all the effects that different design and components have on the way a structure will actually operate.

The builders have also become differentiated into trades and sub-trades. This has also led to a breach in understanding on how one trades particular practice or method affects another, which ultimately affects the way a building performs.

Air-tightness verification of the building envelope is considered critical for the satisfactory performance of controlled environments. In order to achieve a known level of high air infiltration resistance, testing and verification of the building envelope should be undertaken during and after construction. Infrared thermography provides an essential tool for identifying, locating and recording the overall performance in regard to the effectiveness of the air barrier and insight into the thermal qualities of a structure.

The use of temperature differences derived from the thermograms offer guidance as to what constitutes a significant thermal anomaly in relation to universal building physics.

It is the author's view that the processes described in this paper are instrumental in achieving a verifiable level of air-tightness of the building envelope and lack of significant thermal anomalies.

Thermal imaging, pressure testing and to a lesser extent, smoke testing, are essential for demonstrating building envelope deficiencies, along with their locations, to the project manager and sub-trades. Moisture, mold, structural damage, litigation, operating and maintenance expenses, and building sustainability could be positively impacted if the physics of air and moisture movement were better understood and monitored by those involved in the design, construction, inspection, operation and maintenance of buildings. It is paramount that before attempting to control any aspect of the built environment, that all individuals engaged in this process have more than just a basic understanding in thermal imaging, building science/physics, indoor air quality, construction, and psychometry. Buildings must be assessed as a "whole system" to provide real benefits to all involved.

Altering the way we design, construct and maintain structures could drastically reduce many problems that are currently being encountered. The use of these techniques during the construction and commissioning process encourages a cooperative team approach, which leads to the successful remediation of critical building envelope deficiencies.

Why have an Energy Audit?

In these days of uncertainty, it is important to keep operating expenses to a minimum. One difference between those companies that weather these difficult times and those which do not survive will be that the survivors will be those who have reduced their unnecessary expenditures before it is too late.

Unnecessary costs include a portion of your utility costs, which for many until now were just considered “a cost of doing business.” By running an inefficient building, you are overpaying your utility for energy. It just doesn’t make any sense.

A good building energy audit will point the way to reduce your energy costs by 10% to 40%. For large organizations, this can be substantial, and could be the difference between staying afloat and going under.

What is a Commercial Energy Audit?

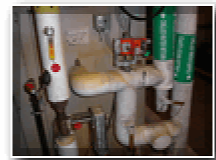
A commercial building energy audit is a study of your building’s energy using equipment. Building energy audits often also look at water consumption (even though that is not technically considered energy). An energy auditor comes out to your building and interviews facility managers, inspects lighting, air conditioning, heating and ventilation equipment, controls, air compressors, water consuming equipment, and anything else that is using energy. The auditor will develop a list of energy conservation measures that could reduce energy usage and costs in your building. Depending upon the level of building energy audit, the auditor will then quantify how much savings potential there is for each of these measures, and the costs associated with implementing them. Some measures will take decades to pay for themselves, while others will start paying for themselves within months.

Once you have read over your commercial building energy audit, our energy auditor will meet with you over the phone to discuss the report, and what your next steps are to start reducing your energy costs.

We **investigate** and **quantify** energy savings potential in:

- Lighting systems
- HVAC Systems and Controls
- Compressed Air Systems
- Renewable Energy Applications
- Electric Motors and Drives
- Process Systems
- Heat Recovery
- Building Envelope Upgrades
- Switching Utility Providers or Utility Rates
- **and more!**



What is an energy audit?

An energy audit establishes where and how energy is being used in buildings. It provides opportunities to save money and energy. Audits can help identify areas of energy loss so you can apply energy-saving technologies, structural improvements or even system retrofits.

There are three types of audits:

- A walk-through audit includes a visual inspection of a building's energy systems and energy use. This audit identifies simple operation and maintenance improvements and whether a more comprehensive audit is needed.
- A standard audit assesses all equipment and operational systems and creates a more detailed calculation of energy use. This audit makes recommendations based on projected energy and cost savings.
- A computer simulation audit predicts system performance and takes external factors, such as weather, into account. This audit is recommended for more complicated systems and buildings as well as new construction design.

Link to Sample Audit sheet.

Guide to Thermal Imaging

Temperature is very important in our everyday lives and is used for many applications such as to see if you are sick, if food is cooked thoroughly or if your car is overheating. Thermal image cameras take measuring temperature to the next level where instead of getting a number for the temperature, you get a picture showing the temperature differences of a surface. Thermal imaging, also known as thermography, is the technique for producing an image of invisible (to our eyes) infrared light emitted by objects with the use of a thermal imaging camera. Thermal imaging cameras provide rapid scanning of a surface that is non-destructive and environmentally friendly, which allows for quick detection of potential problems or defects that will reduce troubleshooting time and preventative maintenance.

What do thermal imaging cameras see?

Thermal imaging cameras don't actually see temperature. Instead they capture the infrared (IR) energy transfer from an object to its environment and produce a real time image in a color palette where hotter objects appear brighter and cooler objects appear darker. IR energy is generated by the vibration of atoms and molecules and behaves similarly to visible light where it can be reflected, refracted, absorbed and emitted. The more these atoms and molecules move, the higher the temperature of the object.

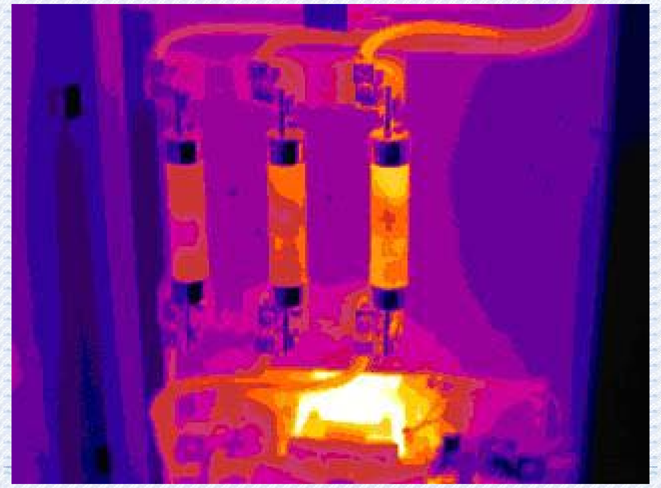
What applications can a thermal imaging camera be used?

Thermal imaging cameras are becoming a common tool in the home inspection industry where they are being used to verify building performance to specifications, to determine the insulation is installed or in good condition, locate air leaks, verify structure design and locate moisture intrusion. Of course these are not the only applications to which it can be used. Their use is limited to the imagination of the user. Primarily it is used where the identification of thermal patterns can be used to find something or diagnose a condition such as poor insulation in a home or an overloaded electrical circuit. Some examples include:

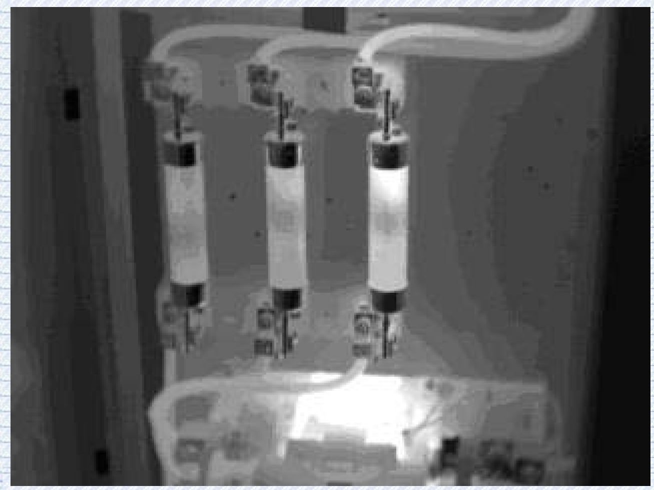
- Substation electrical inspections
- Thermal heat loss inspections of buildings
- Locate radiant heating wires or pipes
- Locate potential areas for mold growth
- Flat roof leak detection for buildings
- Detect thermal patterns on boiler tubes
- Mechanical bearing inspections
- Detect insulation leaks in refrigeration equipment

What are some of the features of thermal imaging cameras:

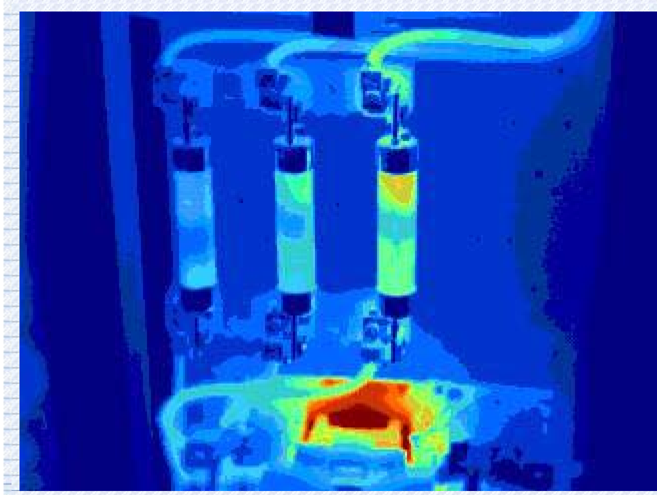
Basically, a thermal imaging camera is capable of, saving the thermal image to either its internal memory or to a memory card depending on the camera capabilities. Once the user has completed taking the images, they can be viewed and edited on the camera or downloaded to a PC where the images can be formatted on a report with the software that is included. Thermal imaging cameras have multiple color palettes such as black/white, iron or rainbow that are user selectable. The iron palette is most commonly used by home inspectors, the black/white palette helps identify details on an image and the rainbow palette has the best thermal sensitivity for displaying the differences in temperature. See sample images below of some color palettes.



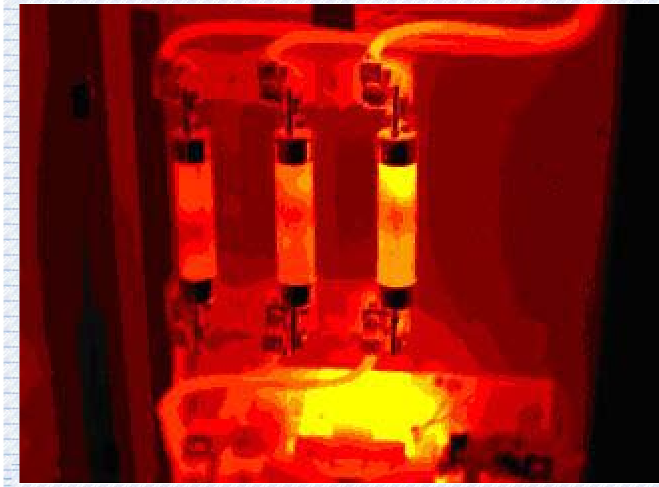
Iron palette of fuse bus bar



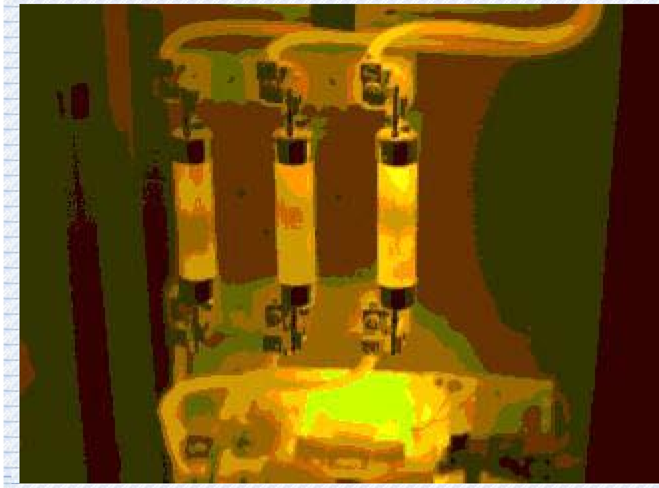
Black/White/Gray palette



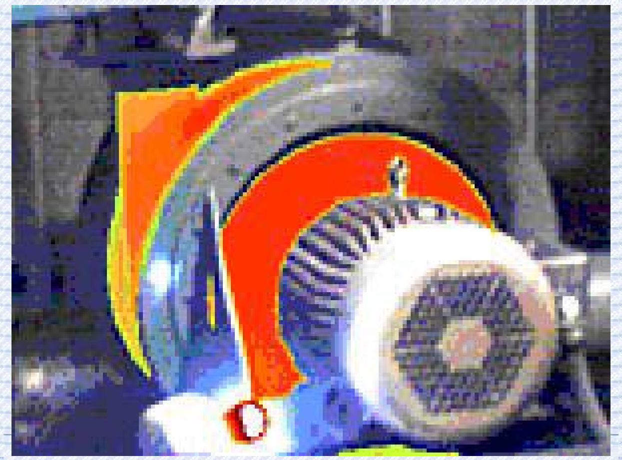
Rainbow palette



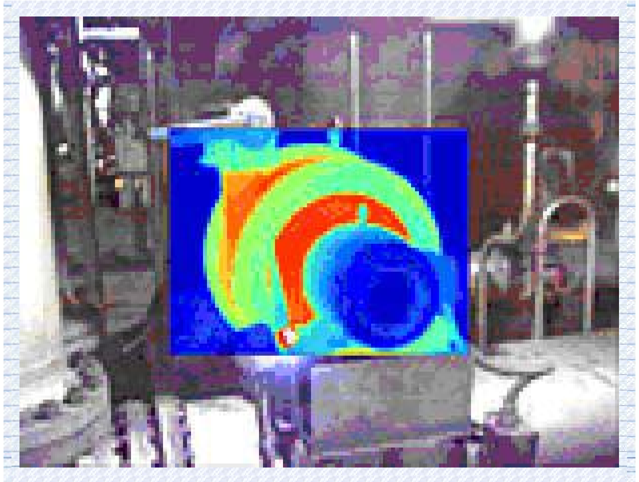
Hot metal palette



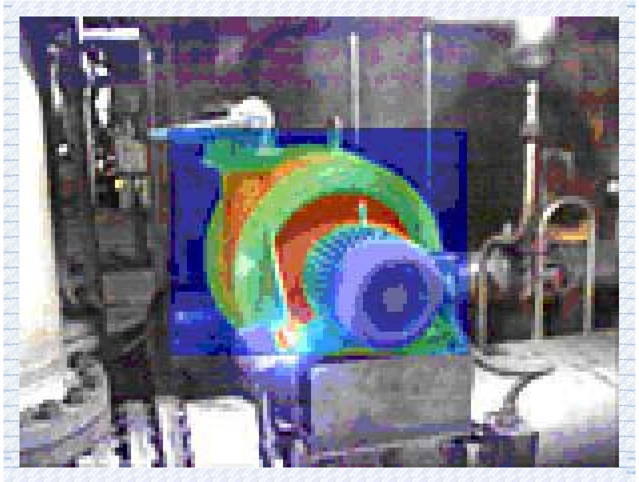
Amber palette



A color alarm feature that allows the user to select a temperature and the camera will only display a color thermal image of anything that is either above or below the selected temperature.



A picture-in-picture feature that will display a color thermal image (which is a quarter of the size of the display) inside a standard digital image. Temperature readings are limited to only the thermal portion of this feature.



An IR Fusion feature that allows the user to blend either the maximum, minimum or average temperature of the thermal image with a standard digital image.

How do I get a good image?

Using a thermal imaging camera may be quite simple, but interpreting the image captured takes knowledge and experience. To help a user obtain the best thermal image to analyze, there are four adjustments that can be made to the camera; focusing, changing the emissivity setting, changing the reflective temperature setting and thermal tuning.

- Just like a standard camera, the lens of the thermal imaging camera will need to be focused to enhance the clarity of the image. Most cameras can be focused by twisting the lens where more sophisticated cameras will have a push button focus.
- Emissivity is the amount of radiation emitted from an object compared to that of a perfect emitter of radiation when both are at the same temperature. A lower emissivity setting would be used for highly reflected objects and a high emissivity setting would be used for low reflective objects. Objects that are non-metal or that have a rougher surface will have a higher emissivity. Adjusting the emissivity is important when taking temperature measurements or when comparing two different objects temperatures. Incorrect

emissivity settings will make objects appear hotter or colder then what they really are. Not all cameras will allow the user to adjust the emissivity of the camera and will be defaulted to wood or drywall.

- The reflective temperature setting allows the user to compensate for surrounding objects temperature reflecting on an object. If reflecting thermal energy from surrounding objects is suspected, move the camera around in the area of the target and see if the hot or cold spot moves with the camera. If it does, it is a reflection from another object, if it does not, it is a true hot or cold spot. In order to find out what the reflective temperature is, the user will need to adjust the emissivity of the camera to 1.0, then place a piece of crinkled aluminum foil on a piece of cardboard. Hold the foil between the camera and the object you intend to view and note the temperature of the foil. Then input the temperature of the foil in the reflective temperature setting on the camera. Just like emissivity, reflective temperature is important when taking temperature measurements or comparing two objects temperatures. Not all cameras will allow the user to input reflective temperature.

- Thermal tuning the camera involves adjusting the span or temperature range that the camera sees while in manual viewing mode. Thermal imaging cameras will have an automatic viewing mode and manual viewing mode. When the camera is in automatic mode, the camera will automatically adjust the temperature scale to what is being viewed which causes the display to change colors frequently when the camera is moved. Manual mode allows the user to adjust the span to a desired range and the camera will always display this temperature range. Using the manual mode is best used to bring out temperature differences of the object being viewed.

Are there any limitations to thermal imaging cameras?

Because thermal energy can be reflected off of shiny surfaces, thermal imaging cameras can not see through glass. If you stand in front of a window while looking at a thermal imaging camera, you will see yourself in the window because of the thermal energy reflecting off the glass. Regardless of what Hollywood movies may show, thermal imaging cameras can not see through walls. It is also important to know that thermal imaging cameras should not be used as the deciding factor that a problem exists. Using other instruments such as a borescope, moisture meter, multimeter or blueprint drawing of the building should always be used to confirm the problem.

Commonly Asked Questions

Q. ***Can I see through walls?***

A. No. While hi-resolution and hi-sensitivity cameras can create the appearance of seeing through walls, what you are actually seeing is transmitted thermal energy. For example, if you look at the interior walls of a home when it is cold outside, you will likely see the studs in the wall. What is showing on the surface is cold transmitted from the outside, through the studs, to the surface of the drywall. It appears that you can see into the wall and you are actually only seeing the different temperatures on the surface.

Q. ***Can I detect plumbing leaks?***

A. Yes. Thermal cameras are a useful plumbing leak locator. Most cameras have a temperature difference sensitivity of .10 degree Centigrade or better. It doesn't take a lot of temperature difference for the camera to see the leak. The issue is allowing that thermal energy difference enough time to transfer through the flooring to the surface.

Q. ***Can I detect air leaks?***

A. Yes. Similar to plumbing applications, this ties directly to the camera sensitivity. Because the temperature change required is so slight, you can detect draft areas around doors, windows or in commercial environments leakage of expensively treated air through ducted air systems.

Q. ***Will this work for moisture?***

A. Yes. Moist materials will retain thermal energy differently allowing the camera to pick up the differences. You should always double check a potential spot of moisture with a moisture meter since there are several things that can create the thermal anomaly you are seeing.

Q. ***What is PIP?***

A. Picture in Picture (PIP) technology in thermal cameras allows you to overlay a thermal image on top of a regular digital image. Depending on the camera, you may be able to resize the thermal image box. Some cameras also allow for fusion or blending, which allows you to fade the thermal image out over the digital image, increasing visibility of what is below the thermal image. This capability can permit reading of machine labels to identify the specific device being checked or can be used to add detail to exactly where an image was taken.

Q. ***What is emissivity?***

A. Emissivity is the amount of thermal energy an object either emits or absorbs. This is relevant to thermal cameras because highly reflective materials absorb thermal energy, thus the camera can not get an accurate reading of temperature. For example, if you heat a black, PTFE resin-lined frying pan that has a chrome exterior, the black side will read a temperature value closer to the actual temperature, whereas the chrome side will give you values that are far from actual. Most materials fall close to the common preset emissivity value in the camera, but this setting can be changed to accommodate different materials.

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