Electrophysics Resource Center:
Thermal Imaging

White Paper:

Secrets to a Successful Thermal Imaging-based Building Energy Audit

Electrophysics®
IR Cameras for Thermography Professionals

Groupe SOFRADIR

373 Route 46, Fairfield, NJ 07004 Phone: 973-882-0211 Fax: 973-882-0997
www.electrophysics.com

Secrets to a Successful Thermal Imaging-based Building Energy Audit

Today, thermal imaging has become an important inspection tool for identifying heat loss, energy leaks and underlying factors that are critical to the energy usage in a commercial building or home. This white paper reviews fundamentals of an energy audit, the different types of infrared cameras that can be used in energy audits, the use of a blower door to improve infrared inspections, thermal behavior of windows and reporting.

Because of rising energy costs, there is a renewed focus on energy conservation throughout the world. The impact of these higher costs on the economy, the effects of green house gas emissions on the environment and the impact of escalating utility bills on businesses and households has created a serious interest in performing energy audits as a self-inspection as well as a potential business opportunity for progressive contractors. Clearly, even a limited plan of attack on energy waste has the potential to save billions in energy costs.

As an example of the energy losses that can occur in a building, the accompanying diagram of a home shows that 40% of home energy losses occur through the ceilings, with 25% through walls, 15% through windows and 10% through floors and 10% through drafts (such as unblocked chimneys, windows and doors).

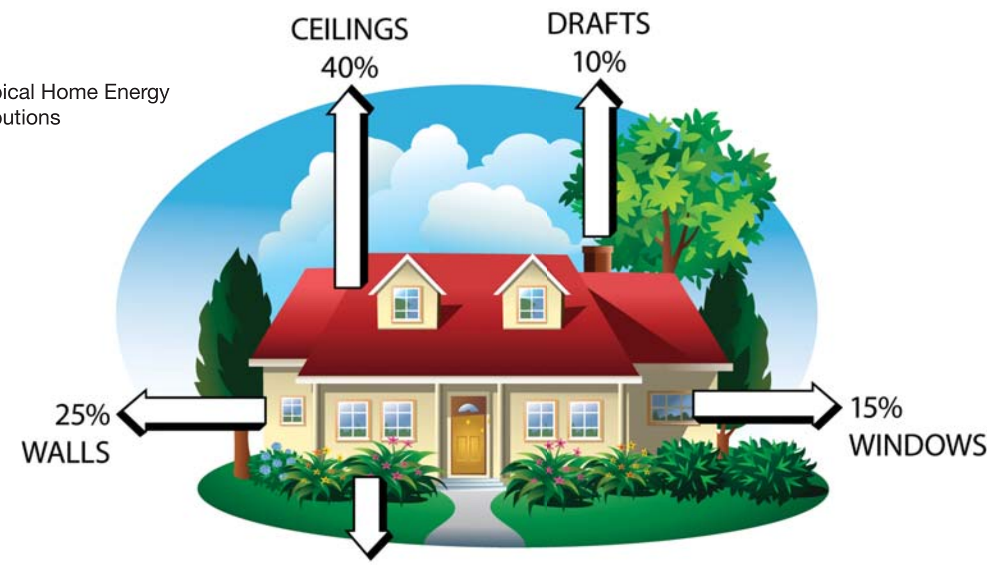


Figure 1: Typical Home Energy Loss Contributions

Typical Home Energy Losses

- 40% through ceilings
- 25% through walls
- 15% through windows
- 10% through floors
- 10% through drafts (chimneys, windows and doors)

Thermal Imaging as an Inspection Tool

It is well known that thermal imaging is an easy to apply and easy to interpret inspection tool that can be used in a host of building envelope applications including home and commercial building energy audits, remediation (post flooding or other storm damage clean up), commercial roofing inspection and electrical/mechanical maintenance programs. While available for over 30 years, today thermal imaging infrared cameras are less expensive and more rugged than previous models, enabling contractors to add this powerful technology to their toolbox. Coincidentally, the conditions for offering energy audits and moisture detection services have improved due to renewed attention on energy efficiency and health and liability concerns over mold in buildings.

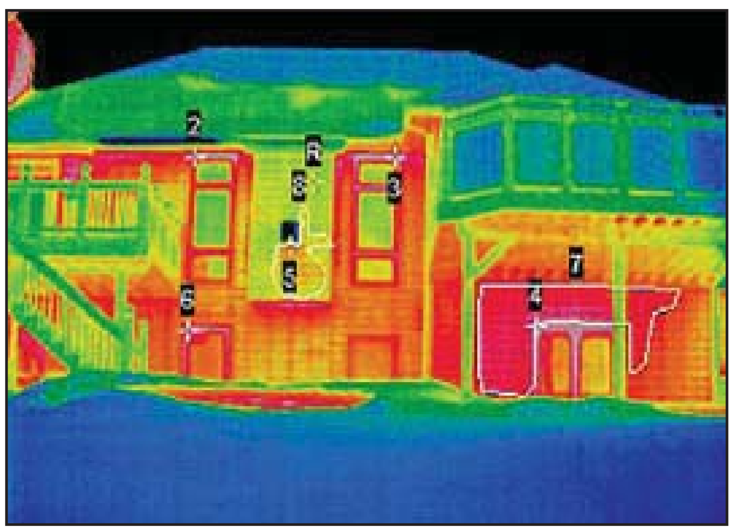


Figure 2 Thermal image of the exterior of a house. The different colors indicate different surface temperatures. The thermal camera permits point measurements to be made (shown with labels).

A building is a complex assembly of parts and thermal imaging is very effective at inspecting underlying problems without actually having to tear into the infrastructure. A thermographic inspection provides useful information about a building's envelope such as air in-leakage, moisture ingress, thermal bridges, cavity wall insulation, ceiling/wall junctions and energy efficient windows.

What problems can be identified with a thermal camera?

1. Missing insulation
2. Insulation that has settled in walls creating cold pockets
3. Air leaks around windows, doors and any other systems penetrating the building envelope
4. Defective insulated glass windows
5. Wet ceiling and walls

Infrared Camera Options for Use in Energy Audits

A thermal imaging infrared camera is in many ways similar to a camcorder. It features a digital imaging sensor available with different levels of pixel resolution usually describes as having a horizontal by vertical pixel format, a lens and the necessary electronics to create a video signal and the memory needed to store snap shot images. In addition, various software packages are either included or offered for sale that create reports and organize inspection programs. Typical thermal camera resolution standards are:

- Low Resolution - 160x120 - 19,200 pixels or less
- Mid Resolution - 320x240 (¼ VGA) – 76,800 pixels
- High Resolution - 640x480 (VGA) – 307,200 pixels

As shown in the chart below, infrared cameras are available with a number of different features. Higher resolution cameras have the highest performance (such as best image quality and best ability to see defects) as well as the most features (such as an integrated visible camera, fusion of visible and thermal images and real-time video output) but also cost the most.

ACQUISITION COSTS			
Resolution	160x120	320x240	640x480
Image Quality	Adequate	Good	Best
Ability to see defects	Poor	Good	Best
Integrated visible camera	Some models	Most	All
Image fusion (mixing thermal and visible imagery)	Limited	Most	All
Real-time video output	No	Some	All
Cost	$5,000-$10,000	$15,000-$25,000	$20,000-$50,000
Cost per month[1]	$180	$470	$620

[1]Based on 3-year financing and lowest cost per category

EZ Therm 880
160x120 Resolution

TVS-200
320x240 Resolution

HotShot HD
640x480 Resolution

Figure 3 Infrared Cameras having Low, Medium and High resolution

Generally speaking, when infrared cameras are used frequently for billable work, it will be easier to cost justify the fully-featured cameras. These higher performance cameras enable the user to view building exteriors, when it is often necessary to see the entire façade of a building, verses inside work where only a section of a single room can be viewed with a lower resolution device.

In the table below is shown typical charges for Infrared Home Inspections in a metropolitan area. (These charges may vary with geographic location). The charges are based on reasonable costs to reach the dwelling and up to 1 hour for report generation. Many home inspectors expand their use of thermal infrared cameras to the inspection of larger commercial properties where the rates often are significantly higher (about $500 per half day, $800-$1000 per day).

TYPICAL CHARGES FOR INFRARED HOME INSPECTIONS	
Small Home – Single Story <1500 sq/ft	$250-$350
Medium Home – Single/Two story dwelling <4000 sq/ft	$350-$600
Large Home > 4,000 sq/ft	$500+

Energy Audits – Getting Started

In cold conditions, in order to improve energy efficiency, the main aim is to reduce heat flow out of the building. The components of the building envelope - windows, roofs and walls - and air infiltration into those components are all important sources of heat loss that must be inspected. In an otherwise well-insulated building, windows are the most important source of heat transfer. In hot conditions, the greatest source of heat energy is solar radiation. This can enter buildings directly through windows or it can heat the building shell to a higher temperature than the ambient, increasing the heat transfer through the building envelope. Solar gain can be reduced by adequate shading from the sun, light colored roofing, spectrally selective (heat-reflective) paints and coatings and various types of insulation for the rest of the envelope.

It is difficult to detect temperature differences on the outside surface of the building during windy weather, rain or with solar heating of exterior. Because of this difficulty, interior surveys are generally more accurate.

If air-conditioning is employed in a hot, humid climate, then it is particularly important to seal the building envelope. Dehumidification of humid air infiltration can waste significant energy. On the other hand, some building designs are based on effective cross-ventilation instead of air-conditioning to provide convective cooling from prevailing breezes.

A thermographic inspection can be a survey of the interior or exterior of the building. The auditor decides which method would give the best results under certain weather conditions. Interior scans are more common, because warm air escaping from a building does not always move through the walls in a straight line. Heat loss that has been detected in one area of the outside wall may have originated at some other location on the inside of the wall. Also, it is more difficult to detect temperature differences on the outside surface of the building during windy weather, rain or with solar heating of exterior. Because of this difficulty, interior surveys are generally more accurate.

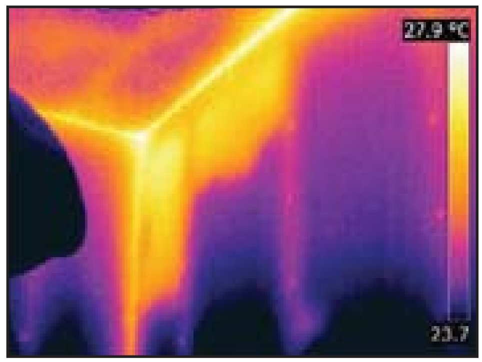


Figure 4: Internal Walls with collapsed/settled insulation

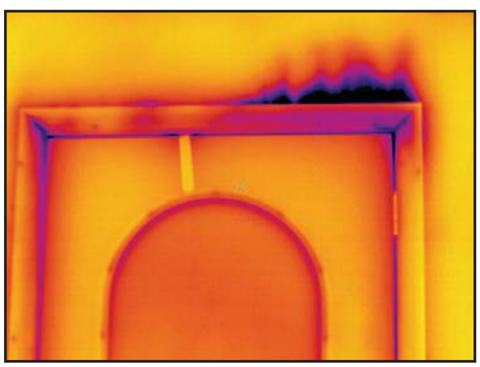


Figure 5: Infiltration around exterior door trim

Figure 6: Poor workmanship

Figure 7: Exhaust fan duct lacks proper insulation

Figure 8: Wet ceiling insulation

Performing a Home Energy Audits with a Thermal Imager

Before beginning the process of performing infrared scanning of homes, a few more tools are required to do the job properly. The most important tool that's needed in addition to a thermal infrared camera is a blower door. A blower door is a powerful fan that mounts into the frame of an exterior door. The fan pulls air out of the house, lowering the air pressure inside. The higher outside air pressure then flows in through all unsealed cracks and openings. These tests determine the air infiltration rate of a building and increase the temperature change in suspect areas making the thermographic inspection both easier and more accurate.

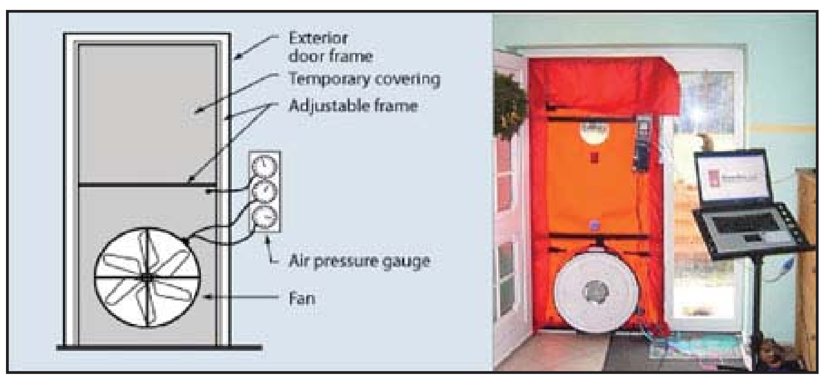


Figure 9: A blower door can help to determine how air tight a building is and to ensure that air sealing work is effective.

Blower doors consist of a frame and flexible panel that fit in a doorway, a variable-speed fan, a pressure gauge to measure the pressure differences inside and outside the home, and an airflow manometer and hoses for measuring airflow.

There are two types of blower doors: calibrated and un-calibrated. It is important that auditors use a calibrated door. This type of blower door has several gauges that measure the amount of air pulled out of the house by the fan. Un-calibrated blower doors can only locate leaks in homes. They provide no method for determining the overall tightness of a building. The calibrated blower door's data allow the auditor to quantify the amount of air leakage and the effectiveness of any air-sealing job.

Preparing for a Blower Door Test: Take the following steps to prepare the home for a blower door test:

- Close windows and open interior doors
- Turn down the thermostats on heaters and water heaters
- Cover ashes in wood stoves and fireplaces with damp newspapers
- Shut fireplace dampers, fireplace doors, and wood stove air intakes

These are some reasons for establishing the proper building tightness:

- Reducing energy consumption due to air leakage
- Avoiding moisture condensation problems
- Avoiding uncomfortable drafts caused by cold air leaking in from the outdoors
- Making sure that the home's air quality is not too contaminated by indoor air pollution.

A REAL WORLD EXPERT'S COMMENT:

"I always suggest using the infrared BEFORE turning on the blower door. Specifically I'm looking for issues with missing and damaged insulation. Once the blower door is on (usually 20-50 Pascals), things change fast and, over time, it is possible to cool down the envelope (during a "winter" inspection) to the point where you can't see much about insulation.

With the blower door on, however, anything that changes tends to be related to air leakage. Air leaking directly into the conditioned space can be seen as well as indirect leakage and many bypasses. It is often possible to infer the direction of flow as the source end, in cold weather, is coldest.

Another issue that shows up is insulation performance. Before the door is on, you may determine that insulation is present. After depressurization you may see how well it is actually performing. This is particularly true for batt insulation. I've seen two layers of 9" fiberglass batts rendered virtually nil under depressurization and whole insulated walls and ceilings drop 20F in a matter of minutes due to interstitial air movement.

After air sealing is done (or attempted!), the blower door and infrared camera combination can again pay huge returns by either confirming the work was done properly or showing where problems continue to exist. The attached is spray applied foam in a very large commercial building that was 99.9% effective as an air barrier but the 0.1% let enough air through in enough places that the whole job was a disaster. Using large fans (rather than blower doors) to depressurize the space, infrared clearly located the many small voids that had been unintentionally left and repairs were easily made and verified—all before the sheetrock was installed!"

John Snell – Snell Infrared

Test Procedures: The test is performed with doors and windows closed. Decisions often need to be made concerning doors to semi-conditioned spaces. The rule of thumb for basements and similar spaces is to include any area which is at least semi-heated (even if unintentionally, as in an unfinished basement with a furnace). Often, it makes sense to test both ways, which is easy and quick once the blower door is set up.

The test determines whether or not intentional openings like ventilation equipment are temporarily sealed. For a description of how an existing house normally behaves, such openings are usually left uncovered. On the other hand, if a new house is being tested for sufficiently tight construction, it may make sense to remove any intentional openings from the measurement by sealing them up. Since the test depressurizes the house, sucking air in through all the openings (including flues), it is important that all combustion devices be disabled during the test. Heating systems and gas water heaters must be shut off. Pilot lights should be extinguished. All wood-burning appliances in the house need to be out, which requires prior notification for occupied houses during the heating season.

Heat Loss and Window Issues

Energy losses through windows can represent 22% to 37% of the total heat lost in the average house. Careful window selection when building a new house or renovating an old house can make a significant difference in reducing heat loss. Typically double-glazed windows exhibit a well-understood pattern of increased heat loss around the perimeter, due mainly to thermal bridging or "edge-effect" losses. Other areas of heat loss are un-insulated sash pockets and inadequate caulking which leads to air leaks.

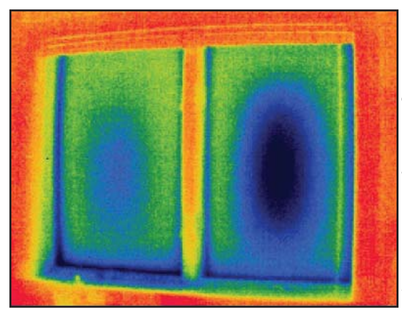


Image courtesy The Snell Group™

Investigations about an unusual thermal pattern discovered with Argon filled windows have lead to a better understanding of window performance and concerns about product quality. The problem was first identified by condensation in the central portion of the window. This thermal pattern was verified with a thermal imaging camera. It was determined that the cause of this anomalous pattern was related to the loss of some of the insulating argon gas installed in the window during manufacturing. This problem is not uncommon for certain types of windows. As these windows age, the problems usually become more pronounced and, in some cases, a total failure of the window by implosion results.

Construction of insulating glass units: Typical insulating glass (IG) units are constructed using two sheets of window glass separated by spacers. The unit is sealed and filled with dry air or an inert gas. A desiccant is often installed in the spacer to minimize internal condensation of moisture. The exact design and placement of the spacers, sealants, and desiccants, as well as the specific type of insulating gas and fill technique used, may vary with the type, brand, and design needs of the window. Early IG units were rather crude by comparison to today's high performance fenestration although many continue to perform even after fifty years. Premature failures of sealants, in particular, were not uncommon, resulting in poor window performance and condensation forming between the panes of glass.

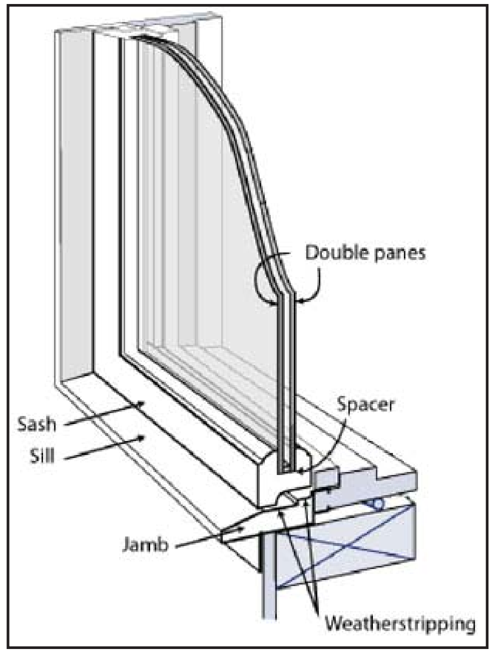


Figure 11: New energy efficient technologies are available to produce windows with improved performance.

Significant performance gains came from improving fill-gas mixtures, as well as installation techniques. Nitrogen-filled windows soon gave way to argon-filled windows because of the decreased thermal conductivity and reduced convection between panes of this heavier gas. With increased performance, however, came new problems. It was not unusual to find an argon-filled IG unit devoid of gas after a year or two; in fact studies of early units showed nine out of ten had lost their argon!

Some may have been inadequately filled during manufacturing, but most probably failed due to poor construction or inadequately designed or failed sealants. The sealants and construction techniques used in many of the first of these windows simply were not adequate to contain the gas.

In nearly all cases IG units share a similar thermal pattern as shown in the thermal image at the right. During the heating season on very cold days, the typical pattern of condensation that forms on the inside surface of the window is concentrated around the edges of the window. It is also not unusual to also see a wider area along the bottom edge due to several factors, including cooler temperatures in the lower portions of the room, reduced convective warming of the lower window due to the sill, and cooling due to inner window convection. Not surprisingly a thermogram of a typical IG unit inevitably shows a similar pattern.

The relative thermal performance of three windows—single-glazed (top), double-glazed with nitrogen gas (right) and double-glazed with argon fill (left), is readily apparent in this thermogram taken from inside during the heating season.

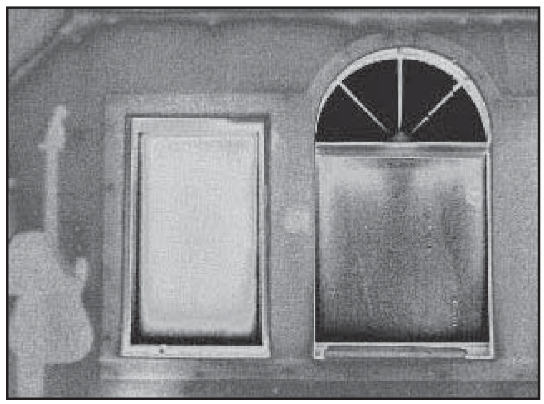


Image courtesy The Snell Group™

Use this check list when inspecting windows?

1. Is there condensation between the glass panes?
2. Is the window glass bowed? Use a straight edge to check.
3. Is the window more than 5 years old?

Determining the cause of window problems: Windows exhibiting this anomalous pattern are argon-filled units, and generally not large ones. Over time the argon gas escapes from the window, but it is not easily replaced by air, leaving the internal space at a negative pressure. The panes of glass are thus pushed together resulting in increased heat transfer and, when conditions are right, condensation in the center of the window. The causes for the argon loss are interesting. Some is certainly lost due to inadequate design or construction, especially of the spacer in the corners. Sealants too have long been recognized as a weak point. Argon molecules are smaller than most of the gases which compose air, it can travel through many sealants which were previously used to contain other gases. Some sealants obviously allow argon to pass through them, but not allow air to replace the displaced argon.

The difference in partial pressure between the gases inside the window and the air also causes the argon to be lost. Air is approximately one percent argon; with the inside of the window at ninety percent or greater, gas will flow out to equalize partial gas pressures. Researchers estimate that argon may escape three times faster than it is being replaced.

Condensation formed first on the right window which was exhibiting a more advanced stage of argon gas loss than the left window. The thermogram shows that in fact both windows have some argon loss. Desiccants are also probably a mechanism for loss. Many IG units adsorb not only water vapor but also other molecules, including argon. Over time some of the gas is adsorbed onto the desiccant, again resulting in a negative pressure inside the unit. Adsorption also increases during cold weather.

All of the above factors probably work together with the result being that over time the unit loses argon and pressure. When conditions are right, especially during colder weather, thermal stresses may become so great that the window unit may actually implode. Reports indicate that smaller units, with a short dimension of 10”-20”, are particularly vulnerable where pressure induced deflection exceeds the material failure point.

Window manufacturers have been working on several fronts to minimize the problem of argon depletion. Changes have been made to the way units are filled to assure they are actually full at the time of manufacturing. Sealants have also been improved, and in some cases, two types of sealants are used rather than a single one; designs also now incorporate longer sealant pathways so that the gas must go further if it is to escape. Spacers and sealants are more carefully installed, especially at the corners where significant breaks have occurred in previous designs. Desiccants are now being used that do not adsorb argon as readily; additionally larger quantities of desiccant are being used. Some manufacturers are even beginning to pay attention to the air temperature/ pressure conditions at the time of manufacturing.

Generating Reports

Thermal cameras typically include some type of report generation software. Report content varies with service provider but there are a few elements that a home energy inspection report should include.

- Both thermal and visual images of each building defects and suspect areas including identifying text of the scene location
- Some general information about the time of day, outdoor conditions including sun levels, wind, ambient temperature.
- Statistics on air in-leakage and the deviation from a normal size dwelling. Consider assigning a priority or severity scale for each problem.
- Recommended actions
- Estimated energy savings and Return on investment

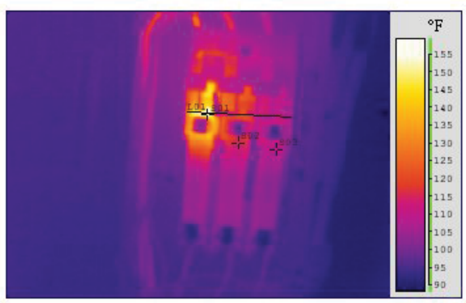
Electrophysics

ELECTROPHYSICS CORP.
373 Route 46 Fairfield, NJ 07004
973-882-0211 toll free: 800-759-9577
info@electrophysics.com

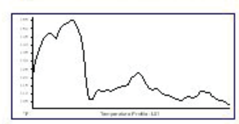
Electrical System Sample Report

Incident Summary	
	Chiller Room
Equipment	Fuse Block
Incident Date	6/13/2006 11:19:29 AM
Recommendation	Check fuse clip tension
Severity	Medium
Units	°F
Global Emissivity	1.00

Inspection Detail	
Thermographer	Bill Martin
Component Temperature	154
Reference Temperature	117
Temperature Rise	36.4
Component Emissivity	0.95
Background Temperature	60



IR image file:
sca panel 2.eif



Comments

Re-inspect after repair is made and check for imbalanced load before taking circuit off load just to make certain it is a connection related problem.

* All tabulated readings are in °F.

All images taken with an Electrophysics HotShot® Thermography System.
This report written in Electrophysics ReportIR Software (IR Vis Spots Profile Template.doc).
www.electrophysics.com

Training

Various applications training programs are available to the interested thermographer. Such classes will make individuals much more efficient in performing their work and will improve the level of recommendations made based on understanding thermal images. While operating a camera is very straight forward interpreting the images is not always. Like any sophisticated instrument training should be considered as part of the investment. Third party independent training are a good place to start.

Typical Training Program Topics

- Qualities of good data
- Infrared camera basics
- Hands-on practice
- Heat transfer basics
- Radiometric basics
- Principles of building inspections
- Conduction inspections
- Air leakage inspections
- Blower Doors
- Moisture inspections
- Building standards
- Report and Analysis software

For more comprehensive White Papers
visit our online Knowledge Center.
www.electrophysics.com/thermal-imaging

Electrophysics®
IR Cameras for Thermography Professionals

Groupe SOFRADIR

373 Route 46, Fairfield, NJ 07004 Phone: 973-882-0211 Fax: 973-882-0997
www.electrophysics.com

Edition: 06-09 rev03