The Use of Infrared Thermal Imaging for Home Weatherization

From the initial audit to the final quality inspection, a thermal imager can help control WAP program costs, improve work quality and ensure effective performance of installed measures.

Figure 1: Icicles like this are a good indication of poorly performing insulation and/or ventilation.

Thermography is an essential tool for anyone involved with home weatherization, but this is especially true for those in the Department of Energy Weatherization Assistance Program (DOE WAP). Since WAP was started in 1976, weatherization assistance services have been provided to more than 6.2 million low-income families using Federal funding administered by the States with the weatherization services being provided by local community-based agencies.

While modern infrared cameras are lightweight and easy to use, accurately interpreting the image typically requires more training and experience.

From the initial audit to the final quality inspection, a thermal imager can help control WAP program costs, improve work quality and ensure effective performance of installed measures. Many of the ways the technology is currently being used in home weatherization are illustrated in this paper with a number of specific, clear examples. While the material included is particularly relevant to WAP, it is equally relevant to insulation contractors, home and remodeling contractors, energy auditors, utility efficiency programs and thermographers who inspect buildings.

Introduction

Buildings of all sorts can be troubled by problems related to insulation, air leakage and moisture that can be difficult to diagnose and resolve. The major problems found typically include:

- Excessive energy use due to missing or damaged insulation, insulation that is performing inadequately, and excessive air-leakage across the thermal envelope.
- A thermally uncomfortable living space.
- Moisture damage due to leaks or condensation, especially in the walls or roofs.
- Ice damage on sloped roofs in "snow belt" regions.
- Poor HVAC distribution or performance.
- A failure to understand hidden construction details.
- "Sick-building syndrome," mold growth and other health-related issues.

Often the problems—as well as their causes and consequences—simply cannot be seen or may reveal themselves only after significant damage has been done. Homes in the "snow belt" (Fig. 1), for example, can end up with extensive ice dams resulting from roof/ceiling insulation and vent systems that do not perform adequately. Air leakage can also prove very problematic or time consuming to understand and reduce. One of the most troubling problems any WAP auditor faces is determining where insulation exists—and doesn't—in an existing home. Success in correcting problems like these is often illusive because we cannot "see through walls" and the root causes are not obvious.

While modern infrared cameras are lightweight and easy to use, accurately interpreting the image typically requires more training and experience.

Perhaps the greatest value of infrared thermography is that it provides a means of seeing the otherwise invisible thermal signatures associated with many building problems. When properly used, thermography enables auditors and crews alike to understand building issues, locate problems, verify building performance, and validate solutions. While all WAP programs operate under a well-defined structure, there is typically plenty of room to incorporate infrared inspections at many points in the process. When people act on this information, significant savings result and buildings end up being more comfortable!

What is Infrared Thermography?

An infrared camera or imager is not unlike a regular camera except it sees heat instead of visible light. All surfaces radiate heat energy, and, as an example, we have all felt it given off by the sun or a stove burner. Infrared cameras are electronic devices especially designed to detect this radiation and then convert it into a thermal image or "thermogram". When properly used a thermal imaging system can display temperature differences as small as 0.05°C; often typical of what is found with an insulated cavity and a framing member.

Today's lightweight, portable, battery-operated cameras record the thermal data either as still, digital images or as video. The image is displayed live in a viewfinder or on an LCD view screen. The various radiant temperatures are shown in the image as different colors or shades of gray. Although it may sometimes be useful to display temperature values, this is usually not required for most building work. Rather the differences or relationships in the image are of greater interest.

Given the right conditions, most buildings exhibit characteristic thermal patterns that can be readily interpreted by a qualified person. The infrared systems themselves are quite easy to operate and, thus, many people, called thermographers, use the technology for building inspections of various kinds. The task of interpreting the imagery, understanding the root cause of problems, and finding solutions are, however, all more difficult than simply operating the camera. Because of this, a working knowledge of buildings—both construction details and thermodynamics—is essential.

Thermography has been used since the mid-60s to solve building problems. During the late 1970s and early 1980s, a time when home energy prices rose dramatically, thermography was embraced widely as a tool to help improve building performance. However, because the price of cameras was high, in excess of $20,000, they were rarely used in WAP except occasionally as a training or monitoring tool. Since 2000, dramatic advancements in the manufacturing of cameras and competition in the marketplace have caused the price of systems to drop to between $3,000–$7,000. Now they are being widely used by WAP auditors and, in many cases, by the crews at the jobsite. Additional details about cameras are discussed later in this paper.

At these prices the economics become very persuasive. Assuming a $7,000 camera used to conduct 200 inspections per year (two inspections per day over thirty 4-day weeks) over a 5-year useful life, the added cost of the camera alone is $7 per inspection! The time-savings should be a wash or a net savings based on improved efficiencies with the audit, crew time on the job and post-job quality control. Clearly, based on these assumptions, infrared can play a huge role in helping WAP meet dramatically increased production targets recently set by the Obama administration for 2009–2010.

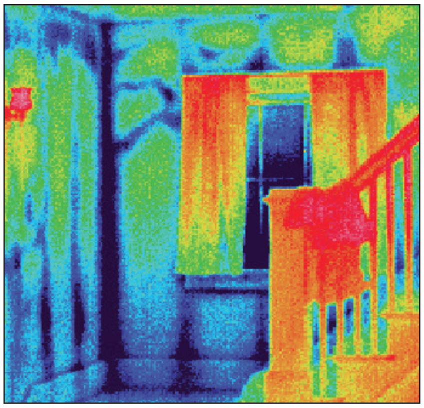

Figure 2: When conditions are right, it is possible to locate missing or damaged insulation, such as this poorly installed injected ureaformaldehyde foam.

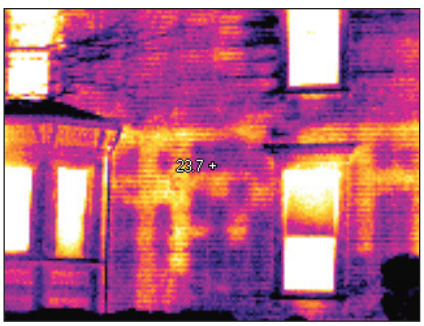

Figure 3: Improperly installed insulation can yield an irregular thermal pattern.

Thermography in WAP

Thermography is now being widely used in many programs at all levels. Good models for use have been proven to work. Specifically these include:

1. On the initial audit the auditor is able to:

- Better understand the existing condition of the home, including the definition of the envelope, whether or not it is insulated and, if it is, where and how effectively.
- Locate air leakage sites and the relative extent of the leakage.
- Visualize and better understand many of the common thermal bypasses.
- Develop a "framing map" for any remedial insulation work needed.

2. While the crew is implementing the recommended weatherization measures, the infrared camera can again be used to:

- Confirm framing details and resolve any questions, specifically those related to sidewalls, knee walls, slant ceilings or cathedral ceilings.
- Monitor the installation of blown cellulose shortly after placement.
- Verify and speed up the understanding of air leakage in conjunction with the blower door.
- Monitor and verify air sealing work before leaving the job site.
- valuate moisture problems.

3. During the final inspection or quality monitoring checkpoint:

- Validate the thoroughness and effectiveness of both insulation and air sealing work and, importantly, document the work.
- Provide visual feedback (thermal images), both positive and negative, to the crews as part of a continuous improvement process.
- Virtually eliminate the root cause of many "call backs," particularly missing insulation and comfort issues.

4. The technology can be used with great benefit to educate homeowners and to train crew members by showing thermal images, rather than just talking about the problems.

Inspection Procedures

Getting good results from thermal imaging requires qualified thermographers to follow accepted inspection protocols. Several important standards exist to support this work including, among others, the following:

- ASTM C1060 - Practice for Thermographic Inspection of Insulation Installations in Envelope Cavities of Frame Buildings.
- ISO 6781 - Thermal insulation, qualitative detection of thermal irregularities in building envelopes, Infrared Method.
- ASTM E1186 - Air Leakage Site Detection in Building Envelopes and Air Barrier Systems.

In addition, the Canadian government issued the National Master Specification (NMS) Section 02, Thermographic Inspection Services: Building Envelope, in July 2006. This standard offers a great deal of excellent guidance that can be modified to help any WAP with developing a standard inspection protocol. RESNET/BPI is also in the process of developing an inspection standard as well as a protocol for certifying thermographers; both should be of value to anyone in the WAP.

Commonly accepted procedures suggest the following:

Figure 4: Properly installed cellulose is an excellent insulation. Unfortunately it is often poorly installed with missed areas and settling the most common quality problems.

Figure 5: Batt insulation is susceptible to air infiltration. The fiberglass shown here does not stop airflow directly into the home or indirectly into the ceiling section.

Insulation checks

Missing, damaged or non-performing insulation will stand out clearly in a thermal image when there is at least a 10°C (18°F) stable temperature difference between the conditioned space and the outside air. Warm or cold-weather work are both possible, though the later is often easier. It may be possible to do work with less of a temperature spread due to differences in the thermal capacitance of the building materials. The inspection is typically done from both inside and outside but the best results are usually gained from inside because of fewer influences. That said, a better overall understanding of the building can often be gained from larger views from the exterior.

It is important to know the type of insulation in the building and construction details. Insulation, especially fiberglass batts, may be in place but not performing as it should. Each type of insulation has a characteristic thermal pattern. Figure 2 shows a classic pattern associated with injected foam insulation in a wood-framed wall. This type of insulation, no longer on the market, was susceptible to shrinkage and cracking when poorly installed.

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

The costs of poor performance of insulation can be immense. In addition to excessive energy consumption and reduced comfort, there may be costly freeze-ups of water pipes, as well as health issues associated with mold growth in cold spots and damage to roofs and interiors caused by ice dams, condensation, and water intrusion.

Air Leakage Location

As has been well documented in the WAP, excessive air leakage can account for up to half of the energy used to condition buildings. Of course adequate air exchange is essential for the occupants’ health and safety, but most buildings have a far higher rate of air exchange than is necessary. The problems can be as straight-forward as a failed door weather seal or as complex as an interior wall or ceiling plenum. The leakage pathway is often complex and, without infrared, extremely difficult to visualilze (Figure 5).

Air leakage inspections are best conducted when air movement is directed and controlled. This is best accomplished in conjunction with a blower fan door that can create a pressure difference, typically 20–30 Pascals negative, across the envelope. During the heating season the resulting sites of air infiltration appear cooler. The work can be done any time of year the indoor/outdoor temperature difference is greater than a few degrees. Blower door fans are also widely used in both the audit and the onsite air sealing work to quantify air leakage rates.

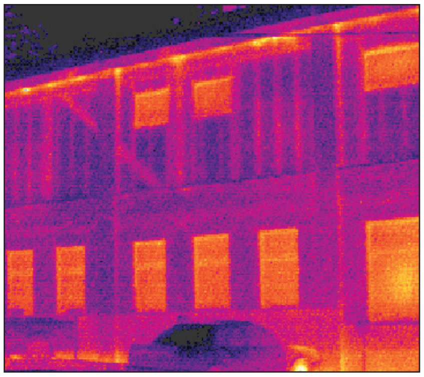

Figure 6: All the framing and insulation is clearly visible in this apartment building. Pressure differences in the building, known as stack effect, result in air leaking past the envelope through various pathways and exiting out near the top plate of the wall. The fiberglass batt insulation does little to slow the movement of air.

Most types of insulation are not effective at reducing air movement through the thermal perimeter. Good construction practice includes interior air sealing; if this is not in place effectively, air can move through the interior and exterior surfaces and through the insulation.

Unfortunately, fiberglass batt insulation is particularly susceptible to this problem (Fig. 6). Thus, while the insulation is present, it does not perform as expected, especially when the building is under a pressure gradient.

Moisture Intrusion or Condensation

One goal of weatherization is to create tighter thermal envelopes; however this, in turn, can result in moisture creating additional problems. Water can intrude through a small crack or form due to condensation. Good building techniques typically must deal with both air sealing and control of moisture sources to minimize problems. Thermography again can play a key role by identifying wet building materials and cold spots that can result in condensation.

Locating moisture with thermography is often challenging because water, which can evaporate and cool surfaces, also has both a high thermal conductivity and a high heat capacitance. Typically the findings from the camera are confirmed with a moisture meter.

Determining the source of the moisture can also be difficult. Condensation, rather than leakage, is often the culprit so it is important to identify sources of air leakage that can transport moist air into the wall sections along with the cold spots that can result in it condensing. The classic case is that of warm moist air leaking past the insulation in a mobile home; as it contacts the cold underside of the metal roof it condenses, and often freezes, causing the occupants to think, mistakenly, that the roof is leaking. Damage in buildings from condensation, which can be considerable, includes mold growth and reduced insulation values.

Infrared Cameras: What is Important?

Many excellent choices exist for infrared cameras for buildings work but there are some that are more appropriate than others and some that should be avoided altogether. Care should be taken to clearly define the real needs so that systems that are evaluated for purchase will result in those needs being met fully. Infrared programs often allow a sales person to talk them into purchasing cameras that are much too complex or, in an effort to economize, they purchase low-cost systems that simply cannot do the job. There are a number of factors that must be considered in addition to cost and after-sales service including:

Ease of Use: Generally, if more than one or two people will be sharing the use of a system, it must be very simple to use. Image adjustment, focusing and basic operation must all be easy if the system is to be used well. Avoid complicated systems.

Image Display: A high-quality view screen is essential to diagnosing an image and it allows more than one person to view the thermal image—whether the homeowner, the crew member or a state auditor.

Ergonomics: Most systems are quite lightweight but not all are easy to use. Try a system

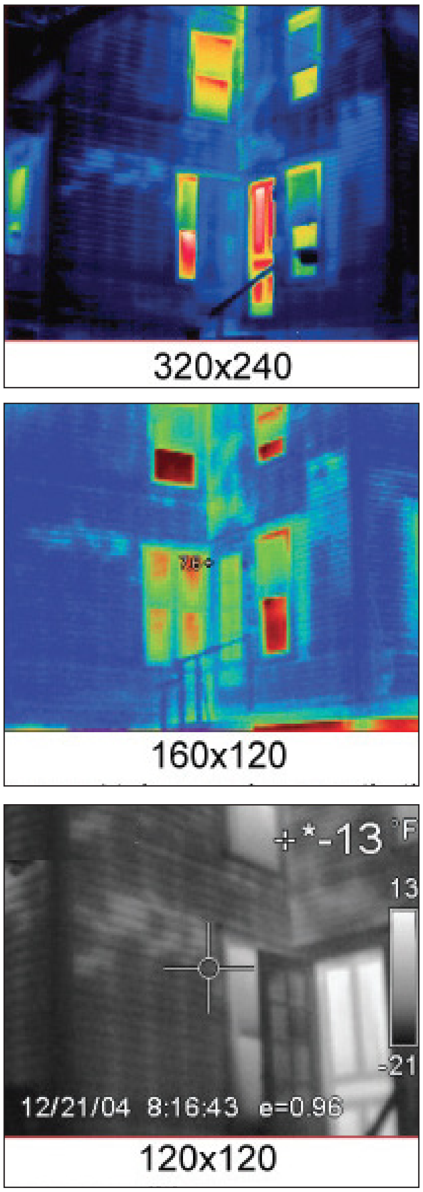

Figure 7: Three different array sizes can all produce excellent results when used properly. *Note: images were not taken under exactly the same conditions.*

in the field for a long enough period of time to know you can use if comfortably in the many, varied positions required.

Thermal Sensitivity: For buildings work a system should be able to resolve temperature differences of at least 0.1°C at 30°C (often termed 100mK in a spec). For buildings work, sensitivity is important and more sensitive is better. Strong consideration should be given to systems with better sensitivity, down to 70mK. The difference will allow you to work more days and longer on any given day. In other words the additional cost of improved sensitivity is an investment with real returns.

Field of View (FOV): The overall area viewed at any distance, described by the FOV spec, is given as two angles describing the horizontal and vertical angles of the image. For WAP a "normal" FOV of approximately 20°x20° works well. Avoid telephoto or very wide-angle lenses. Typically the ability to change lenses is not worth the additional cost. Most cameras have some sort of "zoom" function but this is only an electronic enlargement of a section of the existing FOV and not a true zoom capability. While modern infrared cameras are lightweight and easy to use, accurately interpreting the image typically requires more training and experience.

Detector Array Size: Without going into too much detail, this spec relates to the number of pixels. More pixels mean greater detail. Excellent systems for home weatherization are being made with 120x120, 160x120 and 320x240 arrays (Fig.7). Avoid smaller arrays even if the price is attractive! Larger arrays typically cost more. New 640x480 arrays, while impressive and useful, are probably more than is needed for most residential work.

Focus: Cameras come in several varieties including fixed focus, manual focus and motorized focus. Fixed focus cameras, while useful, are limited in what they can portray and tend to have a very wide FOV. Motorized focus cameras are generally more than is needed, leaving manual focus as the preferred option.

Batteries: Battery run time, re-charge time and total life are each important. Batteries may be either removable or built-in and both can work well, all else being equal.

Image Palettes: Most thermographers work in either gray or monochromatic color. Most cameras allow the image palette to be changed, either in the camera or in the analysis software. Some palettes work better in some cameras than in others!

Frame Rate: 9 Hz systems have become widely used and can work as well as 30 Hz and 60 Hz systems.

Visual Image: A very useful, and, thankfully, now common, feature of many cameras is a built-in visual camera which produces a visual image linked electronically to the corresponding infrared image. Some are better than others but most will provide a clear visual documentation of the infrared image. Several cameras will display the two images in a "fused" mode that is very useful; however, beware that in some the alignment of the visual and infrared images is better than others.

Voice or Text Annotation: Both can provide another useful means of documentation that is tied electronically to the infrared image.

Radiometric Measurements: Generally radiometric temperature measurement is not

Fortunately many in the WAP have extensive training in building science, providing a good foundation on which to become good thermographers after additional training and experience.

necessary for most buildings work. That said, having at least a spot measurement capability can be useful but, again, it is not essential. Often new thermographers pay far too much attention to temperature and not enough attention to the image. A subset of radiometry are two features, "R-value" and "dew point indication," that should be avoided as they are overly simplistic and, potentially, dangerously misleading.

Image Storage: Images are stored electronically either on a small card or on internal flash storage. Both can work but make sure you can download to the computer used.

Image Analysis and Reporting Software: Most cameras come with some sort of software included in the price. With these you can typically perform basic image adjustments and analysis as well as write simple reports. Some software programs are an additional cost. Some are priced a great deal more, but typically these packages offer far more features than what is really needed for a successful program. In the end, evaluate several systems and try them before purchasing. While systems will inevitably continue to improve and drop in price, waiting is foolish as tremendous value can be had now.

Qualifications of the Thermographer

Although the thermographic inspection of buildings may appear simple, successful use requires qualified personnel with related experience. Both training and experience are essential. An intimate knowledge of construction techniques, practices, materials, and failures is also important. Fortunately many in the WAP have extensive training in building science, providing a good foundation on which to become good thermographers after additional training and experience. As has proven true in other facets of WAP, documentation of both training and experience are as important as an appropriate form of "testing" to ensure qualification.

While the actual operation of most infrared systems is fairly simple, interpretation of the image can be quite complex. Failure to train people on both camera use and image interpretation almost always results in serious problems or program failure. Typically two-day training is sufficient to get a person who already understands building dynamics started. Three to six months of qualifying experience, with support from a thermography expert, results in a highly skilled person who can optimize the results of the investment. We have found it important that thermographers in a program periodically get together to discuss their findings, preferably with an expert facilitating the session.

Conclusion

When properly used by qualified individuals, this remarkable technology can play a powerful role in visualizing otherwise invisible building problems and conditions. In weatherization personnel are already using thermography to assure the performance of their buildings, diagnose tough problems and checking work quality. The bottom line is a more efficient and effective program.

While a foundation of expertise must underlie the successful use of thermography for building diagnostics, getting started with most of the applications is not difficult especially in WAP where many have a good basic knowledge of buildings. The primary return on an investment in building thermography is gaining a higher level of assurance that buildings will perform as intended and occupants will be more comfortable, usually at a lower cost.