Getting Started in Infrared

by John Snell

Today's IR cameras are easy to use and relatively affordable, but correctly interpreting the image takes experience

During the late 1970s and early 1980s, I supervised residential insulation projects in central Vermont while working with a couple of regional agencies. Despite our best efforts, we had many problems with blown-in insulation, which was becoming popular at the time.

On one occasion, I was doing the final inspection on a newly insulated Victorian — a three-story balloon-framed monster — when I realized I could look down from the attic into empty stud cavities in the exterior walls. Desperate to know how bad the situation really was, we called in a guy with an infrared scanner. The equipment available in those early days was cumbersome and expensive. It required nearly perfect conditions to provide even crude images, and the only way to get a hard copy of the output was to snap a photo of the CRT view screen. Even so, the IR technician was able to confirm that the house was only about 60 percent insulated.

From that point on, we began using IR imaging as part of the final inspection on all newly insulated homes. I was so impressed

Figure 1. The first commercially available IR cameras weighed anywhere from 10 to 30 pounds and had to be cooled with liquid nitrogen or compressed argon gas (far left). Their modern counterparts are dramatically less expensive and easier to use (left).

with the technology, I quit my job and went to work for the thermographer. In 1986, I started my own company, which now offers infrared training across the U.S. and internationally.

Today's equipment is easy to use. Image quality is high, and prices have fallen dramatically (**see Figure 1**). When cameras costing less than $10,000 began appearing in 2002, I couldn't imagine prices going any lower, but excellent equipment is now available for half that price, and more limited (though still useful) versions sell for as little as $1,500. However, the affordability and easy availability of the equipment have a potential downside: Builders who buy an IR camera with the expectation that they'll learn to use it through trial and error are likely to struggle at first, and risk making costly — or at least embarrassing — mistakes. In my experience, a two-day training session in IR-imaging basics is worth about a year of flopping around on your own. It's like anything else in the building trades — having the right tool isn't

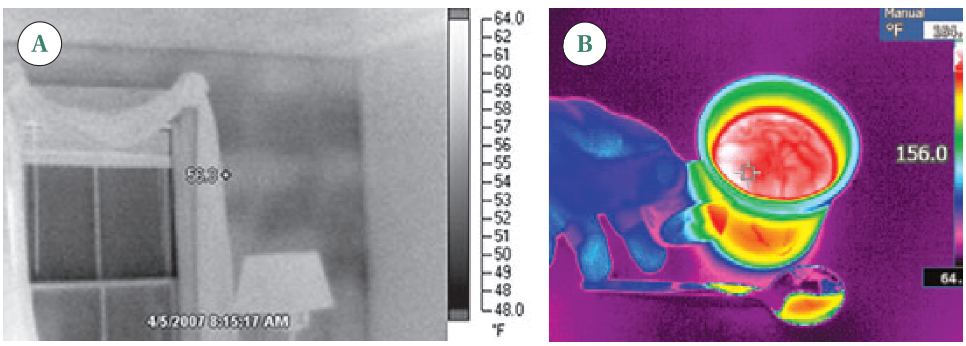
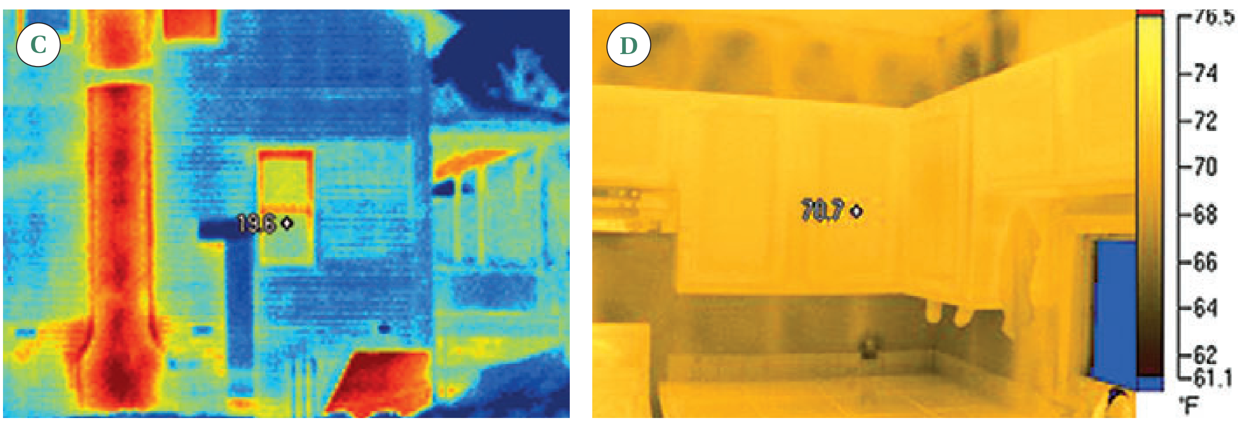


Figure 2. In a grayscale image, cooler surfaces appear dark, with lighter areas indicating greater warmth (A). In the "rainbow" palette (B), the temperature scale is displayed in a full color spectrum. The red-blue palette (C) is a variant of the rainbow palette, while the amber image (D) is similar to grayscale but based on shades of yellow.



the same thing as knowing how to use it effectively.

There are two standards you should become familiar with, even if you don't always follow them: ASTM C 1060, Standard Practice for Thermographic Inspection of Insulation Installations in Envelope Cavities of Frame Buildings; and RESNET's Guidelines for Thermographic Inspections of Buildings. Both provide a good foundation.

IR Imaging Basics

An IR camera works by sensing the radiant energy given off by objects in its field of view. It does this with an array of built-in thermal detectors, the number of which determines its "array size" (see "Shopping for an IR Camera," page 36). The camera's built-in software converts the radiation into a visual image called a thermogram.

A matter of interpretation. The right IR image can allow the operator to draw some very detailed conclusions about what's happening beneath the surface of an object. But it's important to understand that IR images aren't like medical X-rays — they're really just detailed maps of variations in surface radiance. The conditions under which the image is taken — the time of day, the difference between indoor and outdoor temperature, and other factors — determine how much that map will let you deduce about what's hidden from view.

Color choices. The color-coding of an IR image can be varied to suit the situation and the user's preference. In the early days, most IR images were grayscale, like the picture on an old black-and-white TV set. The warmest areas were white, the coolest were black, and areas between those extremes appeared as varied shades of gray (**Figure 2, previous page**).

Most cameras still let you display images in grayscale, but simple color images usually show things better. The best color palettes are intuitive, meaning that warm surfaces are indicated by warm colors like red, orange, and yellow, with cooler surfaces in blues or blacks. The best palette for a given application varies with the camera brand and model. The key is to find the palette that shows the greatest contrast while displaying the scene intuitively.

Span and level. In addition to deciding on a color palette, the user also must select the upper and lower temperature limits of the subject area, a setting sometimes known as thermal contrast, or — more technically — the span setting. Depending on what you select, it's possible to put the full range of colors within a narrow span — of, say, 4°F — or a very wide one, of 100°F or more (**Figure 3**). The best setting will clearly show a high level of contrast in the area of interest. The camera operator has the option of displaying a scale at one side of the image, which keys the colors in the image to the temperature.

Many cameras have a function that will automatically set the span to encompass the warmest and coolest objects within its

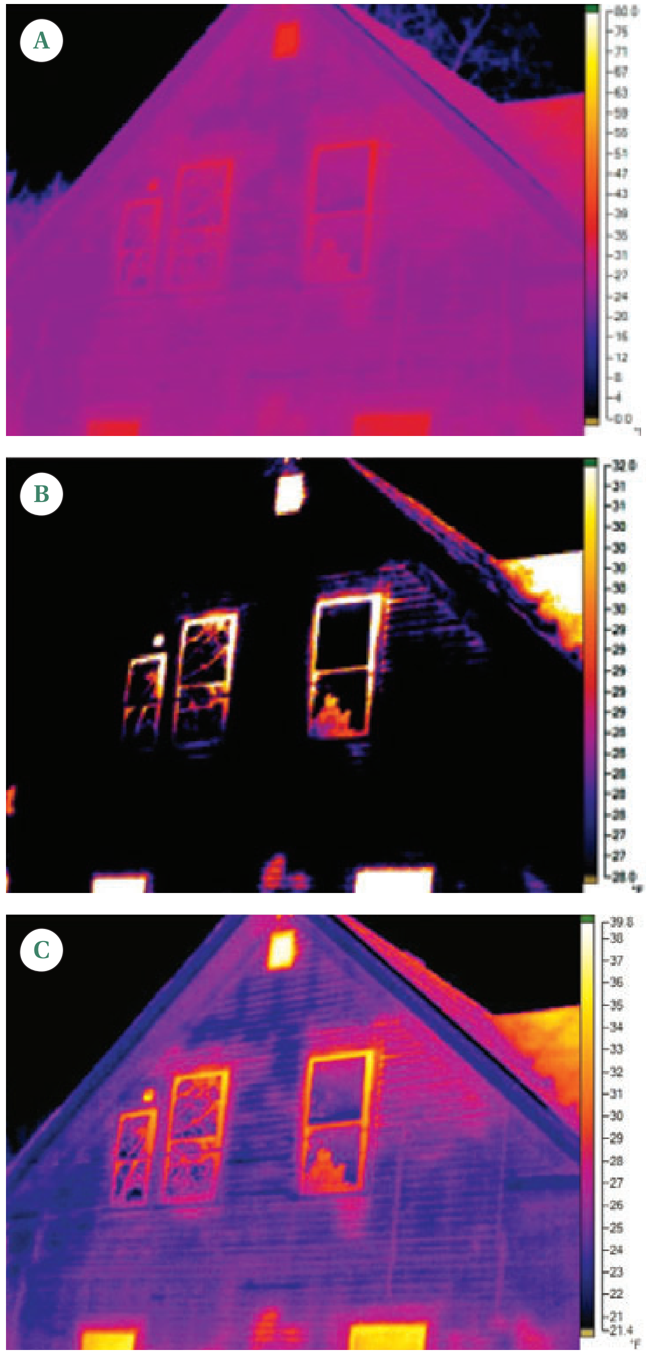


Figure 3. The thermal span in image A is an overly wide 80°F, which has the effect of clumping temperature variations in the area of interest into a very narrow color band, washing out most detail. At the other extreme, too narrow a temperature span (B) makes some areas appear white hot, while adjoining surfaces — which are really only a few degrees cooler — appear to be extremely cold, obscuring smaller but significant variations. When the correct span setting is chosen (C), such small variations are clearly visible.

field of view. This is useful at times, but if the area contains a very warm object, like a hot wood stove or a light bulb, or a cold one, like a window, the auto function will set the span so wide you'll probably lose too much contrast and detail for the image to have much value.

A second adjustable range, called thermal level (similar to "brightness"), determines where on the temperature scale the selected span will appear. If you've already selected a 4°F span, for example, you can choose whether you want that area of interest to fall between 10°F and 14°F or between 64°F and 68°F (**Figure 4**). Depending on how you tweak the level setting, you can make things look extremely hot or extremely cold, or — ideally — just right. Almost all of today's imagers have both automatic and manual adjustment modes. The automatic mode is useful, but in most cases the thermographer will also have to do some fine-tuning of the image using manual mode.

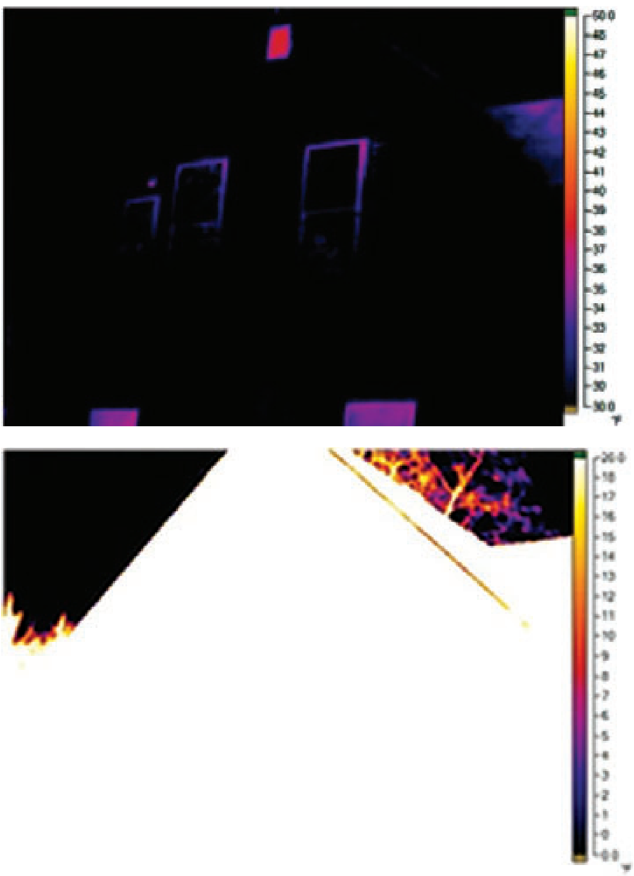


Figure 4. Setting a camera level too low makes the resulting image appear "too cold" (top), while too high a setting will push most of the image area into the range at the high end of the scale (above).

Shopping for an IR Camera

Nearly all manufacturers of IR imagers now sell their products through distributors. You can go online and buy systems from literally dozens of sellers, some of whom sell several competing brands. Although this can lead to excellent prices if you shop around, be aware that it also means there may very little post-sale support from the seller. Imagers are typically quite trouble-free, but if you do have problems you'll probably end up dealing directly with the manufacturer.

While there are several excellent sites that specialize in building-efficiency tools, I've found online sellers of contractor-grade power tools to be equally competitive. You can expect to pay between $2,500 and $3,500 for an entry-level system — suitable for fairly regular use by a general contractor — and $5,000 or more for a system sensitive enough for everyday use by an energy specialist or insulation contractor.

Sensitivity. One of the most basic properties of an IR camera is its sensitivity, which refers to the minimum variation in surface temperature it can detect. Sensitivity is rated in units called millikelvin (mK), or thousandths of a degree on the Kelvin scale; the lower the mK figure, the finer the temperature differences an instrument can detect. Most commercially available systems fall into the 30- to 100-mK range, with 30, 50, 70, and 100 mK being most common.

A 100-mK camera is basically an entry-level instrument. It can be useful when there's a substantial delta-T, but a more sensitive model will be usable for more hours each day, and for many more days in the course of a year. If you're going to invest in a camera that you hope to use year-round, I strongly recommend one rated at 50 mK or better.

Array size. An IR camera is built around an array of miniature detector elements, and the number of individual elements in the array determines how "fine-grained" the images it provides are. A 160 x 120 array, for example, has 160 rows of detectors, each of which contains 120 individual elements, with each element contributing one pixel to the final image. More pixels means more detail for a given field of view.

A 160 x 120 array is a reasonable choice for residential work, though a 120 x 120 array can be used for limited work. For large buildings or commercial structures, a 320 x 240 array will give much better results.

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I suggest you stay away from systems with arrays less than 120 x 120.

Here are some other factors to keep in mind:

• **Ergonomics.** There are many good systems on the market, nearly all of which can work well. But if possible, try one for several hours before purchase.

• **Radiometric temperature measurement.** In most situations, you do not need to be able to measure temperatures, although many cameras will provide the radiometric temperature of a single spot at the center of the image. That's more than adequate for most residential applications.

I'm skeptical of the "dewpoint indicators" and "insulation indicators" offered by several manufacturers. When we're confronting a condensation issue, we will manually determine the dewpoint in a particular area based on the relative humidity. The same holds true for evaluating missing insulation. I'm not convinced that this can successfully be automated — at least not yet.

• **Focus.** Manual focus tends to work very well. Autofocus systems can work well, but typically are not necessary. Some of the very low-cost systems are fixed focus (marketing departments like to call this "focus free"), which can work but significantly limits image sharpness.

• **Fusion of visual and thermal images.** Fusion overlays the thermal image on the visual image or inserts the IR within the visual so you can see where you are while also seeing the IR image (see photo, bottom right). While not essential, this feature is more than just a gimmick. After I've looked at a dozen buildings in a week and taken a hundred images at each one, I can use a little help in remembering where I was! Image fusion simplifies good documentation and can also be persuasive in marketing materials. Be aware that some image fusion systems work better than others, so try before you buy.

• **Lenses.** Most entry-level systems come with a "normal" lens. Being able to change to a wide-angle or telephoto lens — though nice — will drive the price up to approximately $10,000 for the whole system.

• **Image processing and reporting software.** You'll need software — typically included — to make simple image adjustments and basic reports. Keep it simple; more complex, expensive software is usually unnecessary.

The FLIR i7 (left) is a good-quality entry-level camera. Midlevel cameras include the Fluke tiR1, Mikron M7800, and Testo 882 (below). The Fluke tiR32 and FLIR B400 (bottom) are top-of-the-line cameras that can provide high-quality images even under challenging conditions.

The image fusion feature available in some infrared cameras allows the user to accurately superimpose an IR image over a larger visual image.

Understanding Heat Flow and Delta-T

To perform a successful building inspection, it's best to have a minimum, stable temperature difference of 10°C — or about 18°F — between indoor and outdoor surfaces. That's because the kinds of things we're usually looking for, like missing insulation or air leaks in the building envelope, require a sizeable thermal "driver" to show up in an IR image. In energy-wonk shorthand, that temperature difference across the building envelope is known as its delta-T.

Why is delta-T so important? Imagine a situation in which the air temperature both indoors and out is exactly 70°F, and has been for so long that the entire mass of the building has settled at the same temperature.

Under those conditions, there's basically no heat transfer. An infrared image will tell you next to nothing about the structure, because there are no significant variations in surface temperature for the camera to detect. But with a large delta-T — as you'd find on a cold winter morning when the heat in the house has been on all night — framing, insulation, and other features of the structure are likely to stand out clearly (**Figure 5**).

Look for framing. A rough rule of thumb for deciding whether there's an adequate delta-T is to look for evidence of framing. Because the studs in a wall conduct heat much better than the cavity insulation, they'll ordinarily show up as significantly warmer when imaged from the cool side of the wall, or cooler when viewed from the warm side. In an uninsulated building, that pattern will (ordinarily) be reversed, because the open framing cavities will provide even less resistance to the passage of heat than the framing. If you can't see the framing at all, conditions are inadequate for you to see problems.

There are also anomalies that are worth noting. For example, regardless of delta-T, it may be difficult or impossible to see the framing in superinsulated houses or other unconventional structures, such as the residence in **Figure 6**.

Stretching the Working Year

The good news is that even with mid-priced equipment, you should be able to get good-quality images about 300 days out of the year if you properly select the time and conditions. With a higher-priced camera, you'll be able to image at some time nearly every day, under a wider range of conditions.

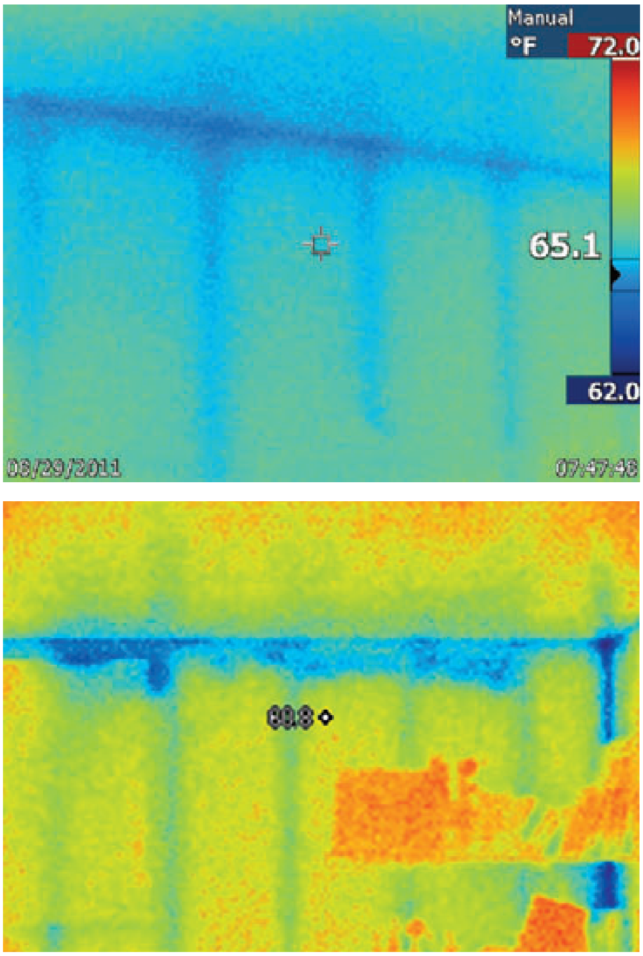


Figure 5. The top image was taken when the local delta-T was low. The wall framing is visible, but with little additional detail. An image of the same wall taken under higher delta-t conditions (from a slightly different angle) reveals voids in the insulation below the top plate (above). A bookshelf and other furnishings are visible on the right-hand side of the image.

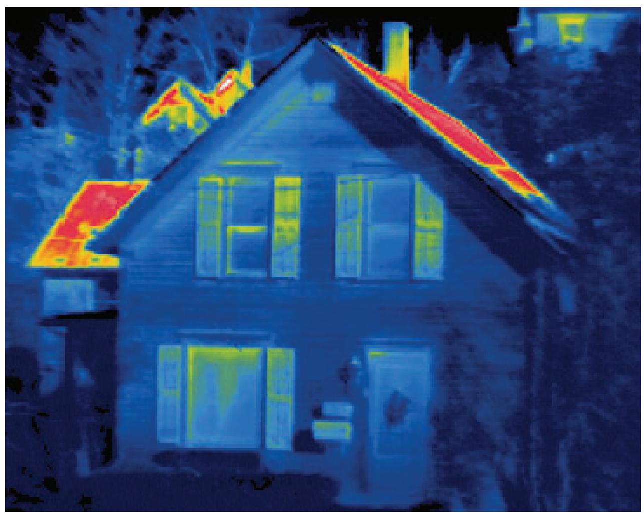
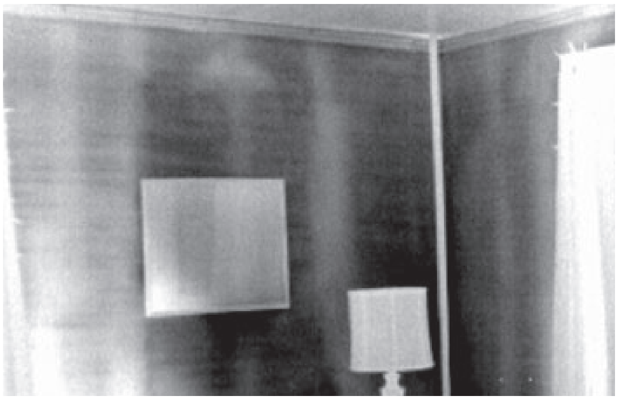


Figure 6. Sometimes it's the structure that's confusing, not the image. This late-1800s house features solid, log-cabin-like walls of stacked and spiked dimension lumber. In the absence of framing or insulation, differences in surface radiance are few and far between.



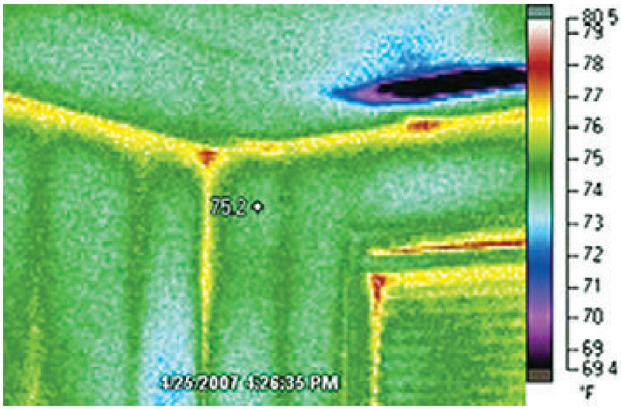


Figure 7. Powering up a building's hvac system can boost the delta-T enough to allow good imaging, but it can also cause uneven surface temperatures. A baseboard heating unit is responsible for the warm streaks in the grayscale image at top. In the air-conditioned structure above, the prominent cool area on the ceiling lies directly in the path of a supply duct.

In the swing seasons (fall and spring), for instance, you may need to arrive early in the morning at home that's been closed up all night. Under those circumstances you're more likely to find good "winter imaging" conditions, where the interior surfaces are warm and the outdoor surfaces cooler. If you schedule an inspection visit for late afternoon or early evening — again, assuming that the house has been closed up all day — you can often perform an excellent round of "summer imaging," with the interior cooler than the out-of-doors. Timing your visits this way won't always pan out; you may find when you arrive that you have to reschedule for another time, but it's often worth a try.

Another trick is to temporarily boost the delta-T by "pulsing" the heating or air-conditioning for 15 or 20 minutes, then waiting another 15 to 20 minutes for the interior temperature to change. This can work well, but it can be troublesome at times, because hvac systems don't adjust the temperature uniformly everywhere. Some envelope surfaces may be flooded with warm or cool air, while others — where furniture is pushed up against a wall, for example — may remain almost unchanged (**Figure 7**). In these cases imaging should be done from the interior only.

Solar confusion. A potentially major complication is the

Incorporating IR Into Your Business

Developing proficiency with an infrared camera can benefit a builder or remodeler in a variety of ways, leading to happier customers and higher profits. When you're bidding on a remodeling job, for example, you can use good IR imagery to locate existing insulation and framing members. That can mean more accurate estimates and better, smarter bids. After insulation and air-sealing measures are complete, you can verify placement and performance and document both, reducing comfort-related callbacks. The resulting images will have value for the life of the building. They can be given to the homeowner as a value-added upgrade, or sold as an additional service.

I encourage energy auditors to include thermography as an extra-cost add-on or as value added; either way it can give you an advantage in a competitive market. Since IR will allow you to do your audit more quickly and effectively, you may choose simply to pass along those savings. You wouldn't do an audit without a stepladder, and you shouldn't do one without an imager.

For most general contractors, the best way to make IR pay is to roll it into your existing scope of services, rather than offering it as a stand-alone. As a stand-alone you'd be competing with others who specialize in home-energy audits, typically for about $200 to $500. It's very tough to compete at that price.

If you're an insulator or a GC who does your own insulation work, you will definitely want to integrate this service. If you learn to use the system effectively, you can expect to pay for it in the first dozen jobs. If you sub out your insulation work, the payback may be slower. But again, rolling it into your existing work processes will provide the greatest return, by providing quality control and allowing you to stand out from competitors who aren't similarly equipped.

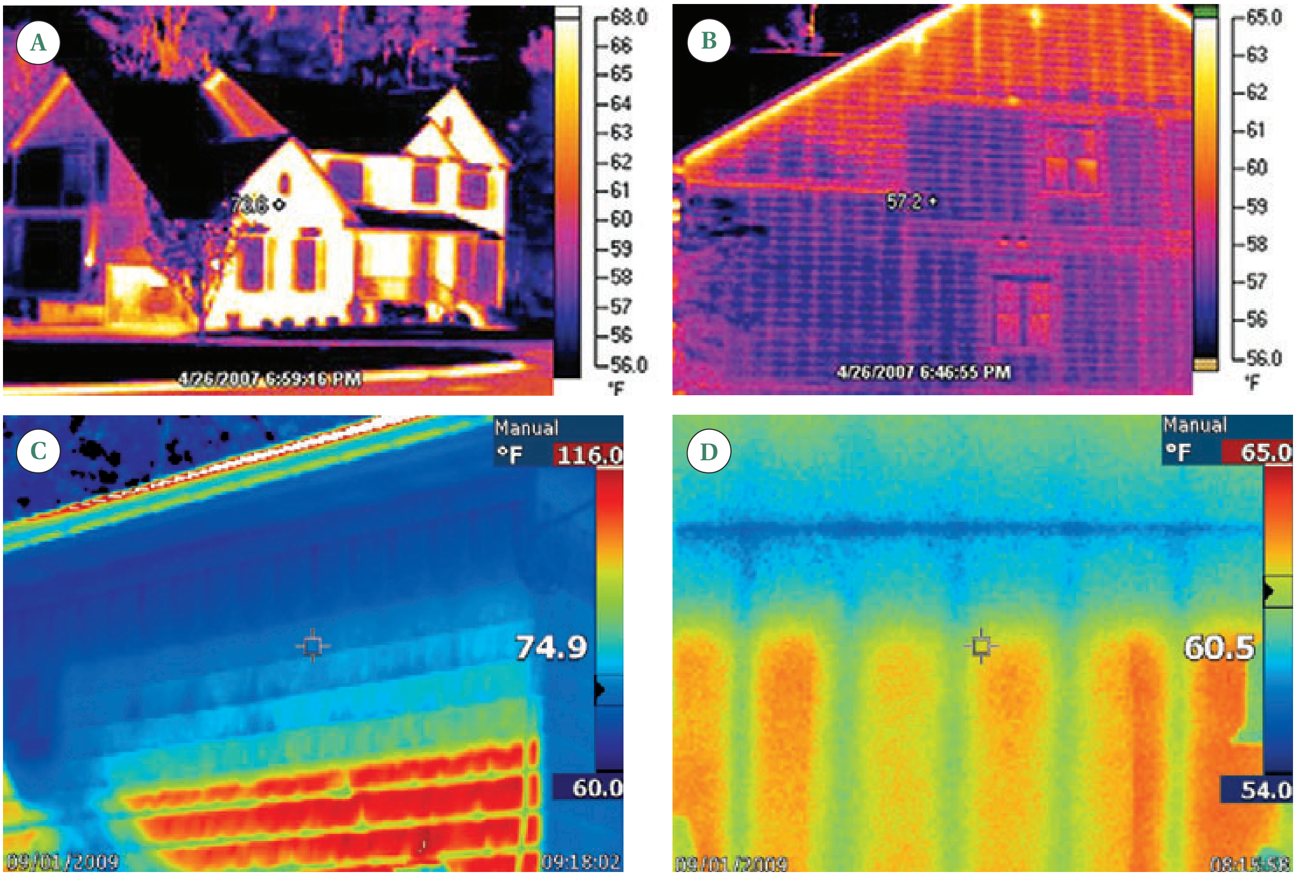


Figure 8. Daylong exposure to sunlight has loaded the south-facing wall of this home with stored heat (A). In the image, taken soon after dark, the roofing has radiated most of its heat to the night sky. The air-conditioned living space in the structure in image B can clearly be distinguished from the uninsulated attic; although the image was taken after dark, the framing in both areas is visibly warmer than the fiber-cement siding, because it retains heat from the warm day. The effect of sunlight on a wall with an eaves overhang is frequently evident from outside (C), and may also be visible on an interior wall (D).

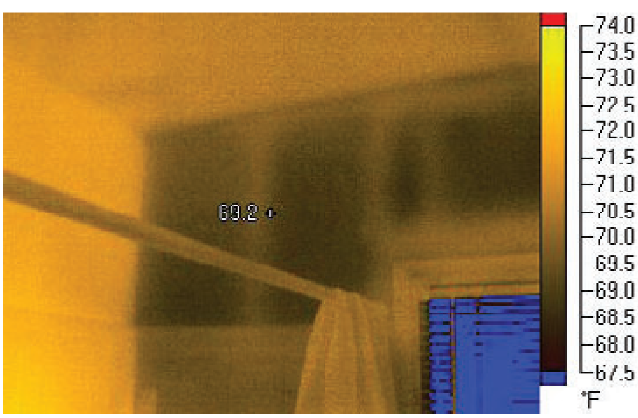


Figure 9. The relatively warm studs in this uninsulated exterior wall are conducting less heat to the outdoors than the framing cavities between them. Note the contrast with the partition wall at left and the insulated ceiling.

heating of the sun. Inside and out, in both summer and winter, too much sun can wreak havoc on otherwise acceptable conditions. Direct sunlight will quickly make exterior inspection work impossible by heating surfaces enough to overwhelm the subtle temperature differences that result from heat transfer through the building envelope (**Figure 8**).

Retreating to the inside may help, but the effect of the sun will show up there too — although delayed somewhat — with potentially confusing results. Thanks to a phenomenon known as capacitance — essentially the difference between various materials' capacities to change temperature — problems can persist well into the evening, long after you might imagine solar loading could possibly be an issue.

A little knowledge is a dangerous thing. I still wince at the memory of a winter evening early in my career when I'd been called in to confirm that a newly constructed cathedral ceiling

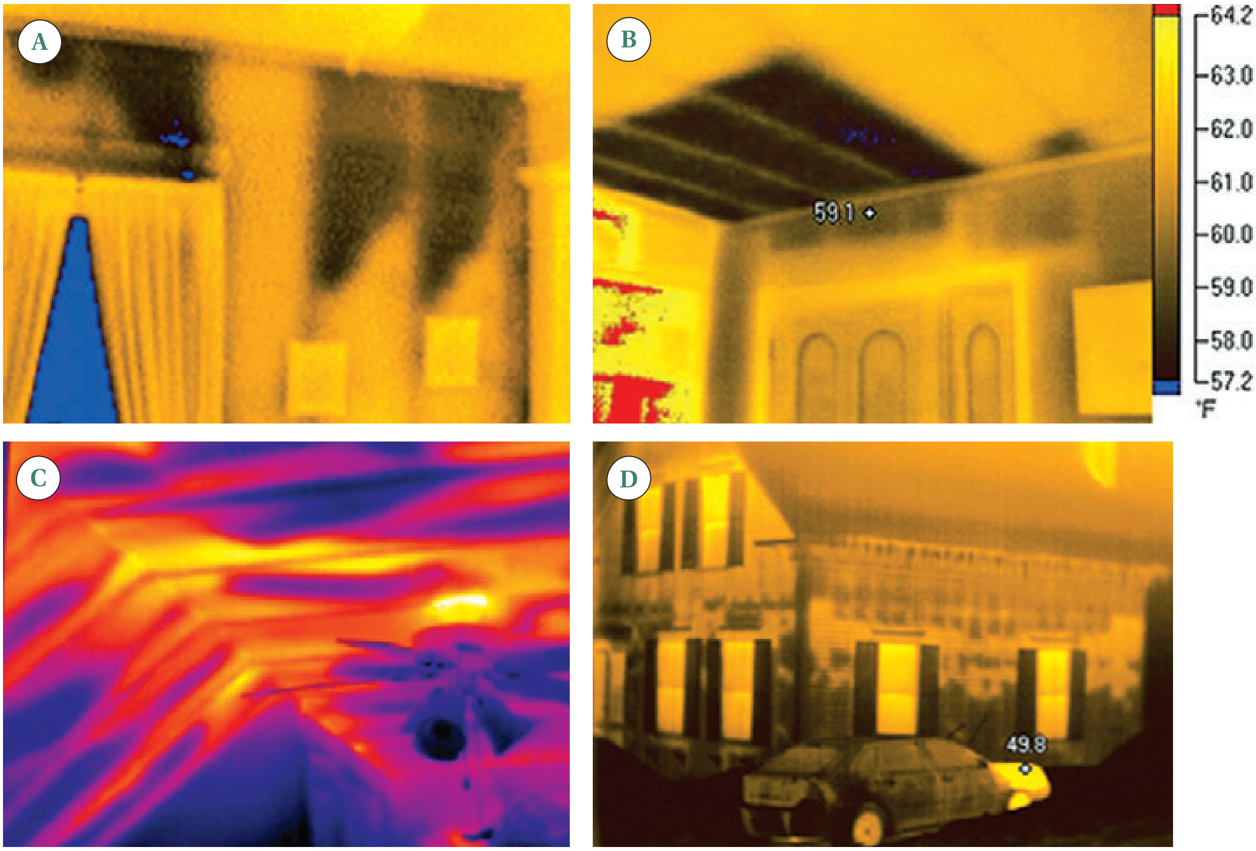


Figure 10. Under the right conditions, thermal images clearly show insulation problems. Shown here are partially filled wall cavities typical of poorly installed loose-fill cellulose (A); uninsulated exterior walls, which the homeowner knew about, and an area of missing fiberglass batts in the ceiling that he did not know about (B); an inept fiberglass batt installation in a flat and sloping ceiling (C); and a hit-or-miss cellulose job (D) — a problem that has become less common thanks to dense-pack equipment and improved blowing techniques.

had been properly insulated. Looking through the viewfinder at the north-facing side of the ceiling, I could see the expected pattern: The rafters clearly stood out as cooler than the framing cavities, indicating to me that they were conducting more heat to the outdoors than the insulated cavities. On the south side of the room, though, the picture was exactly the opposite: The cavities looked cooler than the rafters, which I took to mean that the rafter bays were uninsulated, allowing them to lose heat to the outdoors faster than the surrounding lumber.

I confidently announced to the owner that the south side of the ceiling was not insulated. The contractor — who happened to be standing next to me at the time — thought about that for a few seconds, then reached up and jabbed his hammer through the drywall in the "uninsulated" half of the ceiling, revealing the fiberglass beneath. "I insulated both sides," he said mildly.

Where did I go wrong? I eventually figured out that all through that winter day, direct sun beating on the south side of the roof had actually been pumping heat into the structure. That reversed the usual wintertime heat flow, causing the south-facing ceiling to radiate heat into the room, especially at the framing members, which have less thermal resistance than insulation (**Figure 9, previous page**). After sunset, the insulation and drywall — having

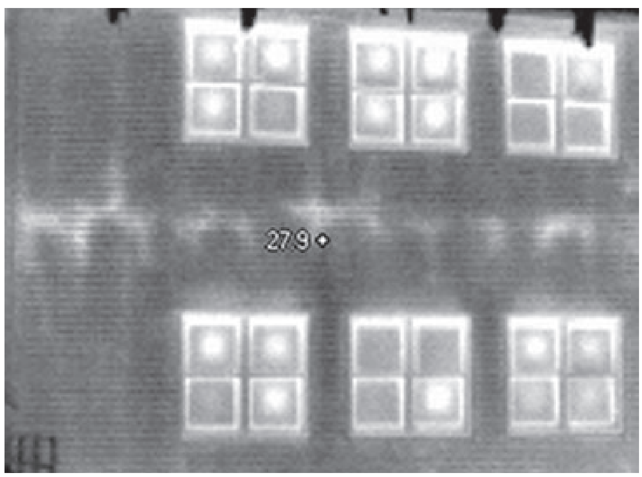


Figure 11. Voids in the insulation are clearly visible in the band-joist area of this two-story home. The characteristic "bull's eyes" on the window glazing are an early indication that the inert gas fill has become depleted, allowing the double panes to squeeze together near the center. IR can readily detect this problem — which is otherwise difficult to spot — and enable a builder or homeowner to make a claim with the manufacturer before the expiration of the window warranty.

little thermal mass — cooled to room temperature more quickly than the lumber, which retained its heat long enough for me to put my foot in my mouth.

Performing an Inspection

When I arrive at the site of an inspection, I typically start by scanning the structure from the outside, if there's no sun and enough delta-T for that to work. If I can see the framing, I'll often be able to see any missing insulation as well (**Figure 10, previous page**). A quick scan from the outside can also reveal problems related to damaged or deteriorating multipane glazing **(Figure 11, previous page)**.

If temperature conditions let you work from the exterior, you can usually quickly get an overall sense of the building. In some cases — when conditions are good — it's possible to conduct an entire inspection from the exterior. But a more detailed assessment will ordinarily require imaging from inside, which is slower because it involves working around furniture, partitions, and other obstructions. I work methodically from room to room and note any problem areas as I encounter them, manipulating the indoor temperature as needed.

Finding air leaks. Insulation problems can easily be seen at ambient pressure, but air leaks show up much more effectively — and uniformly — if you can depressurize the building **(Figure 12)**. We prefer to use a blower door for this, because we also want to be able to calculate the air infiltration volume; in a pinch, though, any large fan — even a whole-house fan or kitchen exhaust fan — can be used, often with acceptable or even good results.

As soon as the home has been depressurized (before doing so, make sure it won't cause backdrafting of any combustion appliances), it's easy to see air leaks from inside. Most leaks will show up quickly, but in areas where air is being tempered by a "plenum" (such as a knee-wall cavity) they may not become evident for up to 20 or 30 minutes.

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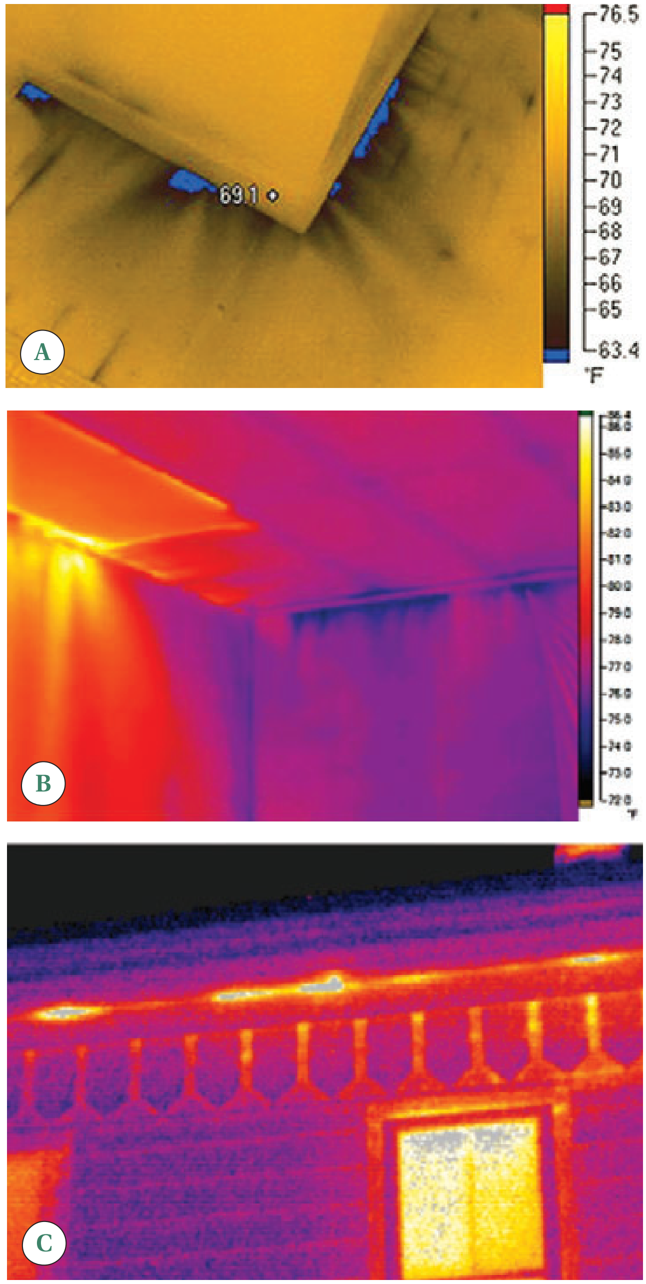

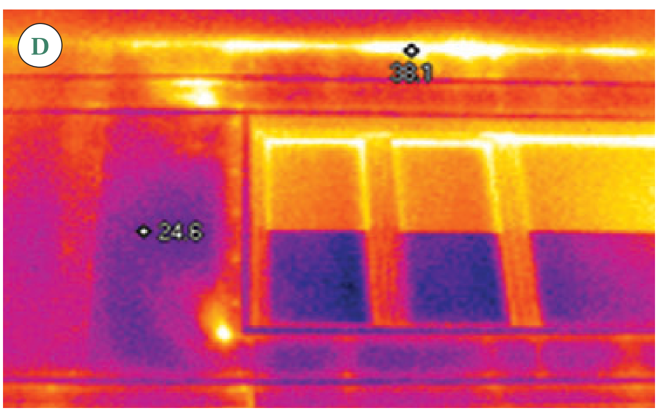

Figure 12. Depressurizing a structure with a blower door reveals characteristic "fingers" of infiltrating outside air, as can be seen underneath this baseboard (A). Infiltration paths aren't always so straightforward: In image B, cool air — probably drawn up from the basement — flows from one intersection of a wall and ceiling, while warm air infiltrating from the attic is visible a few feet away. Exfiltrating warm air from a heated building often shows up as "hot spots" around the eaves (C, D). Note also the air leaks at the window heads (D); the cooler rectangles at the bases of the windows are exterior screens.