A Builder's Guide to

Low Cost, High Performance Upgrades

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Why You Need Blower-Door Testing

Understanding where structures leak is the first step toward building tighter, more energy-efficient homes

BY RANDY WILLIAMS

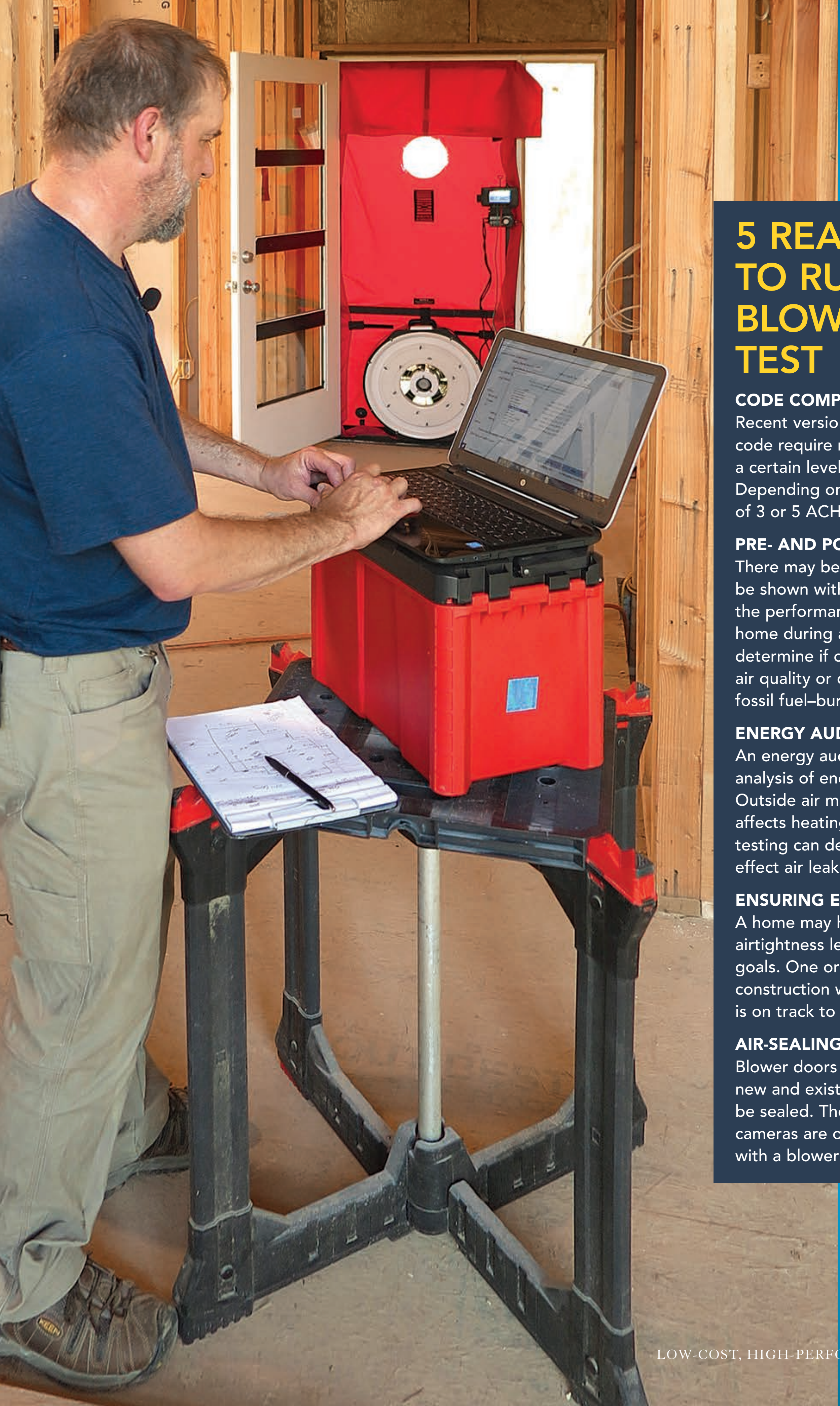
I bought my first blower door in 2009, when new construction was in a downturn and energy auditing and weatherization projects were on the rise. I took a 40-hour course in energy auditing at a local college that included hands-on blower-door training. It took many tests before I became comfortable using it and understood the information it was providing. Though it's one of the more expensive tools I own, I've been able to keep it busy and to add this specialized testing to my business's income stream—as well as improve the airtightness of my own projects.

The main purpose of a blower door is to test the integrity and continuity of the air-control layer, or air barrier. The test is conducted by either pressurizing or depressurizing a building to a specific pressure, typically 50 pascals, and measuring the cubic feet per minute (cfm) of air moving across the fan. The cfm can then be added to a formula to calculate the air changes per hour at 50 pascals (ACH50). For the house shown in the photos, we were checking airtightness and looking for leaks before the walls were insulated, but there are other reasons to perform blower-door tests (sidebar, facing page). What follows is an explanation of how the process works.

Equipment for measuring airflow

There are two manufacturers making blower-door test equipment in North America—The Energy Conservatory (TEC) and Retrotec—and their designs are similar. There's an adjustable frame that fits in most door and some window openings, a nylon panel that fits over the frame, a powerful fan with adjustable flow rings or range plugs that change the size of the fan opening, and a manometer that measures pressure and airflow.

The latest versions of both companies' manometers are very versatile and intuitive. Basically, they are small computers designed specifically for blower-door testing. Both offer several different ways to control the equipment, simply with the



5 REASONS TO RUN A BLOWER-DOOR TEST

CODE COMPLIANCE
Recent versions of the building code require new homes to achieve a certain level of airtightness. Depending on location, a test result of 3 or 5 ACH50 is likely required.

PRE- AND POST-REMODELING
There may be opportunities that can be shown with the test to improve the performance of an existing home during a remodel. You can also determine if changes will hurt indoor-air quality or cause backdrafting of fossil fuel–burning equipment.

ENERGY AUDITS
An energy audit is an inspection and analysis of energy flow in a building. Outside air moving through a home affects heating and cooling costs; testing can determine how big an effect air leaks have on these costs.

ENSURING ENERGY GOALS
A home may have a target airtightness level to achieve design goals. One or more tests during construction will confirm if the home is on track to meet these goals.

AIR-SEALING
Blower doors can help find leaks in new and existing homes so they can be sealed. Theatrical fog and infrared cameras are often used in conjunction with a blower door to find leaks.

MEASURE THE HOUSE

MEASURE THE EXTERIOR Use measuring wheels and laser measures to calculate a home's exterior size. While doing this, make note of any likely sources of air leaks.

CHECK EXTERIOR PENETRATIONS Exhaust, dryer, and plumbing vents, electrical chases, and any parts of the heating and cooling system are likely spots for air-sealing before or after the test.

LOCK WINDOWS AND DOORS Close and lock all windows and exterior doors, which seal better when locked. Interior doors should remain open.

TURN OFF MECHANICALS The blower-door fan can cause combustion appliances to spill flue gasses, including carbon monoxide, so turn off all HVAC equipment, including ventilation fans.

MEASURE THE INTERIOR Use a laser measuring device to calculate the home's interior volume in cubic feet. This is often the most time-consuming part of the test.

manometer and speed control or by connecting to a computer, tablet, or smartphone. When connected to a device, software supplied by the two companies will control the test and also generate a test report.

Preparing inside and out

I always follow the same procedure when preparing for a blower-door test, which prevents skipped steps. I start by walking the exterior of the home. This gives me an idea of the shape of the structure, which may not always be evident from the interior. While on the outside, I look for any penetrations through the air barrier, which will be the most likely spot for air leaks.

After moving inside, I follow the same process of inspecting the home, taking note of potential problem areas and checking all windows and exterior doors to make sure they're closed. All interior doors within the conditioned space of the home must be open. Doors separating conditioned and unconditioned parts of the house, access panels, and attic hatches should be closed.

I turn off any heating and cooling equipment, fossil fuel–burning equipment, exhaust fans, and dryers. I leave my car keys near the controls so I can't leave without turning this equipment back on. I also make sure any fireplace or woodstove fire is out and that any ash is cold and contained; otherwise, it could be sucked into the living space.

I then move on to measuring the home's volume. The Residential Energy Services Network (RESNET), which helps set standards for blower-door tests, suggests that all measurements be taken from the exterior dimensions. I prefer to take all measurements from the interior, however. This gives me a chance to see all of the interior finish material, which is often part of the (if not the main) air-control layer. Measuring from the interior also simplifies the process. I use a laser measuring device, which is easy to see indoors.

I begin by measuring the square footage of the floor area, and then I multiply that number by the height of the building. The calculation is seldom that simple, though. Convoluted designs, varying ceiling heights, and cathedral ceilings all complicate measuring the volume.

Running the test

Once the measurement is complete and entered into the software, I assemble the blower door and connect the digital manom-

ASSEMBLE THE DOOR

INSTALL THE DOOR
Assemble the door's metal frame, and place it on top of the fabric cover before placing it in the opening. Make sure the frame is tight to the opening, and run the outdoor tube before placing the blower in the opening.

ATTACH THE FAN
The blower-door fan forces air in or out of the house and creates a pressure difference. It has a variable-speed motor and an adjustable aperture so that it can measure homes of various sizes and airtightness levels.

CONNECT THE GAUGE
A digital manometer measures the amount of pressure (in pascals) inside and outside the house. Flexible vinyl tubes convey the fan pressure to the manometer and measure the reference pressure with a tube that runs outdoors, its end at least a few feet beyond the house.

eter to my phone, which is now my preferred way to conduct most tests. I choose the exterior door where I'll install the blower door based on wind speed and direction. Wind can have a large effect on the test result, and the blower door should be on the leeward side of the building when winds are greater than 5 mph.

After the equipment is set up, I input some additional information into the software. This includes the indoor and outdoor temperatures (that becomes important when there is a 30°F or larger difference between inside and outside) and the elevation (important above 5000 ft.). Then I can begin the test by taking a baseline pressure. The baseline pressure, which can be positive or negative, is the difference between inside and outside the home and will be accounted for with an automatic adjustment by the equipment software.

After the baseline adjustment is complete, the test prompts me to remove the appropriate flow ring or range plug, which adjusts the size of the fan opening to match the expected leakage rate of the home. If the fan cannot reach pressure, another ring or more range plugs will need to be removed, or if the fan is moving at too slow of a speed to register flow, either the size of the flow ring will need to be reduced or a smaller range plug will need to be installed.

Occasionally, a home may be so leaky that a single blower-door fan will not be able to reach the desired test pressure. When this happens, there are two choices. The first is to use a second fan (or more) to move more air. In a residential setting, this option is rarely used. A second choice is to extrapolate the test pressure. This can be done mathematically, but it is easier to have software calculate the "can't reach 50" number along with the estimated cfm.

Single- vs. multipoint testing

I do multipoint testing on nearly every test I perform. The multipoint test I most often use is the ANSI/RESNET/ICC 380 standard, which starts the test at a 60-pascal difference in pressure and reduces this to 10 pascals; at least five test pressures at equally spaced intervals are required. Each of the test-pressure samples is to be recorded and averaged over a 10-second interval.

I feel this test is accurate and repeatable, and it supplies me with the most accurate effective leakage area (ELA) data. ELA is

RUN THE TEST

ESTABLISH BASELINE
Outdoor temperature, atmospheric pressure, and wind can affect test results. Compensating for natural pressure differences inside and outside the house is part of calibrating the manometer, a process called "establishing baseline." The process has gotten easier as manometer technology has improved.

the cumulative area of air leaks in the shape of a smooth hole. Basically, this gives us an idea of how big a hole is in the building's shell at a natural building pressure. This is a handy visual for homeowners.

There is also the option to conduct a single-point test, which requires only a baseline and then conducts one test sample at 50 pascals with at least a 10-second average. Both test results are supplied in cfm of airflow across the blower-door fan. If you're using Retrotec or TEC software to control the test, it will calculate the ACH50 and cfm per sq. ft. of surface area if the building-size information is supplied. If you're not using software, you'll have to do the calculations yourself.

What can go wrong?

The key to performing an accurate test is inputting accurate data into the formulas or software. Measuring a home for its volume, and to a lesser extent its surface area, can be a challenge. An error in the volume calculation will have an effect on the test results that confirm whether a house has reached code-required levels of airtightness. Temperature, elevation, and wind can also affect the precision of a blower-door test. Using software will improve accuracy; a manual test will require these conditions be taken into account.

Another mistake I've caught myself making is having the wrong setting in the software or manometer for the ring size or number of range plugs. This setting changes a calculation in the manometer as to how many cfm are moving through the fan. I now double-check those settings in the software or manometer so that they match the equipment settings. It takes practice using a blower door to feel like you know what you're doing, but it gets easier with time. □

Randy Williams is a builder and energy auditor based in Grand Rapids, Minn. Photos by Travis Brungardt.

TESTING
With the house prepped and the blower door ready, it's test time. The latest generation of manometers are Bluetooth-enabled, allowing you to control blower speed, monitor and receive test results, and stop the test from a laptop or phone. Modern manometers and their software also make generating reports for clients, builders, and code officials much easier.

TRACK DOWN LEAKS

SMOKE OUT THE LEAKS
A chemical smoke pencil such as this Fog Puffer from TEC allows you to see small amounts of leakage. Penetrations like this electrical service are common sources of air leaks.

FIND IT ON INFRARED
If indoor and outdoor temperatures are sufficiently different, you can see air leaks as changes in surface temperature. More-expensive cameras can detect smaller temperature variations.

FILL IT WITH FOG
If you fill an interior space with theatrical fog and pressurize the house with a blower door, you can often see the fog escaping through air leaks from the outside. Consumer-grade fog machines are available for less than $100.

AIRTIGHT MEASUREMENTS

The data used to designate the airtightness level of a home is communicated in the following industry shorthand.

CFM50
This number represents the cubic feet of air moving across the fan per minute at the test pressure of 50 pascals. This is the most important information supplied by the blower door. We need this number to calculate the ACH50 and cfm50/ft² described below. I have seen numbers as low as 100 cfm50 (a very tight home) and as high as over 5000 cfm50 (very leaky). To be meaningful, the cfm50 metric must also consider the surface area of the home's exterior and its conditioned volume.

ACH50
ACH50 stands for air changes per hour at 50 pascals. Think of the volume inside a structure—the ACH50 number indicates the number of times that all inside air is exchanged with outside air per hour under test conditions. A home that tests at 3 ACH50 will exchange all its inside air with outside air three times per hour at the test pressure of 50 pascals. The formula for figuring out ACH50 is cfm50 x 60 minutes ÷ volume of the structure.

New houses being tested need to meet the code requirement of 3 or 5 ACH50 or less depending on location in the country. When testing existing buildings in my climate, I like to see results under 5 ACH50. Higher results mean there is an opportunity to increase comfort and reduce energy costs. The best test that I ever conducted was 0.33 ACH50, and the worst was just over 15 ACH50.

CFM50/FT²
Air leakage happens through surfaces, yet building codes require testing to be reported as a volume calculation. Many testing professionals and building scientists prefer the information shown as cubic feet per minute per square foot of surface area of the home, or cfm50/ft². A test of 3 ACH50 will be the rough equivalent of 0.15 cfm50/ft². There isn't an exact relationship between volume and surface area; it's dependent on the size and shape of each home.

Secrets of Thermal Imaging

Seek Thermal Compact

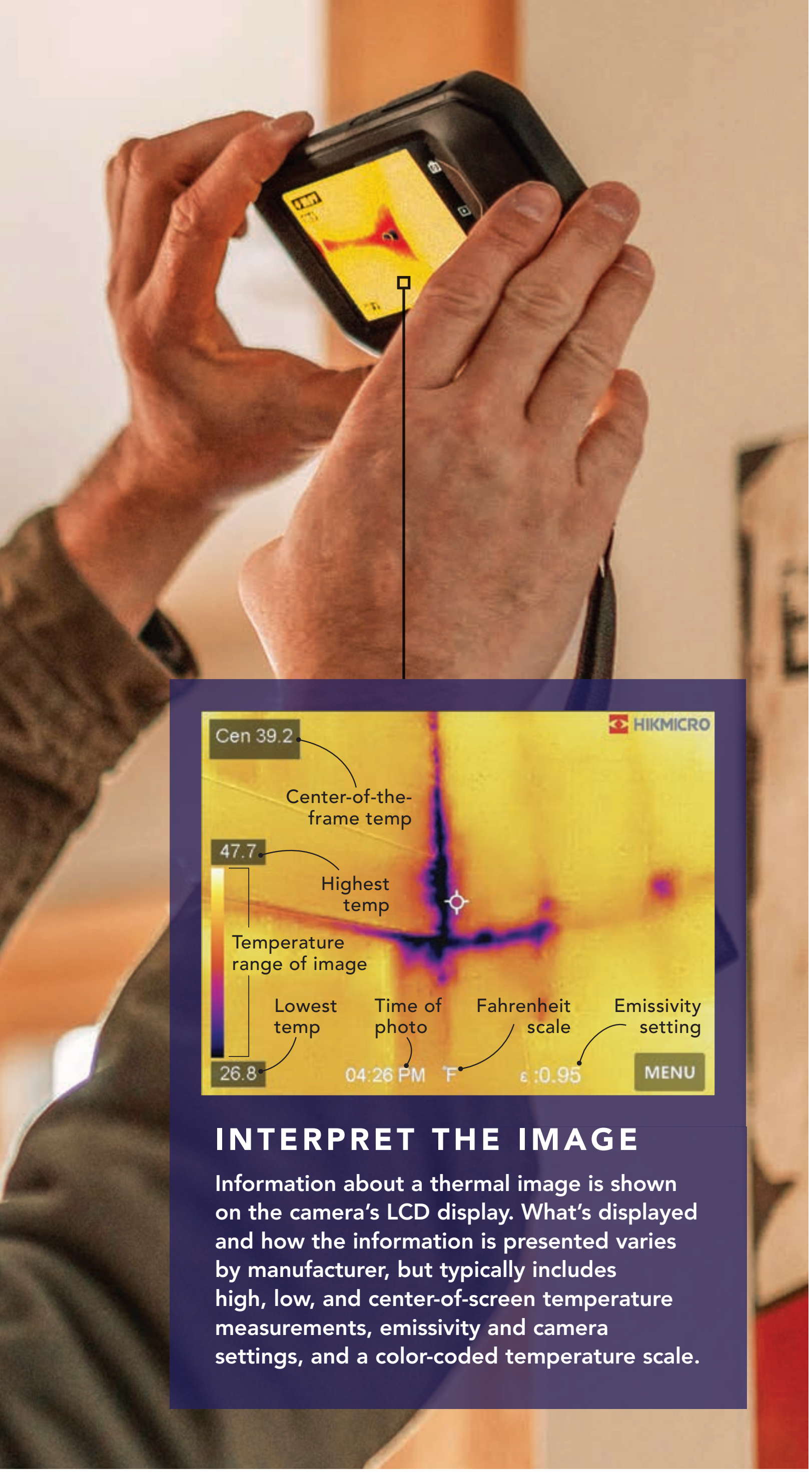
3 CAMERA CATEGORIES

Smartphone attachment
Best for DIYers and occasional use, the smallest and least costly IR camera option is a thermal imaging attachment for a smartphone. These tiny devices plug into the charging port of the phone, so you need an Android- or iPhone-compatible plug-in to match your phone. Prices start around $200 and climb to $400, with more expensive versions offering better resolution.

Hikmicro Pocket 2

Point and shoot
A dedicated thermal imaging camera runs between $500 to $1000. These types of cameras have better image quality and more standard features than the smartphone attachments. These sturdy cameras are meant for the typical work of energy auditors, building professionals, and maintenance personnel who need IR imaging for building diagnostics, repair, and maintenance.

Photos: top, courtesy of Rockwool; product photos, courtesy of the manufacturers.



INTERPRET THE IMAGE

Information about a thermal image is shown on the camera's LCD display. What's displayed and how the information is presented varies by manufacturer, but typically includes high, low, and center-of-screen temperature measurements, emissivity and camera settings, and a color-coded temperature scale.

Pistol grip

Entry-level pistol grip cameras cost about the same as point-and-shoot models ($500 to $1000) and have similar resolution and features, but in an arrangement that you can aim and operate easily with one hand. More expensive ($1000 or more) versions have better image quality and can more accurately measure smaller differences in temperature for industrial maintenance and advanced building diagnostics.

Flir E76

Diagnose comfort problems and building deficiencies without tearing the house apart

BY RANDY WILLIAMS

My thermal imaging cameras are my most-used tools. I use them to find missing and poorly installed insulation in walls and ceilings, to detect air leakage during blower-door tests, to look for leaking pipes and roofs, and even just to explore the temperatures of everything around me. I purchased my first thermal imaging camera in 2009. It was an Extech i3 made by Flir. The $1200 camera had a resolution of 60x60, 3600 pixels, and no digital overlay.

If you don't understand any of those terms, that's OK—you will have a basic understanding of thermal imaging by the end of this article. But know up front that you can now purchase a camera with twice the resolution of my 2009 camera for $600 or less.

Let's start with a common misconception. A thermal imaging camera cannot see through walls like they show on bad TV. Thermal imaging cameras are a type of infrared (IR) camera that measures heat emitted by objects. In other words, thermal imaging "sees" differences in temperature within the camera's field of view. You can see by these different surface temperatures where there is thermal bridging in a wall assembly. You might see wet or even slightly damp areas. Though they are only one type, thermal imaging cameras are often called IR cameras by those in the building industry, and I use the terms interchangeably.

To use an IR camera for building diagnostics, you need a temperature difference (Delta T) between inside and outside the structure of at least 10° or everything in the IR image will appear the same color with little information to be learned from it. Bigger temperature differences are easier to discern and create a more dramatic thermal image. If the indoor and outdoor temperatures are less than 10° different, you may need the air movement of a blower door to exaggerate temperature differences enough to see them.

A camera's resolution and its pixel count determine how clear an IR image is. The bigger the numbers, the sharper the image. The images from my Extech i3 were pretty blurry. My Hikmicro Pocket2 has a resolution of 256x192 with 49,152 pixels, which is a huge improvement. A high-end camera might have a resolution of 640x960 and more than 300,000 total pixels.

There are several manufacturers selling thermal imaging cameras that work well for the construction trades. Flir (now Teledyne Flir) is the best known. Hikmicro is another popular brand. Seek and Fluke also make cameras suitable for the job site. All of the manufacturers I know offer software that you can use to manipulate images for better clarity and to create reports. IR cameras are informative, fun-to-use tools—and considering their steady reduction in cost and increase in performance, I think every conscientious builder should have one. □

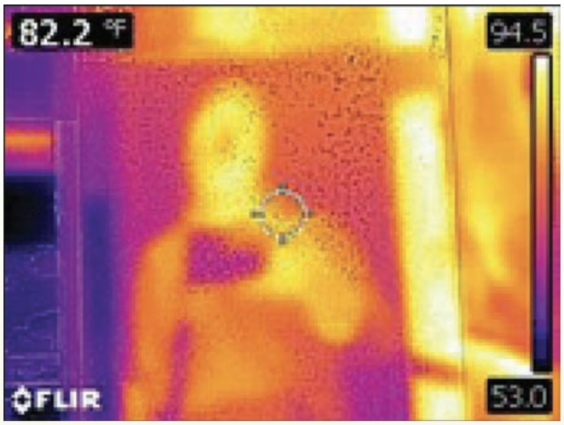
Randy Williams is a builder and energy auditor in Grand Rapids, Minn. Photos by the author, except where noted.

UNDERSTAND WHAT YOU'RE SEEING

Effectively using IR photography requires correctly interpreting the image. Mistakes can happen because of shiny materials, solar gain, and misdiagnosing whether a material or assembly is cold or wet. Here are the main camera settings to adjust and considerations to make when collecting thermal images.

EMISSIVITY

Emissivity is a measure of how efficiently an object radiates heat. Shiny materials reflect heat and have low emissivity whereas dark-colored materials absorb heat and have a high rate of emissivity. Objects with different emissivity values may appear differently in thermal images, even if they are at the same temperature. Matching the emissivity of the material being photographed to the camera's emissivity settings will make the temperatures in the image more accurate. Emissivity settings can be adjusted in the camera settings, and there are charts online with emissivity values of common building materials.



Be aware that a thermal image taken of shiny metal, mirrors, or glass will reflect the infrared radiation away from the camera, creating bright spots and inaccurate temperature readings in the image. If you need to accurately know the temperature of shiny surface, placing a black piece of tape on the object being measured will help.

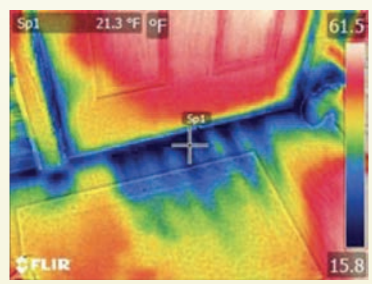
MATERIAL	EMISSIVITY	MATERIAL	EMISSIVITY
Polished steel	0.07	Planed oak	0.885
Galvanized steel (new)	0.23	White EPDM	0.90
Aluminium paint	0.27-0.67	Rough plaster	0.91
Iron	0.70	PVC	0.91-0.93
Oxidized copper	0.78	Glass	0.92-0.94
Oxidized steel	0.79	Paint	0.92-0.96
Galvanized steel (weathered)	0.85	Wrought iron	0.94
Smooth concrete		Unpainted pine	0.95
Black EPDM	0.86	Tile	0.97

LEVEL AND SPAN

Level and span settings allow you to adjust the temperature range seen in the thermal image. Keeping the level setting—the temperature that represents the midpoint of the range—the same and narrowing the difference between the highest and lowest temperatures—the span—can help to clarify what you are seeing in an image. Adjustments can be made in the camera settings before the photo is taken, or after in the camera manufacturer's photo-editing and reporting software, as was the case with this image. By narrowing the temperature span (as indicated by the colored bar on the right side of the images), we can more easily see hot and cold spots in this home.

PALETTE

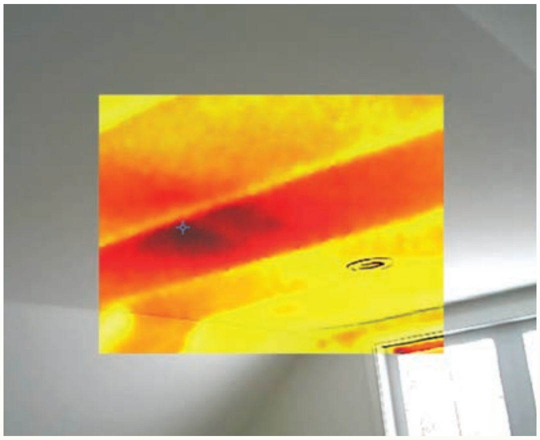
Palette settings adjust the image color before the camera has taken the picture or after in the reporting software. Manufacturers call color settings by different names; the options seen here are found on Teledyne Flir cameras. Changing palette settings may make thermal images easier to understand for clients, who can easily equate red with warm and blue with cold.



DISPLAY

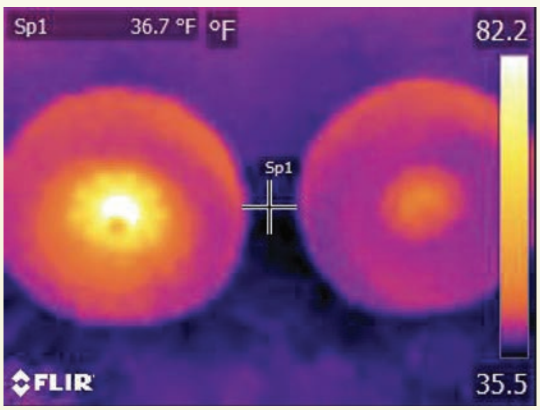
Picture-in-picture mode

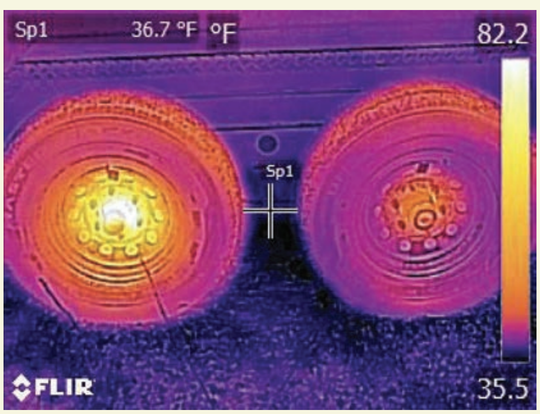
Picture-in-picture display can provide context for building problems by showing IR images within a larger photographed image. In this example from Hikmicro, the thermal image is centered with the digital image surrounding.



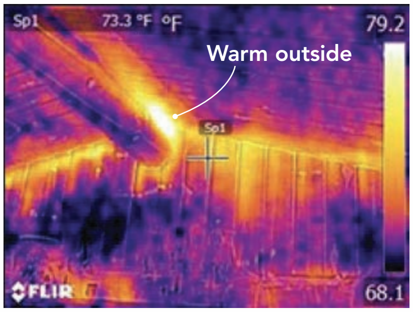
Overlay settings

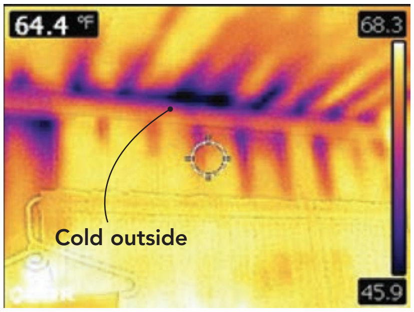
An overlay feature, which may go by a different name depending on the manufacturer, also makes thermal images easier to understand by showing greater detail than the thermal image alone. It's hard to tell if the top image is a hot donut or a truck tire, but it becomes much clearer with the digital overlay shown below it.





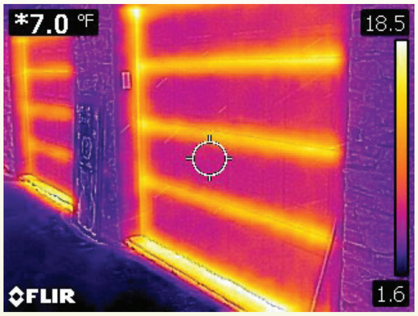
GATHERING THERMAL IMAGES





Anticipate what you should see

When you use your camera to look for or diagnose building problems, have an expectation as to what you think the thermal image should look like before taking the picture. As an example, if the temperatures are cold outside and warm inside, an air leak should look like the image on the right. Cold air from a blower door test is being sucked into the heated home. Blower-door testing an air-conditioned home in warm weather should look like the photo on the left. In this case, warm air is being sucked into the house. If you see something you didn't expect, investigate as to why. You may be seeing wetness, or air being pulled from a neighboring dwelling unit that's hotter or colder than the one you're examining.



Make a matched set

Even with digital overlay or picture-in-picture options to clarify IR images, it's always helpful to make a matched set of IR and regular photographs for the most complete reports and contract documents. More-expensive IR cameras can take conventional high-resolution photographs and IR images at the same time, but it's not difficult to make similar documentation with an inexpensive IR camera and your smartphone or a conventional digital camera.

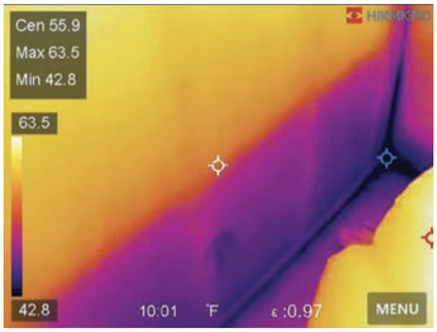
Consider solar gain

It is important to understand how the sun shining on surfaces can affect an image. This exterior photo was taken with outdoor temperatures at –10°F. The left side of the home is shaded with the right side in full sun. You can see how the siding is being warmed by the sun. You can also see how the shadows from the trees lower the siding temperature in spots. If this home is poorly insulated, we may see temperature variations on exterior walls inside the house because of what's happening on the outside.

DIAGNOSE PROBLEMS

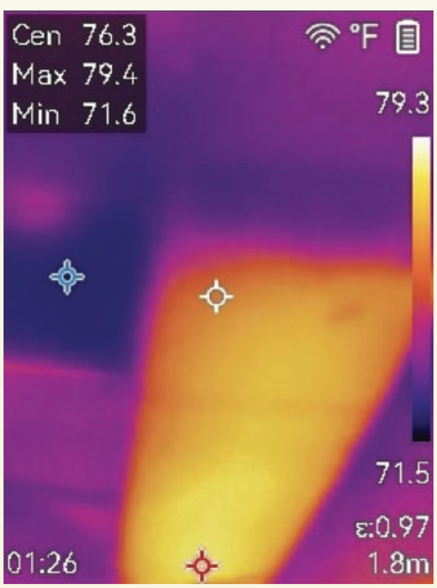
Once you're proficient with an IR camera's controls and understand the images it produces, you can use it to see air and water leaks, locate pipes and framing, and spot missing or ineffective insulation.

SPOT THERMAL DEFICIENCIES



Thermal stratification

Thermal stratification is a phenomenon I see on occasion. This appears as a distinct line showing where warm air has risen in a structure and cold air has settled. What appears as stratification could also indicate a change in the R-value of the assembly, where more conductive materials, like concrete or steel, show up as hotter or colder than the surrounding area. But sometimes, what looks like stratification can actually be missing insulation.



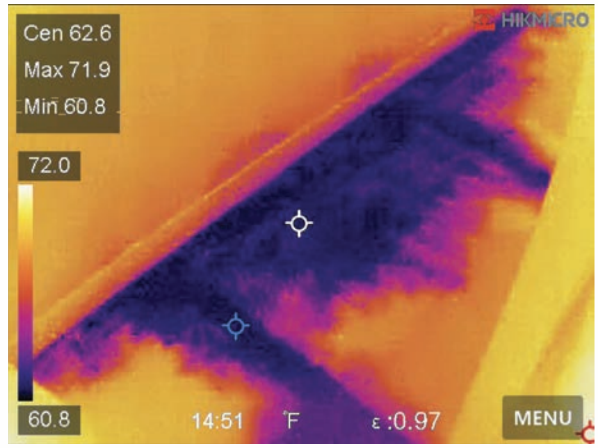
Missing insulation

Missing batt or wind-washed loose-fill insulation will appear significantly colder or hotter than the surrounding area. In IR images, missing insulation has sharper edges than air and water leaks and often takes the shape of a framing cavity.

TRACK DOWN MOISTURE

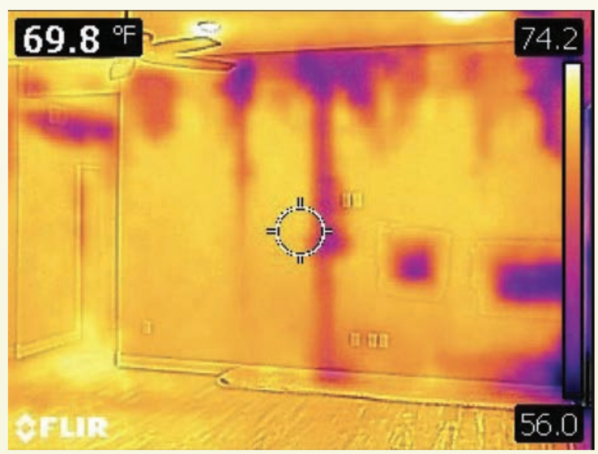
Water leaks

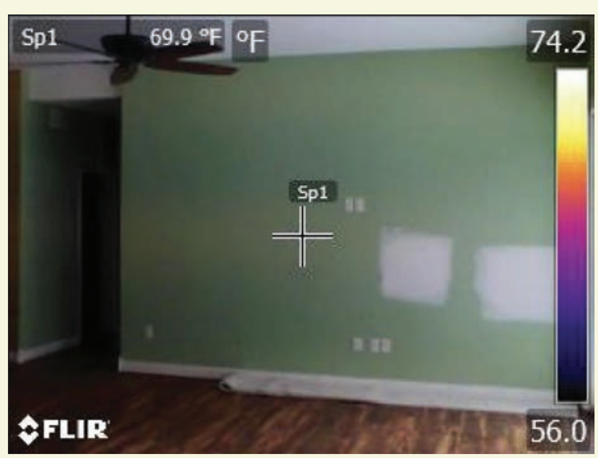
Infrared images don't detect moisture, but instead they pick up on the colder temperature that results from evaporation. Wet surfaces will appear colder than the surrounding area. Small flashing and enclosure leaks are easier to spot when surface temperatures are higher, from artificial heat sources or from solar gain.



Cold vs. wet

Sometimes it can be hard to differentiate between a cold surface—perhaps because of missing insulation, air leaks, or thermal bridging—and a wet surface. These photos show two different thermal conditions. The two square areas on the right are drying drywall patches. The rest of the purple areas are from cold air moving into the wall cavities from the vented, unconditioned attic above. This photo was taken during a blower-door test. When I suspect something is wet, I use a moisture meter to confirm.

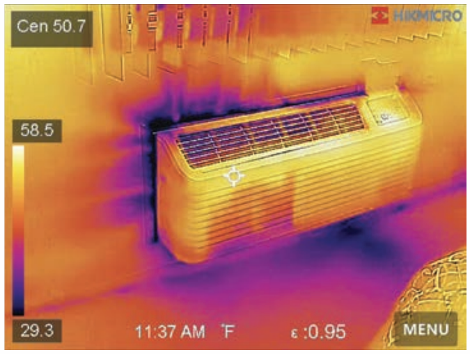




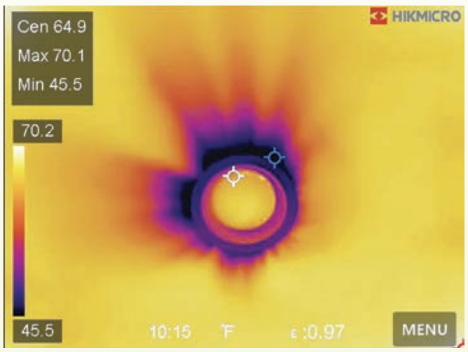
Photos this page bottom left, facing page bottom left and top right: Patrick McCombe

IDENTIFY AIR LEAKS

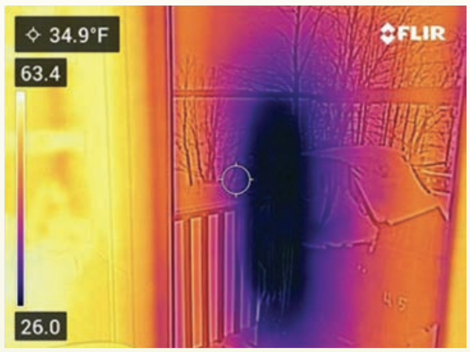
Bypasses
This image shows a significant air leak during blower-door testing. You can see how the incoming exterior air moves through the ceiling. IR cameras are a big help in blower-door-directed air-sealing, but you can learn a lot without a blower door if there's a big difference between indoor and outdoor temperatures.



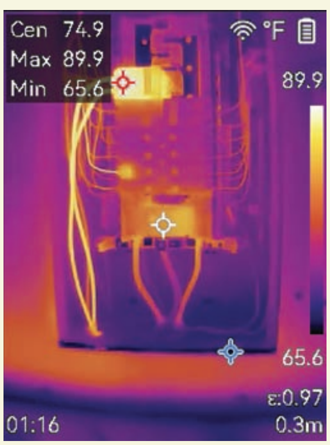
Around penetrations
If you've ever wondered why it's hard to keep your hotel room comfortable, this image is a good demonstration. It shows the air leaks around a packaged terminal air conditioner (PTAC), the kind of system favored by affordable hotel chains because they're inexpensive and offer individual control.



In assemblies
Efficiency experts and home-performance experts and enthusiasts often talk about the energy hit associated with conventional recessed light fixtures like this one. The air leaks add to both heating and cooling loads and are often a source of drafts that lead to comfort complaints.



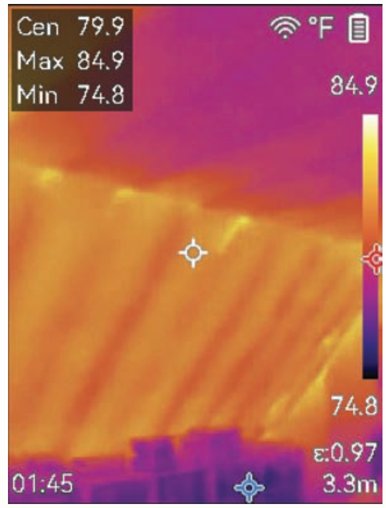
Failed glazing
Dual- and triple-pane glass used for windows and doors is often filled with argon gas. If the gas escapes through a failed seal, the center of the glass will show up as a cold or hot spot. But make sure the image isn't showing a reflection on the glass from inside the room.



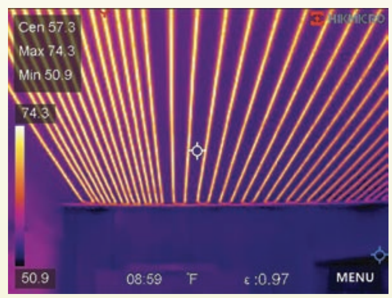
LOCATE HIGH ELECTRICAL LOADS

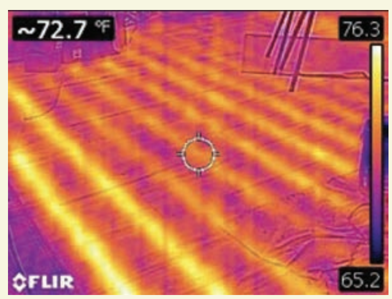
Electrical usage
Part of my job is working with homeowners who have high electricity consumption complaints. Warm breakers or wires inside an electrical panel are tell-tale sign of circuits that use a lot of electricity. I'll use thermal imaging to quickly identify breakers or wires that have been drawing larger amounts of current.

FIND HIDDEN ELEMENTS



Framing
With typical insulation levels and 10° or more of Delta T you can see the framing behind exterior walls, ceilings, and floor finishes. Framing separating conditioned living spaces can be harder to see; exterior framing with unusually thick insulation layers may slow thermal bridging enough to make wood-frame components very difficult to spot.





In-floor heating
Working on radiant floors and (less commonly) radiant ceilings risks damaging hydronic or electric elements and expensive and difficult repair, but IR images will make radiant pipes and wires glow with intensity for easy locating for remodeling or looking for leaks and hot and cold spots.

Practical Air-Sealing

BY ANDREW WEBSTER

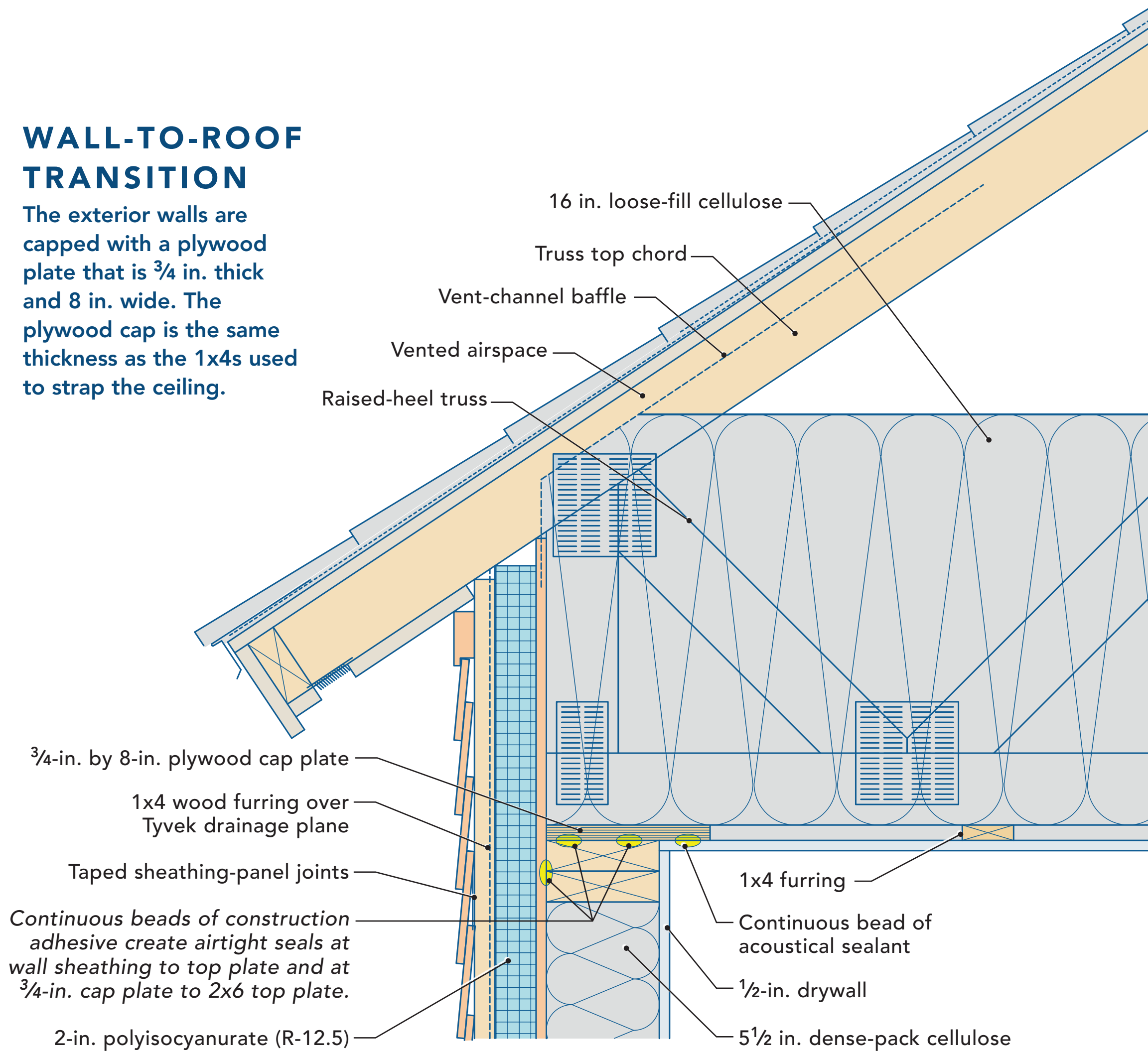
If you aim to build a superinsulated airtight home and want to keep it affordable, your best bet is to use common materials and methods that don't disrupt traditional work sequences very much.

Last year, my architecture firm's founding partner, Bruce Coldham, developed a set of details to create an affordable, durable, and continuous air barrier for a house with a conventionally framed 2x6 wall and a truss roof.

Airtight wall sheathing

We opt to use the exterior face of the wall sheathing as the air barrier, using either Huber Zip sheathing and Zip tape or a handmade version: OSB with Grace's WB Primer and Vycor tape at all joints, burnished or rolled to get the best adhesion.

This strategy keeps the air barrier out of the way of the electricians and plumbers who are called on to punch many holes in our walls. It also provides a durable, inspectable, and affordable solution to reducing air leaks. With a continuous layer (or two) of rigid polyiso over the OSB, we get warm sheathing and good overall wall R-values as well.



WALL-TO-ROOF TRANSITION

The exterior walls are capped with a plywood plate that is ¾ in. thick and 8 in. wide. The plywood cap is the same thickness as the 1x4s used to strap the ceiling.

The wall-roof intersection

For reasons of construction economy, many clients want trussed roofs with traditional eaves and a ventilation channel. The immediate challenge in this design is figuring out how to connect the exterior sheathing air barrier on the walls to the interior drywall air barrier at the ceiling.

The solution is found in a simple plywood cap plate (¾ in. by 8 in.) that is attatched to the exterior walls. To achieve airtightness at this transition requires the use of construction adhesive in two locations: The wall sheathing has to be sealed with adhesive along the 2x6 top plate, and the plywood cap plate has to be sealed to the 2x6 top plate that it's nailed to.

Doing it this way doesn't interrupt the construction sequencing, and the materials needed to accomplish it are typically on site already.

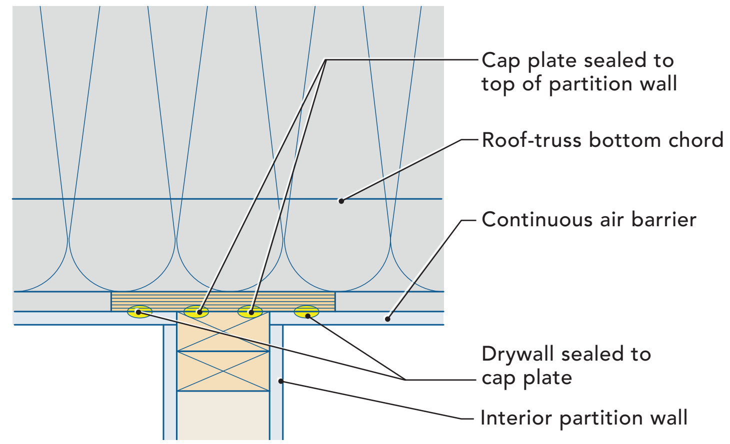
Detailing partitions

With an airtight drywall ceiling, the tops of partition walls threaten to interrupt the air barrier. We could handle this in two ways: either by having a continuous plane of drywall installed before the partitions are erected, or by adding another plywood cap plate atop each partition wall.

Adding a continous layer of drywall demands mobilizing the drywall contractor twice. Adding cap plates helps to keep the normal construction sequence intact.

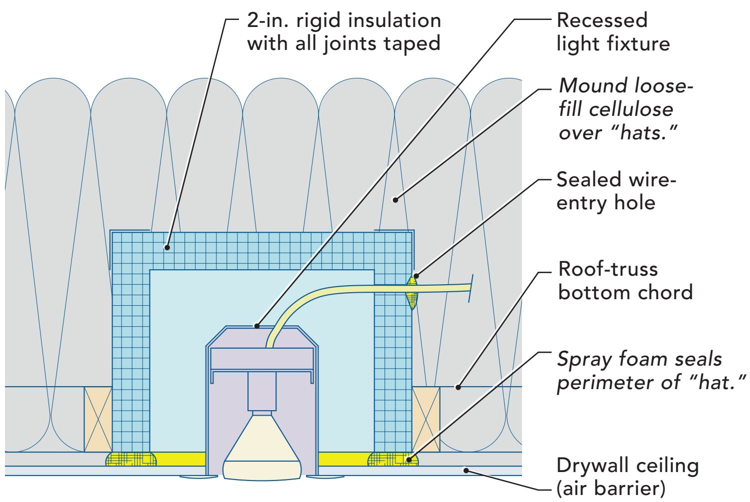
A bead or two of construction adhesive is used to seal the top plate

Photo: courtesy of Coldham & Hartman Architects. Drawings: Steve Baczek, Architect.



AIRTIGHT PARTITIONS

You can install continuous drywall on the ceiling before partition walls are framed, or use this detail to stick to a more traditional building sequence. The plywood caps installed above the partition top plates are wide enough to provide an overhanging lip on both sides of the partition to receive beads of sealant.



DON'T FORGET THE CAN LIGHTS

Air leaks at recessed can lights often lead to winter ice dams. Even recessed cans that are rated IC and "airtight" are known to leak. To create a more airtight ceiling, construct rigid-foam boxes that are air-sealed with tape and canned spray foam. The boxes should be sealed to the drywall before loose-fill insulation is installed.

of the partition wall to the wide plywood cap plate. A similar bead seals the cap plate to the drywall ceiling. The drywall is fastened to the plywood cap plate and to 1x4 furring strips in the same plane.

Finally, any ceiling penetrations, especially recessed can lights, need to be carefully sealed, which can be accomplished with an air-sealed "hat" made of rigid foam and canned spray foam and tape (see drawing above and "Energy Smart Details" in *FHB* #237).

To create an affordable superinsulated airtight home, it helps if the details are simple rather than disruptive. A little creative forethought and a clear plan will help builders get it done. □

Andrew Webster is a principal at Graphite Studio in western New England.

Applied eaves make an airtight hot roof work

We've employed the sheathing-based air-barrier solution regularly since testing it out with energy consultant Marc Rosenbaum at the College of the Atlantic's Davis Student Village. There we achieved near Passive House airtightness with OSB, primer, and Vycor for our wall and roof assemblies.

We have long believed that aligning the weather, air, and thermal barriers is the most bulletproof way of making wood-framed structures in our climate. But this is more expensive to do on a roof than on a wall, because it either complicates the venting requirement or requires an unvented "hot" roof. The current code requirements for hot roofs—designed to avoid condensation on the inside of the sheathing—are more elaborate than earlier methods used in our area.

For a high-performance house with a hot roof, we often use 12-in. I-joist rafters filled with dense-pack cellulose. To comply with the code, this type of roof needs 3½ in. of continuous rigid insulation above the primary roof sheathing in our climate zone.

2x4 eave rafter = 3½ in. of rigid foam. *If a house is framed without any roof overhangs, it's easy to tape the seam between the wall sheathing and the roof sheathing. Once the sheathing is airtight, "applied eaves" are framed with 2x4s, which will be on the same plane as the 3½ in. of rigid foam that is installed next.*

If the roofs are framed without any overhangs, the wall sheathing can extend all the way up to the roof sheathing. Once the sheathing seams are taped, including the seam where the wall meets the roof, we sometimes install 2x4 outriggers to create an "applied eave" (see photo). The height of the 2x4 outriggers matches the thickness of the foam insulation.

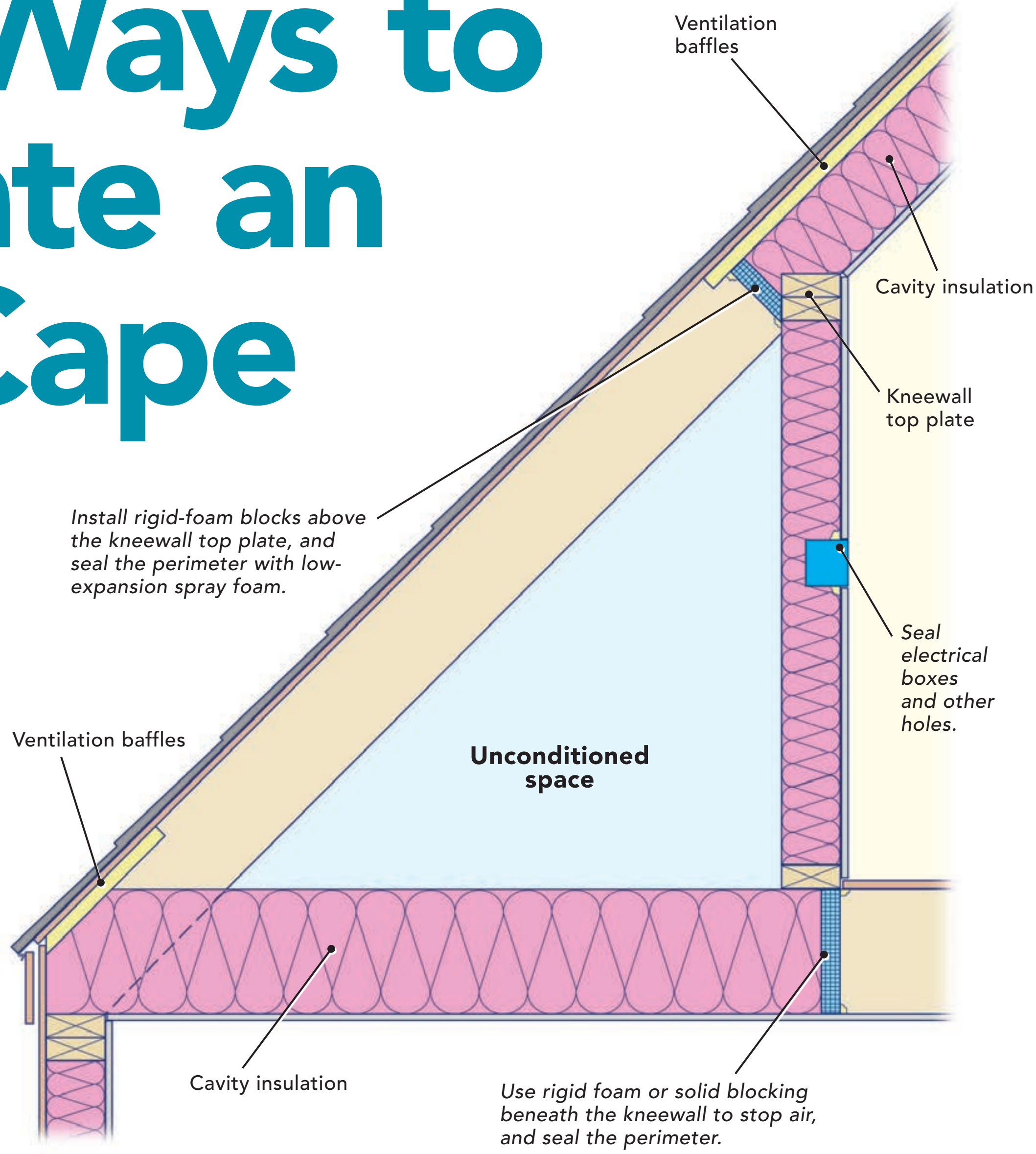
Two Ways to Insulate an Old Cape

BY MARTIN HOLLADAY

Older Cape Cod–style homes may be charming, but they are often poorly insulated. Most have second-floor bedrooms with 4-ft. kneewalls against the sloped ceilings. This creates triangular attic spaces behind the kneewalls. Because it's hard to insulate these areas, many Capes leak heat at the eaves—a recipe for ice dams. The ideal solution, especially if the rafters are not deep enough to allow for code-minimum cavity insulation, is to add rigid foam above the roof deck. If the rafters are deep enough, however, it's more cost-effective to work from the interior.

The first decision is whether to treat the areas behind the kneewalls as conditioned or unconditioned space. From a building-science perspective, the ideal choice is to treat them as conditioned space—bringing them inside the thermal envelope of the house—by running insulation along the full length of the rafters. But if done with care, it's also possible to use the kneewall area as your thermal and air barrier. □

Martin Holladay is a former senior editor.



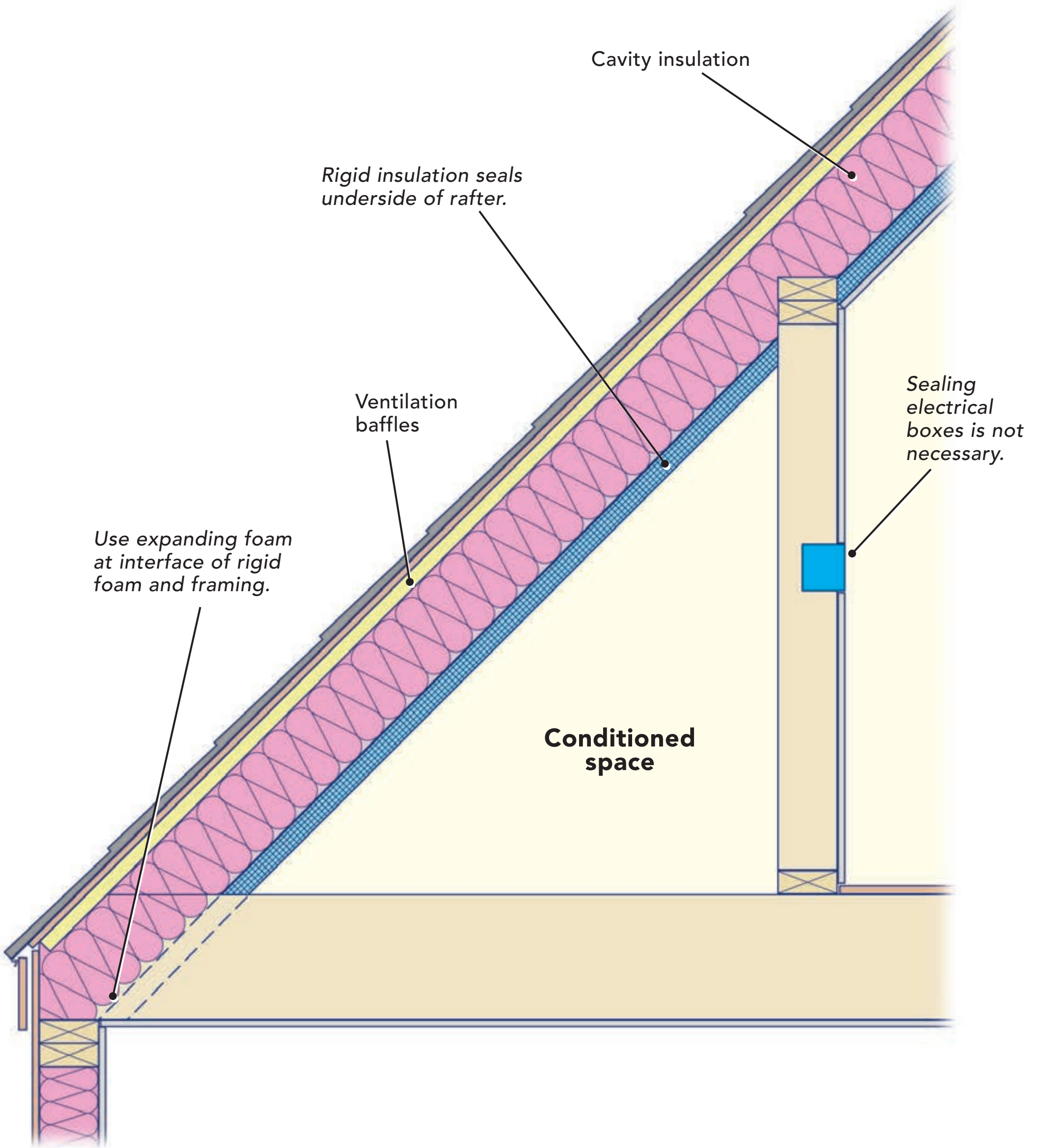
UNCONDITIONED SPACE

One option when insulating from the inside is to treat the crawlspaces behind kneewalls as unconditioned space. The biggest challenge here is that the kneewall space creates a complicated shape that is difficult to air-seal.

You must install rigid-foam blocking or solid-lumber blocking between the floor joists under the kneewall bottom plate to prevent air movement through the joist bays. Without it, conditioned indoor air can leak into the unconditioned attic, or outdoor air can leak into the conditioned spaces. Each piece of blocking needs to be sealed at the perimeter.

Rigid-foam blocking is also required between the rafters above the kneewall top plate. Each piece should extend up to the ventilation baffles between the rafters and should be air-sealed around its perimeter. If the roof is vented but no ventilation baffles are there, they need to be installed. (There are two roof assemblies where ventilation baffles can be omitted: those with a thick layer of rigid foam above the roof sheathing, and those with spray polyurethane foam installed on the underside of the roof sheathing.)

Drawings: Dan Thornton



CONDITIONED SPACE

Although it doesn't reduce the amount of demolition work, it's often still easier to use the plane of the roof rafters as the thermal and air barrier. Creating an air barrier between the conditioned space and the cavity insulation is still required, but keeping this barrier continuous tends to be easier. Since this approach treats the area behind the kneewalls as conditioned space, any floor sheathing in the attic space doesn't have to be removed to gain access to the joist bays below, and air-sealing electrical boxes or similar holes is not necessary.

A continuous ventilation path must still be present, so ventilation baffles are required against the underside of the roof sheathing, extending from eaves to ridge. If the rafters are deep enough, it may be possible to use rigid foam as the ventilation baffles, sealing along the perimeter of each piece to create an air barrier, then filling the rest of the cavity with batts or blown insulation (see "Ceiling Remodel: From Flat to Cathedral" in *FHB* #192). For houses with 2x6 rafters, it's necessary to increase rafter depth to make room for enough insulation to meet code minimums. This can be done by scabbing additional framing to the underside of each rafter, or by filling the existing bays with insulation and then installing rigid foam below the rafters, sealing along the perimeter of each piece. Both options will lower the finished ceiling height.

Building new

If you are designing or building a new Cape, you shouldn't have to worry about the air-sealing and insulation problems discussed here—as long as you plan from day one to include an insulated sloped-roof assembly that brings the attic and kneewall spaces inside the home's thermal barrier.

There are many ways to build an insulated sloped roof. It can be vented or unvented. It can be insulated with fiberglass, cellulose, mineral wool, spray foam, rigid foam, SIPs, or nailbase. Any of these methods can work, as long as the designer has settled on an insulation approach early in the design process, the insulation details are well thought out and are consistent with best practices, the R-value of the insulation meets or exceeds minimum code requirements for ceilings, and workers pay attention to airtightness at all stages of the work.

Air-sealing a Basement

BY MARTIN HOLLADAY

Once you've sealed the air leaks in your attic floor—the cracks where warm air escapes from your house during the winter—it's time to turn your attention to the basement or crawlspace, where cold air leaks in. If you turn off the basement lights and look for daylight, you might be surprised to find some large holes.

Weatherization contractors often use a blower-door test to help pinpoint leaks in the building envelope. Once your house is depressurized, you can use your bare hands to feel for air infiltration. The most common places to find air entering basements are around windows and doors and between the concrete foundation and the mudsill. But some air-leakage paths may surprise you: Air can even seep through the crack at the perimeter of your basement slab or through a sump in the basement floor. Here are five places to check for air leaks in your basement and some advice on how best to seal them.

Foundation walls

Walls made of poured concrete or concrete blocks are usually fairly tight. However, if your basement walls have any obvious cracks, fill them with silicone caulk. If the walls are made of stone and mortar, don't use canned spray foam or caulk to seal cracks. Instead, remove any loose material from these areas, and repair them with mortar and small stones.

Use caulk or canned spray foam to seal leaks near wall penetrations for your electrical service, water service, cable service, or natural-gas service. Your home also may have penetrations for a fuel-oil filler pipe, an oil-tank vent, or a clothes-dryer vent. If basement access is awkward, some cracks may be easier to seal from the exterior.

Rim joists

Air can leak through the crack between the top of the foundation wall and the mudsill, the crack between the mudsill and the rim joist, and the crack between the rim joist and the subfloor. The best way to seal leaks in the rim-joist area is with a high-quality caulk.

Once these cracks are caulked, you may want to reduce air leaks further by installing a layer of closed-cell spray foam at the rim-joist area using a two-component spray-foam kit. (See "Spray Foam for the Rest of Us," *FHB* #221.)

Although spray foam is effective, it is expensive and sometimes messy. If you would rather not use it, you can insulate rim joists with rectangles of 2-in.-thick rigid foam (polyisocyanurate or extruded polystyrene). Seal the perimeter of each foam rectangle with caulk or canned spray foam. Don't use fiberglass batts; they do nothing to slow airflow.

Windows and doors

If your basement has old single-pane windows, they may need new glazing compound and weatherstripping. If the windows are in bad shape, consider replacing them with new double-glazed units.

If you rarely open your basement windows, consider sealing them shut with screws and caulk, or even covering them with rigid foam. (Of course, this advice applies only to small basement windows, not to any egress windows in a basement bedroom.) Don't forget to caulk between the window frame and the concrete.

Every bulkhead entry needs a tight, weatherstripped exterior door at the base of the stairs. Be sure to caulk or to foam the gap between the door jamb and the foundation. If the door is warped or difficult to weatherstrip, it's time to replace it. Most lumberyards can order a custom insulated entry door to fit any size opening. If you're framing the rough opening,

Combustion safety in a tight basement

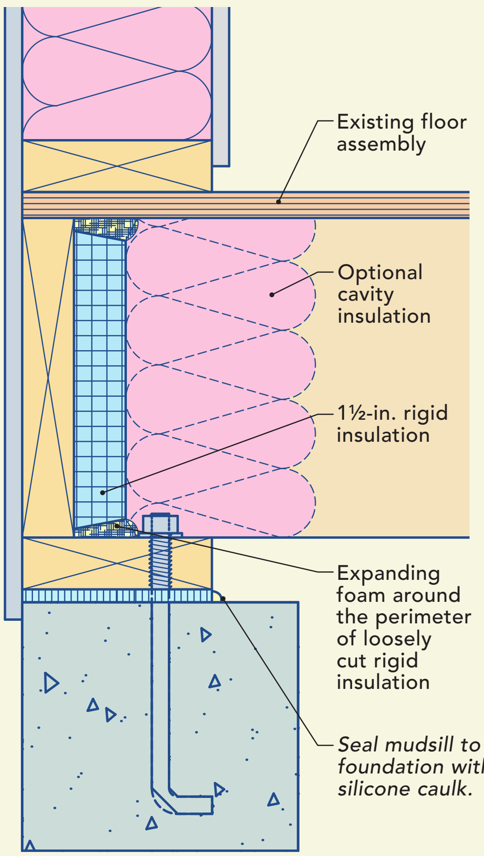
Atmospherically vented appliances—for example, water heaters, furnaces, or boilers attached to old-fashioned brick or metal chimneys—depend on air leaking through cracks in your walls to supply combustion air. If your basement is very tight, atmospherically vented appliances could be starved for air, and exhaust gases may struggle to exit through the chimney. That's why the best appliances for tight homes are sealed-combustion appliances equipped with ducts that supply outdoor air directly to the burners.

Because flue gases sometimes include carbon monoxide, it's always important to be sure that your combustion appliances have adequate combustion air and that your chimneys draw well. If you plan to seal cracks in your basement, arrange for a combustion-safety test of any atmospherically vented appliances once air-sealing work is complete. Contact your gas utility or a home-performance contractor certified by RESNET or BPI for more information on combustion-safety testing.

Drawings: Steve Baczek, Architect

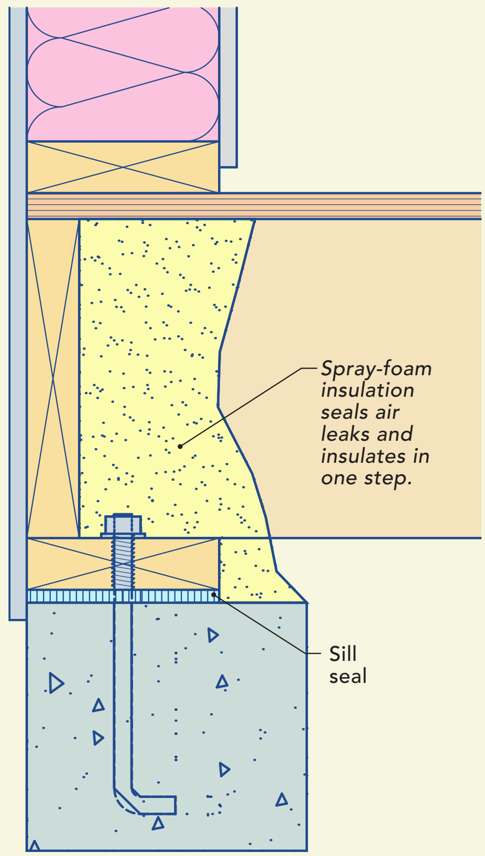
TWO WAYS TO AIR-SEAL AND INSULATE A RIM JOIST

Rim joists are a common source of air leakage in basements and are often left uninsulated. The first step toward an energy-smart rim joist is to caulk gaps between the foundation wall and the mudsill, the mudsill and the rim joist, and the rim joist and the subfloor. As seen in the details shown here, you then can use rigid foam or spray foam to add another layer of air-sealing and to insulate the area.



Rigid foam

You can cut the pieces of rigid foam roughly and somewhat undersize because the perimeter of each rectangle should be sealed in place with canned spray foam. With the rim joist air-sealed and covered with rigid foam, you can now add cavity insulation like fiberglass batts or, better yet, a second layer of rigid foam.



Spray foam

Extend spray foam from the top of the foundation wall to the underside of the subfloor above. In addition to sealing leaks, 2 in. of cured foam will insulate to R-13. Most building codes, including the International Residential Code, allow spray foam installed at rim joists to remain exposed—without protection from a thermal barrier like drywall—as long as the foam is no thicker than 3¼ in.

Test for radon

Radon is a colorless, odorless, naturally occurring gas that can seep through soil into your basement. High radon levels can damage human health. While most homes have relatively low radon levels, some have dangerously high levels.

Sealing cracks in your basement can affect radon levels in your home, either for better or worse, depending on several factors. If necessary, a radon-remediation contractor can install plastic pipes under your basement slab to lower the radon to safe levels.

The best way to determine whether your home needs radon-remediation work is to test the air in your home. For more information on radon testing and remediation, visit http://epa.gov/radon.

For details on radon mitigation, see GreenBuildingAdvisor.com/radon.

use pressure-treated lumber, and seal the frame to the concrete with canned spray foam.

Basement floors

After a new foundation is backfilled, the fill often shrinks away from the foundation, leaving a gap next to the basement wall that allows outdoor air to reach the footings. That's one way for outdoor air to enter a home through cracks in the basement floor or sump pit. Even if a home has no shrinkage gap, air can still reach the footings, especially in areas with porous soil.

If there's a crack at the perimeter of your basement slab, clean the crack with compressed air or a vacuum cleaner, and then fill it with caulk. If you have a sump pit without a tight lid, replace it with a new airtight lid. Sumps that have airtight lids are available from Jackel (www.jackelinc.com).

Basement ceilings

Chases and chimneys that extend from the basement to the attic should certainly be capped at the top, but the bottom of these chases should be sealed as well. After all, once air gets into a chase, it can move sideways into joist bays and partition walls until it finds an exit crack. This belt-and-suspenders approach is the best way to prevent the stack effect from stealing your home's heat.

Cover large ceiling holes with plywood, drywall, or rigid foam, and seal the edges with caulk, spray foam, or housewrap tape. While you're at it, check for holes under first-floor bathtubs or showers. Plumbers typically cut out a big piece of the subfloor to accommodate drain lines and traps; these air pathways should be sealed. □

Martin Holladay is a former senior editor.

Spray Foam for the Rest of Us

When the insulating task is small, a do-it-yourself spray-foam kit may be your best option

BY PATRICK McCOMBE

Spray foam is a nearly perfect insulation. It has a high R-value, it stops air leaks, and it fills odd-shaped and wire- or pipe-filled cavities effortlessly and without gaps. Perhaps the only downside to spray foam is convenience. Ordinarily, it requires a crew and a truck full of special gear and chemicals, making it prohibitively expensive for small insulating and air-sealing jobs.

Realizing this, several companies now sell smaller, two-part insulating kits designed for contractors and DIYers. I've air-sealed acres with cans of spray foam, but until I tested the two-part kits for this article, I had never used one. These kits are targeted to folks who aren't professional insulators. Since manufacturers claim they're easy to use, I volunteered to try kits from five manufacturers and report my findings.

For testing, I chose an attic space with gable walls and multiple valleys. Admittedly, nobody would insulate an entire attic with these kits because it would be cheaper and easier to hire a pro, but this attic space, with its odd-shaped rafter bays and board sheathing, was an ideal test lab. It even was large enough to let me test all five kits on the same job.

Getting ready for foam

Each of these kits includes two tanks of chemicals (parts A and B), 15 ft. of hose, several replaceable nozzles, and a gun that mixes the chemicals and sprays the foam. They're all closed-cell-type foams. Kits are sold in sizes from about 12 board feet (bd. ft.) to 620 bd. ft.; 1 bd. ft. covers 1 sq. ft. at a thickness of 1 in. The manufacturers say you should assume about 25% waste.

It's recommended that the chemicals be between 60°F and 80°F; the higher end of the spectrum will produce the best yield. If the tanks are colder than 60°F, they should be

warmed over several days in a hot room or immersed in hot tap water for an hour or more. Some manufacturers caution against putting them in direct sunlight or near space heaters, although I've talked to weatherization crews that routinely warm foam canisters both ways without problems.

The surface temperature of the materials you're insulating also should be above 60°F. (Cooler surfaces prevent the foam from expanding and adhering properly.) In cold weather, surface temperatures can be increased with space heaters or by waiting for warmer temperatures later in the day. I found that a noncontact infrared thermometer (about $40) was a handy way to check tank and surface temperatures.

Thoroughly mixing the chemicals is also important. At the recommendation of one manufacturer, I mixed the chemicals by rolling the tanks on the floor, which worked fine and was less taxing than trying to shake the 60-lb. tanks.

Cover yourself and everything else

Polyurethane spray foam sticks tenaciously to everything it touches, so the manufacturers suggest wearing disposable coveralls. Unfortunately, the "large" coveralls I ordered from an online supplier were too small for my 5-ft. 10-in., 150-lb. body. I suggest upsizing one or more sizes for a proper fit.

You'll also need goggles and a respirator with combination organic-vapor/P100 particle filters. Snug-fitting disposable gloves and some kind of head covering also are a must. My coveralls had a built-in hood that worked pretty well.

Cover or remove anything you're not insulating because the foam overspray goes everywhere.

The chemical stink is pretty bad, too, so cross ventilation is a good idea. You'll also want the homeowners and their pets to stay out of the house until the smell dissipates, which I found on this project to be about a day.

Make the connections, and check the mix

Once the hoses are connected to the tanks and the two chemicals have been run through them, they can't be disconnected, so it makes sense to do all the preparations before you pull the trigger for the first time. Moving the smaller kits isn't a big deal, but it is a problem for the kits I was using, which come with two 60-lb. tanks. If you're planning to spray in more than one location, start where you'll be using the most foam, as the tanks get noticeably lighter as you spray.

All of the kits have similar gun-and-hose assemblies. Start by attaching the hoses to the proper tank—indicated by a color-coded stripe or label—with a little wrench included with each kit. Next, open the tank valves a little at a time while checking for leaks. Tighten any fittings that leak; it's important that the hoses are airtight.

With the hoses connected and the tank valves fully open, apply a small amount of petroleum jelly (included with the kit) to the part of the gun that receives the nozzle. Then, without a nozzle attached, spray the foam into a waste container—the tank's cardboard shipping box works great—

GUNS N' HOSES

All the two-part kits tested have 15-ft. hoses and spray guns that accept two styles of tip: fan tips for a thin, wide coat and cone tips for a narrow, more forceful stream.

Connect the hoses. *Start by applying a small amount of petroleum jelly to the tank fittings and connecting the appropriate hoses, which are color-coded or identified with labels. Snug the fittings with the included wrench.*

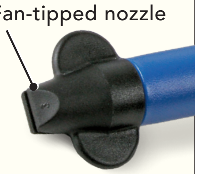
Prep the gun. *Spray guns have a recess or an O-ring that receives the nozzles. Cover either area with a light coat of petroleum jelly to prevent the nozzle from becoming glued to the gun.*

Test the spray. *Without a nozzle, spray the foam into a waste container to ensure you have near-equal streams of both chemicals. If you don't, check the tank temperatures, and confirm that both valves are fully open.*

Be prepared to change nozzles. *Insert either a cone- or fan-tipped nozzle into the gun, and begin spraying. Replace nozzles whenever you stop spraying for 30 seconds or more and whenever you notice a change in performance.*

Cone-tipped nozzle

Fan-tipped nozzle



making sure you see streams of equal velocity for both chemicals. If everything is OK, install a nozzle and get spraying. If you don't have equal streams, check the troubleshooting section of the instructions.

Get spraying

With all the guns, pulling the trigger tighter dispenses increasing amounts of foam. I found that full throttle created more overspray and sometimes displaced foam already in place. This was mostly a problem when insulating overhead, but it also occurred to a lesser extent when spraying stud bays.

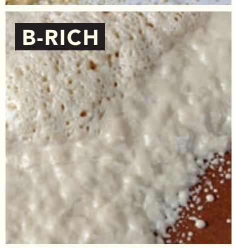
When you're spraying framing cavities, it's important to go around the perimeter of the cavity to ensure that there are no gaps. This technique is called "picture framing." Once the perimeter is filled, you can go back and cover the rest of the area with a light coat.

If the chemicals and the surface are at the right temperature, spraying the proper amount of foam will cause it to froth up about an inch within a minute. Don't apply more than 2 in. of expanded foam in a single pass because a thick layer won't froth as high, it will tend to pull away from overhead surfaces, and you will risk hot spots that could melt the foam.

Let the foam cure for a minute or two, and apply additional 1-in. to 2-in. layers until you've reached the R-value you want. These products claim between R-6 and R-7.7 per in., although closed-cell polyurethane R-values decrease slightly with time. Dow is the only company I could find that lists both the initial and aged values (R-6 and R-5.3 per in., respectively).

APPLICATION BASICS

Spray foam into cavities by first going around the perimeter to fill all the inside corners. Then cover the rest of the field in 1-in. to 2-in. layers until you've reached the desired R-value (about R-6 per in.). Half-throttle reduces overspray and is less likely to dislodge foam already in place.



Know your foam. *Improperly mixed (off-ratio) foam won't perform, so correct the problem as soon as it's noticed. A-rich foam will have a crunchy, glassy-looking surface. B-rich foam will be whiter and have a softer, spongy surface.*

Thin coats are best. *Avoid the temptation to spray too much foam at once. Heavy layers can sag under their own weight or overheat, melting the foam.*

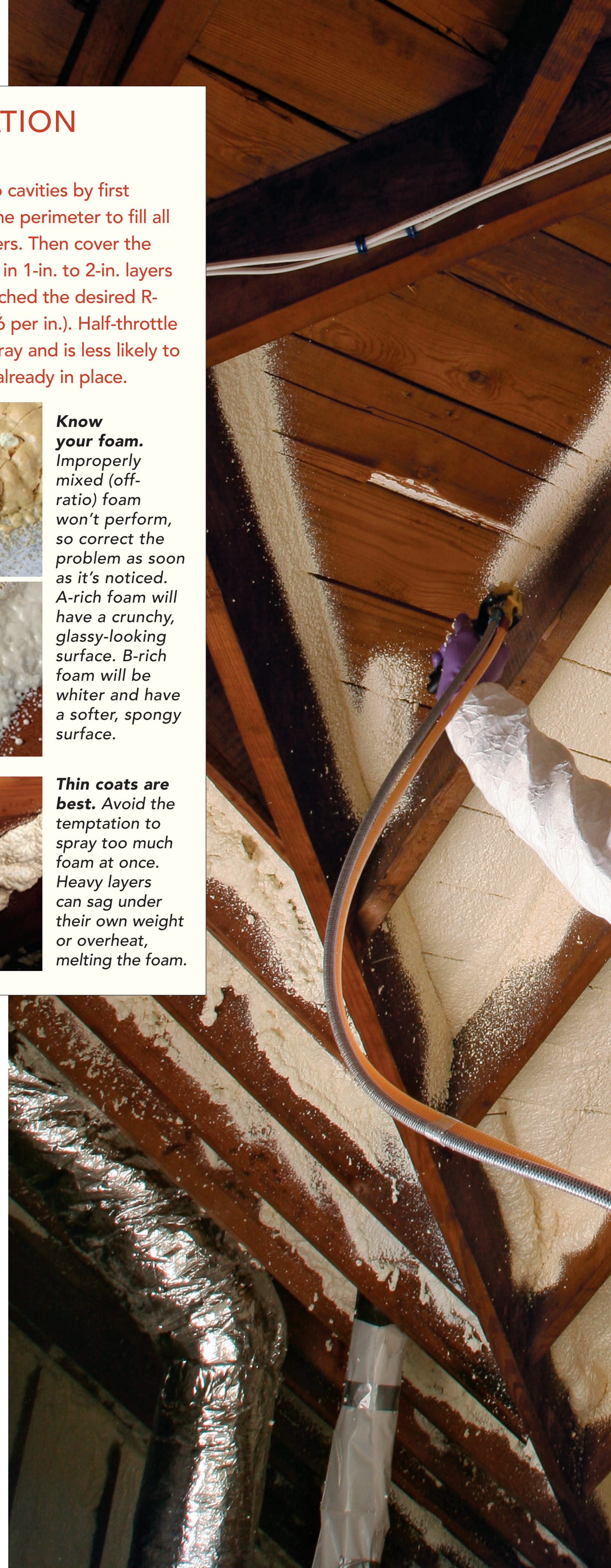
Change tips often

Whenever you stop spraying for more than 30 seconds, you need to swap nozzles. I also found that I got better yield and less spattering with a fresh tip, so it's a good idea to swap them whenever you notice a change in performance. The makers provide several tips in two types: fan and cone. Cone nozzles seem the most useful; their directed stream reaches farther and concentrates the foam. Fan tips are designed for larger areas and can put down a nice even coat on flat surfaces. Unfortunately, you sometimes need to hold the gun in awkward positions to take advantage of the additional coverage, and fan tips also create more overspray.

One idea I picked up from an insulating pro is to apply petroleum jelly to several tips before starting. One guy even goes so far as to tape the lubed nozzles to his coveralls, which seems like a great idea when you're working in tight spaces.

Lessons learned

While these products aren't quite as anxiety-inducing as, say, working with concrete, they can lead to a little stress. Once you get started, you need to keep working until you're done. Manufacturers



claim you can shut the valves and start the tanks again up to seven days later. You can extend that time frame even further by running foam through the hoses at least once a week. I'm not disputing the claim, but with all the preparations required, I suggest getting the work all done at once. With near-constant spraying, I found it took about an hour to empty each of the 600-bd.-ft. kits I used.

One surprise was how hot and uncomfortable small spaces can get with a lot of foam curing, so even in a 60°F attic, I found myself roasting when spraying kneewalls and other cramped spaces. Insulating attics in summer could become quite dangerous, I suspect.

Another thing to keep in mind is that these kits are expensive. Rigid extruded-polystyrene insulation sells for about 50¢ per bd. ft.; these spray-foam kits sell for about double that price, not including shipping. I've successfully used insulation board with a perimeter of canned spray foam to insulate band joists and to seal off thermal bypasses. The added advantage is that you don't need all the protective gear and can work at a more comfortable pace. Then again, cutting and fitting foam around pipes, ducts, and wires isn't fun; sometimes it's near impossible.

Although I expected the foam to come out with the same intensity as that of a professional spray rig, that simply wasn't the case. It takes a comparatively long time to do an entire stud or rafter bay. But insulating large areas is not what these types of kits are designed for. They're really made for hard-to-insulate areas—and at this task, they excel. □

Patrick McCombe is a senior editor. Photos by Justin Fink, except where noted.

DISPOSAL IS DIFFICULT

Finding out how to dispose of the spent tanks proved difficult because the rules vary throughout the country as well. The Department of Environmental Protection here in Connecticut couldn't say without testing whether the material was hazardous waste.

One company representative told me that liquid leftovers are the biggest potential problem, so she suggested dispensing any remaining liquids into a waste container and letting them dry. Once the liquid chemical is gone, you should invert the tank and release the propellent. Then the tanks can be recycled.

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