A Builder's Guide to Air-Sealing

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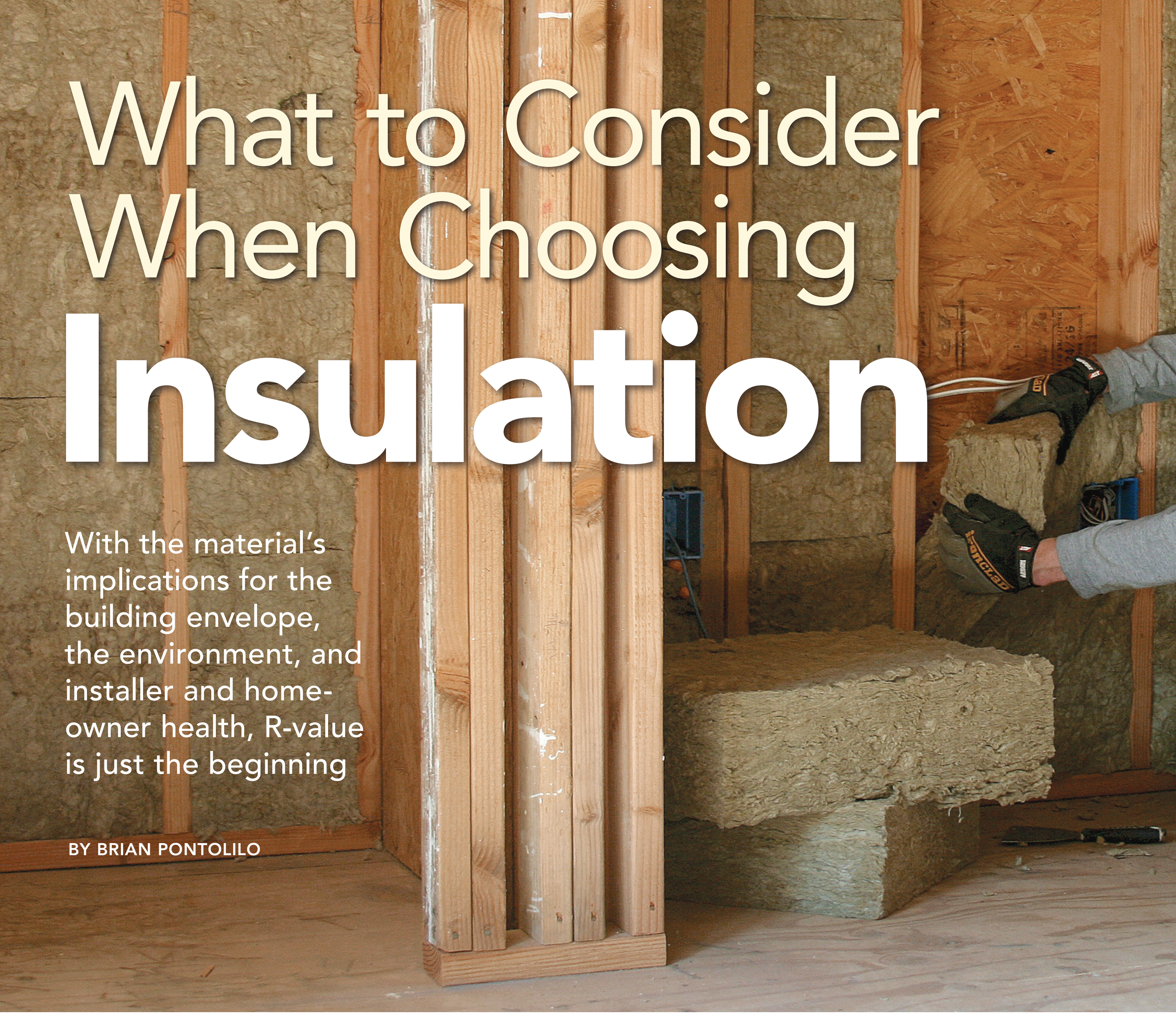


What to Consider When Choosing Insulation

With the material's implications for the building envelope, the environment, and installer and homeowner health, R-value is just the beginning

BY BRIAN PONTOLILO

Choosing the most appropriate type of insulation should be part of an overall strategy of materials selection. The underlying purpose of green building is not to develop marketing brochures that will help sell "green" houses in suburban subdivisions, but to make decisions that genuinely benefit people and the planet. This makes a strong case for finding ways to use insulation and other materials with low carbon emissions.

When I was asked to help teach a class on how to choose insulation, I knew that it would have to include examples of different ways to insulate slabs, basements, and crawlspaces; walls, ceilings, and roofs; and tricky areas like rim joists and kneewalls. I also hoped I could offer a systematic approach to evaluating products so that the folks who participated in the class could learn to determine for themselves if a particular material was right for their specific project. To do this, I started to develop a list of criteria to consider when choosing insulation. When I thought I was done, I ran it by a few colleagues and asked a few designers and builders some specific questions about how they settle on insulation in their work. I ended up with seven or so points that need to be considered when choosing insulation. Then I started to rethink my approach altogether, but we'll get to that a little bit later. First, here's the list of factors I came up with.

R-value

How well insulation slows heat transfer is quantified as R-value. The higher the number the better when it comes to R-value. When you see an R-value listed, it's important to know if it is the total R-value for a product or an R-value for the material, which is usually given as R-value per inch. For example, you can buy an R-13 fiberglass batt designed to be installed in a 2x4 wall, and R-13 is the total insulating value for each

Photos: this page, Rodney Diaz; facing page, Kevin Nielsen

MINERAL WOOL

"Mineral wool" refers to both rock wool, which is spun from molten filaments of basalt or another type of rock, and slag wool, made from blast-furnace slag. Mineral wool contains an average of 70% post-industrial recycled content and needs no chemical flame retardants. It is available in unfaced batts, in semi-rigid panels, and for use in blow-in applications in walls and attics. Brand names include Rockwool and Thermafiber. In panel form, mineral wool can be used below grade and as a continuous layer of insulation on exterior walls to reduce thermal bridging. Mineral wool is air and vapor permeable and provides high fire resistance. Availability may be limited in some areas.

R-VALUE R-2.9 to R-4.3 per in.

COST Moderate

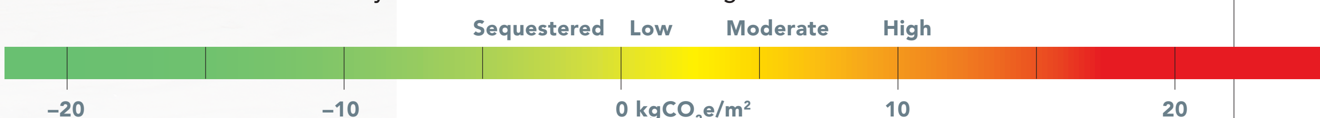
NET CARBON EMISSIONS (see below)
Moderate (R-4 batts, 4.7 $kgCO_2e/m^2$; R-4.3 boards, 5.1)

TOXICITY Low

INSTALLATION Similar to fiberglass (see p. 26). When used as continuous exterior insulation behind a rainscreen, panels may be compressed unevenly by strapping.

WHAT IS NET CARBON EMISSIONS?

Net carbon emissions is a way to account for the climate effects of a material and is an indicator of global-warming potential. Here it is measured in $kgCO_2e/m^2$, which quantifies the carbon released as a result of producing and installing this material as a carbon dioxide–emissions equivalent. Materials with negative values store more carbon than they take to produce and install. The numbers that appear in this article are reported by Builders for Climate Action for a layer of insulation with an insulating value of R-10.



batt. If you are blowing loose-fill fiberglass insulation into an attic, however, the product is likely sold at around R-3 per inch. The total R-value will depend on how deep you blow the insulation, as well as its density.

Because standardized R-value testing measures all three types of heat transfer—conduction, radiation, and convection—R-value is R-value. In other words, whether it is fiberglass insulation or spray foam doesn't matter when it comes to R-value. The marketing material provided by some insulation manufacturers may try to make you think otherwise. Don't be fooled. One product may do a better job of air-sealing than another, but that has to do with air permeability, not R-value. Of course, installation matters, and your insulation will only perform as well as the installation. Ultimately, the R-values you need in an assembly will be determined by code requirements and performance goals.

Air permeability

A continuous air barrier is a key component of any high-performance home, and it's even more important than insulation for durability, energy performance, and comfort. (If air is passing through your insulation, it increases convective heat loss.) When it comes to air permeability, insulation falls into one of two basic categories: air permeable or air impermeable. You can use air-impermeable insulation as the primary air barrier in your building assembly, but that's not to say that air-impermeable insulation is always the better choice.

It's becoming very common for air-sealing to be done on the exterior of the building envelope, with taped sheathing, for example. With a well-detailed exterior air barrier, an air-permeable insulation like mineral wool will perform just fine in the walls.

There are times when an air-impermeable insulation makes sense. One common example is the use of rigid foam to retrofit insu-

FIBERGLASS

Fiberglass insulation is widely available in batt and loose-fill form. Batts come in two standard widths for wood-frame construction and are commonly available with formaldehyde-free binders. Batts consist of spun glass fibers and come with or without a facing, such as kraft paper or foil. Careful installation is essential to avoid gaps that reduce effectiveness. Batts are not an air barrier and can't be used below grade.

In loose form, fiberglass can be blown onto attic floors or, in higher densities, into wall and ceiling cavities. It's available by the bag from big-box retailers. The fibers fill voids more effectively than batts, reducing air leaks, but blown-in fiberglass is not considered an air barrier. Loose-fill in an attic has DIY potential, but dense-pack application requires better equipment and more skill. Use above grade in walls, ceilings, and attics.

R-VALUE R-3.1 to R-4.2 per in. (batt); R-2 to R-4.2 per in. (blown), depending on density

COST Low

NET CARBON EMISSIONS Low (R-3.6 batt, 1.2; R-2.6 blown, 1.8)

TOXICITY Low, but wear a face mask and long sleeves to reduce skin and bronchial irritation (some brands are advertised as no-itch)

INSTALLATION Batts and loose-fill in attics are accessible to homeowners as well as pros, but beware of sloppy work that reduces effectiveness. Dense-pack fiberglass is best left to professionals.

CELLULOSE

Cellulose is shredded newspaper or cardboard and is available by the bag or in batt form. There are no rigid panels. Cellulose has strong environmental credentials, and it's a favorite among many green builders because it has high recycled content. Unlike fiberglass, which has about the same R-value, cellulose sequesters carbon. It can absorb moisture from the air and then release it when the air dries out. But because it readily absorbs water, plumbing and roof leaks can go undetected. It's used as loose-fill in attics and as dense-pack and in batt form in enclosed wall and ceiling cavities. Dense-pack cellulose installed at 3.5 lb. per cu. ft. is more resistant to air leaks than fiberglass, but cellulose is not an air barrier. It can be used in above-grade applications only. DIYers can rent blowers for loose-fill, but dense-pack calls for professional tools and skills. It is typically treated with borate as a fire retardant.

R-VALUE R-3.2 to R-3.8 per in.

COST Low (somewhat more than blown-in fiberglass)

NET CARBON EMISSIONS Sequesters carbon (R-3.7 dense-pack, –1.8)

TOXICITY Low

INSTALLATION Similar to blown-in fiberglass. DIYers can tackle loose-fill in attics, but hire a professional installer for dense-pack. Wear a face mask.

lation from the interior at the rim joists of older homes. The rim area is prone to air leakage. So installing air-impermeable rigid foam, and sealing it in place with canned spray foam or caulk, not only increases thermal performance at the rim joist but also stops air infiltration from outside. It also keeps potentially moisture-rich interior air from reaching the sheathing and condensing (turning into water). That's where vapor permeability comes into play.

Vapor permeability

Air permeability and vapor permeability are connected. Vapor permeability, which is measured in perms, describes a material's ability to allow water vapor to pass through it. At above 10 perms, insulation is considered "vapor open." Mineral wool falls into this category, meaning that water vapor can pass through unimpeded. At 10 perms or less, insulation is considered a vapor retarder (meaning that water vapor passes through, but at different rates) in one of three classes defined by the International Residential Code (IRC):

- Class I: Less than or equal to 0.1 perm. Foil-faced rigid foam falls into this category.
- Class II: Greater than 0.1 perm but less than or equal to 1.0 perm. The IRC puts kraft-faced fiberglass batts in this range, though some may become more vapor open as humidity levels rise.
- Class III: Greater than 1.0 perm but less than or equal to 10 perms. Unfaced rigid-foam insulation generally falls into this category.

To determine if the insulation you are using has an appropriate perm rating for your project, you need to understand the vapor profile and condensing surfaces of the assembly. For example, if you are building in a cold climate, where it is advantageous to slow outward vapor drive in the winter, a kraft-faced fiberglass batt may make sense. If

Photos: this page, Patrick McCombe; facing page, courtesy of BASF

SPRAY FOAM

Available in two basic types—closed-cell and open-cell—spray polyurethane foam has some unique performance characteristics but also raises a few environmental concerns. At 2 lb. per cu. ft. (vs. ½ lb. per cu. ft. for open-cell foam), closed-cell foam is the denser of the two. Closed-cell foam also acts as a vapor retarder, while open-cell foam is vapor open, a difference that becomes important in some applications. Open-cell foam uses water or carbon dioxide as the blowing agent, an environmental advantage, while blowing agents in closed-cell foam remain a sore point among green builders. Newer versions of closed-cell foam use hydrofluoroolefin (HFO) blowing agents, with a relatively low global-warming potential, but older formulations use a hydrofluorocarbon (HFC) with a much higher climate impact. (Icynene has developed a medium-density, closed-cell foam that is blown with water.) While these differences are important, both open- and closed-cell foam share an ability to fill wall and ceiling cavities very effectively and are excellent air barriers. Both are expensive, especially closed-cell foam, but it comes with a higher R-value. Both types are made by mixing two components on-site as they are sprayed by the installer.

R-VALUE R-3.5 to R-3.6 per in. (open-cell); R-6.5 per in. (closed-cell)

COST High

NET CARBON EMISSIONS Moderate to very high (R-4.1 HFO-blown open-cell, 2.9; R-6.6 HFC-blown closed-cell, 23.2)

TOXICITY Stay out of the house during installation. There are reports of lingering odors and/or off-gassing that affect chemically sensitive people.

INSTALLATION Open-cell has a much higher rate of expansion and typically is allowed to overfill cavities and be cut back when cured. Care must be taken not to apply closed-cell foam in too thick a layer, which can cause a fire. Premises should be vacated while foam is applied. Odors from closed-cell foam can linger, but properly mixed and applied insulation is inert once cured.

you were to use a low-perm exterior insulation on the same wall—say, foil-faced rigid foam—you may choose an unfaced batt so the wall could dry more readily toward the interior should it get wet.

Mike Xenakis, building performance lead at New Frameworks, a construction company in Vermont, says that prioritizing bio-based insulation like cellulose has pushed his company toward vapor-open wall assemblies. "That means we need a robust air barrier," he explains. "We're typically building homes with one or less air changes per hour. We do mid-stream blower-door tests and a lot of quality control on the air barrier."

Moisture tolerance

The most common example of when the moisture tolerance of an insulation matters is when it is used in contact with the earth or outside the building envelope, where fibrous insulation is typically not a viable choice. When insulating beneath a slab or on the outside of a basement, the most commonly used insulation types are EPS or XPS rigid foam, because they hold up to wetting. (Both can work, but many green builders avoid the high global-warming potential of XPS.) Because it is water resistant, mineral wool can also be used in these applications, though it is less common.

"I like GPS [graphite extruded polystyrene] and Rockwool under slabs," wrote builder Travis Brungardt in an email. "But if Glavel continues to get cheaper, it's an ideal under-slab insulator—especially in remote areas where access for trucks and heavy equipment is challenging."

Another example of builders choosing insulation for its moisture tolerance is the common option of dense-pack cellulose in double-stud walls, though for different reasons. Dense-pack cellulose is a so-called hygric buffer, meaning that it can absorb, distribute, and release moisture without degradation. "[Cellulose] is an affordable

EXPANDED POLYSTYRENE

EPS is a lightweight rigid foam used in a variety of applications: as a continuous layer of insulation in exterior wall and roof assemblies to cut thermal bridging, under slabs, and on the outside of foundation walls. Unfaced EPS is vapor permeable and available in a number of densities with corresponding compressive strengths. Higher densities do better below grade. The blowing agent for EPS is pentane, a hydrocarbon. EPS does not contain hydrochlorofluorocarbons—potent greenhouse gases—and so is preferred by many green builders. EPS manufacturers in the United States have replaced a brominated flame retardant called HBCD with a polymeric retardant, which is thought to be safer. EPS's thermal performance does not degrade over time. GPS (graphite polystyrene) is an EPS variant that is infused with graphite. It has a characteristic gray color and a higher R-value than conventional EPS. It is more common in Europe than the U.S. and has lower carbon emissions than traditional EPS.

R-VALUE R-3.6 to R-4.2 per in. (GPS, R-4.7 per in.)

COST Moderate

NET CARBON EMISSIONS Moderate (Type II R-4, 6.6; GPS Type II, 4.9)

TOXICITY Low

INSTALLATION Used in wall and roof assemblies, under slabs (at the correct density), on foundation walls, and in insulating concrete forms. Lightweight and easy to handle.

EXTRUDED POLYSTYRENE

XPS is another common rigid foam with slightly higher R-values than EPS. One of the principal chemical differences between the two is that all XPS has until recently been made with a hydrofluorocarbon blowing agent with more than 1400 times the global-warming potential of carbon dioxide (HFC-134a). This alone steers many green builders toward another insulation choice. However, Owens Corning announced a switch to a new XPS formation that eliminates HFC-134a. XPS is not as vapor permeable as EPS (about 1 perm for an unfaced, 1-in.-thick panel), it is somewhat higher in cost, and its thermal performance declines over time ("thermal drift") as the blowing agent slowly dissipates and is replaced with air. Exactly where the R-value bottoms out is unclear, but it's estimated that XPS will decline to R-4.5 in the first 20 years, and eventually to R-4.1 or R-4.2. It is available faced and unfaced. There are three makers in the U.S.: Owens Corning, Dow, and Kingspan.

R-VALUE R-5 per in. (when manufactured)

COST Moderate

NET CARBON EMISSIONS High to extremely high (Owens Corning NGX, 14.3; conventional HFC-blown XPS, 98.7)

TOXICITY Low

INSTALLATION Similar uses as EPS

material, has very low embodied energy, can be repaired, and works very well as a buffer when vapor drive spikes," wrote Dan Kolbert in "A Case for Double-Stud Walls" (*FHB* #291). "It can hold and redistribute vapor, releasing it to the dry side, in ways that foam, fiberglass, or [mineral] wool can't."

Installation details

There are at least as many ways to install insulation as there are insulation types. Some insulation can be installed by a homeowner or general contractor fairly well. Blown-in attic insulation comes to mind. Other types, like open- and closed-cell spray foam, require experienced professionals. In either case, it is critical to know how the material is properly installed and what prep is required.

For example, before you rent a machine and start blowing loose insulation into your attic, make sure all air-sealing work is complete, or you're wasting your time. Sometimes environmental conditions are critical. For a proper spray-foam installation, the chemical components must be warm, and the ambient and surface temperatures must fall in a specific range. If an installer tells you these things don't matter, be wary. A spray-foam installation gone wrong is not an easy thing to make right.

"We prioritize the ability to do a great job on the install with ease and comfort," wrote Brungardt. "Similarly, we like the ability to readily confirm proper installation. You need more than a walk-through look-around and will have to break out the IR camera if spray-foaming, dense-packing cellulose, or using faced batts."

Global-warming potential

Today, every building material should be evaluated for its environmental impact. It's not always an easy equation, and including this criterion doesn't make decisions any simpler. Sometimes a better-performing mate-

Photos, left to right: Matthew Millham; Patricia Steed; Matthew Millham; courtesy of Oliver Klein, 475 High Performance Building Supply

POLYISOCYANURATE

Polyiso completes the trio of commonly used rigid-foam insulation materials. Because of the method used to manufacture it, it is always faced. Foil facing makes it vapor impermeable. One big difference in the field is that polyiso is not rated for ground contact, so it's never used below a slab or to insulate foundation walls from the outside. One of its principal uses is as roofing insulation. Polyiso is subject to thermal drift, with its R-value dropping from about R-6.5 per in. at the time of manufacture to about R-5.6 or R-5.7 per in. over time. Polyiso also has another quirk: Its thermal performance goes down with the temperature, from R-5.6 or R-5.7 when it's 75°F to about R-4.8 when the mercury drops to 25°F, although manufacturers are looking for ways to counter this problem. Like EPS, polyiso is blown with pentane, a compound with a relatively low global-warming potential. Polyiso is more expensive than XPS and EPS and is not recyclable.

R-VALUE R-6.5 when manufactured, declining to R-5.7 over time (lower in cold temperatures)

COST Moderate

NET CARBON EMISSIONS Moderate (5)

TOXICITY Low

INSTALLATION Used like other foam-panel insulation materials

WOOD FIBER

Wood-fiber insulation comes in several forms, including rigid panels, batts, and loose material that's blown into enclosed cavities in the same manner as cellulose or fiberglass. Timber HP is the only U.S.-based manufacturer, though the company's board, batt, and loose-fill products are still being developed. Two imported brands are Steico and Gutex, both manufactured in Europe. Though imported options are expensive, wood fiber has appealing characteristics: It is manufactured from a renewable resource without petrochemicals, it has no embodied carbon, and it has low toxicity. Panels are nonstructural and vapor-open. Wood fiber is often used as a continuous layer of insulation on roofs and exterior walls. European products come in odd sizes.

R-VALUE R-2.7 to R-3.7 per in. (panels); R-3.9 to R-4 per in. (batts); R-3.6 to R-3.8 (blown-in)

COST High

NET CARBON EMISSIONS Sequesters carbon (R-3.8 batts, –1.9)

TOXICITY Very low

INSTALLATION Loose wood fiber is handled like cellulose; panels go up like rigid foam and can remain exposed to the weather for a number of weeks without damage.

rial may also come with a greater climate cost. XPS rigid foam performs excellent below grade. It also has one of the highest global-warming potentials of all insulators. Cellulose has a minimal environmental impact, but you can't use it to insulate below your slab. Sometimes we can change the building assembly to make a more sustainable option work. When we can't, compromises need to be made.

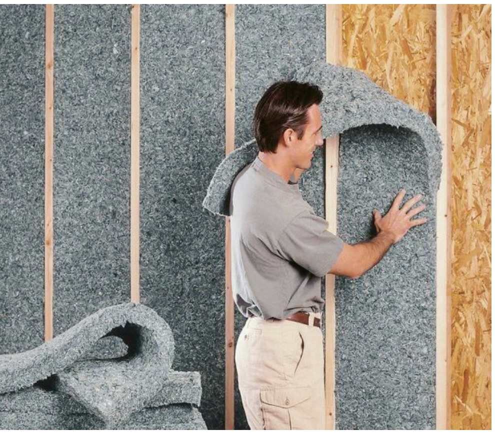
Costs

Every building project has a budget, so every material choice comes with a cost; therefore, cost deserves a place on this list. It may also be the most challenging factor to discuss. First, there's the practical reason that costs vary from one region to the next. We can generalize—fiberglass is probably at the low end of the cost range all around the country; mineral wool is often a premium product. On the other hand, spray foam and cellulose costs vary widely based on how common and available they are in a given region.

The other reason it is difficult to discuss cost is because of the impact an insulation choice has on the rest of the budget. I've talked to enough designers and builders over the years to know that it's much easier to sell clients on nicer flooring or a tiled shower than on energy improvements like insulation. I've also learned that client education is an often-overlooked piece of the puzzle. If your clients understand that more or better insulation is part of a robust envelope, which means they will spend less on their mechanical system, there's a better chance that they'll spring for it. I've often been impressed when I visit high-performance homes at how much the owners know about the nuts and bolts of their house. This is usually a credit to the architect or builder who did a good job of educating them throughout the process.

"It's our duty," says Xenakis. "We have to help our clients understand that there are

COTTON BATTS



R-VALUE R-3.5 to R-3.7 per in.

COST Moderate

NET CARBON EMISSIONS
Moderate (R-3.6 batt, 2.3; R-4.4 loose fill, 3.4)

TOXICITY Low

INSTALLATION Similar to other friction-fit batts, but not as easy to trim. Manufacturers emphasize "no itch" qualities.

Made principally from denim scraps with some additional synthetic fiber, cotton batts can be used only above grade in wall and roof assemblies. Unfaced batts are air permeable and come in oversized widths for a friction fit in framing cavities. Some installers complain it is difficult to cut and doesn't always bounce back after compression. Like other types of batt insulation, it must be fitted carefully around wires, pipes, and other obstructions in wall and ceiling cavities. It is more expensive than fiberglass and mineral wool batts, but Bonded Logic, which manufactures Ultra Touch, promotes its no-itch natural fiber content. It is treated with borate for fire resistance and includes high recycled content (80% postconsumer).

STRAW

Straw has extremely attractive environmental credentials. It is reclaimed agricultural waste, a raw material that is completely renewable and, regionally, widely available. It has very low toxicity, good fire resistance, and very high carbon capture. Straw mostly is used in the form of bales that are assembled into walls on-site and then finished with stucco or plaster. It's also available in panel form. EcoCocon, a European manufacturer operating in the United States as Build With Nature, offers a 15.7-in.-thick structural insulated panel with an R-value of 38. The load-bearing panels with a continuous layer of wood fiberboard insulation cost about $18 per sq. ft. (but this number includes the wall structure as well as insulation). Straw-bale construction is not common, but proponents are passionate about its advantages. It has low R-value per inch, but thick walls make up for it. Bales can be used as structural components or as infill in wood- or steel-framed structures. Straw bales are susceptible to water damage, so buildings need wide roof overhangs, careful flashing over windows and doors, and separation from moist materials. It offers high DIY potential.

R-VALUE R-1.4 to R-2.4 per in.

COST Low (bales) to high (prefabricated panels)

NET CARBON EMISSIONS
Sequesters carbon (R-2.9, –14.5)

TOXICITY Very low

INSTALLATION
Straw bales can be incorporated into buildings as infill or structural components as a low-tech building method friendly to owner/builders. Straw panels are comparable to other types of structural insulated panels (SIPs).

upfront costs, there are overtime costs, and there are environmental costs. We have to weigh it all, specific to each job."

And the list goes on

I recently insulated below a basement slab with EPS rigid foam that I ordered from a company located a couple hours from where the product was manufactured. Had I not been fortunate to be emailing with designer Michael Maines, who turned me on to Branch River Plastics at the time that I needed to order the insulation, I would have used next-gen XPS from the local big-box store at a higher financial and environmental cost.

I got lucky, but availability is a real issue. If you want to use wood fiber as exterior continuous insulation, you probably can't run down the street to get it. But as Maines pointed out to me, when we are building custom homes, we have the time to do the research and source the best products for the job. Maines was the one who suggested I add "availability" to my list of criteria for choosing insulation.

Peter Pfeiffer, principal at Barley/Pfeiffer Architecture in Austin, Texas, brought another consideration to my attention: sound attenuation. In the hot and humid climate where most of his projects are located, he prefers a flash-and-fill insulation system, with a flash coat of closed-cell spray foam to provide R-value, vapor control, and additional air-sealing (though he specs a primary exterior air barrier at the sheathing), and a fill of dense-pack cellulose that he says can effectively hold and redistribute excess moisture created inside the house. Pfeiffer calls this a perfect system and includes the fact that it makes for a quiet interior, which is important to many urban homeowners.

There's even more to consider: What happens to a material at the end of its initial service life? Rigid foam and mineral wool, for example, can often be reused. If insula-

Photos, left to right: courtesy of Bonded Logic; courtesy of Anni Tilt, Arkin Tilt Architects; courtesy of Hempitecture Inc.; courtesy of ThermaCork

HEMP

Hemp is another renewable agricultural material that scores well on the carbon sequester scale, second only to straw. But hemp insulation has struggled to gain a toehold in the market, and supplies of hemp insulation are spotty. A Kentucky company called Sunstrand LLC was producing R-13 batt insulation for 2x4 walls, but the company filed for Chapter 7 bankruptcy. A Quebec-based company, MEM Inc., continues to produce hemp blocks as well as sheets of hemp insulation 3½ in. and 5½ in. thick, with R-values of R-13 and R-20, respectively. The insulation is 88% hemp and 12% polyester. Hempcrete is another form of hemp insulation. It's mixed from hemp hurds (the cores of the plant), plus lime and water, and formed into blocks in steel or metal frames or tamped into moveable lifts to make larger wall sections. The low-density material is not load-bearing. It is vapor permeable. Hemp can be ordered from companies such as American Lime Technology. For more information, contact the U.S. Hemp Building Association.

R-VALUE R-1.2 to R-3.7 per in.

COST Moderate

NET CARBON EMISSIONS Sequesters carbon (R-3.7 batt, –3.1)

TOXICITY Very low

INSTALLATION Hemp panels are installed between studs on 16-in. centers. Hempcrete blocks and wall sections can be made on-site and may have the same DIY appeal as straw-bale construction.

CORK

Manufacturers point to the strong environmental credentials of cork insulation—100% renewable, recyclable, and about as green as it gets if you don't figure in transportation from the western Mediterranean where cork oaks grow. ThermaCork, a supplier, lists panels from ½ in. to 3 in. thick. Expanded corkboard is made from the outer bark of the trees, which reportedly suffer no harm in the harvesting process and may live to be hundreds of years old. Eco Supply Center is a U.S. distributor for ThermaCork. The company says that 95% of cork products come from Portugal and that cork insulation was once common in the United States, having even been used at the White House. It is semi–vapor permeable (2 perms at 2 in. thick).

R-VALUE R-3.6 to R-4.2 per in.

COST High

NET CARBON EMISSIONS Not available

TOXICITY Very low

INSTALLATION Installed like other board insulation. Some versions can be used as exterior cladding, where it weathers from a chocolate brown to a concrete-like shade.

tion can be left exposed—in an unfinished basement, for example—most foam plastics must be covered with something that provides a code-required fire rating. And there are health concerns for installers and folks with chemical sensitivities; at a minimum, make sure you and your installers are taking the appropriate safety precautions for whichever type of insulation you are installing, and educate your clients on the potential risks of off-gassing.

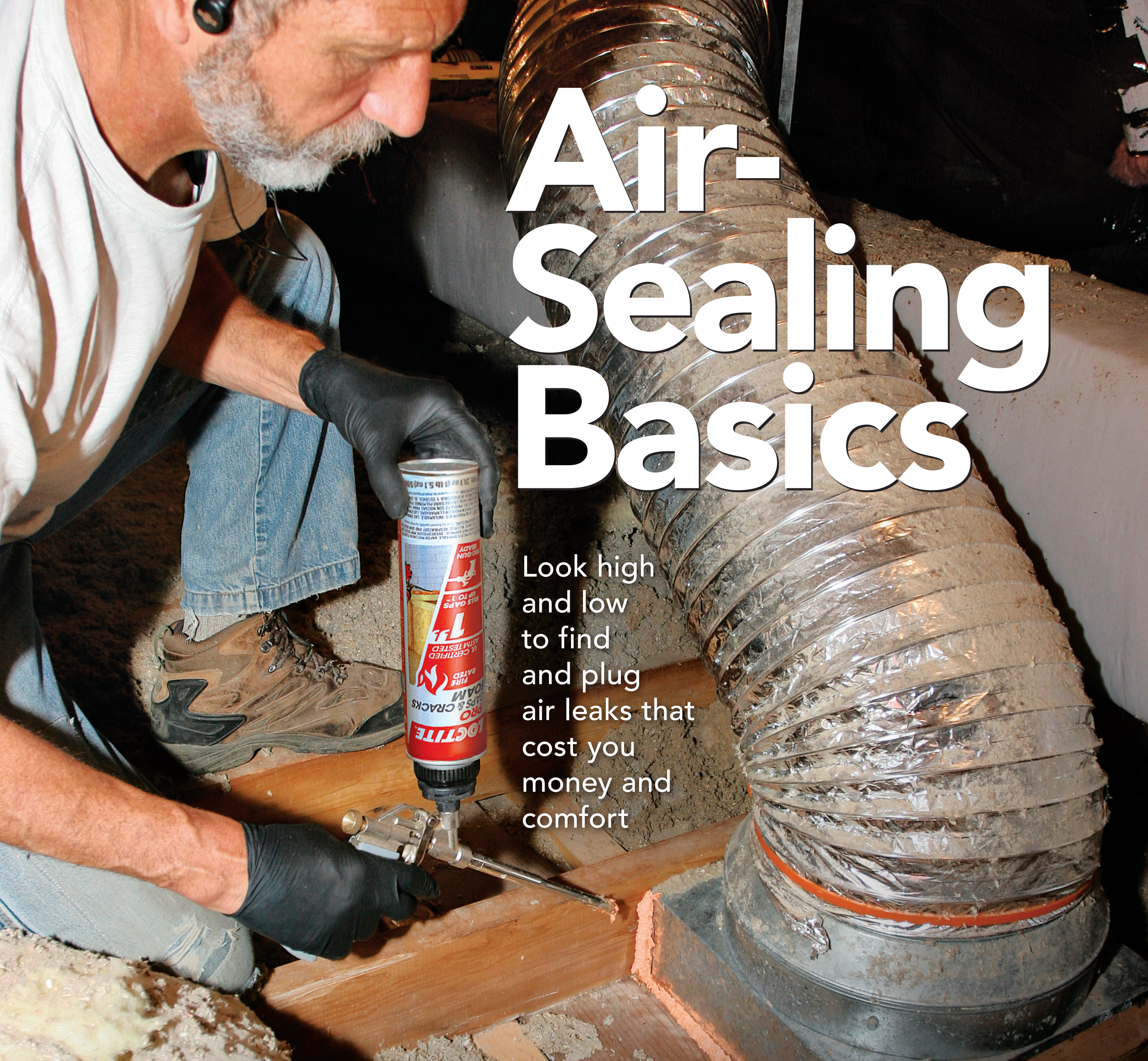
What are your priorities?

I'm wondering now if my list isn't flawed from the start. I came at the topic with efficiency and comfort top of mind. But it seems that any insulation can accomplish this. And the air-, water-, and vapor-control layers can ensure that the building enclosure is durable and tight.

I didn't create this list with an order of importance in mind. I started with the most obvious consideration (R-value) and ended with cost—which is ultimately important to the person writing the checks but has no implication on the quality of an assembly. Reviewing the list now, I am concerned that global-warming potential and human health are toward the end, where they could be interpreted as less important than the other considerations. Maybe human health and global-warming potential should be prioritized. Maybe the question shouldn't be "How do I choose the best insulation?" but "How do I use the most environmentally friendly insulation with the least risk to human health to create a comfortable and efficient house?"

Isn't that what's most important? □

Brian Pontolilo is a former editor at *Fine Homebuilding* and Green Building Advisor. Scott Gibson, a frequent writer for both *FHB* and GBA, contributed to this article.



Air-Sealing Basics

Look high and low to find and plug air leaks that cost you money and comfort

BY MIKE GUERTIN AND ROBERT SHERWOOD

While you might think that air leaks are a problem only with older houses, we've tested old homes that are pretty airtight and brand-new homes that leak lots of air. Air leaks occur wherever there is a joint, gap, or hole in the rigid building materials that enclose a house, such as wall sheathing, framing, and drywall.

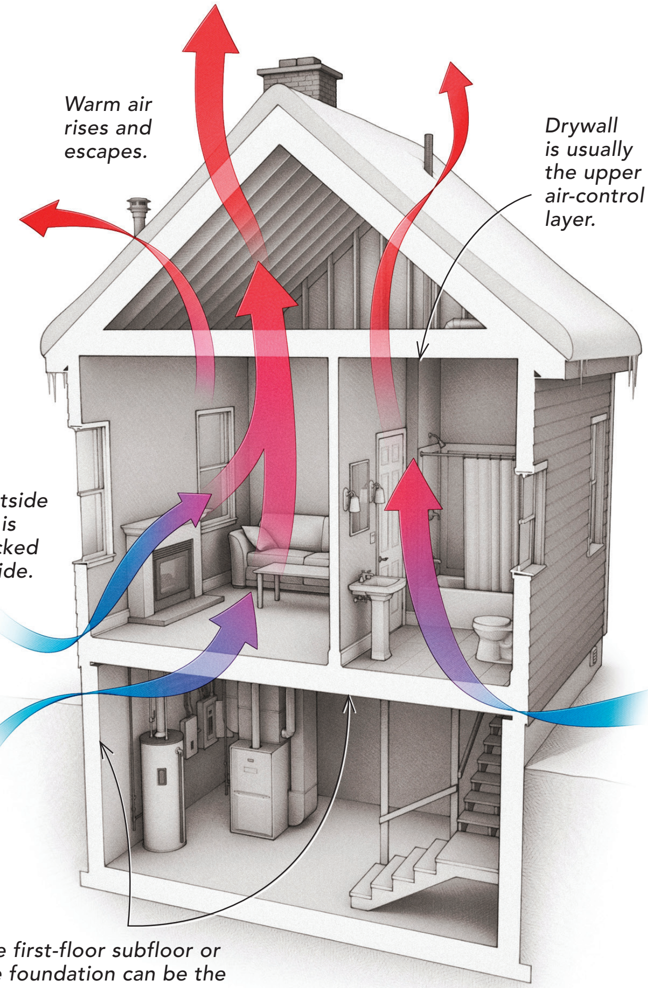
Making an existing house more airtight is pretty straightforward: Find the holes and seal them up. Many air leaks can be found just by looking for spaces between framing and chimneys, electric boxes and drywall, and the mudsill and foundation. The fixes are often simple and use common materials—rigid foam, caulk, acoustical sealant, and spray foam—which are selected based on

Bottom photo, facing page: Rodney Diaz. Drawing: Christopher Mills.

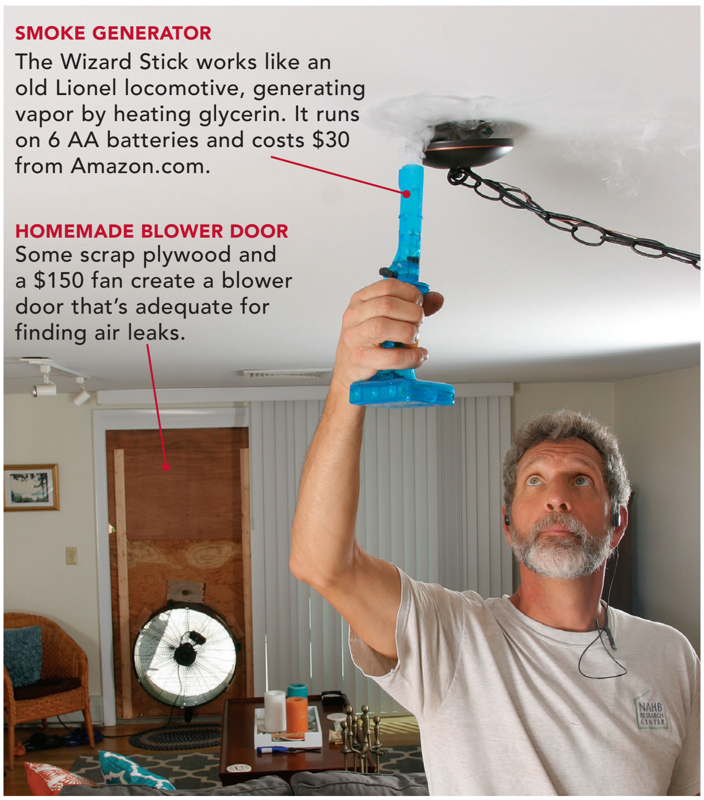
THE PATH TO A TIGHTER HOUSE

HOW HOUSES LEAK AIR

Warm air rises, creating a zone of higher pressure at the top of a house that forces air out of any hole it can find. This escaping air creates a zone of lower pressure at the bottom of the house that sucks in air through holes and cracks. This is the stack effect. Sealing leaks at the top and bottom of the house is the most effective approach for stopping it. The colder it is outside, the stronger the stack effect, so air-sealing can have a big impact in cold climates (zones 4 to 8) and a lesser one in mixed climates (zone 3). It is not as important in warm climates (zones 1 and 2).



TWO TOOLS FOR FINDING AIR LEAKS



SMOKE GENERATOR

The Wizard Stick works like an old Lionel locomotive, generating vapor by heating glycerin. It runs on 6 AA batteries and costs $30 from Amazon.com.

HOMEMADE BLOWER DOOR

Some scrap plywood and a $150 fan create a blower door that's adequate for finding air leaks.

THREE MATERIALS FOR STOPPING AIR LEAKS

RTV SILICONE

Sold for use as an automotive sealant, RTV is rated to 650°F. It's more flexible than so-called fire caulk, which tends to dry and fall out, so it can be a good choice for use around chimneys. Small quantities can be bought at auto-supply stores, but for caulk-gun tubes, Amazon .com is a good source.

ACOUSTICAL SEALANT

Meant for soundproofing, acoustical sealant never hardens, and it accommodates the normal movement of building materials without cracking. You might have to go to a commercial drywall supplier to find it.

SPRAY FOAM

Ranging in price from about $50 to over $100, foam guns make applying spray foam easy. Cans of foam for guns come in several varieties, from minimal-expanding for use around doors and windows to gap-filling for higher-volume applications. It's widely available online and at lumberyards and home centers.

SEAL THE BASEMENT WALLS OR THE

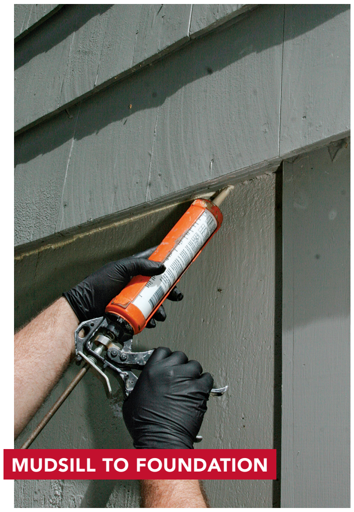
Whether to seal the foundation walls and slab or the subfloor above depends on factors unique to each house. When the basement is conditioned, the foundation walls and slab must be sealed because even though they are underground, air still can leak through the soil. If there are insulated foundation walls or ducts in the crawlspace or basement, use the wall and slab as the air barrier. If the subfloor consists of lumber planks, which leak a lot of air, it's probably easier to seal the foundation walls and slab. Bulkhead doors to the outside are big leaks, but it still might be easier to install a weatherstripped and insulated door at the bottom of the stairs than to seal the subfloor above.

CONCRETE PENETRATIONS

Apply spray foam around sump-pump pits as well as where utilities such as water lines, waste pipes, gas pipes, and oil fills enter the space.

RIM JOIST

The rim joist is prone to air leaks from the multiple gaps: mudsill to rim joist, rim joist to subfloor, and butt joints in the rim joist itself. Install rigid-foam insulation in each joist bay, and seal its perimeter with spray foam.



MUDSILL TO FOUNDATION

Even mudsills set on foam gaskets have gaps. Seal the perimeter with caulk from either the inside or the outside.

BASEMENT WINDOWS

Basement windows are often loose-fit sashes in cast-in-place frames. Use foam gaskets and foam rod to block air leaks.

SLAB TO FOUNDATION

Seal this gap, as well as any cracks in the walls or floors, with masonry sealant.

CHIMNEY CLEANOUT

Seal the perimeter of the door to the frame with high-temperature silicone caulk. The sealant can be cut away and then replaced when the door is opened for cleaning.

BASEMENT CEILING

Use the first-floor subfloor as the air barrier if it's plywood or OSB, if the joist cavities are uninsulated, and if there are few ducts in the basement or crawlspace. If the basement or crawlspace is damp, has dirt floors, or has walls built of unmortared stone, air-sealing the subfloor helps control moisture. In houses with those issues and leaky board subflooring, seal the subfloor with several inches of spray foam. You may also need to dry out the foundation. In all cases, the door to the first floor requires weatherstripping.

TUB OR SHOWER DRAIN

Piece in rigid foam around the pipes, gluing it to the subfloor with caulk or sealant. Fill the gaps with expanding foam.

PIPE AND WIRE HOLES

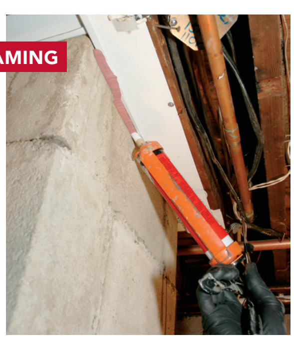
Seal the space between the framing and the wire or pipe with foam or acoustical sealant.

DUCT BOOTS

Seal to the floor with foam or acoustical sealant.

CHIMNEY TO FRAMING

Bridge the space with metal. Fasten it to the framing, and seal it to the chimney with high-temperature sealant or fireblock caulk.



SUBFLOOR GAPS

Apply acoustical sealant or a flexible caulk to the joints.

the hole size and surrounding materials. The energy savings usually pay for the cost of air-sealing within a few years—almost immediately, in fact, if you do the work yourself.

Air-sealing keeps conditioned air inside the house, but it also improves the performance of insulation such as fiberglass, cellulose, and mineral wool by stopping air from moving through it. In addition, because moisture vapor piggybacks on leaking air, air-sealing reduces the possibility of condensation developing in building cavities, which can lead to mold and decay. It's also a first step to adding fibrous insulation to an attic in a cold climate. This type of insulation alone does not prevent warm, moist air from escaping the living space. Finally, air-sealing can block gasoline or CO fumes from an attached garage, or moldy air from a crawlspace. Air-sealing does make it more important to vent bathroom exhaust fans and clothes dryers to the outside.

Air moves in and out of houses due to pressure differences between the inside and the outside. The three main forces driving pressure differences are the stack effect, wind, and mechanical fans. Although wind and fans may be important drivers in warmer climates, the stack effect is often the dominant cause of air leaks in heating climates. The stack effect happens when warm air rises and escapes through holes high in the house, much like how a chimney works. Although it's a weak force, it operates constantly, so it can account for a lot of air movement and energy loss.

Determine your air barrier

Air-sealing starts with deciding which building planes to use as air barriers. A building plane can be the exterior sheathing, subfloor, or drywall. One way to visualize the air barrier is to look at a section drawing of the house and find a continuous line that encloses the living quarters. The insulation should directly contact the air barrier. Generally that means the air barrier is the drywall or sheathing along the exterior walls, the top-floor ceiling or roofline, and either the foundation wall and slab or the first-floor sheathing. Once you've identified the air barrier, look for leaks in it and seal them up, starting with the biggest ones in the attic and the crawlspace or basement.

Finding the holes

Although a visual inspection can find plenty of leaks, it's easier to pinpoint them by pressurizing or depressurizing the house and feeling for drafts with your hand or using a handheld smoke puffer. The smoke moves toward a hole if the house is being pressurized, or away from a hole if the house is being depressurized. It's better to pressurize the house when you are using smoke inside to find leaks, and to depressurize the house when you are using smoke outside the living space. Professionals use a blower door for this, a tool that combines a high-capacity fan with a fabric-covered frame that fits in an exterior doorway. A manometer attached to the fan measures the air-leakage rate of the house to predict its performance or to determine rates of air leakage and assess the progress of air-sealing work.

Blower doors cost about $2600, though, and they aren't commonly available to rent. You can sometimes depressurize a house enough to find air leaks by turning on the exhaust fans, central vacuum, and clothes dryer all at once. But in very leaky houses, that may not create a noticeable pressure difference. Another option is a powerful (5000 to 10,000 cfm) drum fan. One can be had for under $150 (I have a 24-in. shop fan from Harbor Freight) and can be fit into a piece of plywood that mounts to a door or window, creating a low-tech, homemade blower door.

Close all windows, doors, chimney dampers, and attic hatches to maximize the pressure difference. Exhausting air from a house may suck air down chimneys, so turn off combustion appliances such as gas ranges, furnaces, boilers, water heaters, or clothes dryers. Make sure that fireplaces or woodstoves have been out for 24 hours. Clean the ashes out of the firebox to avoid sucking them into the house, and wash potentially lead-contaminated dust from around windows in pre-1978 houses. If you have vermiculite insulation in the walls or attic or otherwise think there may be asbestos in the house, consult an asbestos-abatement specialist before doing any air-sealing. Remember to turn the appliances back on and to relight pilot flames when the work is done. □

Editorial adviser Mike Guertin is a contractor in East Greenwich, R.I. Rob Sherwood is a senior project manager with Conservation Services Group in Westborough, Mass. Photos by Andy Engel, except where noted.

SEAL THE ATTIC

In most homes, the drywall ceiling dividing the living space from the attic is the best air barrier at the top of the house. Seal leaks from above, and cover attic accesses such as stairs or scuttles with a foam box such as the Battic Door or ones available at home centers. We sometimes encounter ceilings covered with tongue-and-groove planks or acoustical tiles and no drywall behind them. These ceilings are nearly impossible to air-seal, so it's easier to seal these houses at the rafter plane by spraying a layer of foam against the underside of the roof and sealing off any attic ventilation. When there is no attic, such as with many sloped ceilings, the drywall still can be used as the air-control layer, but air leaks have to be sealed from inside the living space.

DUCT BOOT

Holes in the ceiling for duct penetrations are usually oversize and can leak significant amounts of air. Seal around them with spray foam or acoustical sealant.

RECESSED LIGHTS

These are notorious for leaking air. The first option is to replace a recessed can with an airtight model or a ceiling-mounted fixture, but you also can build an airtight box around lights that have thermal cutoffs as long as you observe the manufacturer-required clearances.

FRAMING AROUND CHIMNEYS

Insulate the space between the chimney and the framing with mineral wool, then bridge the space by bedding sheet metal in acoustical sealant and screwing it to the framing. Seal the metal to the chimney with RTV silicone or fireblock caulk.

Top-right photos, this page and facing page: Mike Guertin

DRYWALL GAPS

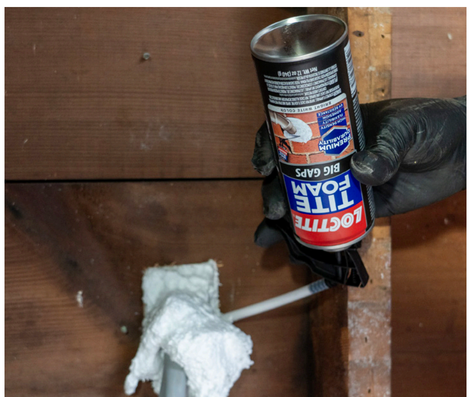
Added up, the gaps between the wall and ceiling drywall and the top plates can amount to a large open area. Seal gaps up to ¼ in. with acoustical sealant and larger gaps with spray foam.

BALLOON FRAMES

Often found on gable walls, open stud bays conduct air from inside the house into the attic even when they are filled with fibrous insulation. Block the bays with wood or rigid foam sealed to the framing.

UTILITY BOXES

Foam or caulk the gap between drywall and electrical boxes, duct boots, and bath fans. Seal holes in electrical boxes, or encase smaller boxes with expanding foam.



PENETRATIONS IN WALL PLATES

Fill holes in the plates and gaps around wires and pipes with spray foam or acoustical sealant.

CHASES AND SOFFITS

Large breaks in the ceiling drywall often occur at utility chases, at corbeled chimneys, and above soffits. Block these holes with rigid materials (foam, plywood, OSB, drywall), and seal them to the surrounding framing and drywall.

Dedicated combustion air. *In tight houses, boilers and similar appliances should be supplied with air through a duct leading directly to the outside.*

Can you make a house too tight?

After air-sealing, have a knowledgeable HVAC technician or energy specialist make sure that your house has enough fresh air for your combustion appliances. Air-sealing can tighten a house to the point where combustion appliances don't receive enough make-up air to perform well. Atmospheric combustion appliances can be a health hazard in a tight house. The exhaust gases from a fireplace, woodstove, furnace, or water heater can be sucked down the flue by exhaust fans. Combustion appliances, or the area they operate in, should be outfitted with air intakes ducted from the outside. Broan makes a motorized damper that can be wired to open when the boiler or furnace fires, providing combustion air when needed while otherwise keeping outside air where it belongs. Intake ducts can connect directly to the burner on some models.

Tight houses can suffer from poor indoor-air quality if water vapor, VOCs, CO_2, and odors build up. You may need mechanical ventilation to bring in fresh air and exhaust stale air. In a balanced ventilation system, fans draw in and exhaust air at the same rate. An improvement to a basic balanced ventilation system is to use an energy-recovery ventilator (ERV) or a heat-recovery ventilator (HRV), both of which transfer a large percentage of the energy from the air being exhausted to the incoming fresh air.

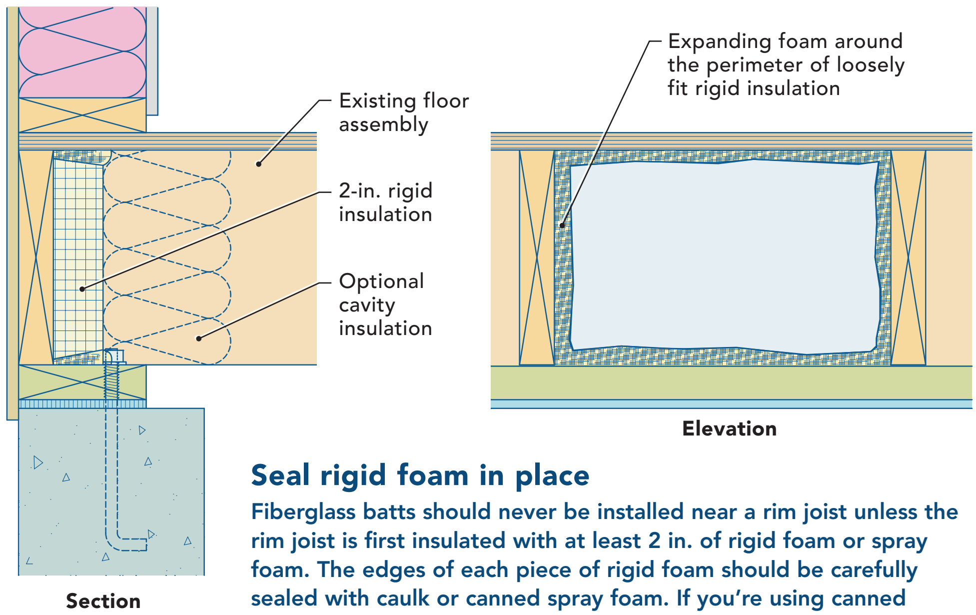
Insulating Rim Joists

BY MARTIN HOLLADAY

In older homes, rim joists (also called band joists) are often uninsulated, even though the only materials that likely separate them from outdoor air are sheathing and siding. Rim joists are above grade, so it makes sense to insulate the joists to the same level as above-grade walls. At the rim-joist area, many building components come together—the foundation wall, the mudsill, the rim joist, the subfloor—so it's also important to seal all cracks against air leakage.

The time-honored practice of insulating rim joists with fiberglass batts is no longer recommended. Because fiberglass batts are air permeable, they do nothing to prevent warm, humid interior air from contacting the rim joists. During the winter, when the rim joists are cold, condensation can cause mold and then rot.

To prevent these problems, only air-impermeable insulation—either rigid foam or spray polyurethane foam—should be used to insulate the interior of a rim joist. Two-story homes usually have another ring of rim joists above the first-floor ceiling. If you need to insulate these rim joists, it's best to hire a cellulose-insulation contractor.



Seal rigid foam in place

Fiberglass batts should never be installed near a rim joist unless the rim joist is first insulated with at least 2 in. of rigid foam or spray foam. The edges of each piece of rigid foam should be carefully sealed with caulk or canned spray foam. If you're using canned spray foam, you'll find that wide cracks are easier to seal than narrow ones, so it's a good idea to cut the rectangles a little small.

Rigid foam is affordable

If you're ready to insulate the rim joists in your basement or crawlspace, you have to decide between rigid foam and spray foam. Using rigid foam keeps the material costs low, but it also requires more labor than using spray foam. Rigid foam also has a few other downsides: Compared to spray foam, it's harder to install in awkward areas (for example, in a tight space where a rim joist is close to another parallel joist). Rigid foam is also fussy to install if the rim joists are the site of lots of wiring and pipe penetrations.

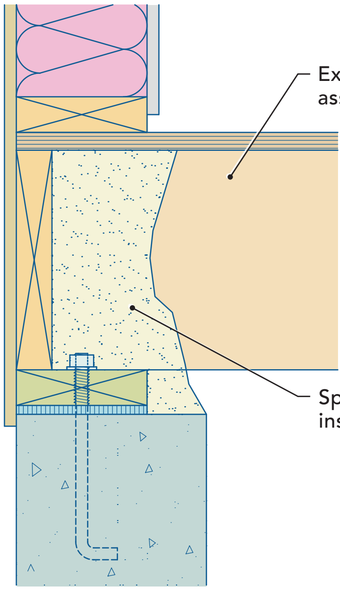
Any of the three common types of rigid foam—polyisocyanurate, expanded polystyrene (EPS), or extruded polystyrene (XPS)—can be installed against a rim joist. Polyisocyanurate is considered the most environmentally friendly of the three foam types; it has an R-value of between R-6 and R-6.5 per in. In colder climate zones, it's a good idea to install at least 3 in. to 4 in. of rigid foam, either in a single layer or in multiple layers. (For a less pricey approach, you can install 2 in. of rigid foam and a layer of fiberglass insulation.) In warmer climates, 2 in. of foam may be enough.

To ensure that humid indoor air won't reach the cold rim joist, the crack at the perimeter of each piece of foam (and at any penetrations) should be sealed with caulk or canned spray foam. If you use canned spray foam, you may want to buy a few lengths of flexible vinyl tubing with a slightly larger diameter than the plastic nozzle that comes with the can. This will make it easier to reach awkward corners. Discard the vinyl tubing when it gets clogged.

Spray foam insulates and seals

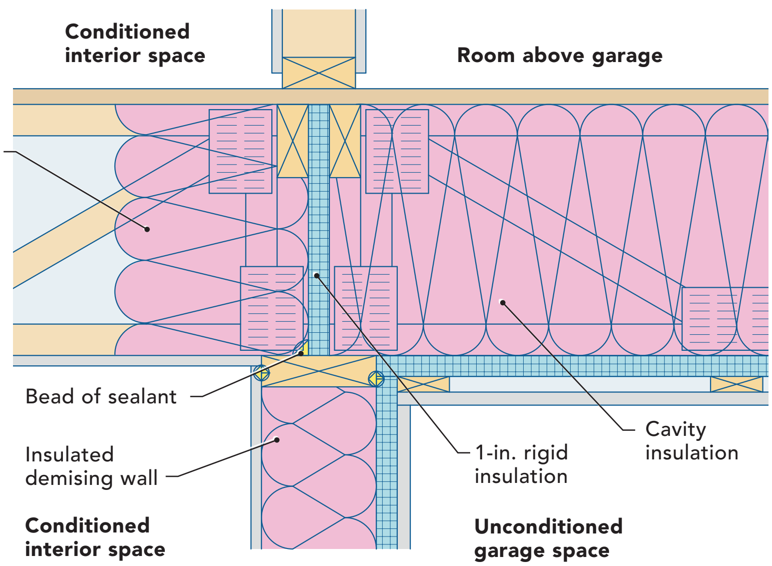
One advantage of using spray foam to insulate rim joists—an approach sometimes called the *critical-seal* method—is that a single product performs two tasks: sealing air leaks and insulating. In mild climate zones, either open-cell spray foam or closed-cell spray foam will work; however, in climate zone 6 and colder zones, it's safer to use closed-cell spray foam.

Unless you hire a spray foam contractor for the job, you'll probably be buying a two-component spray-foam kit. These kits are available at most lumberyards; expect to pay from $320 to $360 for a 200-bd.-ft. kit. If you want to install 3 in. of foam in an



Hit everything with spray foam

To create an effective air barrier, spray foam should extend from the top of the concrete all the way to the subfloor. For good thermal performance, the foam should cover all of the exposed concrete at the top of the wall.



Don't forget the garage rim

If the floor assembly penetrates the air barrier between a house and an attached garage, rectangles of rigid foam should be installed between each joist to prevent air leaks. Each rectangle needs to be sealed at the perimeter with caulk or canned spray foam.

What the code says

Most building codes require rigid foam to be protected with a layer of ½-in. drywall as a thermal barrier. The drywall can be screwed to the rim joist through the foam.

Dow Thermax polyisocyanurate, one type of rigid foam, has a facing that has passed fire-safety tests. That means that most building inspectors don't require Thermax to be protected with a drywall layer, making it a good choice for this application.

Spray-foam requirements differ from those for rigid foam. As long as your cured spray foam is no thicker than 3¼ in., the International Residential Code (IRC) allows spray foam at the rim-joist area to be left exposed, without any protective drywall.

area that measures 1 ft. high by 130 ft. long, you'll need about 400 bd. ft. of spray foam. Once cured, this type of spray foam has an R-value of about R-6.5 per inch. (Most two-component spray-foam kits use closed-cell foam.)

If your basement is cool, store a spray-foam kit in a warm location for 24 hours before you begin. Be careful; uncured spray foam is messy. If you get uncured spray foam on your skin, you won't be able to wash it off. If you get it on objects in the basement, the foam may be impossible to remove. Before spraying, clear movable objects from the work area, and use a tarp to protect things that can't be moved. Wear a respirator, rubber gloves, goggles, a cheap hat, and either a Tyvek suit or old clothes. □

Martin Holladay is a retired editor who lives in Vermont. Drawings by Steve Baczek, Architect.

More options for new homes

If you're building a new house, you can insulate the rim joists using one of the methods suggested for older homes. It often makes more sense, however, to insulate rim joists on the exterior rather than the interior. This can be done by recessing the rim joist 2 in. from the outer edge of the mudsill to provide room for 2 in. of rigid foam.

It's also possible to install a layer of rigid foam on the exterior side of your OSB or plywood wall sheathing; if you go this route, the rigid foam will cover the rim joists as well as the walls.

A third option is to buy engineered rim joists with integral foam insulation. These joists are available from Weyerhauser, which manufactures the TJ Insulated Rim Board, and from Structural Wood Corp., which manufactures the Insul-Rim Plus.

How Good Is Your Air Barrier?

If your goal is extremely low air leakage, choose your materials carefully

BY SCOTT GIBSON

Pointing to benefits ranging from lower energy costs to healthier indoor air, building scientists have long recommended that houses be constructed so they are essentially airtight. Model building codes have followed suit by gradually requiring tighter as well as better-insulated dwellings.

The 2021 International Residential Code (IRC) sets specific airtightness standards for new houses, verified with a blower-door test. Maximum permitted air leakage—described as air changes per hour at a pressure difference of 50 pascals, or ACH50—varies by climate zone and whether the builder follows a prescriptive or performance path to code compliance.

As a result, even builders skeptical about airtight construction should be meeting these minimum standards. Builders and designers who work on high-performance houses left these code minimums in their rear-view mirrors years ago. At the far end of this spectrum are buildings certified by the Passive House Institute, whose benchmark is 0.6 ACH50—very tight indeed.

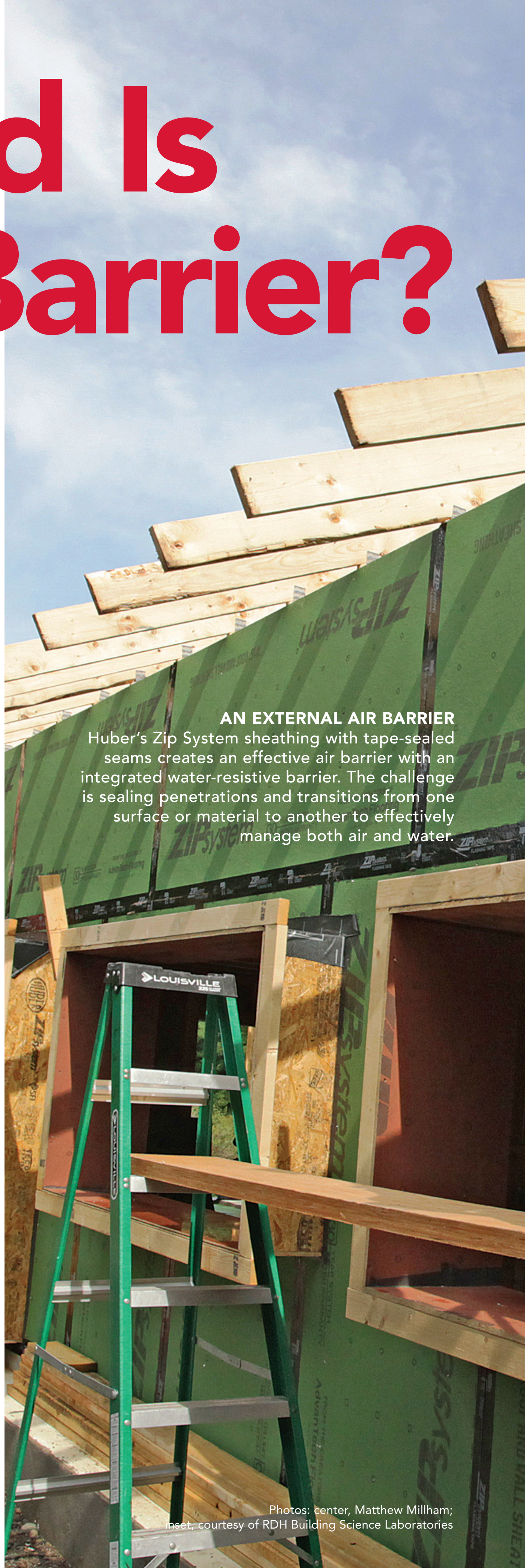
Creating airtight houses requires a range of techniques and materials. An air barrier is not a single material but a combination of materials that together form a continuous air-impermeable layer that should be readily identifiable on construction drawings. Various flashing tapes, sealants, and gaskets are essential parts of the puzzle, but a lot of the heavy lifting is done with materials that cover big areas—sheathing, drywall, housewrap, and peel-and-stick membranes.

How airtight each of these materials is has an impact on the overall airtightness of the building. The more rigorous the airtightness standard, the more important the physical characteristics of the material. The time to ensure airtightness is while the house is being put together. Revisiting the problem later and trying to correct air leaks is expensive and time consuming.

As Laverne Dalgleish, executive director of the trade group Air Barrier Association of America (ABAA), says, "You've got one chance to do this without costing you a phenomenal amount of money to do a retrofit."

First, what is an air barrier?

An air barrier is just one of the four control layers that need to be managed to maintain healthy, comfortable, and energy-efficient spaces. Water, vapor, and thermal (temperature) are the other three, and while many of the materials chosen to build the envelope of a home can operate as more than one control layer, this article will focus just on air barriers. An ideal air barrier should



AN EXTERNAL AIR BARRIER
Huber's Zip System sheathing with tape-sealed seams creates an effective air barrier with an integrated water-resistive barrier. The challenge is sealing penetrations and transitions from one surface or material to another to effectively manage both air and water.

Photos: center, Matthew Millham; inset, courtesy of RDH Building Science Laboratories

MEASURING AIRTIGHTNESS

A standard ASTM test measures how much air passes through a material at a given pressure. Results can be reported in one of two ways (and not all manufacturers report both values). Materials meeting the minimum standard can be considered air barriers. The list below includes a mix of self-adhered, liquid-applied, and sheet products.

Product	*L/s/m^2 @75 pa (standard is 0.02)	**cfm/ft.^{2} @1.57 lb./ft.^{2} (standard is 0.004)
Tyvek CommercialWrap	0.0023	0.00046
Tyvek HomeWrap	0.01	<0.004
ZIP System sheathing	0.0016	
Henry AirBloc 16MR	0.0013	0.00026
Prosoco R Guard Spray	0.0024	0.00048
Tremco ExoAir 130	0.0005	0.00001
Drywall	0.02	0.004
Intello Plus	0.0025	0.00005
SIGA Majvest 500 SA	0.0003	0.00006
Henry Blueskin SA	0.0002	0.00004

* Liters per second per square meter at a pressure of 75 pascals

** Cubic feet per minute per square foot at a pressure of 1.57 lb. per square foot

FLUID-APPLIED BARRIERS Air barriers come in many forms. While self-adhered or mechanically fastened and taped membranes are common, fluid-applied membranes are another option. This spray-applied product, Tremco's Enviro-Dri, forms a waterproof skin over the sheathing that greatly reduces air leakage and requires very little additional air-sealing.

be strong, durable, continuous around the entire building enclosure, and, of course, air impermeable. "Air barriers keep outside and inside air out of the building enclosure," Joseph Lstiburek wrote in a paper published by the Building Science Corporation. "Air barriers can be located anywhere in the building enclosure—at the exterior surface, the interior surface, or at any location in between."

In other words, the air barrier can be in the form of exterior sheathing or a combination of sheathing and a membrane, it can fall in the middle of the wall as a layer of spray polyurethane foam or another impervious material, or it can be on the inside of the building, as a layer of gypsum drywall or specialized building paper.

One air barrier is essential. Some builders and researchers think there should be more than one air barrier in a building—one on the inside and one on the outside.

Air impermeability is key, but what exactly does that mean? In technical terms, it means that air leakage is limited to a certain volume of air at a certain air pressure. The industry standard for a specific material like drywall, housewrap, or sheathing is 0.02 L/s/m^2 (liters per second per square meter) at a pressure of 75 pascals.

Materials leakier than this don't qualify as an air barrier, and builders looking to meet rigorous airtightness standards should think twice about using them.

What material testing reveals

Some materials are assumed to be effective air barriers. They include structural panels such as plywood and oriented strand board, or OSB (at least ⅜ in. thick); concrete, flexible water-resistant barriers; and gypsum board.

A number of these materials have been tested, either by their manufacturers or by independent third parties such as the ABAA, using a standardized test—ASTM E2178. Test results can sometimes be found in the fine print from a manufacturer, although you may have to dig a bit to find them. At its website, ABAA posts results of its own testing of a variety of materials used as air barriers. There are 10 self-adhered sheet membranes on the list of tested products, including Siga's Majvest 500 SA, used by Maine builder Dan Kolbert on a double-stud wall last year. That product showed an air-leakage rate of 0.0003 L/s/m^2, many times better than the air-barrier standard. When tested as part of an assembly (using a different ASTM test method), air leakage was 0.004 L/s/m^2. These results show that the material is a good choice for an air barrier. The same list includes products from the Henry Company, Polyguard, Demilec, and Dörken, among others.

Results also are posted for fluid-applied membranes, medium-density spray polyurethane foam, mechanically fastened commercial building wrap, some rigid board insulation such as Styrofoam, and factory-bonded membranes to sheathing, like Georgia Pacific's DensElement Barrier System. Some of these products show up routinely on commercial jobs but not so much on residential job sites.

According to Dalgleish, the nonprofit ABAA will test materials submitted by association members, who pay a $5000 fee to join. There are no results at the website for plywood or OSB, Dalgleish says, because no one has submitted them for testing. Likewise, the Oak Ridge National Laboratory, a well-known research facility, says it has the means to test material and assemblies that would be used as air barriers but has not been asked to do so. So there is no data to be mined there.

Don't bank on OSB alone

Although OSB is assumed to be a reliable air barrier, a round of private testing by RDH Building Science in Waterloo, Ont., found otherwise. The company was approached by Huber Engineered Woods, which manufactures Zip System sheathing, and was asked to test Zip System, plywood, and OSB for airtightness.

Testing was very limited, involving just one sample of plywood and three samples of OSB, along with three Zip System panels. (The

Photos: this page, Patrick McCombe; facing page top, Travis Brungardt; bottom, Scott Gibson manufacturers of the OSB and the plywood were not identified.) Zip System sheathing is souped-up OSB, coated with a resin-impregnated kraft paper for water and air resistance. Huber executives no doubt felt pretty good about the RDH experiment; it showed extremely low rates of air leakage for 7⁄16-in. Zip sheathing.

Commodity OSB didn't do as well. None of the samples met the air-barrier standard, and one showed five times the air leakage that would be permitted. After the samples had been put through a wetting and drying routine to simulate job-site conditions, the results were even worse.

Jonathan Smegal, the lead researcher on the project for RDH, was careful to point out that OSB manufacturers are not making claims about the material's airtightness. OSB is marketed as structural sheathing, not an air barrier. But given the fact that many builders have been using it for that purpose, the test results were not encouraging.

Dalgleish is not surprised. "Not at all," he says. "That's one of the beefs we have with the code. The code has listed a bunch of materials that you don't have to test. My personal position, and the ABAA's position, is the same: If you don't test it, you don't know."

He adds that manufacturers working in a very price-competitive market are watching for ways to reduce costs and may change manufacturing techniques or product ingredients when the opportunity presents itself. Such changes may not affect a product's structural properties, but they could change its air permeability. "Something manufactured five years ago that was fantastic may not be the same material today," Smegal said.

A MEASURE OF SUCCESS
A blower-door test is the standard for finding out how airtight the building enclosure actually is. Some performance standards, such as Passive House, require extremely low levels of air leakage.

Air barriers as part of an assembly

Performance of the material itself is one consideration, but materials become part of assemblies. In the RDH tests, plywood was tested alone, then tested again after wetting and drying, and again after it was covered with a layer of taped Tyvek housewrap. At this last stage, Smegal's group nailed on sections of vinyl siding to see how that affected airtightness. Predictably, leakage went up as the Tyvek-plywood assembly was peppered with nail holes.

Smegal predicted that a house using a similar assembly as its air barrier should easily be able to pass code-required blower-door testing, but probably would not be able to achieve Passive House tightness. It might be hard, he said, to get the house down to a range of 1 to 1.5 ACH50.

Whole-house results also depend heavily on other parts of the air barrier—components such as windows and doors, seals around plumbing or electrical service entrances, gaskets or sealants under bottom plates on exterior walls, and the many other parts and pieces of the assembled whole. As Smegal pointed out, just because one part of the assembly does not meet the material definition of an air barrier, that does not necessarily mean the building can't be reasonably tight when complete.

Kohta Ueno, a senior researcher for Building Science Corporation, adds that it's often the edges and margins of an assembly where air leaks occur, not through a material itself. "We all know that details and connections are where air barriers fail," Ueno says. "I have done plenty of forensic investigations where they've done a beautiful job on the wall, and a fantastic job on the roof, and basically where they came together

DETAILS COUNT
High-quality tape is often a vital part of a continuous air barrier that connects a number of building components. Here, 3M tape is used to seal an OSB air barrier at the ceiling.

something happens and you have a 1/8-inch gap going hundreds of feet around the building. That adds up to a massive air leak."

Proper installation may be one of the most important details of all. "Everything comes down to the workmanship," says Carl Seville, a Georgia building consultant and green-building certifier. "Well-installed housewrap is better than badly installed Zip."

In the case of housewrap, the material may qualify as an air barrier, but unless it's installed carefully it will be leaky. If the housewrap is being used solely to shed water, a simple weather lap will be fine. But that won't be good enough if the housewrap is supposed to be detailed as the air barrier. "Can you detail a mechanically fastened housewrap as an air barrier?" Ueno asks. "You can, but I seldom see that done very effectively."

When materials are easy to install, it often improves their performance as an air barrier, which helps explain why Huber's Zip System sheathing is so popular. Nail it up, seal seams with Zip tape, and you're essentially done (although walls must still be connected to the rest of the air barrier to make it continuous).

Some prefer interior air barriers

Ueno is among those who think that exterior air barriers—in the form of taped sheathing or either liquid-applied or self-adhering membranes—are the best approach. Some builders take the opposite view. One of them is Ben Southworth of Garland Mill in Lancaster, N.H., a high-performance builder with Passive House training.

On the outside of the building, Southworth applies a combination of pressure-treated plywood and Zip System sheathing and tape, but his principal air barrier is on the inside of the house. He uses a vapor-open European membrane such as Intello over the studs. After blowing insulation into the cavities, he carefully tapes the seams. He then adds 2x3 strapping to create a service cavity before installing the interior finish. This approach protects the air barrier from damage, and wiring and plumbing lines are routed through the service cavity, meaning fewer penetrations through the air barrier.

Southworth can easily hit the Passive House airtightness standard, and he thinks an interior barrier makes the most sense. "That's how they taught us," Southworth says of his Passive House instructors.

SMART BARRIER DOES DOUBLE DUTY
Intello Plus is one of several vapor-variable smart membranes that provide both air and vapor control. It acts as a continuous interior airtight membrane as well as a vapor retarder that changes its vapor permeability in response to the relative humidity of the surrounding air.

CLOSING THE GAP
Spray foam can be part of an air-sealing arsenal, along with tapes, gaskets, and other products made specifically for application at edges and penetrations.

"We're really trying to keep all air, particularly moist air, off the exterior sheathing, that condensing surface," he continues. "It makes more sense to me to have our line of defense be that interior paper rather than the sheathing."

The interior mechanical chase makes the building more resilient, and it allows plumbing or electrical lines to be added later without disturbing the air barrier. With sheathing on the exterior sealed at the edges and seams, Southworth is, in effect, using two air barriers, and he routinely gets very low blower-door test results. "It's not the only way," he says, "but it's how we do it."

Spray polyurethane foam is an air barrier

Spray polyurethane foam is used chiefly as a thermal control layer, but it also can act as an air barrier provided that it's applied in a thick-enough layer. Open- and closed-cell foams have different densities. An open-cell foam must be applied in a thicker layer than a closed-cell foam in order to qualify as an air barrier. Air permeability varies by manufacturer, but air barriers are commonly created with 3 in. of open-cell and as little as 1 in. of closed-cell insulation.

A foam's air permeability is reported in a document called an Evaluation Service Report published by the International Code Council Evaluation Service (ICC-ES). These reports are available online. Once you know the type of foam the installer will use, you can look up the report and know exactly how thick the foam should be applied in order to be considered an air barrier.

When it comes to spray foam, there are a couple of things to keep in mind. First, spray foam is manufactured at the job site by mixing two chemicals together. However unlikely, it is possible that it will be mixed or applied incorrectly. Second, spray foam doesn't always make it to areas where leaks occur, such as the seam between a double top plate on an exterior wall.

Photos: left, Brian McAward; center, Daniel Morrison; right, courtesy of AeroBarrier

"Spray foam is a fantastic air barrier where it is," Ueno says. "It does nothing where it's not. So any time you have a wood-to-wood joint where it's not covered up by the spray foam, all of those are potential air-leakage locations."

AeroBarrier seals from the inside

Another option is a product called AeroBarrier, a liquid sealant that is atomized and forced into gaps and holes in the building enclosure when the building is pressurized. AeroBarrier is a substitute for caulks, tapes, and other air-sealing materials. Airtightness can be verified in real time by technicians, and the company says just about any level of airtightness is attainable. Costs average about $1.50 per sq. ft. of floor area.

One adherent to the AeroBarrier method is Pioneer Builders, a spec builder in Port Orchard, Wash., which typically has four or five houses underway at any one time. According to company vice president Bryan Uhler, Pioneer often aims for an airtightness level of 3 ACH50, sometimes lower, and has found AeroBarrier to be the most cost-effective way to get there. Crews don't have to take any special air-sealing steps during construction—that's a big time saver. And AeroBarrier comes in near the end and seals up the building envelope in a matter of a few hours. He likes the system because it saves time and makes job sites safer by eliminating some ladder work.

Costs cover a wide range

Most builders are looking to minimize costs. Some materials used as air barriers are available at just about any lumberyard or big-box store. They include OSB, Zip System sheathing, plywood, and housewrap. Sealing tapes, such as those from Zip or 3M, also are easy to find. Lumber and sheathing prices spiked during the pandemic but have subsided somewhat in recent months. OSB at 7⁄16 in. thick was available for $0.55 per sq. ft. in October in Portland, Maine, while 15⁄32-in. plywood was $0.75 per sq. ft. and 7⁄16 in. Zip sheathing was about $1 per sq. ft. Housewrap cost $0.16 per sq. ft.

Other materials—particularly specialty European membranes—are a little harder to find and are typically more expensive. The Siga Majvest 500 self-adhering membrane that Dan Kolbert uses was $1.12 per sq. ft. from Performance Building Supply in Portland, Maine. Intello Plus (an interior vapor-variable membrane) was $0.45 per sq. ft. at 475 High Performance Building Supply in New York City. Intello X, an exterior version, was $0.48 per sq. ft. The same company also sells a liquid-applied air barrier called Visconn that can be brushed, rolled on, or sprayed. A 2½-gal. container costs about $200, which boils down to between $1.18 and $1.60 per sq. ft. depending on how it's applied. More-complicated applications, such as self-adhering membranes or liquid-applied membranes, also require more labor than taped plywood or Zip sheathing. That's another cost factor.

Think about the airtightness goal

Builders seeking simple code compliance—3 or 5 ACH50—have more room for error in both technique and material selection than someone looking for Passive House levels. Ueno likens air-sealing strategies to having a budget: The tighter the house needs to be, the smaller the budget of total holes in the building enclosure. In a Passive House, covering large expanses of the exterior with commodity OSB as the primary air barrier may use up a disproportionate amount of your total budget of air leaks, leaving little room for error on closing up all the small potential leaks elsewhere. But if the aim is 3 or 5 ACH50 to meet local code requirements, the choice of a particular type of sheathing or self-adhered membrane may not matter as much.

As Ueno puts it, "The goal you have for your project definitely will start to dictate which approach you will take for air barriers." In in his view, that means an exterior air barrier is the best choice, Ben Southworth's success with interior air barriers notwithstanding. "If you're pursuing ultrahigh performance, an exterior air barrier just basically works better," he says. "That's how you end up with these fantastically airtight houses. You can see it, you can inspect it, you can ensure continuity." □

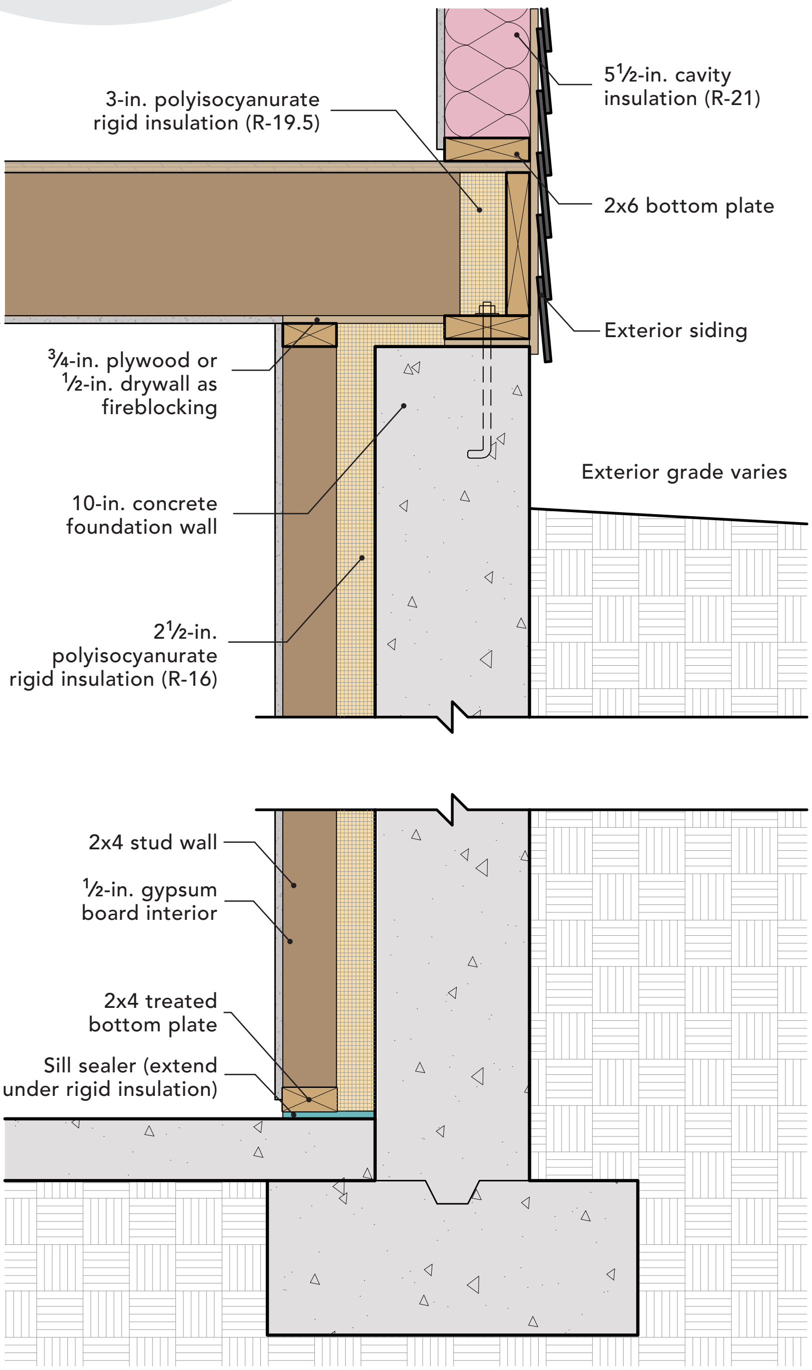
Scott Gibson is a contributing writer for *Fine Homebuilding* and Green Building Advisor.

Before

After

THE MIST THAT SEALS
AeroBarrier is a unique approach to air-sealing a building enclosure. An atomized sealant is forced into cracks in the building envelope under pressure, doing the work of caulks, tapes and other conventional sealants quickly and effectively.

3 Ways to Insulate Basement Walls



BY MARTIN HOLLADAY

Basement-wall insulation can be placed on the exterior side of the wall, on the interior side of the wall, or on both sides of the wall. When the basement wall is insulated from the interior, there are a few different ways to achieve minimum R-values. This article illustrates the three most common options: continuous rigid insulation, a combination of continuous rigid insulation and insulation batts, or closed-cell spray foam. Regardless of the insulation method you choose, here are some things to keep in mind.

The first step is to make sure your basement is dry. Before installing any interior-wall

1 A CONTINUOUS LAYER OF INTERIOR RIGID FOAM

One simple way to insulate the interior of a basement wall is with a continuous layer of rigid foam that is thick enough to meet the minimum R-value for your climate zone. If you can't reach your R-value target with one layer of rigid foam, it's perfectly acceptable to install two layers of rigid foam. (If you are installing two layers, make sure to stagger the foam seams.) Rigid foam can be adhered to concrete with foam-compatible adhesive or can be attached with special fasteners like Hilti IDP or Rodenhouse Plasti-Grip PMF anchors. Once the rigid foam is installed, you can install a 2x4 stud wall on the interior side of the rigid foam, or you can install 1x4 strapping, 16 in. on center, to facilitate installation of the drywall. If you frame a 2x4 wall, don't forget to install fireblocking at the top of the wall.

insulation, verify that your basement doesn't have a water-entry problem. Next, consider your climate zone and code-minimum R-values. Basement insulation required by the 2012, 2015, and 2018 International Residential Code (IRC) is as follows: at least R-5 in climate zone 3, R-10 in zone 4 (except marine zone 4), and R-15 in zones 5, 6, 7, and 8 and marine zone 4. That said, local codes may differ from these general guidelines, so it's worth asking your local building department about minimum R-value requirements in your community.

Note that the IRC lists two different R-value requirements for basement walls: a lower number (for example, R-15 in zone 5) for continuous foam, and a higher number (for example, R-19 in zone 5) for "cavity insulation"—usually interpreted as fluffy insulation like fiberglass installed between studs. Since it is inadvisable to insulate a basement wall with fluffy insulation like fiberglass unless the wall has first been insulated with a layer of continuous rigid foam or spray foam, it's generally best to focus on an approach that uses continuous insulation, and to ignore the "cavity insulation" approach.

On the interior side of a basement wall, all three common types of rigid-foam insulation—polyisocyanurate, expanded polystyrene (EPS), or extruded polystyrene (XPS)—perform well. That said, green builders usually avoid the use of XPS, since most brands are manufactured with a blowing agent that has a high global-warming potential. Problematic blowing agents are also used in most brands of closed-cell spray foam, so if you plan to use closed-cell spray foam, seek out a brand of insulation that uses one of the new, more environmentally friendly blowing agents—for example, Heatlok HFO spray foam from Huntsman Building Solutions.

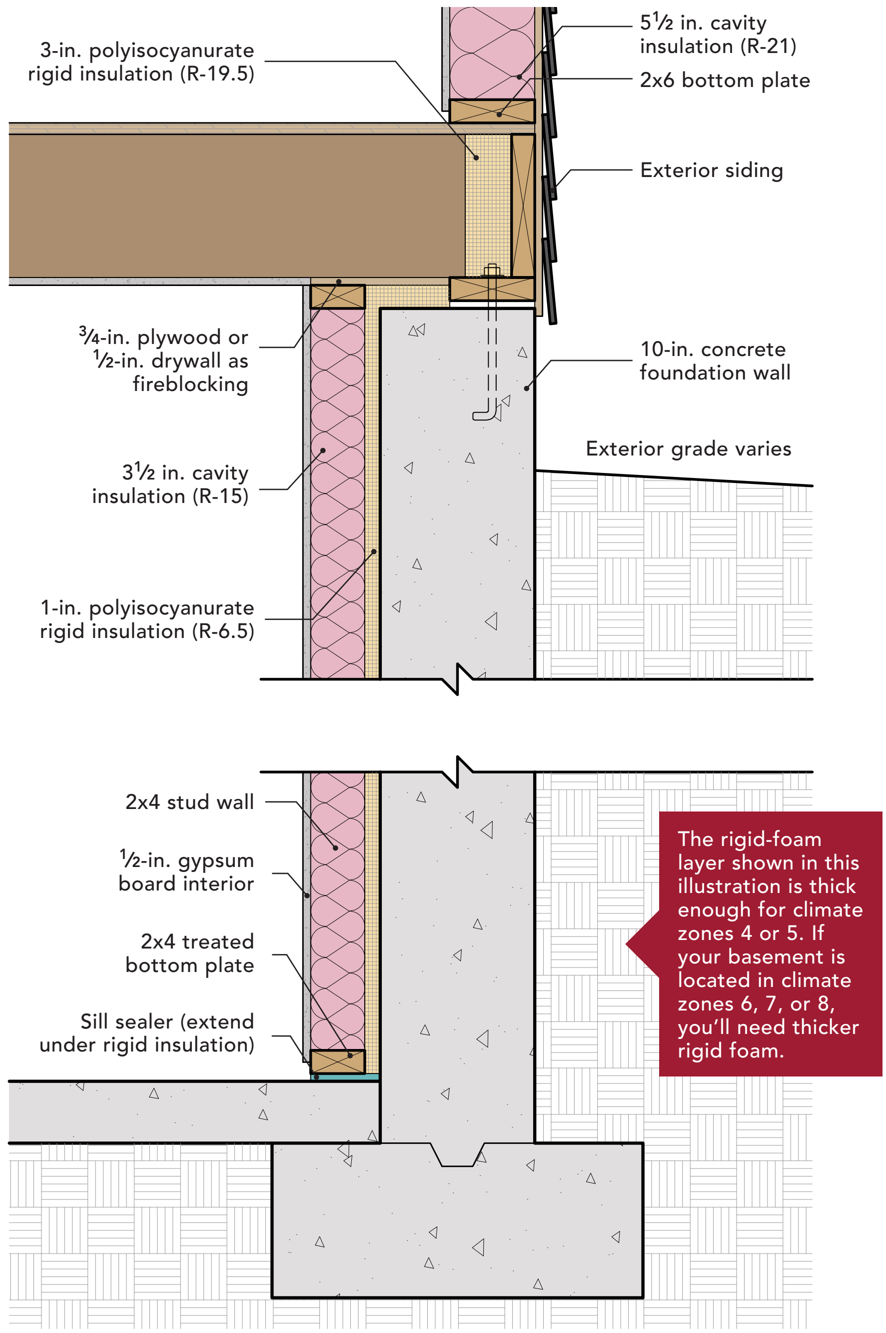
Basement-wall systems should never include polyethylene sheeting—neither between the concrete and the foam insulation, nor between the gypsum drywall and the insulation. In these locations, polyethylene can trap moisture, leading to mold or rot.

If you live in an area where termites are a problem, your local building code may require that you leave a 3-in.-high termite-inspection strip of bare concrete near the top of your basement wall. These requirements vary widely from jurisdiction to jurisdiction, so it's wise to seek local advice on this issue.

Don't forget about airtightness as well.

2 CONTINUOUS INTERIOR RIGID FOAM WITH ADJACENT STUD WALL FILLED WITH FIBERGLASS OR MINERAL-WOOL BATTS

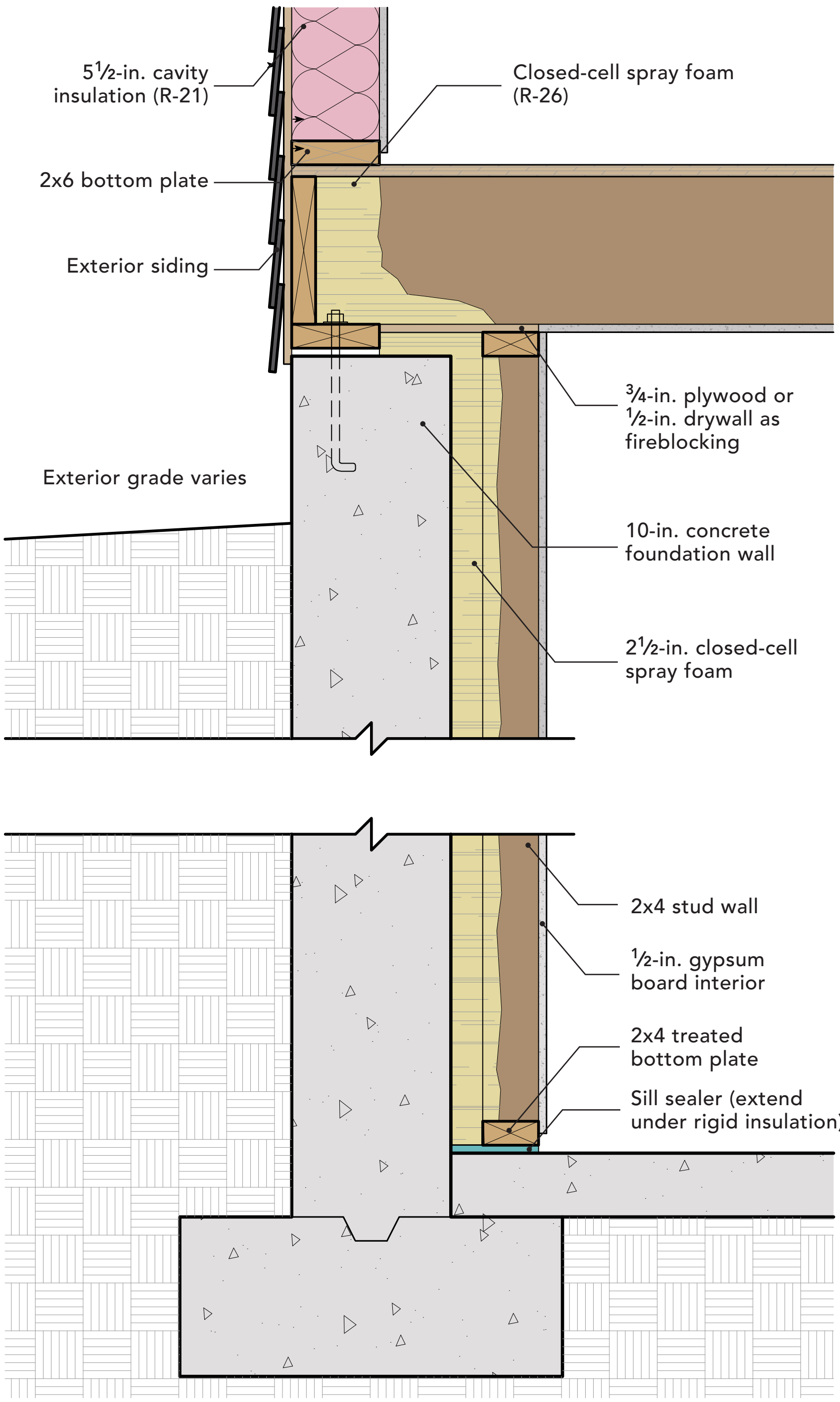
Many builders prefer to leave the stud bays uninsulated, as shown in the previous assembly (p. 20), because it's common for basements to experience occasional flooding, and fibrous insulation becomes a soggy mess if it ever gets wet. On the other hand, you may prefer to boost the assembly's R-value by insulating between the studs. If so, keep two principles in mind. First, your rigid foam layer needs to be thick enough to prevent condensation problems. A conservative approach calls for at least R-2.5 of rigid foam in climate zone 3, at least R-5 of rigid foam in zones 4 or 5, at least R-7.5 of rigid foam in zone 6, and at least R-10 of rigid foam in zones 7 or 8. Second, mineral-wool batts generally perform better in damp environments than fiberglass batts.



3 INTERIOR CLOSED-CELL SPRAY FOAM

If you plan to insulate your basement walls with spray foam, you'll want to frame your 2x4 walls before the foam is sprayed, leaving a gap of 1½ in. to 2 in. between the back of the studs and the concrete wall. The gap will be filled later with closed-cell spray foam. (Note that open-cell spray foam is too vapor-permeable to be suitable for basement walls.)

If your basement has stone-and-mortar walls, you can't insulate them with rigid foam—the only type of insulation that makes sense for stone-and-mortar walls is closed-cell spray foam. Although it's possible to buy do-it-yourself two-component spray-foam kits for this type of job, it's generally less expensive to hire a spray-foam contractor for large jobs like basement walls.



During the winter, indoor air tends to be warm and humid, while concrete foundation walls tend to be cold, setting up ideal conditions for potential condensation. You can limit the chance of condensation or mold by preventing any interior air from contacting cold concrete. If you are installing interior rigid foam, all of the foam seams need to be sealed with caulk, high-quality tape, or canned spray foam. If you are hiring a spray-foam contractor to insulate your wall, make sure that there are no gaps or shrinkage cracks in the foam that could allow indoor air to contact the concrete.

When rigid foam or spray foam is installed on the interior side of a basement wall, the foam must be separated from living spaces by a so-called thermal barrier—that is, a layer of ½-in. drywall or a material that has been approved as equivalent in fire resistance to ½-in. drywall. If you don't want to install any drywall, you can use Thermax, a brand of rigid-foam insulation that can be left exposed (because it has passed tests for thermal resistance), or you can use mineral-wool insulation as a thermal barrier.

And remember—if you're installing interior basement-wall insulation, don't forget to insulate the rim joists.

In most U.S. locations, basement-wall insulation is required by code. Properly installed, basement insulation will save energy, improve comfort, and reduce the likelihood that your walls will be damp. With a lower chance of dampness, there will be fewer opportunities for mold growth—so your insulated basement will probably smell better than it used to. □

Martin Holladay is a retired editor who lives in Vermont. Drawings by Alexandra Baczek.


SPRAY FOAM
FOR AIR-SEALING
Insulating foam sealant products like those in Loctite's TITE FOAM line are often recommended to homeowners or DIYers for retrofitting and air-sealing long after the home has been built—and it's true that this is a fantastic way to seal air leaks in older homes. However, these products are also ideal in new construction. In fact, builders using these products to seal potential future leaks prior to insulating will create an overall better, stronger, and more airtight building envelope.
LOCTITE
TITE FOAM