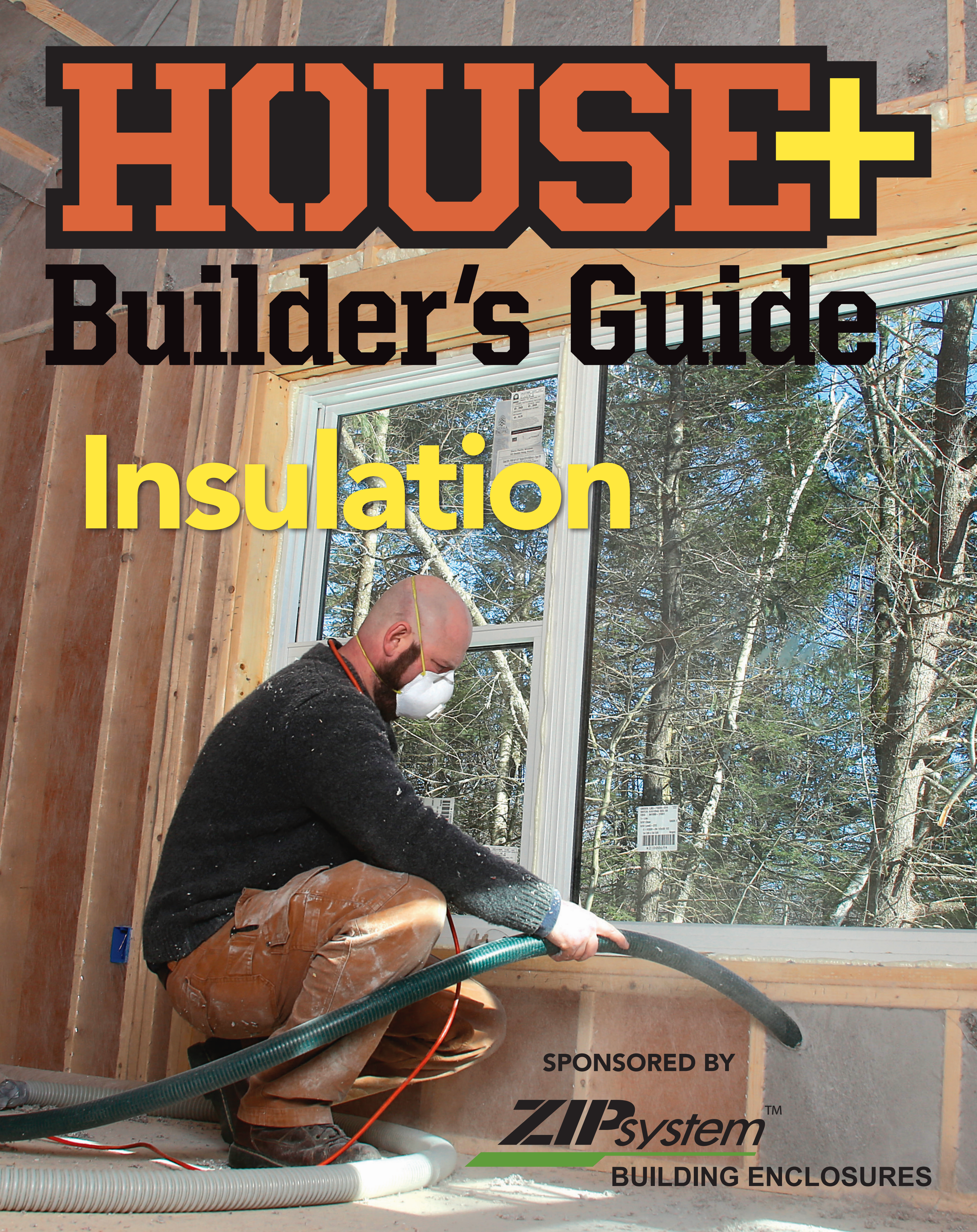

HOUSE+ Builder's Guide

Insulation

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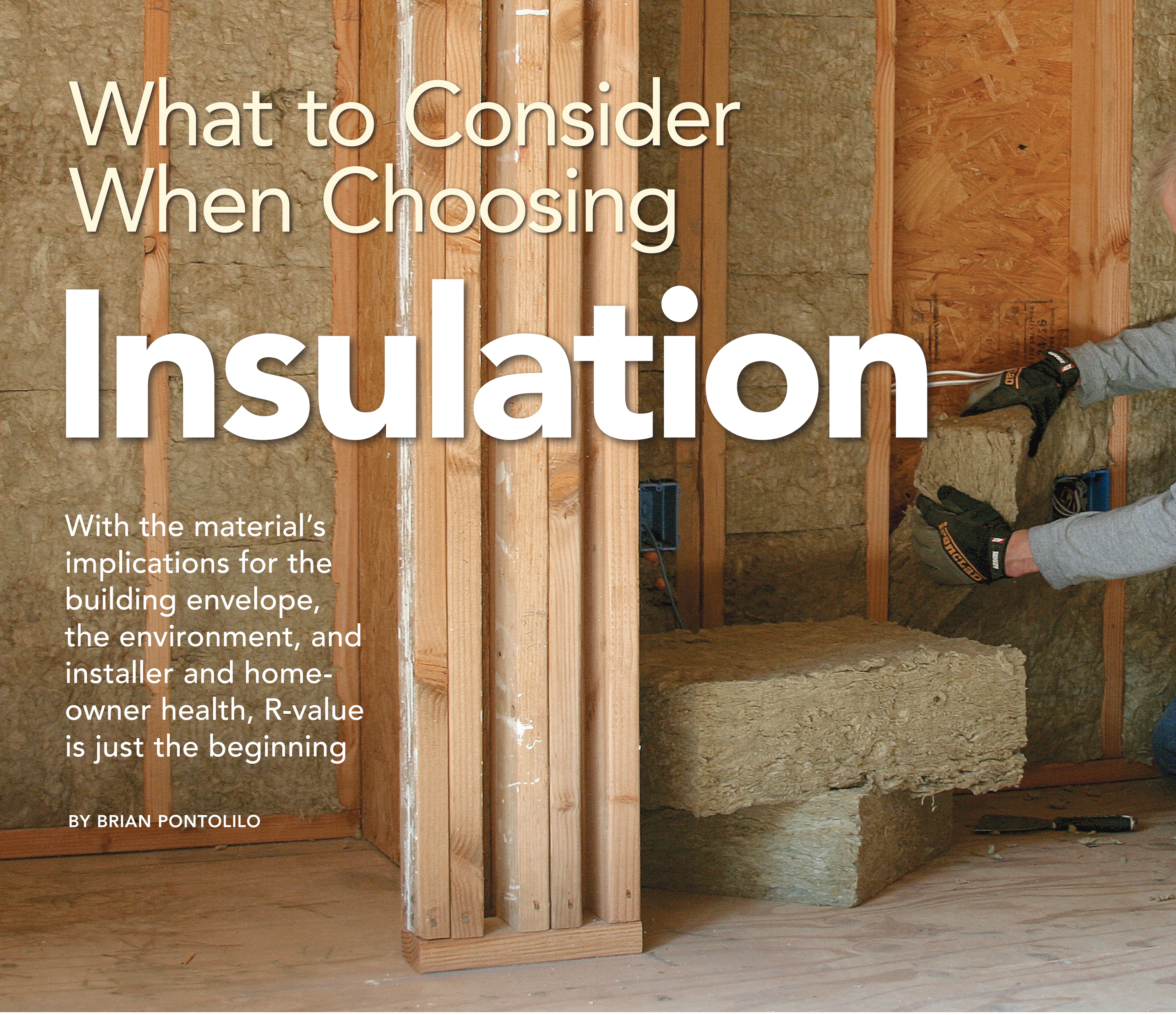


What to Consider When Choosing Insulation

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 material was right for their projects. 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 R-values listed, it's important to know if they are the total R-value for a product or an R-value for the material, which is usually given as R per inch. For example, you can buy an R-13 fiberglass batt designed to be installed in a 2x4 wall. That's the total insulating value for each batt. If

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

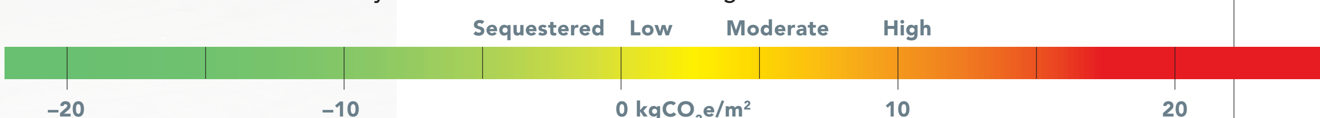
NET CARBON EMISSIONS (see below)
Moderate (R-4 batts, 4.7 kgCO2e/m2; R-4.3 boards, 5.1)

TOXICITY Low

INSTALLATION Similar to fiberglass (see p. 5). 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.



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 good 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 impermeavvv ble. 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 a 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 both 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 hydroflouroolefin (HFO) blowing agents, with a relatively low global-warming potential, but older formulations use a hydroflurocarbon (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 said. “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 tolerances 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, a potent greenhouse gas, 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 differences chemically 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 its 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 they are still in development and production in preparation to launch board, batt, and loose-fill products to the market. 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," said Xenakis. "We have to help our clients understand that there are

COTTON BATTS

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).

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.

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 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).

up-front 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 work is 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 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 you clients on the potential risks of off-gassing.

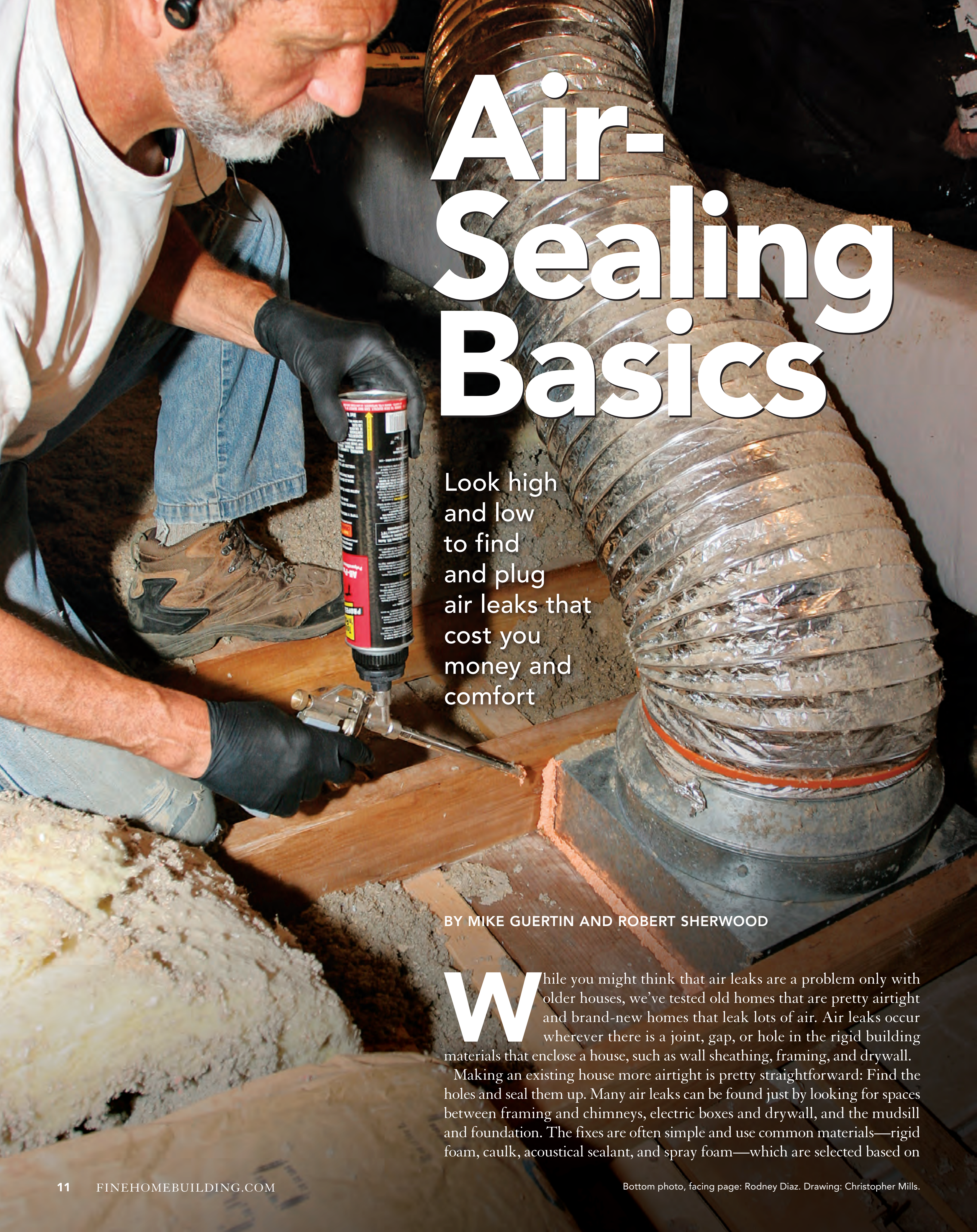
What are your priorities?

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 instead, "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* magazine 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.

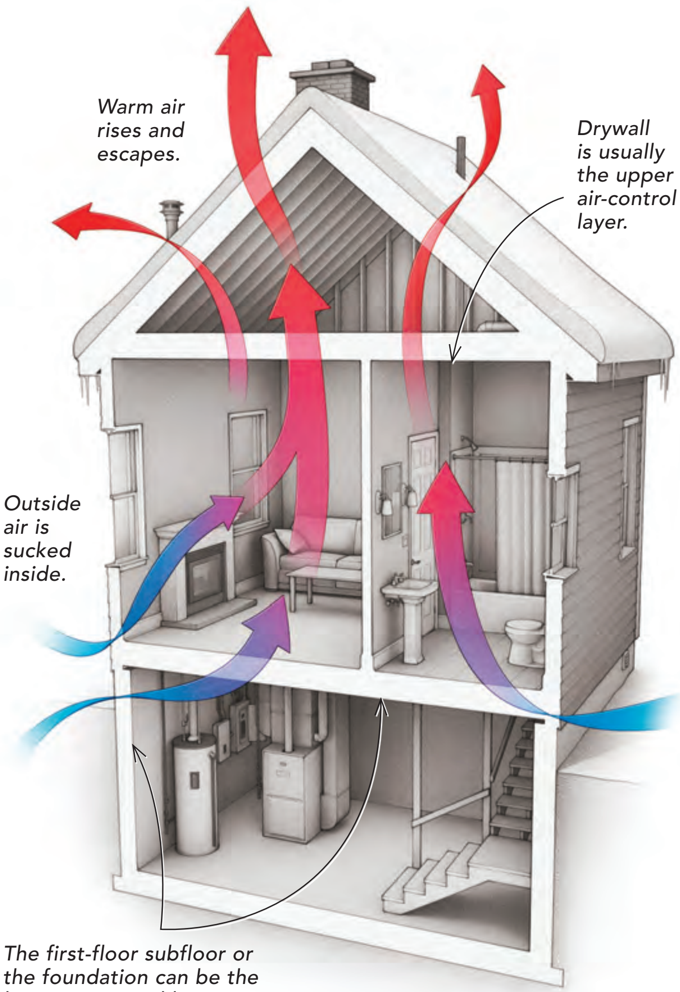
Making an existing house more airtight is pretty straightforward: Find the holes and seal them up. Many air leaks can be found just by looking for spaces between framing and chimneys, electric boxes and drywall, and the mudsill and foundation. The fixes are often simple and use common materials—rigid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

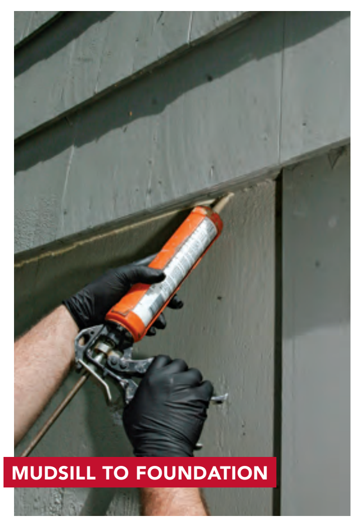
Whether to seal the foundation walls and slab or the subfloor above depends on factors unique to each house. When the basement is conditioned, the foundation walls and slab must be sealed because even though they are underground, air still can leak through the soil. If there are insulated foundation 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

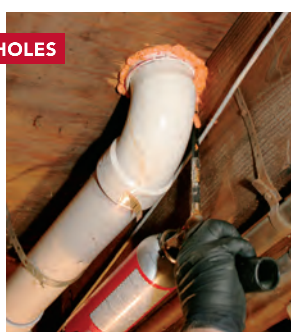
Use the first-floor subfloor as the air barrier if it's plywood or OSB, if the joist cavities are uninsulated, and if there are few ducts in the basement or crawlspace. If the basement or crawlspace is damp, has dirt floors, or has walls built of unmortared stone, air-sealing the subfloor helps control 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.

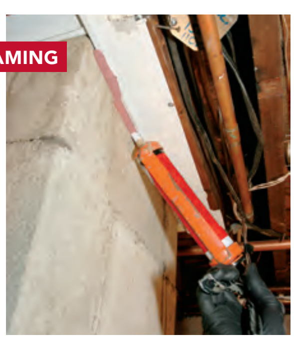


DUCT BOOTS

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.

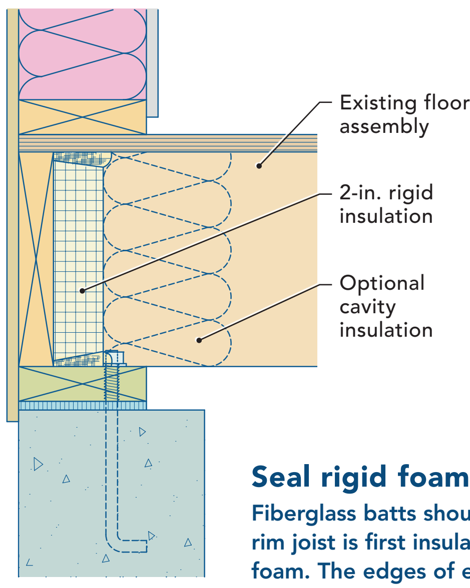
Insulating Rim Joists

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.



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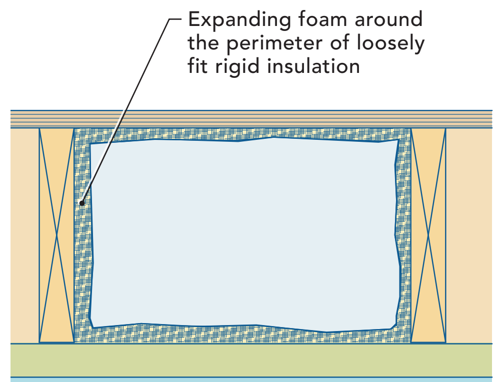


Elevation

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.

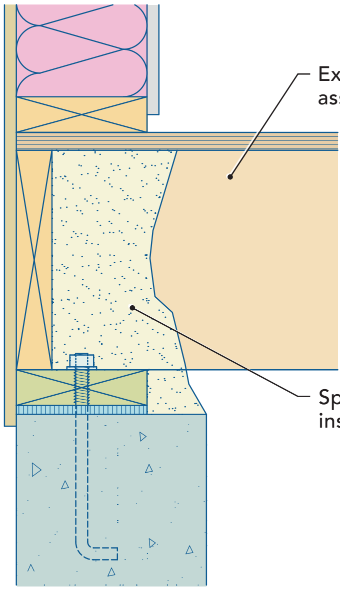
To ensure that humid indoor air won't reach the cold rim joist, the crack at the perimeter of each piece of foam (and at any penetrations) should be sealed with caulk or canned spray foam. If you use canned spray foam, you may want to buy a few lengths of flexible vinyl tubing with a slightly larger 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.

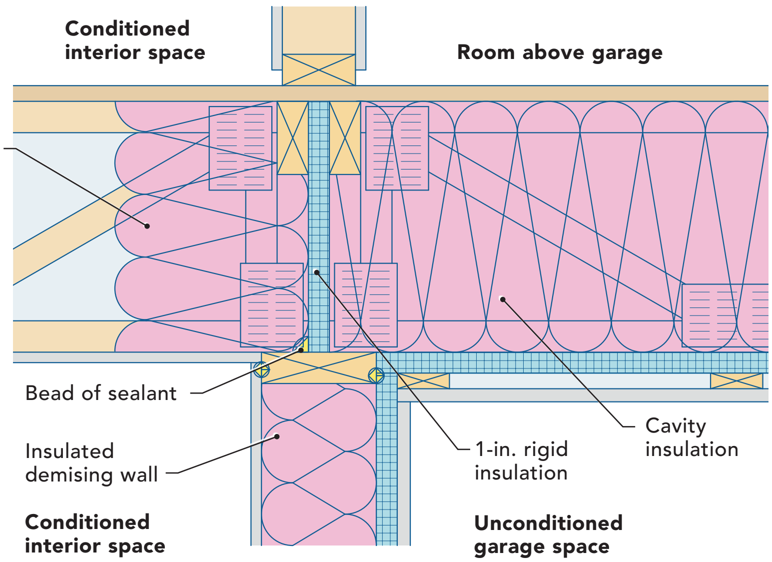
Unless you hire a spray foam contractor for the job, you'll probably be buying a two-component spray-foam kit. These kits are available at most lumberyards; expect to pay from $320 to $360 for a 200-bd.-ft. kit. If you want to install 3 in. of foam in an

Photo: courtesy of Emercor.



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.

Get the Right RIGID FOAM

BY MICHAEL MAINES

POLYISO

POLYISOCYANURATE

Polyisocyanurate, a urethane-based product closely related to spray polyurethane foam, is available in a couple of varieties. Polyiso is always formed between facings of some sort, usually aluminum foil, fiberglass, or fiberboard. It has an R-value of 5.6 per in. at 75° and a compressive strength of 25 psi. The primary blowing agent for all polyisocyanurate foam, pentane—with a global warming potential (GWP) of 5—is benign compared to the hydrofluorocarbons (HFCs) used in the manufacturing of XPS. Unfortunately, the foam will absorb moisture if unprotected and its R-value drops by about half a point per inch in temperatures below 25°.

EPS

EXPANDED POLYSTYRENE

Tiny beads of polystyrene are heated, expanded with a blowing agent, and then molded with steam to form blocks. EPS is most often white in color, and you can see the expanded beads packed together in the finished product. It is produced in a range of types, with R-values from R-3.1 to R-5.0. Lightweight type I EPS (10 psi), which is fine for roofs and foundation walls, is what you're most likely to find at the home center, but type II (15 psi), and type IX (25 psi) are available for residential slabs and foundation footings. In fact, EPS rated up to 60 psi is available for high-load applications.

XPS

EXTRUDED POLYSTYRENE

Formed by injecting a blowing agent as the melted polystyrene beads are extruded through a die, XPS can be virtually any color, but green, blue, and pink are the readily available versions. XPS is generally rated at R-5 per in. and is available in densities from 15 psi to 100 psi, but type X (15 psi) and type IV (25 psi) are the most common. At the same density, XPS is stronger than EPS, but its manufacturing process is the most damaging to the environment. The most common blowing agent, HFC-134a, has a GWP 1000 to 1500 times more damaging than CO_2. The switch over to less damaging blowing agents with a GWP of 7, called hydrofluoroolefins (HFOs), has been slow in the U.S.

Photos: this page and facing page bottom, Patrick McCombe; facing page top, Brian McAward; middle, Andy Engel

Foam-board insulation can boost R-value, slow thermal bridging, and control condensation—but you better choose the right type

Suitable for insulating foundations, walls, and roofs of all types, rigid foam is one of the most versatile types of insulation. It has a high R-value. It blocks airflow and is good at controlling moisture movement. Unfortunately, it's often flammable and releases toxic fumes when it burns. The sheets can be clunky and fragile, and most foam has a much greater environmental impact than fluffy types of insulation. And even though rigid foam can be used in nearly any part of your home's thermal boundary, not all types are suitable for all applications. If you choose to use rigid foam, there is a lot to know. Here are the basics to help you make the right choice. □

Michael Maines is principal of Maines Design and co-author of *The Pretty Good House*.

FOUNDATIONS AND SLABS

Because EPS and XPS are available with good compressive strength and won't degrade in water, they are the two preferred foams for insulating the exterior of foundation walls and under concrete slabs. But when EPS or XPS are used on the inside of foundation walls, they must be covered with a thermal barrier (generally drywall) to protect them in the event of a fire. Because it can absorb water, polyiso is not suitable for contact with soil, but it can be appropriate for the inside of crawlspaces and foundation walls, and many code officials will allow some types of foil-faced polyiso in non-living spaces without requiring a thermal barrier as described in section R316.5.4 of the IRC.

WALLS

Recent versions of the IRC encourage the use of rigid-foam insulation on the exterior to minimize thermal bridging through the framing and to reduce the chances of condensation within wall cavities. Builders in colder climate zones who take this approach can use rigid foam over 2x4 studs and R-13 cavity insulation instead of 2x6 studs and R-20 cavity insulation. A layer of foam on walls in warmer climates can reduce cooling loads. In all climates, a conscientiously installed layer of taped exterior foam can also significantly reduce air leakage.

ROOFS

Rigid foam in roof assemblies allows you to get a lot of R-value in a relatively thin layer, usually only a few inches thick—a problem-solver for remodelers looking to meet current energy codes in existing buildings. Builders and designers sometimes call for a rigid-insulation layer on top of the roof sheathing, which minimizes thermal bridging and, in the proper thickness, reduces the potential for condensation on the underside of the roof sheathing. This type of assembly also brings any attic ductwork into the building envelope, improving heating and cooling efficiency.

KNOW YOUR FOAM

HEALTH CONCERNS

XPS and EPS foam both contain brominated flame retardants in order to meet code-mandated fire-resistance ratings. Brominated flame retardants are considered persistent, bioaccumulative, and toxic to both humans and the environment, and are present in XPS and EPS at 0.5% and 2% by weight, respectively. Polyiso is more fire retardant than EPS and XPS by nature, but still includes a flame retardant. The flame retardants in polyiso are also bioaccumulative, but their health effects are unknown. The blowing agents for all three types of foam are released as the materials age. How fast the gasses are released depends on the material, its facing, and the thickness of the foam. The health effects from exposure to the blowing agents from installed foam insulation is hard to predict and depends on the amount of foam, the type, and the applied facings. Workers cutting foam should have eye and respiratory protection and wear cut-resistant gloves when working with foil-faced foams.

FIRE RESISTANCE

Rigid-foam insulation is made from petroleum products that are flammable and the gasses released when it burns are toxic. So the IRC requires at least a 15-minute thermal barrier, typically ½-in. drywall, over foam insulation. In attics and crawlspaces that are accessed only for repairs or maintenance, foam can be covered with a different material, such as ¼-in. wood structural panels, ⅜-in. gypsum board, or a painted-on intumescent coating. One polyiso product, Dow Thermax, has a Class I fire rating, allowing it to be left exposed in crawlspaces that are only accessed for maintenance and repairs.

THERMAL PERFORMANCE

There are four things to consider:

1. All rigid foams grows and shrink with age and temperature changes—up to 2%—so instead of one thick layer, it's best to use multiple layers with vertical and horizontal seams offset and taped. This prevents air leakage when the foam shrinks.
2. While the R-value of EPS remains constant over time, the R-value of XPS drops to R-4.1 or R-4.2 per in. over time as the blowing agents are slowly released from the foam and replaced with air. Some researchers think this happens over 40 to 50 years. Others say it happens more quickly.
3. When the temperature drops outside, the effective R-value of insulation changes—with EPS and XPS it increases, but with polyiso it decreases. Polyiso manufacturers now account for this in a long-term thermal rating (LTTR), which is usually between R-5.6 to R-6.0 per in.
4. Foam insulation in roof and wall assemblies needs to be thick enough in proportion to the amount of cavity insulation to prevent moisture accumulation on the sheathing. The minimum thickness for roofs can be found in the 2021 IRC, table 806.5. The minimum thickness for wall insulation can be found in the tables in 702.7.

WATER ABSORPTION

High-density (type II) EPS readily absorbs up to 3% of its volume in liquid water. Low-density (type I) EPS will take on 4%. Even though the polystyrene beads are closed to water, there are small spaces around them where water can accumulate, reducing the R-value by 10% to 20% when the foam is saturated. Because of the hit in R-value, best practice is to keep EPS foam dry. XPS can be considered impervious to water, taking on no more than 0.3% by volume. Polyiso can absorb up to 1% of its volume. Most manufactures say to avoid using polyiso when it will be in contact with damp surfaces, but it is appropriate for foundation-wall interiors as long as it's kept at least 1 in. or 2 in. above the slab.

All three types of foam are available in a range of thicknesses, typically in 2-ft. by 8-ft. or 4-ft. by 8-ft. panels.

VAPOR PERMEABILITY

How much water vapor can pass through a rigid insulation is expressed as its "perm rating," and depends on the material, its thickness, and the facing (if any) used on its exterior. EPS at 1 in. starts at 5.0 perms, but the perm rating drops to 2.0 perms or less at higher densities or increased thicknesses. At common thicknesses, unfaced EPS is considered a semipermeable, Class II vapor retarder, but plastic or foil facings can reduce the vapor transmission of EPS considerably. XPS is also somewhat vapor-open (1.1 to 2.0 perms) in thicknesses less than 1 in., and increasingly vapor-closed at 1 in. or more. With its usual foil or fiberglass facings, polyiso is a Class I vapor retarder—it essentially blocks all water-vapor movement.

Perm ratings for a 1-in.-thick insulation layer

Insulation	Compressive Strength	Permeance
EPS	10 psi	5.0 perms
EPS	15 psi	3.5 perms
EPS	25 psi	2.0 perms
XPS	15 psi	1.1 perms
XPS	25 psi	1.1 perms
Polyiso (fiberglass)	25 psi	1.0 perms
Polyiso (foil faced)	25 psi	.03 perms

Class I vapor retarder
Vapor semi-impermeable (1.0 perms or less and greater than 0.1 perms)

Class II vapor retarder
Vapor semipermeable (10 perms or less and greater than 1.0 perms)

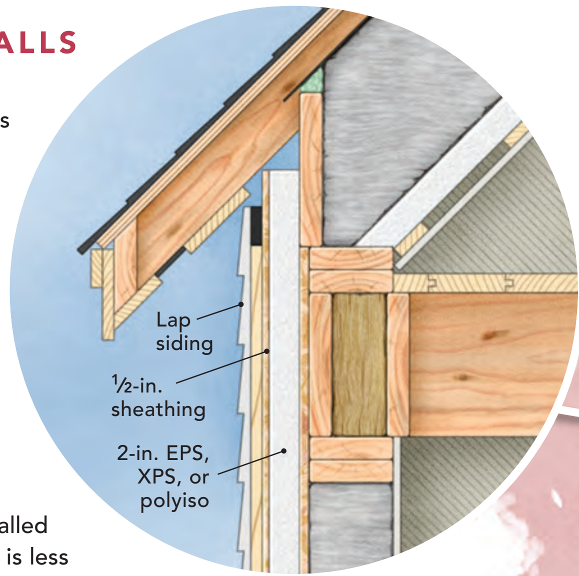
Class III vapor retarder
Vapor permeable (greater than 10 perms)

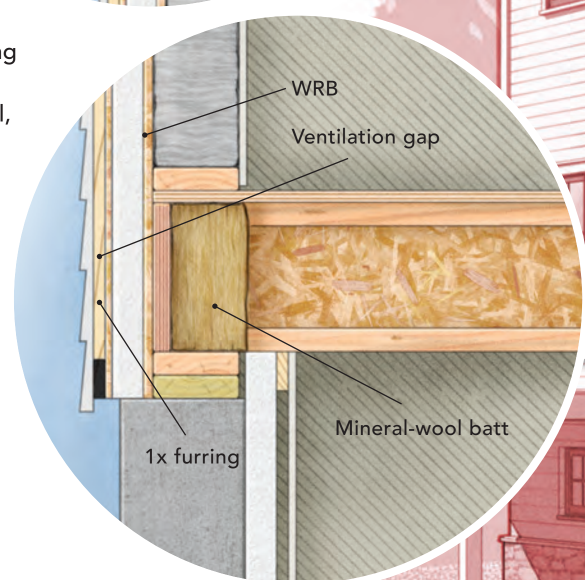
Photos: facing page, Brian McAward; this page, Rodney Diaz

PUT RIGID FOAM TO WORK

EXTERIOR WALLS

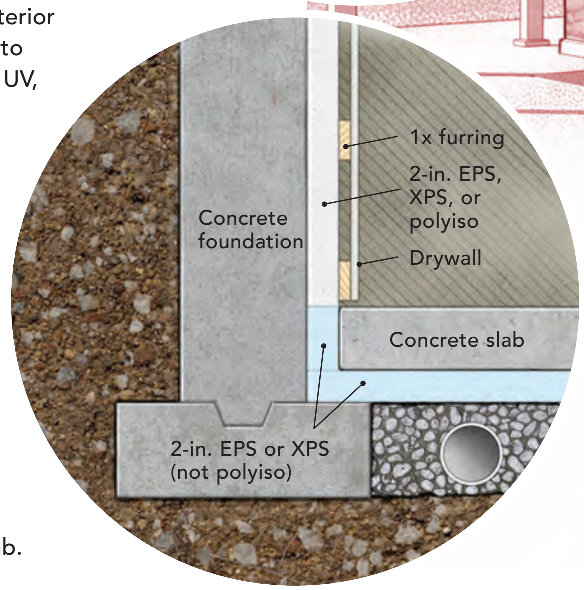
It's best to place the foam layer on the wall's exterior, which keeps framing lumber and sheathing warm and dry. Though some sidings like brick, synthetic stucco, and vinyl can be installed directly over exterior foam, lap sidings require vertical nailers at least ¾ in. thick for siding attachment. Foam installed on the interior of walls is less desirable because it keeps the framing and sheathing colder, making it harder for these materials to dry. Interior foam can complicate drywall, trim, and cabinet installation, because these items must be fastened through the foam layer and into the underlying framing.



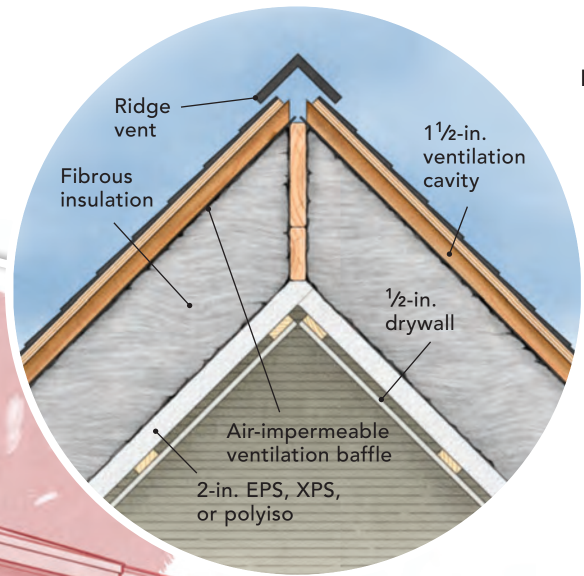


BASEMENT WALLS

Foundations can be insulated from the exterior or the interior. Exterior foundation insulation is prone to damage from string trimmers, UV, and landscaping activities, so it should be protected with a waterproof material. Stucco, metal flashing, and cement board are common choices. Interior insulation needs a fire barrier, usually ½-in. drywall. Installing interior foundation foam before pouring the basement slab allows the wall insulation to come in contact with the subslab insulation, minimizing thermal bridging through the footings into the basement slab.

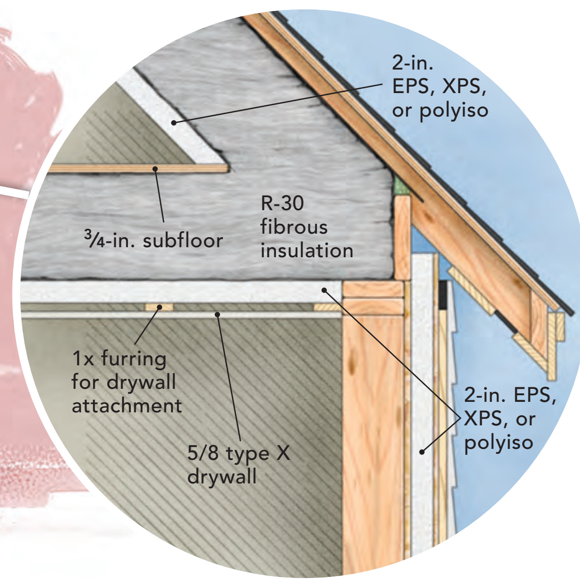


Drawings: John Hartman



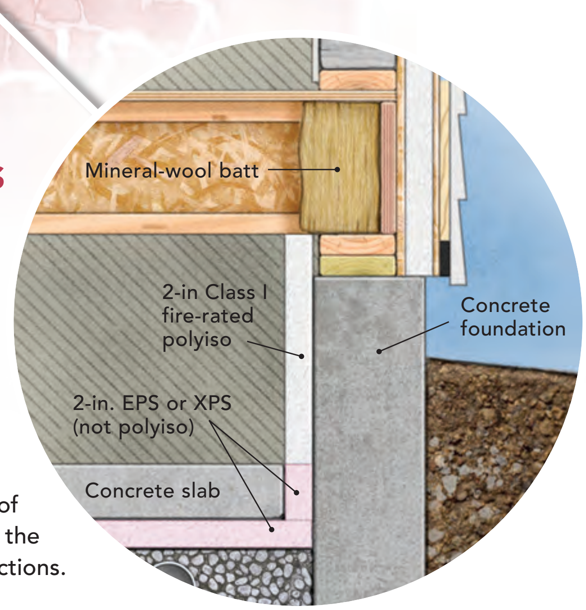
ROOFS

Foam can go on the exterior of the roof sheathing or underneath the rafters. Sometimes the foam is cut to fit between the rafters and placed in layers against the sheathing, but this does nothing to control thermal bridging, so these assemblies should be avoided whenever possible. Although commercial roofs are often installed directly on exterior foam insulation, common residential roofing materials require a second sheathing layer on top of the foam for attachment. Exterior foam must be thick enough to prevent condensation. The thickness depends on the climate, and is specified in table R806.5 in the 2021 IRC.



GARAGE CEILINGS

Unconditioned garages below living space can exact a significant energy penalty because of thermal bridging and air leaks between the garage and living space. This poor separation between conditioned and unconditioned spaces makes the living space above the garage uncomfortable in both heating and cooling seasons. A layer of taped foam can boost the R-value of the assembly, reduce thermal bridging, and control air leaks. The foam layer is attached to the bottom of the joists and then covered with a layer of ⅝-in. type X drywall for fire prevention.



CRAWLSPACES

Conditioned crawlspaces often have a layer of foam on the interior of the foundation walls fastened with concrete screws or plastic cap fasteners (Hilti IDP or similar). EPS and XPS require an ignition barrier (drywall, for instance), but Dow Thermax foil-faced polyiso can often be left exposed in uninhabitable areas. In warmer climates, it's advisable to leave a 2-in.-wide uninsulated gap of exposed foundation at the top of the wall for termite inspections.

DENSE PACK

How to tell the difference between a good cellulose insulation

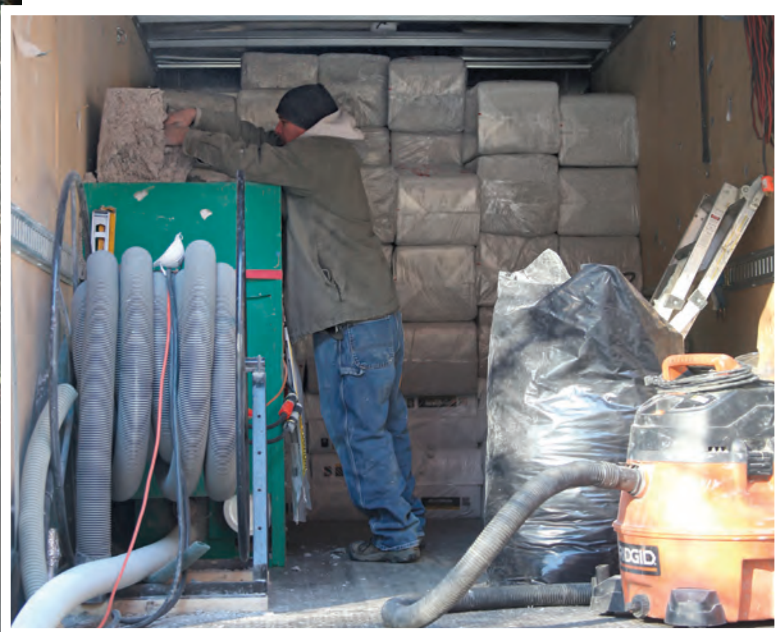
DONE RIGHT

job and a bad one

BY JON RILEY

My first weatherization job was helping my dad insulate and air-seal the attic of the old farmhouse where I grew up. This was in the early 1990s, when he was running a weatherization and affordable-homeownership program in Sanford, Maine. Shortly after I graduated high school in 2000, my dad decided to go out on his own. He offered energy audits to homeowners and introduced the Energy Star Homes program to builders and architects. Eventually his business moved to New Hampshire, where public utilities better subsidized residential energy services. With my dad as inspiration, I started my first weatherization company in 2008.

I've always liked dense-pack cellulose because it does an excellent job of stopping air movement and its hygroscopic nature allows it to absorb and release moisture throughout the seasons. When it comes to customers who want a better insulation than fiberglass batts, I'm often competing with contractors who install spray foam. Spray foam installs faster, but cellulose costs less—plus, it's made of recycled material, is nontoxic, and is highly flame and pest resistant (see "Cellulose:



Teamwork. *Although often separated by over one hundred feet of hose, the cellulose loader in the truck outside and the installer inside the house work as a team. One feeds bales of cellulose into an agitator to loosen the fibers so they can be pushed through the hose on a powerful stream of air. The other, at the business end of the hose, fills the cavities and controls the airflow using a cord with an on/off switch plugged into the end.*

PULL THE NETTING TIGHT

Dense-pack cellulose in new construction requires an air-permeable netting to contain the insulation within the framing cavities during installation. The netting is fastened with a pneumatic upholstery stapler equipped with a large-capacity magazine of staples with ⅜-in. legs. Especially deep cavities are divided into smaller sections to make filling them to the proper density easier.

Start at the top. *The netting is first fastened along the top plate and allowed to hang down to the floor. Then the netting is pulled tight and stapled along the bottom plate.*

Lip-stitch the studs. *Once the netting is face-stapled around the assembly perimeter, it's stapled to both front corners of the studs or framing members with staples placed about 1 in. apart. This method, called* lip-stitching, *draws the netting even tighter across the cavity to help prevent bulging.*

Trim around doors and windows. *Excess netting is trimmed along the bottom plate and around the perimeter of framed openings where it covers doors and windows. The non-woven material cuts easily with a fresh blade.*

The Perfect Insulation," *FHB* #268). And unlike the VOC-heavy spray-foam process, which requires that the work site be completely evacuated, homeowners can live their lives and work can continue while we dense-pack. Dense-pack cellulose can also be installed in freezing temperatures without the expense of temporary heat.

In the beginning I wanted to follow directly in my dad's footsteps, advising builders and homeowners on how to solve their home-performance issues. Soon it became clear that there were few folks who were willing to do the projects without shortcuts. With Dad ever supportive, I decided to buy the equipment and get to work. Unfortunately, most insulation contracts are decided based on price rather than who does the best job. Admittedly, a quality dense-pack job is nearly indistinguishable from an inferior one. The difference is how tightly the cellulose is packed, and you often can't tell just by looking at it.

We blow to a density of 3½ lb. to 4 lb. per cu. ft., which feels like a very firm mattress. At this density, the cellulose packs together tightly enough to virtually stop airflow and so it won't settle over time. It takes a long time to insulate to this density (days for a whole house or large addition), so poorly trained or price-pressured contractors don't take the time to do it right. We've been doing this long enough to know how long a job will take, and we keep a careful count of the bags we blow so we can double-check the density of the assemblies we

Photo facing page right: courtesy of Spotnails

AND FASTEN IT WELL

Cut small pieces on the floor. *Precision isn't critical for the small pieces of netting used to divide cavities, but using a measured piece as a template helps speed the work of cutting a stack of the small rectangles needed to divide the 16-in.-deep rafter cavities.*

Divide deep cavities. *Cavities deeper than 12 in. should be divided into cells using small pieces of netting spaced about 6 ft. o.c. The smaller space makes it easier to reach all corners, ensuring the cellulose is installed at the correct 3½-lb.- to 4-lb.-per-cu.-ft. density.*

Drape and pull. *Ceiling cavities are tackled much the same as walls. The netting is fastened to the ridge and allowed to hang down, then pulled tight and fastened along the bottoms of the rafters before lip-stitching.*

Get the right stapler

Installing cellulose netting requires driving thousands of staples. For this work, pros use an adjustable-speed auto-fire upholstery stapler. The tool shown here, a Spotnails A-11 series stapler (about $200), can hold 168 staples in its extra-long magazine.

insulate. We use the manufacturer's coverage chart (finehomebuilding.com/project-guides/insulation/dense-pack-cellulose-coverage-chart) to calculate how many bags it takes to achieve the correct density. The thicker the framing, the denser the cellulose will need to be in order to be self-supporting. In general, one 25-lb. bag of cellulose will cover approximately 15 sq. ft. of 2x6 wall at 3.5 lb. per cu. ft. or 6 sq. ft. of 2x12 rafters at 3.8 lb. per cu. ft.

New work requires netting

In new construction, dense-packing insulation requires stapling an air-permeable netting (Insulweb is the brand we use) over the framing to contain the insulation while we dense-pack. It's important to keep in mind that the netting isn't meant to hold the insulation in the walls, because when properly installed, dense-pack cellulose is self-supporting. Otherwise, it settles over time, creating cold spots and condensing surfaces. The netting simply seals off the last face of what then becomes a six-sided cavity, holding the insulation in place while we build up enough density to make it self-supporting.

We staple up the netting, ensuring that it's free of wrinkles, which can cause problems when attaching drywall later. First, we staple the netting to the top and bottom plates and then to the outside corners of the studs (or whatever evenly spaced framing members we're cov-

FILL THE CAVITIES SLOWLY

Once the netting is in place, the cavities are filled one at a time using a 6-ft.-long, 1½-in.-dia. or 2-in.-dia. tube called a whip. The tube's sharpened end is pushed through the taut netting toward the far end of the cavity, extended all the way in, and then slowly withdrawn as the cavity is filled.

Fill from the bottom up ... *In an 8-ft. or 9-ft. stud cavity, the whip is inserted near the middle and pushed all the way to the bottom plate. As the cavity fills, the whip is slowly withdrawn. When the cavity is half filled, the whip is removed.*

... and then from the top down. *With the reinserted whip pushed to the top plate, the cavity is then filled from the top down. As the cavity fills, the whip is backed out and withdrawn. Installed correctly, the cellulose is packed tight enough that patching the hole is unnecessary.*

ering). Stapling the corners is important. This step, described by cellulose installers as *lip-stitching*, puts continuous lines of staples on the stud or framing corners. These lines of staples contain the intense pressure of the blower and allow the netting to bulge slightly in the center without stretching too far beyond the stud faces. If the insulation bows beyond the framing, it interferes with drywall installation, so we use a special roller to flatten the filled cavities. Lip-stitching controls the bulge enough so we don't have to remove excess material.

Getting the right density

To achieve the critical 3½-lb.- to 4-lb.-per-cu.-ft. density, installers need to fill the cavities with a small-diameter hose. Our blowers are connected to a hose that steps down gradually. First there's 100 ft. of 3½-in.-dia. hose connected to 50 ft. of 2½-in.-dia. hose, which ends with a 6-ft.-long 1½-in.- or 2-in.-dia. hose, called a whip. The whip is the secret to getting a good dense-pack job. I've seen folks try to use a 3½-in.- or 4-in.-dia. hose to fill a deep roof or double-stud wall, but with such a large-diameter hose, any material more than a few inches from the hose end will not be packed tightly enough to prevent settling.

When filling double-stud walls and deep rafter bays, we section off the cavities with small pieces of netting. Since he's filling a smaller space, the installer can reach all corners, ensuring the entire cavity is at the correct density. Inferior dense-pack jobs have low-density spots, which are common around utilities and inside complex or deep cavities.

Having the right stuff

Our company carries insulation and equipment in our two 20-ft. Isuzu box trucks equipped with Accu1 9400 cellulose blowers. The

Beware of blind spots. *Odd-shaped and hidden cavities are marked with a Sharpie during the netting stage so the insulator remembers to fill these spaces. Blind corners created by adjoining walls are best filled through multiple holes spaced a couple of feet apart, with the hose plunged horizontally into the hidden part of the cavity. Cavities smaller than 2 in. are filled with canned spray foam.*

Don't try this at home

Although some DIYer's claim success dense-packing cellulose with rental machines from home centers, these low-pressure machines make the process very slow and achieving a density sufficient to resist settling is difficult. The process is best left to a specialty subcontractor with a more powerful insulation blower. But before you hire someone, here are some things to keep in mind:

- You'll want to prepare your site for access and you can expect the insulation contractor's box truck or trailer to be on site several days for larger jobs.
- You'll also need power—the author's rig requires two 15-amp circuits, which is typical.
- Once the work starts, insist that your installer save the empty bags of cellulose so you can compare the number of bags installed to the cubic feet of space you're insulating.

blowers are reliable and easy to field-repair, requiring only a few simple tools and a small collection of spare parts.

We use Benolec-brand cellulose and have found it to be the cleanest product on the market today. It has no foreign materials—no plastic streamers or trash mixed in—and it's treated with only boric acid, no ammonia or magnesium sulfate. Ammonia and magnesium sulfate are cheaper than boric acid, but they're more corrosive and can have an unpleasant odor. The cellulose at the big box stores typically has both plastic contaminants and ammonia-based fire retardants, so I advise contacting a local supplier for the good stuff.

A dense-packed day in the life

We typically run a three-person crew. When we get to the site, two people begin air-sealing and installing the netting that holds the cellulose, a process we call *netting*. The third runs power to the insulation blower and runs the hoses to the work area. As soon as we have a wall or rafter assembly fully netted, we get the truck going with one person loading the hopper and one blowing insulation. The third crew member works ahead, air-sealing and netting. On a good day, we are blowing within 30 minutes of arriving at the site, but more often it's 45 minutes to an hour. Throughout the day we monitor the bag count to make sure we are in the right ballpark in terms of material density and production. At the end of the day, we put the truck to bed and clean our work area thoroughly, which improves our relationship with the other trades with whom we're sharing the workspace. □

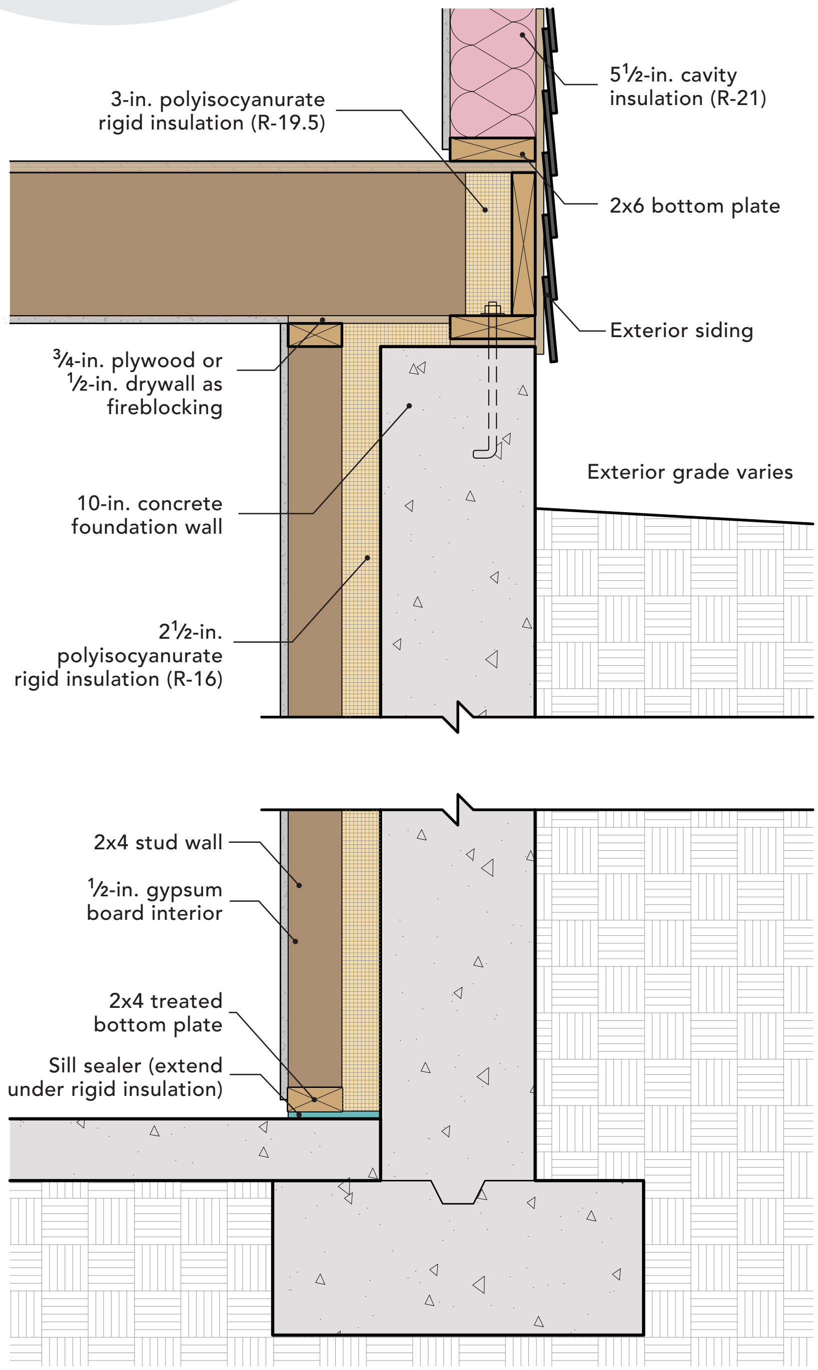
Jon Riley is the owner of Casco Bay Insulation in Portland, Maine. Photos by Patrick McCombe, except where noted.

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.

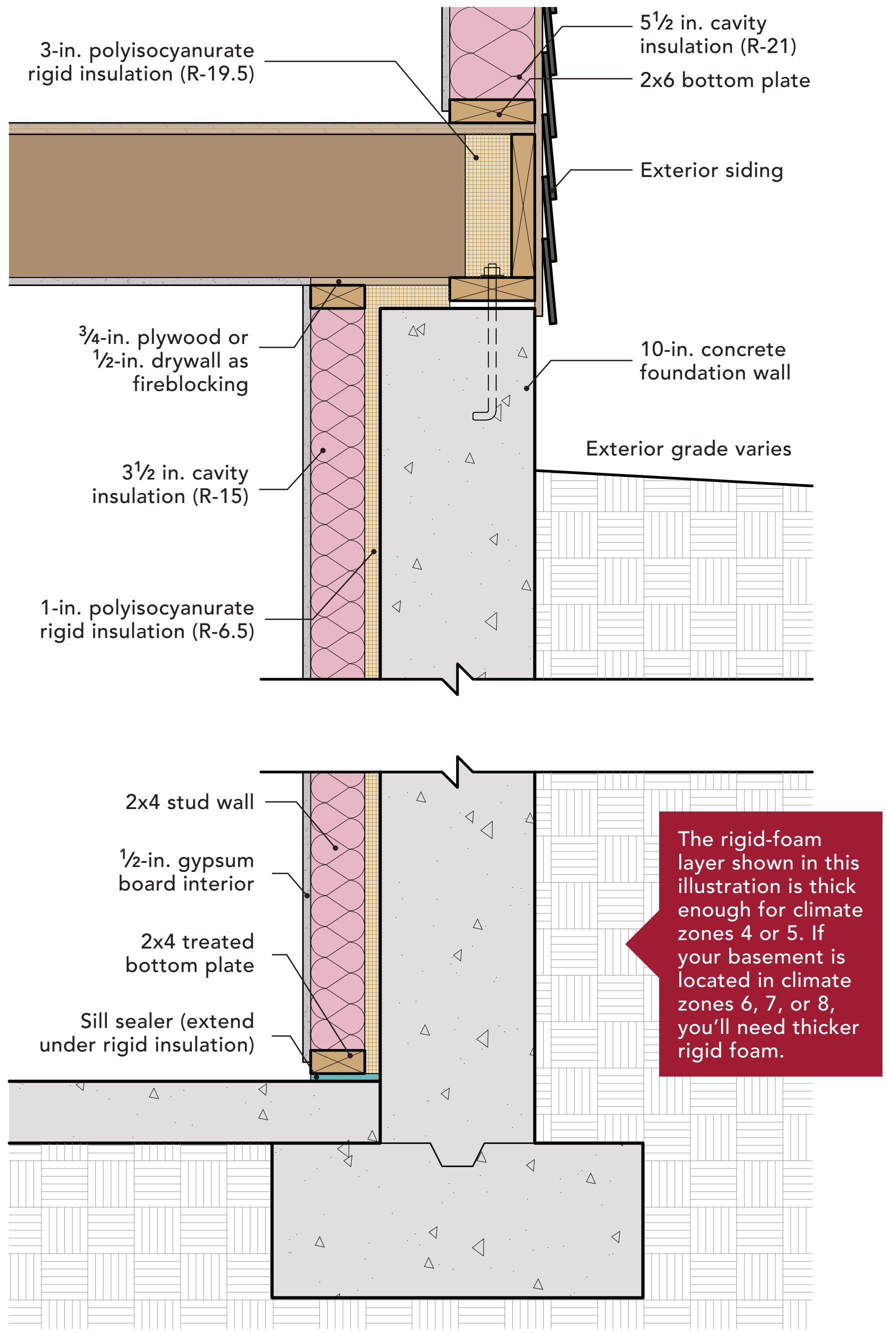
Basement-wall systems should never include polyethylene sheeting—neither between the concrete and the foam insulation, nor between the gypsum drywall and the insulation. In these locations, polyethylene can trap moisture, leading to mold or rot.

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

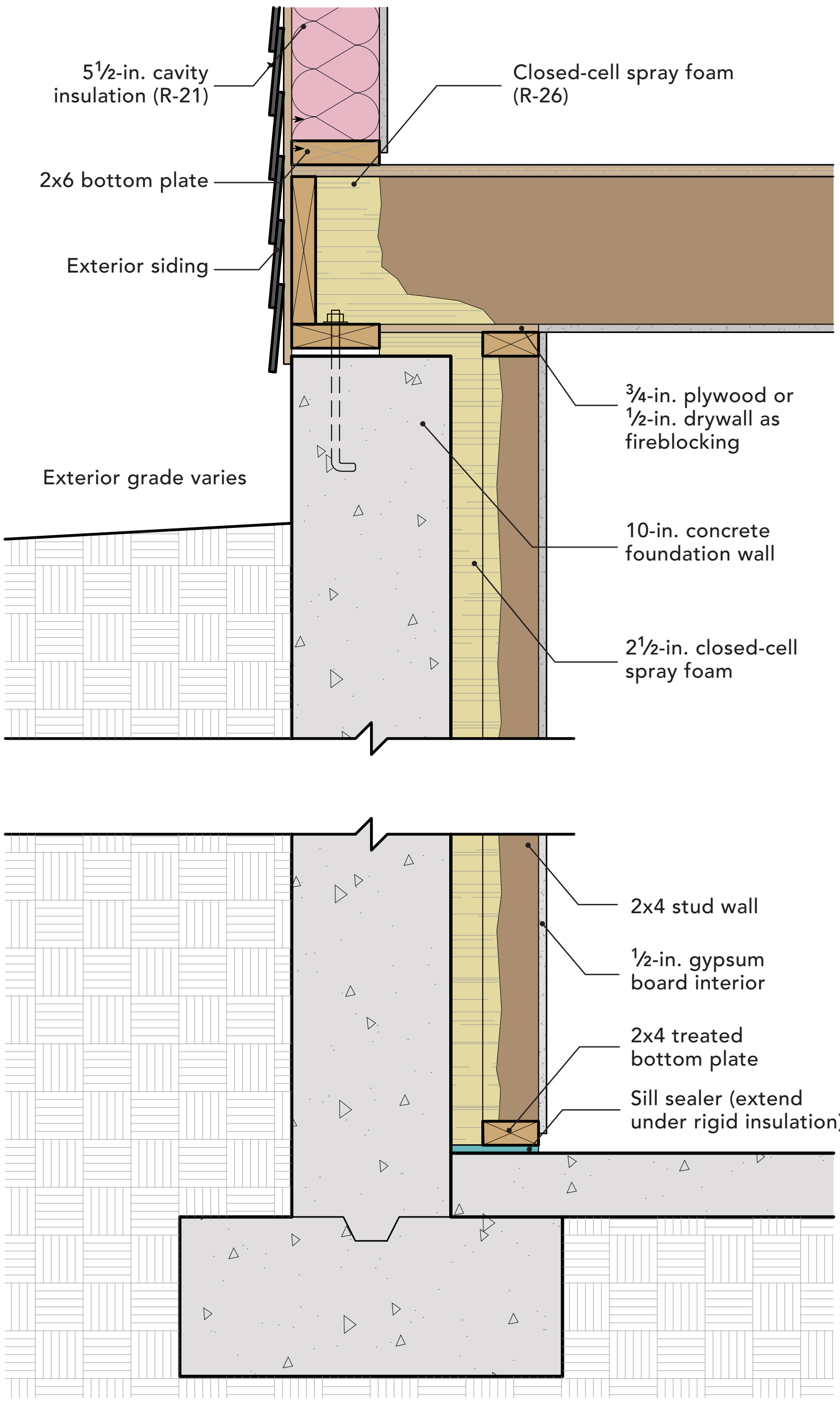
Many builders prefer to leave the stud bays uninsulated, as shown in the previous assembly (p. 20), because it's common for basements to experience occasional flooding, and fibrous insulation becomes a soggy mess if it ever gets wet. On the other hand, you may prefer to boost the assembly's R-value by 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.