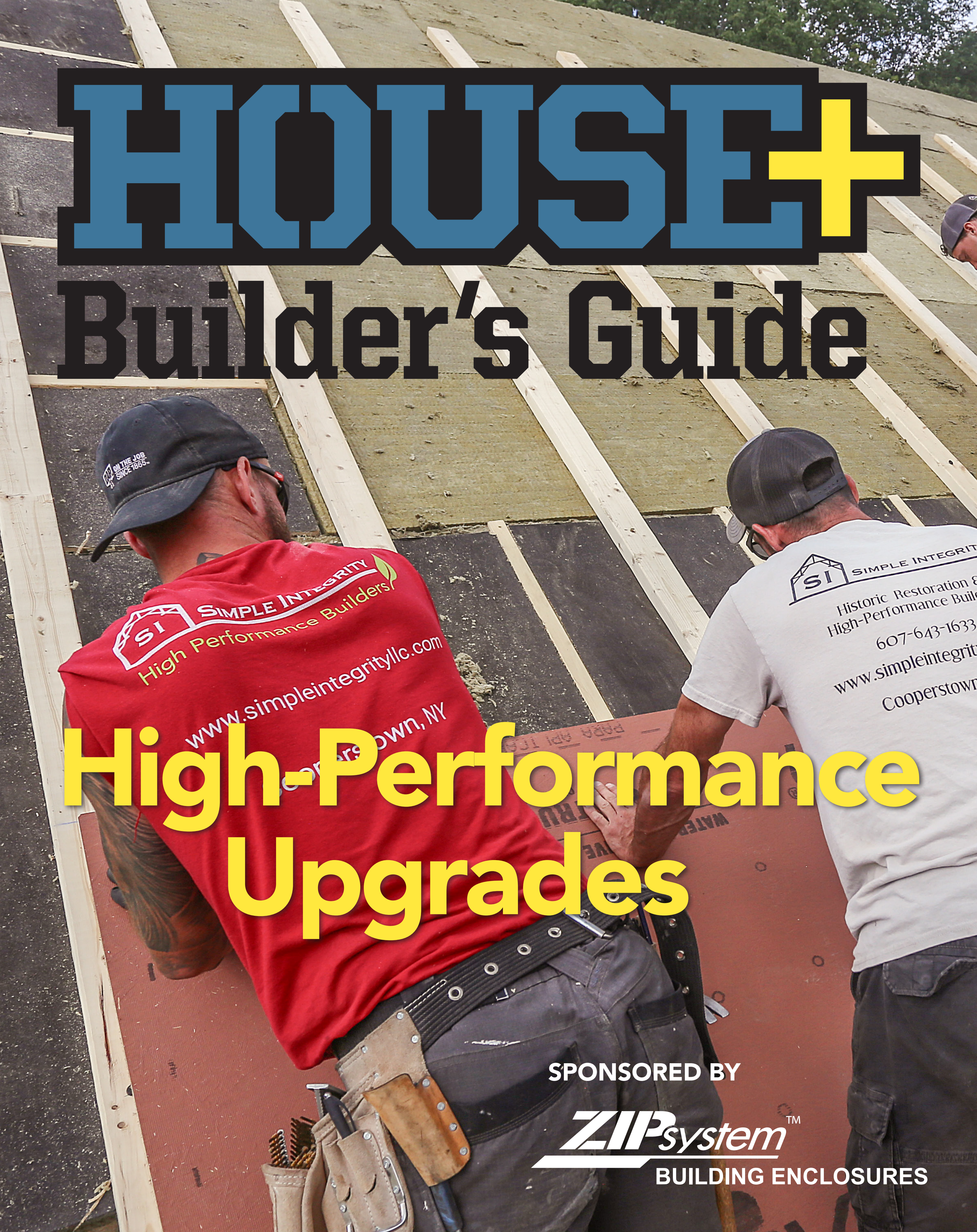
HOUSE+ Builder's Guide

High-Performance Upgrades



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BUILDING ENCLOSURES

CONTENTS

Understanding Larsen Trusses

Hanging a truss outside a stick-framed wall is an old idea that hangs in with modern materials, building science, and energy-efficiency goals

BY BRIAN PONTOLILO

In November of 1983, *Popular Science* published a short article called "Superinsulated House Trusses" that briefly described John Larsen's alternative to double-stud walls. John's approach, which we know today as the Larsen truss, was to build a house with conventional 2x4 walls, install airtight polyethylene sheeting around the building, and then attach to the wall shop-made trusses of long 2x2s joined with plywood gussets. When filled with fiberglass batts inside and out, John's walls would hit R-35 with little thermal bridging.

"I came up with this idea while framing a double-wall house," John wrote in an email. "Normally, experienced framers do the framing much more efficiently than ordinary carpenters like myself. They are, however, not so good at vapor retarder installation, which has to happen at the same time. By using the external truss system, they can frame the structural part of the house and I or a subtrade can come in and wrap the house externally with large sheets of poly, and then install the trusses. In the '80s there was no internet, so we spread the idea by printing ads in building publications and sold manuals with blueprints for $15. We sold hundreds."

In a 2011 interview with Martin Holladay, John said, "I was making the trusses until the late '80s. After that, there wasn't a big demand anymore."

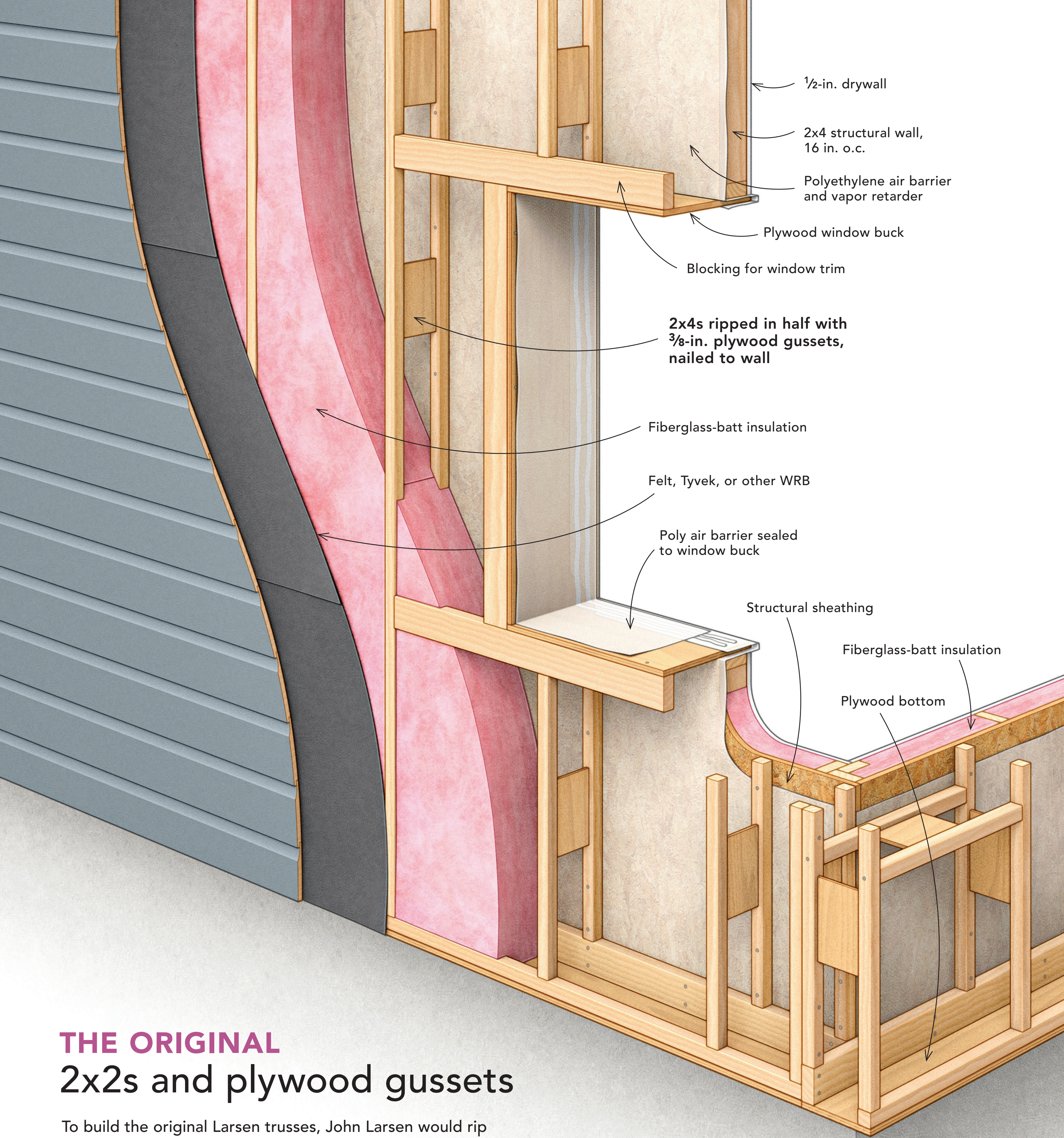
The Larsen truss may not have taken off as a product, but variations on the idea are still widely in use today. In fact, they're a favored superinsulated wall assembly by some cold-climate builders, and for good reasons. They don't necessarily have to be custom-built. Common manufactured products including I-joists and floor trusses can be used. They are a fairly straightforward way to add deep exterior

OPEN-WEB FLOOR TRUSSES

FRAMING LUMBER

I-JOISTS

Photos, top to bottom: Josh Edmonds, Steve Baczek, and Bob Swinburne



THE ORIGINAL

2x2s and plywood gussets

To build the original Larsen trusses, John Larsen would rip 2x4s in half to make a pair of chords. He'd then route dadoes for ⅜-in. plywood gussets that would connect the chords every 24 in., using glue and brads as fasteners. The trusses would be attached to a common stick-framed wall with airtight polyethylene sheeting outside of the sheathing. The houses were insulated with fiberglass batts.

insulation to a wall assembly, which has several benefits. And they offer an exterior insulation option that doesn't rely on plastic-foam products. Like any alternative wall assembly, though, there's a learning curve for first-time builders. And at least one high-performance builder who says there's a lot to like about Larsen trusses has concerns about their durability over the long term.

A pretty perfect wall

A Larsen-truss wall has some similarities with a double-stud wall. The structural aspect of the framing is common—both start with 2x4 or 2x6 walls that will be familiar to builders. In the case of a double-stud wall, it is common for the outer wall to be structural, and load-bearing where necessary. The interior wall is essentially a partition that creates an uninterrupted space for continuous insulation, deepens the cavity for greater R-value, and carries the drywall, trim, cabinetry, and toilet-paper holders. Larsen trusses are attached outside of the structural walls, creating an additional cavity for insulation to the exterior of the sheathing. This is one of the advantages of the system, says New York builder Josh Edmonds.

Josh builds Passive Houses, and even when not pursuing certification tends to use the Passive House Institute (Phius) modeling strategies for his new homes and remodels. Josh says that Phius frowns on double-stud walls, particularly where the outer wall is structural. This is because hygrothermal modeling reveals the possibility of cold sheathing issues, specifically the potential for condensation that can lead to rot and structural failure. (For an alternative perspective, see "A Case for Double-Stud Walls," *FHB* #291). In this way, a Larsen-truss wall is also akin to a house wrapped with continuous exterior insulation. If the trusses are deep enough to achieve the necessary R-value for the climate zone in which the house is built, having most of the insulation outside the wall means that the sheathing will never get cold enough to be a condensing surface.

Josh's rule of thumb is to have about two-thirds of the insulation to the exterior, which means he can build a 2x6 wall and use 12-in. I-joists for the Larsen trusses. For condensation control, the International Residential Code (IRC) calls for a minimum R-11.5 of exterior insulation over 2x6 walls in climate zone 6 where Josh builds. With dense-pack cellulose or mineral-wool insulation, the R-value outside of the sheathing in his Larsen-truss assembly will be in the mid-R-40s. Josh also likes the drying potential of these walls, which can dry readily in both directions. The only vapor retarder in his walls is the sheathing.

"With either cellulose or mineral-wool insulation," he says, "you could have a flashing issue and dump water into this wall system and not have a catastrophic building failure." Moreover, the water, air, and vapor control layers are at the sheathing, so the Larsen-truss system achieves the beneficial characteristics of Joe Lstiburek's "Perfect Wall." All four control layers are to the exterior of the framing, and the water, air, and vapor control layers, along with the structure of the building, are all inside the thermal boundary (or most of it, anyway). They're protected from the elements and the effects of temperature changes.

If you've ever tried to find framing with structural screws through a few inches of exterior insulation, you can imagine how tough it would be to find a stud with a 12-in. screw through 10 in. of rigid insulation. This is another benefit of the Larsen truss. The cavities are commonly filled with dense-packed fibrous insulation, meaning the outer truss flange is available for fastening. To hold the insulation in place, another membrane is installed over the trusses. On a recent project, Josh used Siga's Majcoat, a roofing underlayment, for this detail, but any vapor-open membrane rated for dense-packed insulation could work. The membrane provides an additional water-resistive barrier (WRB).

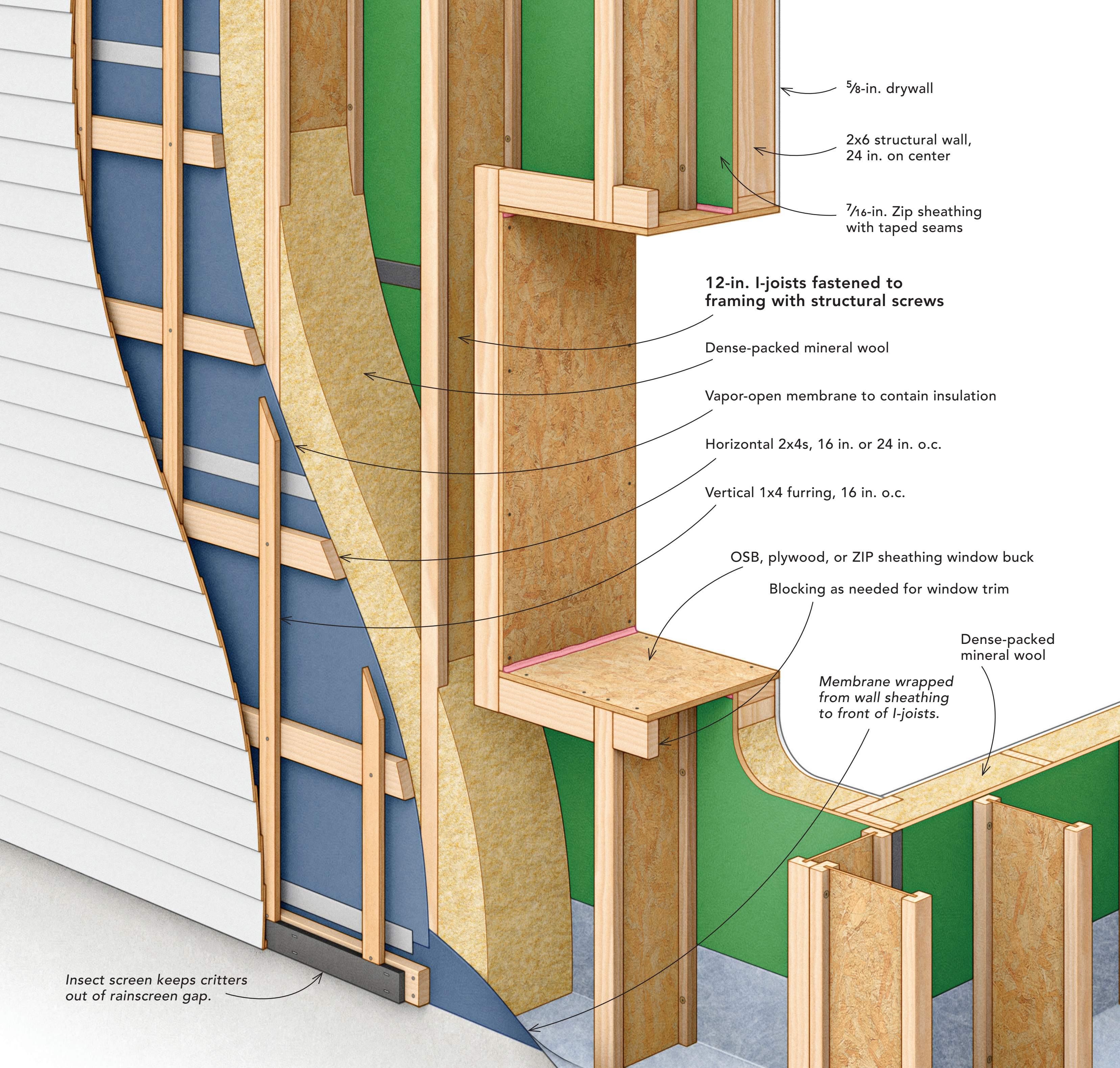
BUCKS AND BLOCKING As in other thick-wall assemblies, windows and doors are commonly installed with bucks—plywood or OSB boxes that extend from the interior wall plane to the exterior wall plane. Inset windows and doors can be installed with common details, but the buck must be flashed and air-sealed to the wall sheathing. And don't forget blocking for trim, if needed.

Furring strips, often installed in a lattice pattern, help to hold the membrane in place and create a ventilated rainscreen gap for the siding. In other words, if you are installing horizontal lap siding, you can run the first layer of strapping horizontally, and the second layer vertically. If you are installing vertical siding, you can switch the strapping layers. In either case, the rainscreen is then detailed as any other.

You can use floor joists

A few years ago, Massachusetts architect Steve Baczek was designing a high-performance home for a property where strict zoning regula-

Photo: Josh Edmonds



ON-SITE MODIFICATION

I-joists cut to fit

I-joists are a common manufactured option for Larsen trusses that are easily cut, notched, and drilled as necessary by the builder. In climate zone 6, builder Josh Edmonds uses a 12-in. I-joist (which measures 11⅞ in.) hung outside of a 2x6 wall to meet his goal of having two-thirds of the total insulation R-value to the exterior of the structural sheathing. Whenever possible, Josh runs the I-joists and the insulation above the top plate so that a little settling of the insulation will never become a problem.

tions were limiting the possible size of the building. Steve asked the town officials how they measured the footprint of a home. It turns out they weren't sure. Steve suggested that they measure from the perimeter of the foundation. The officials agreed. Steve needed thick walls to achieve the project's performance goals, so he decided to design a Larsen-truss wall system because it wouldn't creep into the already tight interior living space the way double-stud walls would. It also wouldn't be counted as square footage. Steve ordered floor trusses to hang on the exterior wall and says they are advantageous for a few reasons, mostly having to do with the open webs.

"People will argue that there's not a lot of cross-sectional area to a ⅜-in. OSB web and it's not going to make a difference in terms of thermal bridging in an R-60 or R-70 wall. And I agree. Loosing 2% of that with an I-joist is not a concern for me," Steve said when comparing the thermal-bridging potential of an open-web floor truss to an I-joist. "But there are still some things I like a lot about the open-web floor trusses in this application. You can screw them directly at 90° into the studs with a palm nailer or 90° driver. And they're light. On the project we did with them, one guy was able to install them by himself."

But the things Steve likes most about open-web floor trusses as Larsen trusses are that you can easily set them on a ledger and that you don't have to make any modifications on-site if you order just what you need. Floor trusses are manufactured with a knockout on one corner where a 2x4 band is attached to tie the trusses together. When using them as a Larsen truss, Steve says that you can attach a ledger to the building to set the trusses on, fitting the ledger into the notch. Also, because truss plants will make whatever you design, Steve says that you can even order them with an angle on one end, which could make it easier to match the roof pitch or to sheath for a water-shedding cap on the trusses.

Josh's I-joists are also a manufactured solution. The joist depth is chosen to meet performance goals. Josh fastens the I-joists to the framing every 2 ft. with structural screws, alternating sides of the OSB web. Though the application and fastening schedule has been approved by an engineer, Josh uses a raft-slab foundation for his homes, so the I-joists are also resting on high-psi rigid-foam insulation. One more thing Josh likes about using I-joists is that they can be cut on-site. For example, when the I-joists run up to the roof eave, the crew can cut them at an angle that matches the roof pitch.

Though manufactured alternatives to John Larsen's original wall truss have gained popularity, Vermont architect Robert (Bob) Swinburne has adopted a site-built solution of his own. Bob has tried a few variations on what his friends call the "Swinburne truss." His first idea was to create a standoff with a block of wood fastened to the framing and a plywood gusset holding a length of 2x4 or 2x6 parallel to the wall. But he's simplified that further to just having the lumber attached to the block of wood fastened to the wall and offset with the framing inside the sheathing. His builder has also switched from framing lumber to local green lumber.

Whether to use a Larsen truss or a double-stud wall, Bob says the choice is partially the builders'. He wants them to be comfortable with the assemblies they are hired to build. Other factors include the complexity and height of the building. Larsen trusses make a lot of sense on wide, single-story houses, he says. The time of year is also a factor. In the winter, he'd rather the crew be working inside. In nicer weather, installing Larsen trusses outside is more viable. And finally, the foundation type matters.

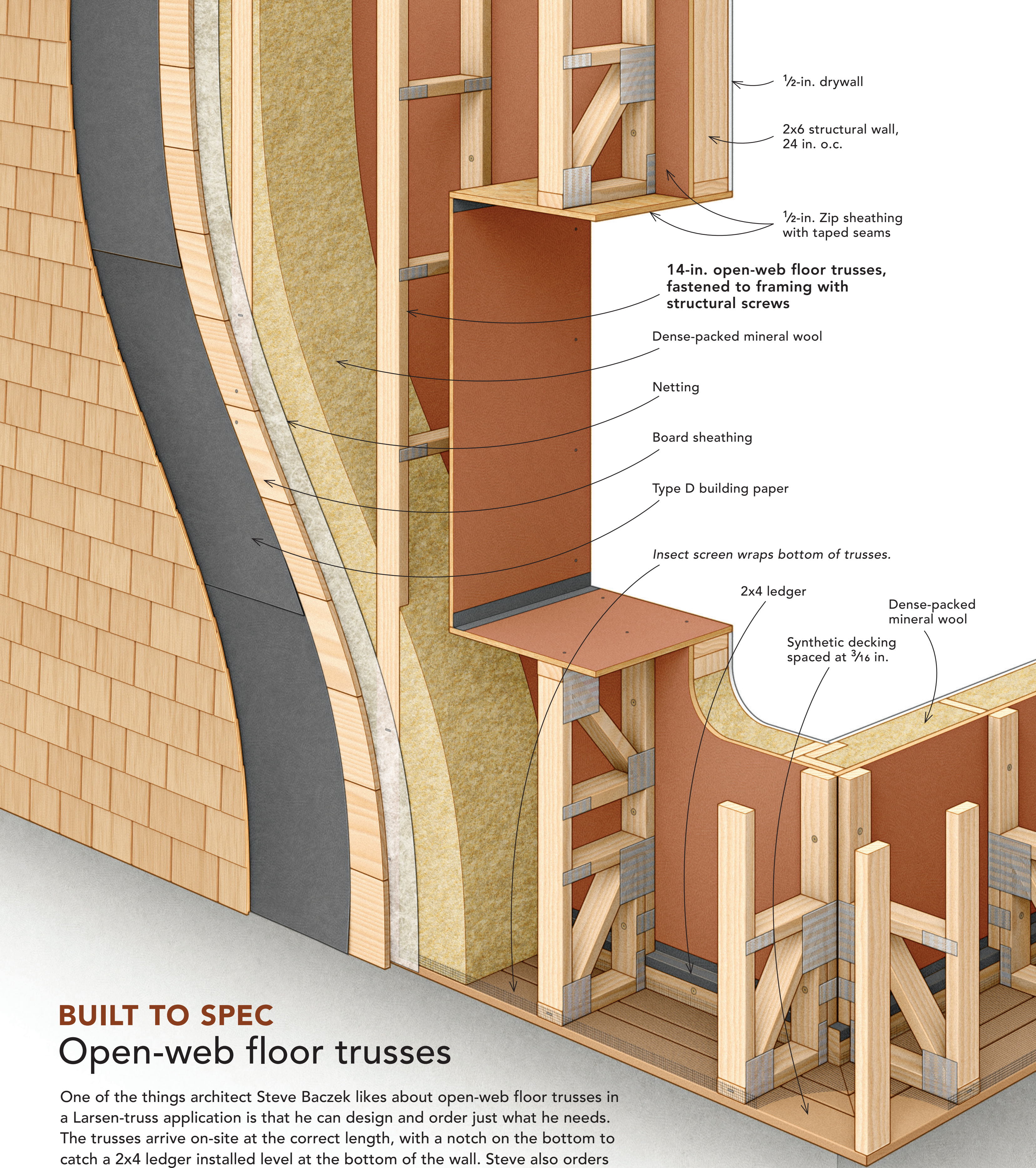
BUTTON UP THE BOTTOM Larsen trusses sometimes sit atop the foundation or the foundation insulation, and sometimes hang outside of the foundation. In any case, you'll need to be able to keep insulation in and critters out. On this project, a combination of insect screen and synthetic deck boards get the job done.

"A standard concrete foundation with insulation to the inside is a good situation for a double-stud wall," Bob says. "If you're using insulated concrete forms or a floating slab where there's a lot of exterior insulation, then a Larsen-truss system starts to make sense."

Details, details, details

Connecticut builder Ben Bogie has used I-joists as Larsen trusses on both new homes and remodels. One of the things Ben likes about this system for remodels is that he can straighten walls as he installs the I-joists. He'll set the joists plumb on either end of a wall, pull stringlines between them, and shim the I-joists to the line wherever the wall is wonky. Ben also likes the fact that he can cover a lot of area fast with this system. After installing a ledger at the bottom of the wall and notching the I-joists to bear on it, Ben only screws the I-joists

Photo: Steve Baczek



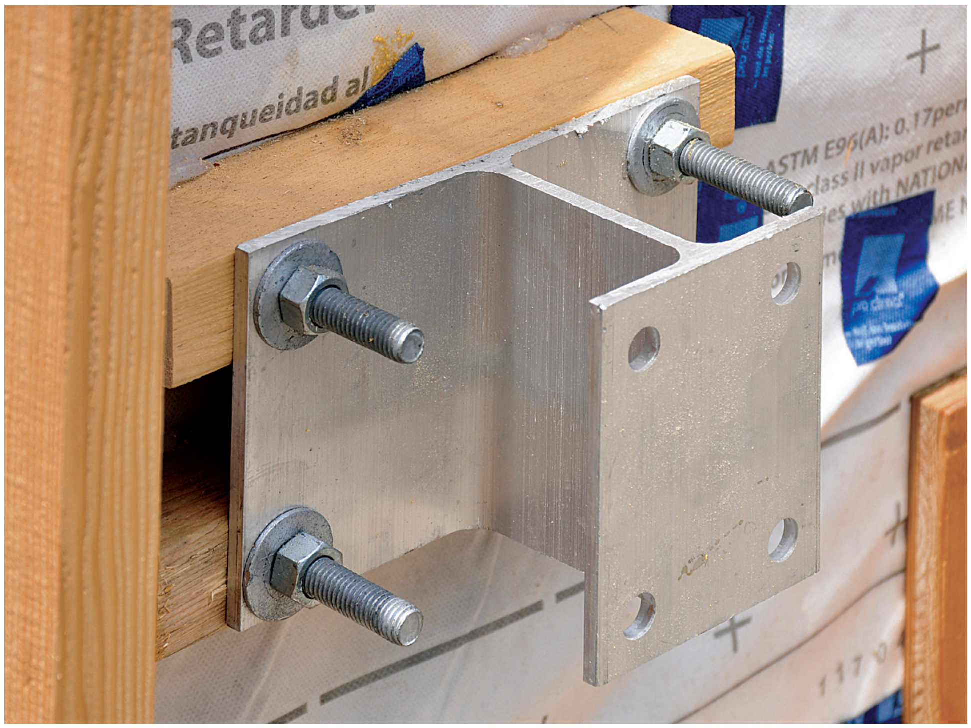
BUILT TO SPEC

Open-web floor trusses

One of the things architect Steve Baczek likes about open-web floor trusses in a Larsen-truss application is that he can design and order just what he needs. The trusses arrive on-site at the correct length, with a notch on the bottom to catch a 2x4 ledger installed level at the bottom of the wall. Steve also orders the floor trusses with a pitch at one end. This detail could be used to match the roofline if the truss were extending the full length of the wall, or in the case of the project illustrated here, be covered and flashed to shed water.

to the framing at the rim joist and the top plate, because that is all his engineer called for. He also said that you'll probably find yourself scratching your head on a few details when building with Larsen trusses for the first time. If you've never built a house with thick walls, windows and doors are one of the first tricky details you'll encounter with a Larsen-truss assembly.

The most common approach to framing window openings is to build a window buck from sheet material. A flangeless window can be installed inside the buck with common details like a sloped sill pan, flashing tape on the exterior, spray foam in the shim space, and air-sealing tape to the interior. Josh prefers a one-piece aluminum sill pan under his windows. One of the key joints to seal is where the wall sheathing and WRB meet the window buck, because this is the main water and air control layer. This can be done with a fluid-applied membrane, tape, or both. Doors can be installed the same way. In both cases it is important to think about what you'll need for fastening trim around the window or door. Also, it's important to consider the placement of trusses next to window and door bucks. Josh says that he occasionally omits trusses when they are too close to windows and doors and will create a space that is too tight to insulate well.



LEDGER-READY Ledgers can sometimes be attached directly to Larsen trusses. Another option is to use hardware like the Maine Deck Bracket spaced appropriately off the sheathing for deck and porch floor and roof attachments.

The gable end is another area where you'll need to plan your details well. Josh sometimes sets the gable truss out to the plane of the I-joists. In this case, the portion of the roof load that hangs over the edge of the structural wall is bearing on the I-joist, a detail approved by Josh's engineer. However, if the roof pitch is low, which means the gable isn't very tall, he sometimes will build a deep rake overhang and run the I-joists to the roof. Josh says there is some insurance to be found in running the I-joists above the thermal boundary on both gable ends and eave walls with raised-heel roof trusses. By packing the insulation above the top plate, a bit of settling will not be an issue.

You'll also need to determine how to handle the bottom of the trusses, install ledgers, and detail outside corners. If the trusses don't land on the foundation, you'll need to detail the bottom in a way that keeps the insulation in the cavity and keeps critters out of it. Some builders wrap a membrane around the bottom of the trusses, but a rigid barrier will be necessary to keep rodents from getting in. Solid lumber and sheet goods will work. You may consider something pressure treated, being so close to the ground.

Your engineer may approve fastening framing lumber to the trusses for ledgers. This is how Josh commonly handles the ledger for a porch roof, for example. Bob has mounted Maine Deck Brackets on blocks fastened directly to the wall sheathing to hold a porch-floor ledger outside of the truss system. In any case, this is not a detail you'll want to leave for the day you need to do the work, nor are outside corners.

Here, too, the solution may be simpler than it seems. When using I-joists for Larsen trusses, Josh completes outside corners with an additional joist, fastened perpendicular to the flange of one of the corner joists. If this sounds like it would be flimsy, keep in mind that all the I-joists will be tied together with horizontal 2x4s, which add a lot of rigidity to the assembly. Bob details the corners by connecting the end trusses on the adjacent walls with corners built from rips of plywood or OSB, leaving gaps where insulation can be blown into the hollow.

A healthy dose of skepticism

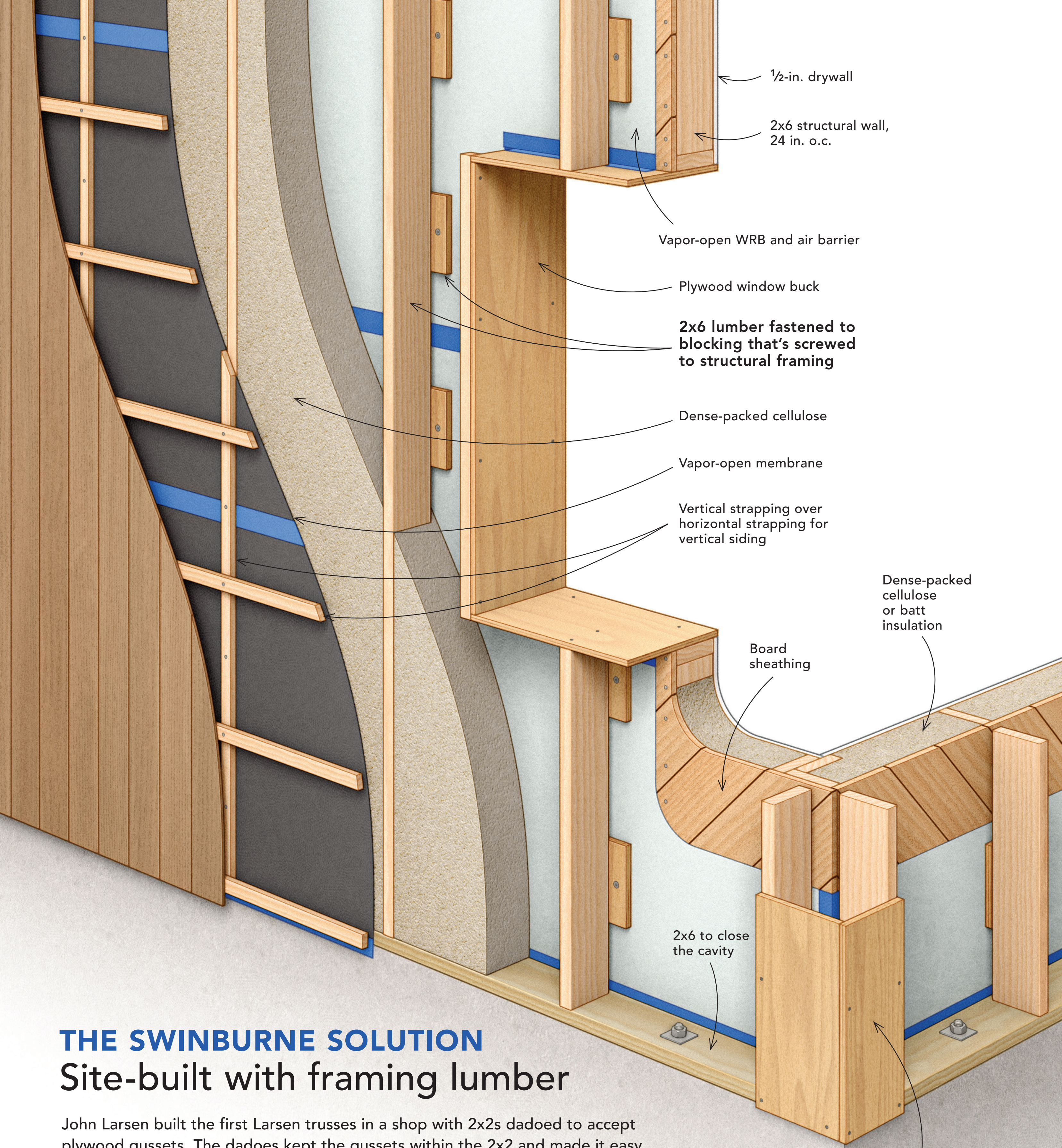
As you can see, there's a lot to like about Larsen-truss wall assemblies. With good planning and a bit of experience, they're a very buildable system too. Some builders make them work from a cost perspective, at least when compared to other high-performance wall assemblies. But at least one builder shared some skepticism about their durability.

"From a building science perspective, this system makes a lot of sense. It's very vapor open to the exterior. With a good, ventilated cladding system, the assembly is going to dry really well. So hygrothermally, Larsen trusses are excellent. They have continuous insulation, and very little thermal bridging," says Ben. "But I do have concerns about them. You are going to be relying on a membrane on the outside of the truss to contain the insulation, and that gives me durability concerns over a long time frame. For 10 or 20 years, I'm sure it's fine. At 50 years, I'm not so sure. And I'm of the school of thought that we should be building homes that will last at least 100 years, if not 200."

Point taken, but let's agree: High-performance homes are high-stakes homes. To minimize risk in a Larsen-truss wall or any other assembly, it's up to all of us to make sure we not only understand the important details, but execute them with precision and care. □

Brian Pontolilo is a senior editor. Drawings by Christopher Mills.

Photo: Bob Swinburne



THE SWINBURNE SOLUTION

Site-built with framing lumber

John Larsen built the first Larsen trusses in a shop with 2x2s dadoed to accept plywood gussets. The dadoes kept the gussets within the 2x2 and made it easy to install batt insulation properly in the cavities. A precise cavity depth is not important with blown insulation, which makes Bob Swinburne's site-built solution an even simpler execution. Bob hangs 2x framing lumber from the wall on blocks of scrap material screwed to the framing. The blocks offset the trusses from the structural framing to minimize thermal bridging.

Working With ZIP

There's a lot to like about these insulating panels, and a lot to learn about building with them

BY BRIAN PONTOLILO

Paul DeGroot is an architect in Austin, Texas, a market where the norm is to fill stud bays with fiberglass batts, sheathe the house with OSB, install a lumberyard-branded housewrap, and nail the siding directly to the wall. When the budget allows, Paul tries to do a little better by using mineral-wool cavity insulation, a ventilated rainscreen behind the siding, and Huber Engineered Wood's Zip System R-sheathing, which includes a layer of insulation to provide a thermal break and boost his assemblies' R-values.

In Austin, code-minimum insulation is R-19 in the wall cavities or a combination of R-15 in the cavities and R-2 continuous insulation or R-13 plus R-3 continuous insulation. With continuous insulation typically installed outboard of the sheathing, Paul recognizes that the latter are better options from a durability perspective. But he's wary of builders' ability to get the details right when installing exterior rigid foam outside of the sheathing. It just isn't common enough yet.

Because R-sheathing panels have insulation on the inside, in contact with the studs, windows and doors can be installed in plane with the sheathing with no need for the fussy flashing details associated with exterior continuous insulation. That gives Paul some confidence.

Code approvals and caveats

Like many products not specifically mentioned in the code, Zip R-sheathing has gone through technical evaluation by the International Code Council's Evaluation Service to be certified for code compliance. The report on the product, ESR-3373, includes a slew of details to help builders, engineers, and architects incorporate and use it correctly.

Just like the standard versions of Zip sheathing, R-sheathing qualifies as a water-resistive barrier (WRB) and as a suitable air-barrier material to meet air-sealing requirements of the International Residential Code (IRC) so long as the panel seams are taped according to the manufacturer's instructions. It's also an option to meet various continuous insulation requirements.

The report specifies the panels must be installed on wood-framed walls of minimum 2x nominal framing with studs spaced no more than 24 in. on center. The panels can be installed horizontally or vertically. Because the foam layer is slightly larger than the OSB layer it's adhered to and overhangs one long and one short edge, it's self-gapping—installers just need to keep track of which edges are which.

The thickness added by the insulation—and the fact that the structural sheathing doesn't itself contact framing—requires a change from standard nailing practices. Most braced-wall and shear-wall applications require a minimum 1½-in. penetration into framing and require specific framing layout, fasteners, and fastener spacing. Fastening tables are included in the ICC-ES report and are available on Huber's website. In seismic and high-wind zones, there may be further limitations and adjustments for framing materials other than Douglas fir, so read all product lit-

Photos: middle, Tim Furlong Jr.; facing page right and inset, Rodney Diaz

R-Sheathing

erature carefully before installing R-sheathing in these situations.

While most installations can be done with common framing tools, builders choosing to use 2½-in.-thick R-12 panels in shear-wall applications may need to size up their nailers to shoot 4-in. nails.

"I'm given the impression by some of the architects I work with that this is being touted as equivalent to, let's say, ½-in. sheathing or 7⁄16-in. OSB," said structural engineer Jon Cowen. "That's simply not the case."

Cowen explained that while Zip R-sheathing has passed testing to be included in the prescriptive parts of the IRC, it has limited struc-

3-IN-1

STRUCTURAL SHEATHING, CONTINUOUS INSULATION, AND WRB

Zip R-sheathing is a 7⁄16-in.-thick OSB panel with Huber's resin-impregnated kraft-paper overlay—a Grade D water-resistive barrier (WRB)—on the exterior-facing side of the panel, and a layer of polyisocyanurate insulation laminated to the inside of the panel. The insulation layer is available in four different thicknesses for four different R-values:

R-3.6 PANELS 1 in. thick with ½ in. insulation

R-6.6 PANELS 1½ in. thick with 1 in. insulation

R-9.6 PANELS 2 in. thick with 1½ in. insulation

R-12.6 PANELS 2½ in. thick with 2 in. insulation

The 4-ft.-wide panels are available in 8-ft., 9-ft., and 10-ft. lengths. The WRB is rated for 180 days of exposure before it must be covered with siding. Seams are sealed and flashing details are incorporated with Huber's seam and flashing tapes and/or fluid-applied flashing products.

A UNIQUE VAPOR PROFILE

Zip R-sheathing is an assembly of three materials with three different perm ratings:

1. The polyisocyanurate insulation has a perm rating of less than 1 perm.
2. OSB is rated at 0.75 perms per in. in dry-cup testing, and 2 perms per in. in wet-cup testing, which means that as relative humidity rises, the OSB becomes a bit more vapor-open.
3. The applied WRB has a perm rating between 12 and 14 perms.

Walls sheathed with Zip R-sheathing will have limited outward drying potential through the low-perm insulation. The cavities will need to be able to dry inward. Should the OSB get wet, however, it will readily be able to dry to the exterior, through the more vapor-open WRB.

tural use, and there have been areas on homes he has engineered using R-sheathing where it couldn't be used. As an example, Cowen points to shear walls.

"Plywood or OSB shear walls have a height-to-width aspect ratio that is a minimum requirement. So, for the height of your wall, let's say 8 ft., the height-to-width aspect ratio that's allowable for a shear wall made of wood structural panels is three-and-a-half to one," he explained, citing the American Wood Council's recommendation for blocked wood structural panels. "The height-to-width requirement for these R-sheathing panels are much, much greater." In other words, you'll likely need an engineered solution to create shear panels when building with Zip R-sheathing.

Cowen solved these problems by using alternative structural sheathing panels in these areas and taking a different approach to insulating them. Alternative shear-wall strategies also include let-in diagonal bracing or metal strapping, or inset shear panels.

Choose the right R-value

When it comes to choosing the right R-value of Zip R-sheathing for a project, Allen Sealock, Zip System product director at Huber Engineered Woods, said, "I find that this topic is one of the most common areas of confusion. I tend to think that the vapor-retarder requirements represent best practice and a more conservative approach, whereas the energy code only takes into account energy usage and has nothing to do with condensation and moisture protection."

Let's unpack that advice with an example: To meet the prescriptive energy code for wood-framed wall insulation in the 2018 IRC in climate zone 6, you can install R-20 cavity insulation plus R-5 continuous insulation (or the R-6.6 Zip R-sheathing). In this scenario, you'd be required to have a class I or class II interior vapor retarder because you don't have adequate R-value of exterior continuous insulation to keep the sheathing warm and prevent condensation (or in the case of R-sheathing, to keep the interior face of the insulation—the first condensing surface—sufficiently warm).

According to the IRC, if you instead use R-7.5 continuous insulation over 2x4 walls or R-11.25 continuous insulation over 2x6 walls, you can omit the class I or class II interior vapor retarder; your painted drywall likely provides all of the vapor control needed because you have reduced the likelihood of condensation forming within the wall. This wall can now dry inward. To Sealock's point, an assembly without a potential condensing surface is a safer assembly, which is why he recommends following the R-value requirement found in IRC table R702.7.1 on vapor control when choosing the right thickness of R-sheathing for your project.

With R-sheathing, you can use whatever cavity insulation you would like. "It comes down to what R-value you are trying to achieve," Sealock said. "We don't have any limitations on cavity insulation." Product literature does recommend that builders include a ventilated rainscreen when using closed-cell spray foam for cavity insulation—that's good advice no matter what you choose to use in the stud bays.

It's also possible to add additional continuous exterior insulation over Zip R-sheathing. When asked about using rigid foam over the product, Sealock said, "It happens occasionally. What it comes down to is whether you're comfortable with what people often refer to as a 'double vapor barrier.' You would be sandwiching the OSB layer between two layers of low-permeance foam. And depending on which school you're from, some people think that's okay; some people think it's not. I tend to think it's okay when everything else is done properly."

When asked the same question about a wall with vapor-open mineral wool as the exterior continuous insulation, Sealock said, "I wouldn't have a problem with that."

Tips from the job site

Jake Bruton is a high-performance builder in Columbia, Mo. He's been using Zip System products for long enough, and well enough, that he's appeared in their advertising. Bruton offers what may be the most important tip about working with Zip R-sheathing.

"It comes shrink-wrapped. Don't remove all the shrink wrap at once," he said, "just take out two or three sheets at a time."

The reason for working in this way, Bruton explained, is that Huber uses a minimal amount of glue to laminate the insulation to the OSB—specifically, Huber uses polyvinyl alcohol adhesives. Left exposed for even a short period of time, the product will delaminate. "This is not a defect," Bruton said. "The manufacturer knows that once the sheets are fastened to the framing, everything will stay where it's supposed to."

Bruton also addressed builders' most common concern about working with the prod-

Want the insulation on the outside?

One of the most common criticisms of Zip R-Sheathing is that the insulation is on the wrong side of the OSB. If you agree, but like the idea of a product that integrates the sheathing, water-resistive barrier (WRB), and continuous insulation, you might be interested in OX-IS from Ox Engineered Products. OX-IS combines fibrous structural sheathing on the inside with a layer of polyisocyanurate insulation and a WRB facing the weather.

The structural layer of OX-IS is the company's Thermo-Ply structural sheathing product, which itself is an approved WRB according to Todd Gluski, director of marketing at Ox. Gluski said that the panel is structurally equivalent to 7⁄16-in. OSB, though nailing schedules may differ. The polyisocyanurate insulation is self-gasketing, said Gluski, and coated with a protective polymer that creates a WRB on the exterior face of the insulation.

OX-IS is available in ½-in., 1-in., and 1½-in.-thick panels with respective R-values of 3, 6, and 9. The panels are 4 ft. wide and are available in 8-ft., 9-ft., and 10-ft. lengths. It is rated at less than 0.3 perms. OX-IS meets the IRC's criteria for a WRB and air barrier when seams are properly taped, as well as the criteria for insulating sheathing.

Gluski said that some other reasons for builders to like OX-IS are its light weight and stable pricing. (Zip System and other OSB products are subject to the ever-changing commodity pricing of OSB.) And finally, when the product is installed with Ox seam and flashing tapes, it holds a 30-year system warranty.

Photo: Rodney Diaz. Drawing: Michael Gellatly.

uct—its squishiness and the potential to overdrive fasteners. His solution is to add a pressure gauge between the air hose and his framing nailer and to have one person responsible for nailing the sheathing. In this way, they don't have to walk back to the compressor each time they need to adjust pressure, which can happen quite often with all of the different materials used for framing today.

Tim Uhler, a framer in Port Orchard, Wash., agrees with Bruton that the product is mostly straightforward to work with. "It's the same install as any plywood panel. It's just slightly heavier and a little thicker," he said. "The only thing as a framer that I had to keep track of is that my outside corners need to lap, [taking into account] the extra thickness of the foam. And inside corners, you need to make that adjustment too." Uhler noted that he thinks it is also important to be particularly careful with layout to minimize waste.

When it comes to the concern of overdriving fasteners, Uhler said, "Try not to go insanely fast, and be picky with your depth control." He explained that because the panel is not only structural, and is also the weather barrier, it's worth slowing down and taking some extra care. It's okay to take out your hammer to finish off a few nails, he said.

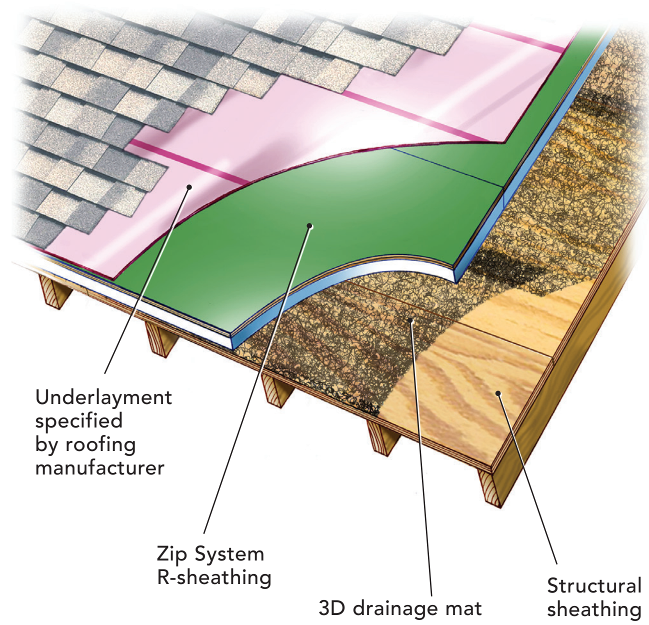
Last year, Green Building Advisor published an article about a severely botched Zip R-sheathing job that generated a lot of discussion. The consensus was that the job never should have gone so wrong, and that in addition to using an inline pressure regulator, it's important to follow the manufacturer's instructions, use an appropriate-size compressor for consistent pressure when nailing, consider an after-market flush-nailing collar for your framing gun, and have patience in learning to work with the material.

Bruton recommends using a circular saw instead of a router to keep the dust down when cutting openings in R-sheathing. Uhler's method is to use a track saw: "You just line up the track, set the depth, and then you always have nice clean edges that are perfectly straight—and it doesn't take any longer."

While most exposed foam edges will be covered with tape, the bottom edge is sometimes tricky to figure out how to protect. Bruton uses a double bottom plate. The lower plate is wider by the thickness of the sheathing than the second plate. If he is building a 2x6 wall with 1½-in.-thick sheathing, he uses a 7-in. bottom plate. The sheathing lands on top of the first plate, protecting the exposed insulation, and the face of the sheathing is flush with the leading edge of the first plate, creating a coplanar joint that can be easily taped or sealed with fluid-applied flashing.

Other builders install blocking against the bottom edge of the sheathing, fabricate custom flashing details, or inset the wall so the face of the sheathing is in plane with the foundation wall below.

A questionable solution for roofs



Zip R-sheathing is not approved for use as structural roof sheathing. However, the company recently released a technical document explaining how it could be used as a nail base panel over existing roof sheathing to add R-value to an insulated roof assembly.

The document says, "The panels do not function as a structural panel, underlayment or air barrier for the roof assembly." It describes the need for a drainage space between the structural roof sheathing and the R-sheathing and an additional roofing underlayment, as specified by the roofing manufacturer, on top of the R-sheathing. In this application, R-sheathing is to be screwed to the roof deck and to the framing with "code recognized nail base fasteners," including FastenMaster HeadLok, Simpson Strong-Tie SDWS, and similar structural fasteners.

Allen Sealock, Zip System product director, agreed that this is not likely where this product is going to shine, but said enough builders are asking about using it on roofs that they decided to offer a way to use it in this application. "We're allowing it, but it wouldn't hold the same 30-year warranty, [or] system warranty," he said. It would "only be a manufacturing-defects, basic-commodity warranty" when the product is used as nail base on a roof.

Wrong-side insulation

Armando Cobo, who designs zero-energy homes for the various climate zones of the southwestern U.S., has worked with Huber as part of an advisory team for Zip System products. "If money is no object, [Zip sheathing] is a perfect product to use," Cobo said. "They have the best tape in the business."

But Cobo said that a sheet of regular OSB and a sheet of ½-in. rigid foam are much more affordable than any Zip products, and that installing the materials separately allows him to decide what he wants to use for a WRB based on the wall assembly, and where he wants to put it. The seams of sheathing and insulation can be staggered, and the insulation is always where he thinks it belongs—outside of the sheathing

Sealock understands why builders feel the insulation is on the wrong side of Zip R-sheathing. "A lot of people get hung up on, 'Oh, the OSB is on the outside and that deviates from Joe Lstiburek's Perfect Wall design,'" he said. "But what we tried to bring is a solution [for] the complexities of detailing—installation of siding and trim and windows through rigid foam. Flashing details [and] all of that is simplified with the addition of the nail base on the exterior."

This is exactly what Paul DeGroot is after. □

Brian Pontolilo is editorial director of *FHB* and Green Building Advisor.

Choosing the Right Construction TAPE

Keeping out air and water for the long haul requires using seam and flashing tape the right way

BY RANDY WILLIAMS

Whether used for covering the seams of a water-resistive barrier, flashing a window, or making an air barrier continuous, construction tapes have become a key part of residential construction. My first experience using a construction tape was taping housewrap seams and window flanges 20 years ago. That tape, which is still in use today and looks like packing tape you'd use for shipping a box, didn't stick so well.

Newer tapes adhere better and do far more than just seal housewrap. But despite advancements in tape technology, you can still use tape incorrectly or use the wrong tape for the job. My work as a high-performance builder and energy consultant in one of the country's coldest areas requires that I use the right tape the right way. I've even done my own research to ensure my clients' homes perform the way they should.

Common applications

Keeping water out of our assemblies is one of the most common ways to use construction tape. Taping the seams of a mechanically attached water-resistive barrier (WRB), like Tyvek, or a factory-applied WRB, such as the one incorporated into Zip System sheathing, can create an effective water-shedding assembly as long as the tape is applied correctly. We can also use tapes to protect window and door rough openings from water damage; to water-seal penetrations through wall assemblies, as with dryer and bath vents; and to seal a foundation or roof to exterior walls. Tapes used for water management often also keep air from moving through assemblies.

Photo: Matthew Millham. Drawing: Francisco Javier González y García.

I always try to use one manufacturer's products on an assembly. For example, when using Tyvek housewraps, I use Tyvek's tape. When I use Siga's air- and vapor-control membranes, I use Siga tape. When you stick with one maker's products, you can be more confident that they've been tested as a system and should perform as intended, assuming you follow the manufacturer's instructions.

Compatible surfaces

Unlike in the old days, modern tapes adhere to a wider variety of construction materials, including engineered and solid wood, rigid insulation (e.g., XPS, EPS, and polyiso), plastics, PVC and fiberglass window flanges, metal, glass, and concrete. For reliable adhesion, some tapes require a primer on OSB or concrete for a better bond. You have to check the manufacturer's data sheets for specific requirements.

How well a tape sticks to a surface is based on several factors. Whether the surface is smooth or rough is one of the biggest factors, with smooth surfaces providing the best adhesion. The porosity of the surface matters as well. Generally speaking, surfaces that are less porous hold tape better than porous ones. The viscosity of the glue on the tape affects how it contacts the surface, which in turn affects adhesion. It's important to remember that the viscosity may change with temperature, and tape that worked well with the temperature and humidity conditions one day may be less reliable the next. Some tapes "creep," or slide off surfaces when temperatures are too high, and other tapes don't stick reliably in low temperatures. Another factor is how clean or dry the surface is. Dust, pol len, and debris should always be removed. Some tapes work on damp surfaces, while others require the surface to be completely dry. In all cases, check with the manufacturer for guidance.

Another factor in a tape's performance is the material the adhesive is applied to that creates the tape. This "support surface" (or "backing") can vary; for instance, a UV-resistant support surface can be exposed to sunlight and is often used in an open-cladding system. Other tapes have a reinforcing band running through them to improve durability and strength, and still others have a backing that can be greatly deformed, as with Zip Stretch Tape. Construction tapes also come in several different widths. Avoid a one-size-fits-all mentality, and choose tape composition and width by individual application.

Tape manufacturers often have a list of materials you shouldn't cover with their products. For instance, Siga says you shouldn't use its Wigluv tape with GE's Silicone 2 Window & Door, Henry's 212 All Purpose Crystal Clear, or Tremco's Spectrem 2 sealants. Before using a particular tape, check with the manufacturer for potential compatibility problems.

Release liner options

The presence or absence of a release liner can slow or speed installation. Certain tapes, such as Zip's Flashing Tape, can be ordered with or without a release liner. Tyvek's Seam Tape does not have a liner, so the tape's adhesive is in direct contact with the tape's backing. Tapes without a liner are faster to install, but the result can be messy if installers aren't careful.

With tapes that have a paper or plastic liner, the liner must be peeled off before the tape will adhere. Pulling the release paper takes more time, but there's less risk of wasted tape and sloppy installation. Some tapes have a split liner, so a portion of the liner can be removed at a time; this simplifies taping corners and allows the tape to be integrated with other water-shedding materials after it is initially installed.

Split liners also make it easier to work with very wide tapes, such as 3M's 12-in.-wide 8067 flashing tape, which has an uneven split at 2 in. from one side and 10 in. from the other. A newer type of release liner has been produced by Rothoblaas, whose tape called Smart Band can be split anywhere on

APPLY PRESSURE
There is a reason why tapes are called pressure-sensitive. Applying pressure, usually with a J-roller, activates the adhesive. You have to roll the tape for it to achieve a full bond to the taped surface, and this pressure needs to be applied along the entire length of the tape. It's so important that you'll often find the rolling requirement printed right on the tape. Other manufacturers want the tape smoothed with constant pressure using a squeegee or similar smoothing tool.

Photos this page and facing page, top right: Matthew Millham.
Photos facing page: top left, Colin Russell; bottom, courtesy of the manufacturers.

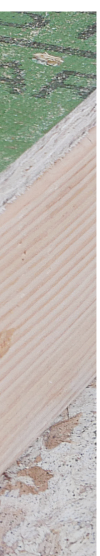
FOR TAPE SUCCESS

LAP SHINGLE-STYLE

When possible, it's best practice to lap taped transitions shingle-style so that the assembly sheds water. I start at the bottom of whatever I'm taping (e.g., walls, doors and windows, corners) and work my way up the assembly. For instance, on a wall I might start taping at the wall-to-foundation connection and then tape any vertical seams to the first horizontal seam, lapping over the previously installed foundation-to-wall tape and continuing until I've made my way to the top.

PAY ATTENTION AT CORNERS

Make sure that any seam or flashing tape is pushed tight into corners, because any radius in the tape complicates trim and siding so much that inevitably someone cuts the tape with a utility knife, allowing air and water into the corner. I like to tape corners using a tape that has a split liner. I cut the tape to the needed length, remove the liner from one side, then apply the tape from the top of the corner, working my way down, peeling and applying short sections at a time. Once one side is completely adhered, I repeat the process on the other side.



FIX FISH MOUTHS

When the outside of the sheathing is the WRB layer, as with some installations of rigid insulation and Zip System, these WRB components are not lapped shingle-style. Instead, the panels are butted together and the seams are taped. In these assemblies, the tape is a critical water-shedding component, so it must be installed flat and without "fish mouths"(gaps) or wrinkles that could funnel water into an assembly. They don't have to be big to be a big problem. Cut out open fish mouths and install a new section of tape. It's cheap insurance.

READ THE DIRECTIONS

There is a wealth of useful information in manufacturers' product data sheets and on their websites. You can learn suitable application temperatures, rolling requirements, compatible and incompatible materials, and available widths and roll sizes. The safest bet is to choose tape and weather-barrier products from the same manufacturer, but you can mix and match successfully with help from the manufacturer's technical services department. Local product reps and technical help can be found on manufacturer websites.

TAPE TYPES

There are three main types of tape used in construction today: acrylic, butyl, and rubberized asphalt, which is sometimes called “bituminous” or “modified bitumen.” There are advantages and disadvantages to each.

ACRYLIC

The most popular tapes—and usually the most expensive—are acrylic. These tapes can be very elastic; one example is Zip System Stretch Tape. Many can be applied in lower temperatures, and they bond well with most surfaces. In some instances, it may take a few hours or even a few days for the adhesive to fully cure to the taped surface.

BUTYL

Butyl is another common material for construction tape. These tapes tend to be slightly cheaper than the acrylics. Butyls are UV- and thermally stable. They can be applied in lower temperatures, but in my experience (see “Low-temp tape test,” facing page), the acrylics outperform most other types of tape in cold weather. Tyvek’s StraightFlash, used in window and door flashing, is a butyl tape.

RUBBERIZED ASPHALT

The last type of tape is made of rubberized asphalt—think of Ice and Water Shield. Rubberized asphalt tapes work well with irregular surfaces but do not adhere in cold weather. Some tapes can “creep” or move when exposed to high heat. Rubberized asphalt tapes tend to be the cheapest. Grace Vycor Plus is a rubberized asphalt tape.

Grace Vycor Plus
TYPE OF ADHESIVE Rubberized asphalt
APPLICATION TEMPS Above 25°F
EXPOSURE LIMIT 30 days
PERM RATING Unknown
AVAILABLE WIDTHS 4 in. to 18 in.
COST 4-in. by 75-ft. roll, $37

Rothoblaas Smart Band
TYPE OF ADHESIVE Acrylic
APPLICATION TEMPS 14° to 104°F
EXPOSURE LIMIT 12 months
PERM RATING .194
AVAILABLE WIDTHS 2.4 in. to 6 in.
COST 4-in. by 82-ft. roll, $35

Protecto Wrap Super Stick
TYPE OF ADHESIVE Butyl
APPLICATION TEMPS –20° to 125°F
EXPOSURE LIMIT 12 months
PERM RATING .012
AVAILABLE WIDTHS 3 in. to 12 in.
COST 4-in. by 75-ft. roll, $32

ZIP System Flashing
TYPE OF ADHESIVE Acrylic
APPLICATION TEMPS 0° to 120°F
EXPOSURE LIMIT 180 days
PERM RATING Less than 1
AVAILABLE WIDTHS 3.75 in. to 12 in.
COST 3.75-in. by 90-ft. roll, $33

the liner. Simply create a nick and the release liner can be peeled apart, which can be convenient in certain places.

From roll to building

I use a couple of different methods to apply tape from a roll. If there is no release liner, I unroll short lengths of the tape, smoothing with my hand as I move along. When I get to the end of the taped section, I cut the tape and then roll the newly taped section with a J-roller.

If there is a release liner on the tape, I choose one of two methods depending on the length of the taped section. If it’s about 10 ft. or less, I cut the tape to length, peel the release liner in about 3-ft. sections, and apply the tape separate from the roll. For longer sections, I use roughly the same method, but I pull the tape right from the roll, removing the release paper in 3-ft. sections as I tape. This method results in fewer seams and less chance for leaks.

Tape keeps getting better

Construction tapes continue to improve. They’ve simplified how we address air-sealing details and help to keep our assemblies dry. Understanding where, when, why, and how to use a specific tape requires some

Photos: center, Rodney Diaz; right, Randy Williams

Siga Wigluv
TYPE OF ADHESIVE Acrylic
APPLICATION TEMPS Above 14°F
EXPOSURE LIMIT 12 months
PERM RATING 1.7
AVAILABLE WIDTHS 2.4 in. to 9 in.
COST 2.4-in. by 131-ft. roll, $53

Pro Clima Tescon Vanna
TYPE OF ADHESIVE Acrylic
APPLICATION TEMPS Above 14°F
EXPOSURE LIMIT 12 months
PERM RATING 8
AVAILABLE WIDTHS 2.4 in. to 8 in.
COST 2.4-in. by 98.5-ft. roll, $40

Tyvek StraightFlash
TYPE OF ADHESIVE Butyl
APPLICATION TEMPS Above 25°F
EXPOSURE LIMIT 270 days
PERM RATING Less than 1
AVAILABLE WIDTHS 4 in. to 12 in.
COST 4-in. by 150-ft. roll, $118

3M 8067
TYPE OF ADHESIVE Acrylic
APPLICATION TEMPS 0° to 176°F
EXPOSURE LIMIT 12 months
PERM RATING .19
AVAILABLE WIDTHS 2 in. to 12 in.
COST 4-in. by 75-ft. roll, $41

research. Most manufacturers have the necessary information on their websites, and many have trained representatives to answer questions. If you choose the right product, follow the instructions, and pay attention to the weather conditions, you will greatly increase your chances of success. □

Randy Williams is a builder and energy auditor in Grand Rapids, Minn.

LOW-TEMP TAPE TEST

Recently, we experienced problems with a high-performance tape bonding correctly in cold temperatures. At 14°F, the tape was applied at the bottom end of the manufacturer's recommended application temperature. To determine if the problem was the tape or something we were doing wrong, I decided to apply several different tapes on different surfaces during cold weather. Some worked better than others; as it turned out, the tape we were using was one of the best overall performers.

Many tape manufacturers suggest that their tapes can be applied during cold weather. All the acrylic tapes have low-temperature applications listed at 14°F or colder; Protecto Wrap's Super Stick, which is a butyl tape, has a listed low-temperature application of –20°F. (But believe me when I say that –20°F is not a temperature in which to be applying tape.)

I recently performed a new cold-weather tape test to see if a single tape's performance was affected by low temps. This test was done on a dozen different tapes applied to several different surfaces with temperatures around 20°F. None of the tested tapes performed as well in the lower temperature as they did when temperatures were more moderate. I expected to have difficulties pulling the tapes off several of the surfaces they were applied to, the hardest being standard plywood. None were difficult to remove, and I pulled off a few with little effort.

Overall, if you're using pressure-sensitive adhesives in cold or very cold temps, I recommend using the acrylic-based tapes, such as Pro Clima's Tescon Vanna, Siga's Wigluv, 3M's 8067, or Zip System's Flashing Tape. The butyl Super Stick also performed well. I used to choose the tape based on the budget of the build, but I no longer do that. Tapes are designed to keep something in or out. Often that's water, which is the number-one killer of buildings. In my opinion, tapes are not the place to save money. Install the best tape you can, perform your own backyard testing, and find the system that works best for you.

—R. W.

Chainsaw Retrofits to Enhance Performance

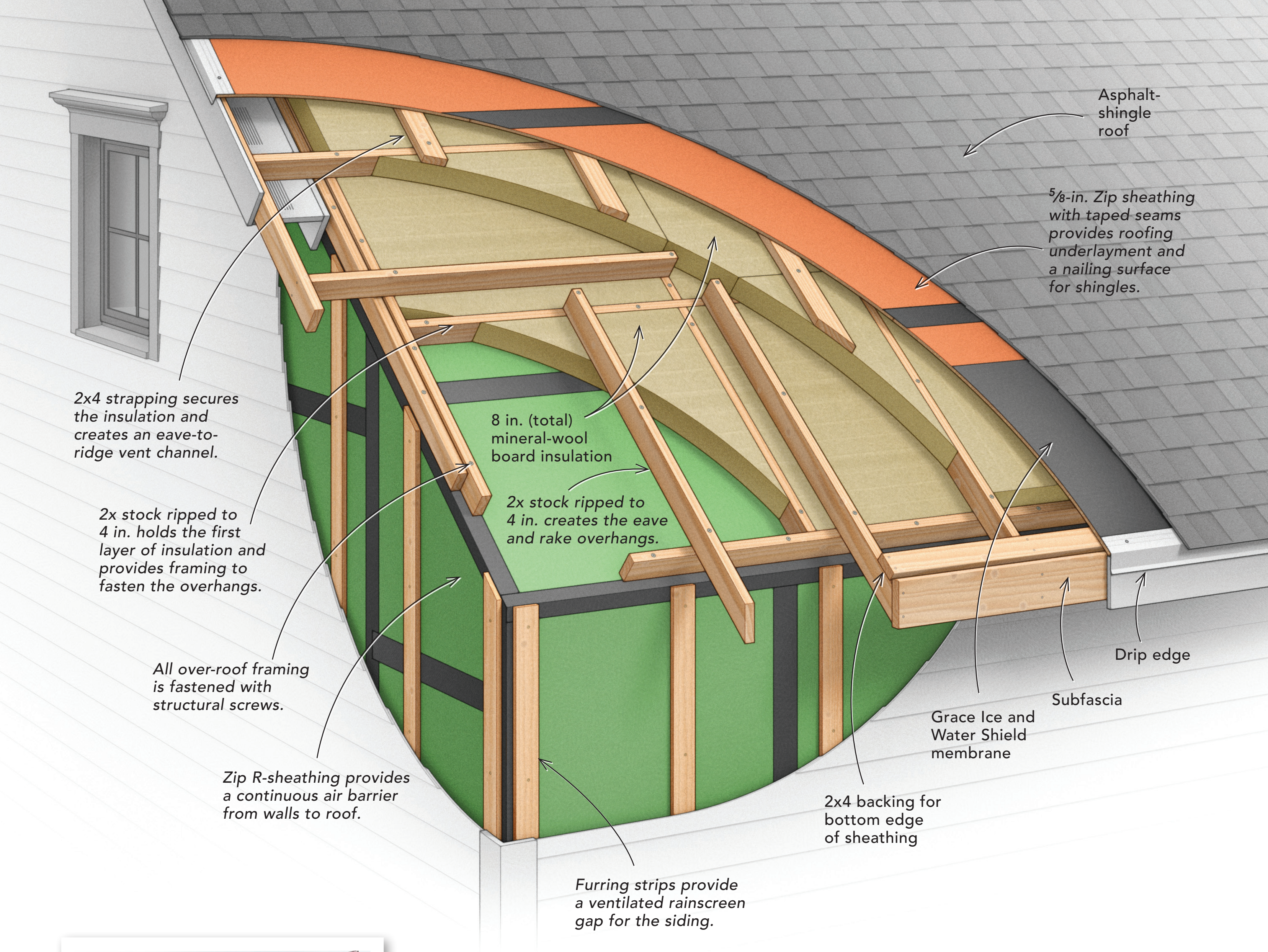
Cutting off the eaves to carry the air and thermal barriers from the wall sheathing to the roof plane is an effective performance upgrade for some old homes

BY JOSH EDMONDS

Our company is known for three unique traits. First, we have a fantastic 25-person team that includes all the trades we need except for excavation and concrete. Second, we try to operate with integrity and break many of the stereotypes that have labeled contractors for decades. We return phone calls, show up as scheduled, and honor our contracts. And finally, we continually hone our building science expertise. We have completed several certified Passive House projects and have finished numerous Passive House–level new homes and retrofits. Even our novice team members have a good understanding of the building science involved in making these homes work. We are blessed with exceptional clients and interesting work, including the farmhouse remodel we are working on here.

This old farmhouse is typical of our upstate New York area. It's a timber-frame house with the siding nailed directly to the studs. There was no sheathing or water-resistive

Drawings: Christopher Mills



Charming, and worth saving. *This timber-frame farmhouse is typical of the 1800s in upstate New York. Its character is enduring, but it needed new windows and doors, new siding, and a new roof.*

Still full of character. *When the remodeling and energy improvements are complete, the house will still be full of traditional farmhouse style.*

FARMHOUSE BEFORE, FARMHOUSE AFTER

Adding thick exterior insulation can make for a roof with a thick fascia and awkward trim proportions. Cutting off the rafter tails helps in two ways. It makes it possible to have a continuous air barrier from the wall sheathing to the roof without finicky details, and it allows the builder to shift the entire cornice upward to maintain the correct proportions.

10 STEPS TO A TIGHT ROOF

STEP 1 REMOVE THE OLD ROOF

The existing roof was metal fastened with gasketed roof screws. The crew unscrewed the panels and passed them down to the ground, where they could be sent for recycling.

STEP 2 DEMO AS NEEDED

The crew removed the lower few feet of roof boards to gain access to the top plate and rafter tails. Before cutting back the rafter tails, they removed the cornice details with pry bars.

barrier (WRB). The roof had the original plank sheathing nailed to the rafters, and at some point a metal roof had been installed. The interior has original wide-plank wood floors and all the character you'd expect from a house of this age. The clients were looking to maintain that farmhouse charm inside, but the exterior needed new siding, new windows and doors, and a new roof. The results of a preliminary blower-door test easily exceeded 10 ACH50. This building clearly needed some air-sealing.

We love the idea of deep energy retrofits but are keenly aware that they do not typically pay for themselves in energy savings. We smile when a project comes across our desk that has a large enough scope of work that energy upgrades are easily implemented as part of the larger process. We have found that to be the sweet spot, allowing us to achieve big performance gains at a low cost. On this project, we had exactly that opportunity. As you will see, the work in the basement and on the walls was straightforward. Updating the roof was a bit more involved.

Envelope improvements start in the basement

Knowing that we'd be doing most of the work on this house from the exterior as we replaced the siding, windows, door, and roof, we had a clear path to upgrading the building enclosure with improved air-sealing and insulation. Because the air and thermal control layers need to be continuous, we had to deal with the basement too.

The farmhouse has a simple block foundation that is in good shape. It appears to have been replaced by previous owners. There are good reasons not to use spray-foam insulation, so we use it sparingly and typically only in situations like this—basements with masonry foundations. The basement is currently dry, but we always plan for the worst. Closed-cell spray foam is vapor-closed when

STEP 3 CHAINSAW TIME!

When the first chainsaw retrofit was done, electric chainsaws didn't exist, but one sure was handy for clipping off the rafter tails on this project. A reciprocating saw would also work, but it is much slower and not as fun. Existing attic kneewalls supported the rafters throughout this process. Otherwise, the crew would have built temporary walls. (Before attempting this yourself, remember to check for nails. And because chainsaws are dangerous tools, brush up on the latest safety guidelines at osha.gov.)

STEP 4 FASTEN THE RAFTERS

Whether it's a timber-frame or stick-framed house, commonly the rafters bear on a top plate that is in plane with the exterior walls. This house had a second top plate that cantilevered out past the wall plane. The crew removed the extra top plate and made up the height difference with ripped 2x8s. After adjusting the rafters to a stringline to help remove some of the sags this building had developed over time, the crew fastened them with structural screws.

installed at least 2 in. thick. The closed pores will handle water better than other insulation types, should it get wet. We also tend not to rely on spray foam for air-sealing except in basement retrofits.

This basement will have spray foam installed without stud walls because there is no plan to finish the space. On projects where a finished basement is in the cards, we build stud walls first, then install spray foam and drywall. When the foam is left exposed, the installers spray a fire-retardant paint over it to meet the fire code. We sprayed 3 in. (R-21) in the rim joist where the basement walls reach above grade. Where the basement walls are below grade, we installed 2 in. for R-14.

As I mentioned, when we removed the existing siding we were staring at the house's framing because it had no sheathing whatsoever. To add structural sheathing, a water and air barrier, and a thermal break, we installed Zip System R-sheathing and taped the seams. Zip R-sheathing is OSB with an integral WRB on the outside and a layer of polyisocyanurate insulation on the inside. We used the 1-in. R-sheathing, which adds R-6 continuous insulation outside of the framing. The sheathing is easy to work with and is readily available in our area, so it was an easy decision. The upcharge from regular Zip sheathing to R-sheathing was only $3000. We had the empty wall cavities filled with dense-pack cellulose, bringing the wall R-value to R-19 in areas where the original framing was 3½ in. and R-25 where it had been remodeled with 2x6 framing.

The house had been uninhabited for a year or two before our clients purchased it, and it smelled badly of rodents. The existing fiberglass in the wall cavities was shredded and tainted by mice. The clients opted to remove the fiberglass when we were putting up the sheathing, and we installed the dense-pack cellulose from the exterior. This choice had more to do with odor than energy. It was a minor cost upgrade but a solid decision.

One of the more unique aspects of this project is the windows and doors. When the current homeowners bought the house, they found a basement full of very nice European tilt-turn windows and accompanying doors, which a previous homeowner had intended to install. We're very familiar with the performance and installation details for these products, so we were happy to use them. We built window bucks with Zip sheathing and installed the new windows mid-wall with Siga air-sealing tapes.

That brings us to the roof. We have done several energy upgrades on houses where we put a lid on them by air-sealing the attic floor. That works when the house has an unconditioned attic with a flat floor. In situations like these, our usual method is to install a thin layer of spray foam on the attic floor, build and install an airtight and insulated attic hatch, and add a bunch of loose-fill cellulose insulation on top. This approach successfully air-seals the lid of the building and adds as much insulation as we can fit or determine is right for the project.

When we're dealing with a finished attic space, like the one in this farmhouse, we need to take another approach. Here, there was unconditioned space behind the batt-insulated kneewalls. The sloped sections of ceiling and a small flat ceiling at the height of the space had fiberglass batts installed as well. There was no air barrier and no roof venting. Our goals were threefold: first, a roof that doesn't leak; second, an air-sealed assembly; third, enough insulation to make the house comfortable and efficient.

Rafter tails needed to go

We knew that adding new roof sheathing would cover most of the roof air-sealing easily and effectively. But air barriers need to be continuous, and this house had timber rafter tails. Air-sealing around rafter tails is tedious and not very effective, and it makes connecting the air barrier from the walls to

10 STEPS TO A TIGHT ROOF CONTINUED

STEP 5 CONTINUE THE AIR BARRIER

Once all the framing was done, the crew completed the Zip System R-sheathing on the wall, bringing it right up to the eave. To bring everything back into plane, they installed new sheathing where they had removed the old roof boards. Then they sheathed the entire roof with Zip sheathing, taping all seams for air-barrier continuity.

the roof difficult. Here is where the chainsaw retrofit gets its name. We used a chainsaw to clip off the rafters so that they would be even with the exterior wall plane. The air barrier now runs up the wall sheathing and, without skipping a beat, continues up the roof plane. We installed Zip sheathing with taped seams over the existing roof boards to create the barrier.

This style of framing makes the house look like a Monopoly house, which is why you may be hearing about "Monopoly framing" these days. It is being used on new homes as well as retrofits, and roof overhangs can be added in several different ways. On this project we installed the roof overhangs above the sheathing and integrated the process with the exterior insulation. You can apply overhangs to the actual eave, but there are good aesthetic reasons to take the approach we did here. Simply put, adding the rafter tails above the sheathing allows us to hide the exterior insulation behind trim that's proportionate to the house.

While we had the roof open from the exterior, we removed all the existing fiberglass batts in the roofline and kneewalls. We will be insulting the rafter cavities all the way from the eaves to the ridge with dense-pack cellulose. The rafter cavities are approximately 5 in. deep, which will give us R-18. The bulk of the roof insulation, approximately 8 in. of Rockwool Comfortboard 80, will be outboard of the sheathing. Comfortboard 80 is a rigid mineral-wool insulation that comes in sheets of various thicknesses and sizes. Installing 8 in. of it will give us an additional R-32, for a total roof R-value of R-50, which places the roof just over code minimum for a new house in our area.

While getting to code minimum on an insulated roof in an old house is a worthy goal, keep in mind that two building assemblies with the same R-values will not necessarily perform equally. This roof is airtight, and we have minimized thermal bridging with continuous exterior insulation. In other words, this R-50 roof will perform much better than a roof with an even higher R-value but poor air-sealing and a thermal bridge at each rafter.

It's important to remember that even the best-laid plans have challenges. Builders know this well. For example, we found an additional plate above the top beam in the existing framing (see photos on p. 31). We couldn't simply cut the rafter tails flush with the wall plane as we had planned. Instead, we had to remove the double plate and build up ripped 2x8s to support the rafters. We also had to order two sizes of mineral-wool boards because of supply problems. We were able to get boards in 4-in. and 2-in. thicknesses, but two pallets of the 2-in. boards were actually only 1¾ in. thick. The work-around for us was to add a ½-in. layer of wood-fiberboard insulation to even out the thickness where needed.

You won't regret venting

There are several ways to effectively insulate a roof, but filling shallow rafter cavities with fiberglass insulation and no venting is not one of them. For insulated roofs and cathedral ceilings we typically go with one of three assemblies. An unvented roof with closed-cell spray foam is simple and works well, particularly when rafter space is limited. The spray foam does some air-sealing (though, again, we don't typically rely on it for that) and provides vapor control. Unvented roofs generally need air-impermeable insulation, either directly above or directly below the roof deck.

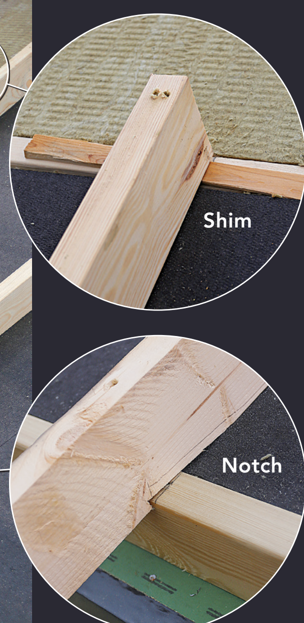
On new builds framed with deep I-joists, we often have space for enough dense-pack cellulose to meet our R-value goals in the rafter cavities and still can include a vent space below the sheathing. These roofs need

STEP 6 FRAME IN THE FIRST LAYERS OF INSULATION

Before installing insulation, the crew needed to attach 4-in.-wide rips of 2x stock around the perimeter of the roof. This frame held the insulation in place until strapping was installed. Parallel 2xs were installed 4 ft. up from the eave and 4 ft. in from the rake. This distance allowed for a full sheet of mineral wool to be installed, and the parallel 2xs provided a structural surface to fasten the roof overhangs above the first 4 in. of insulation.

STEP 7 ADD THE OVERHANGS

The rafter overhangs are 4-in.-wide 2x rips that are fastened to the two runs of framing installed around the perimeter. The framing and overhangs are perpendicular, and so they cross each other, which leaves very little thermal bridging on the roof. The crew ran a stringline to set the tops of each overhang in plane and shimmed or notched the rafter tails as necessary. They also set the stringline to mark the plumb cuts they made with a circular saw.



barrier and, in our climate, a vapor retarder on the inside.

On this project we used the third type of insulated roof, which is a hybrid of sorts. In addition to the Zip sheathing acting as our air barrier, it is also the only vapor control we need. Because mineral wool is air and vapor permeable, the assembly can dry in both directions. The roof can dry inward and outward. In an ideal scenario, when we insulate a roof like this we prefer to have two-thirds of the total insulation R-value on the exterior. That means the air and vapor control layer is well inside thermal boundary. In colder northern climates, this creates a more durable and healthier roof assembly because the sheathing stays warm through our cold winters. (The same is true of walls.)

We also decided to vent the roof above the mineral wool. We created a vent channel by installing 2x4s on the flat running up the roof. They serve to help strap the insulation down and to create a 1½-in. vent space. On top of the 2x4s we installed ⅝-in. Zip sheathing as our roof deck for shingles.

We have recently had several projects run though hygrothermal modeling as a part of

STEP 8 COMPLETE THE INSULATION

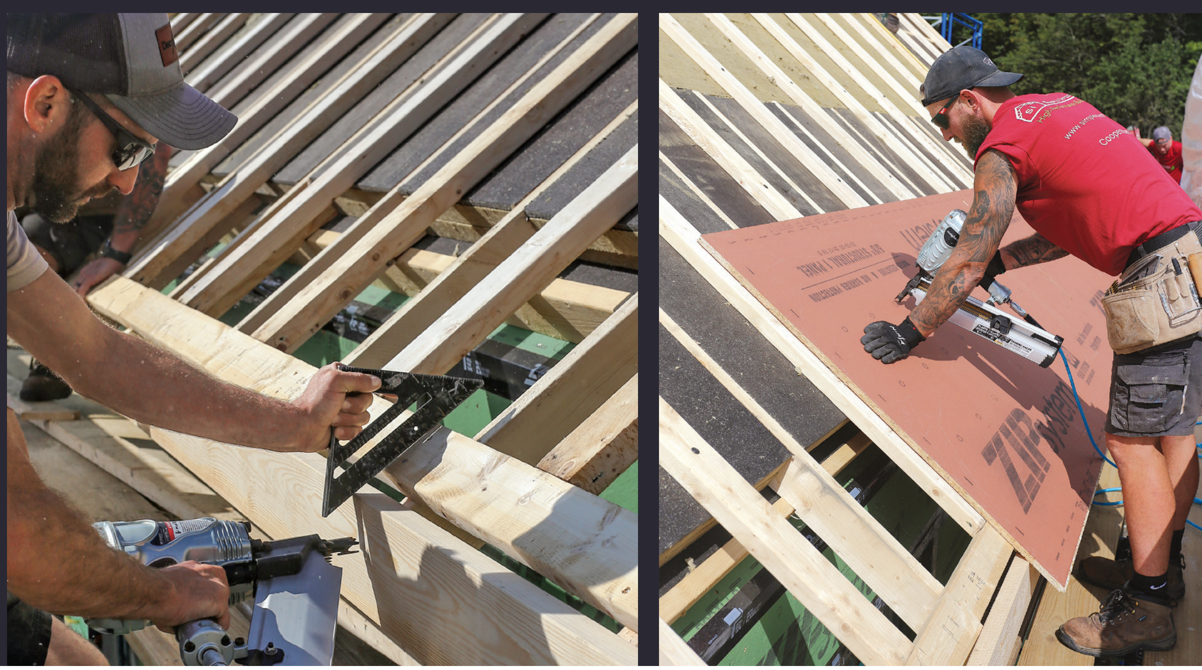
The rest of the insulation was fitted between the rafter tails and over the remainder of the roof.

STEP 9 CREATE THE VENT CHANNEL

Once the insulation was complete, the crew installed 2x4 strapping to hold it in place and create a vent channel from the eave to the ridge. The first piece of strapping was installed parallel to the eave, followed by the long boards that run up the roof.

STEP 10 PREPARE FOR TRIM AND INSTALL SHEATHING

The final steps, before roof trim and roofing can be installed, are to install the subfascia and a final layer of roof sheathing.



Passive House certification. It was helpful to see how a bunch of different roof assemblies performed over time. This assembly would likely be acceptable without the venting, but it is amazing how much better it will handle moisture over the long haul with venting added. The bottom line seems to be to vent your roofs whenever you can. You won't be sorry.

I'm sure there are some people reading this who will wonder if all this work was a waste of effort, or materials, or money, or if it is overly complicated. But this is a house that has lasted hundreds of years and now has hundreds more to go. It still has all the charm of an old timber-frame farmhouse inside, but with the comfort, efficiency, and healthy indoor-air quality of a new high-performance home. While this is for sure a deep energy retrofit, that work wasn't much of the cost or the real focus of the project. It was an opportunity worth taking. □

Josh Edmonds, CPHC, is managing partner at Simple Integrity LLC in Cooperstown, N.Y. Photos by Brian Pontolilo.

THE MUGFORD HOUSE
This circa-1900 Victorian home received Energy Star certification nearly 20 years ago during a significant remodeling project. The current homeowners are hoping to improve energy efficiency and indoor air quality in the home.

Make Updates With

How the work of a home-performance professional can result in a path

Ask ten homeowners what the term "energy audit" means and you might get ten different answers. Many are surprised to learn that it is a legally defined term, with building science–based, national standards that emphasize building durability, comfort, and air quality as much as they focus on ways to reduce energy usage.

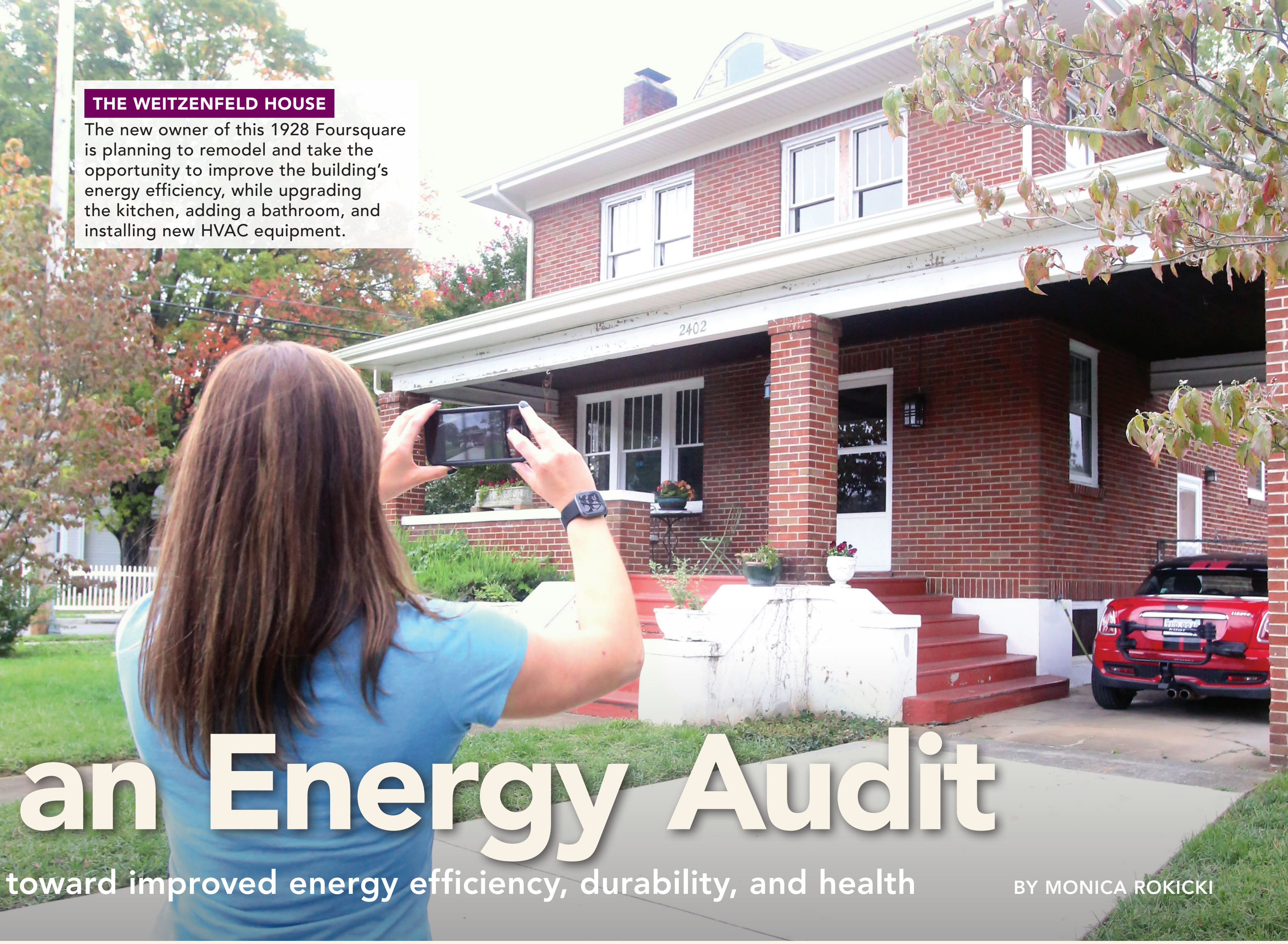
A qualified energy auditor is an experienced, interdisciplinary building scientist. The most recognized certifications for home energy auditors include the Department of Energy's Home Energy Rating System, for HERS rater certification, which focuses on new homes, and the Building Performance Association (BPI) certifications, which focus on performance diagnostics in existing homes. Both perspectives are valuable, because no matter how new a home is, the day after the certificate of occupancy is issued, it's an existing home, with particular conditions based on its climate zone, site, builder and subcontractors, owners, occupants, weather patterns, and more. For this reason, every energy audit will yield different recommendations.

The result of a comprehensive energy audit is a road map for the homeowner, and recommendations are not limited to energy efficiency. They may also include corresponding indoor air quality improvements, suggestions for air monitors, projected dates for major equipment or appliance replacement, and coordination with other relevant home improvement projects. Energy efficiency upgrades are typically also assigned a return on investment because the avoided cost of future energy use can pay for the improvements over time (they may be offset by available incentives or tax credits as well). At my Roanoke, Va., building science firm, Better Building Works, we also include a best-fit feasibility analysis for renewable energy, electrification, and electric vehicle charging, as well as a net-zero-energy plan, in our audits.

In this article I plan to show what a comprehensive energy audit looks like for two different homes, and how the recommendations are similar or different depending upon the owners' objectives and on-site conditions. Both homes are in our tricky mixed-humid climate zone, and both audits were completed in the fall of 2023.

Expectations and assumptions

One of the first things we do is make sure to orient the audit process to address the homeowner's objectives and needs. This means making sure we understand why the homeowner wants an energy audit, and asking them some basic questions, such as how long have they lived in the house, and how long do they plan to live there? We also like



THE WEITZENFELD HOUSE
The new owner of this 1928 Foursquare is planning to remodel and take the opportunity to improve the building's energy efficiency, while upgrading the kitchen, adding a bathroom, and installing new HVAC equipment.

an Energy Audit

toward improved energy efficiency, durability, and health

BY MONICA ROKICKI

to know as much as possible about the history of the house. In the case of these two audits, here's what we knew getting started.

The Mugford residence, built around 1900, is a Victorian home in a historic district. This home experienced a full gut rehabilitation in 2007 as part of a City of Roanoke initiative and was renovated to Energy Star standards at that time. The current owners purchased it in 2019. They are the second owners of the home since the renovation and recently remodeled the basement to add a TV room and shop. While the home is mostly occupied by the two of them and a small dog, they often host their children's families for holidays. Their objective is to increase energy efficiency and indoor air quality.

The Weitzenfeld house is a brick American Foursquare built in 1928. This home has had five prior owners. The current owner purchased the home in the summer of 2023. It will be occupied by two people and a large dog. The owner wants to sustainably improve the building's energy efficiency, upgrade the kitchen, add a first-floor bathroom, and upgrade the heating and cooling system.

When starting an audit, we also want to know what the client's energy bills can tell us. We complete an energy model after the on-site work is complete, but when actual energy use is available in advance, analysis gives us insight into how the building has been performing. This can help us identify anomalies and how energy use changes over the seasons. The lowest monthly usage (usually in spring or fall) helps us quantify energy use not driven by heating and cooling, called "base load."

Finally, before we arrive, we try to state some of our assumptions. This helps us to not be stuck in our preconceptions as we gather more information. In this case, both homes have a basement and two occupied, conditioned levels above grade. Both have relatively large, vented attics with steep roofs. Both homes use gas and electric energy. And both homes will be similarly occupied.

We assumed that the Mugford residence would be well-insulated with a fairly tight building enclosure. There would still be significant air leakage where the upper level overhangs exterior space. Our recommendations for improvement would likely be minimal. Even though the basement is conditioned, annual seasonal energy use would be lower than the Weitzenfeld residence.

The Weitzenfeld Residence has no crawlspace, according to the owner, and the basement is unconditioned. We assumed the blower-door test would show that the home is very leaky. Annual energy use would be very high compared to the Mugford home.

Interestingly, we started to question these assumptions before even visiting the houses when we noticed that the summer energy use at the Weitzenfeld home had been surprisingly low (we had energy bills from the previous homeowner). We had to ask: Since energy usage data is from before the new owners purchased the home, is it still representative? Why is it so low in the summer? If there is no cooling system driving energy usage, are these months showing the true base load?

First, some observations

It's now time for the on-site audit, which typically takes us between two and four hours. Upon arrival, our first step is to set up some basic air monitors for CO and CO_2, along with temperature, humidity, and particulate matter. Then we ask the owners to give us a tour of the house. During this time, we often hear some new information about the home and their plans. And we are also creating a mental map of the home's conditioned building enclosure, which will be documented with conventional photography, notes, and infrared thermography.

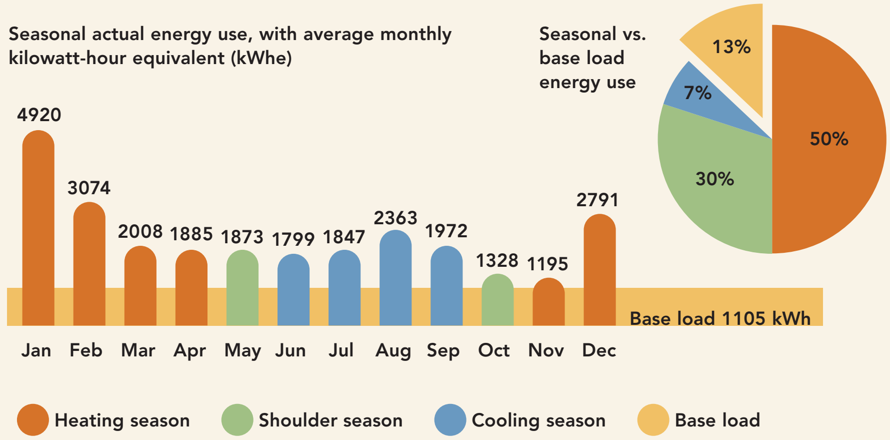
Our assumptions continued to be tested. For the Mugford home, it appeared that the kneewall attic spaces on the upper level and the main attic were not well-sealed. We could see that the basement workshop, which produces a large amount of particulate matter, was at least partially connected to the basement living area and first-floor level above. We also discovered a part of the basement that was formerly a crawlspace, and now has a concrete floor that we were unaware of.

At the Weitzenfeld home, we could easily observe that the unconditioned basement and attic both had many unsealed penetrations into the conditioned space, and that there was virtually no insulation between the basement and the first floor. We also learned that the previous homeowner used the existing fireplace for supplemental heat during the winter, and rarely used window-mounted air conditioning in the summer. This explained the low summertime energy use, and alerted us that winter energy use, while high, would have been even higher without the use of the fireplace. The new owner planned to install central air conditioning and remove the window units. We learned more about the plan to remodel the kitchen and the challenge of routing plumbing and electrical into an area destined to be a small bathroom and pantry, which is adjacent to the back porch.

We also observed a dehumidifier in the basement, and the owner told us that the

THE MUGFORD HOUSE ENERGY IMPROVEMENTS

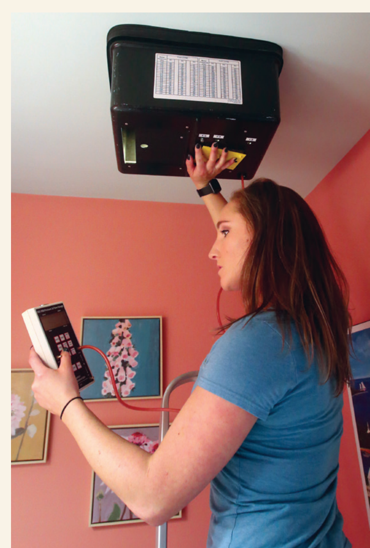
Even though this home had been remodeled in this century, it had some common issues that we verified with a thermal imaging camera, a blower-door test, and indoor air quality monitors.



ENERGY USE SNAPSHOT

From this chart, we can see that the winter heating season accounts for about 50% of total average annual energy use, particularly January. Summer cooling energy usage was nearly as high in August as in December. Spring and fall usage is a little higher that we typically see, as well. Base load is relatively easy to estimate from the lowest-energy-use month of November, and it is likely that the workshop is contributing to a higher base load than average in this home.

First, we look around. *Some issues are easy to spot with a visual inspection, like a lack of air-sealing and poor insulation at the rim joist. We will often verify this with a combination of blower-door testing and thermal imaging.*



Fan flow is measurable. *Exhaust fans in kitchens and bathrooms play an important role in healthy indoor air quality. We try to visually verify that exhaust fans are ducted to the exterior before doing a fan-flow test to verify that the fans are moving an appropriate cfm for the space.*

space is often over 70% relative humidity. There were signs of efflorescence and wetting at the lower side of basement walls. Because the floors showed little evidence of wetting, and the gutters and downspouts were clear and routed to direct liquid water away from the home, we suspected that high humidity levels were the result of air infiltration.

The next step is to record exterior and interior surfaces and materials, and identify potential areas of energy, water, or air leakage. At this time, we also record all equipment model numbers and fuel sources, especially for HVAC compressors and air handlers, furnaces or boilers, water heaters, and major appliances. Later, we'll look these up to verify age, efficiency, and other details about the equipment. We also note all accessible areas where we can see insulation. We look at venting, grading, and neighboring conditions, and identify any areas of water infiltration.

Whenever there is open-combustion equipment inside of the building enclosure, we do combustion-area zone testing to alert the building owner of any unhealthy or dangerous conditions that can result in back-drafting. Even when that testing is not completed, we look for and identify all combustion equipment.

At the Weitzenfeld home we identified an antique gas stove (with no ventilation hood) and a wood-burning fireplace. Both can be sources of indoor air pollutants. Most concerning, however, was the old open-draft boiler, its rusty exhaust-vent piping, and its use of an existing chimney, which is rarely a good idea (note that the clothes dryer—an exhaust fan that exerts around 250 cfm of negative pressure—is nearby). The rusted areas on the vent and boiler were indications of back-drafting because water vapor is a component of combustion air. Staining indicated that this had been occurring for some time. Since the floor above had so many penetrations, combustion air was undoubtedly entering the living areas.

During our energy audits we try to imagine—or ideally, test—the home under a condition we call "family reunion at the winter holiday." What would happen if every bath exhaust, stove exhaust, and dryer were running at the same time as the fireplace is burning, the furnace is on, someone is taking a hot shower, and dinner is cooking on the stove? At the Weitzenfeld home, we'd be concerned.

What about the Mugford's Energy Star home? While there is also combustion

Infrared insights. *With the infrared camera, we scan the exterior walls, particularly where they meet the floors and ceiling, and we verify issues, like leaky and uninsulated kneewall attics and attic hatches.*

RECOMMENDATIONS

From a health perspective, the most significant issue in this house was that particulate matter from the workshop and attic was traveling into the conditioned living space. Our suggested energy improvements were common air-sealing and insulation improvements at the rim joist, in the kneewall attics, and in the main attic:

- Thoroughly air-seal all rim joists and the penetrations between the workshop and the adjacent basement mechanical and TV room.
- Clean and seal all ductwork, particularly the duct system serving the basement and first floor.
- Relocate the air and thermal barrier in the kneewall attics and in the main attic to the underside of the roof sheathing, bringing these areas and the existing heating and cooling equipment into the conditioned building enclosure.

Blower-door benefits. *Blower-door testing reveals more than just how tight or leaky a house is. By running the fan while we look around with the thermal camera, we can often locate the leaks. Follow-up tests after upgrades are complete allow us to verify that the work was successful and to accurately size and commission HVAC equipment.*

POTENTIAL RETURN ON INVESTMENT: 8.3%

This assumes a $12,400 budget with a $1350 tax credit for the homeowners, and a 20% predicted efficiency improvement. The ROI will likely be closer to 10% if energy-cost escalations are included. Another way to look at it: The avoided energy costs over ten years will be $11,047.

equipment at the Mugford home, there are fewer causes for concern. There is a gas furnace serving the basement and first floor, but it is a direct-vent unit, which is much safer than an atmospherically vented furnace. There is a gas stove too, but it has an exhaust fan that vents to the exterior. We were happy to see no unvented gas fireplace, which is quite common in the Victorian-era homes in this area.

Next, an infrared inspection

The first round of infrared thermography occurs at this stage, prior to the blower-door tests. We typically only complete infrareds at the interior, with particular focus on specific areas including the wall-to-floor and wall-to-ceiling intersections, ceilings, and doors or access hatches to unconditioned areas. At this stage, there is little pressure difference between inside and outside, so the infrared camera is usually picking up temperature difference driven by thermal barriers, but we sometimes also discover areas where water leaks have occurred, which will typically have a blob-like appearance.

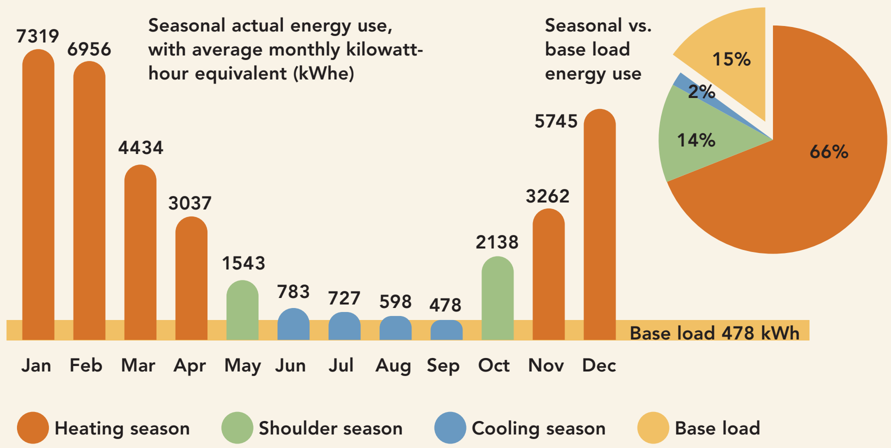
Discoveries often have a silver lining. At the Weitzenfeld property, we noticed an odd metal plate in the basement wall. Infrared thermography revealed that this area was a heat bypass. Around the area, we also found efflorescence, an indication of long-term moisture infiltration. When we removed the plate, we found a small crawlspace with bare earth and no insulation. The good news is that once this space is remedied, it will offer a place for plumbing and electrical runs to the future guest bathroom.

Another silver lining at the Weitzenfeld property was in the walk-up attic, which is very leaky, especially at the attic door, chimney, and top plates of exterior walls. The owner had installed an attic fan after reading some online advice to do so. All of these things conspired together to exacerbate the stack effect, causing high winter energy bills. Fortunately, there was no mechanical equipment in the attic, so there was an opportunity to solve these energy issues and also gain an additional finished room in the attic.

There were also some interesting conditions in the Mugford basement and attic. The workshop was equipped with an air-filtration device to remove particulates created by woodworking, and it had its own stand-alone heating system. But there were multiple air bypasses into the adjoining TV

THE WEITZENFELD HOUSE UPGRADE OPTIONS

The new owner of this home hopes to improve the house by reducing energy use and improving indoor air quality, and by remodeling the kitchen, adding a first-floor bathroom, and potentially converting the walk-up attic to living space.



ENERGY USE SNAPSHOT

From this chart, we can see that winter heating season usage dominates the energy use, and is 66% of total annual average energy use (this data was collected from the previous owner). The very low summer cooling energy usage is puzzling, however. We typically see cooling season usage higher than the spring or fall swing seasons. Base load for the former homeowner may be lower than it will be for the current homeowner, particularly if the new owner uses window-mounted air conditioners or installs new heat pumps and uses them for cooling.

Existing equipment matters. *For our energy modeling work, we need to know the models and efficiency rating of existing equipment that may be left in place or may be recommended for replacement. We take photos to document what was on-site during the audit.*

Finding fixes. *Audits can help owners identify even simple fixes, like this disconnected dryer vent that is currently dumping warm and humid air into the basement.*

Mystery solved. *Unscrewing a metal panel on the basement wall revealed an unconditioned and uninsulated crawlspace under a porch. This space will give the homeowner an opportunity to improve efficiency and run plumbing when adding a new first-floor bathroom in the future.*

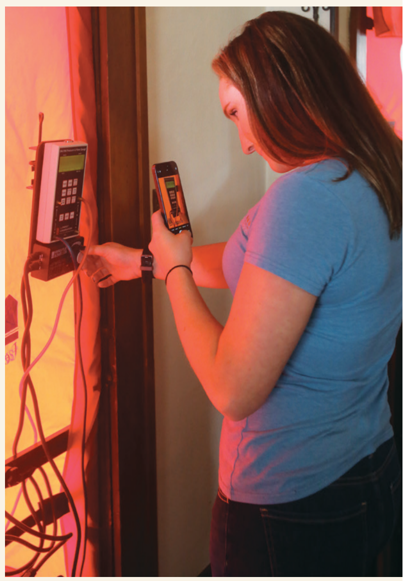
Not so shocking. *Old houses tend to have old electrical panels; we need to know this so that we can consider the necessity and potential costs of a service upgrade if our recommendations require it.*

Not so effective. *It's not uncommon that attic-floor insulation is poorly installed in an older house, particularly because air-sealing was not considered. When thermal bypasses are everywhere, insulation like this is doing very little.*

RECOMMENDATIONS

In this house, our recommendations were more thorough and included replacing combustion appliances and HVAC equipment, and completing air-sealing and insulation work in the basement and attic:

- Replace the bathroom exhaust fan and ducting to the exterior.
- Replace the wood-burning fireplace with a direct-vent gas stove, or better, decommission the chimney.
- Install a sealed vapor retarder in the crawlspace. Remove the access panel. Create a closed, conditioned crawlspace that's connected to the basement.
- Decommission and remove the existing boiler and venting.
- Bring the crawlspace and basement into the conditioned building enclosure by air-sealing and insulating the band joist; consider insulating exterior walls.
- Bring the attic into the conditioned building enclosure and remove the attic fan.
- Install two Energy Star–rated heat pumps, appropriately sized. One will serve the basement and first floor, and the other will serve the upper floor and attic.



Blower-door scenarios. *In a house like this, with a walk-down basement and walk-up attic, both with full doors, we can create different scenarios with the doors open and closed to test our assumptions about where the most leakage is happening.*

POTENTIAL RETURN ON INVESTMENT: 10.9%

This assumes an $11,000 budget with a $1350 tax credit for the homeowner and a 30% predicted efficiency improvement. The ROI will likely be closer to 13% if energy-cost escalations are included. Another way to look at it: The avoided energy costs over ten years will be $12,590.

room and mechanical closet that housed the air handler. Leaky ductwork throughout these areas could spread this particulate matter to the main levels of the house even more efficiently than air leakage.

Kneewall attics are a common feature of existing homes. Despite builder's attempts to keep kneewall attics outside the air and thermal boundary, when they are poorly insulated and air-sealed, they are essentially being conditioned, which is a big waste of energy. In the Mugford residence, this air-sealing and insulation work was incomplete at the second-floor kneewalls. We observed similar discontinuities in air-sealing and insulation in the main, vented attic. A second heat-pump system and associated ductwork was in this attic, essentially operating outside, resulting in lower efficiency and the same air quality issues described in the workshop. In this case, it was potentially distributing unconditioned air, moisture, and dust from the attic into the house. There was minimal insulation, as well as wind-washing, making the actual insulation value around 25% less than the recorded R-value.

While we are investigating a home with infrared thermography, we also record interior thermostat settings and collect the data from our air monitors. We'll later compare these ambient levels of CO and CO_2, air temperature and relative humidity, and particulate matter after blower-door testing—if they are higher or lower, we can learn about indoor air pollutants and ventilation.

Blower-door time

We've learned that we can't predict building tightness. And because knowing the accurate building tightness of a home is critical to proper heating and cooling equipment sizing, ventilation sizing, and determining air-sealing recommendations, we test airtightness with a blower door. With an accurate measurement for the house, we can estimate the total amount of air infiltration that regularly occurs in the home, known as "ACH natural." It is also important to know where the air leakage is occurring. This is where the second round of infrared thermography comes in. With the blower door pressurizing the house, the infrared camera will detect the leaks.

The airtightness results are even more helpful when viewed in relation to the volume of the conditioned building enclosure. For a new home where the conditioned building enclosure is defined and continuous, we do one blower-door test. For existing homes, when we have areas that are thought of as outside of the conditioned building enclosure but are functionally inside of it, like the Weitzenfeld basement, or the Mugford kneewall attics, we run multiple scenarios.

At the Weitzenfeld home, we completed four tests: one with basement and attic doors closed, one with the basement door closed and the attic open, one with the basement door open and attic door closed, and one with both the basement and attic doors open. This accomplishes a few goals. First, it tells us how much air leakage a closed door prevents. Second, it guides decision-making regarding recommended improvements in these areas. Here, we found that the difference in leakage to the attic was about six times that of leakage to the basement. Does this mean that improvements at the attic are more important? Not necessarily. The floor between the basement and the main level is wood that will shrink and swell, and there are many gaps in the boards. The lower difference when the basement door is closed versus the attic indicates that the basement and main level are less separated. The ceilings between the upper level and the attic are plaster—an effective air barrier. We concluded that the attic door was the primary source of leakage, along with the unsealed gaps around the chimney, stair walls, plumbing and electrical penetrations, and eaves.

We also look at air-quality monitors to see if CO_2, particulate matter, temperature, or humidity has changed as a result of bringing air across exterior building penetrations. In the Weitzenfeld home, there was little to no difference, other than a slight dilution in particulate matter. The CO_2 level was unchanged and low, consistent with the high amount of air changes we found in our tests.

At the Mugford home, we also completed four tests. The attic, accessed through a pull-down stair, remained closed except for maintenance, so was left in that state. Instead, we tested various open and closed configurations of the kneewall attics and basement door. The blower-door tests indicated very little difference with the basement door open or closed, which we expected as these two areas are both finished and conditioned. The knee-

10 ENERGY RETROFIT MISTAKES

Here are ten things we commonly see homeowners do when they have not completed a bona-fide energy audit prior to home improvement projects. At best, they're not prioritizing their spending. At worst, they're wasting their money or causing a fire or health hazard.

1 **REPLACING WINDOWS** Windows are expensive and are often not the most important cause of air leakage or heat loss. We've had several clients whose energy costs went up after installing new windows.

2 **INSTALLING INSULATION BEFORE AIR-SEALING** This can result in insulation R-value being diminished by air leakage and moisture issues. An installer who would work in this way may also not know to check for existing knob-and-tube wiring and could create a fire hazard.

3 **REPLACING HEATING OR COOLING EQUIPMENT TOO SOON** Installing new HVAC equipment without making enclosure improvements first often leads to oversized and poorly performing equipment and is generally not a cost-effective way to go.

4 **AIR-SEALING WITHOUT BLOWER-DOOR TESTING** Tightening the home without completing post-retrofit blower-door testing can be a waste of money and may result in an underventilated home and unhealthy indoor air.

5 **NOT VERIFYING INSULATION AND AIR-SEALING WORK** It takes an experienced eye, an infrared camera, and a blower-door test to verify that insulation and air-sealing is completed properly.

6 **INSTALLATION OF MIRACLE PRODUCTS** Radiant barriers, whole-house fans and attic exhausts fans, expensive air-treatment technologies, spray-on products touted as mold controls, and window films are generally gimmicks. Some are benign; others can create health risks.

Ventilate right. *Installing a stylish and powerful range hood fan often means installing makeup air, too. In a tight house, makeup air allows the hood to do its job without causing unintended issues.*

7 **INEFFECTIVE CRAWLSPACE VAPOR RETARDERS** Simply laying down poly sheeting on a crawlspace floor is not effective. This vapor retarder and air barrier needs to be detailed and sealed properly and done in coordination with other air-sealing and insulating work.

8 **UNINFORMED REMODELING** When we remodel a home without considering performance, we miss the most cost-effective opportunity to improve efficiency, air quality, durability, and more.

9 **BIG KITCHEN HOODS** Installing powerful, professional-style exhaust fans over the kitchen range is trendy, and without an engineered makeup-air system, a mistake.

10 **INSTALLING NEW OPEN-COMBUSTION APPLIANCES** Atmospherically vented and unvented combustion appliances create poor indoor air quality and serious health concerns. Sealed combustion is a step in the right direction. All-electric appliances are an even better option.

Photos facing page: top, Rodney Diaz; bottom, courtesy of the manufacturer wall attics were another story. These areas were very leaky, as was the pull-down stair access to the main attic.

Air-monitoring-equipment differences before and after blower-door testing indicated that particulate levels went up after the test. This verified our hunch that particulates from the workshop were entering the conditioned building enclosure. But CO_2 levels went down. Again, this is consistent with most blower-door testing, which is moving air and exhausting or diluting CO_2 levels.

Now we model

After the site visit and once we have all the data, documentation, and numerical calculations together, we complete an asset-basis energy model. This model predicts energy usage for the home with its existing attributes (location, area, volume, fuel types, windows and doors, effective insulation values, equipment and appliance types and efficiencies, and airtightness). It is always completed as if the home is fully occupied for the full year. The results usually vary from the actual utility usage because of several factors including occupancy and homeowner behaviors. But the energy model is still useful, and it is required for underwriting, risk management, and big-data aggregating institutions like insurance companies, banks, and the Department of Energy. This means it can be leveraged at the point of refinancing or sale. And it is also quite valuable to predict proportional savings from potential upgrades, a requirement of any certified home energy audit.

The energy model can be used to discover the optimal combination of energy conservation measures. If any remodeling is planned, this type of energy model can be used to run scenarios, or to estimate the impacts of measures like incorporating a basement or attic into the conditioned building enclosure.

For most existing homes, we use Energy Design Systems's software because it also completes a heating and cooling load calculation. We also use NREL's PVWatts calculator and on-site observation to complete a feasibility analysis for solar photovoltaics. Occasionally, we complete energy audits for homes as the first step of a design process for significant remodels or renovations. In this case, a HERS rating, using more detailed Ekotrope modeling, can be completed and used to apply for Energy Star certification.

Recommendations aren't the end

After energy modeling, we roll all of our data up into a set of recommendations. Final recommendations always begin with durability, safety, and indoor air quality. Enclosure improvements are next, and only then do we recommend equipment and appliance upgrades. Improvements are typically given in phases, depending on the owner's plans for the home. These projects had some recommendations in common (each house also had unique recommendations; see p. 57 and p. 59).

For both homes, we recommended low-ppm CO detectors at each level and a continuous radon monitor. These CO monitors will alert the homeowners to turn off combustion equipment if levels begin to rise. And if continuous radon levels over 2 pC/l are found, they'll know they need to install a radon mitigation system.

We recommended the homeowners replace existing gas stoves with induction ranges. Until then at the Weitzenfeld home, since the existing stove will be difficult to vent to the exterior, and the short-term expense may not be in the budget, we recommend opening a window or door when cooking.

After all recommended air-sealing and insulation is completed, we recommended each home have a new blower-door test followed by proper ventilation calculations, and Manual J heating and cooling load calculations. This is the only way to accurately size HVAC equipment, including balanced ventilation. When it's time to upgrade the water heater, we recommended a heat-pump unit.

When the report is presented to the homeowner, we explain our reasons for each prioritized recommendation, and how the right combination of energy efficiency, electrification, and renewables can yield the highest return on investment.

While the energy audit is the best first step, the process does not stop here. For the best outcomes, we can now provide valuable retrofit project management and verify that work is completed to performance specifications. This will allow us to revisit HVAC equipment sizing and produce a revised energy model for appraisers, potentially increasing a property's value. □

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The serious stuff...

Energy auditors will not complete the audit if ambient carbon monoxide (CO) is over 9 ppm, according to BPI standards, because even at low levels, CO is dangerous. Contrast this with the average level at which CO monitor alarms will sound, 70 ppm, at which point the homeowner should call the fire department and vacate the building.

Moreover, the presence of hazardous materials like lead paint and friable asbestos, or the presence of live knob-and-tube wiring, must always be considered in homes built before 1978 during the audit process, and appropriate removal, encapsulation, or remediation is required by any contractor working on the home.

Other conditions an energy auditor considers that affect indoor air and human health are radon, combustion equipment inside of the home, the potential for biological growth or pests, and a healthy fresh air supply. While many of these topics were not discussed in depth in this article, they are an essential consideration for any certified energy audit or retrofit process. For more about designing, building, and remodeling with indoor air quality in mind, see my online course at FineHomebuliding.com/IAQ.

Beyond the audit. *Risks like lead paint can cause health issues in any home. If you're unsure about the presence of lead or other potential pollutants, test. Some things you can test for yourself with readily available kits, others will require a professional.*