BUILDING Airtight Homes

Start the polyethylene air barrier under the mudsill and seal every seam

Since 1984, I have been building energy-efficient homes with special attention to air sealing. Most conventional new homes,

by Steve Lentz

when tested with a blower door, show a natural infiltration rate of 4 to 8 air changes per hour; my homes are rated at 0.48 to 1.0 air changes per hour (ACH50). My package of energy-saving details costs my customers only about $1.25 per square foot, and they often make back the extra cost with just three to five years of energy savings. Since satisfied customers tell their friends about their low energy bills, my homes have been in steady demand.

Building a tight home does require training your subcontractors. But subs who do quality work may be eager to learn about air sealing, since those skills make them more attractive to other energy-efficient builders.

Basements

Most builders install a poly vapor barrier under their basement slabs. But it's also important to include poly under the wall footings to prevent the foundation walls themselves from wicking up water (see Figure 1, next page). Eliminating this source of moisture lessens the chance of mold and improves indoor air quality.

After my foundation contractor coats the exterior of the basement walls with dampproofing, I install 2 inches of extruded polystyrene foam from the footing to the mudsill. All of my basement footings have perimeter drain tile on the interior as well as the exterior. Finally, I backfill with 3/4-inch crushed stone up to 2 feet of finish grade.

To protect the rigid foam above grade, I use a tough fiberglass material called Ground Breaker, which comes in 50-foot rolls in widths of 12 and 24 inches. These panels are tough — I've never put a hole in one. The top edge of the material is fastened to the mudsill with 3-inch roofing nails driven through the rigid foam, while the bottom is kept in place by the dirt backfill.

Our basement slabs are poured over 8 inches of 3/4-inch crushed stone covered with a layer of 6-mil poly (Figure 2). For the poly, we prefer a brand called Tu-Tuf — a high-density, cross-laminated white polyethylene. Since the poly under the slab is a vapor barrier, not an air barrier, there's no need to tape the seams. Over the poly we install a layer of 1-inch rigid foam. If the basement is getting radiant floor heat, I increase the depth of the under-slab foam to 2 inches.

Air Sealing Begins at Framing

The most important factor in building an energy-efficient house is the installation of a continuous polyethylene air barrier (see "Practical Details for Energy Efficiency," 2/01). This barrier needs to be as airtight as possible, as it snakes its way up from the mudsill, around the band joist, under the wall plates, up the interior edge of the studs, and under the ceiling joists.

If you wait until the framing is complete to think about air sealing, it's already too late. Unless the framers take time to install narrow strips of polyethylene between framing members in key areas, there's simply no way to keep the air barrier continuous.

For the polyethylene to serve as a true air barrier, all seams must also be sealed with either 3M contractor's tape or Tremco acoustical sealant. Since Tremco is a sealant, not an adhesive, there must be a solid framing member behind it for it to work effectively. When sealing a seam without solid backing, we use tape. The red tape from 3M is tenacious and long lasting. I've opened up walls six years after completion and found the tape to be as good as the day it was installed.

Figure 1. Installing polyethylene under a concrete footing prevents ground moisture from wicking up the basement walls.

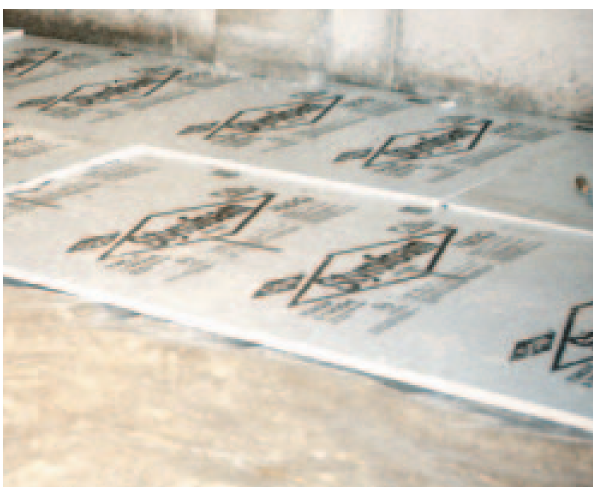

Figure 2. In preparation for pouring the basement slab, a layer of 1-inch-thick polystyrene insulation is installed over 6-mil polyethylene and 8 inches of crushed stone.

Band Joist Details

We frame our floor system so that the band joist is flush with the foundation, while the walls are framed to overhang the band joist by 1 inch. When the band joists are later covered with 2-inch foam, they end up flush with the 1-inch foam wall sheathing (Figure 3, next page).

On my houses, the poly air barrier starts under the mudsill. We staple a length of 6-inch-wide Tu-Tuf polyethylene to the bottom of the sill before it is installed, with about half the width of the poly extending beyond the sill toward the exterior. Every seam gets sealed with Tremco or tape.

I cut the $5\frac{1}{2}$-inch-wide roll of sill seal in half lengthwise before I staple it to the sill, because I find that the narrower $2\frac{3}{4}$-inch-wide strip squashes down better and provides a better seal. Once the sill seal is stapled over the poly, the sill is flipped over and bolted down (Figure 4, next page).

After the subfloor is nailed down and the lines are snapped for the exterior walls, we wrap the exterior of the band joist with poly. Since a band joist gets a lot of abuse during construction, we wrap it with Tenoarm, a tough 10-mil polyethylene from Sweden. Unlike Tu-Tuf, Tenoarm is transparent, so we can see the chalk lines through it where it laps onto the subfloor.

The Tenoarm strips are about 16 inches wide, so they span the band joist and the 5 1/2-inch width of the bottom plate with at least an inch left for overlap. We seal the Tenoarm to the poly sticking out from under the mudsill with tape or Tremco, then fold it over onto the plywood subfloor (Figure 5, next page).

Next, we extend the 2 inches of basement wall insulation up to cover the exterior of the band joist. On the inside, we insert a piece of R-19 fiberglass batt insulation up against the band joist in each bay. The 2-inch exterior foam keeps the band joist warm enough to prevent condensation on the poly.

We frame our exterior walls with 2x6s spaced 16 inches on-center, since 24-inch spacing doesn't provide adequate nailing for siding. Once the walls are raised, the Tenoarm should peek out from under the bottom plate of the exterior walls, facing the inside of the house (Figure 6, next page). On a two-story house, the second-floor band joist is also wrapped on the exterior with Tenoarm. In this case, the Tenoarm extends from the interior over the top plate, up over the exterior of the band joist, and back onto the second-story subfloor.

Insulation

Back in the 1970s, I used to pay an insulation contractor to blow 10 inches of cellulose into my attics. When I inspected the attic of one of my homes a few months after completion, I noticed that the cellulose barely covered the bottom chord of the trusses. My insulation sub explained, "It must have settled." So in 1979 I decided to get my own cellulose-blowing equipment. Now I install 22 inches of cellulose in every attic, so that even after settling, my attics have a minimum of 16 inches of insulation.

To be sure there's enough room for attic insulation, I specify raised-heel trusses. To get the necessary R-value on a stick-built roof, where the rafters come down too low at the attic

Band Joist Detail

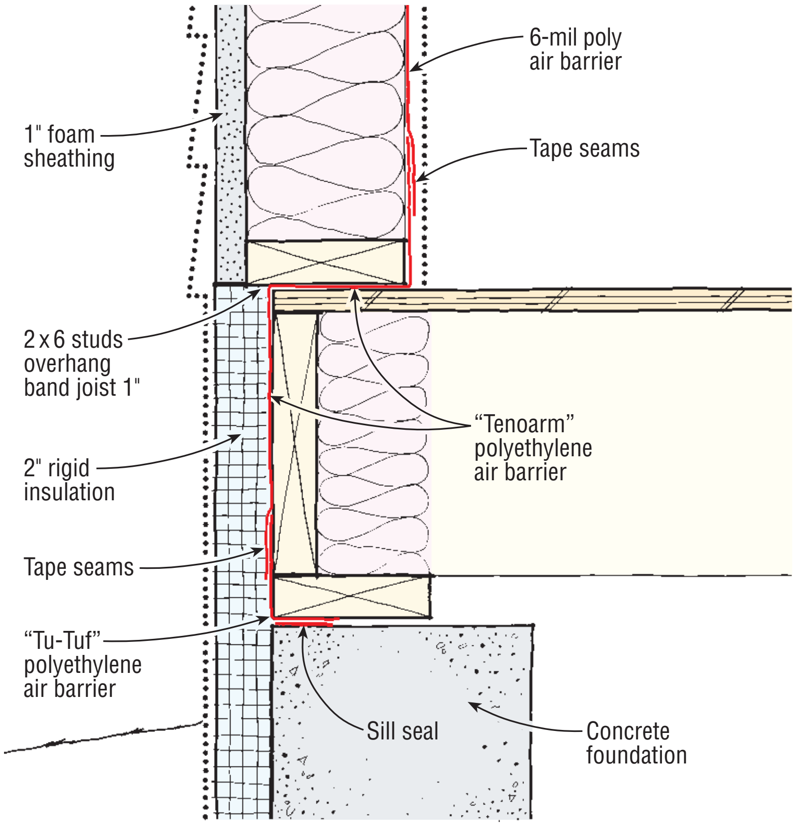

Figure 3. The key to the author's airtight shells is the continuous vapor barrier, which starts beneath the mudsill. Every seam is taped or sealed with acoustical sealant.

Figure 4. Before installing the mudsill, a 6-inch-wide strip of poly is embedded in Tremco sealant and stapled to the underside. A 2 3/4-inch-wide strip of foam sill seal is stapled over the poly, and then the sill is flipped over and bolted in place. The poly flap faces the exterior.

Figure 5. The band joist is wrapped with Tenoarm, a very tough, transparent polyethylene. The Tenoarm has been taped to the white polyethylene stapled to the bottom of the mudsill, and then wrapped up onto the subfloor.

Figure 6. After the walls are raised, the transparent Tenoarm polyethylene sticks out from under the bottom plate, facing the interior. This flap will later be taped to the wall poly.

Figure 7. To keep the air from the soffit vents from disturbing the attic insulation, flaps of poly are stapled between the heels of the attic trusses. The vent channel only needs to extend above the expected depth of attic insulation.

perimeter, I install several layers of rigid foam insulation between the rafters above the wall plates.

To prevent wind-washing of the attic insulation above the soffit vents, we install wind breaks between the attic trusses. These are scraps of 6-mil poly, housewrap, or Tu-Tuf, stapled to the wall top plate and the roof trusses (Figure 7).

Cathedral ceilings. For cathedral ceilings, my minimum rafter size is 2x12, although I've installed wood I-joist rafters as deep as 18 inches. In my experience, when cathedral-ceiling rafters are densely packed with cellulose insulation, no ventilation channels or soffit vents are required. As cheap insurance against possible moisture problems, I include ridge vents above my cathedral ceilings. Although this "hot roof" construction is controversial, I have done it this way successfully for years. I've had several opportunities to open up the ridges of cathedral ceilings completed years earlier, and in every case the rafter bays were dry and free of mold. None of the houses I've built have ever had a problem with ice dams or ceiling condensation. Be careful, though: This approach works only if your ceiling air barrier is airtight.

Blowing walls. To retain the cellulose insulation blown between the studs, I use a translucent permeable fabric called Insulweb. Insulweb is a spunbonded polypropylene fabric full of tiny holes that allow excess air pressure to escape; it is not intended to act as a vapor or air barrier.

After stapling Insulweb to the studs, we make one hole in each stud cavity, about 4 feet up from the floor. We start filling the cavity from the bottom, using a 2-inch rigid or flexible hose. When the stud bay is almost full of cellulose, we direct the hose to the top of the cavity to ensure that the top gets well filled.

When we finish blowing the walls, we count the bags of cellulose to be sure we've used enough. At the recommended density of 3 pounds per cubic foot, a 30-pound bag of cellulose should fill $1^2/_3$ 8-foot wall cavities framed with 2x6s on 16-inch centers. We also check the density by pounding on the installed cellulose: If the cellulose moves, it's not tight enough. If necessary, we go back and squeeze a little more in.

We use fiberglass batts in a few areas, such as behind a tub located on an exterior wall. In this case, the batts and the poly air barrier need to be installed before the tub goes in. The poly behind the tub is taped to the flanges of poly protruding from the bottom plate and the intersecting partition walls (Figure 8).

Electrical boxes. Despite what some insulation contractors will tell you, dense-pack cellulose does not stop air flow — it just slows it down. If you have a leaky electrical box, you can feel the air moving right through the cellulose during a blower-door test. When I started building energy-efficient homes, I was frustrated that there weren't any decent airtight electrical boxes on the market, so I decided to design and manufacture my own. For the past 15 years, I've been selling the Lessco box, an airtight plastic box large enough to accommodate a standard electrical box inside of it (Figure 9). Lessco boxes are simple to install, so it shouldn't take long to train your electrician; they are installed at the same time as standard electrical boxes. After the walls have been blown, we insulate the Lessco boxes by hand with scraps of fiberglass.

Interior Air Barrier

Once our walls are insulated, we install a layer of Tu-Tuf poly over the Insulweb on the inside of the exterior walls, sealing the seams with tape or Tremco. This layer is also sealed to the flap of Tenoarm sticking out from under the bottom plate. (We don't continue the Tenoarm up the walls because it's too thick to form neat inside corners.) Where partitions intersect exterior walls, we install a 2x6 or 2x8 backing stud as a drywall

Figure 8. If a tub-shower unit is located against an exterior wall, fiberglass insulation and the poly air barrier need to be installed before the tub. All seams in the poly air barrier are taped with red contractor's tape from 3M.

Figure 9. The Lessco box is a $6^1/_2$x$7^1/_2$x$2^7/_8$-inch airtight plastic box that's installed at the same time as a regular electrical box (left). After a wall is insulated, the poly air barrier is taped to the flange of the Lessco box (below), and the Lessco box is insulated with scraps of fiberglass or cellulose. Note that all plumbing penetrations in the wall are sealed with contractor's tape.

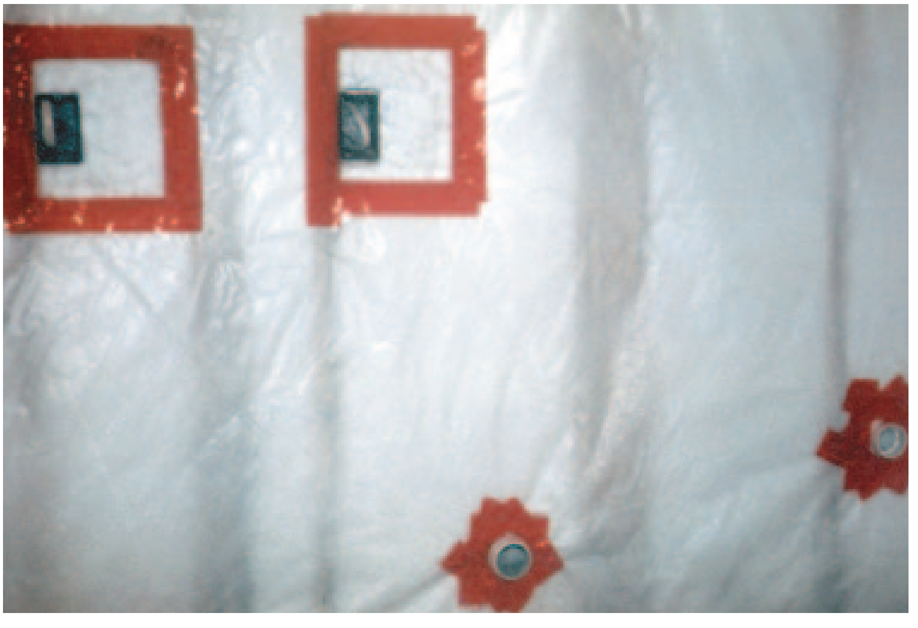

Figure 10. Where a partition intersects an exterior wall, a strip of poly is installed on top of the 2x8 drywall nailer before the partition is built. Note that the wall poly is taped to the Tenoarm poly that protrudes from under the bottom plate.

Figure 11. In homes where the ceiling poly can't be installed in a single sheet, it's installed room by room. When building the top-floor partitions, the framers must install a strip of poly between the top plates and the ceiling joists. Later, the ceiling poly in each room will be taped to the perimeter flaps.

Figure 12. A conventional recessed can fixture can be installed in a site-built foam box. The box, which is sized to provide 2 inches of free air on all sides of the fixture, is assembled with Tremco to seal the seams.

nailer, followed by a strip of Tu-Tuf, which is also taped to the Tenoarm flap (Figure 10).

On the top floor, we prefer to install a continuous layer of poly on the entire ceiling before the partitions go up. To minimize damage to the ceiling poly, we carefully position the partition top plates against the ceiling joists and drive the bottom plates home with a sledge. Any accidental tears in the ceiling poly get repaired with tape.

Install carefully, then cut. Once all of the interior partitions are installed, I go to each second-floor room and cut up the ceiling poly. Considering the care with which it was installed, this may seem strange — but if I don't cut it, I know the electrician will. I cut around the perimeter of the ceiling poly at three of the walls, roll up the plastic, and leave it hanging against the wall on the uncut side. I leave enough plastic at the perimeter of the room to give us something to tape to when it's time to put the ceiling poly back up.

In a home with a bearing wall, where it's not possible to install the ceiling poly in one piece, we install it room by room. Each partition needs to have a strip of poly above the top plate (Figure 11), and any penetration of the ceiling poly needs to be carefully sealed with tape or aerosol foam.

Chimney penetrations. A gas or wood-fired zero-clearance fireplace can work well in a tight home, as long as the fireplace has glass doors and ducted combustion makeup air. Equally important, the customer needs to understand that the fireplace is there to look at, not to serve as a significant heat source.

Where a metal chimney penetrates the ceiling poly, we install the chimney manufacturer's metal firestop collar. We cut the poly 2 inches away from the chimney and seal it to the metal collar with tape. The gap between the chimney and the firestop collar is sealed with high-temperature GE silicone caulk, available from fireplace dealers. High-temperature caulk is rated for use up to 400°F or 500°F.

Ceiling-mounted electrical boxes. I stopped using commercially available "airtight" recessed can fixtures when blower-door testing showed that they leak like sieves. Now I use standard recessed can fixtures and install them in a site-built foam box made from scraps of 1-inch or 2-inch rigid foam with seams sealed with tape or Tremco (Figure 12). I size these boxes to provide at least 2 inches of free air space on all sides of the recessed fixture. We seal the ceiling poly to the edge of the foam box with Tremco. In the attic, we blow 22 inches of cellulose over the top of the box. We have never had a light fixture overheat using this system.

Another way to keep ceiling-mounted electrical boxes from penetrating the poly air barrier is to frame a secondary ceiling below the poly. A closet ceiling or the ceiling above a tub-shower unit can often be lowered to 7 feet or 7 feet 6 inches (Figure 13).

Attic access hatch. I make my attic access hatches out of 3/4-inch plywood with 8 inches of foam glued to the top. The hatch sits on the jamb, which is fitted with rubber bulb-type weatherstripping. Each hatch is closed with two casement window latches, which I buy from my local Weather Shield dealer.

Figure 13. When planning for a light fixture above a tub, it sometimes makes sense to lower the ceiling to keep the electrical box from penetrating the poly ceiling barrier.

Figure 14. A polyethylene "bib" is added around the exterior of each window before it's installed. Several extra pleats of poly are provided at the window corners (left), so that it can later be folded flat against the interior of the studs. A strip of duct tape over the poly (right) provides reinforcement for the staple heads.

Windows and Doors

My minimum spec for window glass is 5/8-inch insulated low-E argon-filled glazing. I've had good success using Pella aluminum-clad wood windows. If the customer chooses optional removable interior glazing panels, the windows are effectively triple-glazed.

Before installing a window, we put a bead of Tremco around the outside of the frame or the extension jambs. Then we attach a 6-inch-wide strip of 6-mil poly to the window frame, stapled through the Tremco every 6 or 8 inches. Adding a 1-inch strip of duct tape over the poly helps prevent the staples from pulling through. It's important to provide a generous bunch of poly at the corners of the window, so the poly can later be folded back flat. To provide slackness at the corners, we extend the strip of poly around a window corner, double back around the corner, and then return a third time.

This provides a kind of poly bib around the window frame. The bib extends toward the interior and is folded flat against the studs when the window goes in (Figure 14). Later we install Tremco between the bib and the main poly wall air barrier. The pressure of the drywall against it makes an effective seal. An exterior door gets the same type of bib, except that it is installed on three sides, not four. Before the door gets installed, we put down a bead of Tremco under the sill. Later, we squirt some aerosol foam under the sill as well.

Sheathing, Housewrap, and Siding

I sheathe my houses with 1-inch rigid foam — either polystyrene or polyisocyanurate, depending on current foam prices. In my area, the code allows walls to be braced with metal T-bracing, although code officials in many areas of the country require plywood or OSB sheathing, at least at corners (see "Bracing Foam-Sheathed Walls," 4/93).

I attach plastic housewrap through the foam sheathing with 1 1/2-inch staples into the studs. After losing a lot of Tyvek to wind, I switched to Rufco-Wrap, which is both cheaper and stronger.

Most of our buildings get vinyl or horizontal cedar siding, nailed through the foam sheathing to the studs. Since windows with wide exterior casing can be hard to integrate with foam sheathing, I have developed a detail that works well for me: I butt the cedar clapboard to the window frames, and install the wide casing on top of the siding. Because this detail requires no caulk, it looks better to my eye than butting the siding to the casing.

Hvac

These days, most customers want central air conditioning, so all of my homes use ducts for heat distribution. I have had good success using the Lennox CompleteHeat, a hydro-air system that provides both domestic hot water and space heat. The heating unit consists of a water heater coupled with a fan-coil unit to distribute hot air through a duct system.

We try to keep as much of our ductwork inside the building envelope as possible. When ducts must run through the attic, we use insulated flex duct buried under 22 inches of cellulose. Where a duct penetrates the ceiling poly, we carefully tape the air barrier to the flex duct. Every metal duct joint gets sealed with duct mastic.

A tight home requires good mechanical ventilation. All of my homes include a heat-recovery ventilator (see "Installing a Heat-Recovery Ventilator," 1/02). Because they are so quiet, my favorite HRVs are those made by Venmar.

My customers are usually delighted to live in a tight, well-ventilated home with low energy bills. Word-of-mouth referrals from satisfied customers make up a large percentage of my leads and keep me as busy as I want to be.

***Steve Lentz** is a builder from Campbellsport, Wisc. He is a life member of the Energy and Environmental Building Association (EEBA) and a past president of the Builders Association of Fond du Lac and Dodge Counties.*

For more information

Energy & Environmental Building Association (EEBA)
Bloomington, Minn.
952/881-1098
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Sources of Supply

Champion Insulation
Lomira, Wisc.
920/269-4311
Distributor of Insulweb fabric

Hanes Industries
Indianapolis, Ind.
800/699-6898
www.hanesindustries.com
Manufacturer of Insulweb fabric

Lennox International Inc.
Richardson, Texas
972/497-5000, 800/453-6669
www.lennox.com
Manufacturer of the CompleteHeat water heater plus fan-coil unit for hot-air heat

Low Energy Systems Supply Company, Inc.
Campbellsport, Wisc.
920/533-3306
www.lessco-airtight.com
Manufacturer of the Lessco airtight electrical box

Nudo Products
Springfield, Ill.
800/826-4132
www.nudo.com
Manufacturer of Ground Breaker fiberglass panels for protecting exterior rigid foam wall insulation

Raven Industries, Inc.
Sioux Falls, S.D.
800/635-3456
www.ravenind.com
Manufacturer of Rufco-Wrap perforated housewrap

Resource Conservation Technology
Baltimore, Md.
410/366-1146
Distributor of Tenoarm, a 10-mil polyethylene air-vapor barrier from Sweden

Sto-Cote Products, Inc.
Genoa City, Wisc.
888/786-2683
Manufacturer of Tu-Tuf, a white-colored cross-laminated polyethylene air-vapor barrier

3M Center
St. Paul, Minn.
800/362-3550
www.3m.com/us
Manufacturer of red contractor's tape

Tremco Sealants
Beachwood, Ohio
800/321-7906
www.tremcosealants.com
Manufacturer of Tremco acoustical sealant