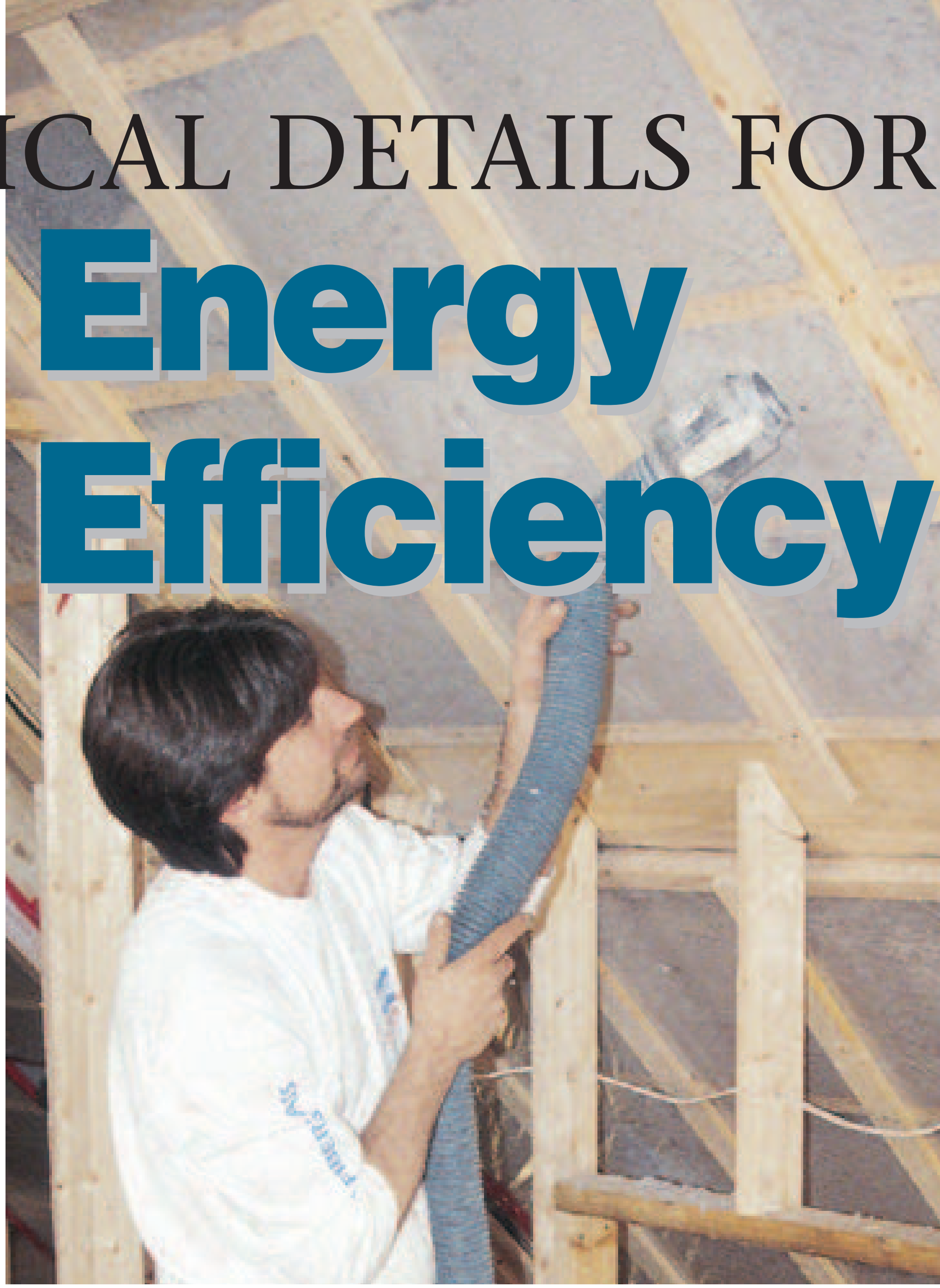
PRACTICAL DETAILS FOR Energy Efficiency



For a tight, energy-efficient house, plan your air-sealing strategy at the framing stage

by Paul Bourke

Over the years, I've developed a simple system to control random air leaks in the energy-efficient houses I build in Massachusetts. Of all the possible energy-saving upgrades, air sealing is the most cost-effective, since about 30% of the heat loss in a typical home is due to uncontrolled air leaks. Using the techniques described here, we build houses with consistently low infiltration rates — 0.6 square inches (or less) of leakage per 100 square feet of shell area, well under the Energy Crafted Homes standard of 2.0 square inches.

Creating a Tight Air Barrier

If you are committed to minimizing air leaks in the houses you build, you need to be sure that everyone on the job site, including the framing crew and the subcontractors, understands the basics of air sealing, and understands your expectations for maintaining a tight air barrier.

In the colder parts of the U.S., builders typically install polyethylene under the drywall, calling it the "vapor barrier." But the most important function of polyethylene is as an air barrier. Moisture follows air leaks, moving through holes in a house, at much greater rates than it passes through solid surfaces as a vapor. Most of the problem-causing moisture that condenses in attics and building cavities is transported by interior air leaking through holes in the air barrier.

An air barrier should be continuous with the thermal insulation. In most cases, the air barrier will be on the warm side of the thermal insulation, but it doesn't have to be. In some cases, it makes sense to establish the air barrier on the outside of the thermal insulation.

Assemble your materials. For a careful air-sealing job, you'll need to be sure you have a few important materials on hand: reinforced polyethylene (for example, Tu-Tuf, Good News Reused, or Tenoarm); Tremco acoustical sealant (a multi-purpose air-sealing caulk that sticks to polyethylene); 3M Builders' Sealing Tape (also called contractors' tape, it's used for polyethylene and housewrap); airtight electrical boxes (from Ryeco or LESSCO); and a good urethane foam gun (see "Sources of Supply," page 8).

Keeping the Basement Warm

We always install 6-mil polyethylene and at least 1 inch of rigid foam insulation under all of our basement slabs. Besides saving energy, the foam keeps the slab warm, greatly increasing comfort and helping to minimize condensation. After installing crushed stone to the depth of the footing, we lay down the poly and then the rigid foam. We also install a strip of 1-inch foam at the perimeter of the slab, between the slab and the foundation wall, as a thermal break (see Figure 1). If the basement floor is getting radiant heat, we'll increase the thickness of the under-slab insulation to 2 inches.

Insulating basement walls. We no longer insulate our basement walls from the exterior, since exterior foam is vulnerable to insect damage, and above-grade foam is difficult to protect. Instead, we frame up 2x4 walls inside the basement, leaving a 2-inch gap between the back of the studs and the basement wall. This allows enough room for the installation of R-19 fiberglass batts, which we cover with flame-retardant poly from Poly-America. One advantage of interior insulation: With the 2x4 perimeter walls installed, all it takes is wiring and drywall for a customer to finish the basement.

Since most basement walls have few penetrations, they are relatively simple to air seal. But be careful of bulkhead doors, which are often leaky. The area between the door and the band joist, especially, needs to be sealed and insulated.

Figure 1. Installing 1 inch of rigid foam insulation under the basement slab keeps the slab warm enough to prevent moisture from condensing on it. The perimeter insulation between the slab and the colder concrete wall provides a thermal break. The cast-in-place pressure-treated window frames will receive low-e argon-filled windows.

Figure 2. Recessing the band joist 2 inches provides room for exterior rigid foam insulation. To provide an air barrier, the foam is carefully caulked in place with Tremco acoustical sealant.

Preventing Drafty Floors

Most houses leak a lot of air through gaps at the perimeter of the floor system. To keep this area tight, four critical areas need to be addressed: under the mudsill; along the band joist; between the band joist and the subfloor; and between the subfloor and the wall plate.

Tight sills. Between the foundation wall and the mudsill, we use regular polyethylene foam sill seal, folded in half lengthwise. Doubled sill seal does a better job of air sealing than a single layer. Any gaps that are too big for the sill seal to handle are filled later, using our urethane foam gun.

Warm band joists. On many houses, the band joists are poorly insulated, so condensation forms on the cold interior surface of the lumber. Keeping the band joist warm with exterior foam insulation prevents condensation that can lead to rot.

Since we frame our walls with 2x6s, we can recess our band joists 2 inches. We attach 2-inch-thick rigid foam to the band joist with continuous beads of Tremco acoustical sealant (Figure 2). The rigid foam, once it is caulked in place, becomes the air barrier. Although Tremco sealant, which is also known as "black death," can be messy to apply, it's the best caulk to use for air sealing a wide variety of materials, including most types of plastic.

From inside the basement, we stuff a piece of R-19 kraft-faced fiberglass batt into each joist bay, behind the band joist. Finally, when we put the subfloor down, we put a continuous bead of construction adhesive along the band joist to prevent any air leaks at the perimeter of the subfloor.

Gasketed bottom plate. We install regular foam sill seal under the bottom plates of our exterior walls. To make the sill seal go twice as far, we usually cut it in half lengthwise. We roll out the foam and hammer-tack it to the subfloor just before we stand up our walls. Instead of foam sill seal, you can also use sticky-backed foam weatherstripping in this location.

Cantilevers. Cantilevered floors are particularly difficult to air seal, especially if wires or pipes create an air path through the floor and up the exterior wall. At the point where the cantilever begins, we install solid blocking between each cantilevered joist. The edges of the blocking, as well as any penetrations through the blocking, get carefully caulked. Because the plywood subfloor over a cantilever is the air barrier, be sure the subfloor is installed with construction adhesive. Finally, the bottom of the cantilevered joists need to be wrapped with housewrap.

Figure 3. When the budget allows, 2x6 studs are spaced 24 inches on-center, and 1x3 strapping is installed horizontally at 16 inches on-center. The air space provides a thermal break between the studs and the drywall. Red 3M tape is used to seal seams and tears in the poly air barrier.

Keeping Walls Tight

Most of our walls are framed with 2x6s, 16 inches on-center. If the studs are spaced wider than 16 inches, the dense-pack cellulose insulation pillows out, interfering with drywall installation. If the customer is willing to pay for an upgrade, we space the 2x6 studs at 24 inches on-center and then install horizontal interior 1x3 strapping at 16 inches on-center (Figure 3). The strapping restrains the cellulose and also provides a thermal break between the drywall and the studs.

When it comes to sheathing, we prefer to use plywood or OSB, unless the homeowner insists on foam. Foam sheathing causes several headaches: the walls need special bracing against racking; window and door openings need to be furred out; and siding can be attached only to the studs.

We always install Tyvek, which we consider the best available housewrap. We tape all seams with Tyvek tape, following the manufacturer's instructions.

Where an interior partition meets an exterior wall, we install a vertical 1x8, 1x10, or plywood piece as a drywall nailer. This nailer needs to be continuous (not a collection of scraps), and it needs to be wide enough to provide room to tape the poly air barrier in the corner.

Insulating Rafter Heels

In many houses, the insulation is thin at the rafter heels, where adequate space for insulation is lacking. This thin insulation can contribute to melting snow and ice dams. On the interior, thin insulation leaves the drywall cold at the corner, encouraging condensation and mildew.

One way to increase the R-value at the rafter heels is to install rigid foam insulation between the rafters. This is fussy work — first, installing 3/4-inch strips of plywood against the top of the rafter faces to maintain a ventilation channel, then cutting each piece of foam for a snug fit.

If the roof is being framed with rafters, an easier solution is to install a band joist and raise the rafters (see *Practical Engineering,* 7/96). Raising the rafters leaves plenty of room for insulation. If the roof is framed with trusses, use raised-heel trusses, which don't cost much more than regular trusses.

Windows and Doors

We build insulated door and window headers out of two 2x10s, a piece of 1/2-inch plywood, and 2 inches of rigid foam. The gap between a window and the rough opening should be sealed using a urethane foam gun or with backer rod and caulk, not fiberglass insulation. (Fiberglass insulation is not an air barrier.) We plan our rough openings for a 3/8-inch gap all around the window or door — just the right gap for a foam gun nozzle. We use Pur-Fil low-expansion foam, which won't distort the frame and pinch the sash.

Attic hatches. Since an attic access hatch is just an exterior door located in a ceiling, it needs to be carefully insulated and weatherstripped. A piece of drywall dropped into the opening is obviously inadequate. In winter, hatches without weatherstripping are often ringed with ice and deteriorated attic insulation.

We build our attic hatches from plywood and glue 4 inches of rigid foam insulation on top. Around the perimeter of the plywood hatch, we screw steel connector strapping. Along the top of the stop, we install magnetic door gasketing, which sucks that hatch down and seals it. When these magnetically sealed hatches are tested with a blower door, they are virtually leak-free.

Think Ahead

We've learned to recognize several areas that can be tricky to seal: walls behind tubs; interior soffits; recessed can lights; attic ductwork; zero-clearance fireplaces; chimney chases; dryer vents; and electrical boxes. If you plan the air-sealing details at the framing stage, sealing these areas will be much easier.

Tubs and showers. If a tub is located on an exterior wall, we install the poly air barrier, taped to the bottom plate, before the tub goes in (Figure 4). Then the area behind the tub is sheathed with plywood, which protects the poly and prevents the cellulose insulation from pillowing out. After the tub is installed, the stud bays can easily be filled with blown-in cellulose from the top.

Interior soffits. If the house has a second-floor soffit, don't forget to install the poly air barrier before the soffit is framed. The poly should be large enough to allow it to be taped later to the rest of the poly air barrier.

Figure 4. When a tub/shower unit is located on an exterior wall, the poly air barrier is installed before the tub goes in. To create a tight air barrier, the poly needs to be taped to the bottom plate of the wall.

Figure 5. Poorly sealed ceiling-mounted light fixtures continuously leak interior air into the attic. When the warm, moist air hits a cold surface, the moisture condenses, leading to mildew or rot.

Recessed cans. In many houses, recessed can lights act like little chimneys, constantly leaking interior air into the attic (Figure 5). If we have to install a recessed can light in an insulated ceiling, we make sure it is an airtight unit rated for insulation contact. We mount the can fixture on a piece of plywood that spans two joists; the plywood provides a surface for taping the poly air barrier.

Wherever possible, especially in bathrooms, we install recessed cans in soffits or dropped ceilings. Because the poly air barrier is installed at the bottom of the joists before the soffit is built, above the electrical fixtures, it remains intact.

Attic ducts. Most of our houses have some ductwork in the attic. At each ceiling register, and wherever a duct penetrates the ceiling poly, we install a section of $3/4$-inch plywood spanning two joists. We usually provide the hvac sub with a stack of 24-inch-wide pieces of $3/4$-inch plywood for this purpose, and the sub installs the plywood (Figure 6). The gap between the plywood and the duct or the flange on the register boot is sealed with a liberal amount of silicone caulk. The ceiling poly gets taped to the plywood.

All of the attic ducts are sealed with mastic or aluminum tape. After the hvac sub has installed the ducts, we always go into the attic to inspect the work, to be sure all penetrations of the ceiling air barrier are well-sealed. New subs usually take some training before they get it right.

Fireplaces. Zero-clearance fireplaces provide many opportunities for air leaks. Usually, we stop the air barrier one stud short of the fireplace, to keep the poly away from high temperatures. We tape the poly to that stud, and then install $1/2$-inch cementitious backerboard between the stud and the fireplace. To maintain the air barrier, the backerboard is caulked in place with high-temperature silicone caulk, which we purchase at an auto supply store. The backerboard eventually gets covered with marble or brick.

Chimney chases. Most chimney

chases allow interior air to rise to the attic through the 2-inch gap between the chimney and the ceiling joists. In many parts of the country, inspectors are being more stringent about enforcing the requirement for chimney firestops. That's good, because firestops improve energy efficiency.

For masonry chimneys, we make our firestops out of 8-inch-wide aluminum flashing, bent on a brake. Our mason cuts a 1/2-inch kerf into the masonry to insert the firestop, which doubles as an air barrier. Each chimney gets four pieces of flashing. We nail the flashing onto the framing, with a continuous bead of high-temperature silicone caulk under the flashing. We also install caulk at all of the flashing seams.

Metal chimneys require firestop kits provided by the chimney manufacturer. All of the gaps and cracks in these firestops need to be caulked with high-temperature silicone.

Dryer vents. Where a dryer vent goes through an exterior wall, we usually install a plywood block between the studs, so that the vent duct has something to rest on (Figure 7). The plywood is attached to small 1x1 nailers and is mounted flush with the edge of the studs. We apply urethane foam between the dryer vent and the plywood and tape the poly air barrier to the plywood.

Electrical boxes. We use Enviroseal airtight electrical boxes, which don't cost much more than regular electrical receptacles). These boxes have a removable wide flange with a foam gasket designed to seal against the drywall. When we install the poly air barrier, we cut an X at each box and stretch the poly over the box. We tape the poly to the box, and then fit the flange on the box, locking the poly in place.

Enviroseal boxes are available only as one- or two-gang boxes. When we need three- or four-gang boxes, we buy airtight electrical boxes made by LESSCO.

Foam the gaps. After the framing is complete and the rough mechanicals are in — but before the insulation and poly — we inspect the house for gaps that need to be filled using the urethane foam gun. Places to check include between the foundation wall and the mudsill; where wires go through partitions that intersect exterior walls; and where wires and pipes penetrate the top plate into the attic.

Polyethylene Air Barrier

Some builders of energy-efficient homes advocate the Airtight Drywall Approach (ADA), creating their air barriers with gaskets installed under the drywall rather than with polyethylene. But since drywall contractors in our area are not familiar with ADA techniques, and since a poly barrier typically accompanies the installation of our preferred insulation, dense-pack cellulose, we don't use the ADA method.

Our insulation sub installs the reinforced poly air barrier according to our

Figure 6. Here, a forced-air register is installed in a piece of 3/4-inch plywood where it penetrates the attic air barrier. The register boot is caulked to the plywood.

Figure 7. Where this dryer vent penetrates the exterior wall (at bottom of photo), a plywood block provides a surface for taping the poly air barrier. This house has horizontal wall strapping, so there was no need to recess the plywood block between the studs. Note that where the partition meets the exterior wall, the penetrations for the plumbing vent and electrical cable are sealed with urethane foam. The photo also shows an Enviroseal airtight electrical box.

Figure 8. Most dense-pack cellulose systems require the installation of a reinforced polyethylene air barrier. Stapling the poly on the side rather than the edge of the studs helps keep the poly from bulging when the cellulose is blown in place.

requirements. The poly gets stapled with 3/4-inch staples using an electric staple gun. For walls that won't receive interior horizontal strapping, the staples are driven into the face (side) of the stud, about 1/4 or 1/2 inch back from the interior edge (Figure 8).

Although a vapor barrier with a 2% gap is still 98% effective, the same is not true for an air barrier. An air barrier needs to be continuous, since small gaps can lead to big problems. All seams and gaps in a poly air barrier must be taped or caulked. For a typical building, we'll use about 12 rolls of 3M red tape, which costs about $12 a roll. Where the air barrier is being sealed to a top plate or bottom plate, or at the rough opening for a window or door, the poly can be sealed with either 3M tape or Tremco acoustical sealant.

We have experimented with installing the poly air barrier on the entire second-floor ceiling before we put up the interior partitions. But since that makes it more difficult for our mechanical subs to access the attic, we don't do it anymore. Usually, our ceiling poly is installed room by room and is carefully taped to the top plates of the walls. At the exterior walls, the ceiling poly gets taped to the wall poly.

Ceiling strapping. We usually strap our ceilings with 1x3s. In most cases, we install the poly air barrier on the bottom of the joists, before the strapping goes up.

Figure 9. Cellulose insulation effectively fills all of the spaces around the bottom chords of roof trusses. Because cellulose is cheap, it can be piled on deep.

Time to Insulate

Any insulation material can work well, as long as it is installed carefully. But if you expect fiberglass batts to match the performance of a blown-in insulation like dense-pack cellulose, you need to install the batts meticulously, without voids. How many fiberglass installers actually take the time to split the batts at every pipe and wire in the walls, much less the attic?

Our preferred insulation is dense-pack cellulose, installed at a density of 2 1/2 pounds per cubic foot. Dense-pack cellulose helps reduce air infiltration and fills in especially well around mechanicals, wires, plumbing, and odd-shaped or tight spaces.

Because blowing cellulose in an attic is relatively inexpensive, you can pile it deep (Figure 9). Before insulating an attic, we install sections of fiberglass batt insulation against the ventilation baffles, to prevent the cellulose from blowing into the soffits. When using blown-in cellulose in a cathedral ceiling, we install extra-rigid ventilation baffles (Durovent from ADO Products), since the cellulose pressure can cause standard baffles to collapse.

Our insulation sub slits the poly air barrier at each stud bay to insert the 2-inch blowing hose. It is the sub's responsibility to patch each hole with 3M tape. When the insulation job is complete, I check that the slits have all been taped. I also check the insulation density by feel, especially near the top of the stud bays. Well-installed cellulose should feel as firm as a car seat, not soft like a down pillow. The poly air barrier should be taut.

Build Tight and Ventilate Right

A tight house, which can't depend on random air leaks for ventilation and combustion makeup air, needs

Locating the Thermal Envelope

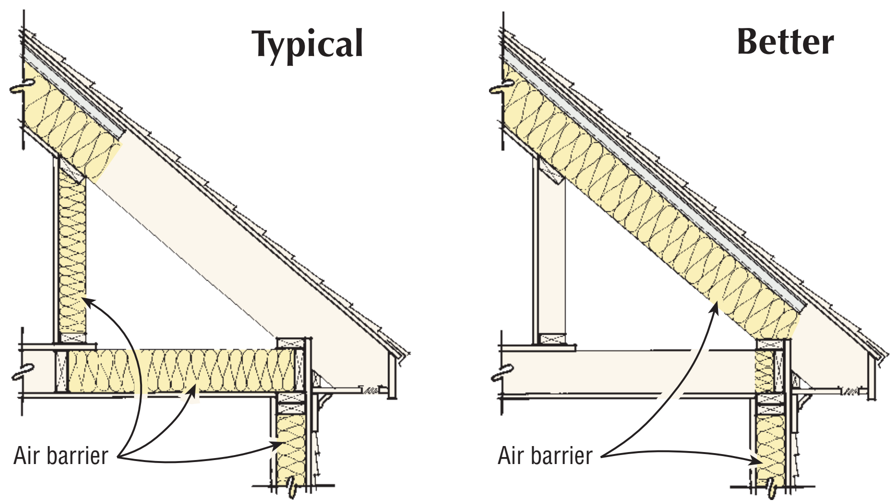
The continuous barrier formed by the insulation and air barrier is called the thermal envelope. Where to locate the thermal envelope depends, to some extent, on builder preference. Should it follow a flat ceiling or the sloping rafters? Should it include the crawl space? In many cases, there is no single right answer to these questions. However, it is important to make a choice and stick with it, and then explain to your framing crew and subcontractors where the thermal envelope is located.

In the past, many builders excluded basements and crawl spaces from the thermal envelope. However, building scientists now recommend sealing and insulating crawl space walls.

In cold climates, the prescriptive requirements of the Model Energy Code mandate basement wall insulation. Including the basement inside the building's thermal envelope is usually simpler and no more expensive than building an uninsulated basement, because insulated basements do not require ceiling insulation, duct sealing, duct insulation, or pipe insulation.

In a typical Cape, the second-floor kneewalls are insulated, as well as a portion of the first-floor ceiling (see illustration). But when the thermal envelope is located at the kneewalls, air sealing becomes very difficult. Interior air can escape through the first floor ceiling into the cold area behind the kneewalls. Exterior air from the soffit vents, which should rise above the insulation in the rafter bays to ventilate the roof, often enters the living area through gaps in the kneewall. An access door in an insulated kneewall is awkward to build, because it needs to be carefully insulated and weatherstripped.

Air Sealing a Cape Kneewall



Creating a tight air barrier in a Cape kneewall is much more difficult if the kneewalls and a portion of the first-floor ceiling are insulated (left). Air sealing is easier if the rafter insulation is brought all the way down to the wall plates (right).

Air sealing is easier when the rafter insulation is extended down to the plates, bringing the triangular crawlspace behind the kneewalls within the building's thermal envelope (see "Air-Sealing the Story-And-A-Half," 8/95). This also permits the area behind the kneewall to be used for storage without the need for an airtight access door.

— P.B.

mechanical ventilation and sealed-combustion appliances.

We ventilate many of our houses with Panasonic bathroom exhaust fans, which are quiet fans designed for continuous operation (see "Simple Whole-House Ventilation," 8/95). We follow the guidelines of ASHRAE 62-1989, which requires 15 cfm per person. Depending on the size of the house, this requirement is easily met with one or two Panasonic bathroom exhaust fans, each controlled by an Airetrak timer/fan-speed controller.

Multiple Benefits

The package of air-sealing details we provide adds between 2% and 2$^{1}/_{2}$% to the cost of our homes — about $4,000 to $5,000 in construction costs on a $200,000 house. However, these details also result in savings. The houses require smaller heating and air-conditioning units, as well as less radiation or ductwork. Because we use sealed-combustion appliances, there is no need for a chimney. In many cases, these savings pay for the cost of the air-sealing measures.

Besides lowering the customer's heating bills, an energy-efficient house is less drafty and therefore more comfortable than a conventional house. During the winter, the indoor air will not be as dry as the air in a leaky house, so residents will have fewer bouts of respiratory infections, asthma, and allergic rhinitus. With fewer air leaks, there is less chance that warm, moist indoor air will leak into cold walls or the attic, where moisture can condense. Because of this, a tight house will be especially durable.

So if you build energy-efficient houses, your customers will be healthier. And they'll be pleased to know that their durable, comfortable, energy-efficient house will have a higher than average resale value.

***Paul Bourke** is a builder based in Leverett, Mass. He is a former instructor in the Energy Crafted Homes program and a member of the New England Sustainable Energy Association.*

Sources of Supply

3M
Construction Products Dept.
3M Center
St. Paul, MN 55144-1000
800/480-1704
www.3M.com
3M 8086 Builders' Sealing Tape

ADO Products
P.O. Box 236
Rogers, MN 55374
800/666-8191
www.adoproducts.com
Durovent heavy-duty polystyrene attic ventilation baffles

Energy Federation Inc.
40 Washington St., Suite 3000
Westborough, MA 01581
800/876-0660
www.efi.org
Retailer of air-sealing, energy-saving, and ventilation products, including Tu-Tuf polyethylene, 3M Builders' Sealing Tape, Pur-Fil aerosol urethane foam, and Enviroseal and LESSCO airtight electrical boxes

LESSCO
W1330 Happy Hollow Rd.
Campbellsport, WI 53010
877/533-8690
www.lessco-airtight.com
Airtight electrical boxes

ParPac
27 Main St.
Swanzey, NH 03446
877/937-3257
www.parpac.com
Good News Reused reinforced polyethylene air barrier

Poly-America
2000 W. Marshall Dr.
Grand Prairie, TX 75051
800/527-3322
www.poly-america.com
Flame-retardant polyethylene sheeting, which can be left exposed in a basement

Resource Conservation Technology
2633 N. Calvert St.
Baltimore, MD 21218
410/366-1146
Distributor of Tenoarm, a reinforced polyethylene air barrier from Sweden

Ryeco Products
21 Laurier Rd.
Penetanguishene, ON L9M 1G8
Canada
800/470-7772
www.ldiindustries.com
Manufacturer of Enviroseal airtight electrical boxes

Sto-Cote Products
Box 310
Genoa City, WI 53128
888/786-2683
Manufacturer of Tu-Tuf reinforced polyethylene air barrier

Tamarack Technologies
P.O. Box 490
W. Wareham, MA 02576
800/222-5932
www.tamtech.com
Distributor of ventilation products, including the Airetrak timer/fan-speed controller

Todol Products
P.O. Box 398
Natick, MA 01760
508/651-3818
www.todol.com
Distributor of Pur-Fil aerosol urethane foam and Pur-Fil foam guns

Tremco Sealants
3735 Green Rd.
Beachwood, OH 44122
800/321-7906
www.tremcosealants.com
Tremco acoustical sealant