Air-Sealing and Insulating a High-Performance Shell

by David Joyce

Take pains to seal all possible leaks, then run a blower-door test before insulating

Editor's note: This is the second installment of a two-part story; "Building a High-Performance Shell" ran in the May 2010 issue.

Our company focuses on energy-efficient retrofits and new construction. Last month, I described the advanced framing and foam-board sheathing that we used in building a new home in Concord, Mass. The house was designed by architect Betsy Pettit of Building Science Corp. for owners who wanted a sustainable home with monthly energy costs that would remain fairly constant from one season to the next. They also wanted a building that was ahead of its time, so that 30 years from now, should they decide to pass it on to their children or sell, they wouldn't be handing off a dinosaur. These goals dovetailed perfectly with our own.

Windows and Doors

To terminate and seal the double layer of 2-inch foil-faced Tuff-R polyiso board around the rough window openings, we lined them with 1/2-inch plywood bucks that project 4 inches beyond the framing. The thickness of the sheathing ruled out installing the windows — Marvin Ultima aluminum-clad low-E argon tri-pane double-hungs (888/537-7828, marvin.com)

Figure 1. Metal strap ties screwed to the jambs secure the windows to the framing (A). Exterior window casings were fastened over the 1x3 siding vent strapping (B). The author preassembled the window trim using composite lumber and PVC subsills (C). Water that bypasses the siding and trim is shed by the foam sheathing's foil face (D).

— using their vinyl nailing fins. Instead, we attached Simpson ST9 strap ties (strongtie .com) to the windows' side jambs, two per side, with 1/2-inch wood screws (**see Figure 1**). After adjusting for an even gap around the jambs, we screwed the straps to the framing. The straps have enough flex that we'd be able to shim the jambs plumb later.

On the exterior, we added flat casings and subsill extensions, made and installed as preassembled units. For all exterior trim, we used TUF Board (800/452-2117, tufboard.net), a wood-PVC composite that doesn't expand and contract nearly as much as some of the solid cellular vinyl trim we've tried. We used a complementary Azek molding under the window sills. The window trim is simply butted around the outside of the windows, installed over vertical strapping that vents both the trim and siding (there's more discussion of the venting ahead). With the windows sealed against the foil-faced sheathing, any water that gets past the trim and siding will drain back out at the bottom of the wall. The painters caulked the joints between the trim and the window jambs but kept the bottom edges caulk-free for drainage.

When installing the exterior doors, we aligned the outside edge of the $5^{9}/_{16}$-inch jambs with the framing rather than with the foam, creating a 4-inch inset. If we had used a deep extension jamb on the interior, it would have prevented the doors from fully opening. Instead, we ordered the doors without exterior trim, applied exterior extension jambs and trim, and extended the sill with TUF Board (**Figure 2**). Over the rim joist below the door openings, we installed a single layer of foam with a 2x8 ledger bolted above it for threshold support. We then covered the ledger with $^{1}/_{2}$-inch foam board and installed a self-adhering flashing pan in the rough opening.

Back-Vented Siding

The prefinished WeatherBoard (800/233-8990, certainteed.com) fiber-cement siding chosen for this project is installed over vertical 1x3 strapping, installed at 24-inch centers over the studs. This strapping creates a venting and drying space behind the siding. The foam sheathing's foil face sheds any water that may be driven past the siding.

We screwed the strapping through the 4-inch-thick sheathing using $6^{1}/_{2}$-inch HeadLok screws (800/518-3569, fastenmaster.com). At this length, the screws get a 2-inch bite into the studs. Passing as they do through 4 inches of foam board, you might expect them to eventually bend under the weight of the siding and allow it to sag. In fact, though, we used the exact same assembly on another job more than four years ago, and the siding shows no signs of movement — so it appears to work pretty well.

Figure 2. To provide an unobstructed swing, exterior doors were installed as if in a conventional 2x6 wall (left). Exterior extensions to the jambs and threshold rely on composite lumber and caulk (below).

Figure 3. The sheathing is strapped on 2-foot centers, directly over the wall framing (left). The top of the venting channels is open to the soffit, ensuring positive airflow from the bottom up. Ridge-vent material blocks the gaps between strapping, forcing an insect barrier screen against the back of the siding (above).

We started the strapping flush with the bottom edge of the sheathing. Lengths of 4 1/2-inch-wide galvanized metal flashing, overlapping the mudsill and foundation, protect the bottom edge of the foam sheathing from UV degradation, bugs, and sparks. We attached a continuous strip of nylon insect screen to the flashing and let it hang until the strapping was installed (**Figure 3**). We blocked between the strapping with strips of Cobra plastic-matrix ridge-vent material (973/628-3000, gaf.com), then folded up the screen and tacked it to the strapping. The vent material holds the screen against the back of the siding, helping to keep bees and other bugs from nesting in the vent space. To prevent the flashing from drooping, we screwed it to the strapping ends.

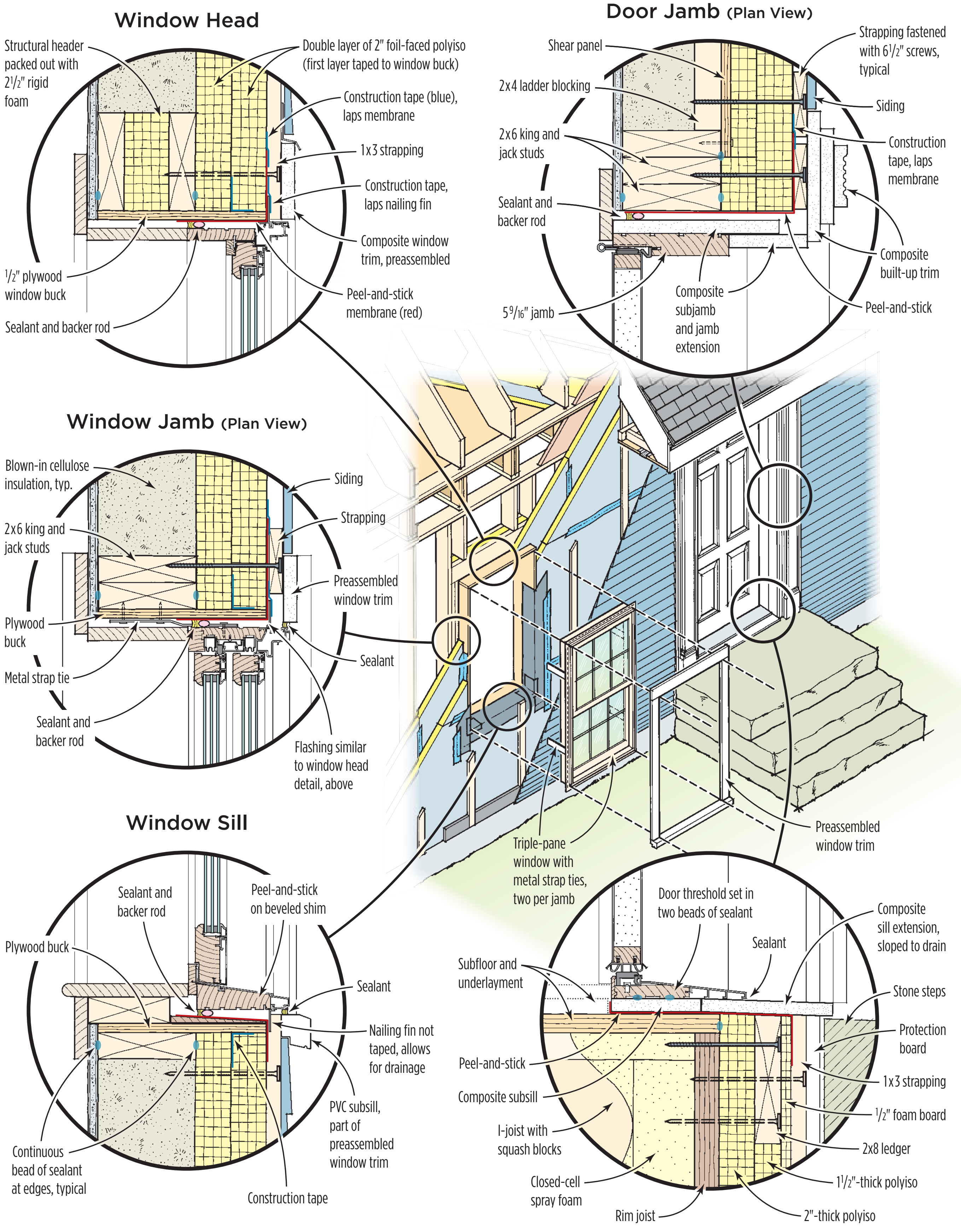
Blocking for trim. At the two-stud outside corners, the 4-inch offset created by the foam board places the strapping conveniently behind the 1x8 corner boards without the need for any supplemental blocking. We preassembled the corner boards from the back using pocket screws and attached them to the strapping with stainless steel trim-head screws.

The strapping installed over the studs on both sides of the windows supports the window trim. But at inside corners and around windows and doors, we needed additional strapping to catch the ends of the siding. In these places, we installed 2x4 ladder blocking in the framing cavities and screwed the added strapping to the blocks through the foam. Because the ladder blocking is installed on the flat in the wall bays, it would eventually be buried in blown-in cellulose insulation and wouldn't add greatly to the conductive heat loss.

Siding installation. The client wanted a particular look for the siding, one typical of older Cape-style homes: The courses start narrow at the base of the wall, with a 1 7/8-inch exposure, and gradually widen over about 15 courses to the standard 4 1/2-inch face (**Figure 4**). You can't effectively overlap 5 1/2-inch-wide fiber-cement

Figure 4. The fiber-cement siding was custom-ripped to allow narrower courses and tighter stacking at the base of the wall.

Window and Door Details



siding at those narrow exposures; it stacks up in a thick pile on the wall. So we played with some mockups and found we had to rip each course to maintain the 1¹/4-inch overlap prescribed by the manufacturer — a dusty and time-consuming process. The siding is blind-nailed in this overlap zone, which is pretty tight. We discovered that if we nailed a little too close to the top edge, the material tended to break out, something we haven't seen when installing Hardiplank. In general, the thinner, less-expensive WeatherBoard required gentler handling than we were used to during installation, and I'm not inclined to choose it again.

We painted both the trim and the siding with two coats of acrylic latex. The vented installation will help ensure a long-lasting, low-maintenance finish.

Air-Sealing and Insulation

To insulate the walls, ceilings, and roof, we used a combination of foam board, spray-foam, and cellulose. Our general goal was to achieve R-values of 45 for the walls and 65 for the level and sloped ceiling areas. In the basement, which would be finished, we insulated the walls to R-25 and installed 2-inch R-10 XPS foam under the slab.

The asphalt-shingled roof is conven-

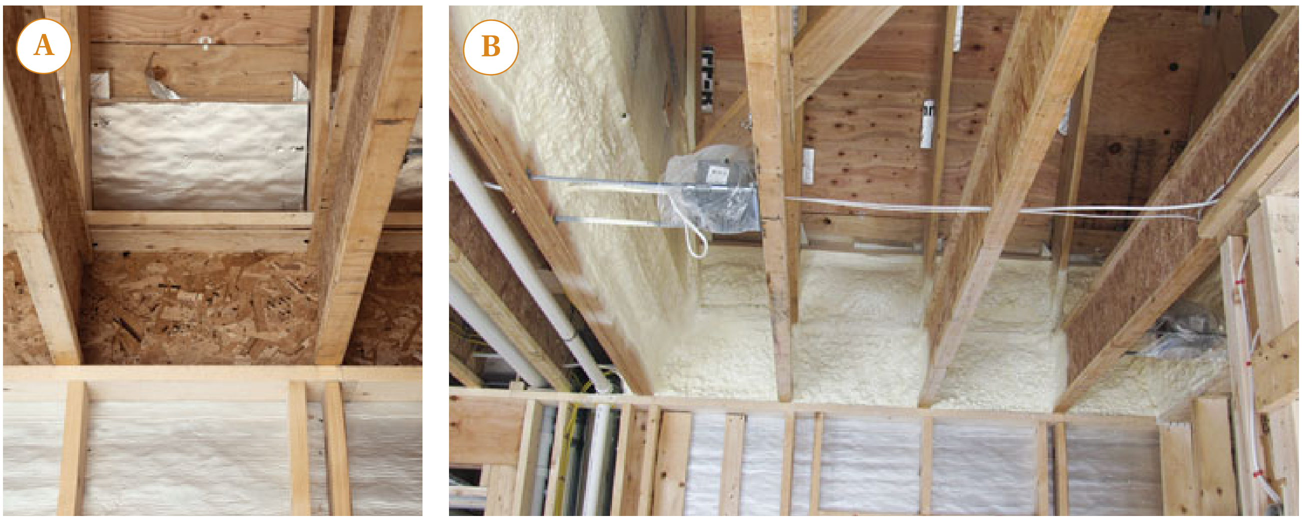


Figure 5. Foam-board vent baffles prevent wind-washing of the cellulose insulation in the attic ceiling areas (A). A 3-inch layer of spray foam effectively air-seals the vent baffles against the framing and insulates the rim joists to about R-18 (B). Sloped ceiling rafter bays were fully baffled with 2-inch foam board, then filled with closed-cell foam (C). Note the insulated rim joist and squash blocks below the single top plate. A layer of 2-inch R-13 foam board completes the sloped ceiling insulation, yielding a total approximate R-value of 70 (D).

Figure 6. Complex framing areas are ideal spray-foam candidates (A). At roughly R-6 per inch, the 2x8 framing bays approach a nominal R-44. Two doghouse dormers were also insulated with closed-cell foam (B). The finished basement walls were insulated to R-25 with a combination of 2-inch XPS foam and R-15 fiberglass batts (C). Note the air-sealing tape over the seams. Spray foam on the rim joist laps onto the XPS on the foundation walls, creating an air seal along the top of the board (D).

tionally vented at the ridge, the Cobra vent balanced with aluminum strip vent in the soffits. For vent baffles at the eaves and in sloped ceiling areas, we used 2-inch R-13 foam board, spaced down from the underside of the roof sheathing with 2-inch foam spacers (**Figure 5, previous page**). We glued the spacers to the sheathing and tacked the board over them, running it to a point about 1 foot higher than the 16 inches of cellulose to be placed in the attic. The eaves baffles are air-sealed against the 2x12 rafters and top plate with a 3-inch layer of spray foam. Over the baffles in the sloped ceiling areas, we sprayed 7 inches of closed-cell foam with a nominal value of R-45; we then installed 2-inch foam board over the rafters. The combined values of the board and spray foam results in a total R-value of around 70.

We also used closed-cell foam to insulate and seal all rim joists, the sloped ceiling areas, and the two doghouse dormers (**Figure 6**). A 3-inch layer of foam at the rims has an R-value of about 18 and provides additional air-sealing at this typically leaky junction.

Basement walls. In the basement we installed 2-inch XPS foam on the foundation walls, overlapping it at the top with

Figure 7. Leaving little to chance, the crew caulked all seams between framing members and subfloor (top). Foam backer rod, sealed with caulk, was used in lieu of expanding foam around window and door jambs (above). Window sealing was time-consuming, with caulk outlining the metal installation straps and the interior edges of the self-adhering window flashing (right).

the closed-cell foam insulating the rims. We framed 2x4 walls in front of the foam and insulated them with fiberglass batts instead of cellulose. We did this because basement flooding is common in the area; if a flood overwhelms the subslab drainage and sump pump, the insulation will drain and dry to the interior without settling. In fact, in an effort to keep things dry, we installed the foundation with its top about 3 feet above finished grade, placing the slab a few inches above the average water table.

Even though the foam sheathing was taped at every seam in both layers and sealed to the framing with adhesive caulk, we still didn't consider it a fully effective air seal. Before blowing in the cellulose, we worked on sealing the framing from the interior, caulking every seam that might constitute an air leak in the shell (**Figure 7**). This proved to be an extensive and expensive undertaking. We used acrylic latex caulk on every joint between double framing members in the exterior walls. We'd put a generous bead of subfloor adhesive under the bottom plates before standing the walls, but you can't visually check for voids or gaps, so we went ahead and caulked all seams between the bottom plate and subfloor. In the basement, we caulked where the 2-inch XPS foam on the foundation walls met the slab, and we sealed the seams with WeatherMate tape (866/583-2583, building.dow.com). We spent about $800 on caulk and more than $8,000 in labor over two weeks, during which time someone from Building Science Corp. periodically came out and identified still more areas that could be caulked.

The air-sealing effort also included a labor-intensive treatment around all the windows and doors. We avoided using expanding foam around the jambs, not because it doesn't seal well, but because it too thoroughly fills the gap. If water were to get past the jamb, it could remain trapped and lead to rot. Instead, we inserted foam backer rod around the jambs, pressing it just beyond the interior edge, then capped it with caulk. This way, any water that gets in still has a chance to dry to the outside, where the underside of the sill is caulk-free and can drain. We caulked around the metal tie-straps, too, and along the edges of the self-adhering membrane protecting the rough openings.

Insulation

The 2x6 wall bays were insulated with dense-pack cellulose, blown in behind a permeable plastic membrane. To support the cellulose in the attic spaces, we had to hang those ceilings first, using stiffer, 5/8-inch drywall to avoid a "quilting" effect over the 24-inch framing centers (**Figure 8**). After hanging the board, we checked from above for light leakage through seams and fixtures, and caulked them all tight. We also caulked the perimeter of the drywall to the top plates, from below.

Against the architect's recommendation, the homeowners insisted on having recessed lighting in the ceilings. Despite their ICF housings, the fixtures weren't airtight, so we covered them from above with expanding foam. Hopefully, the homeowners will use compact fluorescent bulbs to help prevent the cans from overheating and tripping the thermal breaker.

We performed a blower-door and smoke test before installing the cellulose. Even at this intermediate stage, the result — 1.37 air changes per hour at a pressure of 50 pascals (ACH50) — easily met the 1.5 ACH50 we'd targeted as our goal for the finished home. We identified a few leaks along the top plate where air found its way between the sheathing and the framing, and applied more caulking to seal these areas.

In retrospect, I believe that rather than putting all that time and caulk into air-sealing, it would have been more economical to have had every wall bay "picture-framed" between the sheathing and the framing with closed-cell spray foam. Our insulation contractor estimates that this would have added $1,500 to the job cost, but it would have significantly reduced our labor.

Figure 8. Dense-pack cellulose insulation was blown behind a permeable membrane stapled to the studs (top). Attic ceiling areas were sheetrocked first to support the insulation. Attics received a 16-inch layer of loose-fill cellulose with an R-value of 65 (above).

Drywall

With two-stud corners and backerless wall intersections, we used drywall clips instead of nailers to support drywall corners (**Figure 9, next page**). Both the hangers and I were surprised at how easy the clips were to use. Their purpose is threefold: First, they reduce lumber usage; second, without a nailer in the way, areas above the top plates and behind wall tees and corners are easier to insulate; and third, they help prevent drywall cracks in the corners where wood movement can otherwise introduce stresses. Cracks aren't just unsightly; they also can contribute to air leakage through the wall assembly.

The blueboard and skim-coat plaster serve as the primary barrier to air movement through the walls and ceiling. When hanging the sheets, we ran a bead of acrylic caulk at all top and bottom plates, at wall ends, and around all openings, fixtures, and electrical boxes. At drywall clip corners, we simply caulked the vertical seams after installing the board — good insurance should the plaster crack in the corners despite the clips.

Mechanical Systems

This home is heated by forced hot air, with the ducts sized for air conditioning and installed entirely in conditioned space. The furnace is a natural gas-fired Evolution System Plus 95s (800/428-4326, bryant.com) with up to 95 percent AFUE. Instead of installing a cooling-only unit, we used a heat pump that can supply both cooling and heating. It provides heat at temperatures of 35°F and above, relieving the furnace and saving some fuel. A Fantech VHR 1404 (800/747-1762, fantech.net) heat-recovery ventilator delivers the home's makeup air supply. Both the furnace and the Rinnai RC98HP on-demand water heater (800/621-9419, rinnai.us) are sealed combustion units.

Although the cooling load for the house was calculated at $1\frac{1}{2}$ tons, a $2\frac{1}{2}$-ton 18 SEER unit was the smallest available. It's possible this could lead to short-cycling of the system; that remains to be seen. Presumably, as tight-home construction becomes more common, smaller systems will, too.

Solar power. On the roof, a 7-kilowatt photovoltaic array of 230-watt OnEnergy panels (800/237-4277, sharpusa.com) helps offset electrical usage, with excess power generation being fed back into the grid (**Figure 10**).

Figure 9. Drywall clips replace lumber backers in wall and ceiling corners.

Figure 10. A 7-kW PV array on the shed-dormer roof is projected to supply more than 100 percent of the home's electrical consumption (above). A digital electric meter displays a constant readout of power delivered to and from the grid (right).

Home Performance

Effectively air-sealing a home is a tall order, but redundant taping and caulking of seams — along with careful attention to detail — clearly paid off in our preliminary test results. This was confirmed by the blower-door test we did after completing the interior: We achieved .72 ACH50 — nearly 50 percent lower (and better) than the outcome of our preliminary test. Our focus throughout the job on energy and resource conservation has already helped place the home well above the 100 mark required for a LEED Platinum designation.

More important, our efforts will pay back in the home's overall efficiency and performance. Whenever there's leeway in a construction budget, I push for higher levels of insulation. Done properly, it's one investment that can pay for itself fairly quickly and, over time, continue to reduce operating costs.

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