

High-Performance Homes on a Budget



Well-thought-out details make energy-efficient houses both attractive and affordable

by John Abrams

These days, many of us are trying to meet two seemingly conflicting goals: We want to build the finest housing possible, but we also want to make that housing available to people other than the wealthy. In 2007, the company I co-founded many years ago — South Mountain Co., on the island of Martha's Vineyard, Mass. — was given an opportunity to pursue those goals when we were chosen to design and build a neighborhood of eight two- and three-bedroom Cape Cod-style homes. The property — which was designated affordable housing — was part of a 26-acre purchase by a local conservation organization. The homes would be clustered on four acres, and the rest of the land would be

left as protected open space (see **Figure 1, next page**).

A fundamental goal of the project was to make these homes truly affordable, now and in the future; therefore, we would need to design and build them to meet the most stringent requirements for energy efficiency and low maintenance.

I don't believe it's possible to build truly great housing that's cost-competitive with standard American housing, because most of the homes built today don't offer a high level of craftsmanship, durability, comfort, or performance. Ultimately, the goal is to make "standard American housing" that is significantly better than today's sorry norm. Until then, a good-

quality home is going to have a higher cost per square foot.

Still, there are strategies we can employ to keep long-term costs low. One is to build smaller homes, but it's equally important to help buyers understand that true long-term affordability comes from minimizing and stabilizing energy and maintenance costs.

Regarding energy, each of these homes combines a super-efficient building envelope and hvac system with a rooftop photovoltaic (PV) array to generate electricity. The completed homes easily earned platinum status from the U.S. Green Building Council's Leadership in Energy and Environmental Design (LEED) program, the

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highest rating offered. If the homeowners are willing to live a resource-conscious lifestyle, the homes should achieve net-zero energy performance, which means that the PVs generate at least as much power as the home consumes, averaged over the year. (The homes are being carefully monitored, and we're testing our assumptions with a little contest. Any household that consumes no energy — or produces more than it uses — in the 12 months from June 2010 to June 2011 will get a prize: a one-year membership in a local community-supported agricul-

ture endeavor or a \$400 gift certificate to a local fish market.)

Minimal upkeep is another essential. The fiberglass windows, the robust hardware and fittings, the unpainted cedar siding, and the reclaimed cypress trim should need no treatment or maintenance for 25 years or more. Quality materials cost more up front, but they save in the long run.

We were able to complete the two-bedroom versions for \$246,000 — not including the solar electric system — on an island with very high construction costs. We cal-

culate that the high-performance aspects of the houses added roughly 10 percent to the cost. What would these houses cost on the mainland? It's hard to say, but certainly at least 10 percent less.

Honing the costs meant investing more time and effort into design than is typical for the small American house. The plans are highly detailed. Our in-house architects, engineer, and builders worked through every component. After years of trial and error building energy- and resource-conscious homes, we have settled on a suite of details that can be produced efficiently. These details may be useful for other builders and designers, so I'll go through the essentials, starting with the foundation.

Warm and Dry Basements

Like most homes in our area, these have poured concrete foundations and full basements, but the construction and insulation methods are different. Customarily, fiberglass batts are stuffed between the first-floor joists, and the foundation walls are left bare; this results in poor insulation and air-sealing and creates a damp basement that's prone to mold and mildew and requires the use of a dehumidifier all summer.

We use 3 inches of foil-faced polyisocyanurate rigid foam on the inside of the foundation walls and 4 inches of extruded polystyrene beneath the slab, creating what one of our crew refers to as "an R-20 bathtub." (In more recent projects, we've used Type 9 expanded polystyrene under the slab, because its global-warming contribution is a fraction of that of extruded polystyrene, due to the blowing agent used during its manufacture.)

To hold the wall insulation in place, we fasten dovetail-shaped 2-by battens to the inside of the foundation forms, spacing them at 2 feet on-center. The beveled edges hold the pressure-treated battens securely in the concrete after the forms are removed (**Figure 2**). The rigid foam is



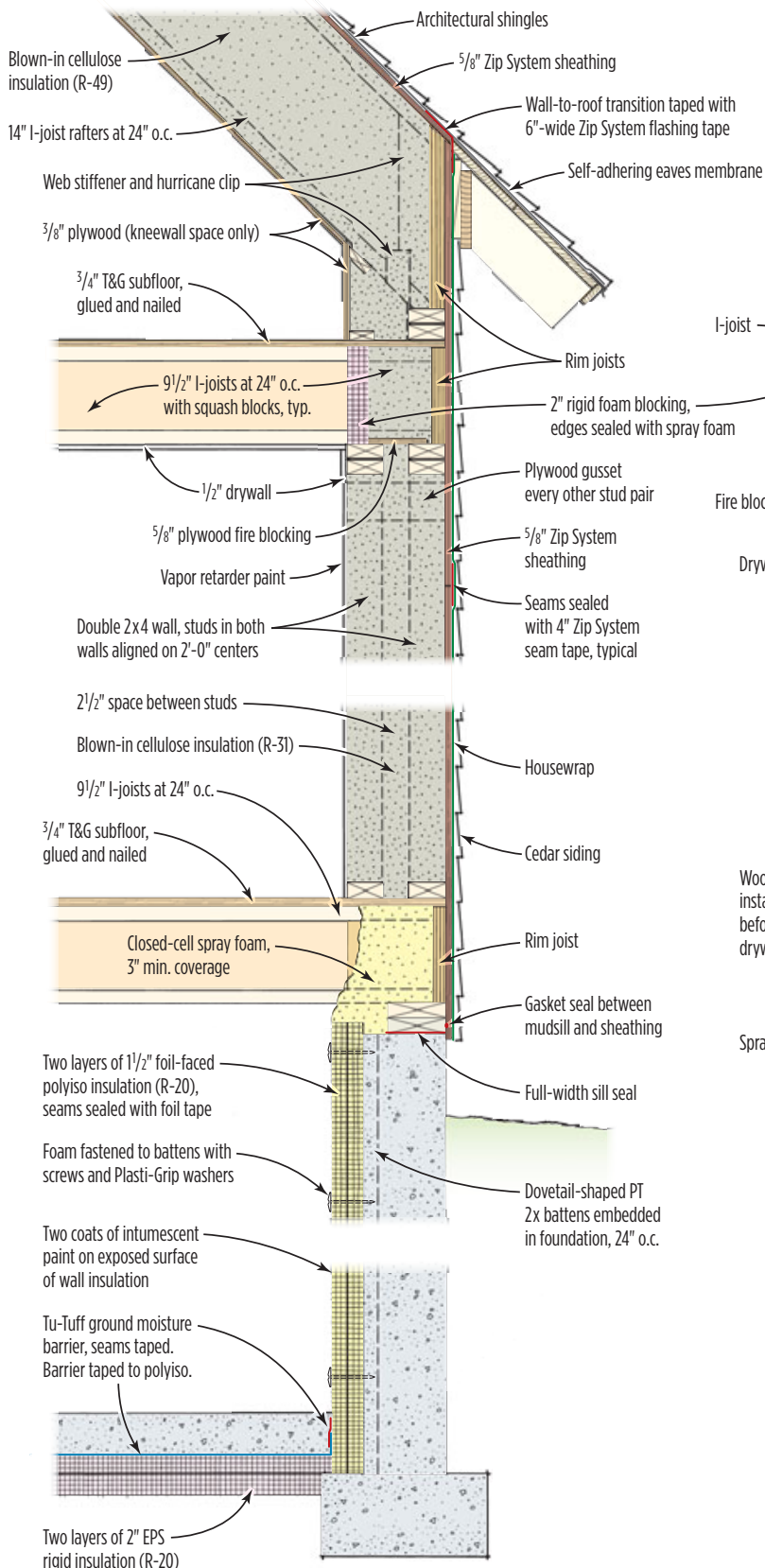
Figure 1. The author's company was chosen to build a community of small, zero-energy homes. The challenge was to keep them affordable, a goal that should be met over time owing to low fuel and maintenance costs.



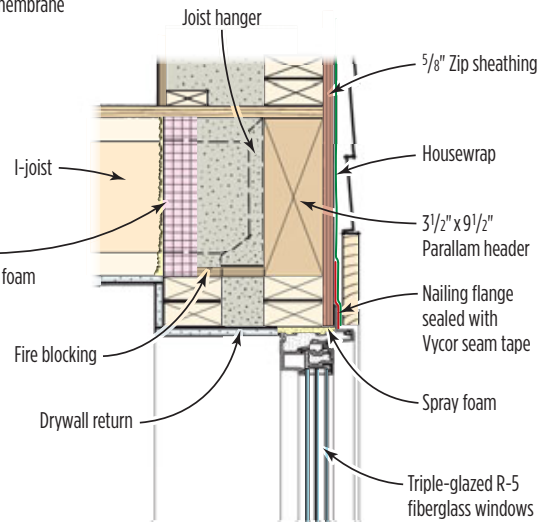
Figure 2. Wedged-shaped battens made of pressure-treated lumber were fastened to the inside of the foundation forms 2 feet on-center. A double layer of 1½-inch polyisocyanurate foam board is attached to the battens with screws and plastic washers.

A Practical Airtight Shell

Section Through Double-Wall Framing



Window Head Detail



Window Sill Detail

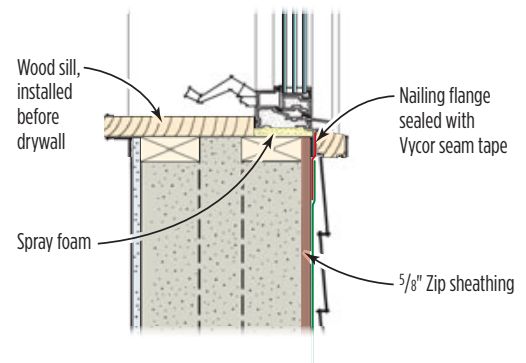


Figure 3. Zip System sheathing, taped at every seam, provides a tight air barrier for the well-insulated I-joist rafters and double-2x4 exterior walls. Gaskets and spray foam ensure a tight transition from foundation to rim joist.

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Figure 4. Double 2x4 walls (left) and 14-inch-deep wood I-joint rafters minimize thermal bridging through the frame. Note that the rafters' bottom plumb cuts are flush with the walls (above).

Figure 5. Precut studs, joists, and rafters saved labor and substantially reduced waste. Even the rafter plumb cuts were made by the lumberyard.



fastened to the battens with screws and Plasti-Grip washers.

The ground moisture barrier consists of Tu-Tuff plastic sheeting (Sto-Cote Products, 800/435-2621) installed on top of the polystyrene before the slab is placed. The wall insulation is installed before the slab is poured, creating an uninterrupted insulation plane and air barrier in the basement. At the top of the foundation wall, sill seal and gaskets connect the top of the foam to the framed wall's air barrier (Figure 3, previous page).

Double-Wall Framing

After years of experimentation with a variety of approaches, we have settled on cost-effective wall and roof assemblies that meet our insulation standards (R-31 walls and R-49 roofs) and minimize thermal bridging — and that our carpenters and other tradespeople are comfortable with.

We use double 2x4 walls with a 2½-inch space between the inner and outer walls, and 14-inch wood I-joint rafters (Figure 4). Everything is framed 2 feet on-center. The double walls minimize thermal bridging because of the space in the middle, and the I-joists do so because their webs are so thin. The sheathing and air barrier are provided by ⅝-inch-thick Zip System

panels (Huber Engineered Wood, huberwood.com).

Our framers speed up the process and reduce job-site waste by having the supplier precut all studs, joists, and rafters — including the plumb cuts (**Figure 5, previous page**). This also reduces overall material use, as the lumber company uses the smallest amount of stock possible to get the lengths needed.

There are some details to consider with double-wall framing. For example, if you frame square openings around deep windows, you decrease the amount of light getting into the room. We solve this by splaying the sides of the openings at 45 degrees. Rather than trying to put trim around the entire opening, we install wood sills before installing the drywall, which is finished to the window jambs. When the drywallers are finished, so is the opening (**Figure 6**).

Another issue is how to make a secure, stiff connection between the inner and outer walls. We do it by aligning the studs in both walls and nailing the bottom plates in place, then adding plywood gussets to the sides of every other pair of studs near the top of the wall.

Site-Friendly Air-Sealing

Our walls and ceilings are insulated with blown cellulose. There are no settling problems with cellulose as long as it's installed to the proper density (**Figure 7**). We handle vapor diffusion by using vapor-retarder paint on the interior walls.

For these homes, we used low-e triple-glazed R-5 fiberglass windows from Thermo-Tech (thermo-techwindows.com). We chose a somewhat lower R-value on the south in return for higher solar transmittance. The doors were fiberglass models from Therma-Tru (thermatru.com).

Good air-sealing is crucial for a high-performance home. These homes have a fully delineated air-sealing path from the foundation slab to the roof ridge. It includes gasketing at the base of the sheath-



Figure 6. Because of the 9½-inch cavity created by the double 2x4 walls, the blown cellulose achieves an R-value of 31. The sides of the deep window wells are beveled 45 degrees to ensure that they let in plenty of light.



Figure 7. The second-floor band joists required blocks of 1-inch polystyrene, spray-foamed in place, to meet insulation goals.

ing and spray foam around windows and doors, but for the most part the air barrier is provided by the Zip System, which consists of 4x8 sheathing panels with specially designed protective tape to seal the joints (**Figure 8, next page**). You simply install the panels, tape the seams, and you're done. Our carpenters really like this sheathing. It installs like plywood or OSB and is an excellent air barrier when the seams are taped. We have used it on every

home we've built in the last four years.

The key to getting the most from this approach is to make sure there are no interruptions in the air barrier. We do this by framing each home without overhangs at the soffits or rakes. After the Zip sheathing is in place, we have a sealed box with no protrusions. We then apply the overhangs. This adds time to the framing process, but the result is a very tight air barrier (**Figure 9, page 7**).

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Note that at the roof, the air barrier is the outer surface of the roof sheathing. These homes are designed and built with “hot” roofs — that is, there is no structural ventilation (**Figure 10, page 8**). In our experience, good insulation and air-sealing will keep excessive heat and moisture out of the roof system, so there’s no need for vents. In fact, we’ve used this roof system for 30 years; it wasn’t part of the code until recently, but long ago we convinced our local building inspectors of its effectiveness. We have never had performance or moisture problems with hot roofs.

The way to test the effectiveness of an air barrier is with a blower door, and our company considers the blower door to

be an important part of our carpenters’ tool kits. We generally do three separate blower-door tests: before insulation, after insulation, and after drywall and mechanicals have been installed. The final tests on these homes ranged from 117 to 184 cubic feet per minute (cfm) at a pressure of 50 pascals — seven to 10 times better than the Energy Star standard. (Some of these homes meet Passive House airtightness standards.)

Optimizing the Mechanicals

A tightly built house needs good mechanical ventilation to keep the indoor air healthy. A home that’s striving for zero energy can’t rely on exhaust-only venti-

lation, which exhausts heated indoor air and replaces it with unconditioned outside air. So we installed heat-recovery ventilators (HRVs), which use heat from the exhaust air stream to temper the incoming fresh air supply. These homes are compact enough that we were able to reduce installed and operational costs by using small, relatively inexpensive single-speed units. Marc Rosenbaum, our building performance engineer, chose a Fantech model SH704, which cost less than \$3,500 installed and draws just 36 watts.

We also helped keep costs down by installing each HRV without controls and setting it to run continuously at 50 cfm — a bit more than the ASHRAE 62.2 requirement of 45 cfm for a two- to three-bedroom home of less than 1,500 square feet. The fresh-air supply is evenly distributed to the homes’ bedrooms and we have a measured exhaust rate of 25 cfm per bath (as opposed to relying on a fan rating to build a system that meets code but isn’t tested).

Heating and cooling are provided by a Daikin RXS24DVJU single-zone air source heat pump. It’s a ductless split system with an outdoor compressor and a single indoor unit. A conventional home would be more likely to use a three- or four-zone model with indoor units in each bedroom, but these small, high-performance homes can be conditioned with a single indoor unit (**Figure 11, page 8**).

Installing one indoor unit instead of three or four provided enough savings to offset the cost of the HRV. Natural convection is sufficient to carry heat to all the house’s rooms, unless the occupants turn the heat way down or keep doors closed. In these homes, we addressed those situations by installing electric radiant ceiling panels for supplemental heat in the bedrooms. Based on past experience, we expect that some homeowners will never use these radiant panels.

At this writing (December 2010), the homes have been occupied for six months. We have energy meters installed in each



Figure 8. Taped Zip System sheathing — applied continuously on the walls, over the plumb-cut rafter ends, and up the slope of the roof — provides the primary air barrier. Note the layer of housewrap under the eaves (left), installed in advance as the rafter tails were being added. Later, the entire shell was covered with housewrap.



Figure 9. To avoid the gaps in the air barrier that typically occur where the rafters cross the top plates, the author decided to apply false rafter tails to the outside of the airtight shell (top), first installing a course of a self-adhering flashing membrane to seal fastener penetrations. Cypress backers were screwed to the back of each tail, then the assemblies were screwed through the sheathing into the rim joist. A TimberLok screw driven diagonally through the top of each tail into the rim helps resist downward forces. Pine-board sheathing completes the open-tail look.

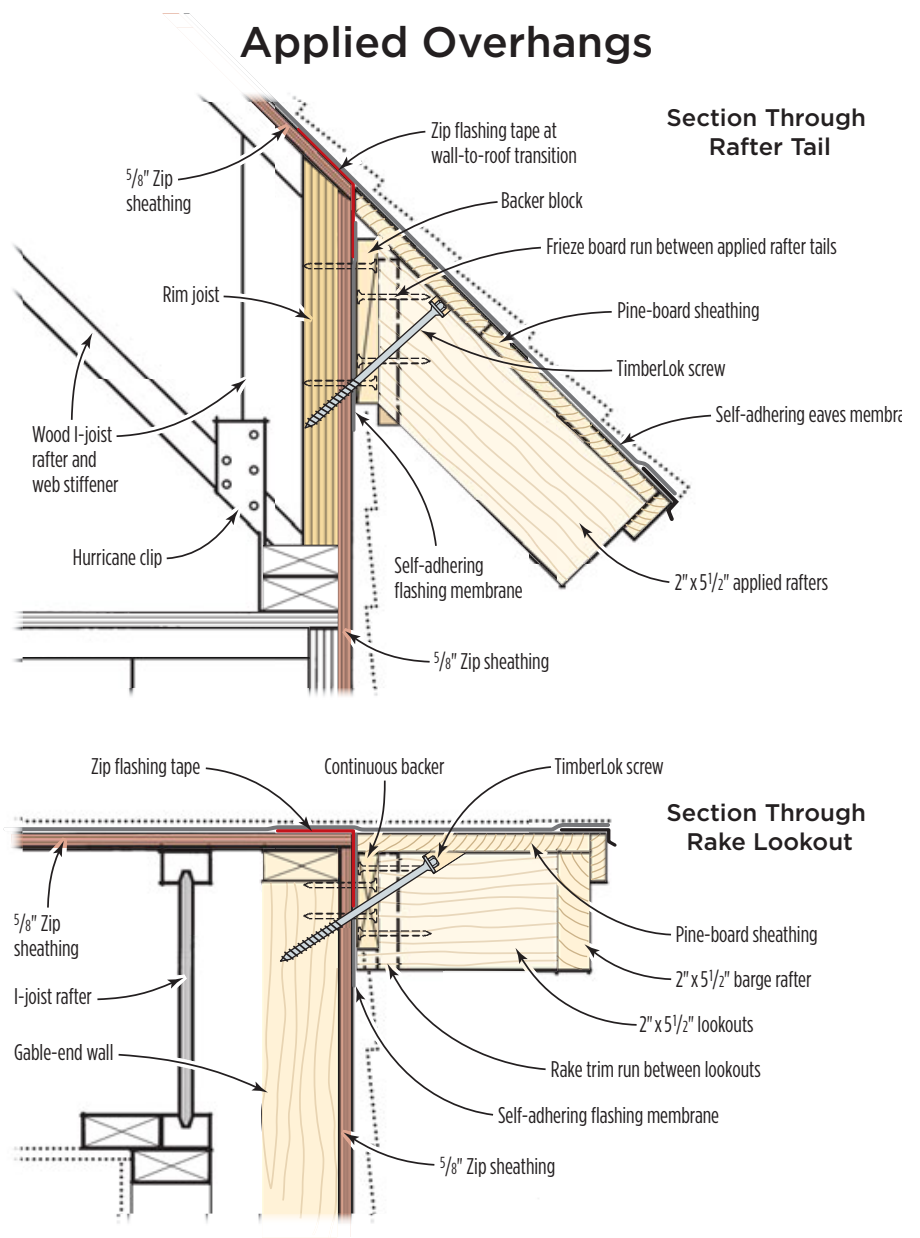
house, and they're read monthly by one of our staff. Six of the eight households have achieved zero energy so far, which means they have used less energy than their PV system generated.

We also installed submeters for specific systems. In addition to giving us more data to work with, these meters have proved to be useful diagnostic tools. For instance, when solar electric production seemed very low on one home, the meter for the PV system told us immediately that the panels weren't supplying power to the house, a situation that would have taken time to diagnose if we had not been submetering. We quickly realized that one of the kids had switched off the AC disconnect.

Solar Economics

As mentioned, the square-foot cost for these homes didn't include the 5-kilowatt Sun Power PV systems (us.sunpowercorp.com), which were paid for by a state grant. The construction details make for great energy performance, but it's the PVs that make it possible for these homes to achieve zero energy.

The market price for the PV system we installed was about \$35,000, but actual costs to the builder or owner can be as much as 45 percent less because of tax and other incentives. If electric rates don't go up at all (an unlikely scenario), savings will equal installation costs in about



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10 years. The system can reliably produce power for at least 25 years.

We offset the panels to one side of the roof in case the homeowners eventually want to install a solar hot-water system or more PV panels.

We're Always Learning

We continue to use most of the construction details from these homes on current new-home projects and have no plans to change them anytime soon. That's not to say that they won't evolve over time; of course they



Figure 10. Unused attic spaces are part of the home's conditioned space, so the rafters are insulated up to the ridge. Note that plywood is used in the attic to hold the insulation in place where there is no drywall.



Figure 11. The insulation and air-barrier systems are so effective that a single mini-split heat pump should be able to provide heating and cooling for the entire home. Electric radiant ceiling panels will provide backup heat if needed.

will. There are some things we already know we would like to do differently.

1. We're not satisfied with the thermal performance of available windows. We're looking for better choices that will meet the budget constraints of the average home.

2. We'd like to provide an affordable option for water heating. We're investigating heat-pump water heaters, which extract heat from the basement or utility room and use a backup electric resistance element to supplement the heat pump during periods of peak demand.

3. These houses are still too expensive. We would like to refine our designs for small homes so that we can cut the cost by 10 percent to 20 percent without sacrificing quality, performance, or aesthetics. We've just begun work on a major design project to try to accomplish this. We'll see where it goes — it's a tall order.

In the end, meeting the goal of building quality homes requires a blending of mind-sets. On the one hand, designers and builders need to think in terms of production — using building methods that keep costs down and projects profitable. On the other hand, we must be willing to push forward and experiment with promising new approaches — with the intention of incorporating successful experiments into the production system.

Ultimately, these are complementary, not contradictory, ways of thinking. More demanding buyers, stricter energy codes, and our own aspirations have made building technology a constantly changing practice. The degree to which we keep learning may be the key to our ability to thrive in an uncertain future. At the very least, it will keep us on our toes!

John Abrams is cofounder and CEO of South Mountain Co., a 35-year-old employee-owned design-build and renewable energy company in West Tisbury, Mass. Thanks to Marc Rosenbaum and Derrill Bazy for their help with this article.