Part II
An Affordable Passive House

by Chris Corson

Sealing the air barrier and eliminating thermal conduction minimizes heating loads

[Editor's note: This is the second part of a two-part story; Part I appeared in the May issue.]

Once all the inner 2x4 bearing walls were framed, we moved on to frame the roof, using mono-pitched raised-heel trusses with 3-foot tails on the south side. We used typical vent chutes and soffit venting at both eaves and roofed with asphalt shingles.

Before setting the trusses, we installed a 6-inch-wide strip of OSB around the second-story top plates, letting it project to the interior (**see Figure 1, next page**). Over this OSB strip, we applied Grace Ice & Water Shield to seal the outside wall corner, then for good measure, taped the membrane to the sheathing with 3M's 8067 flashing tape. The inward-projecting flange would give us a practical way to seal the wall air barrier — the OSB sheathing — to the ceiling air barrier, also OSB, which we fastened to the bottom chords of the trusses. (When it was time to drywall that ceiling, I supervised like a nervous mother, watching to make sure every screw hit wood. I didn't want any random holes in the air barrier.)

With the shell dried in, we began the process of sealing all the joints and penetrations in the OSB — both the structural wall sheathing and the interior subceiling — with 8067 tape and Grace Vycor flashing tape. At the wall base, we taped the subslab vapor barrier to the bottom edge of the OSB, and also sealed window and door bucks and other penetrations.

Outer wall assembly. In the completed shell, the OSB sheathing is actually buried a foot deep inside the wall, behind an outer layer of wood I-joists, whose main purpose is to hold cellulose insulation. Wherever we had to install an I-joist, we made sure to apply Vycor, so that there would be no air leaks around the screws (**Figure 2, next page**). We fastened each I-joist through the sheathing to the interior stud using 5⁄16-by-4-inch RSS lag screws (grkfasteners.com) at 2 feet on-center (**Figure 3, page 3**). For an exterior sheathing — needed to retain the dense-pack cellulose — we nailed up a vapor-permeable (37 perms) asphalt-faced fiberboard sheathing from BP called BH900 (**Figure 4, page 4**).

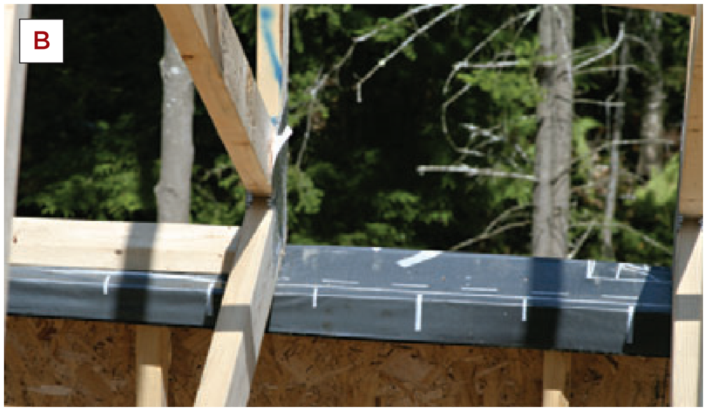


Figure 1. Before setting the mono-pitched roof trusses (A), the carpenters attached an OSB gusset to the top plate of the 2x4 bearing walls (B); peel-and-stick flashing seals the outside top corner of the wall. The roof was conventionally framed (C) and covered with asphalt shingles.

Figure 2. The author applied strips of Vycor membrane at stud locations (above) to ensure that the fasteners securing the vertical I-joists (right) would not create leaks in the OSB air barrier.

Figure 3. Twelve-inch-deep wood I-joists (A) were fastened to the studs of the inner wall with GRK structural screws (B) to create space for cellulose insulation. A metal termite shield protects the foam insulation below (C). The gaps around the window bucks were insulated with spray foam (D).

High-Performance Windows

Top-performing windows are vital to a Passive House. The program has a separate window standard that sets a maximum whole-window U-value of about 0.14. You can pass the standard with less-efficient windows as long as you satisfy the whole-house criteria for energy use and air-tightness, but it's not the best approach, especially in a heating climate. I spent a long time shopping for windows and entry doors for this house and ended up with units manufactured in Lithuania by Intus (intuswindows.com). The windows I bought aren't actually certified by the Passive House organization (certification is expensive and raises the price of windows), but Intus's test data show that they perform well enough to meet the program's specs.

Good windows enhance comfort and simplify space conditioning. Compliant windows have such high R-values that the inner glass surface stays within 5.5°F or so of indoor ambient temperature, which prevents cold convection currents. And because most of this home's windows face south, they contribute a lot of space heating in the winter. In summer, the first-story windows are shaded by a wall-mounted solar array, and the second-story windows by the roof overhang.

According to computer models, windows should be positioned in the "R-value center" of the wall, because this makes for the least heat conduction; it seems like a minor point, but succeeding with Passive House requires a lot of fine-tuning to make sure every Btu is conserved. So we packed out our window openings with engineered-wood window bucks that held the windows at dead center in the wall plane. We applied flashing tape to the window sills and jambs before setting the windows, then — when the windows were in place — foamed the gaps around the frames and integrated the windows into the Tyvek drainage plane with flashing tape (**Figure 5, next page**).

We covered the outer edges of the window bucks with EPS insulation before we applied the trim, in an effort to eliminate thermal bridging around this vulnerable opening. With the extra insulation, the

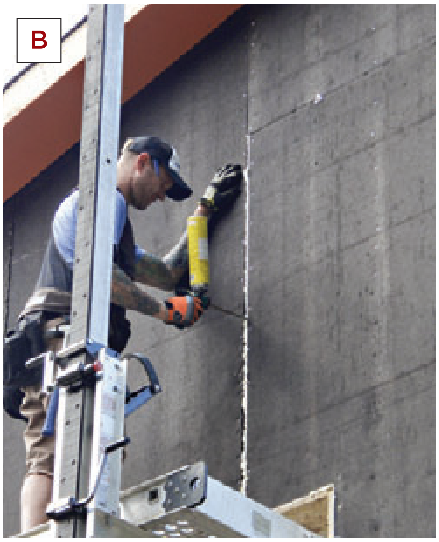


Figure 4. A secondary asphalt-faced fiberboard sheathing (A) was installed over the wood I-joists to retain the cellulose insulation. Edge gaps were sealed with spray foam (B), then the shell was covered with housewrap (C).

Figure 5. The window bucks were protected with flashing tape (A) before the window units were installed (B). Windows were secured with metal clips (C) and frames were taped and air-sealed (D).

Inswing Door Details

majority of the window frame performs just as well as a clear wall section.

Unlike the windows, the inswinging door units were installed on the inside face of the wall (**Figure 6**). A layer of EPS completely covers the plywood bucks.

The exterior is clad with wood siding installed as a vented rainscreen. We first applied housewrap over the fiberboard, then nailed up vertical furring strips for the clapboards (**Figure 7, next page**). At the base of the wall, we also ran horizontal furring for cedar shakes.

Lots of Insulation

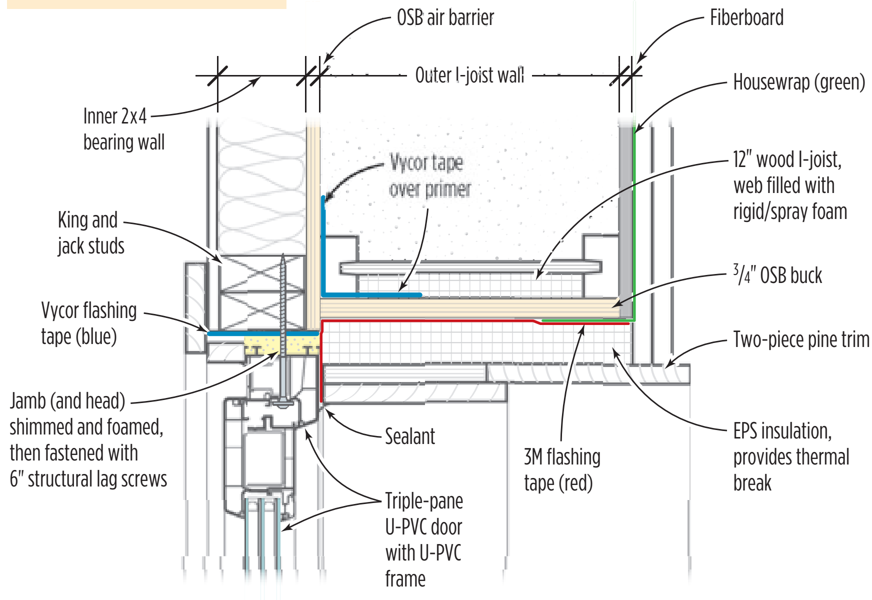
Before the insulation contractor went to work, I wanted to run a preliminary blower-door test. If we passed at that point, I was home free. But if we failed, I would still have access to the leaks.

As it turned out, we cleared the 0.6-ACH50 bar on that first blower-door test. We found some minor leaks and patched them from the inside, then moved ahead with the insulation.

The weather forecast included a chance of rain and snow, so to avoid having the job interrupted, I decided to fill the I-joist cavities from inside the shell — even though that meant cutting holes in our OSB air barrier, which we had just meticulously sealed and tested. But I figured that it was better to go around and retape all the holes in the OSB than to have our insulation guys trying to work from outside the house on ladders and staging (**Figure 8, next page**). The upper part of the I-joist cavities was accessible from the attic, and a lot of the wall blowing was done from up there. In areas of the walls that weren't interrupted by windows, the insulators had a clear shot and could fill the entire cavity from eaves to foundation in one pass.

We encountered a slight glitch when we first started to blow insulation into the outer wall: Our installer had the blower cranked up to high pressure, and shortly after he started we noticed that the fiberboard sheathing was starting to bulge —

Jamb Detail (Plan View)



Threshold Detail

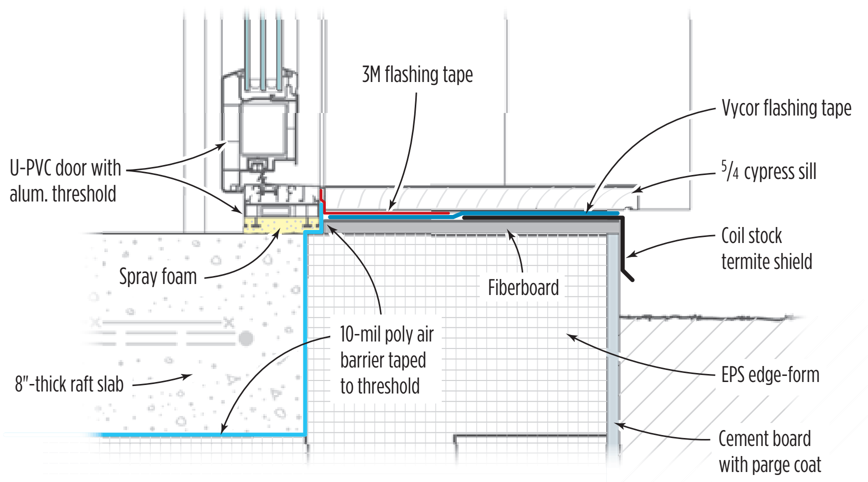


Figure 6. The Intus exterior doors were installed flush with the inner face of the double wall and the door bucks carefully insulated with EPS to cut thermal conduction.

far enough that it would clearly show up in the siding. Luckily we caught it early; the insulation guys reduced the pressure and the problem went away. We still had enough pressure to meet the insulation spec, but I'll be looking at other sheathing materials for my next Passive House project.

It took almost two full days to blow the walls and the attic — because we put in three or four times as much insulation as a typical house would take. When we were done and had taped up all the freshly cut holes, we set up the blower door again, this time measuring 53 cfm50 — or, relative to our volume, .287 ACH50.

Figure 7. Vertical furring strips cut on site from framing lumber (far left) promote drying behind the pine clapboards. Additional horizontal furring provides backing for cedar shakes at the base of the wall (left).

Figure 8. Where possible, wall cellulose was blown into the I-joist cavities from the attic (A), through holes cut in the OSB air barrier (B). Where windows interrupted the cavities, the insulation was blown from below (C). After the insulation was installed, the crew re-installed the cutouts and sealed the holes (D, E). Later, Roxul mineral wool batts were installed in the inner 2x4 wall, increasing overall wall R-value to 58.7.

Mechanicals

We followed Passive House guidelines for balanced ventilation, which call for 24 cfm of continuous exhaust from each bathroom plus 35 cfm of continuous exhaust from the kitchen, for a total of 83 cfm for the house. There's no direct-vent range hood in a Passive House, so the kitchen range has a recirculating charcoal-filter hood.

The balanced supply air is ducted to the master bedroom (18 cfm for each occupant, or 36 cfm) and the second bedroom (18 cfm), and into the living room (the remaining 29 cfm). Passive House specs for the exhaust ventilation rates are based on German ventilation standards, but they also work out pretty close to the U.S. ASHRAE 62.2 standard of .35 ACH.

For this house, we installed a top-of-the-line energy recovery ventilator (ERV) — a ComfoAir 200 from Zehnder (zehnderamerica.com). With ERV equipment, you get what you pay for. This unit cost about $5,500, but it was a smart purchase. For one thing, the performance is astonishing: It's 92 percent efficient and draws just 0.25 watt of power per cfm, or a little over 20 watts for the ventilation this house needs. Also, the unit comes as a complete kit that I was able to assemble myself, and my crew and I ran the ductwork as well, keeping installation costs down (**Figure 9**). Plus, we got excellent service; Zehnder's technicians reviewed my ventilation plans and suggested a few tweaks, and a company rep came to our job to balance the system.

Heating. Given the superinsulated shell, the passive solar gain from the windows, and the high-performance ERV, the home's heating needs are close to zero. For this project, we chose a 12,000-Btu Mitsubishi Mr. Slim mini-split heat pump (model MUZ-FE12NA), mounted on an exterior wall. I paid $1,500 for the unit at a local distributor, with installation costs on top of that. This is the kind of heater you might use for a room addition in a conventional Maine house, but it will be able to heat this entire house when it's needed.

Figure 9. The 92 percent efficient Zehnder ERV kit (A) was assembled and installed by the author (B), including the supply and return ducts and registers (C,D).

Figure 10. A 12,000-Btu Mitsubishi mini-split heat pump provides heating and cooling (left). A single indoor unit (right) delivers the warm air, which will be further circulated by the ERV ductwork.

Figure 11. The north side of the house has practically no windows (A). Solar panels shade the lower south-facing windows in the summer (B). The finished interior features expansive windows and stained concrete floors (C).

The heat pump is rated at 22 SEER as an air conditioner; as a heater, it has a coefficient of performance (COP) above 4 at 47°F. It maintains 92 percent of its rated capacity even at 17°F, and will heat the house until outdoor temperatures hit 13 degrees below zero. During the late phases of construction, with outdoor temps in the 20s, I measured supply-air temperatures at the heating register at 105°F. There's only one indoor register, in the condenser unit itself, which is mounted high on an exterior wall (**Figure 10, previous page**); the small air ducts for the ERV system will serve to distribute the air around the house. I also installed 15 feet of electric baseboard in the house — 1,800 watts' worth — but that's strictly for emergency backup in case the heat pump needs repair.

Domestic hot water. Hot water is supplied by a Steibel Eltron on-demand electric water heater. PV will cover the load in the sunny months, and hopefully the cost will zero out during the year under the utility's net metering program.

High Expectations

We finished the house in January of this year, so the building hasn't been through a complete heating season yet — but we already know that it is exceeding our hopes and expectations. After the house was insulated but before it was completely drywalled and finished, we had about six weeks of inside finish work left to do. Outside temperatures were down in the teens, but the inside of the house stayed a consistent 68°F. If we turned off the heat pump when we went out for the night, the house would still be above 66°F when we came back in the morning.

I am pretty sure that the ERV outperforms its listed specs, too. I measured the supply air at the diffuser one morning when it was 7°F outside and the supply was barely two degrees cooler than the indoor set point. On most sunny winter days, I don't think this house will need much additional heat.

Best of all, we hit our budget target. The house came in at $135 per square foot (**Figure 11**).

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