COLUMN BUILDING SCIENCES

Joseph W. Lstiburek

Zeroing In

Net Zero Houses

BY JOSEPH W. LSTIBUREK, PH.D., P.ENG., FELLOW ASHRAE

So what does "net zero" mean anyway? And what is the difference from a "zero energy house"? A zero energy house is "off grid" and makes all the energy it needs on site using renewables. This is not easy to do and typically involves an ultra-efficient house and energy storage. Good luck. Having said that, I like the ultra-efficient part. I can't help it. Engineers worship efficiency. The storage part worries me.

A net zero energy house "is one in which the total amount of energy consumed in a year is less than or equal to the total amount of energy generated on-site during that year."[*] In a net zero energy house the electrical grid provides the energy storage. Photovoltaic (PV) panels are typically used to generate electrical energy to power the house with the excess electrical energy generated going into the grid.[†] Net zero energy houses also have to be ultra-efficient. As noted, I like the ultra-efficient part. Although the PV part is ready for prime time, it is not cheap. The approach to the PV part is to try to make the system as small as possible. Duh.

We have done a bunch of net zero houses and here is what we have learned. There are practical limits to the efficiency we can squeeze out of the house and its systems and occupant behavior. Double duh. Working within these limits results in a PV system that is not all that "small." We really thought, me included, that for a 2,500 ft^2 (232 m^2) house in a cold climate like Boston or Chicago we could get away with a 5 kW PV system in an ultra-efficient house. Some folks in our firm think it is still possible. Not me. Don't hate me for saying this but a 10 kW PV system is probably what you need based on what we are measuring. OK, maybe, with lifestyle changes, possibly 7.5 kW.[‡] But not 5 kW. And certainly not 3 kW.

Everyone relax a little, but not too much. The PV systems get smaller in warmer climates. Triple duh. Places with real winters, not places with bad golfing weather during January like Washington, D.C., need big systems. But Washington, D.C., is not an easy place either. A 5 kW PV

[*] Pettit, B., Fanney, A. H. and Healy, W. M.; "Design Challenges of the NIST Net Zero Energy Residential Test Facility," NIST Technical Note, September 2014.

[†] Not going to get into how happy this makes the utility companies or the politics of how much it costs to buy electricity from the utility compared to what the utility pays to purchase electricity from an owner.

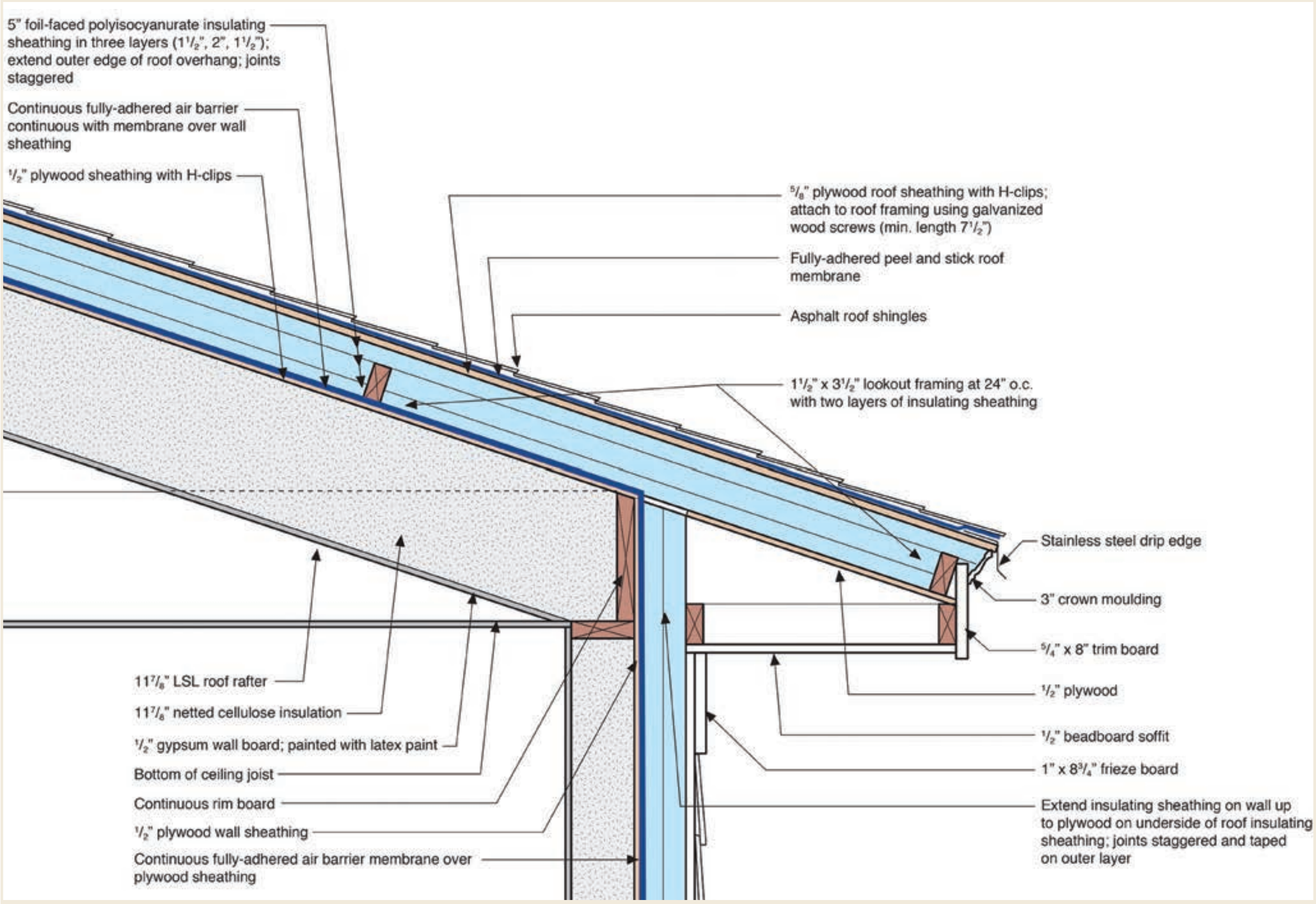

FIGURE 1 Roof Assembly. Note the continuity of the water control layer, air control layer, vapor control layer and the thermal control layer. The "lookout" framing for the overhang is embedded in the rigid insulation. You want a higher R-value roof than this? Easy. Add another layer of rigid insulation. Or two layers. Don't like the cellulose in the cavities? Use fiberglass. Or use low density or high density foam. Whatever.

system with an ultra-efficient house will not get you to net zero even there. D.C. has humidity and AC. My hometown of Toronto? With a real winter? Not a chance. Sacramento, Calif., pretty easy. Not tough to be net zero in California. Kinda explains some of the energy politics. It is easy to be an advocate when your climate is easy.

So what does "ultra-efficient" mean anyway? Different things to different people. I will give you my take. Some folks will say no way "not efficient enough." Others will say "are you crazy that is way over the top." The good news is fundamentally the overall approach works the same for both types of folks. This will make sense later.

Here is the list of metrics for the enclosure and equipment for an ultra-efficient house in a cold climate like Boston or Chicago or Toronto (as defined by me[§]):

- R-5 windows;
- R-10 slab insulation;
- R-20 basement insulation;
- R-40 wall insulation;
- R-60 roof insulation;
- Airtightness of 1.5 ach at 50 Pa or less;
- Heat recovery on ventilation;
- LED lighting everywhere;
- AFUE 95% - sealed combustion condensing for furnaces, water heaters and boilers;
- SEER 18 or more for AC;
- HSPF 10 or more for heating; and
- Appliances from the top 10% of Energy Star.

‡We built an ultra-efficient house with 5 kW of PV for our daughter. The house was 2,800 ft^2 (260 m^2) in Concord, Mass. It did not get to net zero. Ultra-efficient for the house then—five years ago—is not as ultra-efficient as we would do today. Upping the efficiency to "my metric" of ultra-efficiency (on the next column of this page) and a 7.5 kW PV system would have got the house to net zero—with a "conserving lifestyle." Note the "conserving lifestyle" comment.

§Passive House folks relax. Yes, I know you are "ultra" ultra. The approach illustrated will get you to your metrics as well. Read on.

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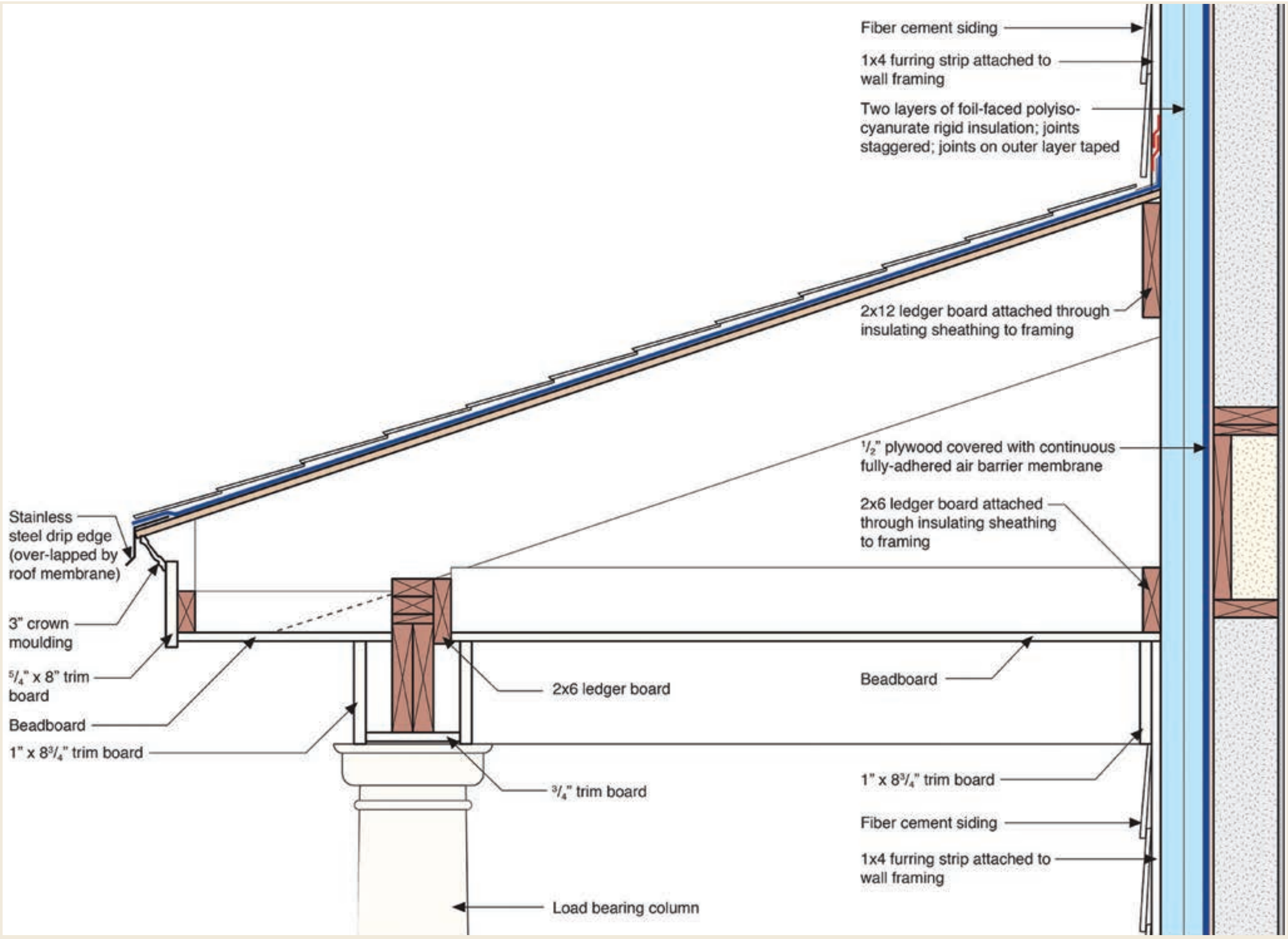

FIGURE 2 Wall Assembly. Note that the "hood" framing does not penetrate the layers of exterior continuous insulation. Further note that the roof is flashed to the exterior face of the rigid insulation. If rockwool is used then the roof would need to be flashed to the exterior face of the fully adhered membrane. You want a higher R-value? Add another layer of continuous insulation.

If this sounds familiar we have been here before ("Building America," *ASHRAE Journal,* December 2008). We have quite a few ultra-efficient houses under our belt since then. The most recent was the NIST Net Zero Energy Residential Test Facility in Gaithersburg, Md. The photographs and figures are from that project. It was constructed in Gaithersburg, Md., on the NIST campus, but it would work in Boston, Chicago or Toronto. Going the other way it would work in Atlanta or Dallas.

A couple of things I will share with you will sound like heresy. And a couple of things will make some of you wonder if it is worth it. For the record, I think it is worth it, but it sure gets annoying sometimes.

Here goes. Don't bother with the passive solar. Your house will overheat in the winter. Yes, you heard that right. Even in Chicago. Are you listening Passive House? You should go with very, very low SHGCs, around 0.2, in your glazing. If this sounds familiar to those of you who are as old as me, it should. We were here in the late 1970s when "mass and glass" took on "super-insulated." Super-insulated won. And super-insulated won with lousy windows compared to what we have today. What are you folks thinking? Today's "ultra-efficient" crushes the old "super-insulated" and you want to collect solar energy? Leave that to the PV.

There's more. When you build ultratight, simple things become hard. Clothes dryers don't work. Not ones that exhaust to the outside. You are limited to condensing dryers or you have to learn to open a window or install a powered interlocked makeup air system. Trust me, go with the condensing dryer approach. Or a clothes line. You will need the interlocked makeup air system for something else.

Here comes the something else. Your kitchen range hood. You need one. One that exhausts to the outside. You do not want a recirculating range hood. Recirculating range hoods are like toilets that never

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flush that keep swirling around.** You need a kitchen range hood that not only exhausts to the outside but one that also has a high capture efficiency. The higher the capture efficiency of the hood, the lower the exhaust flow rate you need to capture the nasties. And you want a low exhaust flow rate to make life easier with the interlocked makeup air system you need to couple to the range hood. We were here before ("Deal with Manure & Then Don't Suck, *ASHRAE Journal,* July 2013). Expect to need a minimum of 100 cfm (47 L/s) of range hood exhaust with a range hood with a high capture efficiency. You now need 100 cfm (47 L/s) of makeup air. Deliver 70 cfm (33 L/s) of it right under the cooking surface and the remaining 30 cfm (14 L/s) somewhere in the common area. The reason for the 70:30 split is that you need a zone of negative pressure around the cooking surface or you don't capture the nasties effectively.

You need to run the bathroom exhausts through your HRV. The HRV has a "boost" setting that gives you more flow for a couple of minutes when you have a dead cow in the bathroom or something that smells like a dead cow in the bathroom. Configuring the bathroom exhaust this way means that your flows are always balanced. What you exhaust goes through the HRV and is matched by an equal flow in through the HRV. The HRV manufacturers have this figured out well.

Fireplaces? Aw man. Open a window. And leave it open. Or, yup, another makeup air fan just for the fireplace. No other way to do it. How about a video of a fire that you can

**I shamelessly stole this line from John Straube.

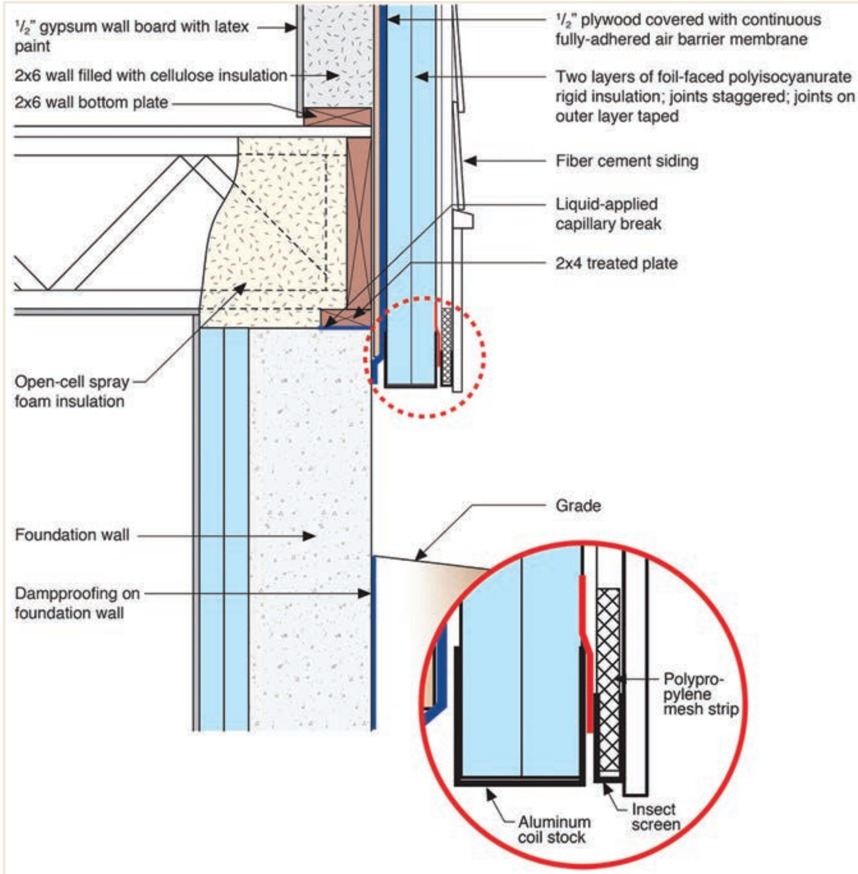

FIGURE 3 Top of Foundation. Note that the fully adhered membrane is sealed to the top of the exterior face of the concrete foundation wall. The membrane will have to be sealed with a mastic or a primer. Also note the physical protection of the bottom of the continuous insulation. This is absolutely necessary to deal with critters. Also note the insect screening.

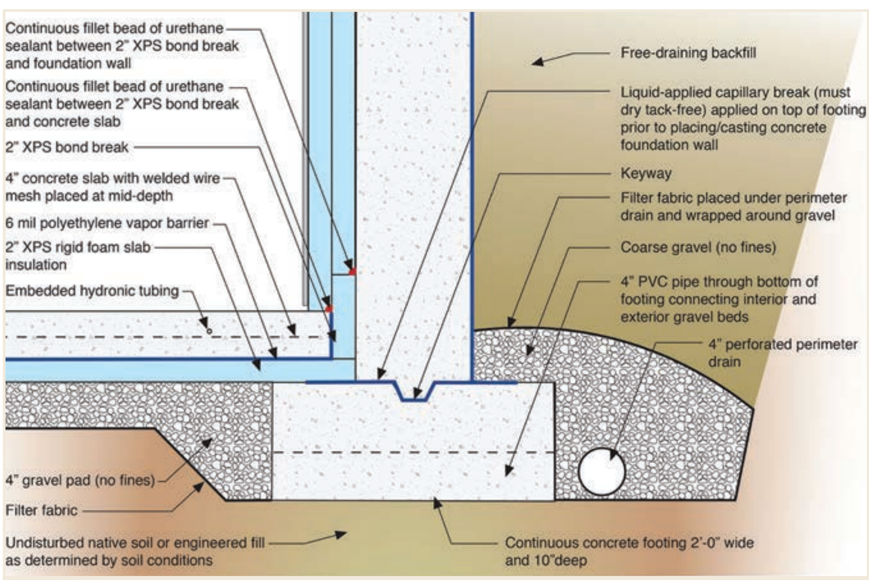

FIGURE 4 Bottom of Foundation. Note the capillary break at the top of the footing. Also, note the two "red" sealant beads. They are absolutely necessary to create an airtight seal between the basement slab and the interior of the perimeter concrete foundation wall. Also note the filter fabric under the gravel pad. Not standard, but a really good idea.

PHOTO 1 (LEFT) No Overhangs. Not yet anyway. Framing is 2 × 6 at 24 in. (610 mm) o.c., advanced framing sheathed with plywood structural sheathing. Could have been OSB. PHOTO 2 (RIGHT) Darth Vader House: Wrapped in a back fully adhered membrane. This membrane is the water control layer, the air control layer and the vapor control layer. It is clearly continuous. It is mastic sealed to the exterior face of the perimeter concrete foundation wall. We end up with an airtight concrete box at the bottom of the house (the basement floor slab is sealed to the perimeter concrete foundation wall that is sealed to a membrane wrapped sheathed structural frame. It does not get tighter than this. In terms of airtightness, it is so simple, so straightforward, so effective even a caveman can do it. Don't like black? Use a blue membrane. Don't like vapor closed? Use vapor open; it does not matter. The plywood or the OSB is the vapor "throttle."

PHOTO 3 Overhang Framing. "Lookout" framing added over the top of the membrane. Rigid insulation is cut to fit into the "lookout" frame cavities and then covered with a continuous layer (or two) of insulation.

PHOTO 4 Continuous Insulation. The entire airtight assembly is insulated above grade with continuous insulation. In this case two layers of 2 in. (50.8 mm) foil faced polyisocyanurate. Could have been XPS or EPS or rockwool up to 8 in. (203 mm) thick.

play on your VCR? That does not do it for me. Don't forget the carbon monoxide detectors. A couple of them. Each level.

Don't pretend that because your house is "ultratight" and "ultrainsulated" and otherwise "ultra" that you don't need to move air around. Trust me on this. You need to mix the air for thermal comfort reasons. You will get hot spots and cold spots. And besides, you need to distribute the outside air to dilute the nasties. Don't forget the air quality thing. Suck the bad air out of the bathrooms and supply the good air to the bedrooms. And don't forget the mixing. Split system heat pumps with two heads don't do it. Even with transfer grilles or no doors. The true believers are not going to believe this. Go ahead. Make me a liar. I would love to be proven wrong on this. Maybe if you live in paradise you don't need to do this. But not Chicago, Boston or Toronto.

So how do you get the house to be ultratight? And ultrainsulated? We have pretty much settled on one approach because it is robust and gets us consistently tight. Real tight. Ultratight. Tighter than even "my metric." German tight. We like advanced frame 2 × 6 construction (*ASHRAE Journal,* November 2009) fully sheathed with plywood or OSB and wrapped with a fully adhered membrane. Outboard of the membrane we go with continuous insulation. Lots of continuous insulation. And we don't care whose. They all work.

This is laid out in *Figures 1, 2, 3* and *4*. This is the "perfect wall" put into practice (*ASHRAE Journal*, May 2007). The roof is an unvented compact roof. The basement is insulated on the interior. Exterior insulation has too many problems. We will save that discussion for another day. Until then, remember that the critters and insects will probably win if you don't listen to me.

The big thing to note is that there are no "overhangs" when the sheathed structural fame is wrapped with the fully adhered membrane (*Photos 1* and *2*). The fully adhered membrane is sealed to the exterior face of the concrete foundation. We end up with an airtight concrete box at the bottom of the house (the basement floor slab is sealed to the perimeter concrete foundation wall that is sealed to a membrane wrapped sheathed structural frame. It does not get tighter than this. In terms of airtightness, it is so simple, so straightforward, so effective even a caveman can do it. And you can have complex shapes, massing and geometries. Try that with a double wall and an architect from California.

Overhang framing is added over the top of fully adhered membrane in the form of "lookouts" (*Photo 3*). The entire airtight assembly is insulated externally above grade with continuous insulation (*Photo 4*).

It does not matter what continuous insulation you use. We have used them all. In this particular house (the "NIST house") we used foil faced polyisocyanurate. We could have used extruded polystyrene (XPS) or expanded polystyrene (EPS) or

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rockwool. Each have their advantages or disadvantages. Thermal resistances vary among the insulations so the number of inches of thickness will need to vary. As a general rule:

- 4 in. (100 mm) of isocyanurate gives you R-24;
- 5 in. (125 mm) of XPS gives you R-25;
- 6 in. (150 mm) of EPS gives you R-23; and
- 6 in. of rockwool gives you R-24.

I view the above to be equivalent. Note that with this approach you can easily go to 8 in. (203 mm) thicknesses of continuous insulation and not get into trouble with attaching cladding when you hold things together with 1 × 4 furring and long screws.

Over the 1 × 4 furring goes cladding (*Photo 5*) and you are done (*Photo 6*).

The implications are pretty interesting. You can use any cavity insulation you want. You want to use cellulose? Go for it. Damp spray or netted? Does not matter. You want to use fiberglass batts? No problem. Blown in blanket? Go for it. Low density spray foam? OK. High density? No problem. From a hygrothermal perspective this works for all climates.

The fully adhered membrane? It doesn't matter if it is vapor open or vapor closed or vapor in between. That goes for anywhere, Atlanta to Ottawa. Neat, eh?

On the exterior the same thing goes, pretty much. The thermal resistance of the exterior continuous insulation is going to have to be increased as you go to colder climates but type of product will not matter. You don't like foams? OK, don't use them. You like fluffy rocks? Go for it. You don't like this blowing agent or that fire retardant? OK, don't use the product. Use a different product. The fundamental approach works everywhere. Note, once again, from a hygrothermal perspective this works for all climates. You not happy with only R-60? Go to R-80. The membrane wrapped sheathed advanced framed wood structural frame is the constant. It gets you the ultratightness and the flexibility to do almost anything else you want to do.

All the details remain the same. Even the windows (*Figures 5* and *6*). One caveat here. With rockwool, you will have to use unflanged windows and a two-stage joint since the water control layer is the fully adhered membrane not the exterior face of the continuous insulation, as is the case with isocyanurate, XPS and EPS.

The approach is not R-value limited or material limited. So everyone should be happy. OK, that will never happen, but most folks will be happy. So be ultratight, ultraefficient and ultrahappy.

PHOTO 5 (LEFT) Cladding Attachment. Pretty straightforward. Cladding is installed over the 1 × 4 furring. PHOTO 6 (RIGHT) Done Deal. NIST Net Zero Energy Residential Test Facility, Gaithersburg, Md.

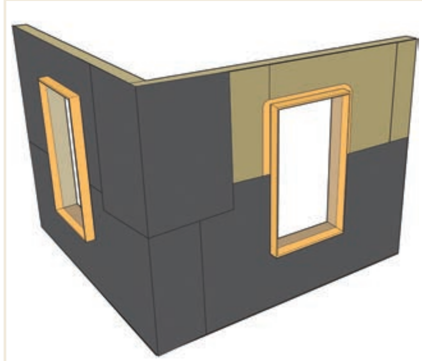

FIGURE 5 Window Framing. Note the plywood or OSB rough opening extension protruding past the exterior face of the sheathing. The protrusion dimension is the thickness of the continuous insulation. The opening is waterproofed with a fluid applied flashing. This detail remains the same for all of the various continuous insulation types.

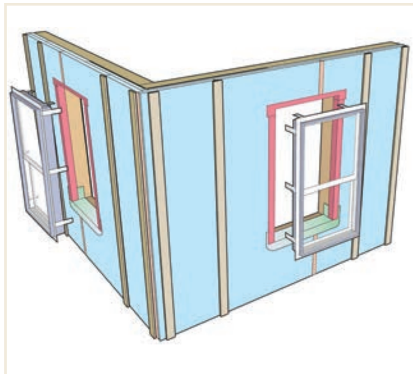

FIGURE 6 Window Installation. Note the mounting brackets attached to standard flanged windows. Mounting brackets for masonry openings are used. Also note the pan flashing. The window is waterproofed to the face of the exterior sheathing. This detail remains the same for all of the various continuous insulation types. One caveat here. With rockwool, you will have to use unflanged windows and a two-stage joint since the water control layer is the fully adhered membrane, not the exterior face of the continuous insulation, as is the case with isocyanurate, XPS and EPS.

Acknowledgments

All photos are courtesy of A. Hunter Fanney, Ph.D., senior research scientist, Energy and Environment Division, National Institute of Standards and Technology. Hunter made the NIST Net Zero Energy Residential Test Facility happen. It actually nets out as net zero. Detailed information can be found at www.nist.gov/el/nzertf/ and in Pettit, B., Fanney, A. H. and Healy, W. M.; "Design Challenges of the NIST Net Zero Energy Residential Test Facility."NIST Technical Note, Sept. 2014. ■

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