BY MARTIN HOLLADAY

"Musings of an Energy Nerd" showcases the best of Martin Holladay's weekly blog at GreenBuildingAdvisor.com, where he provides commonsense advice about energy issues to residential designers and builders. His conclusions usually fall between minimum code compliance and the Passive House standard, which often makes them controversial to both building-science geeks and everyday builders.

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Closed-cell foam between studs is a waste

Open-cell spray foam has an R-value of about R-3.7 per inch, while closed-cell spray foam has an R-value that may be as high as R-6.5 per inch. If you want to install spray foam in a stud wall, and price is no object, then it would seem to make sense to specify closed-cell spray foam, right? Well, not necessarily.

What really matters is the R-value of the whole wall, not just that of the insulation. There isn't much difference in whole-wall R-value between a wall insulated with open-cell spray foam and one insulated with closed-cell spray foam.

To understand why, we need to start by understanding the "trimmability" of cured foam. Closed-cell foam is so dense that it is difficult to trim. To avoid having to trim closed-cell foam in a 2x4 wall, for example, the installer will usually stop at a maximum depth of about 3 in., instead of 3½ in., leaving the typically bumpy surface of cured foam and about a ½-in. gap to the back of the drywall.

Open-cell spray foam isn't as dense, so it's easy to trim. Installers of open-cell spray foam will fill a 3½-in.-deep cavity completely, allowing the foam to expand until it is proud of the studs. Once cured, the soft foam is easily trimmed flush with the studs.

Whole-wall R-values

To calculate the whole-wall R-value of a wall, we have to divide it into areas, each with distinct R-values. For example, a 2x4 wall without any windows can be divided into two areas: insulated stud bays and wood framing.

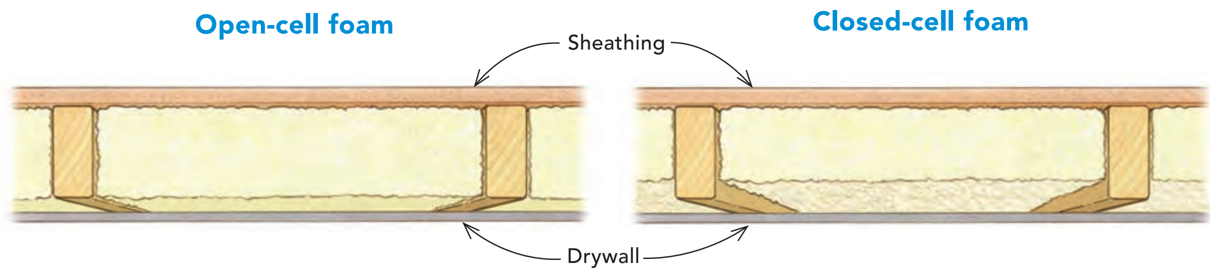
A typical wood-framed wall has a "framing factor" of 25%. That means that about 25% of the wall area consists of studs, plates, and headers. The remaining 75% of the wall consists of either stud bays

Sprayed and trimmed. *Open-cell foam is sprayed to overfill the cavity. After curing, the foam is trimmed flush with the faces of the studs.*

filled with insulation or openings for windows or doors.

To calculate whole-wall R-value, you first need to calculate the whole-wall U-factor. (U-factor is the reciprocal of R-value: U=1/R.) Let's call the U-factor of the insula-

MIND THE GAP



Although the R-value is less per inch than insulation, studs do have an R-value that contributes to the overall R-value of the wall. While open-cell foam gets trimmed flush with the stud faces, closed-cell foam is held back about ½ in. This ½ in. of stud with exposed sides doesn't contribute to the stud's R-value, resulting in a reduction to the wall's overall R-value.

Photos: left, courtesy of Karyn Patno; right, courtesy of Icynene. Drawings: Dan Thornton.

tion “UI,” and the U-factor of the framing “UF.” Here’s how we calculate whole-wall U-factor for a wall without any windows or doors:

Whole-wall U-factor = (UI x % area devoted to insulation) + (UF x % area devoted to framing)

When stud bays are partially filled with closed-cell spray foam, the exposed portion of the studs reduces their R-value in comparison to a wall that is totally filled with open-cell spray foam. For example, if a 2x4 wall has 3 in. of closed-cell foam insulation, the R-value of the studs is based on a stud depth of 3 in., not 3½ in. (because the exposed portions of the studs are basically “indoors” and not part of the insulated wall assembly). As a result, the heat loss due to thermal bridging through the framing is greater in a wall with closed-cell foam than it would be in a wall with open-cell foam.

Consequently, if you install a closed-cell foam insulation with a high R-value per inch between your studs, you don’t really get the full value of your investment. Closed-cell spray foam is expensive, and the incremental cost is mostly money down the drain. There are more cost-effective energy upgrades, such as exterior rigid foam or mineral-wool insulation, as I point out below. It’s also worth considering an even more important issue: Most brands of closed-cell spray foam are more injurious to the atmosphere than open-cell spray foams, since most closed-cell spray foam is manu-

THE PROOF IS IN THE MATH

In a typical wall where 25% of the space is framing, the R-value of the studs and plates has a significant effect on whole-wall R-value. This table compares a 2x4 wall insulated with 3½ in. of open-cell foam to a 2x4 wall insulated with 3 in. of closed-cell foam, as well as 2x6 walls insulated with 5½ in. of open-cell foam and 5 in. of closed-cell foam. The ½ in. of stud left exposed with closed-cell foam is essentially inside the house, and so doesn’t contribute any R-value, bringing the whole-wall R-values much closer. In a 2x4 wall, the gain is only R-0.8, while closed-cell foam in a 2x6 wall yields an increase of R-1.9. Perhaps you’re wondering, “Is it really worth a $3,000 upcharge for such a small improvement?” The increase in R-value is so small that most builders would be better off looking for a more cost-effective insulation upgrade.

Properties	2x4 wall		2x6 wall	
	Open-cell spray foam	Closed-cell spray foam	Open-cell spray foam	Closed-cell spray foam
R-value per in. of spray foam	R-3.7	R-6.5	R-3.7	R-6.5
Thickness of spray foam	3½ in.	3 in.	5½ in.	5.0 in.
Thickness of airspace	0 in.	½ in.	0 in.	½ in.
R-value of spray-foam areas	R-13	R-19.5	R-20.3	R-32.5
R-value of airspace, if any	R-0	R-0.9	R-0	R-0.9
R-value of spray foam plus airspace	R-13	R-20.4	R-20.3	R-33.4
U-factor of spray-foam areas	U-0.077	U-0.049	U-0.049	U-0.030
R-value per in. of framing	R-1.2	R-1.2	R-1.2	R-1.2
Effective framing thickness	3½ in.	3 in.	5½ in.	5 in.
R-value of framing	R-4.2	R-3.6	R-6.6	R-6
U-factor of framing	U-0.24	U-0.28	U-0.15	U-0.17
Whole-wall U-factor (see formula above)	(0.75*0.077)+(0.25*0.24) = U-0.118	(0.75*0.049)+(0.25*0.28) = U-0.107	(0.75*0.049)+(0.25*0.15) = U-0.074	(0.75*0.030)+(0.25*0.17) = U-0.065
Whole-wall R-value	R-8.5	R-9.3	R-13.5	R-15.4
R-value gained by switching from open-cell to closed-cell		R-0.8		R-1.9

factured with a blowing agent that has a high global-warming potential.

The examples aren't perfect

I'm aware that the whole-wall R-value calculations in the table are simplified versions of actual whole-wall R-value calculations. I haven't included the R-value of the exterior OSB sheathing, the interior drywall, or the associated air films. Moreover, the table doesn't reflect the entire range of framing factors of different buildings.

That said, the table is useful. It demonstrates the calculation method and does a good job of estimating the incremental R-value attributable to an upgrade from open-cell to closed-cell foam. While it's true that actual whole-wall R-values will usually be higher than the values shown in the table (due to the R-values of the sheathing, drywall, and air-barrier membranes), both types of wall (open-cell and closed-cell) benefit equally from these additional R-values.

While I've focused on walls, the same analysis applies to cathedral ceiling assemblies. If rafter bays are completely filled with fluffy insulation (except for a ventilation channel directly below the sheathing), thermal bridging through the rafters will be less significant than when 4 in. of each rafter protrudes inward beyond the depth of a skimpy application of spray foam.

So what's the solution?

At this point, we need to consider the use of exterior rigid foam. The calculations for adding thicker continuous insulation on the exterior side of the wall sheathing are much more favorable to incremental investments than the calculations for insulation installed between studs.

If you install a high R-value continuous rigid insulation on the exterior side of the sheathing—for example, rigid foam or mineral wool—all of the insulation's R-value contributes to the whole-wall R-value (except, of course, for areas taken up by windows and doors).

Additionally, unlike between-studs insulation, exterior high R-value insulation helps to minimize the thermal bridging effect of the studs. Used properly, it also reduces the need for a vapor retarder by keeping the sheathing warmer than the dew point. Even though exterior rigid insulation requires extra detailing around windows and doors, it still offers excellent value for your money.