Building a Tight

A construction engineer on the path to energy efficiency describes his strategy for air-sealing the envelope of his own home

I recently built a net-zero energy house for my family; it's the first one in our area. Because I'm in the business of teaching others how to build energy-efficient houses, I naturally wanted my own house to be as energy efficient as possible. Any house—especially one meant to use as little energy as possible—is an assembly of closely linked components, and one of the most important details is an airtight shell. During the construction, we used a blower-door test at three separate times to evaluate our progress.

When a house leaks air, the amount of energy needed to make it comfortable is enormous. Heating and cooling systems are not capable of reacting fast enough to overcome the quick change in air temperature caused by wind blowing into the structure. Through the use of blower-door tests, my company constantly evaluates houses only to find air leakage that's two to ten times the amount mandated by the 2009 International Energy Conservation Code (IECC).

When I started building this house, I knew from experience that the job of minimizing air leaks had to be a team effort that started with training all the tradespeople working on the project. I required that each contractor attend a one-hour seminar on the techniques and benefits of air-sealing. At first, contractors were hesitant to spend time discussing this topic, but by the end of the seminar, they had enthusiastically embraced the concept. They realized that air-sealing was achievable with simple techniques and commercially available products. They also realized that this was a marketable skill that could give them an edge over their competition.

Photo this page: courtesy of George Keithan Jr.

House

BY GEORGE KEITHAN JR.

Air-sealing isn't difficult, but it must be done carefully. The process has a relatively low materials cost, but requires additional labor. On a 2000-sq.-ft. house, a contractor can spend an extra $500 to $1000 in materials and two weeks of labor to seal the home tightly beyond the 7 ACH (air changes per hour) required by the IECC. This effort could translate into an annual savings of 10% to 15% in energy bills. At today's high energy costs, that could pay back in five to eight years, and continue to pay for itself for the life of the building. There are also other air-

BLOWER-DOOR TESTS FIND WHERE THE HOUSE LEAKS

In a house that hasn't been air-sealed, energy efficiency is compromised by the amount of air that leaks in and out of the structure. One of the best ways to see where a house leaks is to perform a blower-door test. A calibrated fan placed in an exterior-door opening depressurizes the house (sucks the air out of the house) at a set pressure. The amount of air that passes through the fan is then measured. While the fan is running, air leaks can be discovered using smoke candles and visual inspection.

TYPICAL HOUSE AIR LEAKS

31%	Floors, walls, and ceilings
15%	Ducts
14%	Fireplace
13%	Plumbing penetrations
11%	Doors
10%	Windows
4%	Fans and vents
2%	Electrical outlets

sealing benefits that don't have a payback but increase comfort for the homeowner. With proper air-sealing, drafts are eliminated in the house, and the house has more consistent room-to-room temperatures. Also, noise from outside is minimized because proper air-sealing blocks travel paths for sound.

An air barrier needs to be complete, flexible, and tough

The concept of air-sealing is simple: Keep air from moving through cracks, gaps, and holes from one side of the wall to the other. Air flows along the path of least resistance. Because a house is like a chimney, there is a pressure differential between the floors. Air typically likes to enter low and exit high. Sometimes the opposite is true. In either case, the most critical points to seal in a house are at the basement (or crawlspace) and the attic.

As long as all air gaps are sealed, air barriers can be located outside or inside the wall. During a new-construction project, however, I think that it's easier and more effective to seal from the outside because you can look at the work. Plus, if after the first blower-door test you find the exterior air-sealing not performing as it should, additional air-sealing on the interior can enhance the overall effectiveness of the system. Air-sealing also must be continuous, and when completed on the exterior of the building, it is visually more apparent that no lines of the air barrier have been broken.

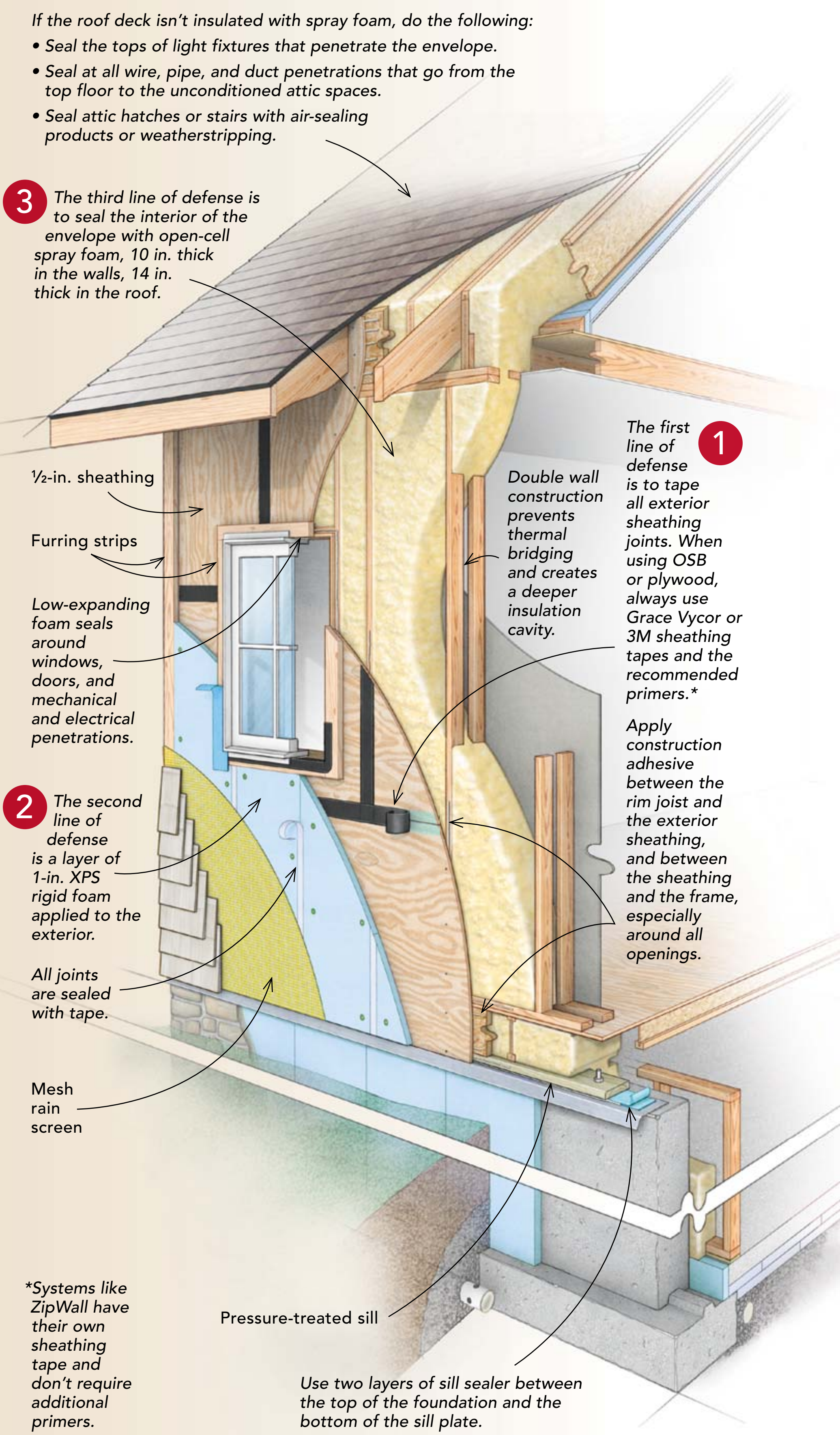
If you put two dissimilar materials together, there will be a gap. There is a gap between wood on concrete, wood on metal, wood on plastic, and wood on wood. For example, sill sealers are used between the top of a concrete wall and the pressure-treated sill plate. Often, sill sealers are too thin to fill irregularities in concrete, so we use a double layer of sill sealer. Then we have a better chance of filling the voids between the concrete and the wood sill at a low added cost.

Air-sealing begins with the sheathing

In my house, we used three levels of air-sealing to get the lowest possible HERS (home-energy rating system) index. The first air barrier is the sheathing, which we glued to the framing with construction adhesive. We then applied sheathing tape to the seams of the sheathing to create an airtight shell.

For the second layer of the air barrier, we installed 1-in. XPS foam board on the en-

THREE LINES OF DEFENSE IN THE



Drawings: John Hartman. Photo top left, facing page: courtesy of George Keithan Jr.

BATTLE AGAINST AIR LEAKS

Unlike an existing house that needs to be retrofitted, a new house can be sealed efficiently as it's being built. The roof deck can be sealed, which alleviates the need to seal penetrations between the upper floors and the attic. There's less chance for error and a better chance that the house will become energy efficient. Think of air-sealing in terms of three lines of defense, with the first being the exterior shell.

1 SEAL THE FRAMING AND SHEATHING

The envelope is the primary air barrier

Begin by installing a double foam sill sealer between the foundation wall and the sill plate (below left). A bead of construction adhesive between the sealer and the aluminum termite shield and between the shield and the concrete fills any gaps. The air barrier must be continuous. Seal the sheathing to the frame and the rim joists with construction adhesive (below right). Prep all sheathing joints with flashing-tape primer and then seal with flashing tape.

2 APPLY RIGID FOAM TO THE EXTERIOR

Create a thermal break, increase the R-value

Foam board can be applied over taped sheathing as an additional air barrier. The panels are applied with recommended fasteners, and the seams are sealed with tape. Seams are staggered if multiple layers are used.

3 SPRAY FOAM

Air-seal all exterior framing cavities

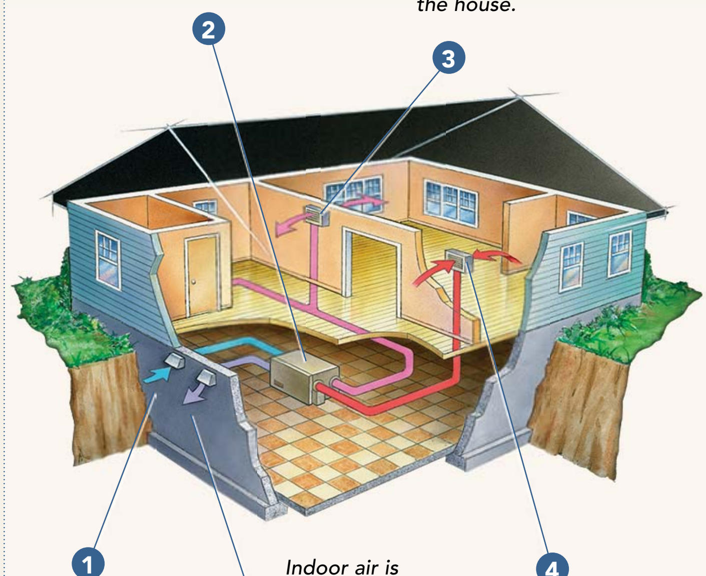
Spray closed- or open-cell foam into all wall- and roof-framing bays when possible. If there is an attic space, spraying the underside of the roof deck rather than the floor of the attic makes the sealing process easier. It's difficult to air-seal all the penetrations between the top floor and the attic, so air-sealing at the roof is simpler and creates a semiconditioned space that won't get too hot or too cold. Windows and doors can be sealed easily with expanding foam during construction.

Adding air to an airtight house

When building a new house, it's important to understand the following concept: Build it tight, and ventilate right. When a house is air-sealed to a minimum number of air changes per hour, the house needs supplemental ventilation. However, most homeowners wonder if it really makes sense to air-seal if they then need to spend more money on ways to get air back into a house.

Remember that a home built without air-sealing may leak 2500 cfm50 (cubic feet per minute), while the same home that's air-sealed may leak only 500 cfm50. An average energy- or heat-recovery ventilator introduces an additional 100 cfm of air to ventilate a house properly. Approximately 2000 cfm of energy-sucking air is still kept out of the house, saving money in the long run.

In my house, I used a Fantech energy-recovery ventilator (ERV) to ventilate the house effectively year-round. Although ERVs are typically used in cooling climates, this ventilator has an interchangeable core that can transform it into an HRV (heat-recovery ventilator). With a tight house, I hoped to use the ERV for the winter so that I would not need to add humidification. Last winter, we were able to maintain 40% to 45% relative humidity in the house with no humidifier. This winter, I am going to change the core to an HRV and see how it feels with that in place. I was a little concerned about the higher relative humidity in the walls on very cold days. In a standard house with lots of air leakage, this could be an issue in a cold climate.



Fresh air enters the heat exchanger, which is made of a conductive material like aluminum or plastic. The energy from the exhaust air conditions the intake air. Air streams are separated to keep exhausted contaminants from entering incoming air.

Semiconditioned outdoor air is pulled to the central blower or directly into supply ductwork, where it is circulated throughout the house.

1 A fan draws fresh outdoor air into the HRV.

5 Indoor air is exhausted outside the home.

4 Conditioned indoor air is pulled into the HRV, where it heats or cools incoming air.

FIRST TEST
1.28 ACH
(547 cfm50)
After sheathing, foam board, windows, and doors were installed

SECOND TEST
0.96 ACH
(410 cfm50)
After spray foam was installed

THIRD TEST
0.66 ACH
(285 cfm50)
After drywall and paint

How tight is tight?

Blower-door test results are expressed in cubic feet per minute (cfm). When measuring air leakage, this value is combined with an industry-adopted standard of 50 pascals (a pascal is a measure of pressure) as a pressure rating and is abbreviated as cfm50.

Blower-door test results also can be expressed in air changes per hour (ACH), the measurement used in code language. Air changes per hour are determined by dividing cfm by the volume, then multiplying that sum by 60 minutes. [ACH = (cfm/volume) x 60].

It's instructive to note that although code specifies a minimum of 7 ACH, a tight, energy-efficient 2000-sq.-ft. house should have a result closer to 2 ACH. For my house, I wanted to be under 0.8 ACH at cfm50 and find out how low we could go. Although blower-door tests are often performed at the end of each stage of air-sealing, our procedure was a bit different. The end result was instructive, as the results above indicate.

Our goal for the first test was to get as close to zero as possible. I was disappointed at first because I thought we would start around 400 cfm.

We knew there would be leakage, but didn't know how much. We never exceeded our expectations, but in the end, we were not disappointed either. When doing research like this, we had to set goals that were going to be tough to achieve at all levels.

tire exterior of the house and taped all those seams. The foam board had two functions. First, it is an additional air barrier; second, it acts as a thermal break between the wall framing and the exterior siding. In a typical scenario, we use 1-in. XPS and then a mesh rain screen to protect the wood siding.

In this case, housewrap was not needed. Housewrap can be used as part of an air barrier, but it is tricky to detail correctly during installation and must be protected throughout construction. Tears and punctures must be fixed before the siding is installed.

The advantage of using housewrap is that it's less expensive than rigid foam and it's faster to install. But for 50¢ to 60¢ per sq. ft. more for the materials, I believe that rigid foam is worth the added expense. And combined with taped sheathing joints that create a better air barrier than housewrap, the two layers make a better system.

The third and final air-sealing was accomplished by using Icynene in the walls and roof. This open-cell spray foam expands 100 times its initial application thickness, which fills cracks and gaps and reduces air infiltration even further. We also sealed all gaps between the windows and door jambs and the rough openings with low-expanding foam.

Even after all this work, problems can arise when the HVAC, plumbing, and electrical subs get on the job and cut out a lot of the air-sealing protection as they install their systems. The greatest leakage comes from chimney chases, wiring penetrations, light-fixture penetrations, plumbing vent stacks, and building cavities used for ductwork. The only thing you can do is to be diligent about sealing leaks as they occur.

In my house, we did not have a fireplace inside the building envelope, so we didn't need to air-seal the flue. Because we used a geothermal heat pump, there aren't any combustion intakes or exhausts.

After we performed several blower-door tests, we were able to see that the successive layers of air-sealing had a tremendous effect on the energy efficiency of the house. With cutting-edge technologies available in wind, solar, and geothermal, it is gratifying to know that the simplest, most cost-effective systems such as air-sealing still make the largest impact when trying to save energy. □

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