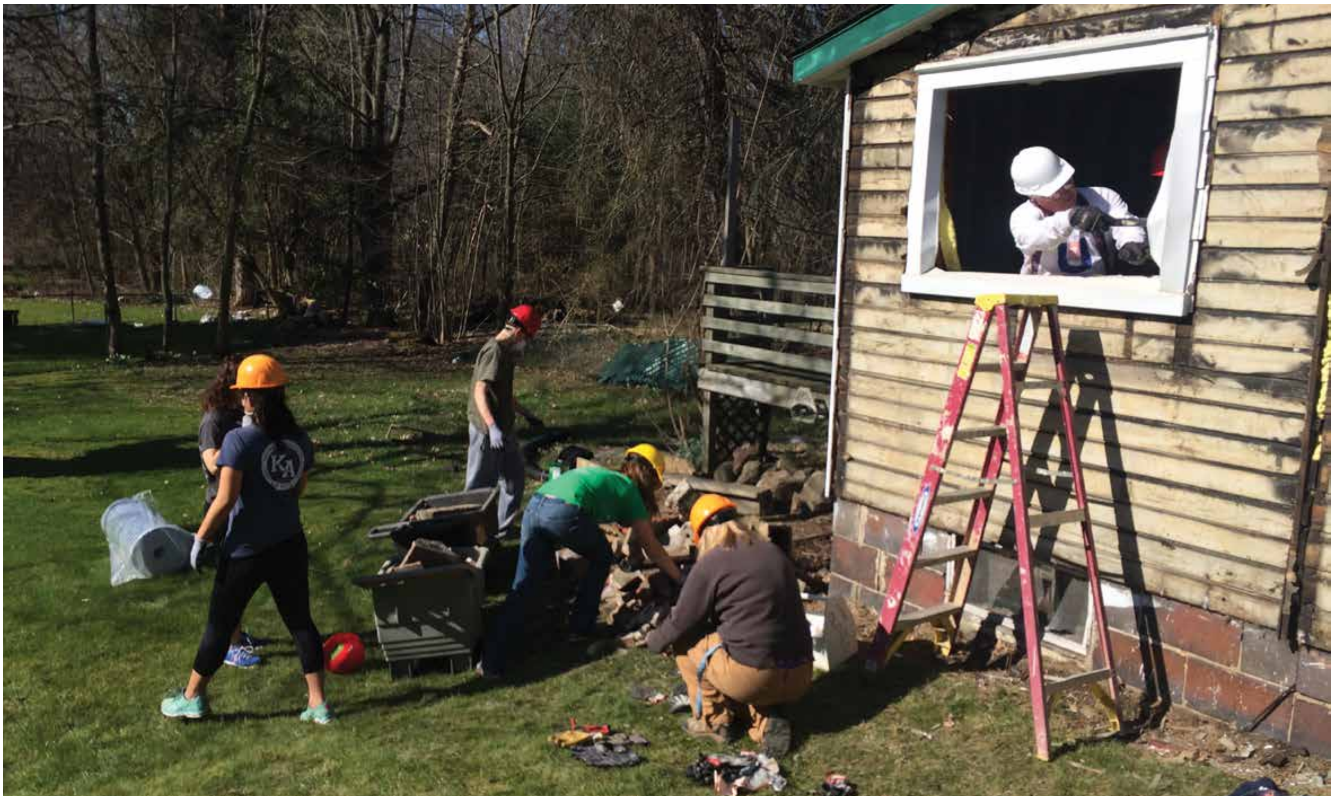

Photos by Nate Adams

A Habitat Energy Makeover

Donated labor and materials made this building-science feat feasible

BY NATE ADAMS

Who knew Habitat for Humanity doesn't just build new homes? I found out early this year, when I got a call from Scott Craven, the construction manager for Habitat for Humanity of Portage County, Ohio. Scott's Habitat chapter normally builds new homes, and Scott found my website while looking for help with this rather tricky existing house. In Ohio, I learned, Habitat is bringing cutting-edge thinking to retrofit work—and proving that you don't have to be rich to do deep energy retrofits.

My company was a good match for this project. Over the last decade, I've evolved from an insulation salesman, into an insulation contractor, into a home-performance consultant. Today, my business brings current building-science thinking to the diagnosis and improvement of existing houses. Using a consultative approach, we start with a full energy audit, applying accurate energy modeling. We then recommend and implement a complete home-performance package: high-performance envelope details, appropriate HVAC upgrades, and air-quality assurance. When we're done, we "test out" to verify the effectiveness of our work—often, as on this project, installing data-logging instruments to monitor energy performance and air quality over time. What follows is the story of the diagnosis, design, and most of the energy work on this Habitat project.

Habitat had originally acquired this home because it fit the requirements of a disabled client who wanted a small home with an open floor plan in a city full of older homes. Sadly, the client passed away suddenly—and the house sat empty while Habitat looked for another client who would be a good fit. Houses don't like to sit: They get wet. So when the project started up again, we had a few extra things to deal with. But on the plus side, we had plenty of volunteer labor, as well as some donated materials (including roofing and rigid

After sitting unoccupied while Habitat for Humanity searched for an appropriate owner, this old one-story house represented a "perfect gut opportunity" for the organization's volunteers, the author says. But moisture and energy issues were a big challenge. The home's measured air leakage was off the charts **(1)**. The dirt crawlspace created a huge moisture load for the interior **(2)**. Mechanicals in the basement were fully depreciated **(3)**, and the roof showed obvious moisture damage **(4)**.

XPS insulation). And we had something of a blank slate: We would be able to make the most of the existing open plan, "cathedralize" the ceiling to make the small volume feel light and spacious, aim for very low air leakage, and design our HVAC solution from scratch.

DIAGNOSIS AND DECISIONS

In March, I inspected the house with Scott Craven and conducted an energy audit. The tiny cellar with its 6-foot ceiling extended under only a quarter of the house. The rest had a low dirt crawlspace. The whole thing was surprisingly wet. Steel Lally columns were rusted through. The furnace and water heater had been red-tagged by the gas company as a hazard. The ductwork was literally being held together with Saran Wrap. A perfect gut opportunity!

In his 2005 book, *Water in Buildings,* University of Illinois research architect Bill Rose noted that every home he has inspected with a dirt crawlspace had moisture problems in the attic. This house fit the pattern: The roof sheathing was moldy, and in some locations, rotten. Our plan would have to address the moisture issues.

Next, we ran a blower-door test. This was one of the leakiest homes I've ever tested. As a rule of thumb, we've found that a blower-door number roughly equal to square footage gives us enough control to solve client problems (that is, a 1:1 ratio of leakage to square footage). This house is only 720 square feet and its blower-door result was a whopping 12,000 cubic feet per minute at 50 pascals (cfm50)—a 16:1 ratio. To be fair, the house was completely gutted, so the real ratio was likely closer to 4:1. Still, a house that leaky is a major challenge.

So here was our situation: The house had substantial moisture problems, it needed complete insulation and HVAC systems, and we had a limited budget. But we did have lots of volunteer labor. I wondered at times if I had bitten off more than I could chew.

MODELING THE ENERGY OPTIONS

Package	Blower Door Target (cfm50)	Heating Btu/hr/sf	Cooling Btu/hr/sf	Heat Load	Cooling Load	Package Cost	Annual Savings	% Savings
Baseline: Old and leaky, R-11 in attic	2,500 (actual)	33	13	23,837	9,561	$0	$0	0%
Package 1: Typical weatherization	700 (estimated)	15	5	10,841	3,810	$12,965	$388	69%
Package 2: Foam board plus spray foam, very airtight	110 (estimated)	8	6	5,634	4,480	$14,200	$506	72%
Package 3: Adds heat pump water heater and ventilating dehumidifier	110 (estimated)	8	6	5,634	4,480	$19,500	$671	77%
Package 4: Omits rigid roof foam, less airtight	400 (actual)	11	7	8,166	5,019	$19,500	$612	75%
Package 5: Adds triple-pane windows	110 (estimated)	7	4	5,392	3,160	$22,000	$690	78%

TREAT modeling software, which the author trusts based on past experience, created savings projections for several retrofit proposals. Based on costs and benefits, the author chose Package 4. The model had assumed very low air leakage (110 cfm50), but the actual Package 4 airtightness (400 cfm50) still resulted in a major improvement over the baseline.

THE DESIGN PUZZLE

We have developed what we call a "comprehensive planning process" that helps break complex problems down into small bites. Beginning with a baseline energy audit, we apply iterative energy modeling to help develop the best path to success, given client problems, objectives, and budget.

My initial thought was to tackle the house with traditional weatherization tactics: Air-seal the attic, dense-pack the walls with cellulose, and put a vapor barrier down in the basement. But the likelihood of a good leakage result with this approach was low, and it failed to address the existing attic moisture problems. We needed to dig deeper. We turned to iterative energy modeling, using TREAT energy-audit software from Performance Systems Development (psdconsulting.com). (TREAT stands for Targeted Retrofit Energy Analysis Tool.)

As we modeled various pathways, a thorough air-sealing of the whole enclosure emerged as the best option. In this case, that meant spray foam. It would cover the moisture problems and encapsulate them, thus eliminating a remediation problem we didn't have a budget for, and at the same time, would solve the Swiss-cheese leakage problem. As long as we were sure to consistently dry the building before sealing it up, moisture issues should remain licked. Spray foam also provided 72% greater modeled energy savings compared with the standard weatherization package and allowed us to confidently use very small heating equipment. Finally, spray foam made the project drywall-ready quickly—a volunteer drywall party was breathing down our necks.

ENVELOPE

Our initial design would have treated the roof and walls the same: 1 to 2 inches of spray foam inside (primarily for the air-sealing benefit), with rigid foam outside for the insulation benefit. The rigid foam was donated by Dow and would be installed with volunteer labor. Our final implemented package increased the roof-deck spray foam and deleted the exterior foam on the roof. The additional spray foam cost more, but this approach avoided the complexity and time of applying foam board to the roof.

The spray foam was not as effective an air-sealing solution as I had hoped. But after the foam was completed and we put a cover on the basement door in the rear, the house was at about 1,500 cfm50. At that point, we did additional air-sealing with a one-part gun foam. I depressurized the house and looked for misses and low spots. That brought it down to about 1,000. Then, I used theatrical smoke and pressurized the house, observing where the fog blew out. The Habitat volunteers helped find the leak points, and I sealed them one by one.

After two rounds of touch-up air-sealing, we got the house down to 440 cfm50 before drywall. My very optimistic target of 110 cfm50 was not likely to happen. I was disappointed about that, but it was still an excellent result: This may be the tightest house in the county. These numbers also imply that the 700 cfm50 target for the non-foam weatherization package was wildly optimistic: I would have been lucky to get this house close to 1,000 cfm50 using traditional methods. Spray foam put this home's heating and cooling load well within range of our chosen HVAC solution.

The author turned to spray foam as a one-pass insulating and air-sealing solution. The foam quickly addressed major air leaks like the big gaps between pieces of the existing board sheathing **(5)**. Volunteers added donated rigid XPS insulation sheets to the exterior **(6)** to augment the R-value of the wall system. Spray foam in the basement cut the heat loss to the ground, as well as limiting the building's vapor load. A foam application sealed the ground vapor barrier to the wall **(7)**. A fog machine **(8)** helped to identify remaining air leaks for point-sealing with one-part gun foam.

ENERGY AND AIR QUALITY

In a house this tight that also had previous moisture problems, we wanted to be sure that it would have sufficient dehumidification in both heating and cooling seasons. Our usual choice for managing fresh air and humidity is a ventilating dehumidifier—a device that brings in fresh air to the duct system and dehumidifies as needed, any time of year. It then distributes the air throughout the home using the duct system. (For this project, the unit was kindly donated by Ken Gehring and Thermastor.)

Combined with a media filter on a central duct system, the ventilating dehumidifier lets us control humidity and particulate matter (PM2.5). Research indicates that by controlling humidity, we help to control volatile organic compounds (VOCs), as well (see, for example, Dr. Richard Corsi's work at the University of Texas). The home should have excellent indoor air quality (IAQ) by design.

In the past year or so, we have begun monitoring some of our project homes using Foobot IAQ monitors. We have noticed that VOC levels spike along with humidity—confirmation of how important good dehumidification is to comfort and IAQ.

With this fresh-air supply technique, the temperature of incoming air can be a comfort problem. Because we lost some of the tempering capability of an HRV/ERV, we ran extra-long uninsulated duct through the basement to help temper the incoming air.

Shown on the next page is the ventilating dehumidifier in the basement. On the right is a 35-foot-long intake line. Nearby is the motorized damper to open and close the intake at high and low temperatures. The "T" allows fresh air to go directly into the HVAC system and bypass the dehumidifier when dehumidification is not required. We have dampers everywhere so that we can easily adjust and balance the system during commissioning. There is also

9

10

The author's preferred HVAC solution for high-performance homes is a central heat-pump system, coupled to a fresh-air intake and dehumidifier **(9)**. A long fresh-air-intake duct in the unconditioned basement helps to temper the incoming air for comfort. Dampers open and close the air intake in response to temperature conditions and prevent unwanted backflow through the dehumidifier. Because the roof was insulated, some ducts could also be routed through the attic **(10)**.

a backflow damper between the dehumidifier and the air handler so that air can't short-circuit through the dehumidifier when it's not operating.

Our TREAT calculations estimated a heating load of 8,166 Btu/hour at 5°F for the insulating and air-sealing package we installed. We trusted that estimate because we've tracked actual system run-times on other homes, using Ecobee thermostats, and we've established that TREAT provides reasonably close projections (typically within 10% or 20% of actual performance).

By comparison, the industry standard Manual J, which contains a variety of "fudge factors" in order to prevent undersized systems, seems to overstate the load by 50% or 60%, particularly in high-performance homes.

The main reason we need accurate calculations is to match the equipment output to the operational requirements. We want the smallest equipment we can possibly install, while still ensuring the house can stay at 70°F on a 5°F day. Also, we want to design the equipment to be running at low stages as much as possible, because that's more efficient.

And there are other important reasons not to oversize the equipment: People are comfortable when equipment is running; fresh-air supply, filtration, and dehumidification occur when equipment is running; and cycling losses don't occur if the equipment doesn't shut off. There is also a thermal mass effect: Slowing down the addition of heating or cooling into the house allows walls, ceilings, and floors to equalize in temperature better. This leads to remarkable comfort.

If equipment is oversized, we lose those benefits. We find that oversized equipment is frequently a root cause of client comfort and moisture problems.

But right-sizing can be difficult. Typically, HVAC manufacturers don't offer equipment that matches the loads of high-performance, small homes. For example, the smallest commonly available furnace is 40,000 Btu—large enough to heat a 2,500-square-foot home. Heat pumps come with smaller outputs, but even the smallest two-stage heat pump can be way too big when operating on its high setting of 24,000 Btu/hour. Even the 14,000 Btu/hour low setting is still a bit high for this house, but it was a compromise we needed to make.

This is our fourth all-electric project, and we've been tracking the projects' usage and energy costs. We've found that air-source heat pumps have similar (and sometimes lower) energy costs compared with natural gas. Part of this is thanks to eliminating the gas meter (homeowners pay $25 per month just to be connected); this savings alone offsets $300 a year in electricity cost. And of course, the all-electric solution avoids the risks associated with fuel combustion inside the dwelling.

Generally, I prefer the highest-end heat pumps (we really like Carrier's GreenSpeed heat pumps). But that didn't fit this home's budget. In this case, a Habitat discount from Goodman allowed us to install a very nice 16 SEER two-stage unit for less than what a basic single stage would normally cost.

At 24,000 Btu/hour, I expect the heat pump alone will likely handle the heating, even at 0°F. Sadly, it is still substantially oversized; but the other choice was mini-splits, and there was no way to get good, fresh, filtered, and dehumidified air with mini-splits without installing a dedicated duct system for fresh air and dehumidification. And having said all that, the system we ended up with is much closer to matching the load than any furnace would have been.

WHAT WE'RE LEARNING

With this project, we are excited to continue challenging some common beliefs in the green-building world:

■ *Air-source heat pumps don't work in cold climates in existing homes.* We have client feedback and system data indicating surprising success in our climate.

■ *High R-values are necessary for a deep energy retrofit.* Our data and experience has indicated a range from R-17 to R-20 does an amazing job.

■ *HRV/ERV is needed to temper incoming air.* We're using a ventilating dehumidifier because HRV/ERVs don't manage humidity well. In high-humidity climates, HRV/ERV equipment can introduce significant moisture loads, which then must be addressed. With long duct runs and tight equipment sizing, tempering shouldn't be an issue. The ventilating dehumidifier fits the bill 100%.

■ *Balanced fresh-air strategy is best in cold climates.* With a tight house, pressurized dehumidification provides better air quality and summer drying potential than a balanced fresh-air strategy.

■ *Mini-split heat pumps are good whole-house solutions.* We use central ductwork with a standard-split heat pump and provide excellent filtration, dehumidification, and central fresh-air distribution. In addition, we track air quality with Foobots. What that has told us is that the approach we recommend works very well. By contrast, our prior experiments with mini-splits have resulted in subpar outcomes.

RADICAL TRANSPARENCY

If we mess this project up, the public will know it. We're going to be data-logging the house with the following tools:

■ Foobot Indoor Air Quality Monitor. This measures temperature, relative humidity, particulates (PM2.5), and chemical pollutants, and logs the data every minute. (Thanks to Foobot for the donation.)

■ Curb Energy Monitor. This tracks whole-house energy usage.

■ Ecobee EMS-02 Thermostat. This controls the heat pump, the fresh-air damper, and the ventilating dehumidifier. The only data-logging thermostat on the market, the Ecobee logs runtime and stage, outdoor temperature, indoor temperature, set point, and indoor humidity.

■ NetAtMo IAQ Weatherstation. The main unit measures barometric pressure, decibel level, carbon dioxide, temperature, and humidity. Simpler units that measure only temperature and humidity will be in the supply and return plenums, with a third being outdoors.

We firmly believe that measured outcomes and transparency will help build public confidence in home performance. It's our policy to show the good and the bad, for everyone to learn from. If we were in DOE's Building America program, we'd probably have a lot more sensors, but this substantial array cost only $1,400, retail. As time goes on, we'll be publishing our data on the Energy Smart Blog and at JLConline.com.

Nate Adams is the founder of Energy Smart Home Performance, near Cleveland, Ohio.

Volunteer labor helped make this project possible, along with generous material donations from suppliers. Cleaning out the cluttered and dilapidated basement was a task tailor-made for volunteers **(11)**. Volunteers also bore the brunt of the hand labor required for the extensive demolition and reconstruction that was needed to create the home's new energy-efficient exterior **(12)**, as well as for the interior detailing **(13)**. That helped make the most of Habitat's limited budget, freeing funds for professional tasks such as spray foam and HVAC installation.