

An Energy Retrofit in Stages



In the real world of tight budgets, energy paybacks are elusive; improved comfort is the payoff

by Jim Olson



I'm a building energy consultant in central Wisconsin. I recently had a chance to perform a major energy retrofit on a modest ranch-style house just south of Lacrosse, Wis. It was a simple two-bedroom home that was probably built shortly after World War II. Such homes are quite common around here; I've heard them called "farmer's widow" houses because they're too small for a typical family. The original house covered just 700 square feet, and a 1970s-era addition off the back

provided an additional 500 square feet. The basement, used mostly for storage, added another 950 square feet of conditioned space (see Figure 1, page 2).

Like many houses of its time, this one was leaky and very lightly insulated, making it expensive to heat and uncomfortably drafty. But it was located in a pleasant established neighborhood where no new building lots were available. While tearing down the existing structure and building a new one on the same site would have been a reason-

able option, the homeowner instead chose to invest in an extensive retrofit designed to make the house even more energy-efficient than comparable new homes, with increased comfort and improved interior air quality as added benefits.

A Three-Phase Plan

The term "deep energy retrofit" has recently emerged as a description of projects like this one, but there's no definite agreement on what that term actually

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Figure 1. While located in a pleasant residential neighborhood, the original “farmer’s widow house” was drafty and poorly insulated (left). A 1970s addition off the back (right) added much-needed square footage but suffered from the same poor energy performance. In addition to leaving the siding exposed to rain and weather, the absence of eaves overhangs in the front created a visually awkward transition to the broad eaves in the rear.

Retrofit at a Glance: Before & After		
	Pre-Retrofit	Post-Retrofit
Envelope leakage	8 ACH@50 pascals (2,100 cfm@50pa)	2.6 ACH@50 pascals (700cfm@50pa)
Insulation	Little to none in original house; some batts in addition	R-60 attic, R-40 cathedral, foamed top plates, R-34 walls, R-7.5 over slab
HERS rating	125 actual	67 Phase 1 (actual); 48 Phase 2 (projected); 0 Phase 3 (projected)
Combustion appliances	Atmospherically vented water heater failed combustion test	Sealed combustion, on-demand water heater
Windows	Single-pane with storms; a few double-pane low-e	Double-pane with heat mirror, fiberglass frames; U-values from .14 to .19; existing south-facing double-pane low-e sash left in place
Interior ventilation	Random/uncontrolled, 2,100cfm@50pa leakage	45-cfm ERV, continuous, with spot ventilation in bath and kitchen
Radon	10 picocuries per liter	To be addressed in Phase 2
Attic ventilation	Soffit, gables, and mushroom vents	Soffits sealed with spray foam; gables and mushrooms only
Overhangs	Only on addition	2-foot overhangs on most of house
Siding and drainage plane	Aluminum lap siding over original cedar lap, tar paper, fiberboard sheathing	Cement-board siding with 3/4" drainage plane on Tyvar, fascia and some trim aluminum clad

Figure 2. An effective energy retrofit requires thorough testing and evaluation of the building before the work begins. It also provides an excellent opportunity to address durability issues — by adding roof overhangs and exterior wall drainage planes, for instance.

means. Depending on who you ask, it can mean achieving a specific energy target expressed in terms of kilowatt hours per square foot, reducing energy used for heating by 50 percent to 90 percent, or reducing total energy use — including lighting, electronics, and other miscellaneous plug loads — by the same percentage. In this project, our goal was to achieve a minimum 75 percent reduction in overall site energy use.

Baseline tests. To establish an “energy baseline” for the house, I performed a blower-door test, scouted for thermal leaks with an IR camera, and cut some exploratory holes to assess the sheathing and insulation (**Figure 2**). I also analyzed the combustion performance of the existing atmospherically vented hot-water heater and the condensing furnace, and measured the indoor radon level.

I then ran the numbers through REM/Rate energy modeling software, which I routinely use as a consultant with Focus on Energy, Wisconsin’s statewide energy efficiency program. On the Home Energy Rating System (HERS) scale, the existing structure clocked in at 125. That’s well



Figure 3. Because the original 2x4 rafters left little space for insulation at the eaves (top left), the area was filled with medium-density spray foam (above), which blocked air leaks and also provided a continuous dam for the cellulose that would be blown into the attic (left). Where excess foam bulged beyond the eaves extensions, the crew cut it away with a sharp handsaw.

short of the nominal 100 rating expected of a new house built to comply with the 2006 IRC, but considering that much of the house contained little or no insulation, it wasn't all that bad.

After discussing a variety of options with the homeowner, we came up with a three-phase plan that would provide major benefits from the outset. Starting with this sort of long-term plan in hand minimizes the risk that work performed early on will interfere with later projects.

Phase 1. The main focus here was a major exterior retrofit, with extensive air-sealing, the addition of rigid foam insulation to the walls and roof, new siding, and the replacement of most of the windows, all but three of which were old single-pane units with exterior storms. We considered adding hard-coat low-e storms to the existing windows instead, but decided that new units would pay for themselves in increased homeowner comfort and lower maintenance, even if the amount of energy saved would be fairly modest.

We also planned to lay a new wood floor over rigid foam on the uninsulated slab floor in the addition. Mechanical

upgrades included a new energy recovery ventilator (ERV) — essential for maintaining high air quality in the newly tightened building envelope — and a new sealed-combustion water heater to replace the old atmospherically vented one. Though somewhat outdated, the existing 90 percent efficient first-generation condensing gas furnace is safe and functional, so the owner decided to postpone replacing it for now.

Phase 1 — which I will describe in detail in this article — is the one stage that we have completed.

Phase 2. With the major gains made in Phase 1, the second phase will deal with some less pressing issues. The existing basement has about 6 feet 4 inches of headroom at best, with plenty of overhead pipes, beams, and ductwork to whack the heads of the unwary. The radon level in the basement was found to be relatively high, at 10 picocuries per liter (pCi/L). Though well above the EPA's 4-picocurie action level, this number isn't an immediate cause of concern because the basement is used almost exclusively for storage. Radon levels in the upstairs living space are

likely to be much lower — probably in the area of 5 pCi/L or so. The eventual solution to both the headroom and the radon issue will be to excavate the basement floor, apply a layer of crushed rock, and pour a new floor slab with a subslab ventilation system to maintain a slight negative pressure, venting the exhaust to the outdoors (see "Radon Vent Retrofit," 12/01).

We will also cover the basement walls with a continuous layer of extruded polystyrene and a 2x4 framed wall insulated with dense-pack cellulose, adding high-quality living space at a relatively modest cost. The studwalls will make it possible to upgrade the sketchy original wiring.

Phase 3. Even further out on the time horizon is the final phase of the project, in which renewables — mostly likely a net-metered PV array and solar hot water — will be added so that most of the home's energy needs can be generated on-site.

Two Approaches to Roof Insulation

With the plan in place, we turned to the structure itself. Our first priority was to deal with the poorly insulated roof. The

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Figure 4. At the interface between the addition and the original attic, warm, moist air flowing through the batts in the cathedral ceiling had been condensing on the sheathing, rusting the nails and staining the plywood (left). Along the addition's ridge, air leaking from inside had left a dirty deposit in the batt insulation (right).



Figure 5. Foil-faced polyiso board, screwed to the addition roof deck (top), supplements the original batts, which were left in place between the rafters. Joints between panels — and the intersection with the board deck of the original house, visible at rear — were sealed with spray foam. The gable-end rake of the original house was extended to meet the addition overhang, providing improved weather protection and a cleaner appearance (right).



original framing was 2x4 rafters with a ceiling below. Although there were a few haphazardly placed one-inch mineral wool batts here and there, it was for all practical purposes uninsulated. The later addition off the back had a 2x6 cathedral ceiling filled with unfaced fiberglass batts. The asphalt roof was in poor condition, and the lack of overhangs on the original part of the house meant that the siding was thoroughly soaked after every rain.

Eaves extensions and foam. Most of the attic was deep enough for us to blow in an R-60 layer of loose-fill cellulose, but the low-sloped 2x4 rafters left little room for insulation at the eaves (**Figure 3, page 3**). To provide sufficient R-value here, eliminate a major source of air infiltration, and supply a protective roof overhang, we pulled off the lower part of the plywood roof sheathing, extended the framing at the eaves, and sprayed the area over the plate and some distance into the attic with Versa-Foam 1.8-pound polyurethane foam, which we ordered directly from the manufacturer. In limited areas where the foam expanded outward beyond the plane of the framing, we cut away the excess foam with a sharp toolbox hand-saw. The gable-end overhangs now tie in neatly with the eaves of the rear addition, doing away with what had been an awkward transition. At the front of the house, where the tops of the windows were high on the wall, we scaled back the overhang a bit to keep from shading the interior too much.

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One problem spot was a short section of roof above a small entry vestibule to the right of the front door. There was no ceiling in the closet below, leaving no room for cellulose. Instead, we cut away the roof sheathing and carefully fitted several pieces of 3-inch foil-faced polyiso board between the rafters, filling gaps between the rafters and foam board with a little spray foam where necessary.

Drafty fiberglass batts. After stripping the old roof, we discovered beneath the sheathing of the cathedral-roofed addition some classic signs of an insulation system that wasn't working too well (Figure 4, page 4). Warm, moist interior air had clearly been moving freely through the insulation for years, cooling and condensing against the plywood roof sheathing and leaving some sections of the batt insulation looking like dust-clogged air filters. Although there was little evidence of decay, the plywood was discolored and the nails fastening it to the rafters were badly rusted.

Rather than tear off all of the sheathing and remove the batts, I decided to remove the sheathing only in areas where our blower-door tests had confirmed the presence of leaking air. We cut away a strip running the length of the ridge and foamed the peak from above, blocking air that had been making its way through the cedar paneling. (A poly vapor barrier stapled to the underside of the rafters when the addition was built effectively slowed air movement through the field, but did nothing at the roof peak and edges.) We used additional foam and some sheets of beadboard to air-seal the transition between the framing of the original house and the roof of the addition.

Exterior foam. Through a local commercial builder, I got a great deal on about a hundred 4-foot-by-13-foot sheets of foil-faced polyiso board left over from a large job. With the air leaks in the roof taken care of, we laid the sheets of foam board directly on top of the plywood, butting



Figure 6. With siding and sheathing removed, potential leaks in the plates were easily sealed with foam (above). Also, as a preventive measure, the exterior bathroom wall was foamed. While nailing up the new sheathing (left), the carpenters took the time to bore holes over each framing cavity — much to the appreciation of the insulation sub who would later fill them with dense-pack cellulose.

them against a new subfascia sized to cover the edges of the foam and the plywood sheathing that would go on over it (Figure 5, page 4).

Walls

The original walls were a hodgepodge of different materials, starting with a layer of fibrous sheathing (locally known as “buffalo board”) over the studs. Over that, there was a layer of lap siding, followed by aluminum siding. The addition had T-111 siding nailed directly to the studs. Our insulation strategy called for strip-

ping the walls to the stud cavities, putting up new sheathing and dense-packing the stud cavities with cellulose, then applying a continuous layer of the same polyiso board we'd used on the addition roof (Figure 6).

Cavity insulation and perimeter foam. We stripped off the old material in manageable stages, keeping a close eye on the weather. While the sheathing was off, we took photographs of each wall to document the location of the framing, in hopes that this would make life easier for some future remodeler (and for ourselves). As

Small House, Many Strategies

Properly retrofitting a typical existing frame house may require a variety of methods. On this project, for example, the ceiling of the original small ranch was air-sealed and insulated from inside the attic, while the cathedral roof of the addition was insulated from above.

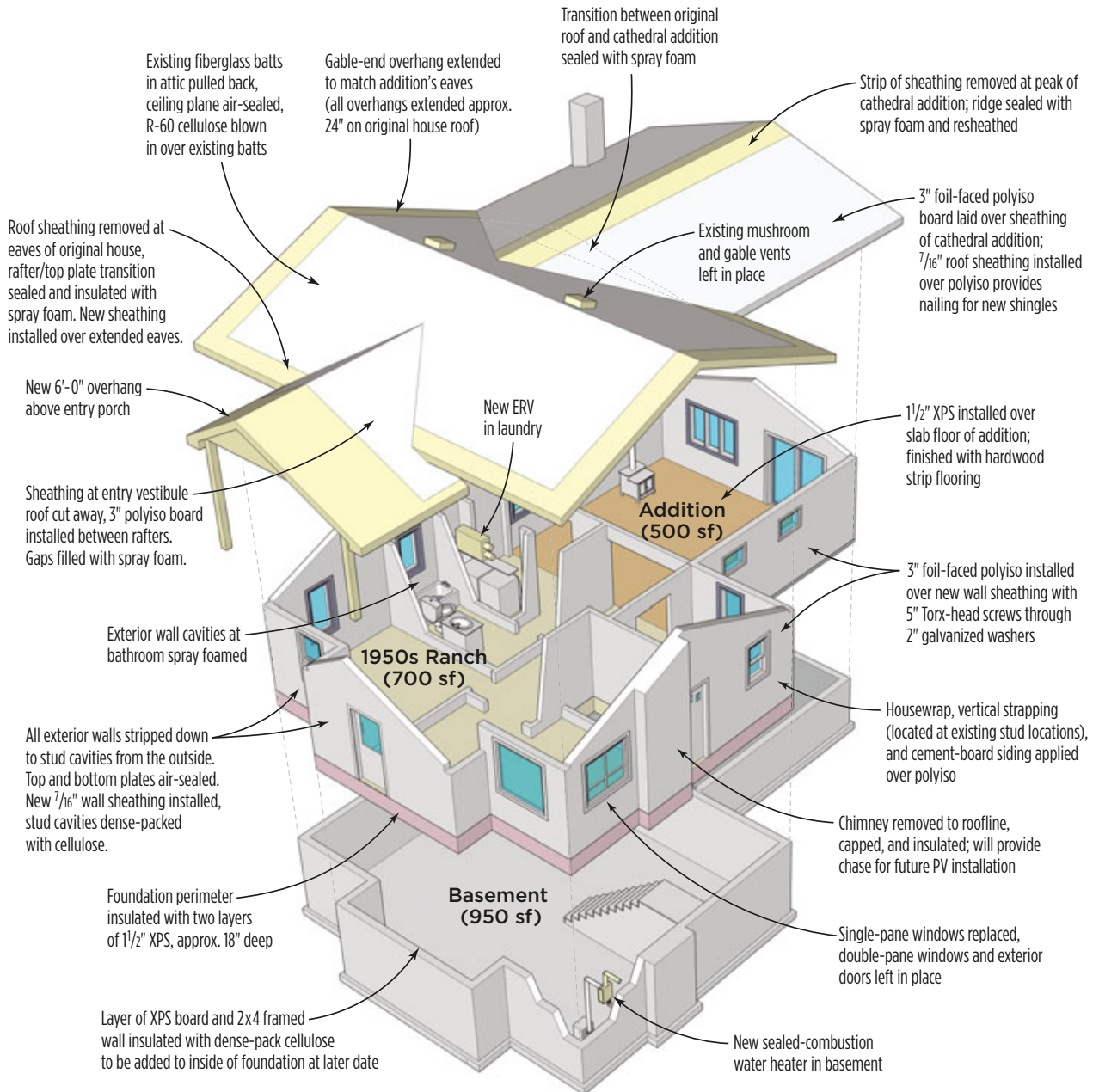




Figure 7. The perimeter of the slab-on-grade addition was insulated with two layers of 1½-inch extruded polystyrene (above left), matching the thickness of the polyiso on the walls (above). Rather than go to the expense of moving the electric meter away from the wall to accommodate the full thickness of the polyiso board, the crew boxed in the area around the meter and filled it with a thinner layer of XPS (left).

we nailed up the new 7/16-inch plywood, we predrilled a 2 1/8-inch hole over each stud cavity. That saved a lot of time and effort for the insulation contractor who later filled the walls with dense-pack cellulose, and also assured us that all of the cavities were filled. While the walls were open, we also applied some spray foam around the top and bottom plates, where both the blower-door test and the infrared images had indicated a lot of air leakage. To eliminate any possibility that high indoor vapor pressure in the bathroom could drive moisture into the framing cavities, we completely filled the stud cavities of that short section of exterior wall with spray foam.

We insulated the perimeter of the foundation with two layers of 1½-inch XPS, digging by hand to a depth of 18 inches or so and packing the soil back around the foam (Figure 7). The exposed foam was later covered with a protective layer of galvanized coil stock (which doesn't dent as easily as aluminum).

After we'd applied the new sheathing, we built out the window framing to finish flush with the surface of the polyiso board, which we fastened with 5-inch

Torx-head screws and 2-inch galvanized washers. We'd used heavier Phillips-head screws on the roof, but we found that they were almost impossible to drive into the walls without the user's weight bearing down on the drive bit. To make sure of hitting a stud every time, we predrilled all the screw holes.

While hanging the exterior insulation,

we had to get creative in a few areas. We couldn't fit a layer of the polyiso board behind the electric meter, for example, and didn't want to go to the time and expense of having the power company move it. Instead, we insulated behind the meter with a single layer of 1½-inch XPS and boxed around it from the bottom plate to the eaves, which made for a cleaner-look-

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Figure 8. After dismantling the old gable-end chimney above the roofline, the crew enclosed the lower part in a framed, insulated bump-out. The vertical strapping over the bump-out — not yet complete on the rest of the wall — is a rain-screen nailing base for horizontal fiber-cement siding.



Figure 9. Once stripped of carpeting and tested for moisture, the slab floor of the addition was insulated with XPS foam board fit tightly between lengths of 2-by furring (above). Including the insulation, the finished floor, consisting of $\frac{1}{2}$ -inch plywood and $\frac{5}{8}$ -inch prefinished oak, raised the room's threshold by almost 3 inches (right). A gently sloped transition was added later.



ing transition than boxing just around the meter itself. After completing the insulation and sheathing, we applied a layer of housewrap to act as a drainage plane and screwed vertical strapping over the studs to provide a nailing base for new rain-screen siding.

The original fireplace was no longer operable, and after we replaced the atmospherically vented gas water heater, the masonry chimney was no longer needed. To eliminate it as a major source for exfiltration, we cut it off at the roofline, capped it, and enclosed it in an insulated chase that lay completely under the overhang (**Figure 8**). This was easier on the budget than taking apart and disposing of the entire chimney, and it even added a small amount of thermal mass inside the new thermal envelope. Looking ahead, the insulated space within the old chimney will make a convenient chase for running wiring or plumbing for a roof-mounted PV or solar-thermal array.

Addition Slab

The concrete slab floor in the addition had been covered with carpeting. When we peeled it up we found no signs of mold or moisture, and a cup test confirmed that moisture wasn't a problem. We fastened nominal 2x2 sleepers to the concrete and fitted cut-to-size sheets of $\frac{1}{2}$ -inch XPS between them (**Figure 9**). We then put down an oak finish floor, raising the level



Figure 10. The ERV that supplies the tight retrofitted house with fresh air (above left) is installed at head height in an often-used area, making filter changes easy. The ceiling opening where the flex duct from the new bathroom fan transitions to rigid duct in the attic was enclosed in a plywood box and sprayed with foam for air-sealing and protection from foot traffic (above). The thin, uneven layer of rock wool covering the floor was later covered with 18 inches of loose-fill cellulose. An inexpensive combination thermometer-hygrometer (left) makes it easy to keep an eye on temperature and humidity in several locations, indoor and out.

of the original floor by nearly 3 inches. Fortunately there was room to accommodate this with a gently sloped threshold.

Mechanical Upgrades

We replaced the old, inefficient (and unsafe) water heater with a Takagi T-K3 sealed-combustion demand heater. The new RenewAire EV 130 ERV was installed on a conveniently located shelf in the closet that houses the clothes washer and dryer (Figure 10). It draws supply air through a vent high in a sidewall and exhausts the outgoing air through a run of rigid duct that exits low in the wall, thus avoiding penetrations into the attic. The loud old bath fan was replaced with a Panasonic WhisperLite and the old, non-functional range hood replaced with one that works.

Keeping an eye on temperature and

humidity. To get a handle on any changes in indoor air quality, we also installed an inexpensive wireless thermometer/hygrometer from Radio Shack. The model we chose accepts up to three remotely located transmitters (which are purchased separately from the receiver), allowing us to put one in the basement, one in an upstairs bedroom, and a third outdoors.

Crunching the Numbers

A post-retrofit blower-door test confirmed that the house was much tighter: The pre-project figure of 2,100 CFM50 (about 8 ACH) had fallen to just 700 CFM50 (about 2.6 ACH). But because we were interested in qualifying the project under the Affordable Comfort Institute's Thousand Home Challenge program — which aims to document one thousand deep-energy retrofits that meet its strin-

gent criteria — we collected monthly figures on post-retrofit gas and electricity consumption (details on ACI's Thousand Home Challenge is available at thousandhomechallenge.com). For comparison, we also collected energy-use figures for the year before the project began (Figure 11, page 10).

Unexpected result. As Figure 11 shows, overall energy as measured in MMBtu — a unit that makes it possible to express gas and electric use as a single number — declined sharply. That's consistent with the improved insulation and tighter building envelope, and it's quite close to the pre-project projection based on the REM/Rate energy modeling program. But even a small house is a complex system, and changes in one area can have unexpected results in another. Soon after the completion of the initial phase,

Tracking Energy Use

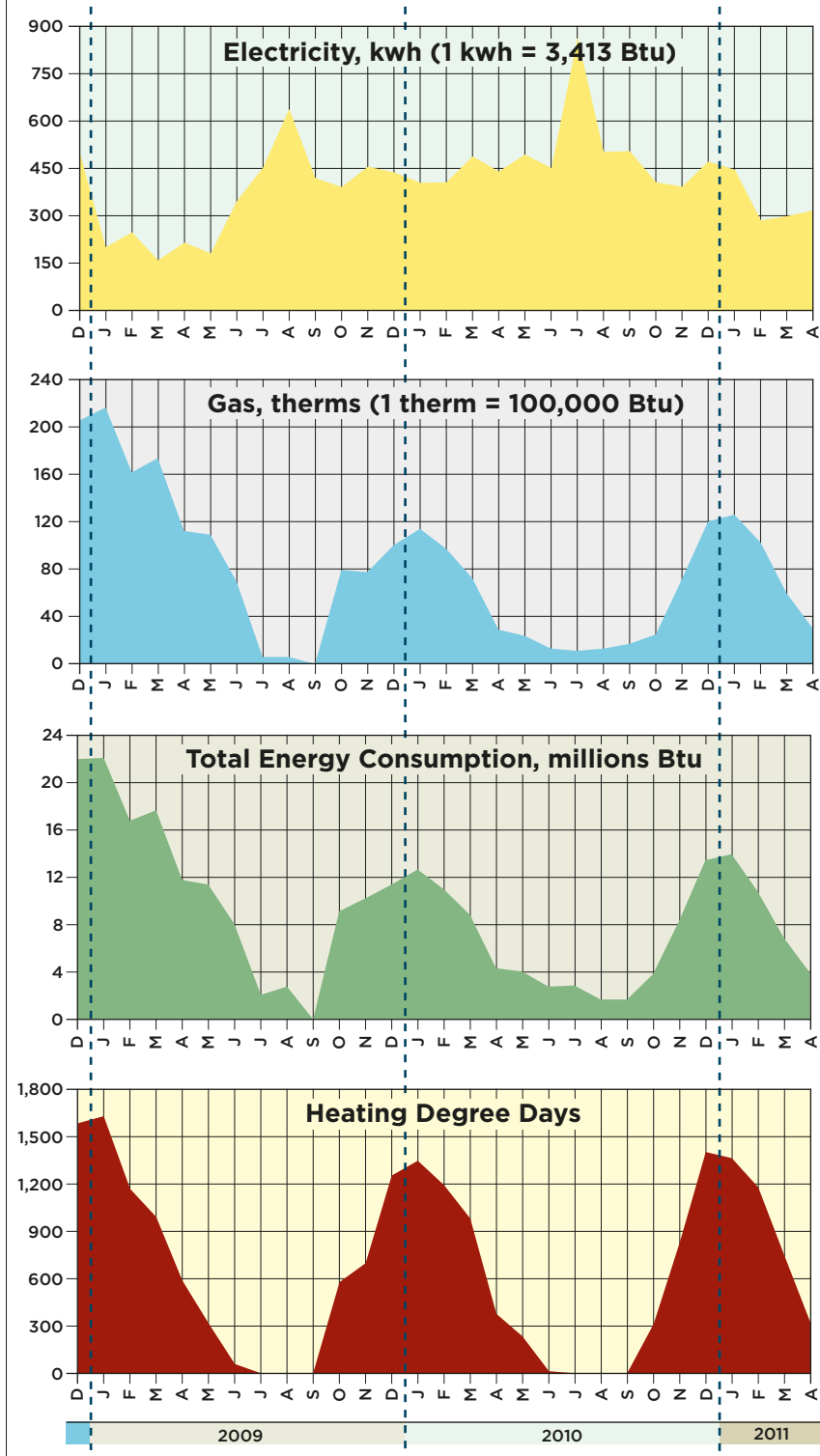


Figure 11. While natural-gas consumption was dramatically reduced as a result of tightening the house, electrical consumption did not follow the same curve. This was at least partly due to unforeseen moisture buildup in the home, which necessitated the use of a basement dehumidifier — thus the spike in electrical use in July 2010. Basement moisture will be dealt with in the second phase of the project.

the indoor humidity began to rise as a result of reduced air leakage and a relatively high water table around the original basement.

That problem will be dealt with permanently during Phase 2 of the project, along with the minimal headroom, absence of insulation, and elevated radon level. For now, though, the indoor humidity is being kept under control with a dehumidifier. As a result, post-retrofit electricity consumption has remained about what it was before the work began, offsetting the gains made by changing incandescent lights to CFLs and installing new energy-efficient appliances.

Cost and value. The original, unretrofitted house was a bargain-priced \$90,000 when purchased late in 2008. Still, this was not an inexpensive project. The original \$60,000 budget for the first phase of the work (which hadn't included the new floor in the addition) had crept up to \$70,000 by the time we were done. The Phase 2 improvements are expected to add \$13,000 and the renewable energy production envisioned for Phase 3 another \$30,000. State and federal tax credits and incentives totaling around \$25,000 should reduce the net cost of all three phases of the project (which will bring the home to near net-zero) to about \$88,000.

Will the homeowner ever get the return on that substantial investment? The answer in this case is almost certainly no. But there were other good reasons to do the work. The appearance of the home is much improved, and future maintenance costs will be less. Most important, though, the living space is now warmer, more comfortable, and healthier. The current homeowner expects to remain there for the rest of her life, and sees the \$300-per-month net cost of the improvements (based on a 15-year mortgage at 4 percent) as money well-spent.

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