Remodeling for Energy Efficiency

BY BETSY PETTIT

In America, there are around 58 million houses that were built before the last energy crisis. Because these pre-1970s houses have little or no insulation, they are all ripe for energy-efficiency improvements. Houses eat up 20% of the energy used in this country and account for 21% of the carbon dioxide that contributes to global warming. This adds up to a huge opportunity.

America's old houses can be made much tighter and can even approach net-zero energy use. Here, I'll highlight three houses that my company, Building Science Corp., has renovated. Each house had different limitations and learning curves. I share one of the houses with my husband and business partner, Joe Lstiburek, and two of them have been used as our office space.

Renovating an old house is an expensive process. It's also a delicate process because the end product must retain its charm. Most old houses are still around because people love their timeless form, floor plan, trim, details, and historical significance. Renovating an old house is a surprising and challenging process because many of them have undergone numerous renovations over the years. You never know exactly what you'll find.

Can a 150-year-old house approach zero energy use? Three case studies point the way from the 19th to the 21st century.

OUR FIRST RENOVATION
pp. 52-53

A TRICKY VICTORIAN
p. 55

THIRD TIME IS A CHARM
pp. 56-57

In old houses, most systems are at the end of their useful life

A hundred years can take its toll on infrastructure, and this is often the case with old houses. The water line from the street, electrical wiring, plumbing, mechanical systems—all are often nearing the end of their life. It would be foolish to renovate a house without replacing these basic systems. Windows often no longer function as intended, either. Their ventilation properties are hindered by layers of paint, or they simply became swollen shut years ago. If neglected, siding can need repair or replacement, too.

And while the shape, floor plan, and details of an old house allow it to endure, people often think they need an addition to provide another

BSP-064

bathroom, bedroom, office, or better views. Then they spend money building an addition, only to spend all their time in this new space because the rest of the house is uncomfortable. They don't really get more space in this deal; they get a smaller space that's comfortable.

Energy upgrades are cheaper than you think

While the cost of fixing wet basements and adding bathrooms can add up quickly, energy upgrades don't have to put things out of reach. In fact, they don't really cost that much more because they're integral to the decisions and choices made in the renovation process.

If you consider a renovation as a whole system, you might find that you can add modern conveniences (such as an extra bathroom, bedroom, or office space) and comfort without building an addition, and reduce your energy costs in the process. The basement and attic are already built; you just need to use them. By adding rooms in the basement and attic, you often can reconfigure the floor plan to accommodate an extra bathroom, a larger kitchen, or a master suite.

Replacing the furnace, the boiler, or the HVAC system might cost $10,000 before you are done. But the upgrade could easily save $1000 a year in heating and cooling costs. Even in simple payback terms, this new system would pay for itself after ten years. Amortized into a 30-year mortgage, it costs $27 per month; the savings works out to $83 per month for a net gain of $56 per month. Because we know energy costs are rising, these numbers will only get better.

Case studies illustrate real-world challenges

The three homes featured here have several things in common. First, they are all more than 90

Structural repairs eat into the energy-upgrade budget

Built in the 1860s, this house was a typical New England Greek-revival farmhouse. It had a basement prone to flooding, sagging floors, a leaning barn, and old, inefficient mechanical equipment. The structural and water issues were expensive to fix, so we looked for ways to save on energy upgrades. We took different approaches to fixing the house and the barn (drawings facing page). Because we wanted to keep the barn's timber-framing visible, all insulation went to the outside of the wall sheathing on the barn. On the house, we aimed to maintain interior finishes wherever possible.

Overall, our strategies worked. The house's Energy Star rating for homes was 91 out of a possible 100 points (www.energystar.gov). We doubled the living area by bringing the barn and attached shed into the conditioned space while increasing power consumption by only 8%. We used the renovated barn as our office space for 10 years while fighting a zoning battle to allow this "commercial" use. In the end, we lost the zoning battle, and now the barn is a huge guest house with full kitchen and bath.

OUR FIRST RENOVATION

WHAT WOULD WE DO DIFFERENTLY?

We did what we thought we could afford at the time, but in trying to save money, we scrimped in ways we would not do again. The 6-mil polyethylene (drawing top right, facing page) was a risky control layer for the barn and has been working except for some areas where the roof leaked at the intersection of the new cupola that we installed. Today, we would use a peel-and-stick roofing membrane rather than plastic and be very diligent with the flashing and counterflashing around the cupola.

The waterproof membrane covering the basement wall was meant as a drainage plane for the granite-block foundation. We've learned that this is probably an unnecessary and expensive extra layer; the surface of closed-cell foam forms a hard skin that sheds water.

SPECS

Completed: 2000

Conditioned space: 2600 sq. ft. before; 5240 sq. ft. after, including the barn

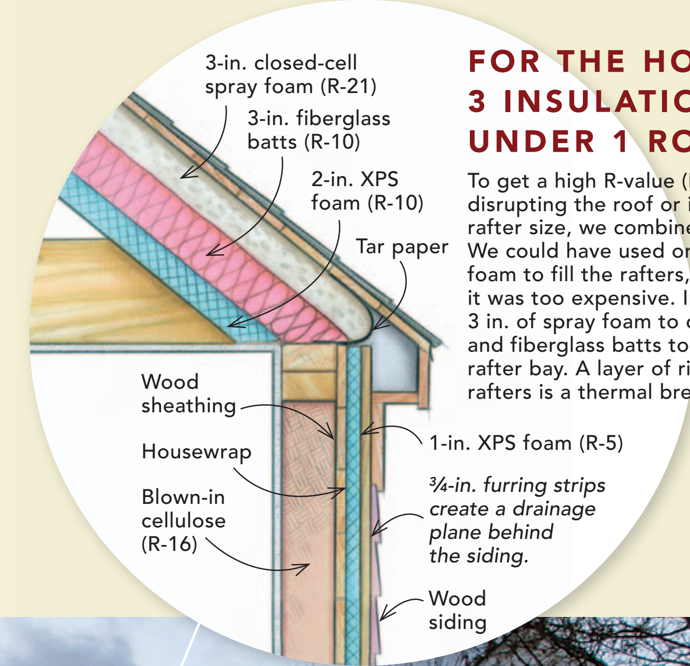
Bedrooms: 4 before; 6 after

Bathrooms: 2 before; 4½ after

Cost of renovation: $125 per sq. ft.

Annual utility cost:

- Before: $1.90 per sq. ft.; after: 86¢ per sq. ft.
- Gas: $3000 a year before; $2400 a year after
- Electric: $1950 a year before; $2100 a year after

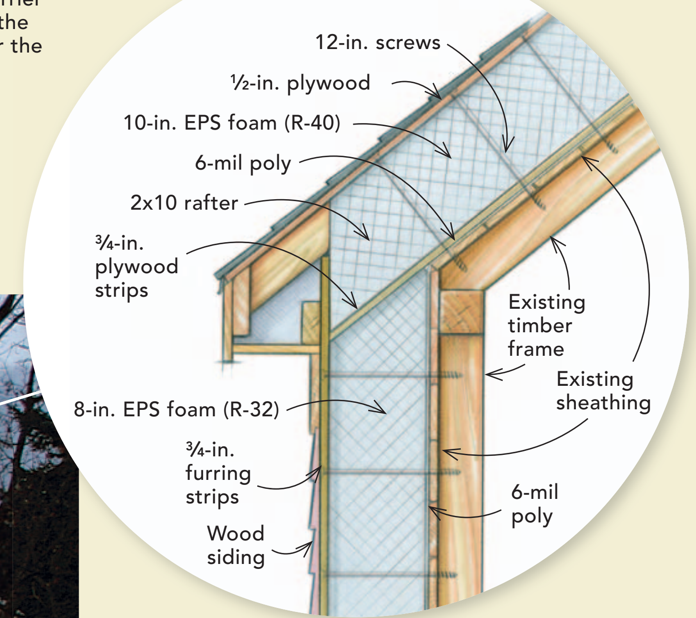


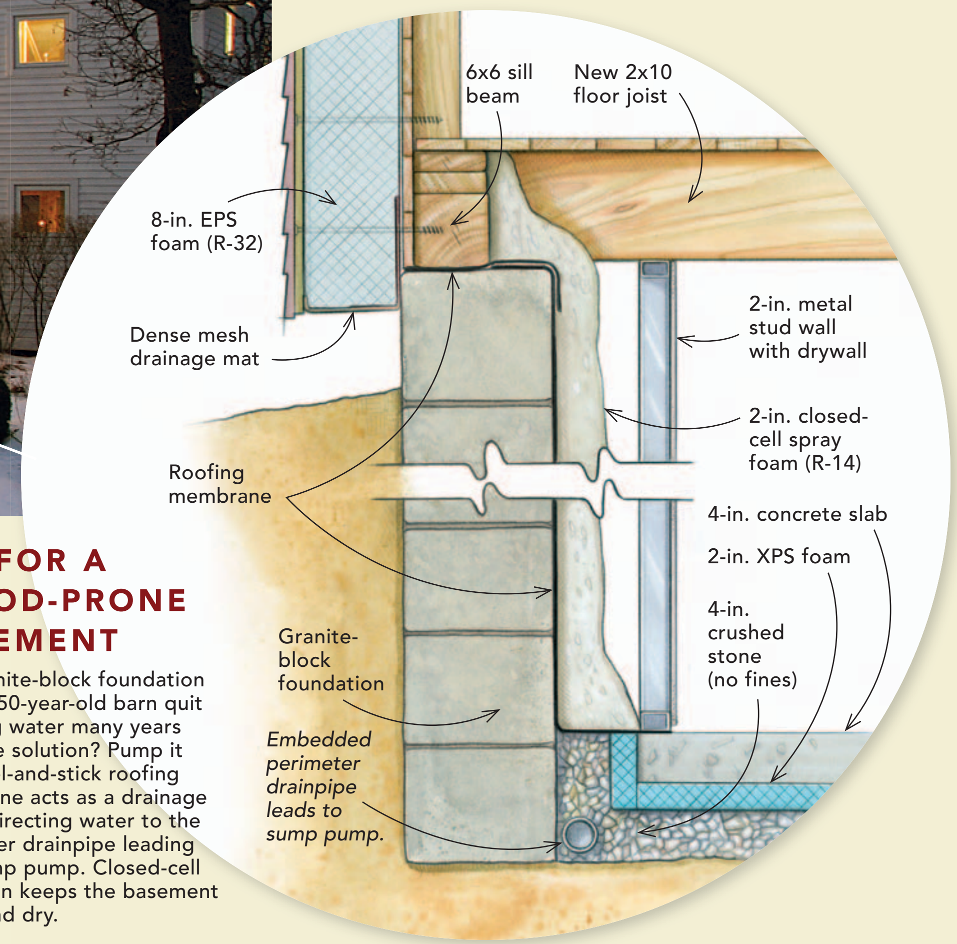
FOR THE HOUSE, 3 INSULATIONS UNDER 1 ROOF

To get a high R-value (R-40) without disrupting the roof or increasing the 2x6 rafter size, we combined insulation types. We could have used only closed-cell spray foam to fill the rafters, but at the time, it was too expensive. Instead, we used 3 in. of spray foam to create an air barrier and fiberglass batts to fill the rest of the rafter bay. A layer of rigid foam under the rafters is a thermal break.

A CALCULATED RISK FOR THE BARN

Because we wanted the timber-framing visible, we put the insulation outside the barn after wrapping it with plastic. Why plastic? Because structural and water-related repairs had drained our budget, and we thought we could save by using plastic (rather than self-adhering roofing membrane) to control air and vapor while acting as a drainage plane.





FIX FOR A FLOOD-PRONE BASEMENT

The granite-block foundation in this 150-year-old barn quit blocking water many years ago. The solution? Pump it out. Peel-and-stick roofing membrane acts as a drainage plane, directing water to the perimeter drainpipe leading to a sump pump. Closed-cell insulation keeps the basement warm and dry.

Drawings: Bob La Pointe

BSP-064

years old. Two of them were built in 1860 and the third in 1916. Second, they all had their major systems totally replaced: new wiring, light fixtures, plumbing, and mechanical systems, including the addition of central air-conditioning. Third, they all had attic spaces that were incorporated into the living space of the house by moving the insulation from over the second-floor ceiling to under the roof. Fourth, they all had insulation added under a new basement slab, as well as insulation applied to the inside of the exterior foundation wall. Fifth, they all had at least some windows replaced, and all had new window openings added in critical areas to provide better views of the yard and better daylighting to the home. Sixth, all the homes had bathrooms and bedrooms added. Finally, we replaced inefficient window A/C units with central A/C systems in each house.

Because of the work in the basements and attics, all the homes had increased living area without increasing the footprint of the home. And while the living space increased by 30% to 100%, all of them saw a reduction of energy use that ranged from 30% to more than 100%. While the renovations cost more than $100 per sq. ft. for each home, all were appraised at val-

Seven steps to net-zero energy use

In renovating old homes into superefficient ones, there is a definite path to success: Start where you can get the most bang, and work your way down the list. After you get past item 5, the house will be efficient enough to downsize the mechanical equipment, which you replaced in step 1. If you're planning to go at least through step 5, keep that in mind before buying a new boiler or HVAC unit.

1. Upgrade the mechanical systems

An old furnace or boiler is often the worst energy user in an old house. Many houses built prior to 1920 still have old coal-fired boilers that were converted to gas or oil. These units are workhorses, but use a lot of energy. A new furnace or boiler can save energy dollars right away. Replacing window air conditioners, which we did in all these houses, with a central system also can save energy right away, as long as the ductwork has been placed in the conditioned space. Solar water heating is a good option to add here if you can afford it, but at the very least, upgrade the efficiency of hot-water production by coupling the tank to the boiler.

2. Bring the basement and crawlspace inside the house

Warm, dry basements and crawlspaces can extend living and storage space. Wet basements are the source of high humidity levels and discomfort in the summertime in old houses. They also can be the source of mold growth that gets distributed around the house. Spray foam is a fast, effective way to bring these areas into the conditioned space while sealing the leaks between foundation and floor framing.

3. Superinsulate and air-seal the roof

If air leaks in at the bottom of the house, it leaks out at the top, which makes a house cold and drafty in winter. A poorly insulated roof also can make a house hot in summer. Air-sealing is a by-product of good insulating, so it's really a one-step process. Using spray foam under a roof also can eliminate the need for roof venting, which is tricky in complicated roofs.

4. Replace the windows

With the bottom and top of the house sealed and insulated, the next opportunity is the walls. And old windows are like big holes in the walls. Old windows often leak both air and water into the house while functioning poorly. They might not open and close properly, and can be obscured with storm windows and screens that diminish the amount of light that can enter. Properly installed, Energy Star (or better) windows seal the holes in the walls to keep out water and weather extremes. (For more, see "Installing Replacement Windows" at FineHomebuilding.com.)

5. Insulate the walls

Filling empty wall cavities with cellulose is a cheap, easy, effective way to warm up an old house. Blowing cellulose into existing wall cavities is an art, to be sure, but there are many contractors who have been doing it for years. In fact, there are now inexpensive ways to check with infrared cameras to make sure that all voids have been filled without disturbing the existing plaster or sheathing on outside walls.

Because siding or shingles on old houses might also have worn out, we take the opportunity to install foam sheathing on the outside of the house before re-siding.*

6. Buy Energy Star (or better) fixtures, appliances, and lighting

Once you have reduced your space-conditioning and water-heating loads, the lighting, appliance, and plug load will be your next big energy item. A new Energy Star refrigerator will use 15% less energy than a standard model. Replacing old light fixtures with pin-based compact-fluorescent fixtures ensures your electric bill will stay lower (up to 30%).

7. Add a renewable-energy source

Once your energy consumption has been reduced significantly, it becomes reasonable to produce your own energy with systems such as photovoltaics, wind power, or hydro, if you happen to have a stream nearby.

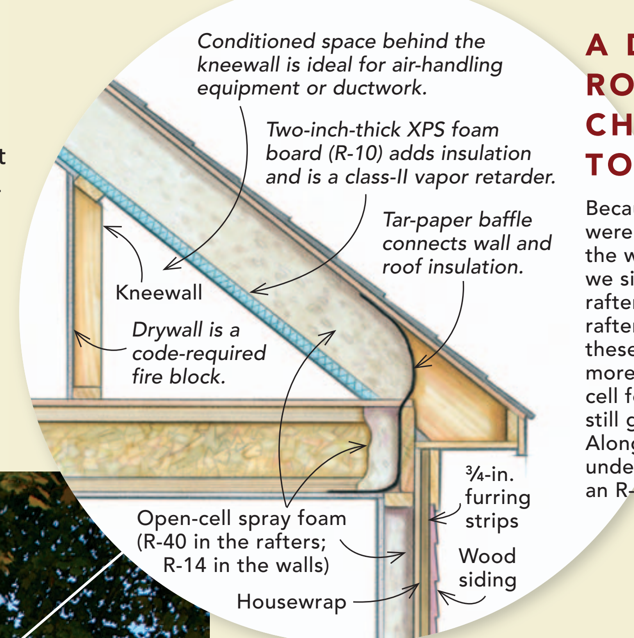
Until you slash the energy usage, though, it's not worth the investment in renewable power sources. Conservation is still the cheapest game in town.

* Go back to step 1 and reduce the size of the mechanicals. An airtight house with insulation on all six sides of the cube and good windows provides predictable performance, so the mechanical contractor won't have to guess at the quality of the enclosure. Downsized mechanical equipment can defray the cost of steps 2-5.

Historic districts can complicate energy retrofits

This two-family Victorian house (circa 1860) was difficult to upgrade because we weren't allowed to remove siding, replace the windows, or dig into the slate roof.

The historic commission did, however, allow us to remove and replace the siding and windows on one wall where the siding was damaged and needed replacement, so we injected open-cell foam, added housewrap and furring strips, and replaced the siding on that wall.



A DEEPER ROOF IS CHEAPER TO INSULATE

Because the 2x4 rafters were sagging under the weight of the slate, we sistered 12-in.-deep rafters to them. Deep rafter cavities such as these mean that the more-economical open-cell foam can be used and still get high R-values. Along with 2 in. of XPS under the rafters, we got an R-value of 50.

SPECS

Completed: 2003

Conditioned space: 2150 sq. ft. before; 2750 sq. ft. after, plus 1000 sq. ft. of dry, warm basement space

Bedrooms: 4 before; 4 after

Bathrooms: 2 before; 4½ after

Cost of renovation: $125 per sq. ft.

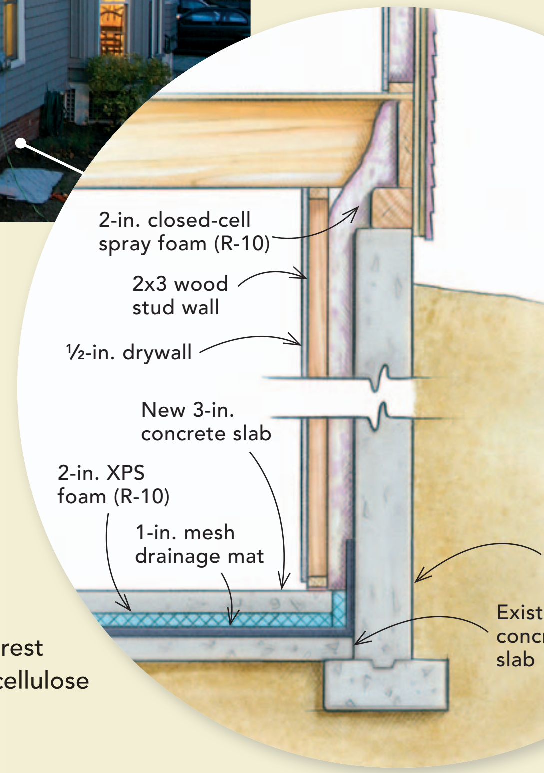
Annual utility cost:

- Before: $2.34 per sq. ft.; after: 83¢ per sq. ft.
- Gas: $3600 a year before; $1474 a year after
- Electric: $1440 a year before; $830 a year after

WHAT WOULD WE DO DIFFERENTLY?

Historic commissions all over the country favor historical authenticity over durability and energy efficiency with regard to windows, chimneys, roof finishes, and other elements. Faced with these restrictions, we compromised and used all-wood simulated divided-lite replacement sashes for two-thirds of the window units. Because the openings were so far out of square, the sashes never fit quite right.

We weren't prepared for the battle over siding replacement. In the future, we'd like to replace the rest of the siding. When we do that, we'll insulate with cellulose and foam sheathing.



A DRY BASEMENT TO BEGIN WITH

This house had no standing water in the basement, nor was there evidence of previous flooding. Because the basement had historically been dry, we didn't install a perimeter drain and sump pump. Rather, we installed a drainage mat on top of the existing slab (to trap errant seepage) and placed 2 in. of rigid-foam insulation on top of that. We then topped the assembly with a new slab to make a warm, dry storage area.

ues exceeding that cost after the renovation was complete.

Some things are different in each case, too. The two oldest homes had major structural issues that needed to be repaired before other work could be done. Foundations needed to be rebuilt, and additional columns and beams were added for support. One house, the Greek revival, had frequent basement flooding that had to be stopped, and its attached barn was leaning enough to fall down. The Victorian was in a historic district, so even though the chimneys were structurally unsound and the old slate roof was beyond its useful service life, they had to be repaired (at a great cost) rather than replaced.

Durability and energy efficiency are intertwined

Making a flooded basement livable is a great example of how one type of repair is directly related to another. On one of these projects, we needed to stop water from leaking into the old rubble foundation with a perimeter drain and a new slab. Adding insulation under the slab and inside the walls keeps the space free of condensation and also saves energy.

The durability and functional upgrades illustrated in this article cost a lot. By spending a little more, we were able to reduce our energy costs tremendously. After cutting energy consumption, the stage is set for affordable site collection of renewable power to offset the remaining energy needs, which could bring these houses to net-zero energy use or even energy producers. □

Betsy Pettit, FAIA, is an architect and a principal of Building Science Corp., now located in the Victorian house featured here. Photos by Daniel S. Morrison.

THIRD TIME IS A CHARM

Closing in on net-zero energy use

This 1915 foursquare is an American classic found in almost every town in the country. Interior plaster was in great shape, the layout was excellent, and there was no structural damage to speak of. Other than adding a few new windows to the back (for better views to a pond) and updating the kitchen, we didn't disrupt the interior too much. By insulating the basement and roof, we almost doubled the living space of this house without adding an inch to the footprint. And the utility bills were cut by 60%.

WHAT WOULD WE DO DIFFERENTLY?

Better windows would be the next place to reduce energy loads in this house. A triple-glazed unit with heat-mirror technology might further reduce the heating load, allowing us to get closer to zero.

SPECS

Completed: 2007

Conditioned space: 2000 sq. ft. before; 3600 sq. ft. after

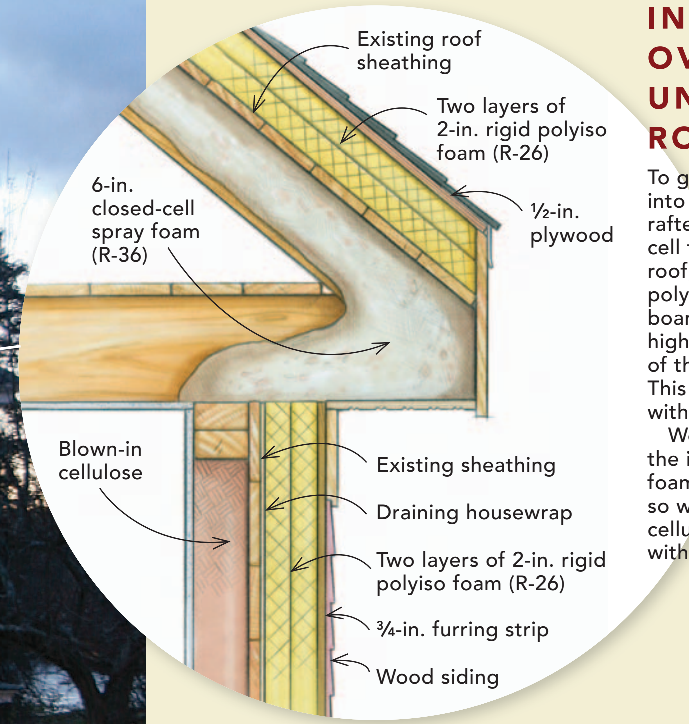
Bedrooms: 4 before; 4 after

Bathrooms: 1½ before; 3½ after

Cost of renovation: $100 per sq. ft.

Annual utility cost:

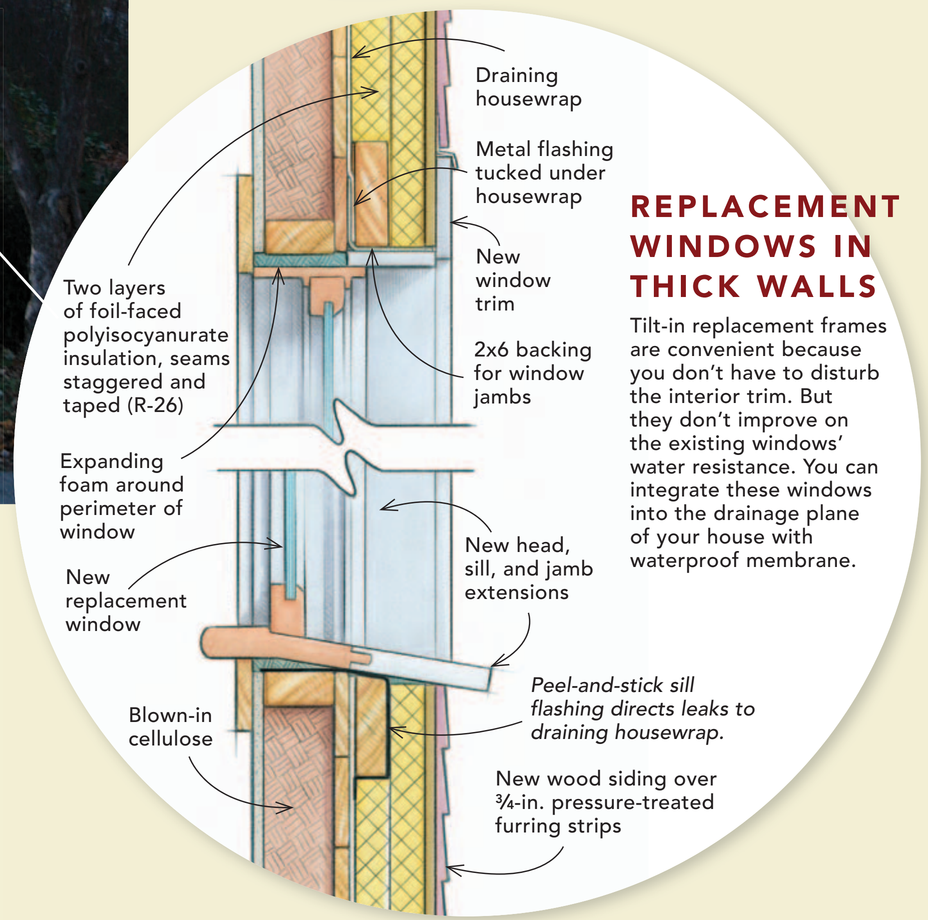
- Before: $1.68 per sq. ft.; after: 37¢ per sq. ft.
- Gas: $2400 a year before; $858 a year after
- Electric: $960 a year before; $471 a year after



INSULATE OVER AND UNDER THE ROOF DECK

To get the most insulation into the shallow 7-in. rafters, we used closed-cell foam. On top of the roof, we added 4 in. of polyisocyanurate foam board, which has the highest R-value per inch of the rigid-foam boards. This yielded an R-60 roof without reframing.

We didn't want to disrupt the interior plaster to spray foam into the wall cavities, so we filled the walls with cellulose and covered them with rigid foam.



REPLACEMENT WINDOWS IN THICK WALLS

Tilt-in replacement frames are convenient because you don't have to disturb the interior trim. But they don't improve on the existing windows' water resistance. You can integrate these windows into the drainage plane of your house with waterproof membrane.

FineHomebuilding.com

Look for the Magazine Extras section on our home page to learn an installation method for replacement windows in thick walls.

How much insulation do you need?

Because the earth is such a great buffer to heat loss and gain, the insulation needs in a house grow as you get farther from the ground. Naturally, they're greatest at the roof, which is baked by the sun all day and chilled by the sky at night.

We specify significantly higher levels of insulation than are required by the International Energy Conservation Code, and we think it is money well spent. When you're attempting to approach net-zero energy use in homes, energy that isn't used is always the cheapest energy.

R-10 under the basement slab

It is easy to add 2 in. or 3 in. of extruded (or expanded) polystyrene under a new slab before pouring the concrete. This could cut into headroom a bit, but the benefits outweigh the cost.

R-20 basement walls

Warming basement walls is often the best protection you can get from mold growth. Additional living space is an added benefit. Energy codes in most cold climates call for at least R-10, but if you can afford the additional insulation at this time, it is well worth it. Both closed-cell spray foam and rigid-foam insulation are good choices.

R-40 in the walls

By warming above-grade walls, you eliminate chilly convection currents inside a room, which can increase your actual living space because furniture no longer needs to be moved away from exterior walls. While the building code asks for at least R-19 in most cold climates, it is worthwhile to use as much insulation as you can afford.

R-60 in the roof

Adding insulation to the roof (rather than the attic floor) brings extra living and storage space into the home at little cost. It also reduces summer cooling loads. It's often easy to provide more than the code minimums because of deep rafter cavities. If you're reroofing the house, consider putting rigid-foam board insulation on top of the sheathing as we did in two of the case studies here. After judging the performance of the first two houses, we increased our recommendation from R-40 to R-60.

BSP-064