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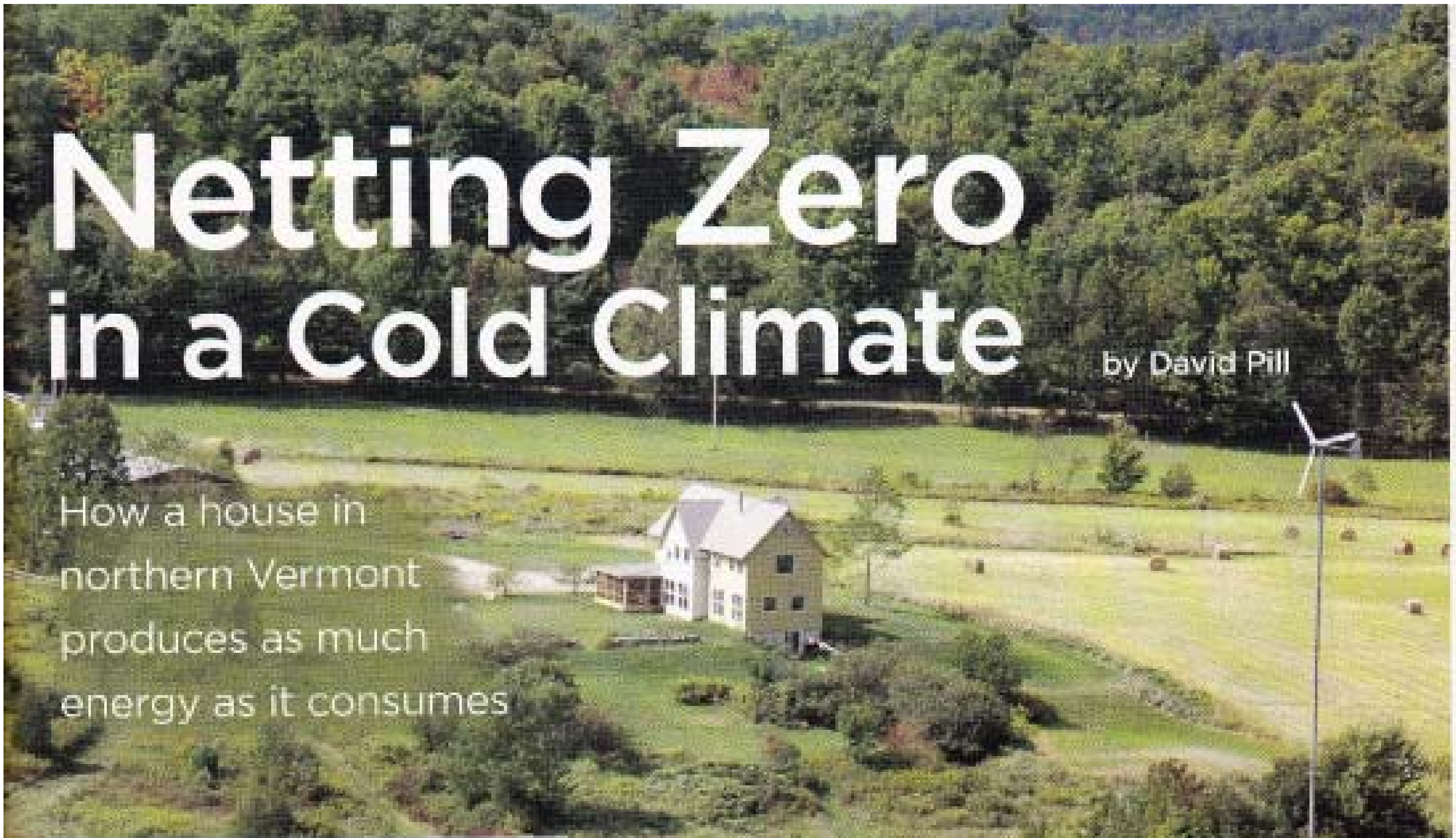
Netting Zero in a Cold Climate

by David Pill

How a house in northern Vermont produces as much energy as it consumes



As an architect, I've been educating myself in green building practices for nearly 20 years, through reading and attending workshops and conferences. So when it came to designing a new home for my family in northern New England, I had definite goals in mind.

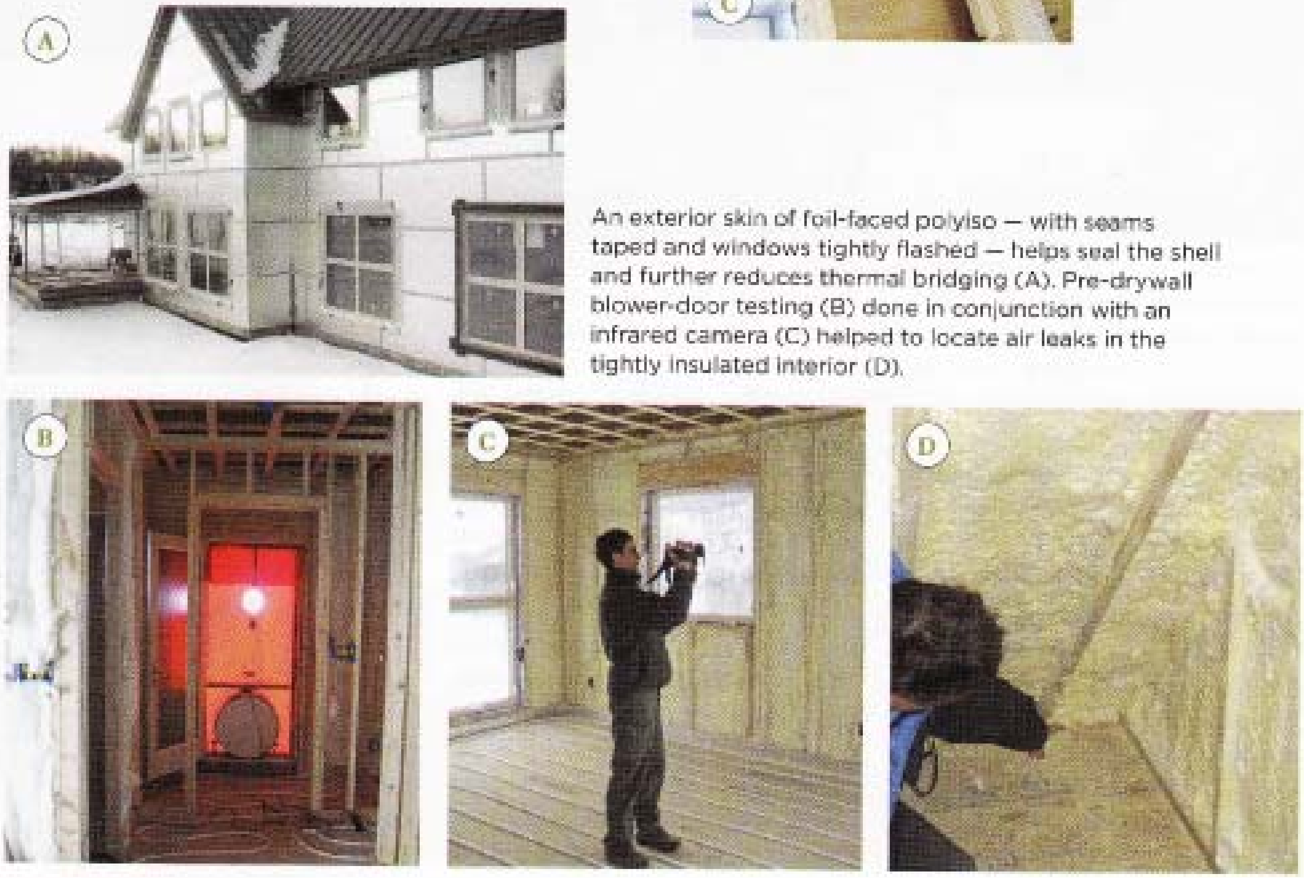
First, I wanted to create a house with as little environmental impact as possible. Second, I wanted to use the most conventional methods possible, so that the house would be relatively affordable and include construction details that could be incorporated in future projects. From the outset, my family and I decided that the house would not release any carbon emissions from the burning of fossil fuel, and that it would generate its energy on site. The challenge was to do this in a very cold climate.

Assembling the Team

As much as the architect in me wanted to design a house based on aesthetics alone, I knew that wouldn't work. So one of the first things I did, after finding the property but before getting beyond some conceptual planning, was to find a skilled builder — Jim Huntington of Charlotte, Vt. — and a talented energy consultant — Andy Shapiro of Energy Balance in Montpelier, Vt. — to collaborate on the project. This is called "the integrated design approach" in the building industry, but it's mostly common sense: Bring the right knowledge and experience to the table at the design stage, knowing that every decision you make at the beginning will have implications later in the process. As I worked on the floor plans and elevations, Jim weighed in on buildability issues, and Andy focused on the building envelope, mechanical systems, and the energy model. We met as a group several times during the design stage, and I met individually with each of them at other times and coordinated the flow of information. Tom Reilly, P.E., of Salem Engineering in South Burlington, Vt., also worked with Andy on the heating system design.

Planning for certification. I hoped to have the house certified by a third party, so I went to Efficiency Vermont, the local administrator for the Energy Star for Homes and LEED for Homes programs. I also learned about a new local program, Vermont Builds Greener (VBG), being created by Vermont's Building for Social Responsibility organization (bsr-vt.org). Going through the LEED for Homes and the VBG checklists was not only a way to

Achieving low heating loads starts with good insulation: Two layers of 2-inch EPS provide a nominal R-26 below the slab (A). Advanced framing techniques like single top plates (B) and two-stud corners (C) reduce thermal bridging.



An exterior skin of foil-faced polyiso — with seams taped and windows tightly flashed — helps seal the shell and further reduces thermal bridging (A). Pre-drywall blower-door testing (B) done in conjunction with an infrared camera (C) helped to locate air leaks in the tightly insulated interior (D).

gain third-party certification, but it helped organize the design process and ensured that I made the right choices early on.

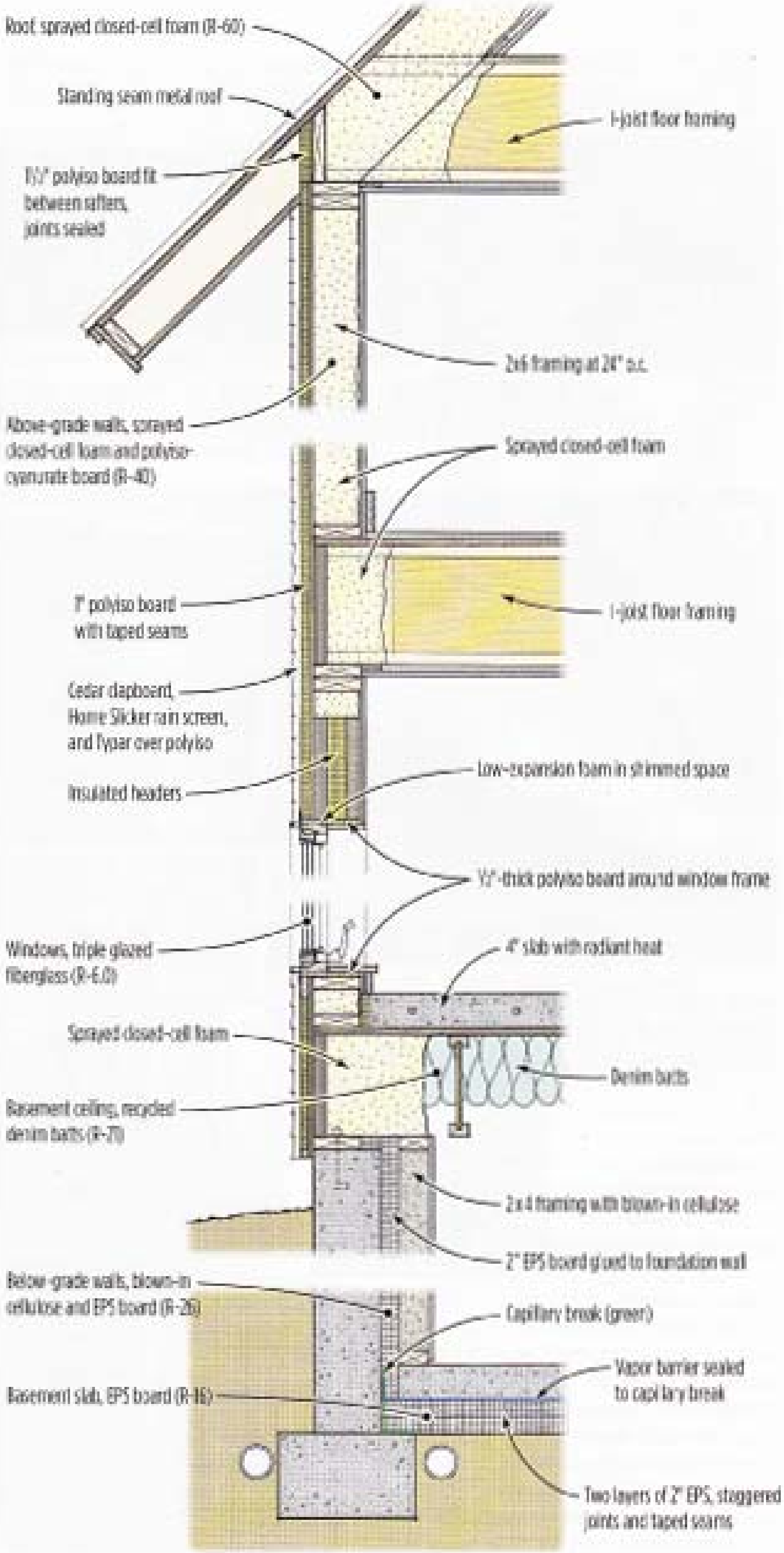
Assessing the site. I visited the property at different times of the day to understand how the sunlight moved across the site and to study the views and the topography. A ridge to the east and a high knoll to the west seemed to create a wind funnel along the north-south axis, and I began considering wind power. I looked into setting up wind-monitoring equipment but decided against it when a neighboring landowner who works for a manufacturer of wind-energy assessment equipment advised me that it wasn't necessary at that site. (He was right: Although it's unusual for the region, there has been adequate wind at our property.)

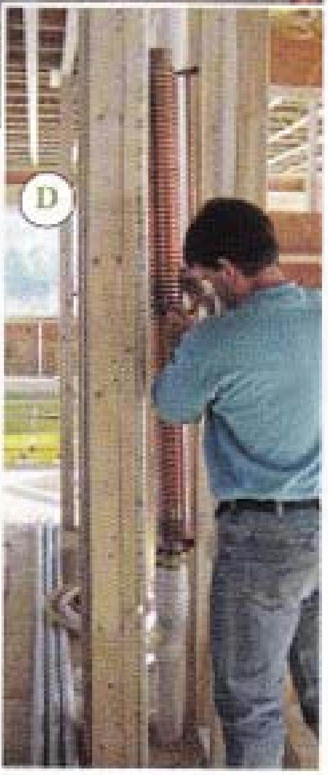
Energy-First Design

Deciding early on to build an ultra-efficient, all-electric house meant we could use a single renewable fuel source with one set of energy units. The target was clearly defined — to design a house with as little energy load as possible, then choose an appropriately sized and affordable source of site-generated electricity. Whether we ended up using the wind or PV panels to generate power, I knew we would have to create a very efficient house and make the most of every kilowatt hour. The local electrical utility, Green Mountain Power, offers net metering, meaning I could return excess capacity to the grid in exchange for utility power that I might need in the winter.

Tight shell. Everything I had learned about efficiency told me to create simple forms, without a lot of dormers, odd shapes, and nooks and crannies — in effect, what had the potential to be an architecturally bland box. But I also knew that the architect in me wanted to alter the box to give it a sense of scale and some detail. I drew ideas from the farmhouses

Section Through Thermal Envelope





What goes up must come down: The wind turbine will be dropped every five years for general maintenance and lubrication (A). In the basement, an Econar ground-source heat pump uses the drinking well to provide hot water for both domestic use and space heating (B). A Hitachi variable frequency controller converts single-phase to three-phase power, allowing for the use of an efficient variable-speed well pump (C). A GFX wastewater heat recovery pipe reclaims an astonishing 30 percent of the heat from hot water used for showers and returns it to the domestic supply (D).

and outbuildings in the surrounding rural area. I started with a simple 20x60-foot clapboard-sided gabled rectangle, set on an east-west axis to maximize solar gain, then added a cross-gable clad in corrugated galvalume and a wraparound porch, which helps to bring the scale of the house down. I gave the first story an open floor plan to make best use of daylight, and stacked the first- and second-story footprints to simplify construction. Operable windows on the north and south walls would allow the steady summer breezes to ventilate the house — the only accommodation to cooling loads, which are not large in northern Vermont.

I worked with the plan, elevations, and wall sections simultaneously, while Andy used Energy 10 software (sbicouncil.org) and his own spreadsheets to model energy use. One of the most difficult challenges was deciding which views to take advantage of without exceeding the square-foot percentage of glazing dictated by the energy-efficient design. For example, I would ordinarily have eliminated most of the north-facing windows, but the view up the valley to the north was not to be ignored. So we ended up greatly reducing the number of east- and west-facing windows and adding others on the north elevation — in the master bedroom and above the kitchen counter. While we do pay a small energy penalty in the winter, the views and natural light we receive more than make up for it.

We chose fiberglass-frame triple-glazed windows from Thermotech, with U-values of .17 (R5.8) for the operable casements and awnings and .15 (R6.7) for the fixed units. South-facing glass would have a .61 SHGC (solar heat gain coefficient) and the rest of the windows .37 SHGC. In shopping for highly efficient custom windows, we found Thermotech's pricing competitive, and that influenced our decision. However, since the windows were installed and we've been living in the house, we've experienced some problems with the windows and found the customer support poor, so I wouldn't recommend the product.

We used advanced framing techniques to the greatest extent possible, with studs on 2-foot centers and the entire building designed in 2-foot modules for ease of construction. We took advantage of solar heat gain by including a 4-inch-thick radiant slab in the first-floor living area, and ⅝-inch skim-coat-plastered drywall throughout the house.

Plug and appliance loads. We specified fluorescent lights and the most efficient conventional appliances we could find. We also chose the highest-efficiency HRV available in our market at the time.

Hot-water savings. Besides conserving hot water, using low-flow shower heads also cuts down on pumping energy (as do low-flow toilets). For further savings, we also included a gravity film heat exchanger, or GFX (WaterFilm Energy, gfxtechnology.com) — a simple copper coil that wraps the drainpipe coming from the showers. The GFX reclaims heat from shower water that would otherwise be lost down the drain, using it to preheat incoming cold water to the domestic hot-water tank. DOE studies have shown up to 30 percent savings in water-heating energy with these devices. (In our case, because we monitor how much hot water we use and the electricity used to heat it, Andy was able to determine that we're also saving 30 percent.)

Providing Heat

After we had designed a tight shell, preliminary calculations with Energy 10 predicted an energy load for heating of 8,482 kilowatt-hours per year (kWh/yr). Andy's model accounted for HRV effectiveness and assumed we would be able to get the shell to a reasonably low blower-door number of 600 cfm at 50 Pascals — tight but achievable as long as we paid attention to air sealing.

The low heating load narrowed the number of practical options for the mechanical system. We looked briefly at the possibility of a hybrid system using solar thermal panels for hot water and space heating, but this would have required either a fossil-fuel appliance for backup or electric backup, which would have increased overall energy use. Given the low design loads, the simplest non-fossil-fuel option for the heating plant was a ground-source heat pump. (At the time we were building, the available air-to-air mini-split heat pumps were not as efficient in cold climates as they are today, or we might have considered those.) We chose an Econar model (econar.com) that also produces domestic hot water fairly efficiently.

Because we had to drill a well for our drinking water, it made sense to use the same well for heating — a type of open loop setup, common in New England, in which domestic water and water for heating are drawn from one well and the return water from the heat pump is delivered back to the same well near the top of the water column. A bleed control activates if the well water gets too cold. In our system, the bleed water will dump into an existing shallow well, but so far the control has never had to be activated.

Ground-source heat pumps produce more output heat energy than the energy consumed in operation, as measured by the COP, or coefficient of performance. Heat-pump manufacturers typically advertise the AHRI (Air-Conditioning, Heating and Refrigeration Institute) rating for the heat pump, which is tested under conditions much more favorable than we see in the North. These ratings are also for the heat only and don't include the other pumps and controls in the system.

Monitoring equipment is critical for measuring the performance of individual components as well as overall system efficiency. A wind data logger (A) displays current wind speed and tracks wind speed over time; a dedicated meter (B) records AC power produced by the turbine. A meter on the heat pump (C) constantly monitors temperature and flow of water into and out of the unit and converts the data into Btu output, while a flow meter on the domestic hot water line (D) measures hot-water consumption.

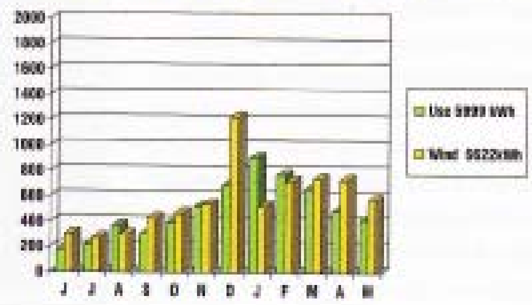
Total Annual Electrical Usage: Modeled vs. Actual*

				Projected Use	Actual Use*
Heating	Annual heating load	8,482 kWh	➡	2,189 kWh	1,865 kWh
	Effective COP for heating	3.874			
Domestic Hot Water	Annual load for hot water	3,557 kWh	➡	1,258 kWh	862 kWh
	Effective COP for hot water	2.826			
Appliance & Plug Loads			➡	4,332 kWh	3,272 kWh
Total				7,779 kWh	5,999 kWh

* Usage data from 6/08-6/09

At right is a bar graph showing wind-turbine production compared with total household energy use over a one-year period. The chart above illustrates how annual energy load for heating and hot water, as modeled in Energy 10, are divided by the heat pump's effective coefficient of performance (COP) to arrive at projected usage. Effective COP accounts for the energy required not only for the heat pump itself but for all pumping and controls as well. The COP for domestic hot water is lower because the heat pump has to work harder to reach 120°F, as opposed to 90°F to 100°F for the radiant floor. Energy consultant Andy Shapiro has monitored this and two other systems and determined actual effective COP for the Econar unit to be about 2.5 to 2.7 for heating and about 2.3 for domestic hot water.

Turbine Production vs. Use, June 2008 to June 2009



Because we would be providing power on site, we had to account for the total energy needed to run the system, not just the heat pump. So Andy calculated what he calls the "effective COP," which includes pumps and controls. To do this accurately, you have to dive into the unit's engineering data, like performance across a range of possible groundwater and heated-water temperatures. By looking at the conditions we expected for each month of the heating season and for domestic hot water all year, Andy estimated the annual effective COP for the system for both heating and hot water.

He also found that using a Gould variable-speed well pump with a VFD (variable frequency drive) controller saved about 50 percent of the pumping energy and increased the effective COP by around 13 percent compared with using a conventional single-speed well pump.

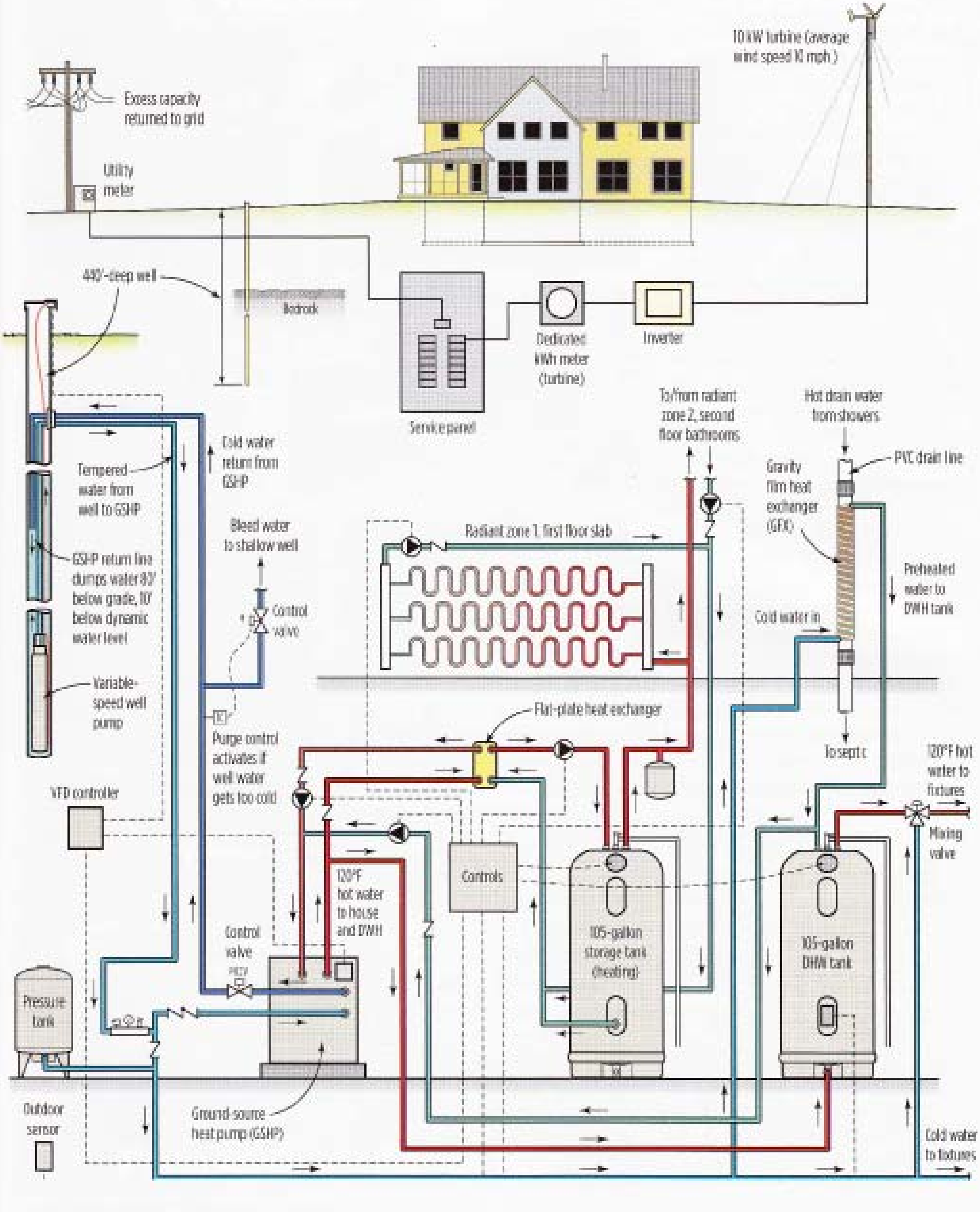
Providing Power

The decision between wind and PV was driven partly by the presence of wind, partly by the cost of PV panels, which has since come down, and partly by rebates available at the time. At $27,000, the cost of a 10kW Bergey turbine, installed, was about half the cost of the 7kW PV system that would have been needed to produce comparable electricity. At that time, the tax credit for alternative energy was capped at $1,500. If I were doing it now, I might choose PV, because it's gotten much cheaper, plus it's a simpler setup with less maintenance expense. The turbine will need to be taken down every five years for lubrication.

Wind is also politically tricky — some people love the sight of windmills and some hate them. We were fortunate that our neighbors were actually pleased at the prospect of seeing a windmill. Noise is another issue: The spinning blades definitely produce sound, but when the wind is already blowing, the windmill tends to become part of the background noise.

In looking at wind power, you need a good idea of average wind speed at the site. As the speed increases, power production increases exponentially. At an average wind speed of 12 mph, our Bergey turbine is far superior in output to PV. Wind monitoring would have been very expensive, so I studied wind maps, spoke to the neighbors, and looked for any other signs I could see, such as flagging of trees. I ultimately concluded that it would be

Wind Turbine and Heating System Details



Interior finishes include a polished radiant slab on the first floor, hardwood floors upstairs, and custom cabinetry throughout the house.

cheaper to buy the system and sell the used equipment if it didn't work out than to spend money on an assessment tower and monitoring equipment. As it turned out, we have an average speed of around 10 mph, less than we originally thought but still enough to offset our energy use.

Finally, Construction

One of the most critical parts of the construction process was running a blower-door test before drywall so we could seal any leaks we found. Our energy model had assumed 600 cfm50, and that's what we achieved.

Overall cost. The cost of the house, not including the land, was $196 per square foot — about the same as comparable custom homes in this area. That includes the cost of the ground-source heat pump and radiant slabs ($28,000), but not the cost of the wind turbine ($27,000). Superinsulating the shell added around 6 percent to the cost, while keeping the shape simple helped keep costs down. We did, however, choose custom cabinetry and higher-cost fixtures, so the overall cost of the home has as much to do with our finish choices as it does with energy efficiency or "green" design.

Heat-pump cost. Ground-source heat pumps have the reputation of being very expensive. For one thing, they are most efficient at heating when used with a low temperature emitter like a radiant slab, which adds to overall expense. In our case, the addition of the GFX and the variable frequency drive on the well pump also added expense, as did some extra controls, gauges, and shut-offs in the hydronic system. Compared with conventional forced-air heating or hot-water baseboard, a ground-source system is costlier, but then so are systems that include radiant heating and condensing boilers. When installed where there's already a standing column well (or one has to be drilled anyway), a ground-source heat pump may turn out to be only slightly more expensive than radiant heat with a condensing boiler, and it allows for the use of renewable energy to power it.

Monitoring Energy Use

Because we live in a rural area, we spend much of our time at home. We are a family of four: my wife and I and our two children, ages 10 and 18. My wife works from a home office, and nearly all of our meals are cooked at home. Though the house has been designed for maximum efficiency, our family is keenly aware of how to "operate" the house so it reaches its potential.

In addition to the power company's electrical meter, the house has several monitoring devices that give us regular feedback — a wind data logger, a kWh meter on the turbine, a kWh meter and a Btu meter on the heat pump, and a flow meter on the domestic hot water line at the water softener. With these meters and the main utility meter, I can track how much energy we produce given the amount of available wind and how many kilowatts (or Btu) of energy the heat pump produces for both space heating and hot water. Because everything is electric, I can simply read the utility meter and subtract our total energy production from the wind turbine to arrive at our net gain or use. Monitoring energy use in a single unit is not only easy to understand, but the feedback gives us incentive to try to lower the usage. As we do this, certain habits change and become new habits, and small changes add up.

To date, after three years, the turbine has produced around 20,000 kWh and we've consumed around 21,000 — a net use of only 1,000 kWh, costing around $140 for all three years. If we didn't have the windmill and were paying for all our electricity, it would have cost about $80 per month for heat and utilities — a sustainable energy cost. The larger point is that building a low-load house in a cold climate is not only affordable but readily achievable, not in the future, but right now.

***David Pill** is an architect in Shelburne, Vt. The home featured here achieved LEED Platinum and has a HERS score of 0.*