A Closer Look

Zero-Energy Homes

With a balance of conservation and renewable production, these houses make as much energy as they use

BY SCOTT GIBSON

Energy bills for some homeowners can be as much of a burden as a mortgage, only a lot less predictable. If you heat with oil, you already know this. In August 2008, filling the two oil tanks in my basement cost $2800. By the following spring, it was $970. Unsettling ups and downs in energy prices aren't the worst of it. Housing accounts for more than one-fifth of all the energy used in the United States. Burning fossil fuels to heat houses and to generate electricity is driving up levels of atmospheric carbon dioxide and transforming the planet's climate to the point of no return.

Green building attempts to address both of those problems by promoting energy conservation. But energy efficiency is only one of several goals in most green-building programs, which are equally concerned with sustainable materials and indoor-air quality, among other things. Even the most rigorous green-rating system, LEED for Homes, requires that homes meet the Energy Star standard, which isn't enough to get a home to net-zero energy use. Net-zero houses focus on energy, and energy alone, which some experts argue is the greenest thing you can do. These houses are designed to produce as much power as they use during one year.

There are several ways of defining just what net zero means: measured on-site, by source energy, and by total carbon emissions. Semantics aside, though, a variety of experts have found ways to reduce net-energy consumption to next to nothing. In the most basic explanation, there are two steps to designing a zero-energy home. First, reduce the heating, cooling, and electrical loads. Then produce the energy that you need on-site with renewable sources. The trick is to strike a balance that achieves these two goals affordably. Here, I'll look at the way these principles have been successfully applied to three designs: a wind-powered house in

NET Zero IN CHARLOTTE, VT

Powered by the breeze. Architect David Pill used closed-cell spray foam plus an inch of rigid polyisocyanurate insulation over the sheathing to insulate the walls of the house he designed for his family in Vermont. The roof is insulated with spray foam alone. Pill also chose a ground-source heat pump and radiant-floor heating system, but careful solar orientation and the mass of a 4-in.-thick concrete first floor provide most of the heat the family needs on a sunny day, even in winter. Power for the all-electric house comes from a 10kw wind turbine that stands atop a 120-ft.-tall tower.

Photo: Jim Westphalen

specs

- **HERS index:** 0*
- **Conditioned space**: 2700 sq. ft.
- **Walls:** 2x6 framing with closed-cell polyurethane foam, wrapped in 1-in. polyisocyanurate foam, R-40
- **Roof:** Sprayed-in foam, R-58
- **Foundation:** EPS and blown-in cellulose, R-21, plus EPS under slab, R-16
- **Windows:** Triple-glazed
- **Wind-turbine capacity:** 10kw
- **Heat source:** Ground-source heat pump, supplemental woodstove
- **Air-conditioning:** None
- **Electricity consumed:** 5999kwh annually
- **Electricity produced:** 6622kwh annually
- **Other fuels used:** 200kwh wood
- **Cost per square foot:** $200
- **What's notable:** The all-electric house is also LEED-platinum certified.

*A net-zero house has a HERS index of 0. Each one-point decrease from a code-minimum score of 100 equals a 1% decrease in energy use.

Designer: David Pill

General contractor: Jim Huntington, New England Housewrights

NET Zero IN WHEAT RIDGE, CO

Net zero for less. Habitat for Humanity and NREL teamed up for a zero-energy project in Wheat Ridge, Colo., that uses only conventional materials and techniques. Double 2x4 exterior walls are separated by 3½ in. of continuous insulation. Two layers of fiberglass batts in the stud cavities and a third horizontal layer between the two walls bring the wall R-value to 40. Using raised-heel trusses and a thick layer of blown-in fiberglass insulation in the attic gets the roof's R-value to 60. The small house has a gas space heater in the main living area and electric baseboard heaters in the bedrooms, but no central heating system. The house has only a modest photovoltaic array.

specs

Designer: National Renewable Energy Laboratory, Habitat for Humanity
General contractor: Habitat for Humanity, Metro Denver

- **HERS index:** 0
- **Conditioned space**: 1280 sq. ft.
- **Walls:** Double 2x4 offset 3½ in., insulated with fiberglass batts, R-40
- **Roof:** Blown-in fiberglass, R-60
- **Floor:** Fiberglass batts, R-30
- **Windows:** Double-glazed, low-e
- **Photovoltaic capacity:** 4kw
- **Heat source:** Gas space heater, electric baseboard
- **Air-conditioning:** None
- **Electricity consumed:** 3585kwh annually
- **Electricity produced:** 5127kwh annually
- **Other fuels used:** 1665kwh gas
- **Cost per square foot:** $116
- **What's notable:** Although the house was initially given a HERS-index rating of 25, the occupants were able to use less electricity than predicted, so they reduced their index to zero.

Charlotte, Vt.; a house in Wheat Ridge, Colo., built by Habitat for Humanity; and a remodeled ranch house in Squam Lake, N.H.

The balance between energy demand and production

Efficient construction and renewable energy are the yin and yang of net-zero design. Paul Norton, a senior engineer at the National Renewable Energy Laboratory (www.nrel.gov) in Colorado, says that "the critical question" in a zero-energy building is how much money should be invested on each side of the equation.

Making a building modestly more efficient doesn't cost much. But the cost of saving energy with building improvements, such as more insulation or better-quality windows, gets progressively more expensive as the energy gains become progressively smaller. Eventually, the cost of additional building improvements outweighs the cost of adding more renewable energy.

Norton says that 50% to 60% of the total energy savings in a net-zero building typically comes on the building-efficiency side before adding renewable energy starts to pay bigger dividends. But when, exactly, does a builder know when to stop adding more insulation? When does it make more sense to add photovoltaic capacity instead of upgrading from double-pane to triple-pane windows?

Computer modeling software can help designers to decide where to spend money most effectively and how buildings will perform with different wall assemblies, windows, and amounts of insulation.

Photos: this page, courtesy of DOE/NREL; facing page: Scott Gibson. Chart facing page: Dan Thornton; source: DOE.

NET Zero IN SQUAM LAKE, NH

Wrapped in a thick coat. In a gut rehab of a 1970s ranch on Squam Lake in New Hampshire, Ben Southworth of Garland Mill Timberframes sprayed the 2x6 wall cavities with foam and added 6½-in.-thick SIPs on the outside of the house to bring wall values to R-52, about three times as high as currently recommended by the U.S. Department of Energy for that climate zone. The same combination of sprayed-in foam and SIPs brought roof insulation to R-73. A ground-source heat pump provides heat, and solar collectors produce hot water. The house is powered by a 7.5kw photovoltaic system.

Designer: Ben Southworth
General contractor: Garland Mill Timberframes

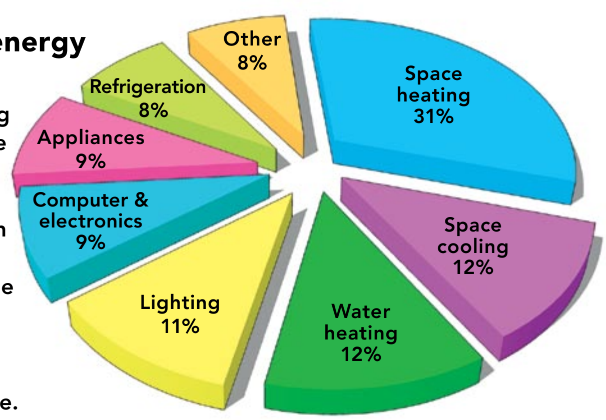
specs

- **HERS index:** 12
- **Conditioned space:** 3400 sq. ft.
- **Walls:** Structural insulated panels over original framing with sprayed-in polyurethane-foam insulation, R-52
- **Roof:** SIPs over sprayed-in foam, R-73
- **Foundation:** Sprayed-in foam, R-42
- **Windows:** Triple-glazed
- **Photovoltaic capacity:** 7.5kw
- **Heat source:** Ground-source heat pump
- **Air-conditioning:** None
- **Electricity consumed:** 7020kwh annually
- **Electricity produced:** 7200kwh annually
- **Other fuels used:** None
- **Cost per square foot:** $400
- **What's notable:** This retrofit also qualified for a LEED-platinum rating.

Builders approach net-zero design in different ways, depending on how harsh the climate is, how much they have to spend, and whether the project is new construction or a renovation. As illustrated here, there's not just one solution. Keep in mind that even the best plans don't always follow a script. Balky heating equipment, colder-than-normal temperatures, the unpredictable habits of homeowners, heavy snow that covers PV panels, and a host of other unknowns can keep even the most well-designed homes from actually reaching net zero.

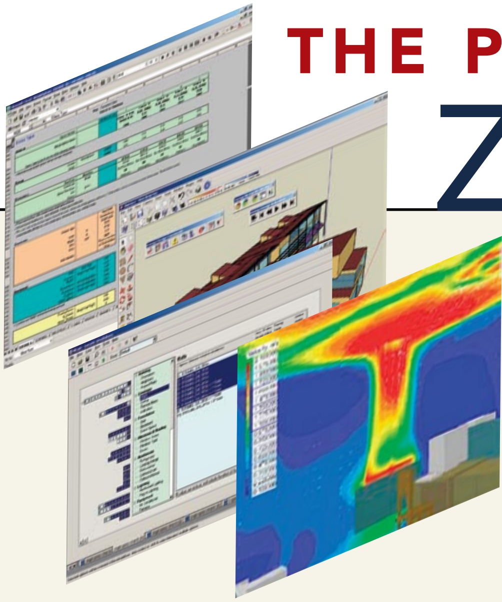
How we use energy in our homes

To avoid overtaxing a typical renewable energy source, designers have to plan a conservation strategy. Usage surveys like this one from 2007 show where the most productive energy cuts might be made.



Reduce electrical use from the start

An average U.S. home used about 11,232kwh of electricity in 2007, according to the U.S. Department of Energy (chart right). In a



THE PATH TO zero energy

Armed with up-to-date surveys of energy use, energy designers employ software to create scenarios of the most viable energy-efficient house. Developed under the auspices of the U.S. Department of Energy, software such as BEopt, EnergyPlus, and DOE-2 creates models of a building's energy performance based on building type, weather patterns, amount of insulation, and HVAC details. Below is a collection of four interdependent net-zero strategies. To be successful, a house can't have just one or two—it needs all four.

1. Build a tight, well-insulated envelope

A continuous air barrier is essential to reducing energy losses. A variety of building materials—including housewrap, sheathing, and drywall—can be part of an effective air barrier as long as the detailing is correct. Add lots of insulation. In cold climates, wall R-values of 40 and R-60 roofs are not uncommon in zero-energy designs. Controlled ventilation is also a must. Because zero-energy buildings are so tight, mechanical ventilation is a prerequisite to controlling interior moisture and keeping indoor air healthful. A heat-recovery ventilator can recoup some of the energy that would otherwise be lost in outgoing air.

2. Choose the right heating and cooling equipment

The point of working hard to build a tight, well-insulated shell is to reduce the size and cost of heating and cooling equipment, and to run it with as little energy as possible.

Heat pumps extract latent heat from the air, the earth, or water and concentrate it with the help of a compressor and a closed loop of refrigerant. Heat can be transferred to water or air for distribution in a house. In summer, the system can run in reverse and function as an air conditioner.

High-efficiency gas or oil is a viable alternative that can meet the extremely low energy demands in a net-zero house, provided that the house produces enough electricity on-site to balance the scales. Some new-generation gas furnaces and boilers have efficiency rates greater than 95%.

Wood or pellet stoves can easily heat a whole house if homeowners are willing to put up with some extra work. The most efficient designs still don't burn as cleanly as heaters running on natural gas or propane. Some argue that a woodstove is carbon neutral because it is only releasing into the air the carbon that trees recently captured.

Electrical-resistance heat makes it easy to measure net-zero performance. All you have to do is read the meter. When heating loads are extremely low, electric heat may be a reasonable option. It's inexpensive to install and easy to zone by room. It's 100% efficient, at least at its point of use. But keep in mind that most electricity coming from the grid is produced in coal-burning plants (big carbon penalty) and is only about 30% efficient.

3. Reduce the demand for electricity

Because a net-zero energy house has to make as much energy as it consumes, every electron counts. Passive-solar design reduces the need for electric lights during the day and makes it possible to install smaller heating and cooling equipment. Other steps include installing what's called an energy "dashboard" to monitor electrical consumption in real time. Installing energy-efficient appliances and lighting is one of the easiest ways to cut consumption. Shutting down phantom electrical loads is another easy fix. The hidden electrical losses resulting from such phantom loads account for as much as 6% of the country's total electricity consumption, according to government estimates.

4. Install renewable-energy systems

Getting to zero energy is impossible without the addition of a renewable-energy source—that is, one that does not burn a fossil fuel. Photoelectric panels and, less frequently, a wind turbine can be used to generate electricity. Solar hot-water collectors usually provide domestic hot water and can help with heating.

Photovoltaic systems must be sized using certain

Photos: left, courtesy of Breakwell Hearth Products; right, Krysta S. Doerfler; facing page, top: Scott Gibson; facing page, bottom: courtesy of DOE/NREL. Screen images: courtesy of DOE/NREL. Drawing: John Hartmann.

Receive credit for producing electricity with net metering

When grid-tied homes produce more electricity than a house can use, two-way meters allow homeowners to bank kilowatt hours during the long sunny days of summer and then draw on the surplus during the winter when production can't meet demand. Called net metering, this process is similar to a savings account for electricity. Most states allow net metering, but there are no standardized fees that utilities pay for power that is generated by rooftop photovoltaic arrays or wind generators.

High feed-in tariffs—the rates that utilities are required to pay for power from private sources—make investments in renewable energy more attractive. A number of states are considering feed-in tariffs, including Indiana, Maine, Michigan, and Minnesota. In Gainesville, Fla., rates were set in 2009 at 32¢ per kilowatt hour, nearly three times the rate that homeowners paid for electricity. That would allow a homeowner to break even on a cost basis even if a house were a net consumer of energy.

assumptions about how much electricity mechanical systems, lights, and miscellaneous plug loads will use, and then the unknown must be factored in. As it stands, government and utility subsidies are essential for making photovoltaics affordable for most Americans.

Wind turbines for residential use are somewhat difficult to place. Wind conditions can be highly variable, even in the same town, and most sites require careful monitoring to predict whether the investment in a turbine is worthwhile. Still, where it works, wind can cost less than half an average photovoltaic installation.

Solar hot water systems can provide 40% to 80% of domestic supply but generally need a backup energy source, such as electricity or gas, to heat water when solar panels can't. Costs also vary widely, from a few thousands dollars for a simple system to more than $10,000 for a system big enough for a small family in a cold climate.

zero-energy house, every kilowatt hour is precious because the cost of producing power on-site is so high.

Photovoltaic-generated electricity costs about $9 per installed watt before tax credits and rebates; that means it takes an investment of $900 to run a single 100w lightbulb. Wind-generated power can be cheaper on a per-watt basis. Opportunities for wind turbines are more limited, though, and a wind turbine still represents a big capital investment.

Making a big dent in consumption is usually the result of many small changes. A basic list should include the use of Energy Star appliances, efficient CFL and LED lighting, and the elimination of phantom electrical loads. Collectively, these steps can have a major impact on power consumption. At the Wheat Ridge house, for example, measured electricity use over one year was 3585kwh, less than one-third of the U.S. average.

Heat and cool efficiently

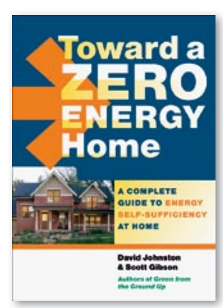
A well-insulated envelope requires less heat, and very low heating demands bend the rules of conventional thinking. Efficient distribution and interior moisture control become challenges when heating and cooling equipment don't have to run often. Heat generated by people, pets, and appliances is suddenly a factor. Conventional houses are heated and cooled by brute force. In a net-zero design, it's a lot subtler. In some instances, a small space heater is all that's needed to heat an entire house.

The first alternative to mechanical heating and cooling is passive-solar design. Joseph Wiehagen, a senior research engineer at the National Association of Home Builders Research Center, says a well-built building shell can reduce heating and cooling costs by 50% or more. Architect David Pill's Vermont house (pp. 60-61) combines radiant-floor tubing and solar-heat gain to warm the first-floor concrete slab. The slab absorbs heat from the sun and releases it slowly at night. Above, only second-floor bathrooms are connected to the radiant-floor system. Because the house is so tight and so well insulated, though, those zones are rarely turned on. The design of the house alone carries a lot of the heating load.

When it comes to choosing mechanical equipment to fill the gaps, there are no pat answers. The best solution depends on a variety of factors, including climate, geography, and the site's solar potential. "Designing for the climate is much more critical," Wiehagen says. "You don't go in with a rule of thumb anymore."

Clean power is the benefit

Renewable energy is essential in a net-zero design. Solar hot-water collectors, photovoltaic panels, and wind generators all are sources of clean energy that create no carbon emissions. Solar and wind potential varies considerably around the United States, reflecting differences in local weather patterns, latitude, and geography. If weather and household patterns are as expected, energy use should net out at zero. As always, the devil is in the details. □



Scott Gibson is a contributing writer. With David Johnston, he coauthored *Toward a Zero Energy Home*, which will be published this year by The Taunton Press.