The Future of American Homes: Net-Zero Energy

Conserve and produce. *The formula for a home that makes all the energy it needs is simple, in theory. First, the designers conserve as much energy as possible with a tight and well-insulated envelope and with efficient heating, cooling, and appliances. Then they add enough renewable energy, like the solar panels seen here, to meet the home's needs.*

Falling technology costs, proven building methods, and new energy codes may soon make electric bills a thing of the past

FINE HOMEBUILDING FOR MARVIN WINDOWS & DOORS

Since the 1970s, green-building proponents touting the advantages of energy-efficient homes have claimed that sustainable construction would become the standard building method within just a few years. While still only a relatively small percentage of new homes can legitimately claim to be "green," the number of energy-efficient houses that outperform current building codes has increased dramatically in the last decade. Part of the growth is due to the expansion of voluntary green-building programs that require thoughtful material choices and/or exceed minimum energy-efficiency standards. One of the green-building programs that has seen the most dramatic growth is the U.S. Green Building Council's (USGBC) LEED for Homes. The number of single-family homes certified by the USGBC has grown from 31 in 2006 to over 18,000 annually.

Not all environmentally friendly homes, however, have been enrolled in these programs. Some architects and builders have simply targeted net-zero-energy performance for their homes. The net-zero designation indicates that a house generates as much energy on-site during the year as it consumes. An advantage of net-zero building is that there are no prescribed steps to reaching net-zero; it's a quantitative measure of performance. This means that it's possible to turn an existing 1917 house into a net-zero house simply by adding enough photovoltaic (PV) panels to offset the energy consumed. This, however, would be terribly inefficient. In practice, the net-zero-energy approach is a combination of energy-reduction strategies and a renewable energy system.

After using conservation methods to reduce the amount of electricity used throughout the year, a net-zero designer offsets that amount with a renewable energy source such as PV panels. The home's electric service is connected to both the grid and the PV panels in a system known as net-metering. On bright, sunny days, the PV panels can produce far more electricity than the house uses at that time, so excess electricity feeds into the grid. The house, in effect, is a power supplier to the grid, and the electric meter runs backward. During the night or on cloudy days when the household demands exceed the PV panels' output, the system takes electricity from the grid, and the meter runs forward. When the inflow and outflow of electricity through the meter balance at the end of the year, net-zero is achieved.

The future is now

For 20 years, the Department of Energy has been running a residential construction research program called Building America that tests different methods of improving the energy efficiency, comfort, and durability of houses. In 2013, the DOE began using the information gathered from Building America projects in its Zero Energy Ready Home program. The aim is to encourage the construction of well-insulated homes that require only a relatively small PV array to meet their energy needs. Further recognition is given for houses that include the renewables to meet net-zero. The program provides builders with technical support for construction and with marketing support by publicizing the concept and educating consumers. The DOE wants to make net-zero-energy construction available to home buyers in every part of the country.

Net-zero is not hard to achieve, and the information and building practices are well known. The most recent version of the International Energy Conservation Code calls for substantial insulation and air-sealing, bringing net-zero closer to reach for code-built homes as local jurisdictions adopt components of this code. But there were only about 160 houses registered in the Zero Energy Ready Home program through the middle of 2014. This is about to change, however. The California Energy Code, referred to as

CASE STUDY:
SUBURBAN NET-ZERO

This new home was built in an existing neighborhood in a Boston suburb. The architects had to overcome two problems: First, the small site with neighboring houses and trees limited solar access; second, the street orientation was 45° off of solar south. Resale value was important to the homeowners, so the style of house had to fit the neighborhood. The architects oriented the traditionally styled entry and garage to face the street, but canted the main wing of the house at an angle for southern exposure. The tall, steep roof holds a PV array large enough to offset all electrical usage and is high enough to prevent shading from the neighboring property. The southeast-facing solar-thermal collector produces hot water when it's needed—early in the day. Marvin triple-pane windows allow plenty of solar gain during the winter and are the entryway's signature element.

SPECS

Location: Newton, Mass.

Architect: Maclay Architects, Waitsfield, Vt.

Builder: Affinity Builders, Concord, Mass.

Building envelope: Walls, R-40; roof, R-67; foundation, R-20

Windows: Marvin Tripane

Air infiltration: 0.13 cfm per sq. ft. at 50Pa (between 1 and 2 ACH50)

HVAC: Mitsubishi air-source heat pump and Renewaire ERV

Size: 5329 sq. ft.

PV system: 9.45 kw, roof-mounted

Title 24, is taking a dramatic leap forward by requiring that all homes built in 2020 and beyond be net-zero.

Steps to a net-zero house

Although a house doesn't need to be enrolled in a formal program to reach net-zero, the design and building process requires careful planning and a command of building science—the study of physics, heat and moisture transfer in houses, and the interrelationship of building products and assemblies. The design phase of a net-zero house begins with architectural style, the same as with any other home. Net-zero doesn't impose constraints in this realm. This is important, because aligning the style and appearance of the house to the homeowners' taste means they're more likely to care for and maintain it over the long term. Durable, long-lasting construction is easier on the environment than carting houses to the landfill every 30 to 50 years.

Style and budget are matters of personal taste and circumstance. Just as budgets vary with traditional homes by size and the quality of their fixtures and finishes, so does the cost of net-zero homes. Production builders such as Meritage claim they can build net-zero houses for as little as $200,000 in some markets. (Material and labor costs vary by market, but the amount of solar production needed to offset heating and the number of sunny days also affects cost. Northern climates require more solar investment—perhaps an additional $6000 to $12,000 according to some estimates.)

With the budget and style decided, the next step is the siting of the house.

Turn to the sun

It's important that a house take advantage of the sun's energy and warmth as much as possible. Orienting its long axis east-west so that the large roof plane faces south maximizes exposure to the sun. This provides two opportunities for solar energy. The first is solar gain: If the house has a heating season, the sun should flood in through southern windows and warm the house during the day. Because the sun is low in the sky during the coldest months of the year, it can stream unfettered through the windows. Thermal mass inside the house—concrete or stone floors and/or interior concrete or masonry walls—absorbs solar gain during the day and releases the heat over a period of hours after the sun fades to the west. During warmer months, overhangs and shading devices prevent solar heat gain.

Orienting the long axis of the house southward also provides real estate for PV panels. This is one area where planning a net-zero-energy house influences the shape of the building. The most common location for PV panels is on the roof, so the south-facing roof face may need to be large enough to accommodate the panels needed to achieve net-zero. The ideal panel installation cants the panels at an angle that's particular to the house's location, so getting the roof pitch close to this ideal angle improves PV-panel performance.

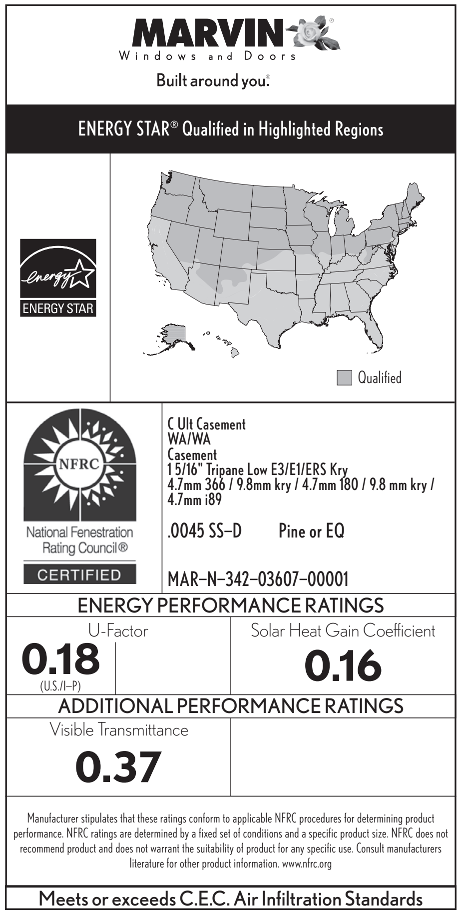
Recent studies have made a case for west-facing PV panels as well, because the electrical production of south-facing PV panels maxes out much earlier than electric demand. Consider your house during the height of summer: South-oriented PV panels achieve maximum production between 11:00 am and 1:00 pm. Yet electricity demand peaks on the grid around 5:00 p.m. as outdoor temperatures max and people cool their homes after they've arrived from work. Although west-facing panels produce 20% less electricity during the day than south-facing panels, they produce it when the need is highest. Consequently, some utilities pay higher prices to net-metering customers for electricity produced after 2:00 pm. In fact, California offers a $500 subsidy for west-facing panels.

Seal the envelope

The building envelope is the exterior shell of the house—the roof, walls, windows, doors, and basement or slab. While the job of the envelope is to keep the weather out, houses have been spectacularly leaky until recently, allowing outside air in and expensively conditioned air out. Air moving through small gaps around window framing and leaky window seals, through electrical outlets and recessed lights, and through attic hatchways and chimneys is substantial enough to allow the entire air volume of a house to exchange several times per hour. A leaky house is uncomfortable, costly to heat and cool, and very likely to have poor-quality air. Air-sealing, that is, plugging these gaps, is a critical step to building a high-performance house—one that is highly insulated and efficient enough to become net-zero.

To learn the tightness of a house's envelope, builders conduct a blower-door test by depressurizing the house and measuring the amount of air that moves through the envelope. Builders of net-zero houses might target between 0.6 and 3.0 air changes per hour with the house depressurized to 50 pascals.

In a house that's this well sealed, or "tight" in building-science terms, it's necessary to rely on mechanical ventilation for controlled air exchange. In many climates in North America, designers choose a heat-recovery ventilator (HRV) or an energy-recovery ventilator (ERV). These devices recover the energy contained in the outgoing conditioned air and use it to temper the incoming air to save energy and improve comfort.



High-performance windows are a net-zero must-have. *Window rating labels, like the one seen here from Marvin, list performance ratings such as U-factor and solar heat-gain coefficient, that must all be carefully considered in a zero-energy home.*

If air-sealing is about controlling convective heat transfer, insulation is about controlling conductive heat transfer by putting a material that heat doesn't travel through easily between the exterior siding of the house and the interior drywall. Because the amount of insulation determines how effectively the conditioned air inside the house is isolated from the outdoor temperature, it also determines to a large extent the heating and cooling load for the house. Deciding on the optimum insulation thickness in a net-zero house is based on two things: local climate and when the return on investment in insulation diminishes to the point that the money is better spent on PV panels.

Performing such a cost analysis differs from the approach taken by Passive House, a high-performance building strategy from Germany that's been drawing interest in the last few years in the United States. Passive House sets an annual cap on the amount of heating-and-cooling energy a house uses. Passive Houses rely on superinsulated walls, often 12 in. thick or more. From a return-on-investment perspective, the extra insulation might not make sense. While designing a development of town houses in Philadelphia, high-performance home designer Ted Clifton compared Passive House and net-zero strategies and found that the Passive House version of the town house had half the heating load of the net-zero version but cost a third more to heat. Compared to a standard code-built home, the payback period for the added expense of net-zero construction (including the PV panels) was half that of the Passive House.

Understand window ratings

Of course, a house isn't just air-sealing and insulation statistics. It needs windows and doors for light, fresh air, style, framed views, and a connection to the outdoors. It's important, however, that doors and windows have good insulating qualities and very low air-leakage rates, because the holes punched in the walls for doors and windows are a potential weak spot for heat transfer and air infiltration. When it's time to choose windows, though, many homeowners are tempted to throw up their hands when they're confronted with a broad range of styles and a sheet of numerical ratings that make little sense to those outside the industry.

Choosing windows doesn't have to be overwhelming; once you've been introduced to the concepts of how windows and doors perform, it's not difficult to follow. An Energy Star rating should be the starting point for window and door selection. It ensures that windows and doors meet a benchmark

CASE STUDY:
NET-ZERO REMODEL

The windows in this ultra-energy efficient, shingle-style remodeled lakeside home frame views of the shoreline and lake from nearly every room, strengthening the indoor/outdoor connection. The remodel used the same footprint as the original structure but substantially increased insulation levels and is extremely well air-sealed. All windows are high-performance Marvin Ultimate triple-glazed units. The orientation of the lot and preferred view are to the west, so the main axis of the house runs north-south instead of the preferred east-west. By focusing on conservation efforts to reduce the load, the smaller, south-facing roof faces were enough for a PV array to achieve net-zero.

SPECS

Location: Lake Sunapee, N.H.

Architect: Maclay Architects, Waitsfield, Vt.

Builder: Estes & Gallup, Lyme, N.H.

Building envelope: Walls, R-40; roof, R-60; foundation, R-21.8

Windows: Marvin Tripane

Air infiltration: 0.072 cfm per sq. ft. at 50Pa (about 0.6 ACH50)

HVAC: Mitsubishi air-source heat pump and Venmar HRV

Size: 4275 sq. ft.

PV system: 9.75 kw, roof-mounted

Before the remodel.

performance level based on three criteria: how well they insulate, how much solar heat passes through the glass, and how airtight they are.

U-factor reports a window's insulating properties by measuring the flow of nonsolar heat through the window. You can think of it as the rate of conduction; the lower the U-factor, the less heat will flow through the window. (U-factor is the reciprocal of the more familiar R-value used to rate insulation. R-value measures resistance, so higher numbers are desirable.) The airspace between glass panes serves as insulation by interrupting the path of heat through the window. A single clear pane may have a U-factor of 1.04, but a sealed double-pane unit can be as low as 0.5. Adding a third pane can improve the U-factor to 0.3. Replacing the air with certain gases further improves the insulating value of the window. Manufacturers use argon or krypton because they're inert—chemically stable and nonreactive—and because they reduce heat loss, as they are less conductive than air. Argon and krypton also reduce convective losses; because they are heavier than air, gas movement within the insulating space is reduced.

With a virtually invisible metal or metal-oxide coating on the glass, insulating windows are more efficient. This coating is transparent to visible light, but it blocks long- and short-wave radiation by reflecting it. Known as a low-e (for low-emissivity) coating, it's common today even on low-cost windows. Depending on the nature of this thin coating and which window surface it is applied to, the coating can reflect heat back into the room to conserve it or filter sunlight to keep heat out. Using a coating on two different glass panes can fine-tune the amount of heat that's retained in each direction.

Windows don't just insulate; they also can warm a house. The amount of the sun's heat a window lets through is the solar heat-gain coefficient (SHGC). SHGC ranges from 0 to 1, where 1 is uninterrupted heat gain. A clear-glass, two-pane insulated window can have an SHGC between 0.56 and 0.68. A triple-pane window with low E3 on one glass face and low E1 on another can reduce SHGC to 0.15. The low-e coatings that improve a window's U-factor tend to decrease the SHGC, so designers have to make trade-offs between the two characteristics. Unlike U-factor, where a lower value will perform better in most climates, SHGC is not one size fits all. In cold climates, high SHGC is desirable, but the opposite may be true in warmer climates.

While the characteristics of glass are an important consideration in high-performance homes, the material used in the window frames is important as well. Although we tend to think of a window as primarily glass, the frame makes up 20% to 30% of the unit. Marvin's Integrity fiberglass frames maximize the insulating ability of a frame because their strength permits hollow construction and because fiberglass is one of the least conductive frame materials.

Another measurement to pay attention to on a window is the air leakage (AL). AL measures the amount of air passing through the window assembly, a source of heat gain and loss. It is expressed in cubic feet per minute through a square foot of window, and the Energy Star threshold of 0.3 represents a good performance value.

Use a systems approach to choose windows

Builder Ted Clifton points out that building a net-zero house is a matter of looking at the house as a system. The goal is to maximize the house's overall performance rather than any single part. Even in relatively moderate climates such as the Pacific Northwest, net-zero houses have wall assemblies in the R-40 range. Windows are much lower compared to that. Upgrading from a basic double-pane R-3 (U-0.33) window to a triple-pane unit is a worthwhile investment because the performance increase is spread over the large surface area of all the windows in the house and makes a large enough difference to justify the moderate increase in cost.

Some net-zero-house designers opt for high-performance windows imported from Europe. These windows may have the equivalent of R-7 (U-0.15), but studies of net-zero strategies have found that their high cost can't be justified. According to calculations in Gary Proskiw's paper "Identifying Affordable Net Zero Energy Housing Solutions," it takes approximately 160 years for the cost of an imported Passive House window to pay for itself with energy savings.

Doors are less of a concern because they're a relatively small portion of the building envelope. Here, airtightness is more important than R-value.

It's also important to get the number of windows right, not just the type. In a heating-dominant climate, most windows will be on the south-facing side of the house. It's typical to limit glazing on the south side

HIGH-PERFORMANCE GLAZING OPTIONS FROM MARVIN

Marvin offers thousands of window and door options with two or three panes of glass and a range of glazing options to meet the performance challenges of any climate. The correct glazing selection can meet code requirements and provide optimal and cost-saving energy efficiency.

Insulating glass
Marvin's standard glazing is insulating glass (IG) with Low E2 and argon gas. IG glass is double-glazed and, compared to a single pane, cuts heat loss significantly because of the insulating airspace between the glass layers.

Tripane glazing
Tripane glazing provides enhanced energy performance. Available in products where glazing thickness can be wider than ¾ in., these windows feature two coated panes of glass with a third pane between them. Marvin offers Tripane in a variety of low-e configurations for a range of solar heat-gain control.

Insulating gases
Insulating gases are pumped into the spaces between panes of glass to slow the transfer of heat, increasing the insulating power of a window or door. Marvin products contain argon gas as the standard insulator but also offer a krypton/argon/air blend for even greater energy efficiency. The addition of krypton to this gas blend lowers the U-factor and increases the insulating capabilities in narrow airspaces.

to about 6% of the house's square footage. More than that, and the house will overheat on a sunny winter day despite freezing outdoor temperatures. In regions with less heating demand, the amount of glazing might be less. In both cases, overhangs that shade the windows from the higher track of the summer sun should be used to shade the windows from solar heat gain. The east and west sides of the house require a different approach. Because the sun is close to the horizon at these compass points, it's not possible to shade with overhangs, so the amount of glass is reduced to equal 2% to 3% of the house's square footage on these orientations. An additional strategy to deal with the sun on each side of the house is to tune the windows to the orientation. This means using high SHGC windows on the south face even at a slight insulating loss, and windows with low SHGC values on the east and west sides to help control heat gain where overhangs can't provide shading.

Use heat pumps for efficiency

The next step in designing a net-zero home is to make the most efficient use of the energy consumed by the HVAC system. That's why most net-zero-house designers specify an all-electric house. Burning fossil fuels invariably involves lost energy; for instance, the most efficient fuel-fired furnace is 97% efficient. Heat-pump products have a coefficient of performance (COP) greater than 1.0. COP is the ratio of the heating or cooling provided per electricity consumed. The fact that the number is greater than 1.0 means that for every unit of energy put into the system, you get more than one unit out. Air-source heat pumps can reach a COP of 4.0. They are popular because they offer cooling as well, and because they are relatively inexpensive.

Ground-source heat pumps are another possible heat source. Although more efficient than air-source heat pumps and easily integrated with domestic hot-water production, ground-source systems are more expensive. It's often more feasable to use an air-source heat pump, even if it means increasing the size of the solar array slightly.

Reduce plug loads

All appliances in a net-zero home should be chosen carefully for efficient performance. Once again, Energy Star is the starting place, but keep in mind that not all Energy Star–rated appliances are equal; some go well be-

Light is a complex part of the zero-energy equation. *Naturally lit spaces reduce the electrical load of artificial lighting and can warm a house in the winter. Proper shading and the right windows can minimize that heating effect in the summer. Window location and selection are key factors.*

yond the minimum-qualifying threshold. To evaluate the relative performance of models within an appliance category, check their Consortium for Energy Efficiency (CEE) category (often listed on the Energy Star label). CEE—a partnership of manufacturers, the Department of Energy, utility companies, and environmental groups—ranks qualifying appliances in several tiers: Tier 1 appliances meet basic Energy Star standards, Tier 2 is awarded to machines exceeding the Energy Star standard, and Tier 3 is for the highest performers in the category. (Certain appliance groups also have a Tier 4.) Researching the energy consumption of Energy Star models and choosing the most efficient will maximize conservation and lower the size and cost of the solar array required to reach net-zero. Everything counts, from the TV to the laundry machines.

When it comes to lighting, LED prices have fallen enough, their color quality is good enough, and their efficiency great enough that they are the only real option. Using the lights to illuminate surfaces rather than trying to light spaces not only requires fewer fixtures but makes for better light. Of course, using windows and glazed doors to provide daylight where it's needed is also a good approach to passive lighting.

With the home's solar orientation, building-envelope details, windows and doors, HVAC system, appliances, and plug loads determined, the designer can now calculate the amount of renewable energy needed.

Generate electricity on-site

In most cases, the electrical demand is met with PV panels. In the last six or seven years, the cost of PV panels has fallen 40% to 50% and is now between $4 and $5 per installed watt. Just as importantly, efficiency has increased during that same time. Solar modules used to be between 7% and 8% efficient; now they are 15% to 16% efficient. A PV array of a particular kilowatt size now takes up only about half the space it used to, making it easier to achieve net-zero in denser suburban areas where roof area or solar access may be more limited.

Additionally, there are federal and state rebate programs that help defray the cost of adding renewable energy to a house. As California's net-zero effort goes into effect, it's likely to influence codes across the country, driving down the cost premium of better building envelopes and improving the performance of all new houses.
