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Hurricane Relief Efforts & the Solar Community

Courtesy Jim Sicile

Our planet's warming ocean waters have led to stronger hurricanes. As a result, category 4 and 5 hurricanes Harvey, Irma, and Maria have taken a serious toll this season, claiming 272 lives thus far, and devastating homes and communities in Texas, Florida, and much of the Caribbean.

In the aftermath of Hurricane Maria, the spotlight has been on Puerto Rico. At least 48 deaths were reported and, in addition to extreme flooding and collapsed and damaged roads and buildings, their entire electrical grid was knocked out. A full three and a half weeks after the storm, recovery efforts were still extremely slow and, according to the Puerto Rico Electric Power Authority, only 15% of the island's electricity had been restored.

In light of these storms, the Solar Energy Industry Association (SEIA) has realized that they, and the solar community as a whole, are in a unique position to help bring power back to these communities. In an effort to coordinate product donations, volunteers, and contributions to get solar equipment to impacted communities, SEIA has joined with federal agencies, such as the Federal Emergency Management Agency and the U.S. Army Corps of Engineers, logistics groups, and on-site solar companies. Working together, they are identifying the areas of most critical need and delivering supplies and help.

After the initial disaster relief response, SEIA plans to work with solar companies, battery suppliers, and financiers to install PV systems at essential service facilities, such as hospitals, fire and police stations, emergency shelters, and food and water distribution centers. They hope to highlight that solar, energy storage, and microgrids can help restore power, and be the basis of a more resilient grid.

If you would like to be a part of this effort—donating equipment, time, or money—or share with SEIA information of renewable-energy relief efforts already underway, visit seia.org/disaster-response.

—Justine Sanchez, for the *Home Power* crew

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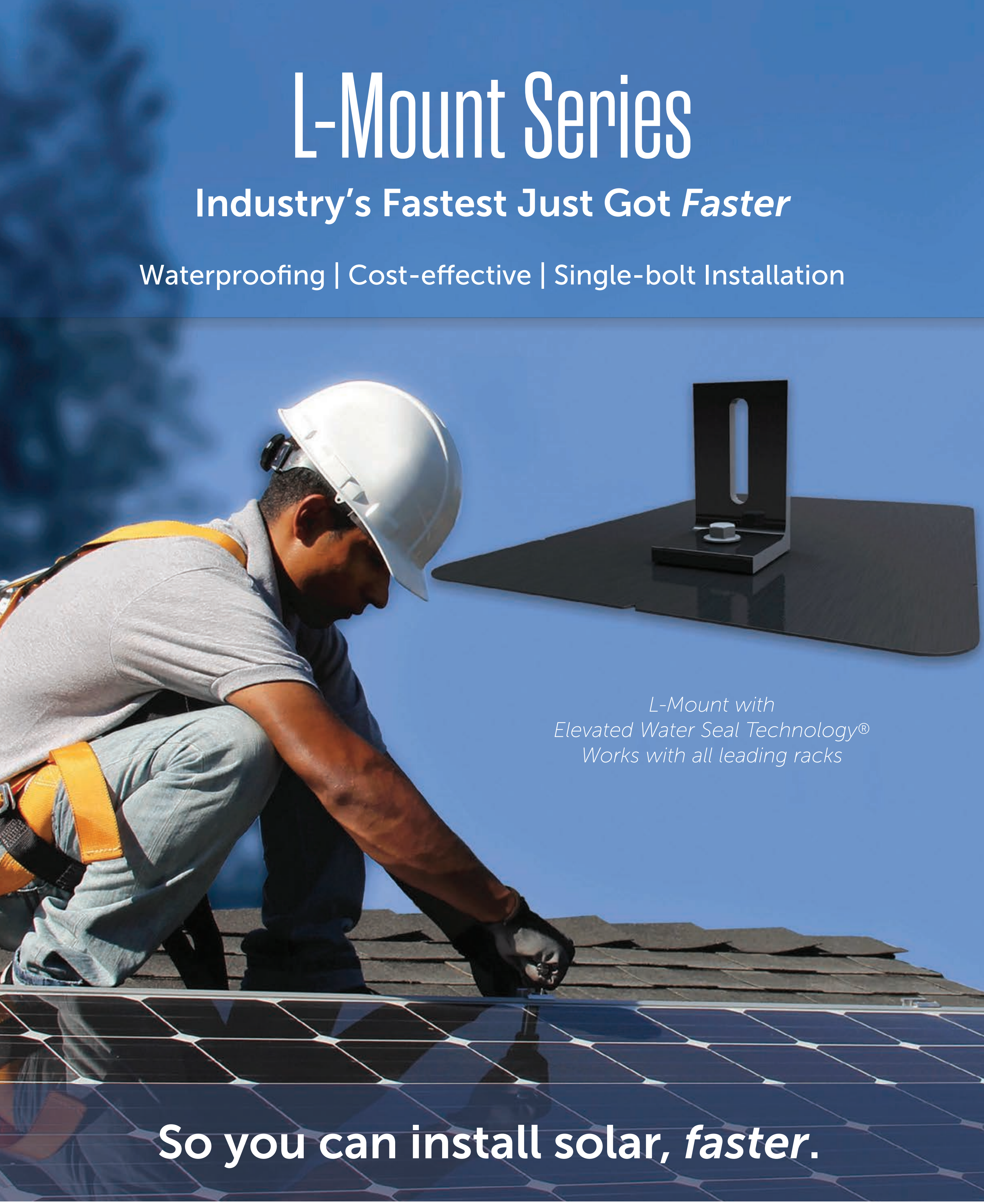
—Bernie Sanders



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On the Cover

Sarah Elvington and Benjamin Root with their 5.3 kW batteryless grid-tied PV pergola in southern Oregon.

Photo: Benjamin Root IV

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Photos courtesy: Benjamin Root IV; Habitat for Humanity EBSV; GE

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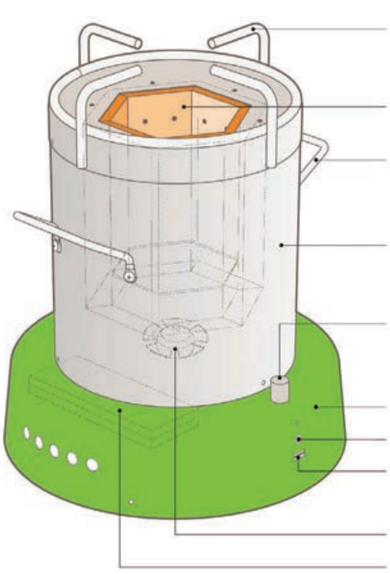

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Photos: Vaughan Woodruff; courtesy ACE

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Art Director	**Ben Root**
Senior Editors	**Michael Welch, Ian Woofenden**
Senior Technical Editor	**Justine Sanchez**
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contributors

this issue's experts

Allison Bailes is a recovering physicist who found his calling in the world of building science. His company, Energy Vanguard, does training, consulting, and HVAC design. He writes a popular blog at energyvanguard.com.

Environmental writer **Juliet Grable** lives in southern Oregon, where she writes about sustainable building, renewable energy, and issues related to water conservation and watershed restoration. This year, she completed training to serve as an Ambassador Presenter for the Living Building Challenge.

Thirty years ago, **Kathleen Jarschke-Schultze** answered a letter from a man named Bob-O who lived in the Salmon Mountains of California. She fell in love, and has been living off-grid with him ever since. *HP1* started a correspondence that led Kathleen and Bob-O to *Home Power* magazine in its formative years, and their histories have been intertwined ever since.

Ryan Mayfield is the principal at Renewable Energy Associates, a design, consulting, and educational firm in Corvallis, Oregon, with a focus on PV systems. He also teaches an online course in conjunction with *SolarPro* magazine and HeatSpring.

Erik North founded Free Energy Maine in 2008 and is the company's president and primary energy advisor. He graduated from the Maine State Housing Authority's Residential Energy Auditor program in 2008 and completed the Building Performance Institute's (BPI) Building Analyst program in 2010. Erik is a member of the Maine Association of Building Efficiency Professionals and a participating Energy Advisor with Efficiency Maine.

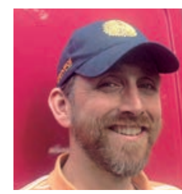
Hugh Piggott lives off-grid on the northwest coast of Scotland. He builds small wind turbines, writes books about how to do so, and has taught construction courses around the world. Hugh also installs hydro and PV systems, and writes about off-grid renewable energy systems.

Benjamin Root has over 20 years on-staff with *Home Power* as art director. Mixing artistic inspiration with technical nerdism, Ben especially loves dispelling the myths and misconceptions of renewable energy. He approaches graphic design from the eyes of an educator, with the intent of helping everyone become successful and satisfied renewable energy users.

Justine Sanchez is *Home Power*'s principal technical editor. She's held NABCEP PV installer certification and is certified by ISPQ as an Affiliated Master Trainer in Photovoltaics. An instructor with Solar Energy International since 1998, Justine teaches PV Design courses. She previously worked with the National Renewable Energy Laboratory (NREL) in the Solar Radiation Resource Assessment Division. After leaving NREL, Justine installed PV systems with EV Solar Products in Chino Valley, Arizona.

Essie Snell researches a wide range of established and cutting-edge energy-efficiency technologies spanning multiple sectors. Some of his core areas of expertise include home energy management systems, Internet of Things devices, water heating, and black-box technology evaluation. Essie holds a bachelor's degree in engineering physics from the University of Colorado at Boulder.

Michael Welch, a *Home Power* senior editor, is a renewable energy devotee who will celebrate his 27th year of involvement with the magazine in 2017. He lives in an off-grid home in a redwood forest in Humboldt County, California, and works out of the solar-powered offices of Redwood Alliance in nearby Arcata. Since 1978, Michael has been a safe-energy, antinuclear activist, working on the permanent shutdown and decommissioning of the Humboldt Bay nuclear power plant.



Vaughan Woodruff owns Insource Renewables, a solar contracting firm in Pittsfield, Maine. His firm, along with Assured Solar Energy, was selected to run the Solarize Freeport campaign. He is a NABCEP Certified PV Technical Sales professional, NABCEP Certified Solar Heating Installer, and an instructor for Solar Energy International.

Home Power senior editor **Ian Woofenden** has lived off-grid in Washington's San Juan Islands for more than 30 years, and enjoys messing with solar, wind, wood, and people-power technologies. In addition to his work with the magazine, he spreads RE knowledge via workshops in Costa Rica, and lecturing, teaching, and consulting with homeowners.

Zeke Yewdall is the chief PV engineer for Mile Hi Solar in Loveland, Colorado, and has had the opportunity to inspect and upgrade many of the first systems installed during Colorado's rebate program, which began in 2005. He also has upgraded many older off-grid systems. He teaches PV design classes for Solar Energy International.

Contact Our Contributors

Home Power works with a wide array of subject-matter experts and contributors. To get a message to one of them, locate their profile page in our Experts Directory at **homepower.com/experts**, then click on the Contact link.

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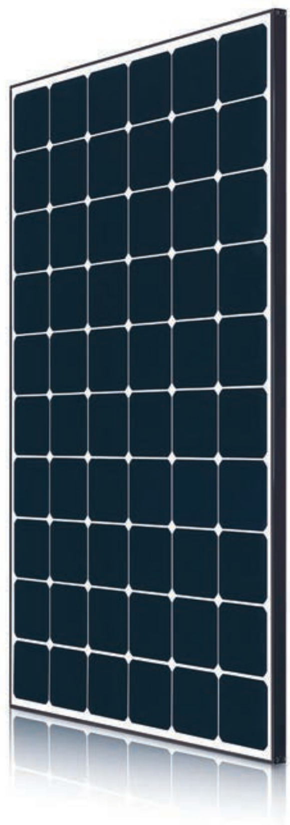

Courtesy LG Electronics

LG Electronics

NeON R PV Modules

LG Electronics (lgsolarusa.com) released its NeON R 60-cell modules aimed at the residential PV market, available in 350, 355, 360, and 365 W. All metal contacts are on the back for a more aesthetic front. Efficiency ranges from 20.3% to 21.1%, with a positive-only power tolerance of +3/-0 and an improved temperature power-loss coefficient of -0.3% per degree Celsius. A reinforced frame provides front-side loading up to 125 pounds per square foot. LG offers a linear performance warranty of at least 87% of initial output after 25 years.

—Justine Sanchez

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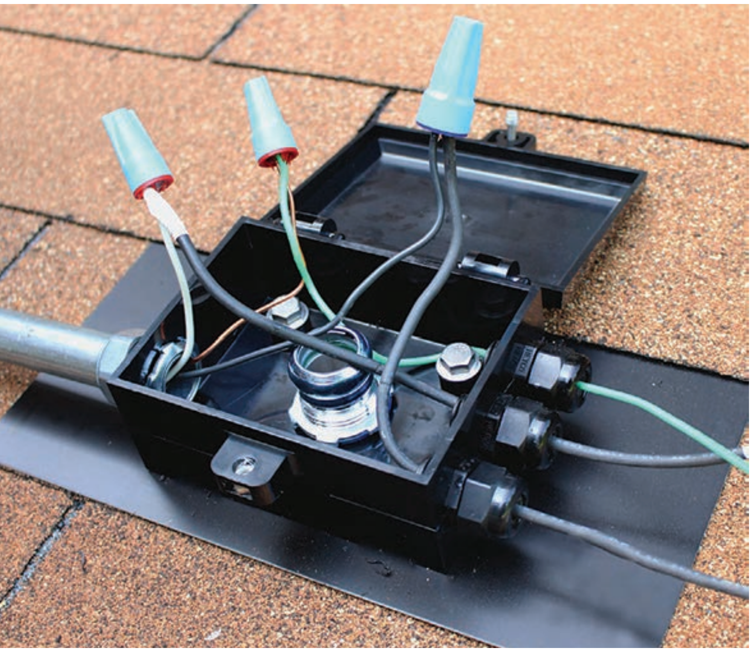
Blue Ion 2.0 LFP Battery

Blue Planet (blueplanetenergy.com) released its Blue Ion 2.0 lithium iron phosphate (LFP) maintenance-free battery designed for off-grid systems. It is available in 8, 12, and 16 kWh capacities (within a single enclosure) at 48 VDC nominal voltage. Additional units can be paralleled for higher capacity. This package integrates Sony cells with a battery management unit and a 250 A circuit breaker. Battery life is stated to be 8,000 cycles at 100% depth of discharge. The Blue Ion 2.0 cabinet—24 by 24 by 39 inches—includes wheels and feet that can be lowered once the cabinet is in place. It has a maximum weight of 500 pounds for the 16 kWh version. Battery status can be monitored remotely via a proprietary app. LFP batteries are known for their thermal and chemical stability. This product comes with a 15-year performance warranty.

—Justine Sanchez



Courtesy Quick Mount PV

Quick Mount PV
Q-Box

Quick Mount PV (quickmountpv.com) offers a flashing-integrated junction/pass-through box. The Q-Box is a waterproof enclosure that can accommodate transition array wiring (up to two strings) from conductors in free-air to inside conduit on composite shingle roofs. The polycarbonate 5.5-by-5.75-inch box is attached via anchor bolts and sealing (EPDM) washers to the top of the 12-by-12-inch anodized aluminum flashing. Holes for cord grips and conduit are made during installation, and conduit can either pass through the back into the attic space or exit the side of the box. Waterproof wire nuts are included and rated to 600 VDC. Installers supply their own cord grips and conduit fittings, which must be raintight or suitable for wet locations.

—Justine Sanchez

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ian@renewablereality.net renewablereality.net/pvdw2018.html

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25-year Cable Ties

Courtesy HellermannTyton

HellermannTyton (hellermanntyton.us) manufactures the T50R-PVDF-BK, a 25-year-rated plastic cable tie for wire management. Made from polyvinylidene fluoride—which has high UV, chemical, and temperature resistance—they are designed to reduce cable management failures over the warranty lifetime of a PV system. These 8-inch cable ties have a 50-pound tensile strength and feature smooth edges to prevent cable damage. The listed temperature range is -40°F to 284°F.

—Justine Sanchez

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Courtesy African Clean Energy (2)

ACE 1 Ultra-Clean Biomass Cookstove

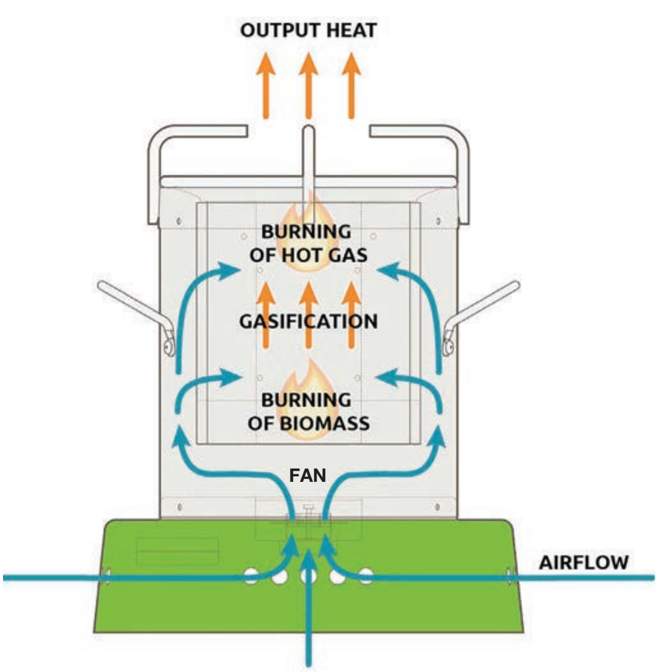
by Ian Woofenden

Worldwide, roughly one in three meals are cooked by burning biomass—most often wood or charcoal. But traditional fires are problematic, exacerbating deforestation and air pollution, and causing health issues. In Central America, I often see open cooking fires in one corner of simple homes. The walls and ceilings in that part of the building are coated with black soot, which also likely permeates the lungs of the residents. And I see the poor rural dwellers cutting down native trees because they need many large pieces of wood to fuel their inefficient open fires.

More efficient ways to burn wood for cooking have been developed, including "rocket stoves." Aprovecho, a nonprofit focused on sustainability, was key in developing this technology, which in its beginning, was a horizontal tube connected to a vertical tube, with specifically proportioned parts. These stoves create an airflow and burning pattern that consumes small pieces of wood efficiently and cleanly.

Until recently, most rocket stoves were hand-built on site, out of metal or masonry. This was a low-tech and relatively low-cost approach, but limited to those who had some fabrication and building skills. Now, African Clean

ACE 1 Biomass Cookstove Operation



Energy (ACE) is promoting wider use and adoption of this technology via its integrated, manufactured product, the ACE 1—a solar-powered, forced-air rocket stove with a single vertical chamber.

ACE has refined the basic rocket stove design, replacing the elbow and pipe size ratios with a six-sided, fire-brick-lined vertical cylinder and a fan, run by a lithium battery that is recharged by a small PV module. The fuel is a handful of small, dry twigs and wood scraps. Once the fire is started, the carefully designed airflow facilitates the "rocket" of a fire. A rheostat controls the fan speed to regulate the burn rate, as does how much fuel is fed into the stove.

Once started, the stove burns cleanly and efficiently. The colleague who introduced me to the ACE 1 had two of them at his campsite. Just 2 to 3 feet above the stove, there was a clean nylon canopy—with no signs of soot.

The manufacturer estimates that the stove cooks with 15% to 50% of the wood required for an open fire. A shoebox-full of small twigs and wood scraps can cook a few days' worth of meals. This is life-changing, especially for women in many cultures who previously had to spend significant parts of their day walking to gather fuel. And, instead of cutting down entire trees, only small scraps are needed to fuel the ACE stove.

ACE has made this product even more useful by adding a USB port to charge cellphones or other USB-powered devices.

African Clean Energy is based in Lesotho, southern Africa, with branches in Cambodia and Uganda. For more information, see africancleanenergy.com.

Courtesy African Clean Energy (4)

Lesotho

Cambodia

Cambodia

ACE 1 Specs

Shipping package size: 13 × 13 × 14 in.

Stove diameter & height: 12 × 12.5 in.

Firebox diameter & height: 4 × 5.5 in.

Weight: 10 lbs.

PV module: 5 W crystalline

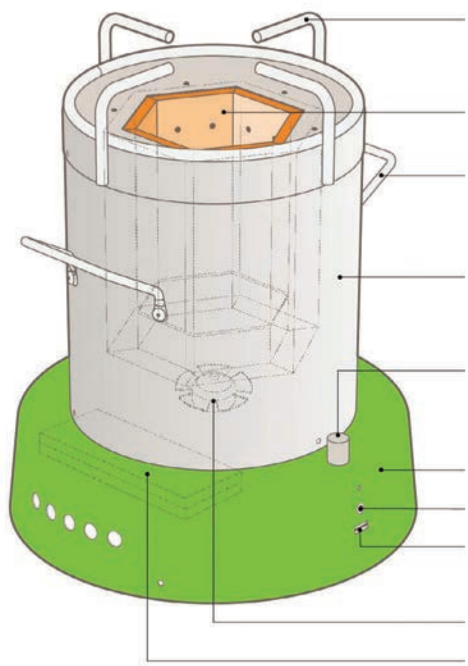
Battery: Lithium iron phosphate, 5 Ah

Light: LED, 100 lumens

Fuel consumption: 750 grams in 50 min. (high fan) to 100 min. (low fan)

Heat output: 2–5 kW

Cost: $250 ($150, plus $100 shipping to North America)



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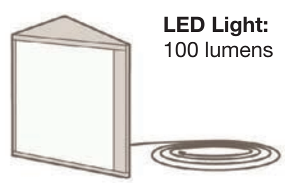

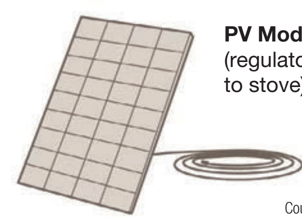

Courtesy African Clean Energy (4)

More than 30,000 ACE stoves have been manufactured and put into use around the world. ACE is at work on more improvements and broadening distribution of the cookstoves.

The author's outdoor kitchen—cooking fritters efficiently with wood via the ACE 1.

An upcoming version will include a second port. In one product, three very essential functions are served—cooking, lighting, and phone charging. It's a brilliant application of renewable energy technologies.

When you see and hear rocket stoves start to burn—with a roar—it is impressive. But building a unit yourself is a large hurdle for many people. Though I've schemed about building a rocket stove for my homestead, it hasn't happened. Ordering online and having an ACE stove a week later started a love affair with this technology and product. I look forward to getting more of these units, both for my homestead and for my developing-world work.

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PV System Salvage

I wanted to let you know about a change we made earlier this year to the solar-electric system on our home. There has been a lot of commercial development in our area, to say the least. I noticed one of the buildings slated for demolition had a recently installed array of solar panels. I took down information about the developer and after six months of pursuing him through four contact references, I was able to get salvage rights for the system from the demolition contractor. I arranged for a local solar contractor to remove and reinstall it at our house. Our old system came off and the new system, with 5.4 kW of capacity and a larger inverter, was installed. It is pumping out more electricity than we use in a year, more than compensating for the addition of our Nissan Leaf EV. Below is a view of the new PV array layout.

I am working with my neighborhood association to incorporate the old system—3.5 kW of Sanyo PV modules and a 3.0 kW Sunny Boy transformerless inverter—into a new shelter to be built as part of a landscape rework. AC power from the inverter will feed into the association's electrical system in grid-tied mode, and supply up to 1,500 watts of offline backup power during daylight hours for use by the local emergency response communication hub designated to assemble at the facility in the event of a disaster.

Jack Herndon • Seattle, WA

Courtesy Jack Herndon

My Moment with Richard

My first encounter with *Home Power* cofounder Richard Perez was in the summer of 2000 at a SolWest workshop in John Day, Oregon. My son Alex was fresh out of college, so he and I went on a road trip from Tacoma, Washington, to John Day. There was to be a solar fair preceded by a weeklong workshop about solar electricity. The classroom and hands-on workshop took place on the second floor of a building in town, at the office of the SolWest energy fair. Our first day was spent in a classroom with 25 other enthusiasts from different parts of the country. Richard introduced himself and told us how far he had come from the early days before MPPT (which he would explain in-depth later). He had a sort of "mountain man" look, but his smile gave way to his kindness, and his talk showed his intelligence.

Joe Schwartz was there to help facilitate the hands-on instruction. He was well-seasoned in solar technology, and did most of the mechanical work. Together, they were a good team, and I knew from the start that it was going to be a good class. Each morning, Richard explained a different aspect of solar-electric systems, such as batteries, charge controllers, inverters, and solar-electric modules. In the afternoons, we helped Joe build a system for a solar-powered office. Four PV modules were mounted on the roof, and wires were sent through a conduit into a small closet area to a charge controller. Also in the room were six Surrette 12 VDC sealed batteries connected to an inverter.

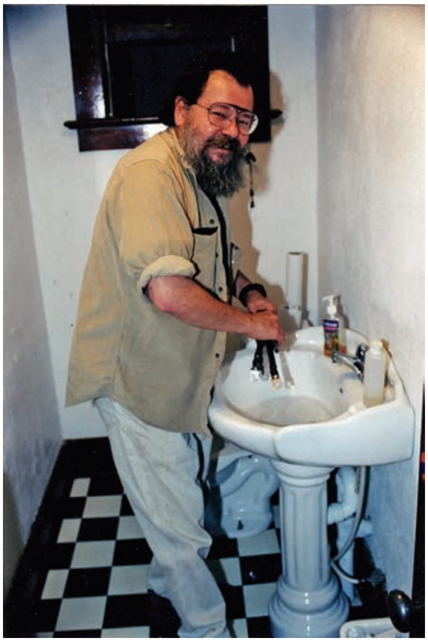
On the third or fourth day, Richard wanted to show us the different inverters' waveforms—pure, square, and modified sine—on an oscilloscope. We needed a battery for the demonstration, so someone went back to the small closet area and removed a battery from the string of six. After the demonstration, it was time to return to the work area. Someone entered the small closet and we heard a KABOOM! The top of one of the sealed batteries blew off, spewing acid.

Joe hurried to a local store to buy baking soda, which would neutralize the spilled battery acid. Richard seemed pretty calm; he knew right away what had happened. Apparently, when the battery was removed for the classroom demonstration, the positive and negative cables of the remaining string were left dangling. Upon returning to the work area, someone accidentally bumped one of the wires, causing the two leads to contact and short-circuit. After the dust settled and the baking soda was cleaned up, we had all learned something very important about battery safety.

I caught up with Richard as he was cleaning the battery cables in the bathroom sink, and he said with a smile, "Can you believe that? We just talked about battery safety in class…" I told him I would send the pictures I had taken during the workshop. They were lost for many years, but I recently found them. I thought I would share my moment with Richard. I think there should be a column in *Home Power*: "My Moment with Richard." It might get a lot of good stories…

Dave Cozine • Tacoma, Washington

Courtesy Dave Cozine (2)



Tryin' It Again

Colorado, Nevada, and Utah are pushing for the increased use of electric cars by establishing a regional electric-car-charging network. Most people probably think electric cars and related hybrid cars are fairly new technology. Well, have you ever heard the old expression, "There's nothing new under the sun?"

Let's take a brief trip back into history. According to the website hybrid-vehicle.org, a German named Moritz von Jacobi made an electric boat that sailed on the Neva River in Russia around 1839. The boat had a 1 horsepower electric motor fed by current from a Grove cell, an early battery. In that same year, a Scottish inventor named Robert Anderson made a crude electric carriage.

Perhaps the first usable vehicle was an electric railway patented in 1885 by Ernst Werner Siemens, another German inventor. His rail car had wheels driven by an electric motor. This motor drew electricity from rails, which were insulated from the ground and connected to a generator. In 1887, a British man named Magnus Volk developed a more advanced electric carriage propelled by a 1 horsepower Immisch electric motor and other components that gave it a speed of 10 miles per hour.

And finally, the first type of what we call the electric car—in 1897, the London Electric Cab Company started service using a vehicle called the Bersey Cab. It was powered by a 40-cell battery and a 3 hp electric motor, with a range of about 50 miles.

The history of hybrid cars is fascinating. Ferdinand Porsche was a German engineer, and around 1900 he invented the first truly hybrid car. Called the "Mixte," it used a gasoline engine that ran constantly to power a dynamo, which charged a bank of accumulators. These then sent current to electric motors in each front wheel. The system was very simple, with no need of a transmission, gears, clutch, etc.

Next came the Krieger Hybrid in 1903. It used a gas engine to supplement a battery pack, and much of the model appears to have been copied from Porsche. The Auto-mixte, produced in Belgium in 1906, had a 24 hp engine that drove a motor dynamo connected to a gearbox-less transmission and then to the rear wheels by chain final-drive. Normally, the engine alone could be used to propel the car. When the load was light or if braking was required, the dynamo driven by the engine or the final drive (regenerative braking) could be used to charge a bank of 28 Tudor batteries in series. When the load was heavy, the battery could be used to drive the dynamo as a motor to assist the engine, or the electric motor could be used to drive the car on its own. Before modern times, the last hybrid car was the 1921 Owen Magnetic Model 60 Touring model. It used a gasoline engine to run a generator for power to electric motors in each of the rear wheels.

At one time, electric cars were widespread in the United States. An October 2, 2012, *New York Times* article entitled "Why Your Car Isn't Electric" points out that in 1900, 34% of cars in New York, Boston, and Chicago were electric. Around 1900, the Electric Vehicle Company was the largest car maker in the United States, and the article goes on to state "...when a series of shady business dealings drove the New York-based company into bankruptcy, it took electric cars down with it....in the lull in electric car development that followed, gasoline-car companies improved their technology and made their vehicles cheaper."

Will electric cars really take off this time? It has been tried before, and before, and before. Only the next few years and decades will tell.

Milton Ammel • via email

Courtesy Sumit Flikr

Excellent EVs

Thanks for the excellent article on electric cars in *HP180*. I just read it, because I borrow *Home Power* from my local library—there's enough paper in the world already. I did find one small part of it somewhat perplexing, however, relating to cost. If a person really does their homework, they can score a pretty decent deal on a plug-in hybrid.

I got a 2015 Volt plug-in hybrid when the 2016 models debuted. I took out a 36-month, $1,000-down lease on it. I can drive 10,000 miles per year, and pay a little more than $175 per month. I also get three free years of OnStar connection and free oil changes. My wife recharges the car at work, for free. We also have a Prius, so our gas savings are monumental. We are also helping to forestall climate change. No monetary value on that, in our opinions.

I cannot wait to read the electric motorcycle article. I have a different twist to this—far more economical, although more limited, to be sure. I bought a used iZip electric bike for $600, and I got it with the preferable Li-on battery. It is fantastic. My son is a teen and I am a retiree, so it helps me keep up with him, and negotiate hills and wind. Love your magazine.

Jeff Raywood • Holland, Michigan

EV Charging Off-Grid

I have been following the discussion about off-grid electric vehicle (EV) charging with interest. I thought I would pass on details about my system for charging a Chevrolet Bolt.

To run our home's PV system, I learned computer coding, and then built a diversion control using an Arduino microcontroller that interfaces with our MidNite Classic charge controller's RS-232 interface. This control diverts all available energy that's not needed by the batteries into our domestic water heater tank. This hot water is then used for domestic purposes and also heats the house using our radiant floor heating system. The solution to our EV charging was to find an electric vehicle supply equipment (EVSE) device that could be interfaced with the diversion control and also was capable of being user-friendly to the needs of an off-grid PV system.

I found the OpenEVSE. It is easy to communicate with the device at short distances using transistor-to-transistor logic

Courtesy Will Eert

Courtesy Will Eert

(TTL) serial communications. Using TTL allows us to turn the device on and off remotely and increase or decrease the charge rate. Because it is suitable for use in an automatic control system and is capable of being controlled to vary its charge rate in proportion to the energy available for it, it's very solar-friendly!

EVSE on, off, load-shed, increase charge rate, and decrease charge rate algorithms are coded into the diversion control. When the array output is above a certain wattage (2,000 W); the hot water tank is above a certain temperature (140°F); and the battery SOC is above a certain point (90%), the EVSE turns on at the minimum charge rate—6 A at 240 VAC. The diversion control then monitors certain system parameters. If more power becomes available as the batteries increase their SOC and hot water tank heats up, the EVSE charge rate is increased. Care is taken not to exceed the inverter's maximum load. Provisions are made to shed loads and for a rapid shutdown if various system parameters are exceeded. As insolation diminishes at the end of the solar day, the EVSE charge rate is reduced to a minimum. The EVSE turns itself off at the end of the day when surplus electricity is no longer available.

The system functions automatically and manages the available energy for the house to ensure that, as the first priority, the batteries get charged; that, secondly, some hot water is always produced; and that, thirdly, the car charges. So long as there is enough sun on the modules, the batteries always remain within 0.3 V of the MidNite Classic charge settings regardless of system conditions. There is also a manual on/off button coded into the control, enabling the car to be charged manually, regardless of system parameters.

So far, we've been able to put the energy equivalent of 87 miles into the car in one day, while automatically charging our batteries and heating our 120-gallon water tank to 158°F. This code is open-source; it can be found on MidNite Solar's forum (see bit.ly/MidniteEVSEcode) and also on the OpenEVSE forum.

Will Eert • Rossendale, Manitoba, Canada

Errata

In "Gear" (*HP180*), Trojan AGM batteries were incorrectly reported to have a "smart carbon" additive.

write to:

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Using PV Energy During Outages

I have a grid-tied PV system and get credit from the electric company for surplus energy my system produces. However, this summer we have had many utility outages, leaving my house without electricity—even though there's a power source on my rooftop.

The whole community here on the reservation uses grid-tied PV electricity, so outages affect everyone. Outages are getting costly for us, as we've lost lots of refrigerated and frozen food when there's no power.

Should we get a generator? Can I hook it up to my system? If so, what do I need?

Dan Wood • Lake Havasu, California

A batteryless grid-tied solar-electric system shuts off when the grid goes out. The first reason is that you don't want to be energizing the utility lines coming into your house; this prevents danger to line-workers and keeps your PV system from trying to run the entire neighborhood. The second reason is that the loads in your house rarely match the solar input on your PV array. If there is more sun than loads in the house, it's fairly easy to control. But if the loads demand more power than the available sun, where does the extra come from? When the grid is up, it comes from the grid, but if the grid is down, the only reliable way to do this is to add batteries to provide the extra power.

The most common option to get backup power from a grid-tied PV system is to use a battery-based grid-tied inverter. These inverters can connect both to the PV system and batteries, and to the grid. If the grid goes down, the inverter automatically isolates some or all loads from the grid, and continues to power those loads from a combination of batteries and the PV array. There are many possibilities for adding a battery-based inverter to an existing PV system:

- Adding an AC-coupled battery-based inverter and keeping the original grid-tied inverter;
- Replacing the grid-tied inverter with a high-voltage charge controller and adding a battery-based inverter;
- Reconfiguring the array to use a standard charge controller and adding a battery-based inverter; or
- Using a high-voltage battery bank with an inverter, such as the SolarEdge StorEdge inverter.

A cheaper option for limited backup is a grid-tied inverter from SMA America that has a "secure power supply" feature. These inverters do not connect to batteries and can only provide electricity when the sun's shining on the array. In sunny conditions, they can provide up to 1,500 or 2,000 watts, depending on the model. You simply plug your load into a special outlet when the grid goes down. However, you'll need to be present to do this, it's not an automated solution.

Another option for backup power is just to add a gasoline-powered generator that you manually start and plug your desired appliances into when the grid goes down. You can also have a propane- or natural gas-powered generator that automatically starts a few seconds after the grid goes down, and a built-in transfer switch to attach your loads (often the entire house) to the generator. None of these generator options interface with a standard batteryless grid-tied PV—it still shuts off when the grid goes down.

An SMA Sunny Boy inverter with connected Secure Power Supply backup outlet.

Lena Wilensky

Some grid-tied battery-based inverters have options for generator input. The inverter not only controls transferring from the grid, but also can turn the generator on and off as needed.

In all cases, it's a good idea to reduce your requirements for grid power, since it will make system upgrades less expensive. In hot, dry areas, evaporative coolers can replace traditional air conditioning and provide more efficient cooling. Designing houses to reject solar heat gain in the summer can also help reduce cooling loads, but this can be hard to apply to existing housing. For refrigeration, a fairly new (5 years or younger) Energy Star-qualified fridge and freezer can cut the cost of backup power compared to an older fridge. A super-efficient DC fridge can operate directly from batteries and cut energy use further.

Zeke Yewdall • Mile Hi Solar

Wind Turbine Problem

My wind turbine is producing power, but when I connect it to my regulator, I cannot detect any DC current and it does not charge my batteries. It's the second regulator—both of which were new—that I have been unable to detect any DC voltage out of. What am I doing wrong?

Nicholas Godwin • via e-mail

I suspect that when you say it is producing power, you mean voltage. As long as a battery is connected, it acts like ballast, preventing the turbine's voltage from rising much higher than the battery's voltage. If you are running the turbine without the battery connected, be careful—the voltage will rise with the increasing speed of rotation, can soon become hazardous and damage equipment.

Assuming there's an adequate wind resource, these problems are likely to be due to defective wiring or a damaged controller. You can check the turbine wiring by shorting the wires together—called a "brake switch"—connecting all three phases together. The turbine should slow drastically and then come to a standstill.

If it is producing voltage but there is no short-circuit current, there's likely a poor connection in the wiring. Test your connections by trying to pull them apart. Check that they are all clean and tight. It is also important to have good connections to the battery, or the battery charge controller could be damaged by the rising turbine voltage.

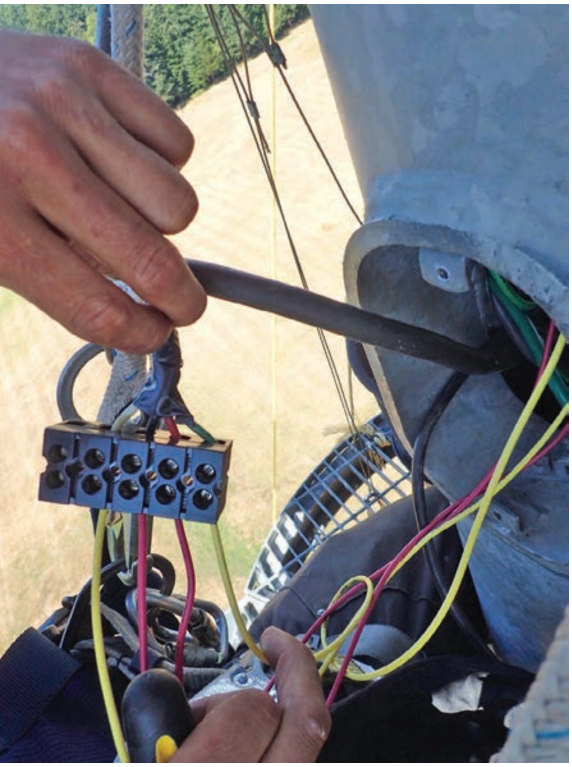
Make sure your controller is suitable for a wind turbine. A wind turbine connected to a solar controller's input is likely to damage the turbine. Connecting your turbine to any controller without a battery connected is also likely to damage it.

In most cases, a wind turbine will be connected to the battery via a rectifier and a fuse or breaker, and not directly via a charge control device. You will need a diversion controller, which diverts surplus energy into a dump load to protect the battery from overcharging. These vary from crude relays to sophisticated PWM controllers, such as the Morningstar TriStar or Schneider Electric's C40. You must configure them for diversion rather than for solar control mode. It is good practice to use a separate fuse or breaker for each—the charge-control electronics and the wind turbine.

One exception, in situations where the controller lies between the turbine and battery, is the MPPT controller, but very few of these are suitable for wind systems. You would need to protect this controller using a voltage-limiting device like the MidNite Solar Clipper.

If you don't understand, or lack confidence, then buy the wind turbine and controller as a package and follow the instructions. Always make sure that the dump load and the battery are both securely connected; use fuses or breakers before you connect a wind turbine to any controller; and put the brake switch on before working on these connections.

Hugh Piggott • Scoraig, Scotland



Ian Woofenden

Checking wiring connections at 120 feet is no easy chore.

Slab Insulation Strategies

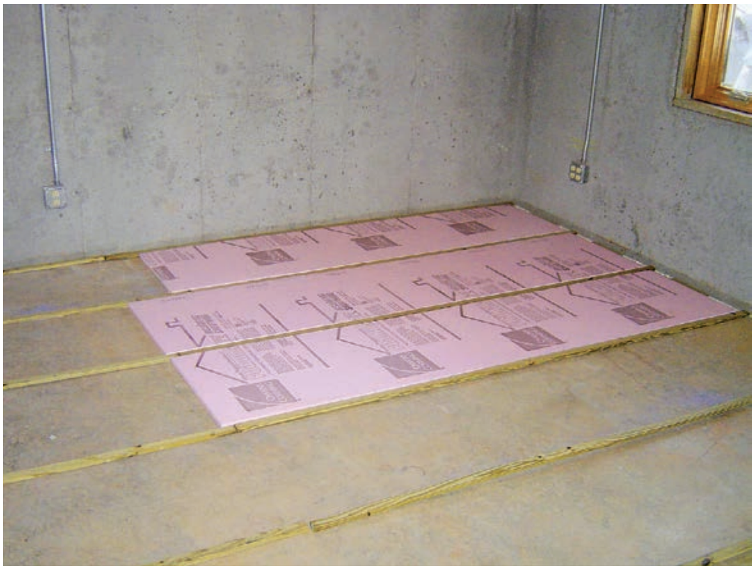
I bought a 1970s-era house that I am retrofitting to be more energy efficient. I upgraded the wall and ceiling insulation and have sealed gaps and cracks. I have started to replace the windows, too. My biggest conundrum is the slab floor, which is undoubtedly uninsulated. What can I do to reduce the heat loss through the slab in the winter and help make the floor more comfortable for us? What should I do around the slab's edges and footer?

James Sand • Fargo, North Dakota

You've started with your energy-efficiency improvements in the right order, James. The above-grade parts of the building enclosure will have more heat loss in winter and more heat gain in summer than the below-grade foundation walls and slab.

Since you're in North Dakota, I've assumed that the slab is the floor in a basement, not a slab-on-grade foundation. You also didn't mention

Adding insulation above a concrete slab.



Allison Bailes

condensation, but I wouldn't be surprised if moisture accumulates on the basement walls and slab. A big benefit of insulating those surfaces is that you reduce the chance of condensation. My final assumption is that you have no bulk water problems. If you have water leaking in from the outside—either from the top of the foundation walls, through the foundation walls, or up through the slab—you must deal with that problem first.

When you set out to make a more efficient building enclosure—defined as the boundary between conditioned and unconditioned spaces—you need to consider the flows of heat, air, and moisture. If you insulate your basement walls, for example, but don't stop indoor air from finding a path to the cool concrete foundation wall, condensation could develop there. That water could then run down and rot the wall or wet the insulation, creating mold and mildew problems.

You'll need to use control layers—insulation for heat-loss control, an air barrier for infiltration control; a vapor retarder for water vapor mitigation; and a water control layer for bulk water (on the outside) restriction. You'll want these layers to be continuous, so pay special attention to transition zones: floor to wall, wall to band joist, wall to window.

If you use air-permeable insulations like fiberglass or mineral wool, include an air barrier between the insulation and the conditioned space. In your climate, include a vapor retarder between the insulation and the foundation wall as well. Some types of insulation, such as closed-cell spray-foam or rigid foam-board, give you all the control layers you need.

The most commonly used rigid foam insulation for slabs is extruded polystyrene (XPS). You could also use expanded polystyrene (EPS), but should choose a high-density type. Mineral wool insulation also comes in higher-density rigid "boards" and can handle the compression required of floor insulation. Once you insulate on top of the slab, you can install a floating floor, which isn't attached to the slab, or you can fasten the subflooring to the slab through the insulation.

As for how much insulation to install on the slab, an R-value of 10 would be adequate in a cold climate. With XPS, that would be about two inches. If you don't have much headroom in the basement, using one inch of XPS at R-5 would give you almost as much benefit as R-10. If you can't give up even that much headroom, you can cover the slab with cork flooring or another material that will provide a little bit of R-value and raise the mean radiant temperature.

If you have a slab-on-grade foundation, insulation is more important because the slab's temperature is less influenced by steady-state temperatures, which occur deeper underground. In warm climates (IECC climate zones 1 through 3), insulating the perimeter should suffice. But be mindful about the details—don't give termites an easy path through the insulation and into wood. In cold climates and for new construction, you can wrap the whole exterior of the slab in insulation or insulate on the interior; with existing homes, you'll have to work from the top. R-10 would be enough in cold climates; R-5 in warmer places.

Allison Bailes • Energy Vanguard

Off-Grid Planning

I'm interested in using off-grid systems on some property my brothers and I purchased. The problem is, my part of the property is in a valley, and surrounded by trees. I'm concerned about how far up the mountain I will have to go to clear land for either a PV system or a wind turbine. I don't want to lose the beautiful forest.

The house I would like to build on the property will be no more than 500 square feet, but I have to use medical equipment, so it needs to be all-electric. Last year, I used 1,097 kWh for my electric loads in my existing home, which is about 1,000 square feet. I have a gas water heater and floor furnace—my gas bill is about $37 per month.

Also, can the electricity from a wind turbine or solar-electric array provide power for multiple small homes?

Tom Baldwin • Saint Albans, West Virginia

Solar-electric modules need sunshine—there's no way around that. Looking at your property with a solar siting tool such as a Solar Pathfinder will give real data on how much sunshine a given spot receives. Either buy or borrow such a tool, or hire a professional to evaluate your site and compare the various options.

Selectively harvesting a few trees to create a solar window can be a worthy trade-off between generator run time and preserving the forest. In the tall-tree country of the Pacific Northwest where I live, resourceful folks sometimes put solar-electric arrays on high roofs, on towers, or even in trees to capture more solar energy. I have a 450-watt array that is at 125 feet on a tower, and even being half the size, it still gives me two-thirds as much energy as the 900 W array on my roof—there's a lot more solar exposure up there.

Sometimes, siting PV modules to receive adequate sunshine requires ingenuity.

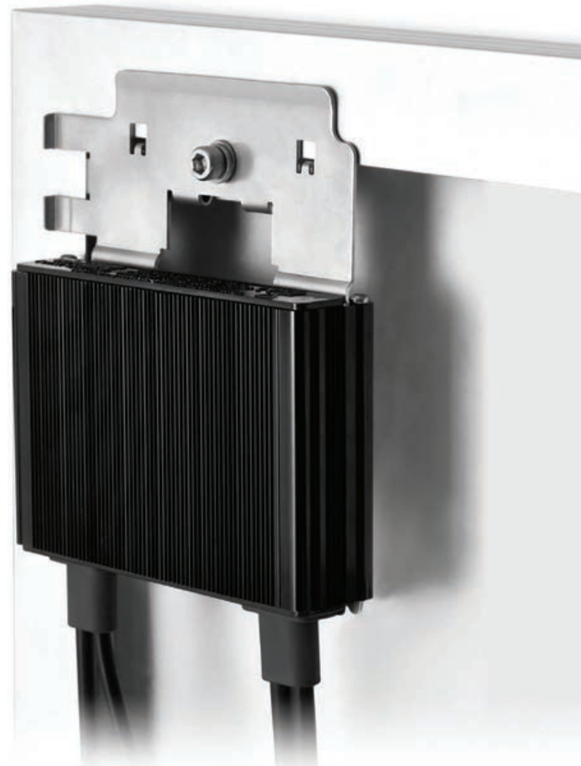
Ian Woofenden

Wind generators also need to be well above the trees and surrounding landforms. The standard rule is to site them at least 30 feet above anything within 500 feet. Pay attention to how tall the trees will get over the years—because towers don't grow.

In addition to determining your resources, analyzing your loads is crucial to good system design. In your current home, 1,097 kWh per year is very modest usage—are you sure it's accurate? If it is, taking this electricity thriftiness off-grid will make a system less expensive. You'll also need to figure out how you're going to heat water and provide space heating. In the early days of off-grid living, many people used propane for refrigeration, water heating, space heating, and even lighting. As prices for solar-electric systems have come down, off-gridders have shifted more loads to electricity. I've been using PV power for refrigeration for more than 30 years now, and recently installed a minisplit heat pump for opportunity heating using my surplus wind power. Exactly what loads you run—and how much you'll need to rely on a generator—depend on your energy resources and your willingness to adapt your loads to the available resource.

Certainly, more than one home can share a renewable energy system, though there may be technical and social issues. Systems can be designed to power whole communities, in fact. The sizing issues are the same—how much energy potential does your site have, how much energy-capturing equipment will you invest in, and how much energy will the homes use? Multiple families on one system means either sophisticated controls and automated backup or very good awareness and communication between all of the users.

Ian Woofenden • *Home Power* senior editor



The increased energy harvest from using PV optimizers is site-specific, but their additional benefits can be enough to justify their use.

Courtesy SolarEdge

PV Optimizers

When I took a PV design class early in 2017, DC optimizers were presented, but the economics were not explored. In Jim Riggins' article ("Heliospiti at 5 Years: Lessons Learned" in *HP179*), the author's situation suggests investigating the economics of optimizers before making that decision. One manufacturer's website explains that optimizers increase the electricity output of the PV modules by up to 25%, especially at shade-challenged sites. One seller's price for a SolarEdge P320 optimizer, for example, was $80. When used on a 320-watt PV module, this should provide an output increase of up to 80 watts (25% of 320).

That's $1 per watt. My question is, why would I pay $1 per watt (or more) when the retail price for a monocrystalline PV module is about 75 cents per watt? Add in racks and we're still looking at $1 per watt worst-case, versus a $1 per watt gain with optimizers, best-case. Has the economic window for DC optimizers already closed?

Pete Gruendeman • La Crosse, Wisconsin

The economics of how much extra energy can be gleaned by using optimizers is site-specific, and relies on factors such as partial array shading, varying module manufacturing tolerances, module temperature differences, varying levels of module soiling, and so on. That makes it very difficult to arrive at an estimate of how much additional energy can be harvested.

However, you need to look at the whole package, and consider that the SolarEdge (SE) inverter is less expensive than other grid-tied inverters of the same capacity. For the system I put in about three years ago, buying the SE inverter plus optimizers was close to the same cost as buying a different string inverter of the same size without optimizers.

The optimizer-based system also comes with two additional benefits—module-level monitoring (which I find helpful in identifying individual module problems that would likely otherwise go undetected) and built-in module-level rapid shutdown capability. Rapid shutdown is an add-on that you can purchase with other string grid-tied inverters, but currently it is only at the array-level. However, module-level control, which is discussed in the 2017 *NEC* Article 690.12, will be required in 2019 (see my article on "PV System Rapid Shutdown" in *HP175* for more information).

Justine Sanchez • *Home Power* senior technical editor

write to:

asktheexperts@homepower.com

Published letters are edited for content and length. Due to mail volume, we regret that unpublished letters may not receive a reply.

Sun & Shade

With a Double-Duty PV Pergola

by Benjamin M. Root IV

Although "rooftop solar" has become synonymous with residential-scale solar-electric systems, your home's roof isn't necessarily the only—or best—location for a PV array. It certainly wasn't for our situation.

All photos Benjamin M. Root IV

Comment & Discuss this article @ homepower.com/182.28

This glass-on-glass Lumos Solar GSX PV module and rack system provides a weathertight roof surface, yet allows light to pass between the cells, creating a lively shaded space beneath the pergola.

Several obstacles—shade, orientation, size, complicated roof angles, dormers, and vents—can preclude a rooftop PV installation, but that doesn't mean you have to give up your PV dreams. This was the case for our home in southern Oregon.

In a climate that can reach triple-digit temperatures in the summer, my fiancée Sarah and I value the canopy of oak trees that shade the roof of our rural 1960s ranch-style home. Their shade significantly reduces our reliance on mechanical air conditioning. And, while a PV system ranked high on our list of home improvements, it seemed absurd to cut down shade trees so we could install a rooftop PV system to make electricity, which would then be needed to provide cooling that the trees had provided originally. Besides, Sarah is a botanist specializing in native plant habitat restoration—there would be no tree-cutting on our little plot of nature.

A solution wasn't that difficult: Our south lawn was big, with room for gardening and entertaining, and a near-unobstructed solar window. Adding a ground-mounted PV array would have been relatively straightforward but without ancillary benefits. Instead, we decided to build a pergola shade structure and mount the PV array on top of it. We'd gain a cool hangout zone in the yard, and the PV modules could do double-duty: making electricity and acting as a roof over the new patio.

web extras

"Residential Building-Integrated PV" by Paul Mync in *HP130* • **homepower.com/130.38**

"Architectural PV Design Considerations" by Michael Welch in *HP142* • **homepower.com/142.44**

"PV Pergola" by Mike Taylor in *HP146* • **homepower.com/146.56**

"Platinum with PV" by Kelly Davidson in *HP158* • **homepower.com/158.42**

"Gear: Lumos Solar GSB Bifi Module System" by Justine Sanchez in *HP177* • **homepower.com/177.13**

"Solutions: PV Canopy for a Bocce Court" by Ian Woofenden in *HP175* • **homepower.com/175.16**

Choosing PV

I'd long been attracted to bifacial and other glass-on-glass PV modules. With no back sheet, bifacial PV modules can achieve higher power production due to additional reflected and ambient sunlight reaching the back surface of the cells. In locations with the right reflective surface below the array (such as light-colored concrete, white gravel, snow, water, etc.), production can be boosted by as much as 25%.

For our application, additional appeal was the slick look of glass-on-glass modules. From underneath, you can see the silicon cells—unlike other PV modules, which have opaque backings. Between the individual cells, a small amount of sunlight can stream through. The effect beneath the array is like dappled sunlight coming through trees.

Although several companies offer glass-on-glass PV modules, in most cases, the modules had a typical aluminum frame and a junction (wiring) box on the back. For us, this created three problems.

- First, mounting the modules to shed water like a typical roof would have been tricky; rain would just drip down between the module frames.
- Second, building a traditional roof to protect the area beneath would have meant sacrificing the efficiency and aesthetic benefit of using bifacial modules.
- Third, exposed wires look ugly—we didn't want a bunch of wiring pigtails and cable ties interfering with the otherwise stylish patio space beneath the pergola.

At that time (spring of 2015), my best lead was Lumos Solar's LSX Series modules, which had been in production for more than 10 years. These frameless glass-on-glass modules mount via a proprietary through-bolt. I was hopeful that their frameless design might have a weatherproofing solution, enabling the array itself to provide a leak-proof, contiguous surface—no such luck. However, Lumos was gearing up for a new product—the GSX—that integrated a rack with the module and would be weatherproof. It was due to be released that autumn. I was sold.

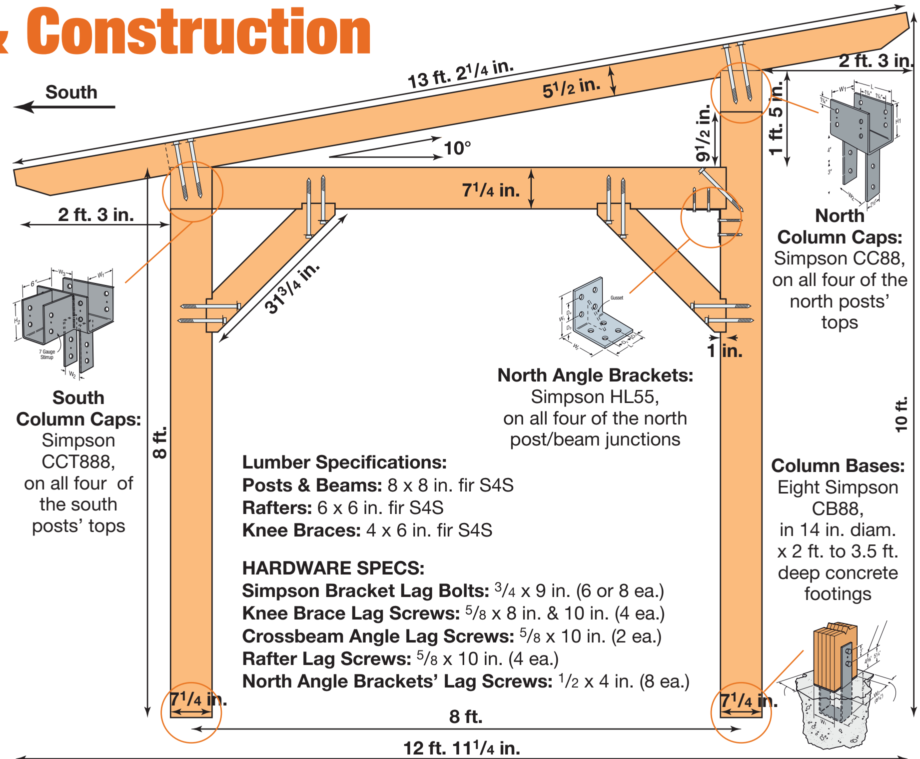
Pergola Design & Construction

The pergola structure was designed to maintain a 200-square-foot footprint and be no more than 10 feet tall. This allowed positioning close to the property line, but necessitated a 10° tilt angle and restricted the total array area.

Each north/south pair of posts has an 8-by-8-inch beam spanning them, creating a bent. The east-most and west-most bents have two additional 24-inch-long, 4-by-6-inch knee braces.

This whole substructure, including its attachment to the concrete footings, is held together using Simpson Strong-Tie architectural-grade brackets and 3/4-inch through-bolts.

Six 6-by-6-inch Douglas fir rafters were spaced to align with and support the 5-inch-wide, 13-foot-long GSX mullions on the approximately 67-inch PV module span. Rafters were birdsmouthed and fastened to the top beams using four 5/8-by-10-inch lag screws on each rafter.



Left: Mike Singer and the author assemble bents of 8-by-8s on the ground.

Below: Monica Martin and Mike bolt the first bent to its foundation brackets.

Planning & Designing a PV Pergola

Typically, a well-built structure will also support a rooftop PV array. But we were starting from the ground up, building a structure that would also serve as the array mount. That meant no roof sheathing, sizing rafters to match mullion width, and spacing them to match PV module spans. It also had to be sturdy enough to support the weight of several thousand dollars' worth of PV modules, and deal with the potential wind- and snow-loads on the array.

The final set of constraints in the design came from our county's planning, building, and electrical permitting department. The ideal spot for the pergola was near our south property line. However, because the adjacent property has agricultural zoning, the county required a building setback of 20 feet. Locating the pergola that far into the yard would have sacrificed lawn and created a less-useful strip of land between the structure and the property line. But I had an alternate plan—in our county, a 10-foot-tall, 200-square-foot structure can be built without a building permit or setback restrictions. Overhangs aren't counted against the footprint, so that allowed us some additional room for modules. I thought that if I built the legitimately unpermitted structure first, then, in theory, I could add a PV array to it later.

Make no mistake—I made sure in advance that this plan was legit with the county. The PV system itself had to be permitted and inspected to be grid-tied, so I needed to make sure that the structure would be able to legitimately hold the array, even though it wouldn't be permitted and inspected itself. After some discussion, I got verbal approval. Others thinking of a similar approach to permitting loopholes should do their homework and proceed at their own risk.

Since we were planning to use the area under the array as outdoor living space, we also wanted it to be attractive. We weren't fans of stick-built, dimensional-lumber carpentry, but finances and my own limited building skills ruled out both metal welding fabrication and traditional mortise-and-tenon joinery. We consulted Jeff Sharpe, a structural engineer with Sharpe Energy Solutions, to make sure the structure would be robust enough to support the array and its loads. We ultimately settled on a modernized post-and-beam design with lag bolts and steel brackets.

The pergola was designed around an 8-foot (north-south) by 24-foot (east-west) footprint using eight, 8-by-8-inch Douglas fir posts, spaced 8 feet on center. Eight-by-eight beams top the south line of 8-foot-tall posts, extending past the posts about 32 inches east and west. The north line of posts, topped by a similar beam, sits at 9 feet, 6 inches, to allow the rafters and array to stay within the 10-foot height restriction.

Left: Joining bents together with the first south crossbeam.

Below: Cranking in big lag screws is hard work in the hot sun. Matthew Reynolds takes a breather.

Below: The finished pergola with six 13-foot-long 6-by-6 rafters spaced for the PV module span.

With the pergola size dictated by county restrictions, and the PV modules defined by our desire for an attractive shade structure, the capacity of our system was limited. At 39.5 by 67 inches each, we could fit 20, 265 W GSX modules, for a 5.3 kW rated system in a footprint of about 13 feet north-south by 29 feet east-west (about 380 square feet).

The 10-foot maximum height, and standing room beneath, resulted in a 10° array tilt—much shallower than the "ideal" 32° tilt for a grid-tied array in our location. But the resulting decrease in annual energy production was predicted to be only about 6%; we felt it worth the compromise.

I built the pergola like a kit—measuring, cutting, drilling, notching, planing, and staining the posts and beams in my driveway over several weeks. Then I lured five friends with the promise of beer, and we put the substructure together in one afternoon with only minor wrestling and problem-solving. (Special thanks to David, Kate, Matthew, Mike, and Monica, for their muscle and perseverance, and Sarah and Abby for providing delicious sustenance.) I waited to notch and position the rafters as I prepped for the PV array installation, since spacing was critical to fit the tight tolerances of the GSX rack.

Above: Six GSX mullions were bolted in place to the rafters with 16 3/8-inch lag screws per mullion. Top- and bottom-edge GSX transoms were installed with internally routed PV interconnect jumpers. Jumper locations and connector polarity were meticulously marked in advance to avoid irreversible errors—once the PV modules were in place, accessing the wiring would be nearly impossible.

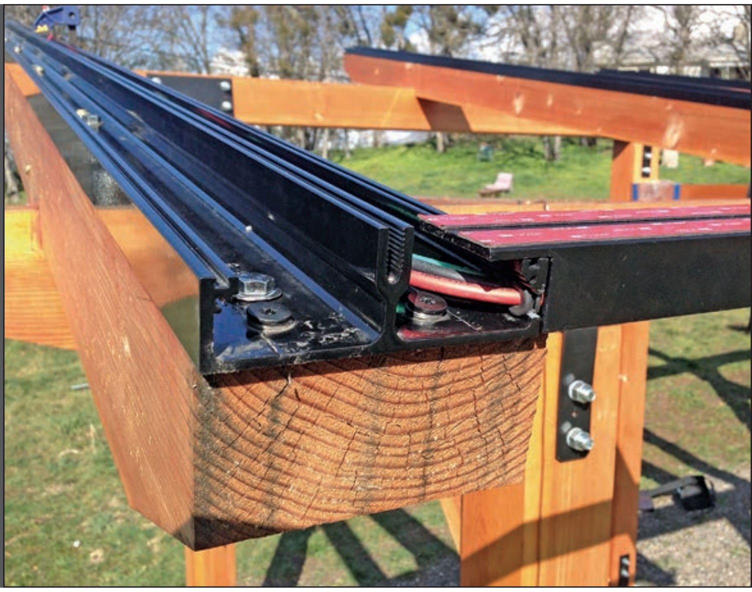
The GSX System

The GSX modules are frameless. The rack system uses extruded aluminum "mullions" (channels) that support the left and right sides of modules in landscape orientation. Mullions are continuous for the array's full "height," and module junction boxes and series interconnection leads are routed inside the mullions. The module's thick glass edge rests on a rubber gasket on the edge of the mullion.

The modules' horizontal top and bottom edges are supported from below by "transoms"—extruded aluminum box-beams. Tabs on the transom ends rest on the mullions in the same way as the PV modules do. Double-sided 3M tape helps keep the module and transom aligned and in place. On top, the narrow gap between modules was sealed with silicon caulk.

Above the mullions, aluminum pressure plates secure each module. Each plate is the depth of a module and is held down by machine screws that thread into the center rib of the mullion. Here, too, a rubber gasket protects the glass from the pressure of the plate above, squeezing the glass in place. Ultimately, full-length top caps and end caps add an aesthetic, seamless finish to the installation.

Below left & right: GSX documentation showed PV wiring within the racking structure, but routing jumpers from one column of PV modules to the next required cutting slots at the ends of the mullion sidewalls. This allowed interconnect jumpers to be fed through the transom. Then, the transom was slid into place as the wires were slid into the slots. Rubber grommets on the wires help protect the insulation.

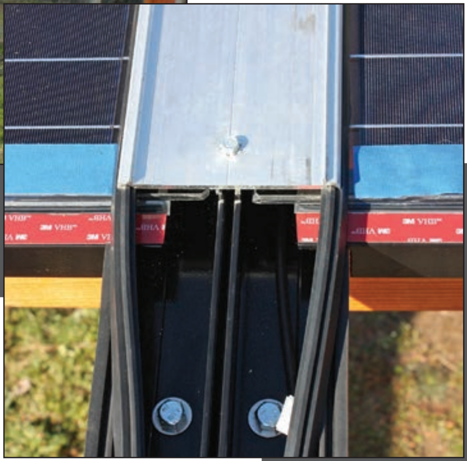


Above: The first module in place! The spans of the structure made positioning the heavy glass modules tricky.

Mounting the Modules

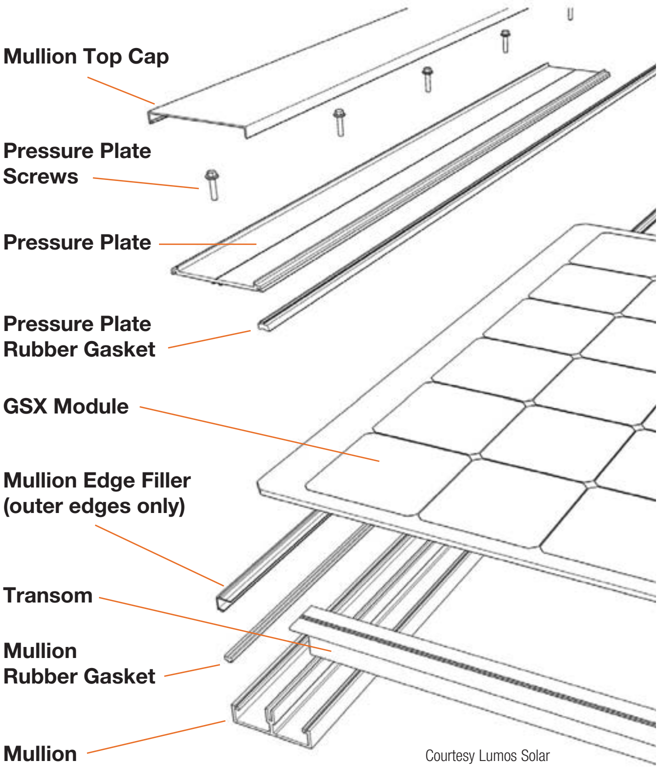
Sarah and I installed the modules ourselves. We averaged one module per hour, and were only slightly surprised that our speed didn't increase as we got the knack for what we were doing—but as we placed each successive module, the places to stand and work got smaller and smaller. Much of the challenge was hefting each 67-pound module up the ladder and positioning it in place on the edges of the mullions, while shimmying around on the top of the pergola without dropping the heavy, expensive piece of glass into the void below. Placing the last module was the trickiest since we had to work entirely from ladders.

Professional installers might be faster installing this product once they are familiar with the process, but this system will likely never be as quick to install as top-down racks and conventional modules. For us, though, that didn't matter. This was a once-in-a-lifetime project, so it was more important to do it right and have it look good than to do it fast.



Left: The hardware assembly in place—the top plate, modules, transoms, and mullion, including rubber gaskets. The double-sided tape on the transom still has its red backing. A strip of blue tape was applied to mask a line of caulk.

GSX Assembly



Courtesy Lumos Solar

Below: Progress was incremental, module by module. Top plates couldn't be secured until adjacent modules were placed, and adjacent rows needed to be in place before the seam could be caulked.

PV wires exit the GSX assembly through the bottom of a transom and pass through a four-pole disconnect before travelling underground to the inverter 175 feet away.

Excessive labeling satisfies *NEC* requirements, nerd inquiries, and "don't touch" scare tactics.

Power Electronics

There are many reliable and efficient grid-tied inverters on the market. My decision to go with SMA America's Sunny Boy 5.0 was based on two features. First was the Secure Power Supply (SPS), which offers up to 2 kW of backup power during a grid outage. This is not battery backup power, and thus is dependent on adequate solar insolation at the time. While it may be argued that most grid outages occur during times of low solar insolation, the idea of having even a little emergency backup power was still appealing. Like many batteryless grid-tied system owners, I intellectually accept that our PV system won't function without the grid, but emotionally it is troubling. Secondly, and similarly, if we ever want to add battery backup via AC-coupling, the Sunny Boy inverter is a sure-match with the Sunny Island inverter.

The transformerless Sunny Boy 5.0 US is rated at 5 kW output at 97% CEC efficiency. I was concerned that the array's bifacial production might overwhelm the inverter or, at least, might result in some energy loss due to clipping during peak production. But I was reassured by SMA tech support that the 5 kW unit could handle the peaks without damage. While some clipping (at 5.07 kW maximum) has occurred, it has always been in cases of edge-of-cloud effect on partly cloudy days. That means that they were instantaneous peaks, not sustained periods of high production, so no significant quantity of energy was lost. During clear spring and summer days, with smooth production curves, the midday peaks have been closer to 4.7 kW—well within the inverter's operating range (see the example graph). It will be interesting to see what happens on future clear winter days, when cooler temperatures drive voltage higher.

The 5 kW SMA Sunny Boy 5.0 US grid-tied inverter with Secure Power Supply connects to a subpanel in the shed.

Tech Specs

Overview

Project name: Pi Acres PV pergola

System type: Ground-mounted, batteryless, grid-tied solar-electric

Installer: Owner installed

Date commissioned: Vernal equinox, 2017

Location: Jackson County, Oregon

Latitude: 42.37°N

Solar resource: 5 average daily peak sun-hours at a 32° tilt, 180° azimuth

ASHRAE lowest expect ambient temperature: 17.6°F

Average high summer temperature: 96.8°F

Average monthly production: 633 AC kWh (min. Dec. = 217; max. July = 1,056), estimated

Utility electricity offset annually: 87%, estimated

PV System Components

Modules: 20 Lumos Solar GSX 265, 265 W STC, 31.0 Vmp, 8.54 Imp, 38.6 Voc, 9.05 Isc (front-side irradiance only)

Array: Two 10-module series strings, 5,300 W STC total, 310 Vmp, 8.54 Imp, 386 Voc, 9.05 Isc

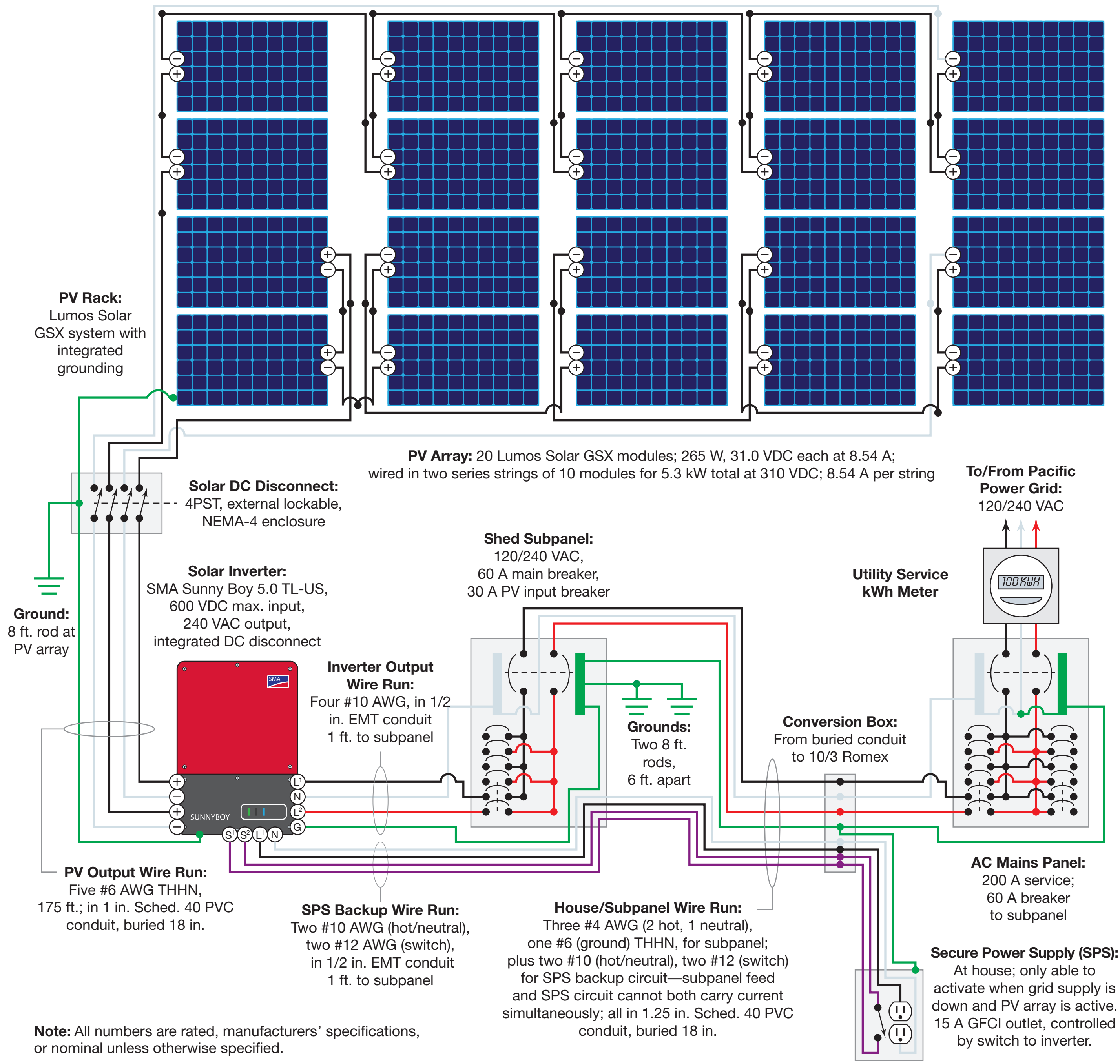
Array installation: Lumos GSX mounts installed on 180°-facing pergola, 10° tilt

Array DC disconnect: IMO SI16-PEL64R-4, enclosed 4-pole DC switch

Inverter: SMA Sunny Boy 5.0-US, 5 kW rated output, 600 VDC maximum input, 100–550 VDC MPPT operating range, 240 VAC output

System performance metering: SMA browser interface via LAN or Sunny Portal

Batteryless Grid-Tied PV Pergola System



The Rest of the Gear

Besides the Lumos GSX modules and rack and the SMA Sunny Boy inverter, almost all other components were typical AC distribution wiring. A 60 A branch circuit was added to my AC main service panel at the house, and a new subpanel was installed in my mower shed, 150 feet away. The Sunny Boy is mounted next to the new subpanel, and connected with a 30 A breaker. The inverter's SPS power and switching wires return to a dedicated outlet in the house, in the same conduit as the subpanel's branch circuit from the house. A Cat5e cable in its own 1/2-inch conduit carries inverter data back to my local area network in the house.

On the inverter's DC input side, another buried, 175-foot, 1-inch conduit run conveys the four #6 AWG conductors, plus ground, from the PV array. Those wires originate in a four-pole DC disconnect at the array. This redundant disconnect was not required by code, but I liked the ability to shut down the system at the source, as well as at the inverter's integrated disconnect at the shed. This gives me the ability to work on the inverter with no hot wires on the input side, and without doing complex maneuvers like tarping the 380-square-foot array.

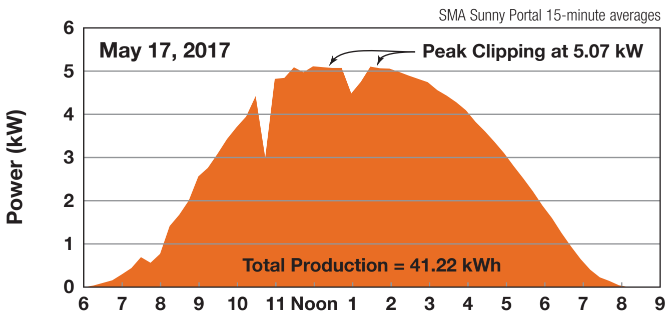
Projections & Performance

Typical summers in our area of southern Oregon are long, hot, cloudless, and dry. But even in the wintertime, we can have clear, cold days that are perfect for PV production. If our array had been tilted at 32° and oriented true south, it would have received an annual average of 1,819 kWh per square meter or almost 5 peak sun-hours per day. Plugging our array and location specs into the PVWatts online calculator, including our array's 10° tilt, the available insolation is 4.7 average daily peak sun-hours; the array is predicted to produce 7,580 kWh per year. December is predicted to be the worst month, with 1.5 average peak sun-hours (7 kWh production) per day. July is expected to be the highest production month, with 8.0 peak sun-hours (34 kWh) per day.

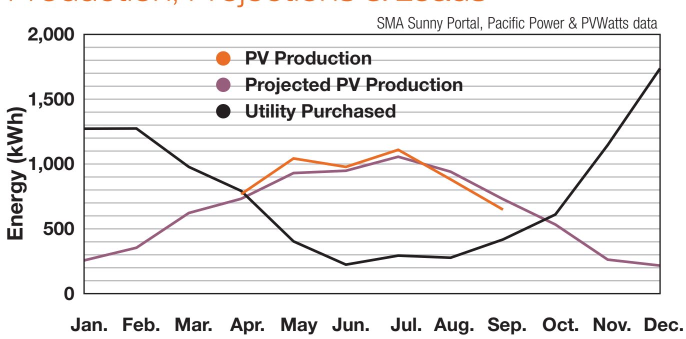
So far, production has been slightly outperforming these projections (see the graphs). I'm not sure why; perhaps it's due to the additional bifacial production, which I didn't account for in the calculations. Estimates are just that, and there are many variables in the PVWatts calculator that I left at their default values. If we're generating more energy than expected, though, why complain?

To determine what an estimated 7.6 MWh per year of production really means, we need to compare it to our annual energy use. Our all-electric home was built in 1965, with R-11 walls and single-pane, aluminum-framed windows. A 25-year-old air-source heat pump provides heating. The water heater is even older, with negligible insulation and (likely) a heating element compromised by scale from years of mineral buildup. Without efficiency improvements, our average annual electricity usage comes in at 8.7 MWh, meaning that the PV array will meet about 87% of our yearly loads. But we have a plan for reducing our loads to reach net-zero annual energy use (see the "Increasing Efficiency" sidebar).

Peak Production Day with Clipping



Production, Projections & Loads



Increasing Efficiency

One of the typical, but often unforeseen, influences of a newly installed PV system is a newfound awareness of one's energy use. The PV production meter is fun to watch; conversely, the usage meter is a reminder of what you're up against. Real-time data inspires us to reduce our loads and make PV production go further.

Some of our home-efficiency improvement plans are easy and inexpensive; others are longer-term and require a larger financial investment. Our average December energy use is about 1,500 kWh, but our July use is only about 400 kWh. From that, we assume that most of our electricity goes to space heating, which is where we plan to focus most of our efficiency upgrades:

- We've already installed an EPA-rated wood-burning heater in the previous open fireplace. Besides offsetting some of the electrical load from the heat pump, I'm sure we're losing less electric heat up the chimney than before. We like the heat better, but fire-tending is work, so it's not a full-time offset.
- As the right sizes become available from the local Habitat for Humanity ReStore, salvaged double-pane, vinyl-framed windows are being used to replace the old single-pane, aluminum-framed units. The performance characteristics of these replacement windows are usually unknown (the rating labels are long gone) but the efficiency gain is still worth it, especially considering the low cost.
- There's no subfloor insulation in the crawl space. Fiberglass is cheap, but the labor is a hassle. I'll get to it, I promise.
- There's some spray-foam insulation needed around the ceiling penetrations, and the attic could use more insulation. Blown-in would be best, but batts are less of a hassle. Either way, it'll be an easier fix than the crawl space.
- Eventually, we'd like to replace the aged air-source heat pump with a two-head minisplit system. It could be argued that this would have been a better up-front expenditure than buying a PV system, but at the time we committed to the PV system, we weren't sure how long the solar federal tax credits were going to last.
- I found a salvaged solar water heating (SWH) system for $500 on Craigslist. While our rooftop solar exposure isn't perfect, SWH system performance isn't as affected by shading compared to a PV system. In summer, some shading will likely prevent system overheating. In winter, when trees have shed their leaves, we'll get better insolation on the collectors. I'm considering it bonus free energy.

We added an aboveground swimming pool this summer. Running the 3/4-hp pump filter for the suggested eight hours a day will add about 5 kWh per day to our summertime loads. Luxury costs energy. Perhaps we should just assume that the pool loads are offsetting our temptation to use air conditioning in the house.

Twenty 265 W Lumos Solar GSX PV modules, rated at 5.3 kW, are expected to produce 7.6 MWh per year, about 87% of the home's yearly load.

GSX modules have 60 bifacial monocrystalline cells in a 39.5-by-67-inch footprint. Without any perimeter frame, the double layer of glass is just under one-third of an inch thick; each module weighs 67 pounds.

System Costs & Payback

I've heard it argued that ground-mounted systems don't cost much more than rooftop systems. Perhaps this is true for the simplest of systems, close to the home. In our case, the costs were greater.

There were 350 feet of wire runs, ranging up to #4 AWG, and trenching. Copper is expensive, and trenching required two excavators—one with a jackhammer to break through the basalt the house sits on. When it came time to fill, I used 14 yards of decomposed granite to line the trench and protect the conduit from big rocks in the tailings. These kinds of costs don't exist for a roof-mounted array.

Then there were the costs of this custom project. The GSX modules were $1.65 per rated watt (including shipping)—a bit higher than the $1 per watt seen in 2016. The GSX rack added another $0.67 per watt (including shipping), whereas rooftop systems can be as low as $0.12 per watt and simple ground-mount racks about $0.30 per watt.

The pergola itself is arguably an intrinsic system component—every ground-mounted system requires a foundation and structural system to support the array. We chose large wood members and strong brackets. Our dual-use requirement and aesthetics drove the price up even further, with a total structure cost of $6,800. We were careful to not include any project costs that didn't relate directly to the system function in the total for PV system equipment that would be eligible for tax credits.

After the federal and state tax credits, the final cost of about $2.57 per watt may sound high compared to the Oregon average rooftop system cost of about $1.30 per watt. However, this premium makes sense to me given the countless variables: a ground-mounted system 350 feet from the AC main distribution panel; the addition of a subpanel; the cost of a county-required replacement of the original AC distribution panel; and finally, the unquantifiable added value for us of using the PV pergola as shaded outdoor living space. At the current utility retail rate of $0.11 per kWh, it will take about 16 years of energy production to offset our investment. After that, our energy will be free. The shaded patio value is priceless.

About 380 square feet of covered patio space provide shade and rain protection. The space is ready for a barbeque, cafe table, and—once the jasmine grows up the trellis—maybe a daybed.

Lessons Learned

As a homeowner, but one who's professionally well-versed in PV systems theory, I thought I had a pretty good grip on installing my own system. Little did I know that the devil was in the details.

Murphy Rules

- Our old Federal Pacific AC main distribution panel (MDP) was deemed outdated and "dangerous," and needed to be replaced before the PV system could be intertied. This was a job I left for the pros, and an expensive one.
- That same MDP was positioned directly above our old "cabinet"-style water heater—a no-no according to current *National Electrical Code (NEC)* standards. I had to remove the water heater so the PV system could pass the electrical inspection. Yes, I wanted to replace the water heater with a solar water storage tank anyway—but not right then.
- The house is built on a basalt inclusion (solid rock). A second excavator, with a jack-hammer attachment, was needed to trench to the house.
- That same rocky ground made it impossible to drive the second ground rod required for the MDP replacement. Luckily, the inspector let us lay it in the trench.

Better Luck Next Time

- Sometimes, DIY retail prices just don't make up for a PV professional's wholesale prices. The five #6 AWG wires, which had colored insulation and were cut to length for the DC run, cost me three times as much as a single 1,000-foot roll of black wire would have cost an electrician. But marking wires (#6 AWG or smaller) with colored tape goes against the *NEC*. In the end, that wire cost me more than having the pros install the AC wire run, which had larger wires and conduit.
- My cordless drill couldn't drive the 5/16-inch screws specified by Lumos to attach the mullions to the rafters, so I used my big Milwaukee drill. I unknowingly sheared the heads of most of the screws. Luckily, before installing the rack, I noticed one or two loose or missing heads, so I inspected the rest. I replaced *all* of the fasteners with larger-diameter lag screws. That rack isn't going anywhere now, but what a scary realization of what could have happened.
- I planned for the trenched conduit runs to skirt the yard's perimeter, as I wanted to steer clear of our future garden plots. But I didn't plan for the 360° rule—which necessitated adding an awkward in-ground pull box. It was a hassle to install and a potentially weak link in the wiring. Straight-shot trenches would have been a cheaper and easier solution for running wires, and likely deep enough to be out of the way of gardening.
- At the time I committed to the GSX product, their highest-performance modules were rated at 265 W. That product is now rated at 300 W. With basically the same infrastructure (and a larger inverter), we could have had a higher-capacity array and met our yearly loads at a lower cost per watt.
- Tolerances planned for on a computer model don't necessarily work in the real world. I was frequently either cutting it too close or making it too tight. Slop happens, and sometimes needs to be allowed for.

Root Pergola & PV System Costs

PV System	Cost
20 Lumos Solar GSX 265 PV modules	$7,950
Electrical contractor: Mains panel & 150 ft. conduit run	3,465
Lumos Solar GSX PV rack	2,753
Wire, conduit, connections, misc.	2,151
Shipping: PV modules, rack, inverter	1,786
SMA Sunny Boy 5.0-US	1,542
Trench labor & fill	1,160
Permits	604
Safety labels	84
DC disconnect, four-pole, enclosed	64
Total PV System Cost	$21,559

Pergola	Cost
Wood: Posts, beams, rafters & knee braces	$2,915
Simpson Strong-Tie brackets	2,118
Miscellaneous hardware, including bolts & lags	778
Footings: Concrete & forms	505
Timber-framing labor (Thanks, Sam!)	300
Stain, paint, caulk & supplies	124
Beam-saw rental	60
Total Pergola Cost	$6,800
PV System & Pergola	$28,359
Federal Tax Credit (30%)	-$8,508
Oregon Tax Credit	-$6,000
Grand Total	$13,851

In the End

We bit off a big and relatively expensive DIY project that took more than a year to complete. It was a year with 350 feet of open trench through the yard; dozens of receipts for hundreds of parts and pieces (each representing a trip to the hardware store); pages of design notes and mathematical calculations (including trigonometry); and a myriad questions for my electrical inspector, professional PV-installer friends, and hardware-store salespeople. We second-guessed ourselves, changed our minds, swore, skinned our knuckles, and tweaked our backs, but ultimately celebrated.

Now, we have a beautiful, high-tech PV array that, after our household efficiency upgrades, will cover all of our electricity needs. Someday, it will do it for free. The PV modules ride on a beautiful multiuse structure that provides shade, rain protection, privacy, and ambiance in the yard for entertaining guests or just for ourselves. And it gives Sarah and I the satisfaction of using existing technology to do something good for humanity and the environment.

Sarah and I are getting married on our property in the summer of 2018, and the ceremony might just happen under the PV array. Not so much because we are those kinds of solar nerds (though maybe we are, a little), but more so because it's the nicest spot in the yard. Stay tuned for wedding photos.

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Efficiency & Solar Design Pair Up for Affordable Housing


Courtesy Habitat for Humanity EBSV

by Juliet Grable

The neat row of nearly new homes on Edes Avenue in East Oakland, California, belies the fact that the neighborhood was once a blighted salvage yard and construction material recycling site. The duplex development includes passive solar design, water-conserving landscaping, and PV arrays on every rooftop, turning a former brownfield site into a model of green building.

On the Greener Path

This development was completed by Habitat for Humanity East Bay Silicon Valley (Habitat EBSV) in 2010 and is now home to 54 families that qualified through Habitat's application process, which sets minimum and maximum income levels for different household sizes for program eligibility. Habitat EBSV's large service area, which covers 3,000 square miles across Alameda, Contra Costa, and Santa Clara counties, includes distinct urban challenges. The affiliate often acquires brownfield properties and rehabilitates them with new residential developments, and also performs retrofits on existing homes. In 2000, under the influence of David Sylvester, a "green" general contractor, the organization started focusing on green building.

"That's when we started thinking about how to reduce wood use in our buildings," says Ben Grubb, construction manager for Habitat EBSV. Under Sylvester's leadership, they began using advanced framing techniques (AFTs), which reduce lumber use, allow more insulation, and reduce thermal bridging. These techniques include installing studs 24 inches on center, employing raised heels in the attic framing, and using drywall clips to facilitate the construction of insulated corners.

During a 22-home project in Livermore, the team honed their AFTs and also refined their site design, orienting the homes to optimize rooftop solar PV production and to take advantage of passive solar gain. However, it's the Edes Avenue development, built in three phases starting in 2006, that showcases the affiliate's deepening knowledge of green building.

"In each phase, we incorporated more energy-efficiency and indoor air quality (IAQ) features," says Grubb. In addition to employing several AFTs, they specified zero-VOC paints and zero-formaldehyde finishes, and began using blown-in cellulose in place of insulation that contained formaldehyde. They also started adding radiant barriers to attics and used efficient tankless water heaters that worked well with the compact floorplans. (Today, the affiliate uses both tank-style and tankless water heaters in its developments, depending on unit layout.)

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The Edes Avenue development illustrates Habitat EBSV's green building, and includes 54 two-, three-, and four-bedroom homes.

The average size of the PV arrays in the Edes Avenue development is 2.3 kW.

Evolving Efficiency

The Habitat EBSV's evolution mirrors the national organization's efforts to boost energy efficiency and overall sustainability. "Habitat has always been focused on providing affordable homes, but they have to be affordable and efficient over the long term," says Derrick Morris, director of construction at Habitat for Humanity International. About 10 years ago, the organization adopted a national policy to build to Energy Star standards at a minimum. The emphasis on energy efficiency recognizes that viable home ownership depends on more than just an affordable mortgage. Homeowners must also be able to afford to operate and maintain the home, and lowered utility bills are a big part of the equation.

Many affiliates, including Habitat EBSV, go well beyond these standards. Habitat EBSV was using the LEED rating system as a metric of achieving its goals, and has completed LEED Gold- and Platinum-certified homes. The affiliate relies on California's GreenPoint Rated system, which is more flexible, has a slightly lower entry point, and is tailored to California building codes (see "Build It Green's GreenPoint Rated System" sidebar).

Courtesy Habitat for Humanity EBSV (2)

Construction techniques must be compatible with the Habitat model, which relies on both paid and volunteer labor.

Advanced Framing Technique Benefits

Technique	Benefit
24-in. on center framing	Spacing studs 24-in. oc rather than 16 in. reduces lumber used & reduces thermal bridging
Wall intersections framed with single 2-by-6 nailer	Allows for insulation behind corner & reduces thermal bridging
Two-stud interior corners	Reduces lumber needed by 33%
Headerless windows using rim joist or modified truss blocking	Allows structural header to be insulated inside floor or attic space; reduces thermal bridging
Single window sills	Reduces framing lumber & decreases thermal bridging
Drywall clips used in place of wood backing	Reduces framing lumber needed; reduces thermal bridging; reduces drywall cracking
Raised heel trusses	Allows full-depth insulation at eaves
Precut framing lumber before delivery	Reduces lumber waste on-site

Courtesy Habitat for Humanity EBSV (2)

Passive solar design, which includes south-facing windows with awnings, allows winter solar heat gain but reduces unwanted gain during the cooling season.

Build It Green's GreenPoint Rated Program

The GreenPoint Rated program is a third-party certification program administered by the non-profit Build It Green. Available for both new and existing homes, the program has certified 43,000 homes in California. GreenPoint Rated has evolved to keep up with changes in California building codes, including California Codes and Regulations and Building Energy Efficiency Standards (also known as Title 24, Part 6). GreenPoint Rated Version 7, which went into effect on January 1, 2017, includes four compliance pathways for energy efficiency, including a pathway for net-zero energy and one for all-electric homes.

The program utilizes a point system and recognizes four levels of certification for new homes:

Certified: 50–79 points
Silver: 80–109 points
Gold: 110–139 points
Platinum: 140+ points

Projects earn points in one of five categories: energy efficiency, water conservation, indoor air quality, resource conservation, and community, which includes such things as walkable neighborhoods. In addition, the program set minimums for the number of points earned in each category. For example, a certified project must earn at least 25 points in the energy efficiency category and at least six points in water conservation.

Existing homes can earn labels which recognize green building practices for remodels, additions, and/or other upgrades. Projects that earn between 25 and 49 points qualify for the "Elements" label, while projects that earn 50 points or more are recognized with a "Whole House" label.

The homes are rated by GreenPoint raters, who work with the contractor or homeowner to create a customized checklist of design features and construction practices for the project. The rater evaluates the project several times through design and construction and takes responsibility for all documentation and submittals.

For more information, visit **builditgreen.org.**

Success with Partnerships

As with most affiliates, Habitat EBSV depends on partnerships, including some of the national organization's sponsors. For example, an ongoing partnership with Simpson Strong-Tie helps further the affiliate's goal of reducing wood, as the company is willing to fabricate custom brackets. Tipping Engineering, a "super-inventive" Berkeley-based structural engineering firm, offered pro bono services on the Edes Avenue project and suggested many of the advanced framing techniques that were eventually implemented.

Since 2002, every new home that Habitat EBSV builds has included a PV array, donated by Pacific Gas & Electric Company's Solar Habitat Program and Grid Alternatives, a

Volunteers lay engineered wood flooring.

Partnerships with nonprofit Grid Alternatives and PG&E have enabled every new home to include a PV array.

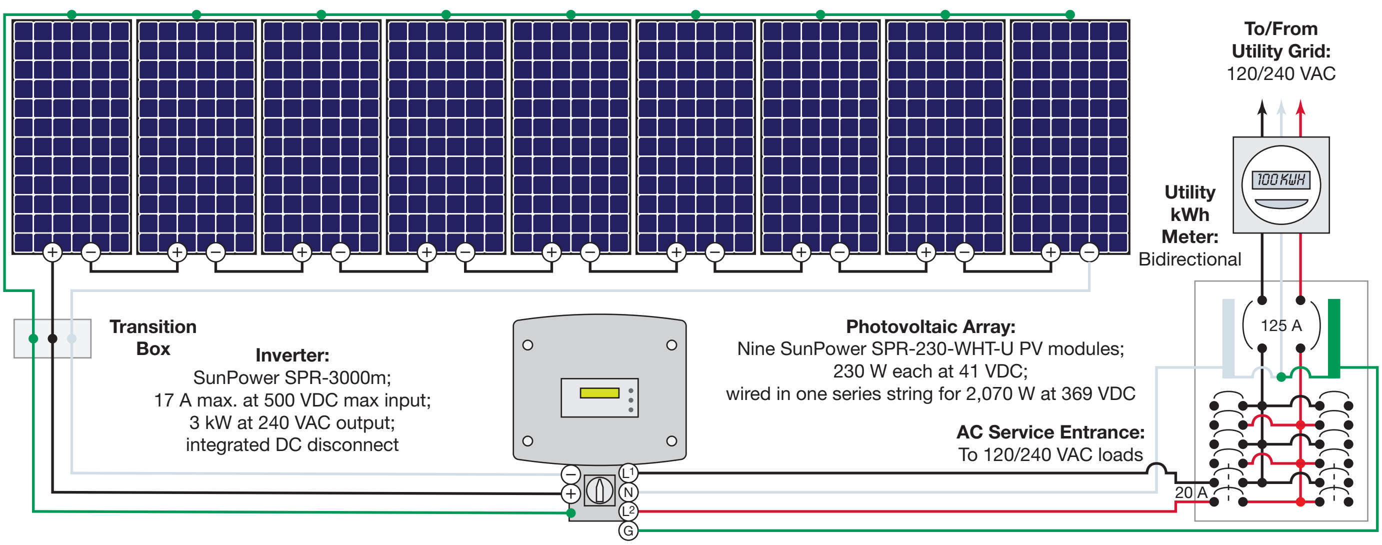
Courtesy Habitat for Humanity EBSV

national nonprofit that provides volunteer labor to install PV arrays on low-income housing. Though the size depends on the roof area, the arrays usually range between 2.1 and 2.5 kW. On average, the arrays save homeowners $500 each year.

Like all affiliates, Habitat EBSV relies on volunteer labor, including "sweat equity" from homeowners. In addition to paid staff, AmeriCorps provides skilled labor over 11-month (minimum) terms—in exchange, they receive a living and rental stipend, and an education award at the end of their terms. AmeriCorps workers undergo extensive training, including an intensive two-week orientation in the fall and a series of 15 clinics throughout the year which cover every aspect of building—from home design and sustainable construction to safety and scheduling.

The AmeriCorps members work under a construction supervisor, such as Grubb, and they in turn coordinate groups of volunteers. This way, as many as 40 to 50 people may be working on a project at one time. Long-time volunteers, such as Oakland resident Laura Goderez, sometimes coordinate small groups of less-experienced volunteers, as well. Goderez, who was first attracted to Habitat for Humanity through President Jimmy Carter's work, has been volunteering for Habitat EBSV for more than 20 years. During this time, she has noticed changes in both materials and building techniques; for example, she

A Typical Edes Avenue PV System



The Grid Alternatives team closes the DC disconnect on the SunPower inverter for the first time.

Courtesy Grid Alternatives (2)

remembers when houses were built with studs 16 in. on center rather than 24 in. Goderez says she enjoys the constant learning. "I've learned a lot about building, and I know what's 'behind the walls' of the homes I've helped build."

The affiliate continues to explore methods of increasing its projects' energy and cost efficiency. According to Grubb, newer projects reveal a more nuanced approach to passive solar design—for instance, sizing, locating, and shading windows to optimize solar gain in winter and minimize it in the cooling season. The designs also cluster kitchens and

A few of the many volunteers who helped Grid Alternatives with PV system installation.

Habitat for Humanity Edes Avenue Project Specs

Project: Edes Avenue Homes

Location: Oakland, California

Architect/designer: Pyatok (architect), Tipping Engineering (structural)

Builder/contractor: Habitat for Humanity EBSV

Size: 900; 1,100; or 1,200 sq. ft.

Type of residence: Two- & three-story duplexes

Certifications: LEED Platinum, GreenPoint rated, Energy Star rated

Design & Construction

Passive solar features: Exterior wood shades on south- & west-facing windows; stained concrete floors downstairs for thermal mass; building faces south for winter gain

Wall system: 2-by-6 wood framing with advanced framing techniques

Features

Attic/roof: Radiant barrier, 40-year light-tone composition shingles; insulated with formaldehyde-free fiberglass for R-38

Foundation/basement: Slab-on-grade, stained concrete floors for thermal mass

Windows: PlyGem double-pane vinyl with low-e glass; sound transmission class (STC) 35

Indoor air quality: Zero-formaldehyde finishes, zero-VOC recycled paint

Other: Recycled cementitious siding; high fly-ash content concrete; 95% recycling rate for construction debris

Systems

PV array: Batteryless grid-tied; 2.3 kW average, SunPower PV modules & inverter

Heating: Carrier gas forced-air

Cooling: Tamarack whole-house fan; no AC

Water heating: High-efficiency Rinnai gas tankless

Other green features: Homes plumbed for future solar water heater

Lighting: Global Green LEDs

Appliances: Whirlpool Energy Star range & refrigerator; Habitat does not provide dish- or clothes-washers

Landscaping: Bioswale collects all rainwater and filters through bricks quarried on-site; drip irrigation system; California native drought-tolerant plants

Courtesy Habitat for Humanity EBSV

Landscaping with drought-tolerant native plants is one of the affiliate's strategies for conserving water.

baths in proximity to shorten water lines, to use less energy heating water. The affiliate seeks to reduce framing materials in part by pre-cutting as much lumber as possible, so it arrives on-site as a kit, and by re-using scrap lumber for blocking. The projects also consider lifestyle impacts by strategically locating them near public transportation, and confining parking to garages on the bottom floor. As of this writing, Habitat EBSV is working on a 20-home development in Martinez, a 30-home condo project in Fremont, and a 42-home duplex development in Walnut Creek.

A demonstration home funded by a grant from Samsung enables Habitat EBSV to try out new techniques and systems, including "headerless" windows, which transfer loads to the rim joist or truss system, and a variable refrigerant flow (VRF) heat pump system. Grubb says they are seeking feedback from homeowners and studying utility bills to learn the impact of these techniques.

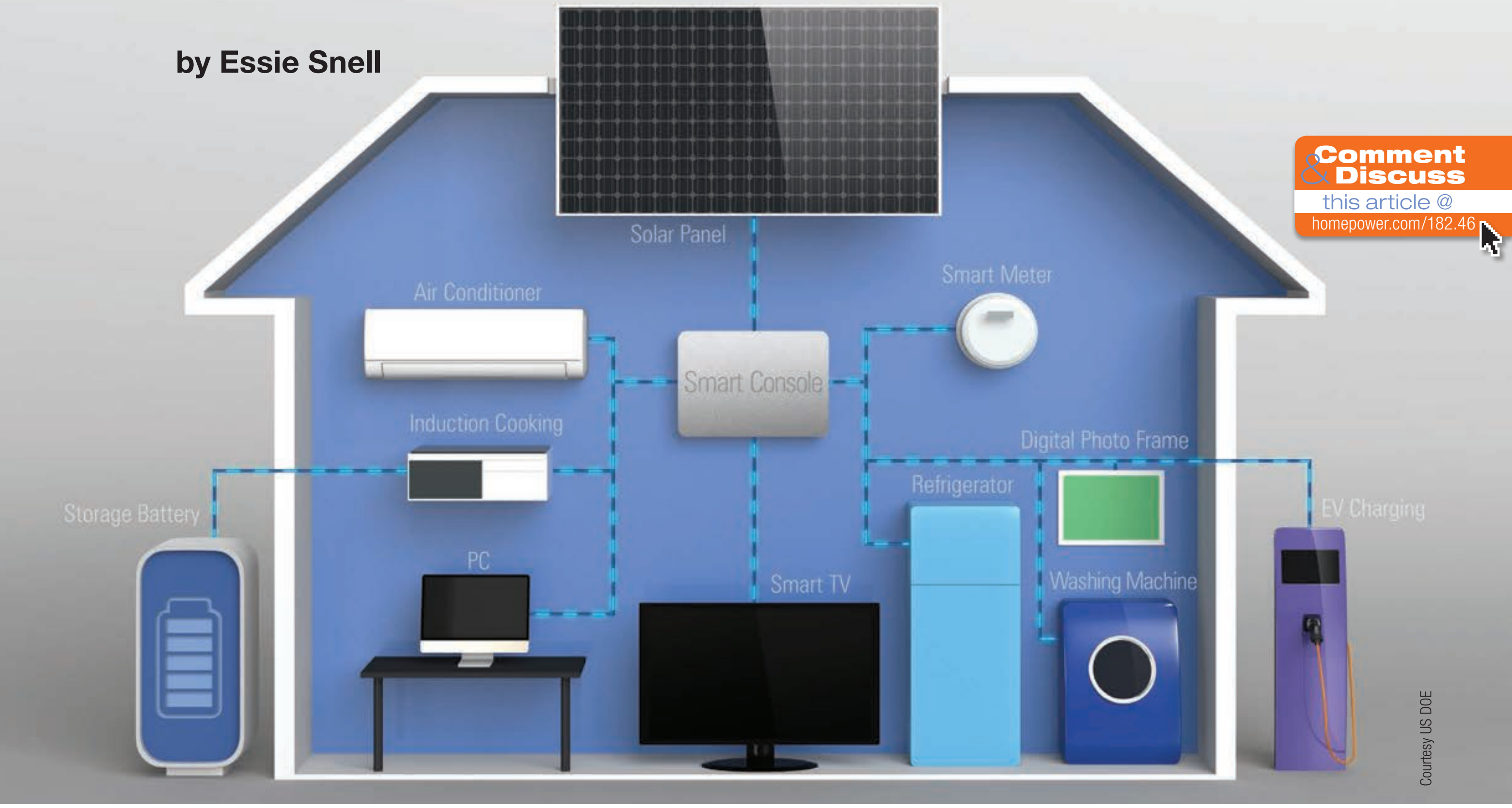
Goderez, the long-time volunteer, says she is proud to be associated with an organization that is at the forefront of green building. But in the end, it's the homeowners that keep her coming back.

"At the end of one day, I happened to be standing near the house of one of the homeowners," says Goderez. "He came out, saw me, and said, 'I have to go run an errand, but when I come back I want to invite you for a cup of coffee....in my house.' That is what makes me keep working with Habitat. I know I made a difference for that man and his family."

Your Smart^er House

Home Energy Management Systems

by Essie Snell



Courtesy US DOE

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Home energy management (HEM) systems—comprising "smart" networked devices that can provide information and dynamically adjust energy use within a home—have been evolving for decades and finally appear poised to enter the mainstream. However, with hundreds of players entering the home automation space, the increasing availability of myriad smart devices, and an increased vendor focus on customer security and convenience over energy savings, it can be daunting for even seasoned energy experts to figure out how best to approach this market, much less find ways to realize the many benefits HEM systems may yield.

The good news is that most of the HEM devices currently available (across multiple manufacturers) tend to fall into one of several product categories. Some of these devices are beginning to see widespread market penetration, while others are still in the early stages of development and dissemination, but each offers unique opportunities for energy savings, demand reductions, and energy-use information.

Existing HEM devices continue to change, and new wireless-enabled "smart" products keep emerging: smart thermostats, smart plugs, connected lightbulbs, smart appliances, and in-home energy-use displays (EUDs). Each of these devices has unique and distinct advantages and disadvantages, but, effectively combined into an HEM framework, they have the potential to provide relevant, granular, and actionable energy-use data; directly reduce energy consumption through automated control algorithms; and enable sophisticated demand-response (DR) and load-shifting functionality. These latter two abilities can allow consumers to help utilities improve the operation of the electric grid, promote renewable energy adoption, and lower their electricity bills by reducing their appliances' power draws during peak periods.

The "Common Home Energy Management Devices" table summarizes and compares the costs and savings associated with these devices. Although the dynamic nature of the control algorithms used and the potential to prompt behavioral change make it difficult to estimate representative energy savings for many HEM devices, the granular data collected may offer new approaches to measurement and verification that will facilitate a better understanding of potential savings.

This article originally appeared in *Home Energy* magazine's Summer 2017 issue, which you can view at www.homeenergy.org. It is reprinted with permission.

Smart Thermostats

Smart thermostats were among the first HEM devices to flourish in the market. In fact, 2016 data from the E Source Residential Customer Insights Center suggest that 6% of all residential customers have now installed smart thermostats in their homes. That growth is especially impressive in light of the fact that smart thermostats only emerged onto the market in 2011 with the release of the Nest Learning Thermostat. With straightforward programming, appealing online portals and mobile apps, attractive designs, and a better overall user experience than traditional programmable thermostats, it seems that smart thermostats are here to stay. In fact, their unique set of features may even help to make them a central interface point for HEM systems.

Many of the smart thermostats on the market offer a variety of energy-saving strategies. These strategies include trying to learn occupant preferences (to autonomously improve temperature setpoint schedules); occupancy sensing; behavioral prompts; and tracking the user's smartphone location to regulate heating, ventilation, and cooling (HVAC) equipment when no one is home. Given the variety of energy-saving tactics involved and the technology's comparatively recent introduction into the market, research establishing average energy savings remains ongoing. However, utility program evaluations performed to date indicate that the level of HVAC energy savings realized has ranged from 5% to 19%.

In addition to providing energy savings, virtually all smart thermostats on the market offer sophisticated DR capabilities, with two-way communication and comprehensive reporting functionalities that utilities can take advantage of when they are trying to reduce power demand in their region. In many cases, smart thermostats can even combine multiple control strategies to maximize demand reductions while also maintaining occupant comfort—an improvement on previous generations of HVAC DR controls. Utility evaluations indicate that average per-home demand reductions ranged

Courtesy Nest Labs

The Nest Thermostat E can be controlled remotely via a proprietary app that runs on a smartphone, enabling users to adjust their heating and cooling systems at the touch of a button.

Common Home Energy Management Devices

Device	Typical Retail Cost	Energy-Saving Strategies	Energy-Savings Potential	Demand-Reduction Potential
Smart Thermostat	$100–300	Schedule setting, occupancy sensing, geofencing, maintenance notifications, HVAC system adjustments, automation using weather data or input from home security components, education, behavioral prompts	5–19% of HVAC energy consumption	0.7–1.6 kW
Smart Plug	$20–60	Schedule setting, occupancy sensing, geofencing	2–21% of connected load	Varies (0.4 kW with window air conditioners & 0.3 kW with dehumidifiers)
Smart Appliance	Varies (comparable to high-end versions of conventional appliance)	Education around energy use	3–6% of appliance energy consumption	0.05–5.0 kW depending on appliance
Connected Lightbulb	$15–100 (excluding wireless hub or switch)	Schedule setting, geofencing	Unclear	Unclear
In-Home Display	$100–450	Education & some behavioral prompts	4–15% of whole-home energy consumption	Unclear

The ecobee4 is a smart thermostat that offers external temperature and occupancy sensors for rooms without a thermostat, and features voice control via Amazon's Alexa platform.

from 0.7 kW to 1.6 kW during DR events. These levels of demand reduction are generally similar to those achieved by traditional direct load-control programs using switches, but the smart thermostats can provide improved occupant comfort, longer event durations, and better data to support program managers.

Finally, in the context of HEM, smart thermostats offer another potentially enormous benefit. Because they're designed to know when users are home and can respond to DR signals—and because users are likely to engage with the thermostat's screen (or mobile app) on an ongoing basis to adjust temperature settings—they may be great candidates to act as the central interface for HEM systems. Not only might they replace EUDs as the source of information on a home's energy use, but they might also be well-positioned to coordinate the way a home's HVAC, plug loads, lighting, and appliances respond to a DR event. Nest is one company that is already moving in this direction. The Nest thermostat's built-in ZigBee wireless compatibility allows it to talk to many smart meters, and the Nest Developer program is fostering interconnectivity with a diverse array of smart products from other companies, ranging from connected cars to home appliances.

Smart Plugs

Essentially a newer Internet-enabled version of smart power strips, smart plugs are just gaining a foothold in the market. Whereas smart power strips generally provide six to 12 outlets and work by autonomously turning devices on or off based on the power draw of a single control device, occupancy, or a preset schedule, smart plugs are Internet-enabled and typically offer one or two controllable outlets. Unlike smart power strips, smart plugs usually don't provide current- or occupancy-based control strategies. Instead, they allow users to set schedules for their plug loads, turn them on or off remotely, and even monitor each plug load's power draw (the kind of granular data that studies show is most effective in getting users to change behavior) via an online portal or mobile app. Given this functionality, a number of smart plugs are currently being marketed as residential lighting controls (for plugged-in lamps) that can save energy and also provide security benefits by allowing users to program lights to turn on and off when they're away from home—an electronic version of the old mechanical timers. Current estimates of potential energy savings from smart plugs range from 2% to more than 20% of the connected load.

Many smart plugs also provide DR functionality, giving utilities even more options to consider for their load management programs. One notable example is Con Edison's CoolNYC program. Launched in 2011, this was one of the first programs in the United States to target window air-conditioning units for DR purposes using a smart plug called the ThinkEco Modlet. The program has been very successful to date: Con Edison now has tens of thousands of participating customers, with each smart plug providing an average load drop of around 0.4 kW. Unsurprisingly, given Con Edison's positive results, other utilities, like Baltimore Gas and Electric, Commonwealth Edison, Consumers Energy, and CPS Energy, have recently started to offer their own window air-conditioner DR programs.

Despite the inherent flexibility of smart-plug devices, the main barriers to further market penetration appear to be their high upfront cost, a lack of awareness about these products on the part of customers and utilities, and (with the possible exception of the smart products focused on lighting) a somewhat vague value proposition to end users, who may not know how best to implement these products.

The ThinkEco Modlet offers an Internet-enabled product with two outlets. It can be used to capture energy-use data on a variety of 120 VAC appliances.

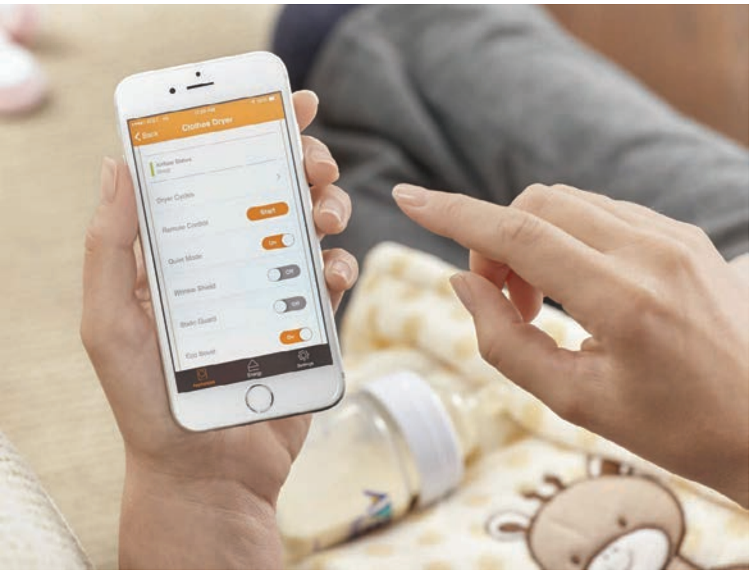
Smart Appliances

From an energy perspective, smart appliances are appealing primarily for their potential to automatically adjust power draw based on control signals from a utility. The utility signals can be related to changing electricity prices, a DR event, or even the real-time availability of renewable energy on the grid. The exact control strategies employed tend to vary depending on the type of device and the manufacturer, but examples of smart appliances and their capabilities include:

- Clothes washers that can delay the start of the wash cycle, recommend using cold water instead of warm or hot water, or reduce power to the motor and/or heater.
- Clothes dryers that can postpone the beginning of the dry cycle, automatically enter an energy-saving mode, or reduce heater power draw for a set period of time.
- Refrigerators that can delay the time of their next defrost, raise the freezer temperature setpoint by a few degrees, or disable antisweat heaters.
- Dishwashers that can delay the wash cycle or turn off their heater during the drying stage.
- Electric ranges with multiple ovens that can prevent the larger oven from heating up, prevent self-clean, reduce burner heat output, or even disable burners entirely.
- Microwave ovens that can reduce power output (leading to slightly longer cook times), reduce lamp-light levels, or reduce fan speed.
- Electric storage water heaters that can adjust temperature setpoints, turn off the heating elements entirely, or ramp heating elements up and down dynamically to provide energy storage and frequency regulation, balancing power supply and demand on a sub-second level.

GE's ConnectPlus module plugged into the GeoSpring hybrid water heater allows users to control and monitor water heating use via a smartphone. Users can change the water heater's operating modes and temperatures, select vacation mode, and receive maintenance alerts.

Courtesy GE (2)



Whirlpool offers smart large appliances that are Google Home- and Alexa-compatible, allowing users to adjust timers, temperatures, and wash cycles from their smartphones.

Courtesy Whirlpool

Smart appliances aren't inherently more energy efficient than "dumb" appliances (though they are often Energy Star-qualified), but they may save energy during DR events or critical peak pricing periods. Some also provide granular energy-use data or offer users the ability to control them via a mobile app.

Several challenges remain to be resolved before these devices become more prevalent in the market. Smart appliances can be expensive and their load-shaping and DR capabilities can be difficult to explain to end users. Many of the power-reducing features may create more problems for customers than they solve—customers may pay more for an appliance that doesn't always do what they want, to get benefits they don't fully understand. Perhaps for this reason, smart appliances have remained fairly niche products, and it's unclear how successful they may be in the future. A notable exception is the grid-interactive electric water heater. These water heaters can provide substantial DR benefits without leaving users with cold water.

Connected Lightbulbs

LEDs are more energy efficient than other lightbulbs, and they're more controllable. Many manufacturers are now selling Internet-enabled LED products that can be controlled remotely and, in some cases, change color for entertainment, ambiance, or even health (by mimicking the color of the sky in the morning, afternoon, and evening to influence circadian rhythms).

Considering the higher upfront cost of these connected lightbulbs, their main selling points thus far are convenience, security, fun, and potential health benefits, ranging from better sleep to improved productivity. The focus has not generally been on energy savings, but some products do offer features like dimming based on ambient light levels or geofencing (in which the system is able to track the location of a user's phone to turn off lights when the user leaves the house). Although the individual load reductions they offer may be fairly small, connected LEDs have potential use in future DR applications.

Courtesy Philips

Philips Hue LEDs are color-adjustable A19 bulbs. Multiple app options and device compatibility make it a flexible lighting option, with remote dimming and schedule-setting.

Left & right: LIFX's Gen 3 LED doesn't require an additional hub or gateway to be controlled via a smartphone. Its app can also control the color selection.

Courtesy LIFX (2)

GE's C-Life smart LEDs can be controlled via a smartphone app and a Bluetooth connection, although they cannot be controlled out of the house or out of their range.

Courtesy GE

In-Home EUDs

EUDs were once considered an essential HEM technology, but utilities' interest in—and activity around—them has waned, and they may soon be made obsolete as the information they provide increasingly becomes available through a variety of other channels, including mobile apps, web portals, and, possibly, smart thermostats. A variety of studies have shown that intermittent whole-home energy consumption data is less effective at promoting behavioral change than real-time, granular, device-specific data, which can prompt savings of 15% or more. At their most basic, EUDs are physical displays that show users how they are consuming energy (often using data from a smart meter). Depending on its sophistication, an EUD may also provide historical data for comparison, show current electricity prices, and enable the utility to communicate with the end user. The purposes of this information are:

- To show customers how they use energy, with the goal of promoting energy-efficient behavioral change.
- To provide time-of-use (TOU) customers with the information needed to minimize their utility bills by shifting their power draw away from peak periods.

Courtesy TED

The Energy Detective (TED) Pro Residential system can accommodate up to four Spyders (32 individual circuits) for more precise measurement of individual loads. TED Commander is a cloud-based portal that enables data collection, remote monitoring, graphing, trending, and data export. Data can be viewed on computers and smartphones.

The Potential for Interactive Benefits

Although it remains to be seen just how interconnected HEM devices will ultimately become, more comprehensive systems offer a variety of potential benefits that individual devices may not provide. For example, the Alarm.com Smart Thermostat can monitor contact sensors throughout a house that are installed as part of the home's security system, and can automatically pause or dial back the HVAC system if a window or door is open, while sending an alert to users to let them know what it's doing. Ceiling fan company Big Ass Fans' residential Haiku fan can now communicate with both Nest and ecobee thermostats, enabling the fan to be turned off remotely via the thermostats. These are just a few ways that interconnection may open up new opportunities for energy efficiency.

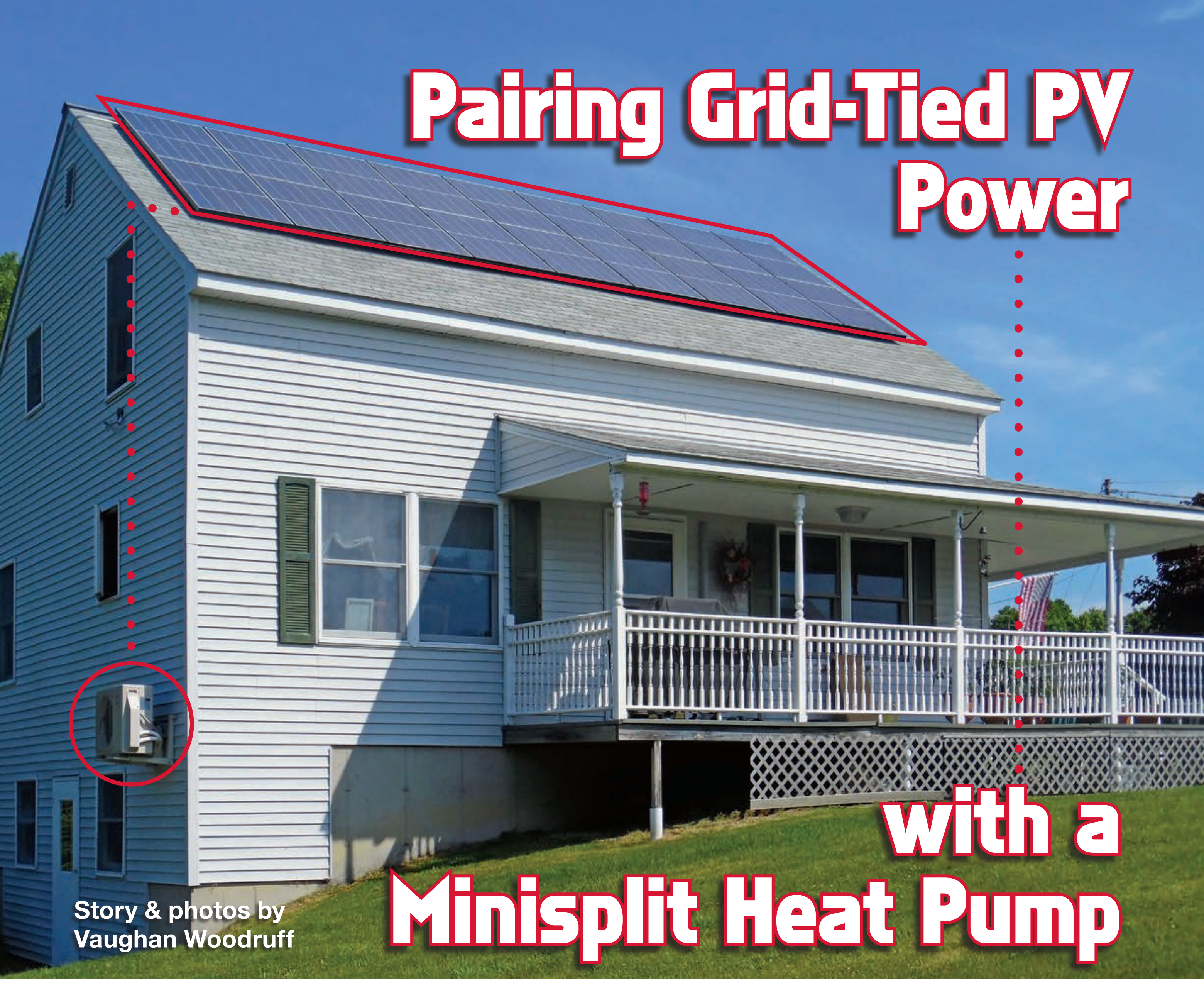
Courtesy Whirlpool

Whirlpool's 6th Sense Live connects to an online database of energy prices to determine the least expensive time to run its Smart Grid-enabled appliances, such as this front-load washer.

Interconnection can also make energy-use data more available to the end user. Irrespective of the individual HEM devices themselves, research has consistently shown that customers value energy-use feedback and will often act on it to increase energy savings—at least in the short term. In the case of HEM systems, however, it's unclear where this information will come from or how customers may access it. Possible options include:

- A networked EUD that can communicate with smart devices in the home.
- An all-in-one HEM web portal or mobile app that displays data and allows customers to adjust their devices from a single place.
- A utility-provided mobile app that provides energy-use data (and may offer suggestions on consumption reduction strategies).
- Customers' smart-thermostat displays and apps.

All of these approaches are viable with current technologies, but figuring out which specific strategies will work best in the long run will require utilities and HEM manufacturers and vendors to work together. Because many HEM devices currently offer stand-alone apps and may not share data effectively with other devices unless they are connected to a central hub, partnerships will be vital in realizing the benefits that interconnectivity may eventually provide.



Pairing Grid-Tied PV Power with a Minisplit Heat Pump

Story & photos by Vaughan Woodruff

Once upon a time, powering resistance electric heating appliances with a PV system was considered a no-no. Today, the high efficiency of minisplit heat pumps and the decreasing cost of PV modules is making solar-electric space heating a viable solution.

An advantage of minisplit heat pumps (MSHPs) is they are an efficient electricity-based heating and cooling appliance. Paired with a net-metered, grid-tied PV system, solar electricity can then be used to offset a home's heating and cooling demands. Heat pumps use electricity to move heat, either by expelling it from inside the house during the summer or by extracting heat from outdoor air and moving it inside during the heating season. By using electricity to move heat instead of generate it, an MSHP offers an efficient method of using electricity to condition a building. In many climates, an MSHP is two to four times as efficient as electric resistance heat.

MSHPs can use solar electricity directly to provide high-efficiency cooling or heating. When the output of the PV system exceeds the electrical demand of the home, net-metered systems export the excess to the grid. In many locations, the local utility provides credits for this exported electricity.

In climates with high cooling loads, MSHPs provide a much quieter and evenly distributed cooling option than traditional window-unit air conditioners. In many cases, the electrical consumption of an MSHP is half that of an efficient window unit. Since PV generation and cooling demand often coincide, solar electricity and cooling via an MSHP can be a good match. In these applications, a significant portion of the electricity generated by the PV system can be directly consumed by the MSHP.

In the winter, when PV generation is lower, homeowners can draw upon net-metering credits to offset electrical consumption, including the draw of an MSHP. This article explores leveraging a net-metered PV system along with an MSHP to move a home toward net-zero energy use, and includes methods for sizing a PV array to accommodate an MSHP's load.

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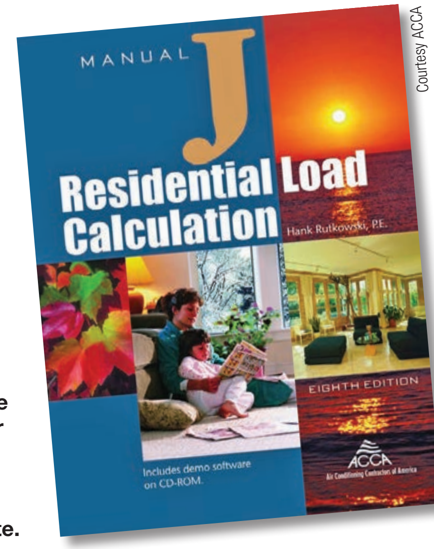
Estimating MSHP Electricity Consumption

The most challenging part of sizing a PV system for an MSHP is to determine how much electrical energy the heat pump will consume. For new construction, heating professionals typically use a Manual J calculation to estimate the heating demands for individual rooms and for the whole home. Heating demand depends upon the building envelope's thermal efficiency and surface area, the local climate, and the indoor temperature required to keep occupants comfortable.

The Manual J calculations consider the surface area of the various walls, ceilings, and floors that make up the building envelope, the R-value of those assemblies, and the heating-degree days in the locale. There are some proprietary programs that will perform these calculations (see "Resources"), though it is often best left to a qualified heating professional. Local energy auditors and heating supply companies also may provide these services.

Estimating MSHP electrical consumption also requires knowing how much of the heating season the unit will be able to satisfy the heating demand. Each MSHP manufacturer provides heat capacity tables to find the MSHP's maximum output based on indoor and outdoor temperatures. If the MSHP's heating capacity exceeds the heating demand of the area it is serving, then the estimation becomes a bit easier. If the MSHP is unable to provide the necessary heating capacity as outdoor temperatures drop, your backup heater will need to take over—or you'll need to specify a higher-capacity MSHP.



Courtesy ACCA

Make sure your home heating strategy can meet your needs—only then can you determine how large of a PV system will be needed to offset your heating load. Online Manual J calculators can help provide a more precise estimate.

For an existing home, the historical fuel consumption can help with estimating the heating demand. When making this determination, it is important to subtract the fuel consumption for other appliances, such as stoves, dryers, and water heaters. Some of this can be done by determining the baseline fuel usage during the nonheating season, when the only regular load not being used is the heating system. As you can see, this takes some nuance and ballpark estimating.

As an example, let's say that you have a two-story home that uses 1,000 gallons of propane over the course of a year. After looking at your fuel deliveries, you determine that roughly 300 gallons of propane is used for water heating and other appliances. If the upstairs and downstairs are zoned separately and you keep the upstairs bedrooms cooler than the rest of the home, you might estimate that 450 gallons of the remaining 700 gallons of propane represent the demand for first-floor heating. To determine the MSHP heating capacity that will sufficiently handle the heating load for this space in the depth of winter requires calculating how much electricity it would take to offset 450 gallons of propane.

First, multiply the heating capacity of a unit of propane (91,600 Btu per gallon) by the heater's combustion efficiency. This could range from 60% for inefficient models to more than 90% for modern condensing boilers. This results in an estimate of how much propane is being used for heating. For example, if you have a propane boiler that has an average efficiency of 80%, the amount of heat energy used by 450 gallons of propane is approximately 33,000,000 Btu (91,600 Btu/gallon × 450 gallons × 0.8).

Next, convert those Btu per year to kilowatt-hour (kWh) per year equivalents to determine the amount of electrical energy that would be needed. There are 3,412 Btu per kWh, so 33,000,000 Btu/year divided by 3,412 Btu/kWh equals 9,672 kWh per year. Since this is the electrical consumption for electric resistance heat, we then use the expected coefficient of performance (COP) to estimate the electrical demand for an

PV Policy Considerations

The use of a grid-tied PV system to offset heating and cooling demands of an MSHP is fundamentally driven by net-metering policies. In the summer, when solar production is high, using an MSHP for cooling is a viable option—a properly sized PV system can offset an MSHP's energy use. However, in winter, when PV output is usually lower, there may not be enough energy to offset an MSHP's energy use directly. To remedy this requires storage, with the "storage" usually being net-metering credits with the electrical utility.

With recent efforts to roll back net-metering benefits for future solar customers across the United States (see "Net-Metering & Beyond" in *HP177*), it is important to understand whether local utility regulations promote or deter approaches such as those outlined in this article.

In states with favorable net-metering provisions, combining an MSHP with a PV system makes annual net-zero energy use attainable in most climates in the continental United States. In states that provide less favorable benefits, the ability to offset MSHP energy use may be limited. As load-management controls become more prevalent—i.e., the ability to turn appliances on and off to match solar production or the real-time cost of electricity—MSHPs provide a potential diversion load for directly consuming solar electricity.

Other than direct-gain passive solar heating, an MSHP may be the easiest way to use solar energy for efficient space heating—and it's definitely easier to retrofit than passive solar strategies.

MSHP. For an MSHP with a COP of 3.0, the estimated electrical demand from our example would be adjusted to approximately 3,224 kWh per year. COP is the ratio of the average heating capacity of the MSHP to the electricity required to run the unit. Higher COPs equate to more efficient use of electricity and lower operating costs.

An MSHP's COP depends on the individual model and the outdoor climate. A high-efficiency MSHP used where temperatures rarely fall below 40°F might attain a COP of 4.0. In colder climates, where the average winter temperature is closer to 20°F, the COP will be lower, perhaps 3.0. The "Coefficient of Performance" table shows examples of expected MSHP performance for single- and multizone MSHPs at various temperatures. If the MSHP is being installed to reduce the consumption of other fuels, the energy content for the specific fuel type must be used (e.g., a therm of natural gas contains 100,000 Btu). The calculations when offsetting electric resistance heat is much more direct, since there is no need to convert between Btu and kWh.

Most of the above computations consider only the avoided fuel consumption related to providing heat—they do not account for the energy demand of heat distribution, which can be high, especially in homes that use older forced-air furnaces with a large, inefficient blower. During times with lower heating demands, the electricity that would otherwise be used to power the furnace blower can be used to run the MSHP instead. For example, the 500 W it takes to power a blower fan could offset 5,000 to 7,000 Btu per hour of heating load if instead used to power an MSHP.

Options for Small Spaces

In *HP180*, we explored the various types of MSHPs and how they might be used. Some homeowners simply install a single-zone MSHP to offset the heating for the core portion of their house. Others use multiple single-zone MSHPs or multizone units to provide heating in several areas of the house. However, it is often impractical to use MSHPs to heat and cool small spaces, such as small bedrooms and bathrooms. The cost of adding an additional zone on a heat pump is relatively high compared to adding electric resistance heat. While electric resistance heat is more expensive to operate, the electrical savings from a heat pump is minimal if the heating demand is small.

For example, a standard-sized bathroom (40 to 50 square feet) may require 150 to 200 kWh of electricity to heat annually. If a heat pump were used instead, this electrical demand could be reduced by 100 to 120 kWh. For many locales in the northern United States, 100 W of additional PV capacity would provide the equivalent electrical savings of the heat pump. In this scenario, installing an additional heat pump zone would be five to 10 times more expensive than adding 100 W of additional PV capacity. As a result, it is more effective to use a heated towel warmer, electric floor mats, a baseboard resistance heater, or a heat lamp to provide the occasional heating demands in this space.

Coefficient of Performance

Outdoor Temp. (°F)	Single-Zone (9,000 Btu/Hr. Model)		Multizone (24,000 Btu/Hr. Model)	
	High Efficiency	High Capacity	High Efficiency	High Capacity
-15	2.7	1.5	--	1.6
-5	3.2	2.0	2.1	1.8
5	3.8	2.1	2.5	2.0
15	3.9	2.3	2.9	2.0
25	3.9	2.5	3.2	2.0
35	4.2	2.7	3.3	2.5
45	4.6	3.2	4.7	2.8
55	5.0	4.0	4.8	3.0

Based upon published heating capacity tables for Mitsubishi and Fujitsu cold-climate MSHPs

Modern technology allows minisplits to be programmed to operate in step with PV production, either through simple scheduling or based on actual PV output data.

Baseline Comparisons

While electricity is relatively easy to meter, measuring the heating load of a room or an entire home is a far greater challenge. If MSHPs are being retrofitted into an existing home, it is rather difficult to estimate how much heat may be required to maintain occupant comfort. Energy audits that utilize blower-door tests and infrared cameras can help, but there is also a human element involved. Some people like to keep their homes warm so they can traipse around in their underwear all winter, while others are happy to don a sweater and set the thermostat lower.

Estimating heating loads is both science and art. It requires understanding building science and assessing one's comfort. Historical energy use can help, though it often includes another challenging factor to pinpoint: hot water consumption.

Some case studies have been performed to better understand the performance of MSHPs in real-world conditions. A study conducted by EMI Consulting for Emera Maine—an electrical utility serving central and northern Maine—metered the electrical consumption of MSHPs installed as part of a pilot program.

The study found that MSHP electrical usage varied greatly. Homeowners who used their MSHP only for localized heating and relied heavily on their main heating system saw increases in electrical consumption of fewer than 1,000 kWh per year. In applications where the thermostat for the main heating system was set significantly lower than the MSHP temperature setting, the usage was far greater (6,000 kWh or more). On average, the single-zone heat pumps used approximately 3,000 kWh over the course of the year and offset an average of 300 gallons of heating oil.

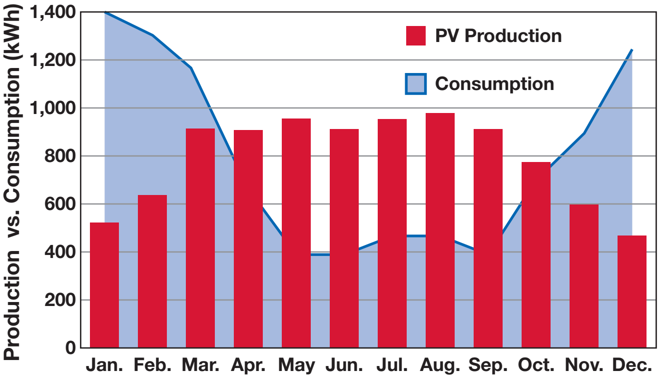
While these numbers provide a snapshot of a small sampling of system use for a specific geography, they help illustrate the scale of electrical consumption that might be experienced in certain applications. The average heating degree-days for the area studied ranged from 6,900 to 7,800 and the housing stock in the region is some of the oldest in the country. Homes that are more efficient and/or located in warmer areas have lower demands.

Sizing the PV Array

If an MSHP is not the sole source of heating and utility energy is available as backup energy, a margin of error exists for sizing a grid-tied PV system to offset an MSHP's consumption. Even if the PV system is undersized, occupants won't have to suffer through a cold winter without enough heat— they will simply have a larger electricity bill.

Estimating the PV capacity needed to offset electrical demand is far more straightforward than estimating heating demand. PVWatts (pvwatts.nrel.gov) can be used to estimate how much energy a PV array is expected to generate at particular locations and conditions. This tool helps find how much electricity (kWh) is generated by 1 kW of PV modules per year. After adjusting this number for shading, divide the MSHP's expected yearly consumption by PVWatts' estimated output, which results in the number of kW needed to offset the MSHP's demand.

PV Production & Electricity Consumption in a Net-Zero Home with MSHPs



For example, let's say we're installing a PV system in Grand Rapids, Michigan, on a 10:12 roof (40° tilt) that faces southeast (135° azimuth). According to PVWatts, the expected yearly output of a batteryless grid-tied PV system will be roughly 1,180 kWh per kW of PV capacity. If the shading from trees and snow derates the total output by 10%, this means each kW of installed capacity can offset approximately 1,060 kWh per year. With an annual electrical demand for the MSHP of 3,224 kWh (from above), roughly 3.0 kW of PV capacity will be needed (3,224 ÷ 1,060 = 3.0).

In estimating heating needs, there is always a bit of inexact science. How much PV you install to offset your MSHP use really comes down to your personality. Undersizing an array will require purchasing more utility electricity. Oversizing it may lead to forfeiting unused net-metering credits to the utility. Some may use surplus electricity to charge an electric vehicle, power an electric water heater, or simply run the MSHP a bit more as credits are due to expire. As with all home power solutions, it's important to figure out how the use of MSHPs and a PV system fits your long-term energy-use goals.

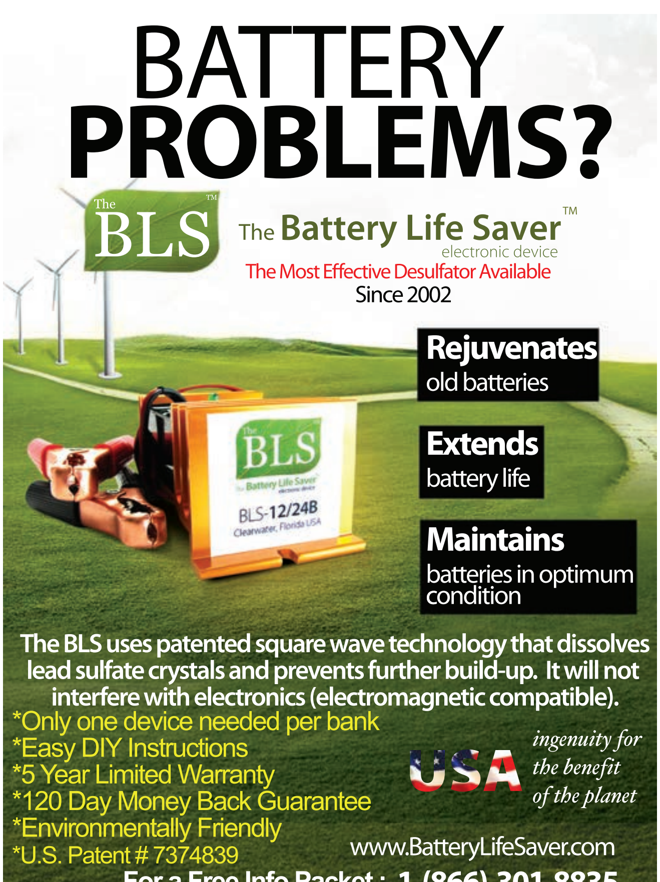
When used in high-efficiency homes and moderate climates, MSHPs may be able to provide the majority of a home's heating demand. In many applications, however, the use of backup heat is necessary.

Resources

ACCA-approved Manual J calculators • **bit.ly/ManualJ**

Emera Maine Heat Pump Pilot Program • **http://bit.ly/2hBPHkB**

NEEP Guide to Sizing & Selecting Air-Source Heat Pumps in Cold Climates • **http://bit.ly/2zfTD2k**



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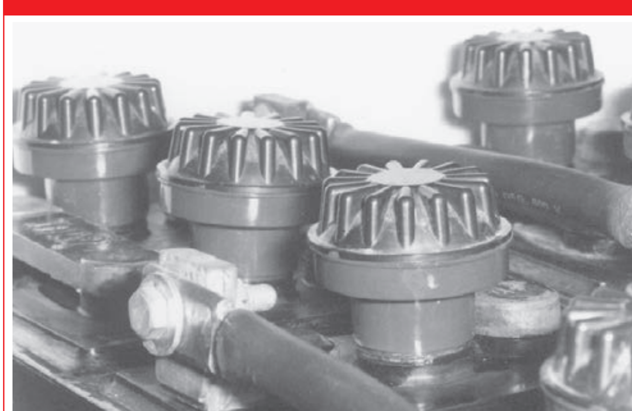

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	7.5kW	6"	Up to 450	Up to 10032	176	$2,870
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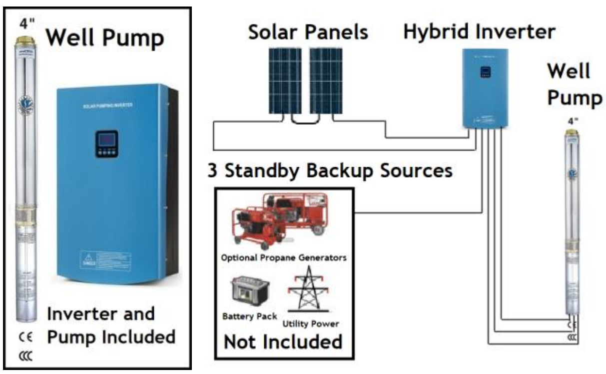

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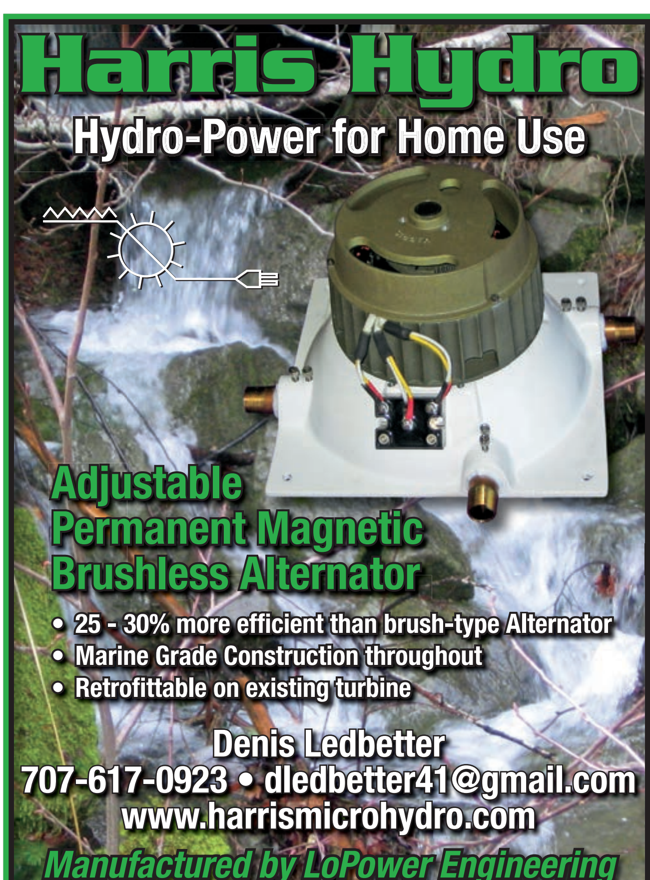

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2017 Circuit Requirements

by Ryan Mayfield

In the 2017 *National Electrical Code (NEC)*, Article 690, Part II ("Circuit Requirements") was subject to a handful of significant changes—especially to the sections PV designers are accustomed to using in their everyday designs.

Often, *Code* changes help clarify the requirements. In some of these sections, though, new methods are introduced. This article focuses on some of the biggest changes.

Article 690.7

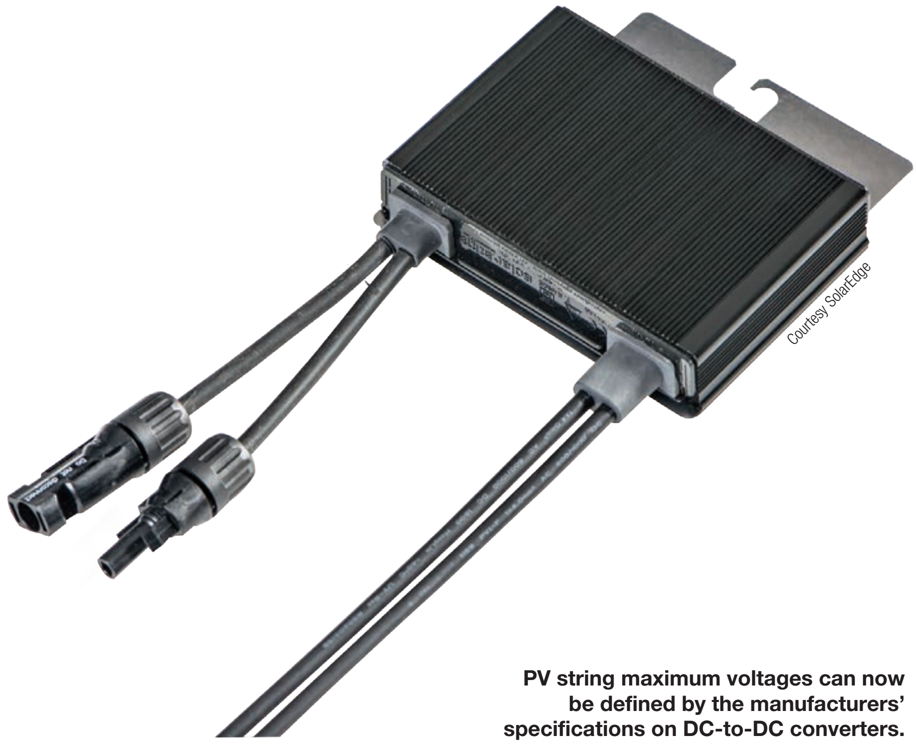
Article 690.7, "Maximum System Voltage," was changed in several ways. For PV system DC circuits for one- or two-family dwellings the maximum system voltage allowed is 600 VDC (unchanged from previous *Code* cycles, but moved up in this section). For PV system circuits located on buildings that are not one- or two-family dwellings, system voltages up to 1,000 VDC are allowed. For circuits not on or in buildings, there's a maximum system voltage of 1,500 VDC and the restrictive high-voltage rules of Article 490 Parts II and III do not apply to the PV system circuits. Once the exact circuit limitations have been determined, 2017 *Code* then outlines the methods for calculating the maximum voltages.

Article 690.7(A) provides three options for calculating the maximum circuit voltage for PV source and output circuits. The first two still require that the sum of the voltages for series-connected modules be adjusted for the lowest expected ambient temperature, either through calculations or the supplied table. Prior to 2017, the table applied only to crystalline and multicrystalline modules for when the manufacturers didn't supply temperature correction factors. Using values in the table results in a more conservative result than the module-manufacturers' values.

A third method for arrays with a generating capacity of 100 kW or more, uses a documented and engineered industry-standard method for calculating maximum system voltages. The definition of "generating capacity" was added to Article 690.2 and is essentially the AC power output of the system (i.e., the sum of AC inverter outputs). The Sandia paper—*SAND 2004-3535, Photovoltaic Array Performance Model*—is cited in the associated informational note as one such standard method. This calculation may become more common, since it results in longer string lengths and cost savings, especially in large systems, where adding even a single module in a string can have significant cost implications.

Under the 2017 *Code*, an alternative maximum system voltage calculation can be used for large-scale PV systems, resulting in significant cost-savings.

Ryan Mayfield



PV string maximum voltages can now be defined by the manufacturers' specifications on DC-to-DC converters.

The other notable addition to the 690.7 section of the 2017 *NEC* is DC-to-DC converter voltage calculations. The subsection discusses circuits connected to single converters and circuits connected to two or more series converters. For single converters, the *Code* specifies that the maximum output voltage shall be the converter's maximum rated output.

For two or more converters connected in series, the *NEC* specifies that the maximum voltage shall be determined by the instructions for the converters. In many cases, the converters work in conjunction with an inverter to hold the output voltage at a fixed value, regardless of the number of modules and converters in the series string. For example, if a module is connected directly to a DC-to-DC converter and the converter manufacturer allows for up to 30 of the converters in series, the maximum output voltage is not 30 times the module's temperature-corrected voltage, but rather the voltage limits of the converter, as documented in the installation manual. While these converters are not new to the industry, this is a good example of the *Code* catching up to the technology.

The final statement in this new section states that if the converter instructions do not list the maximum voltage, then the maximum system voltage shall be the sum of the converters' maximum rated output voltage. This allowance gives both designers and inspectors good guidance.

Article 690.8

In 690.8, "Circuit Sizing and Current," current calculation methods were changed. Section 690.8(A)(1)(2) was added to allow a professional engineer to calculate the maximum circuit current for PV systems with generating capacities of 100 kW or greater. A documented design is required with "the calculated maximum current value shall be based on the highest 3-hour current average resulting from the simulated local irradiance on the PV array, accounting for elevation and orientation." This is a simulation that can be run via software programs such as NREL's System Advisor Model, using historical data sets and site-specific adjustments. This new calculation method has the potential to help reduce conductor sizes to help match real-world-system current values.

In no case can this new method result in a maximum circuit current less than 70% of the 690.8(A)(1)(1) calculation—the traditional calculation PV designers are accustomed to. As with the maximum voltage calculation, this section also references S*AND 2004-3535* for calculating maximum current.

Article 690.9(C)

A notable 2017 change in Part II of Article 690 is 690.9(C), "Photovoltaic Source and Output Circuits." A single overcurrent device can now protect the modules and conductors in source and output circuits. The 2014 rules required that all ungrounded current-carrying conductors have overcurrent protection, meaning both positive and negative PV conductors in systems that use a non-isolated (transformerless) inverter. The justification for this change is outlined in the informational note that follows the rule, which explains that the advanced ground-fault protection methods integrated into the power electronics help provide the necessary overcurrent protection. Under this method, all overcurrent protection devices (OCPDs) need to be placed in the same polarity for all circuits.

Section 690.35(D) was removed in the 2017 *NEC*. This requirement prohibited using USE-2 wire in free air for arrays connected to non-isolated inverters. This section removal, along with the change in 690.9(C), is a boon for installers looking to replace old transformer-based inverters on existing arrays. Many of those arrays have OCPDs on one half of the circuit (often on the positive side), and module interconnections and home-runs that use USE-2. However, the disconnecting requirements do require disconnecting both sides of the circuit, so that still needs to be considered.

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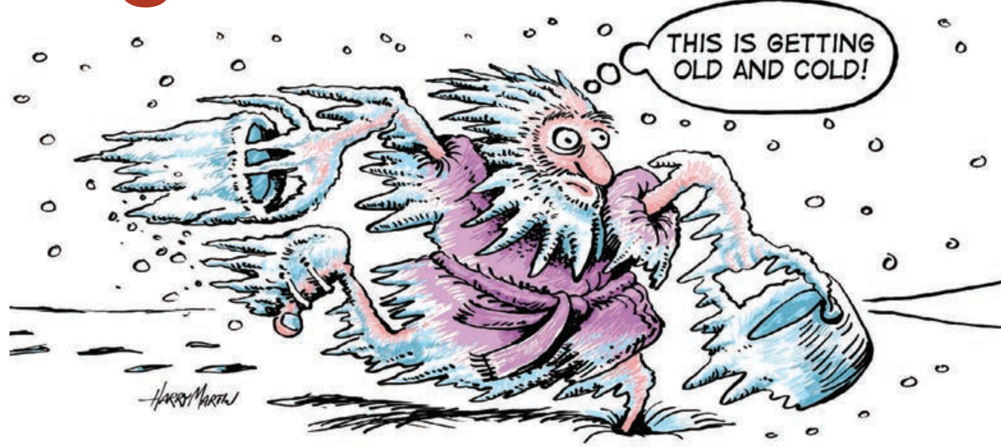
Winterizing Water

by Kathleen Jarschke-Schultze



When my husband Bob-O and I bought our little piece of paradise 27 years ago, one of the most exciting features was having a natural spring supplying our domestic water, and all of our homestead water, via gravity. The flow was a gallon per minute, but locals had assured us that the spring had never run dry.

Spring Time

Our whole valley and the surrounding hills had once been one large cattle ranch. Our house was the round-up cabin—used by ranch hands when they brought in the cattle for branding, tagging, medicating, or breeding. There was still a very stout cattle chute and corral beyond the nearby not-so-stout, open-sided hay barn. Being the historical water source for the cabin, the spring was deeded to our parcel when the cattle ranchland was divided into smaller pieces and sold. It is not on our parcel, but is our spring.

The spring is across a creek and up a steep hill about 1,000 feet from the road. Surrounded by brush and a few trees, it seeps from the ground into a 12-inch terra-cotta pipe section set upright in the ground. A heavy steel lid keeps the dirt and wildlife out. The water rises in the pipe up to a 3/4-inch pipe. The small pipe is buried, sometimes very shallow, down the hill to join a buried, 1,000-gallon concrete cistern. From the tank, a 1 1/2-inch buried pipe goes down the hill, under the road, and pops out of the creek bank about 5 vertical feet above the creek. From that juncture, the pipe crosses the creek, protected by a steel casing, and disappears on the other side of the bank into the dirt, where it passes under our driveway and connects to the house plumbing in a protected corner of the carport next to the house.

Cold Reality

During our first winter, the disadvantages of this water system were revealed to us. The pipe where it crosses the creek is exposed to freezing temperatures. That year, the water in the pipe was frozen solid for more than a month. As the pipe froze at the creek, the freezing spread up the pipe, underground. When the weather warmed, we had to wait for the underground pipe to thaw, too. Through it all, Bob-O proudly asserted we still had "running" water—he would run to the creek, break a hole in the ice, dip out a bucketful of water, and run back to the house.

When we planted our first garden, we knew we would need more water than the spring could supply. We bought two 1,300-gallon water tanks, installed them uphill from our house (on our side of the creek), drilled a well, rented a small trencher, and buried water pipe everywhere we thought we would ever need a faucet. We pumped water from the creek using a PV-powered pump directly powered by two 190-watt PV modules on a small tracker. The 380 watts of PV can run the submersible pump or be switched to help charge the house batteries. When the creek got low, we pulled water from our first well for garden watering. The spring-fed system was relegated to supplying only the house's water.

Once our microhydro system was installed and was producing surplus energy, we wrapped heat tape around the pipe crossing the creek. We also wrapped the pipe junction in the carport. Except in the coldest of winters, this kept the water flowing. We experience four distinct seasons here, and at least once a year our house water freezes. I prepare for this by listening to weather reports for when really cold weather is predicted, especially if it will be a prolonged cold snap. I fill two 5-gallon water jugs for the kitchen and two 7-gallon buckets for the bathroom. This usually gets us through the freeze.

Drier Days

In recent years, our spring has dried up in the heat of summer. When this happens, we bypass this spring-water system by attaching a hose to the solar pump in our well. We attach the other end of the hose to a faucet at the side of the house, open the house faucet, and use the PV modules to pump water from the well and fill the spring's cistern. We only have to pump for a few hours every three or four days to keep the house water supply topped up.

All of these water and pumping systems have evolved over the years as money, time, and need jockeyed for

continued on page 62

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position. With Bob-O's large overhaul of our garden water/fire protection storage system three years ago, we ended up with two empty 1,300-gallon water tanks, a very old tracker, and two equally old PV modules.

Water Security

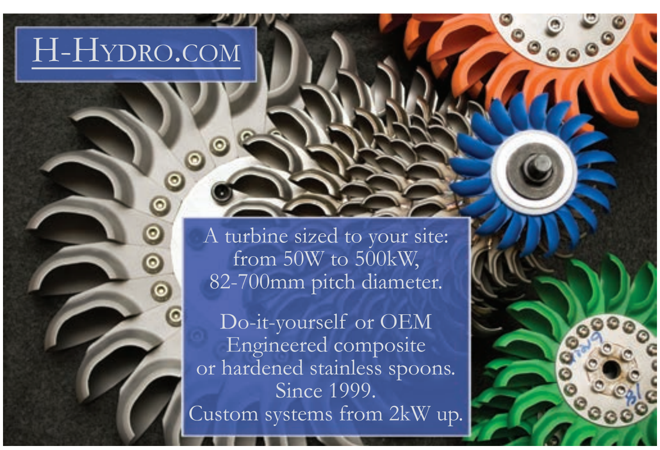
This past summer's large project was to provide the house with a clean, freeze-proof water supply. No more water jugs taking up counter space, no more flushing the toilet with water dipped from a bucket. I was excited. Bob-O measured, and developed the plans and the list of needed parts. Of course, he used parts we had on hand first. Like those two empty water tanks.

It took a few days of work with the big backhoe to dig out and flatten an area for the tanks on the hillside behind the house. A load of sand for a stable base was deposited by our dump trailer, but spread by hand. Using a big backhoe, with its 16-inch bucket, Bob-O dug a 2- to 4-foot-deep trench for the pipe depending on the size of rocks he hit. At our fence line, he used the smaller Kubota, with its 10-inch bucket, and finished digging the trench to the well's existing pipe, an irrigation pipe junction, and down to the side of the house, where the new pipe would enter the basement wall to join the house plumbing.

The biggest outlay of cash was for the 1½-inch PVC pipe and fittings. Bob-O also installed shutoff valves at several key junctions. While he had the trench open, he laid some electrical conduit and pulled some wire through it, for a future PV array. He's an electrician—what else can I say?

I filled a water jug and a single bucket for what I hoped would be one last time. Bob-O joined the house pipes last, which took a couple of hours. We both noticed the pressure was not quite as strong as the spring system, but the elevation of our tanks was lower than the concrete reservoir, so this wasn't surprising. This wasn't a problem, as we don't have any water-pressure-driven appliances.

Now, it's the beginning of September, and the spring has dried up. We'll switch the house water system back to the spring once the rains come. I'll still be reading the weather reports, though, and when sustained freezes visit us this winter, with a few turns of some valves, we'll have water flowing into the house. Bob-O's system allows us to use the spring's water whenever the changing weather allows. As big of a project as it was, our homestead is now much more resilient and secure.



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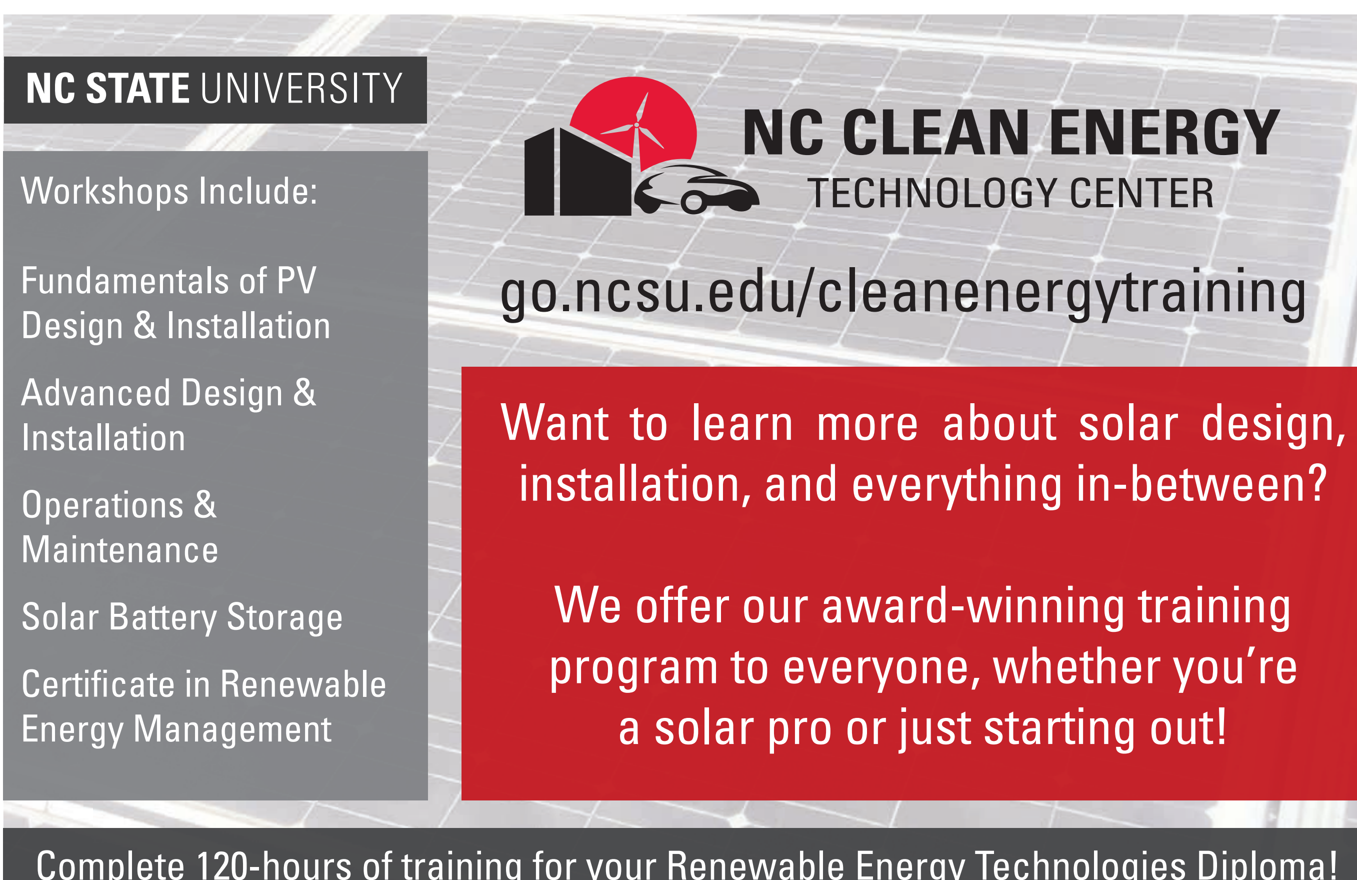
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Wind-Washing

As outside temperatures start to drop, your home's insulation problems and air leaks may become more obvious. You may feel more drafts in certain rooms or hear the furnace kick on more often as it struggles to maintain a certain temperature setting. Contributing to these problems is wind-washing, which compromises insulation and whisks heat out of the home. While you may not be familiar with the expression, you may be well-acquainted with its home-chilling effects.

Wind-washing is wind-driven air pressure moving through the wall or roof assembly, which lowers the insulation's effective R-value. This often occurs at building corners or in attic spaces where the house faces a prevailing wind. Wind can drive air into attic soffits on one side, through the attic insulation, and out the soffits on the opposite side.

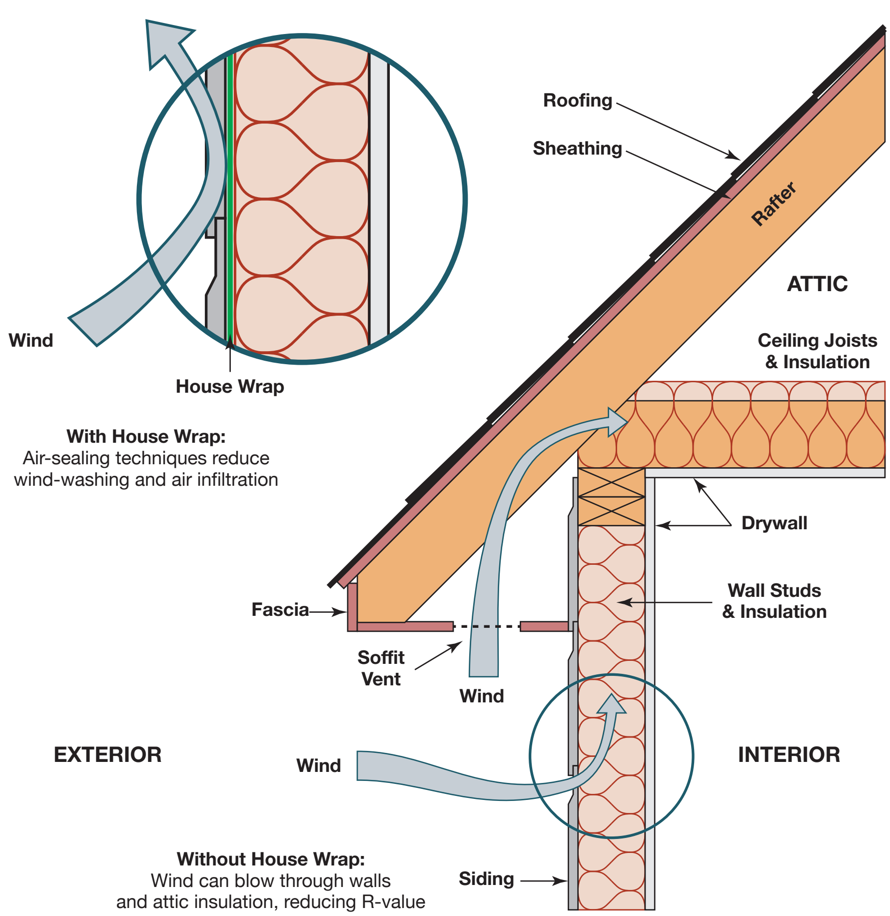
Most insulation works by trapping pockets of warm air and slowing the movement of heat. Fibrous insulations, such as fiberglass and rock wool, are porous and allow wind to flow through their fibers. Denser insulations like blown loose-fill cellulose are less prone to wind-washing, and solid insulations like XPS foam board or most spray foams are barely affected.

If your home has drafts, a blower door test by an experienced energy professional is a good first step to identify exactly where drafts are occurring. Home facades with open exposure (in a field or on a waterfront) or facing a persistent wind (in New England, Nor'easters) should be paid particular attention. Caulking wall penetrations (electrical boxes, cable lines, telephone lines, around window frames, etc.) and proper weatherization can help minimize wind-driven drafts.

Unsealed soffits in vented attics and kneewall spaces can also be vulnerable—wind will gust into the attic (or into living space if the soffits are adjacent to rooms), pushing into the building frame and insulation. This can be solved by installing foam blocks flush against existing attic baffles and sealing with foam gap sealant. Another method is installing attic baffles/proper vents with a built-in wind barrier. Both of these methods ensure that the wind travels up the venting rather than into your house or the insulation.

—Erik North • freeenergymaine.com

Effects of Wind-Washing on Insulation R-Value



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