Mountain Solar

by Kelly Davidson

In the coal-heavy state of West Virginia, solar shines at Rita Hennessy and Sean Palmer's new custom-built home in Shepherdstown.

Matt Hovermale (2)

After nearly two decades living in a drafty, 1940s Cape Cod-style home on the outskirts of Charles Town, West Virginia, Rita Hennessy and Sean Palmer were ready for an upgrade from the post-war cinder block and brick construction. "Even though we had made improvements through the years, it was still leaky and incredibly inefficient—cold in the winter and hot in the summer," Palmer says.

Planning for retirement, the couple—Hennessy, a National Park Service park ranger with the Appalachian National Scenic Trail, and Palmer, an engineer for a biotech company—paid off their mortgage ahead of schedule. In the years that followed, they focused on saving to realize their dream of buying land and building a home that better suited their lifestyle and values. After relying on West Virginia's coal-powered grid electricity for nearly two decades, the couple made energy conservation a top priority, vowing to reduce their carbon footprint with passive solar design and a rooftop solar-electric system. "We are very concerned about climate change, and we want to do our part," Palmer says.

Site & Design

"Our mission was to find a property with good southern exposure that was close to the Appalachian Trail (AT) and near protected lands," Hennessy says. The couple focused their search along the AT corridor—looking first in Maryland, hoping to move closer to Palmer's parents. "In Maryland, all the available land near the AT had steep slopes that were either east- or west-facing, which wouldn't work for our solar plans," Hennessy says. "We started looking in Virginia along the AT, but we didn't find anything suitable there either."

About two years into the search, the couple returned their attention to West Virginia, and in the fall of 2010, found a site just outside of Shepherdstown—14 wooded acres with southern exposure on a three-acre clearing. Hennessy and Palmer took more than a year to consider their building options. Finding a local architect with passive solar expertise proved more difficult than they expected. When their local search came up empty, they researched Web-based design firms and found Alabama-based architect Debbie Rucker Coleman, who specializes in passive solar and sun-tempered homes (see "Media" in this issue). "She had good reviews, and we were impressed with her credentials," Palmer says. "The only real downside to working with a remote architect is that it takes a little more time to exchange ideas through emails and phone calls."

The process began with Coleman's 20-page questionnaire in which the couple described their lifestyle, and outlined their budget priorities and energy-efficiency goals. Initially, Hennessy and Palmer envisioned a smaller, single-story home—roughly 1,500 square feet—but answering the questionnaire made them realize that they wanted about 600 more square feet to accommodate a larger kitchen, a walk-in closet in the master bedroom, and a more spacious common area for entertaining. "We host a lot of parties. We'll have 35 or more people in the house on any given occasion," Hennessy says. "It became clear that we wanted a little more space."

They browsed the plans available on Coleman's website, and while they found inspiration in several designs, none were quite right. "We thought we would adapt one of the existing plans to meet our needs, but our list of modifications ran quite long, so it made more sense to start from scratch," Hennessy says.

Maximizing Passive Design

With the exception of a loft, the 2,148-square-foot design remains true to Hennessy and Palmer's original vision for a one-story house. In viewing plans online, the couple loved the second-floor towers and atriums featured in several of Coleman's larger home designs, but the complexity of the roof and window schemes came with high construction costs that would have exceeded their $350,000 construction budget. Coleman came up with an affordable compromise—a 287-square-foot loft featuring a row of south-facing clerestory windows for daylighting and fresh air, and for providing summer passive cooling. "Even though the air-conditioning needed in this well-insulated home would probably cost less than $100 per year, Rita and Sean wanted the clerestory to keep the house cool without electricity," Coleman says.

Clerestory windows, which are opened and closed by remote control, aid in cooling the house by venting any accumulated hot air.

Large windows on the home's south face provide ample daylighting to interior spaces. They also admit solar gain in the winter, reducing the home's need for supplemental heating.

Courtesy Rita Hennessy

Dozens of emails over the course of one year gave way to the "RISE" design (a combination of the first two letters of the homeowners' names), and the home's ability to take advantage of rising air for passive cooling. A key feature is a series of seven operable clerestory windows at the peak of the south roof—which are opened and closed by remote control. At night, when outside temperatures drop below indoor temperatures, both the clerestory windows in the loft and the awning windows that sit low on the first-floor wall are opened to naturally cool the home. As the warm air in the home rises and is drawn through the clerestory windows, cooler air enters the lower windows, creating a thermosyphon of air movement. To capture the "coolth," the windows are closed as early in the morning as possible, typically by 7 a.m. However, Hennessy says that "once the nighttime temps climb above 75°F, the passive cooling is no longer effective."

Instead of a true south orientation, Coleman recommended that the house be oriented 10° east of south. In their West Virginia climate, having the façade favor a more easterly direction can help minimize afternoon heat gain during the summer and maximize early morning heat gain in the winter. Overhangs also help minimize heat gain in the summer, keeping

Thick, insulated walls and double-pane windows slow heat transfer, keeping the house cool in the summer and warm in the winter. The 4-inch-thick concrete floor acts as a thermal battery, storing and releasing passive solar heat gain.

High-Performance Glazing

For energy efficiency and passive solar gain, the home uses double-pane, fiberglass-framed casement and awning windows from Inline Fiberglass. All of the RISE windows have a maximum U-factor of 0.28—the lower the U-factor, the greater a window's resistance to heat transfer and the better its insulating value. The south-facing windows have an SHGC of 0.42 (meaning 58% of solar heat is blocked), and the other windows (east, west, and north) have an SHGC of 0.24 (blocking about 76%). Inside, honeycomb shades or interior shutters further reduce summertime heat gain and provide a small amount of insulation during the winter.

"At the time of window selection, Inline was one of the few companies that made windows that met the solar heat gain coefficient (SHGC) and U-factors required by the home's design specifications. Other U.S.-based companies have since improved their specs," Palmer says.

the sun from shining directly into the windows throughout the afternoon. Oriented with its long dimension to capture the winter sun for free heating, the home features a 4-inch-thick concrete slab-on-grade floor, which is insulated with 3 inches of rigid-foam insulation (R-15). The thick concrete floors provide thermal mass to absorb solar gain in the winter and also help moderate temperatures during the summer. The foundation stem walls are also insulated with 3 inches of rigid foam.

The home uses doubled, 2-by-4 stick-frame walls on 16-inch centers with a 1/2-inch space between to form an 8-inch-thick wall. The air space between the stud walls creates a thermal break between the interior and exterior. With fiberglass batts between the studs to total R-30, and 1 inch of closed-cell spray foam to the exterior, the walls total about R-36, almost triple the code minimum (R-13 in their county) for wall insulation. "While spray foam isn't all that green—it is petrochemical-based and has a high embodied energy—the amount we used is far less compared to the amount of foam used in structural insulated panels, which we had considered as a wall option," Palmer says.

The roof is framed with manufactured wood trusses, which allow lots of insulation in the flat ceilings. In the bedroom wing, for example, 15 inches of blown-in fiberglass insulation were applied over 1-inch closed-cell spray foam (for R-60). A combination of fiberglass batts and spray foam were used for the vaulted, sloped ceilings throughout the rest of the house, for about R-66 total.

Auxiliary Cooling & Heating

Given West Virginia's hot and humid summers, keeping the house cool was a priority. While the operable windows provide some passive cooling, a 22-inch-diameter whole-house fan mounted in the attic boosts ventilation, helping move air throughout the house. Most effective whenever outdoor temperatures drop below indoor temperatures, the AirScape fan draws fresh, cooler air into the living space through open windows, the warmer air exiting through the roof vents. The fan can move 725 to 2,590 cfm, drawing 21 to 210 watts— far less power than a central air-conditioning system. At about $1,300, it is also significantly less expensive.

While the couple says that the fan works well for cooling, the window-opening strategy moves enough air so they rarely need it. However, in late July and August, when the humidity peaks and night temperatures remain in the 80s, they use a minisplit heat pump to keep the indoor temperatures cool and comfortable.

In the winter, they typically keep the house at about 69°F with one firing per day in their masonry heater. When outside temperatures drop below zero, they burn two or three fires. Popular in the wood-sparse tundra of Scandinavia and Russia, this massive heater works by directing the heated gases from a small, hot fire through baffled chambers, where nearly all the heat is absorbed by the masonry. Usually, one or two fires will provide enough heating for a 24-hour period. Because the fires burn at very high temperatures, very little ash or smoke is produced. The couple purchased a kit from Empire Masonry Heaters, and hired a mason to assemble the core. A subcontractor hired by the builder finished the exterior with river stones collected from the property. The Phoenix kit, roughly $1,300, included the core, doors, cleanouts, damper, and a pizza/bread oven.

Sean checks out the minisplit multizone heat pump, which provides auxiliary cooling during the hottest part of summer.

Rita pulls a pizza from the Empire masonry heater, which serves as a backup source for space heating.

For backup cooling and heating, they consulted with building systems engineer David Butler of Arizona-based Optimal Building Systems. This service is part of Coleman's design package. Based on information provided on the plans and specifications, as well as phone calls and correspondence with the couple, Butler developed the home's heating, ventilation, and air-conditioning (HVAC) system specifications. "More often than not, passive solar and other high-performance homes end up with grossly oversized HVAC equipment. This not only undercuts potential energy savings, but can lead to comfort and moisture-related problems," Butler says.

Butler used Manual J protocol (often called "heat load calculation" or "cooling load calculation") to estimate how much heating and cooling the home might require. However, based on his experience, the Manual J "significantly overstates" heating loads, even for conventional homes, and ignores internal and solar gains. Knowing that, he says, the numbers are merely a starting point. Given the low electricity rates in the area (about 9.5 cents per kWh), Butler calculated that a ground-source heat pump would be less expensive to operate than most other HVAC options. However, with the home's small heating and cooling loads, it would have taken the couple many years to recover the system's high installation costs. Instead, he recommended an electric Mitsubishi Mr. Slim multizone minisplit heat pump, with two ductless wall-mounted units (for loft and living areas) and a small ceiling-mounted ducted air handler for the bedrooms—all supplied by a variable-capacity outdoor unit. The system has a SEER rating of 17.5.

Minisplit systems work like a standard air-source heat pump, with an outdoor condenser/compressor, but without

Courtesy Rita Hennessy (2)

The 2,148-square-foot floor plan includes three bedrooms and two bathrooms on the main level. The home's semidetached garage can be accessed via a workshop space off the laundry and mudroom.

Sean and Rita's dog guards the air-source heat pump's outdoor unit.

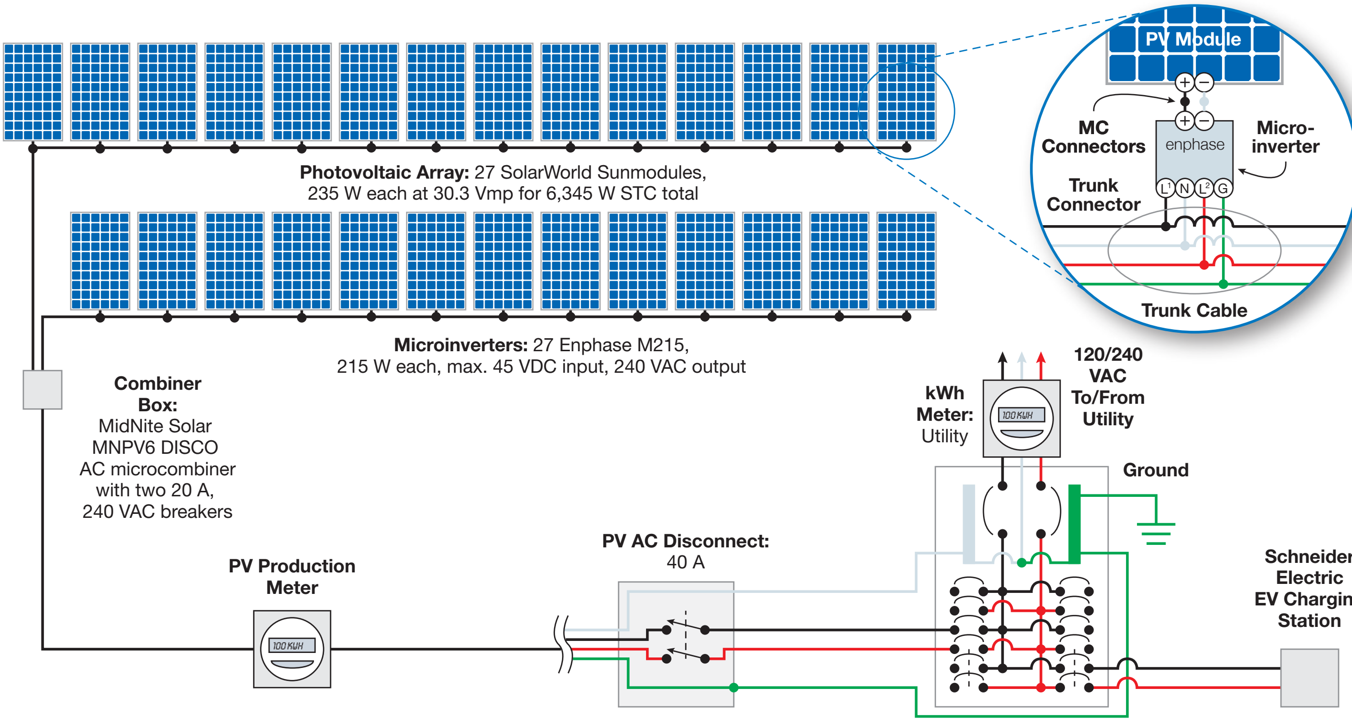
the expense or space required for ducts. The systems are more efficient, with fewer conditioning losses than with a conventional furnace. However, without ducts, there was the problem of getting conditioned air to the bedrooms. With each distribution unit costing about $3,500 installed, it would have been too expensive to put individual wall units in each bedroom. Even the smallest minisplit unit, he says, would have had several times more capacity than a bedroom's peak load need—thus leading to large temperature swings as the unit cycles.

Instead Butler recommended ducted air distribution. The 8-inch-tall Mitsubishi ducted air handler, concealed in the hallway's dropped ceiling, preserves the thermal integrity of the primary ceiling. The duct runs down the hall, feeding the bedrooms, where ducts are routed in the attic above the primary ceilings and buried under 16 inches of blown-in fiberglass insulation.

Beyond Passive

Hennessy and Palmer were determined to offset any electricity their home used with a batteryless grid-tied PV system. They turned to Mountain View Solar (MTVSolar) in nearby Berkeley Springs, West Virginia.

Hennessy/Palmer Batteryless Grid-Tied PV System



Note: The PV and inverter wiring shown has been simplified; see inset for details. DC equipment grounds omitted. All numbers are rated, manufacturers' specifications, or nominal unless otherwise specified.

"With a new home, there's always some guesswork involved in adequately sizing a PV system," says Pablo del'Aguila, the crew lead/field engineer at MTVSolar. "We used the electricity bill from their old house and then made adjustments based on the new home's specs. Based on the size of the house and the loads of the more efficient appliances, we came up with a conservative estimate."

The guesswork paid off. The couple records daily system production data from the Enlighten website. Since its installation in July 2012, the system has produced more electricity than the home has used. Since November 2012, when the couple moved in, the 6.3 kW system has generated an average of 700 kWh per month, while the home consumed an average of 563 kWh per month. Thanks to the excess generation, the couple has never paid an electricity bill for the home. The microinverter-based system allows for module-level monitoring, making any future troubleshooting easier. An additional tie-in point was also added to accommodate system expansion.

With the exception of a propane cooktop and the wood-burning masonry heater, the home features all-electric appliances, including one of Hennessy's favorite items—a Thermador steam and convection oven, which cooks food more efficiently with steam and reduces baking and roasting

Tech Specs

Overview

System type: Batteryless, grid-tied solar-electric

Location: Shepherdstown, West Virginia

Solar resource: 4.6 average daily peak sun-hours

ASHRAE lowest expected ambient temperature: -0.4°F

Average high temperature: 91.4°F

Average monthly production: 700 kWh

Utility electricity offset annually: 125%

Photovoltaic System Components

Modules: 27 SolarWorld Sunmodule, SW 235 W STC, 30.3 Vmp, 7.77 A Imp, 37.5 Voc, 8.19 Isc

Array: Two microinverter strings—14 module/inverter pairs and 13 module/inverter pairs—or 6,345 W STC total, 240 VAC

Array combiner box: MidNite Solar MNPV6-DISCO AC microcombiner with two 20 A breakers

Array installation: Iron Ridge XRS Rail mounts installed on roof facing 10° east of south, 33.75° tilt (parallel to roof)

Microinverters: 27 Enphase Energy M215, 215 W each, 215 W rated output, 45 VDC maximum input, 16 to 36 VDC MPPT operating range, 240 VAC output

Mountain State Solar

Although West Virginia leads the nation in underground coal production (coal is found in 53 of West Virginia's 55 counties) and 99% of the state's electricity is derived from coal, the state is a good candidate for solar electricity.

With 4.6 average daily peak sun-hours, West Virginia had an estimated 1.7 MW of PV capacity in 2012.

The 2012 edition of *Freeing the Grid*—a report produced by Interstate Renewable Energy Council and Vote Solar Initiative—grades all states on the effectiveness of their net-metering and interconnection practices in promoting rooftop solar and small-scale renewable energy. West Virginia earned an "A" for net metering, which is available to residential consumers with systems rated up to 25 kW. Net excess generation is credited to a customer's next bill at the retail rate with no annual true-up (perpetual rollover). The state also earned a "B" for interconnection policies.


Matt Hovermale (2)

In addition to powering their home, Rita and Sean's PV system also provides the power for an electric car-charging station. Here, Sean plugs in a friend's EV.

Rita stands in the kitchen, which features a Thermador steam oven and other Energy Star appliances.

time compared to a conventional oven. "We cooked a 14-pound stuffed turkey about half the time (in 2.5 hours), and it was golden-brown and fabulously moist inside," Hennessy says.

The PV system's gross cost was $34,860, or $5.50 per watt. After rebates and incentives, the net cost was $14,402—$2.28 per watt. The couple benefited from a $10,458 federal tax credit and $4,000 state tax incentive (including a state tax credit for the 240-volt car charging station in the garage). The couple currently owns a Prius but does plan to buy a plug-in vehicle in the near future. "The state tax credit for the charging station was so good we couldn't pass it up. It just seemed easier to install one during construction while the walls were opened up rather than to add it later," Hennessy says. "We planned for the future."