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SOLAR

Home Alone—Living Off the Grid

by Cathlene Casebolt

What does a low-consumption house look like? Can comfort and conservation co-exist? The design and metering of a sun-powered home in Arizona suggest answers to these questions, and more.

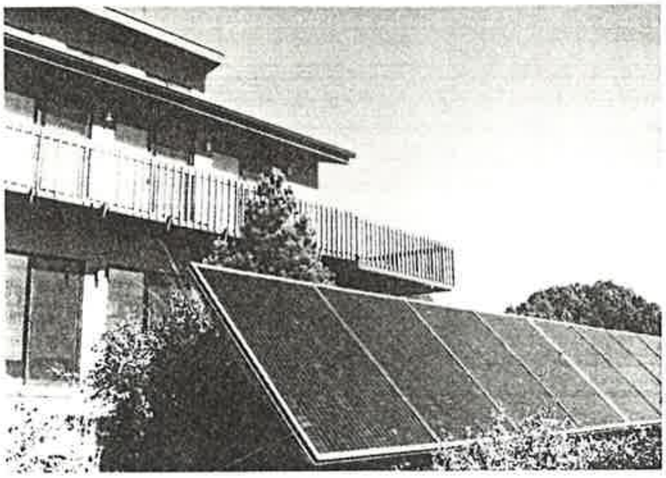
When Bob Hammond built a house near Prescott, Arizona, he decided to get off the utility grid. To do so, he designed a home that uses only about 855 kWh of electricity a year, a fraction of the 9,300 kWh of neighboring homes. He turned to photovoltaic (PV) solar panels to generate electricity from direct sunlight, designing a 1,400W system that is totally independent of the utility power grid.

In the process, however, like many stand-alone homeowners, he learned that other factors besides power generation loom large—energy efficiency, conservation, and load management. Even though PV systems are practical and reliable, the amount of electricity they can generate is limited by their size, the amount of sunlight available each day, and module efficiency.

The high cost of electricity in a stand-alone home, initially about 50¢ to $1 per kWh, forced Hammond to take a hard look at his home's electrical requirements. Keeping them in check could help keep energy needs cost-effective. In 1990, Hammond's efforts became the subject of a study conducted by Pacific Gas & Electric Co. (PG&E), a utility in Northern California trying to assess the benefits of serving customers off the grid. Hammond monitored the house for a year and collected data on its performance.

The study showed that life in a stand-alone home is different than life in a grid-connected home. While it requires changes in behavior and commitment to a changed lifestyle, it is possible to live comfortably in a stand-alone home. It also provides a window into the future by showing how grid-connected customers might reduce their energy consumption in a world of high electricity costs and scarce water resources.

Cathlene Casebolt is a researcher for the National Center for Appropriate Technology in Butte, Montana.



Bob Hammond

To generate the energy needed to run his stand-alone home, Bob Hammond installed an array of photovoltaic (PV) solar panels, *lower right*, which generate electricity from direct sunlight.

The House That Bob Built

Completed in 1989, Hammond's three-level house is wood-framed with a stucco exterior. It has 2,600 ft² of floor area, and the walk-out basement is earth-sheltered on the west and north sides. At the time of the PG&E study, two adults occupied the home about 13 days a month. Currently, though, the house is occupied about four days a month.

Since the house is about 1,200 ft from the Arizona Public Service grid, it qualified for utility service, although connection would have cost about $5,700. Hammond chose to build a PV house without a backup generator: "I wanted to experience the real-life experiences of those who can't hook up to the grid." And, having worked in the PV field for nearly two decades, Hammond was anxious to test what the industry has learned about solar technologies over the years. The house became his working laboratory.

A Well (Over)Sized PV System

The technical aspects of the generation system are these: Electricity is provided through a 1,400W Mobil Solar Ra-155 PV array, consisting of four 24V direct current ($24V_{DC}$) subarrays paired at two Trace C30A voltage regulators, which disconnect the PV array from the batteries when a certain voltage is reached. Output of the regulators is connected to 20 Delco lead-acid, maintenance-free batteries. A 2 kW Trace inverter converts $24V_{DC}$ from the 1,050 amp-hour battery bank to 114V alternating current

($144V_{AC}$) to run household equipment and appliances. A Vanner battery equalizer equalizes the battery bank's charge so that all batteries have the same capacity. The PV system, which cost $12,000, was also the sole source of power during construction.

Even though the house uses only 855 kWh a year, the PV system is capable of producing about 2,409 kWh a year. Hammond deliberately oversized the system. Since his system does not include a backup generator, he wanted to safeguard against running out of electricity, and to reduce running down his batteries which shortens their life. Additionally, he realized his electricity usage would expand over time. With the system sized as it is, "I only use 32% of available energy, and I could easily double my load and have a fair safety margin," Hammond says.

Passive Design, Positive Results

"Living in a stand-alone home is easy, as long as it's designed right," Hammond explains. And, indeed, energy-efficient design was a priority in his home. He selected a remote, hilltop site about 20 miles north of Prescott for its "ideal climate." Because the area requires very little heating and no cooling, passive solar features, such as the large expanse of high-efficiency south-facing glass, heat the home to a comfortable level during the winter months. This solar heating system is so effective that the backup system, a woodstove, is used only 15–20 nights a year. Cathedral ceilings and open architecture help to circulate air and evenly distribute heat throughout the house.

Hammond boosted the home's overall efficiency by upgrading insulation levels, exceeding those recommended by the U.S. Department of Energy. Using fiberglass and rigid foam, the 2 x 6 stud exterior walls have an insulation value of R-26, and the ceiling is insulated to R-40. (Department of Energy recommends R-30 and R-19 for ceilings and walls, respectively). Foundation footing, basement slab, and basement walls are R-5.

To keep electrical requirements to a minimum, there is no mechanical air conditioning system or fans. Roof overhangs and decks block solar gain through south windows in the summer months to prevent overheating. Increased ceiling insulation, a double radiant barrier, and passive ventilation also help keep the house cool.

Hammond says the home's design allows temperatures on the second and third floors to moderate quickly according to the outdoor temperatures. It stays cool, for example, on even the hottest days. "We vent the house at night when it's cool outside, and close it up during the day. It stays very comfortable," he points out. As a result of both the thermal mass (concrete) and earth-sheltering, the basement level stays at a constant temperature year-round, 60–70°F.

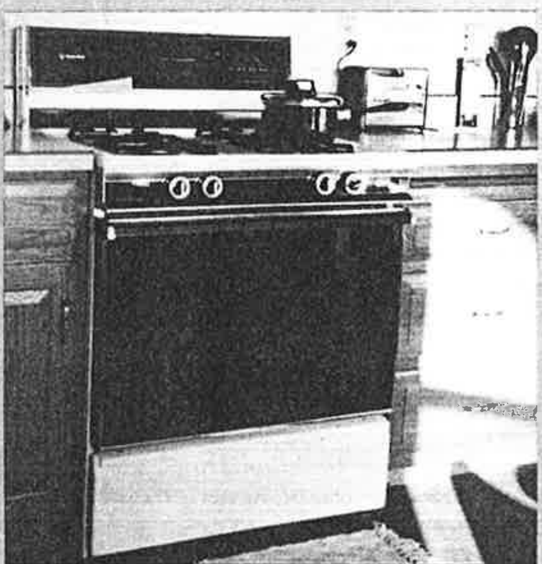
The south-facing windows also function as an effective daylighting tool, reducing the need for electric lighting. For those times when electric light is necessary, Hammond installed high-efficiency fluorescents, in the 5–25W range.

One More Miscellaneous Use of Electricity

One of the surprises from the PG&E solar home monitoring project was the discovery of the gas oven's electricity use. Almost all new gas ovens use electricity to ignite the main burner. Electric ignitors are familiar components on furnaces, clothes dryers, and the burners on ranges. They consume tiny amounts of electricity. But oven ignitors are different: they draw over 350W and they operate all the time the oven burner is on. As a result, the oven ignitors consume significant amounts of electricity (much to the consternation of Bob Hammond). In fact, a gas range may use more electricity to cook small items (like a potato) than a microwave oven!

These electricity-intensive ignitors are not necessary because more efficient alternatives are available. Apparently stove manufacturers selected the 380W glow bar ignitor because it was cheap, very reliable, and complied with California (and later, federal) efficiency standards outlawing standing pilots. In addition, appliance manufacturers probably recalled a catastrophe they experienced with an earlier electric ignitor for commercial clothes dryers in which nearly half of the units failed.

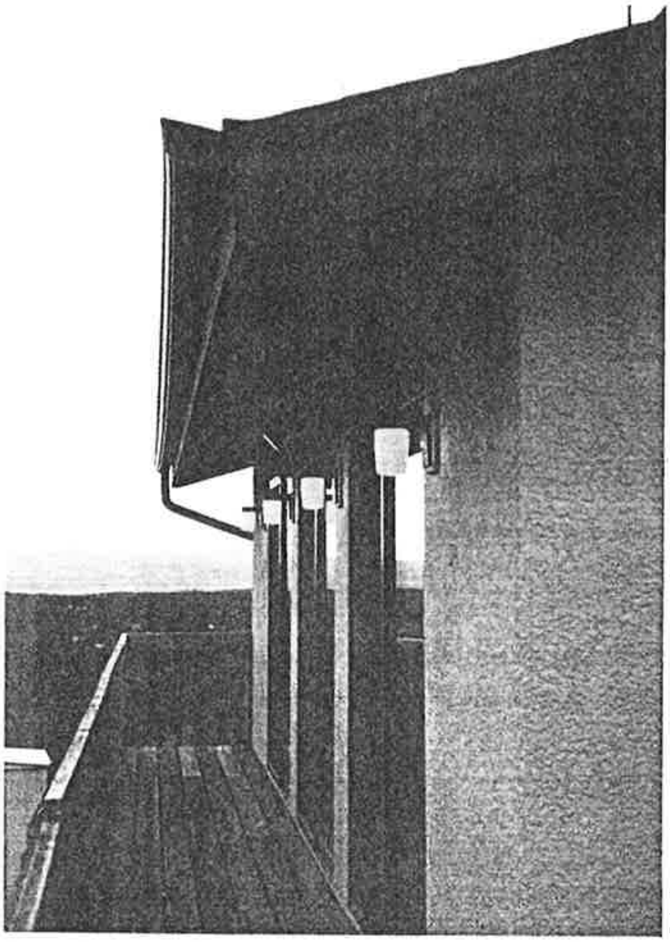
An intermittent ignition, a device which turns the ignitor off once the burner is lit, would cost oven manufacturers about an additional $20, which translates into about a $50 increase in the oven's retail price. Obviously the payback time for this design change depends on the price of electricity and the number of baking hours. Nevertheless, the extra cost should be recovered in 4–7 years. In the highly competitive appliance market, manufacturers have been reluctant to add $50 to the price of their products for no visible reason. There is a good chance that federal appliance efficiency standards will close this loophole in future revisions. The requirement will probably not cause the price of ovens to rise $50 because the cost of ignitors will fall as economies of scale are exploited.


Bob Hammond

A "hidden" load, the glow bar in this oven-range consumes 400 W continuously, both during ignition and while the flame is burning, a fact not addressed in the product literature.

When the 380W glow bar disappears, one more miscellaneous use of electricity will disappear with it.

— Alan Meier



Bob Hammond

Every element of the stand-alone house is designed with energy conservation in mind. South-facing windows function as a daylighting tool, reducing interior lighting needs. A deep roof overhang regulates the solar gain during hot summer months, and exterior lights are compact fluorescents which use less energy than standard bulbs.

There are a few 40W and 60W incandescent lamps, but these are placed in low-use areas such as closets. Lighting uses only 4% of total electrical consumption.

Low Loads

Recognizing the importance of energy efficiency in stand-alone homes, Hammond selected loads based on maximum efficiency rather than first cost, even though energy-efficient users typically cost 2–5 times more than conventional ones. Energy-efficient loads allow for a smaller, and therefore less expensive, PV system. Their long-term economic benefits far outweigh initial cost.

For example, realizing that the refrigerator would be his biggest energy user, Hammond selected a 16 ft^3, manual defrost SunFrost unit. Although it cost $2,228, it uses only 257 kWh year (based on full-time occupancy), about one-sixth the consumption of a conventional unit. "I never imagined I'd spend that much on a refrigerator," he recalls. "But, I discovered that it makes perfect economic sense for this house." (Data collected for the PG&E study showed that the SunFrost's actual energy use was 25% higher than the company's published data, but still considerably less than a conventional unit.)

The gas oven-range and the water heater use propane gas. "I use very little propane," Hammond says. "If I lived there full-time, propane would cost less than $100 a year." The home does not have a washing machine or clothes dryer, reducing total energy requirements by 10–20%. However, Hammond does plan to install both appliances in the future.

Nary A Drop Wasted

Since the home is also not connected to a public water system, water conservation is an equally important issue. PG&E concluded that reducing energy consumption to the level that Hammond accomplished is more practical in new construction than retrofit, but that water conservation is universally practical.

Initially, household water was hauled by truck and stored in a 1,200 gal cistern, at a cost of about 7¢ per gal. In March 1990, Hammond installed a system to collect rainwater from the roof, which is stored in the cistern and ultimately filtered and used for all household purposes except drinking. One in. of rainwater provides about 748 gal of water. Water from the cistern is gravity-fed to a 0.5 hp pressure pump, which then supplies water to household fixtures. The pump's energy consumption is negligible at only 47 kWh per year.

To reduce water consumption (as well as the electricity used to power the pump) significant water-conservation devices, such as a low-flush toilet (1.4 gal per flush), and low-flow showerhead (3 gal per min), were installed. To further reduce consumption, however, occupants turn the showerhead off while lathering, resulting in a 3-gal shower.

These devices, coupled with prudent use of water overall, washing dishes only once a day, and washing laundry at a commercial laundromat, for example, reduced consumption to 9.8 gal per day per person, compared to 80–100 gal per day in a typical home. Nearly one-third (3.2

Bob Hammond

The SunFrost refrigerator installed here above a kitchen cabinet uses one-sixth the energy of a conventional unit. Although it is the most efficient model available, the requirements of this stand-alone house were stringent enough to demand a few consumer alterations such as this cookie sheet condensation pan. (SunFrost recommends drilling a hole in the cabinet, attaching tubing to the hole, and running the tubing into a jar to collect the condensate.)

gal) of this water is used to flush the toilet, amounting to about three flushes per person per day, which is accomplished by not flushing each time the toilet is used.

Lines that supply water to the fixtures are quite long in the three-story house, and a considerable amount of water (nearly 1 gal) was wasted before becoming hot at the tap. To eliminate this waste, Hammond incorporated a closed-loop circulating system, which keeps hot water circulating through the system by a thermal siphon so that hot water is immediately available. All hot water lines are heavily insulated with rigid foam and fiberglass to eliminate heat loss.

"There is incredible incentive to conserve water," Hammond says, "because if my cistern runs out, the water is gone. Then I'd have to haul it again." And, at 7¢ per gal, it can get pretty costly.

The Stand-Alone Home.

R. Stover

System Knows Its Limits

Managing loads in a stand-alone home is as important as selecting them. "It's a matter of survival," Hammond says, "because without a backup generator, when my batteries are out of juice, I am out of everything. For example, I can't pump water and I have no lights." Understanding the PV system's limits and managing loads accordingly not only keeps electricity consumption to a minimum, but also keeps the inverter from tripping off when the load becomes too heavy.

The 2,000W inverter can deliver 1,200W of continuous power, or 2,000W for 20 min. Since base, or continuous, loads account for about 35% of total energy consumption, remaining loads must be carefully managed to stay within the system's limits.

The house has all the conveniences of a conventional home, including appliances, entertainment equipment, office equipment, and power tools. Out of necessity, Hammond learned quickly which appliances and equipment can—and cannot—be used simultaneously. He discovered, for example, that occupants can't use the 1,200W microwave and the 1,100W toaster at the same time.

Paying For The Sun?

Idaho Power Co. predicts that the market for photovoltaic (PV) electricity generation will continue to grow, and plans to become a player. To learn about the technology and its products, and to expand customer service by providing electricity to remote homes, the utility launched a pilot PV program.

The utility has allocated $5 million to design, build, install, and maintain PV systems for its customers. In return, customers pay 5% of the system's total cost, and a fixed monthly lease fee equal to 1.6% of the system's cost. Idaho Power's John Wennstrom says the monthly fee could run $50–$800 per month, depending on the equipment installed. An average residential system costs about $10,000.

Everyone in the Idaho Power service area is eligible for the program, but because constraints on some sites make PV inappropriate, each potential site is extensively analyzed—including an evaluation of energy uses and recommendations to reduce the electrical load as much as possible—to ensure that a PV system is both technically and economically feasible.

While most inquiries have been for remote homes, grid-connected customers have also expressed interest. "Their reasons for doing this are not economic," Wennstrom says. "They are buying for insurance reasons, to make sure they have power in an emergency." Undoubtedly, though, those who participate in the program will find it useful to go down the conservation path taken by Bob Hammond, described in the accompanying article. Interested customers may also find that energy savings in the long run make it a viable option.

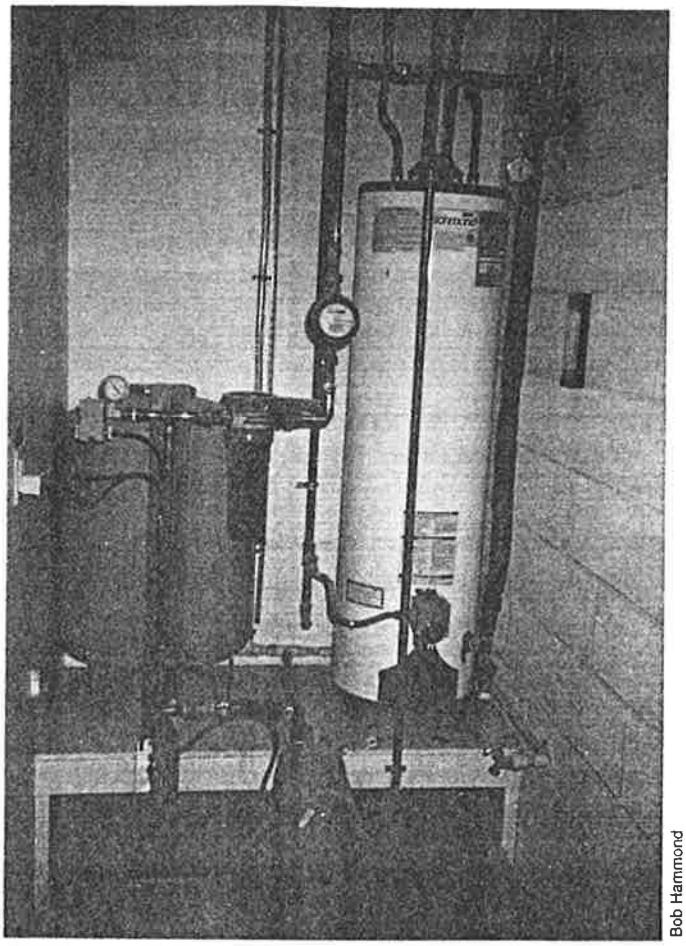
The three-year pilot program began in early January. Within a month, more than 150 customers inquired about it, and six systems were in progress, with construction expected to begin this spring.

Courtesy of Idaho Power

The Idaho Power photovoltaic (PV) program helps customers in remote locations take advantage of a less expensive option for electricity—solar collection. Construction is under way here on a PV array for a water pumping system for a cattle ranch, designed to process over 10,000 gal per day.

Energy Diet of a Stand-Alone Home

Energy User	Capacity: Rated (W)	Capacity: Monitored, steady(W)	Average Daily Usage: Hours in use(hr)	Average Daily Usage: Watt-hours per day(Wh/d)	Average Daily Usage: Part of total(%)
120 V_{AC} loads					
Lamps					
Two 13W fluoresecents	15	11	3	33	1
Five 18W fluoresecents	20	20	3	60	3
Two 7W incandescents	7	5	0.5	2	0
Six 40W incandescents	40	36	0.1	4	0
One 60W incandescent	60	59	0	0	0
Hair dryer (High)	1,200	0	0	0	0
Coffee pot	825	798	0.1	80	3
Toaster	1,050	1,110	0.1	111	5
Gas range, self-cleaning	1,200				
Clock-control		3.1		See small continuous loads	
Ignitor		0.6	0.1	0	0
Glow plug	400	398	0.1	40	2
Microwave	1,200	1,243	0.1	124	5
Clock-control		3.6		See small continuous loads	
Computer	150	61	2	122	5
Printer	180	11	0.3	3	0
Fascimile	140	13	0.2	3	0
Switch	8	2.0	0	0	0
Telephone	10	4.2		See small continuous loads	
Television	95	58	0	0	0
"Off" (remote control)		6		See small continuous loads	
Radio	15	3.6	0	0	0
Vacuum	1,080	818	0.1	81	3
Fan (High)	288	252	0	0	0
Shop tools	246–1,440	151–841	0.2	99	4
Battery charger	35	2.8	0.2	1	0
Water pump, 0.5 hp	373	1,280	0.1	128	5
Subtotal				**891**	**36**
Small continuous loads (base load), 27W total:					
Gas range clock-controller		3.1	24	74	3
Microwave clock-controller		3.6	24	86	3
Clock, bedroom	5	2.4	24	58	2
TV, "off"		6	24	144	6
Seven ground fault circuit interrupters		4.9	24	117	5
Inverters		7	24	169	7
Subtotal				**648**	**26**
0–12 V_{DC} loads					
Security system	0.8	0.6	24	14	1
AH meter, insolation	2.5	2.6	24	55	2
Data aquisition system	1.7	0.5	24	12	0
Radio		3	24	72	3
Subtotal				**153**	**6**
12-24 V_{DC} loads					
AH meter, 24 V_{DC} loads	2.5	2.3	24	55	2
AH meter, refrigerator	2.5	2.3	24	55	2
Subtotal				**110**	**4**
0-24 V_{DC} loads					
Refrigerator					
Freezer	64	66	6.5	429	18
Refrigerator	64	68	2.8	190	8
Lights, stairs		0.4	24	10	0
Battery equalizer	0.3	0.02	24	1	0
Voltage regulator					
Two required, relay closed	2.1	2.1	12	50	2
Data for each, relay open	0.2		0	0	0
Subtotal				**680**	**28**
TOTAL				**2,482**	**100**



A 0.5 hp pressure pump and filtering system, *left*, allow residents to use rainwater for all household purposes except drinking. Note the deliberately unblanketed water heater. Since a wood-burning stove provides the only heat in the house, the pump room can get somewhat chilly, and the extra few degrees of heat from the unblanketed water heater insure that the temperature in the pump room never drops below freezing.

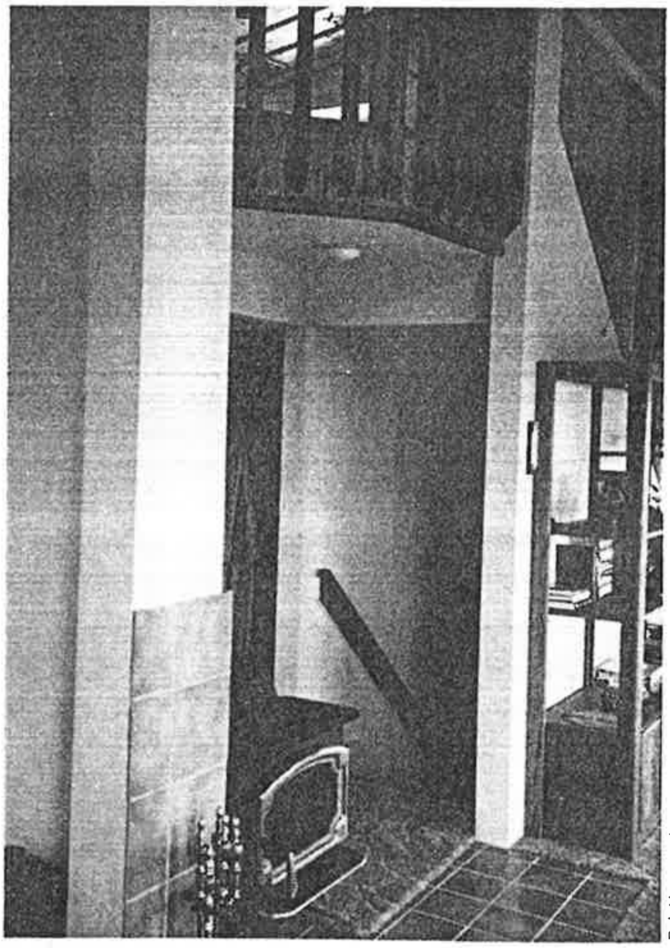
Load management, he says, has become a way of life. And his efforts have paid off—he has never gone without electricity.

Base loads consist of inverter losses, remote-controlled television (while turned off), microwave oven clock-controller, gas range clock-controller, radio, clock, voltage regulators, security system, lights, battery equalizer, and ground-fault circuit interrupters. In gathering energy consumption data, Hammond discovered several "hidden" base loads that, while often undetected in grid-connected homes, can contribute significantly to energy consumption in a stand-alone home. For example, remote-controlled equipment such as television sets and video cassette recorders contribute to the continuous load even when they are turned off because the equipment must be "on" in order to read signals from the remote controls. His television, when off, accounts for 6% of daily electricity consumption. Similarly, ground-fault circuit interrupters, which are required by code in bathrooms, kitchens, and outside electrical outlets, account for 5% of total consumption, or 43 kWh.

Even though it is propane-fired, the oven-range constitutes a significant load because of its "glow plug," an electronic ignition device that consumes 400W continuously when the appliance is operating (this information did not appear in manufacturer's product literature). Consequently, Hammond uses the oven during daylight hours to minimize battery discharge (see "One More Miscellaneous Energy Use").

Lifestyle of the Conservationist

Living in a stand-alone home has meant a few lifestyle changes for Hammond. He uses energy-intensive equipment during daylight hours (except on cloudy days) to minimize battery cycling. Since the batteries are generally fully charged by 10 a.m., "excess" electricity can be used directly from the PV array. He turns his fax machine off after business hours, and avoids unnecessary loads such as night lights during the day. Dishes are washed once a day, and the shower is turned off while lathering. Minimal energy and water consumption has become the rule.



Open architecture allows air to flow freely, thus eliminating the need for fans or other circulation devices.

Hammond says his lifestyle changes were "insignificant" in terms of adapting to a stand-alone home. Instead, the major adjustment involves economic issues related to remote living. The lack of an infrastructure and common services, such as utility service, mail delivery, and road maintenance, coupled with the high cost of food and other products and limited income opportunities, make remote living expensive.

Seven Dollars Per Month

According to PG&E's data, Hammond's house uses 2.34 kWh per day, or 855 kWh per year. Hammond says that if his house were connected to a utility grid, his electricity bill would be an enviable $7 a month (based on a rate of 10¢ per kWh and on full-time occupancy).

Hammond believes his experience can benefit grid-connected and stand-alone homeowners alike. Energy-efficient design, conservation, and load management make sense universally. "Everyone," he says, "can benefit from learning to become frugal with power without sacrificing comfort."

Overall, Hammond is quite pleased with his home. While boasting low electricity and water consumption, it offers a very comfortable living space. He's so pleased, in fact, that his next project will be to duplicate the house in Phoenix. ■