Toast, Pancakes & Waffles

PLANNING WISELY FOR OFF-GRID LIVING

by Allan Sindelar
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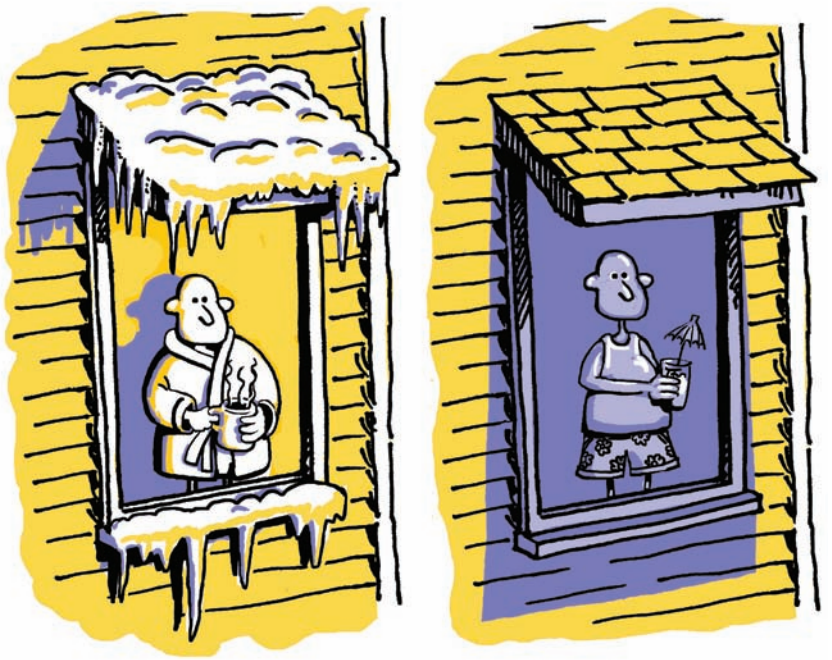
Living well on a small and finite amount of electricity is not mysterious or difficult. It starts with careful adherence to three basic principles:

1. Shift inappropriate loads to other forms of energy.
2. Reduce waste through efficiency, and increase conservation.
3. Use energy in proportion to the amount available.

The average home here in New Mexico uses 600 kWh of electricity per month, or about 20 kWh per day. This works out to a bill of about $50 per month, plus base charges. By comparison, a 1 kW PV array in a modern off-grid power system produces about 5 kWh per day in summer and a bit less than 4 kWh per day in winter. This is less than 25% of the amount of electricity used by the typical home. Yet for plenty of off-grid homes in New Mexico, a 1 kW system yields more than adequate power to run all of the lights, appliances, and electronics that make a comfortable life.



All forms of energy are not created equal. Electricity is a specialized, high-quality form that is not suited to all applications, but great for some: lights, electronics, and motors, plus a few other specialized uses.

A load analysis—a systematic and methodical listing of everything you expect to power in your home—has always been an essential part of off-grid power system design. For each load, the expected power consumption and hours of use are listed. (For information on completing a load analysis, see the "Assessing Loads" sidebar.) There are no one-size-fits-all solutions—each off-grid system is uniquely designed to its site, loads, budget, and the personal wishes of its owners.

Shifting Loads

All forms of energy are not created equal. Electricity is a specialized, high-quality form that is not suited to all applications but great for some: lights, electronics, and motors, plus a few other specialized uses. By matching the best form of energy to its appropriate use, electricity consumption can be greatly reduced while enhancing comfort and convenience.

Five common uses of electricity in conventional on-grid homes won't typically show up in an off-grid home. Each consumes too much energy to be appropriate when the supply is limited by typical PV system costs. All five of these use electricity in ways best served by other forms of energy.

Space Heating. Electricity may be used to run thermostats, pumps, and boiler controls, but in an off-grid system it is not usually turned into actual heat. The sun's heat is best used directly. Build or retrofit your home to hold in as much heat as possible by maximally insulating the structure's walls, ceilings, and/or attic spaces, and floor. Seal gaps and cracks well. If you're building a new home, incorporate passive solar strategies by using properly sized south glazing and plenty of thermal mass. If you have or are planning in-floor radiant heat, active solar thermal collectors ("solar heat") can be installed to decrease or avoid boiler use. Otherwise (or in addition), plan to use wood or propane heaters to provide space heating.

Water Heating. Use the sun directly to heat your water with a solar hot water system and use a high-efficiency propane water heater as backup.

Tankless gas water heaters are an option for some homes. However, in areas where hard water predominates, the cost and hassle of the increased maintenance and repairs due to scaling buildup tend to offset potential energy savings. Tankless water heaters use multiple small tubes to heat water quickly. The minerals build up in the small passages, decreasing the unit's efficiency.

Assessing Loads

A load analysis is a listing of everything you expect to power in your off-grid home with the power consumption and hours in use summed and averaged to estimate normal daily energy consumption. For most off-grid homeowners, a load analysis should reflect winter living habits, when consumption is greatest.

It's a rigorous and time-consuming process, but necessary. For system designers, it serves four purposes:

1. Lists and quantifies actual loads, so the system can be sized to meet the home's needs.
2. Helps identify ways to use less energy to achieve the same result, which can reduce system size and cost.
3. Helps identify overlooked or inappropriate loads, potential problems, and special cases, so that alternative ways of achieving the desired results, while using less electrical energy, can be suggested.
4. Serves as a document of record. That is, if a system proves insufficient in the future, a record was kept of how much energy use was expected. Actual consumption can then be reevaluated, and loads reduced or the system expanded.

For the client, a fifth benefit arises that is really the most important of all: a valuable self-education process. Most of us who have lived with utility power have taken it for granted: We use it as needed and pay the bill each month. We have had little reason to know how the energy is used: how much and for what. The load analysis process is an excellent consciousness-raising activity. By understanding how and where you're using solar electricity, you are far more likely to be satisfied with your power system—and its limits and blessings—over the many decades you will own it.

Many PV system installers or dealers offer forms to help the load analysis process. For more information, read "Getting Started with Renewable Energy: Professional Load Analysis and Site Survey," available from *Home Power* Web Extras at www.homepower.com/webextras. Once you have an understanding of how to perform a load analysis, you can use an inexpensive measurement device, such as the Kill A Watt meter, which allows you to plug in any AC device and measure its power and energy consumption.

Cooking. Plan to use a gas range and oven, not an electric one. But beware: Many gas ovens use electric "glow-bars" that can draw up to 500 W continuously when the oven is on.

Also consider a solar oven, if your lifestyle allows. Many of the common-sense solutions to living well when you're off the grid are simply reapplying lost wisdom from days before electricity was taken for granted. For instance, a summer kitchen, often located outdoors in a screened porch on the north side of the home, allows for preparing summertime meals without overheating the home.

Clothes Drying. In most parts of the country, a solar clothes dryer (also known as a clothesline) or an indoor drying rack can be used year-round. To back up these strategies, however, your standard clothes dryer should use gas, not electricity, for heat.

Air-Conditioning. Space cooling is usually only needed during summer months—when more PV power is often available—but conventional whole-house air conditioning is still too large of a load. Good passive design—like having adequate overhangs to shade windows, having trees and shrubs shade the house, and using good ventilation strategies—can often eliminate the need for any mechanical cooling. Otherwise, fans and evaporative cooling ("swamp coolers") work well in arid climates. Ultra-efficient DC evaporative coolers are available that work very well.

Improve Efficiency

Efficiency is always the first step in reducing consumption. Efficiency expert Amory Lovins of the Rocky Mountain Institute calls this "negawatts"—energy not consumed is energy that does not need to be produced. A good guideline is that for every dollar spent on upgrading efficiency, about $3 to $5 can be saved on PV system costs. Here are some good ways to start reducing waste through greater efficiency:

Lighting. Compact fluorescent lightbulbs (CFLs) use one-third the energy of incandescent bulbs to generate the same amount of usable light. Modern CFLs have eliminated the flicker and harsh colors reminiscent of fluorescent lighting of years past, and will fit in most lamps.

LED technology also has rapidly advanced in recent years, and "bulbs" are now available, generally through online sources, to fit most lighting needs. LEDs typically use approximately 5% to 15% of the energy of an equivalent incandescent bulb, but are significantly more expensive than CFLs.

Consider task lighting rather than area lighting—focus light where it is needed, rather than lighting an entire room. Use multiple lights in different locations, switched separately. Being off-grid doesn't limit you to boring lighting. Plan your lighting to meet building code and functional needs with maximum efficiency. Then add decorative lighting wherever you wish—just control it separately, and use it with discretion and only when you have the energy reserves to afford it.

Refrigeration. A refrigerator is one of the biggest electrical loads in an efficient home and is often the single largest daily user of electricity in an off-grid home. Older conventional refrigerators consume two to five times as much electricity as the most energy-efficient new models.

Mainstream brands—like Amana, Maytag, and Kenmore—have become quite efficient in recent years and are affordable. However, the specific model must be carefully chosen, using Energy Star guidelines (see Access). The most efficient full-size modern units only use a bit more than 1 kWh per day,

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which will be reported on the yellow Energy Star tag—for instance, "This model uses 392 kWh/year."

Super-efficient refrigerators that sip even less energy are available, such as the Sun Frost or SunDanzer brands. But their designs are not quite as convenient as modern mainstream fridges, and they can be more expensive. However, in some cases, the difference in price can make up for the extra PV modules needed to power a mainstream fridge.

If you want a full-size freezer, plan to locate it in an unheated outbuilding or portal, shaded from direct sun and preferably placed in a relatively cool space. In a cold climate, a freezer located outdoors will use very little electricity in the winter. Again, choose the most efficient modern model available. Chest freezers use less electricity than upright models because they do not lose as much cool air when the door is opened. Also consider past approaches to keeping food: Home-canned preserves and vegetables can be a satisfying means of storing food without a freezer.

Clothes Washing. Front-loading clothes washers use far less electricity, water, and water-heating energy than conventional top loaders, and there are now many efficient models to choose from. But make sure to buy one from a store with a forgiving return policy: Some modern sine wave inverters are not compatible with high-efficiency, electronically controlled washers.

Computer. A laptop uses less energy than a desktop model, as it's designed to run on stored battery power. But desktop models with LCD monitors are getting more efficient all the time. An inkjet printer uses less energy than a laser printer. Plug peripherals into plug strips so you can easily turn them off when they're not in use.

Heating. If you plan to have central heat with full thermostatic control, it must be hydronic—meaning hot liquid.

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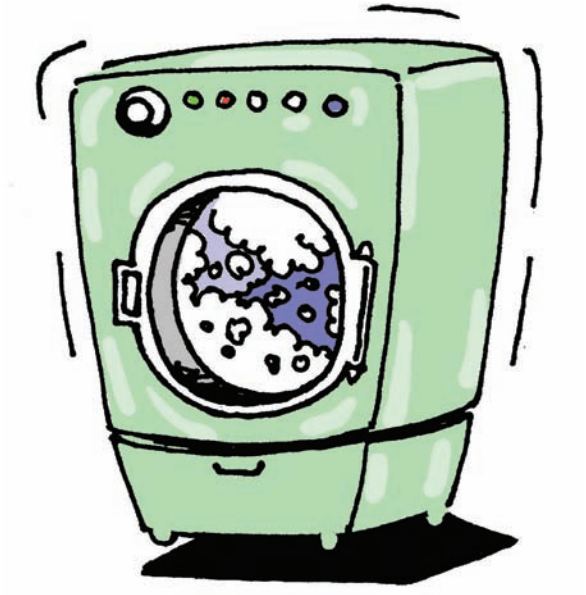
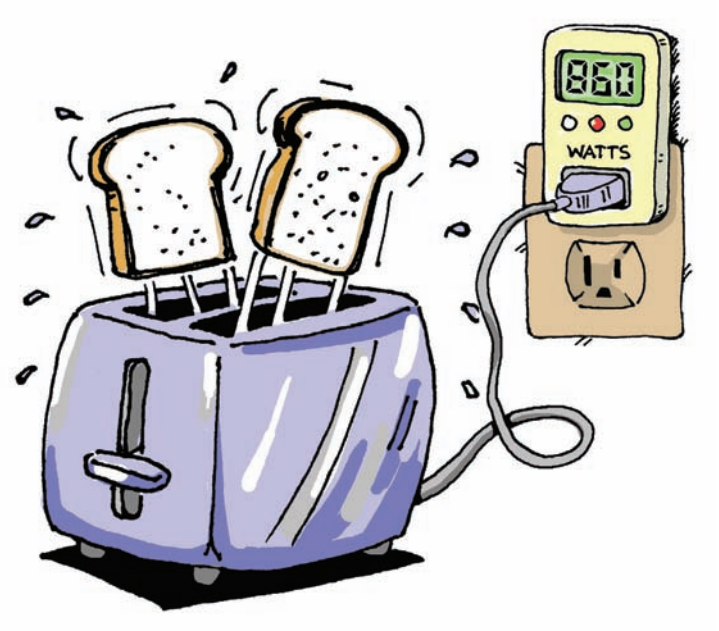
Either in-floor, baseboard, or wall-panel radiant is fine. A conventional hydronic system uses a substantial amount of electricity: Although manufacturers of radiant boilers and heating systems have put great effort into maximizing thermal efficiency, they've put less into electrical efficiency. For a home that is served by conventional utility power, the relatively low electrical demand of a conventional hydronic heating system is acceptable. In an off-grid home, however, a conventional hydronic installation will often lead to disappointing results. When a standard boiler system is installed in an independently powered home, the electrical demand of the heating system alone can exceed the daily output of the renewable power system.

Cost-effective modifications for controlling and distributing hydronic heat are available that use a fraction of the electricity of a conventional system. Larger-diameter tubing and multiple parallel loops allow smaller pumps to be used. A master thermostat that shuts off all power when





Toast, waffles, or pancakes: Off-grid living means not that we go without the energy that we need, but that we live more in tune with the natural rhythms around us.

the call for heat is satisfied reduces the phantom load. Since off-grid homes use batteries, smaller DC primary and zone pumps may be substituted for the single large AC pump and zone valves. A knowledgeable hydronic engineer who is familiar with low-head DC circulators—plumbed typically in a primary/secondary loop configuration—may be able to design an ultra-efficient system for your off-grid home.

Otherwise, gas space heaters or a wood heater are good heat sources, especially in a thermally efficient home. Pellet and corn heaters can be used off-grid, but their fans, feed screws, and electrical controls are in continuous duty during winter and can be significant loads. Interest in geothermal heat pumps is growing, but they are typically impractical for an off-grid home, since, like an air conditioner, the compressor requires a lot of energy. Total electrical consumption for these geothermal systems ranges from about 10 to 30 kWh per day depending on the climate, season, and home construction and size.

Phantom loads are any devices that consume small amounts of power continuously, even when they're supposedly turned off. To point out their significance, phantom loads account for about 6% of the entire residential electricity consumption in the United States. Any appliances that include a remote control or have an internal power supply are probably phantom loads: stereos, TVs, DVD players, most computers and peripherals, and the AC adapters ("wall cubes") used with many small appliances.

The only way to eliminate a phantom load is to physically or electrically unplug the device from its outlet. These loads can be plugged into a power strip, which is turned off when not in use. When building or remodeling, add switches to conveniently control outlets intended for known phantom loads, such as audio/video equipment. A tip: Battery-powered clocks work just as well as the plug-in kind.

Off-Grid Design & Discretionary Loads

Off-grid home power systems are usually based on winter needs, since winter loads are typically greatest. Shorter, colder days mean more indoor activities and increased use of lights, and most homes will have added heating loads. Shorter days also mean less solar energy collected. A well-designed home power system in a sunny climate will typically meet 80% to 90% of the home's winter base electrical load, usually with an engine generator making up the rest.

Note that just adding 10% to 20% more PV power capacity won't eliminate the need for occasional backup charging. Predictions of monthly solar irradiance are based on historical averages, and weather patterns never play by the rules of system design. Sometimes, weeks of bright winter sun—and full batteries—will prevail; other times, occasional long cloudy periods will necessitate running a generator to keep batteries charged. Plus, occasional equalizing (a controlled overcharge) of a battery bank is needed. A power system will need a substantially oversized array and battery bank to eliminate all generator charging, and most budgets don't allow this. Typically, the goal is to balance minimal generator charging, which will usually occur in winter, with a PV system that is sufficient to meet the majority of winter energy needs.

A PV system that is sufficient during most of the winter will provide an excess of charging power the rest of the year, when days are longer and loads are typically fewer. Herein lies a wonderful paradox of off-grid living: After going to the effort to live within the bounds of the system's reduced output in winter, you may have more energy available than you can use in other seasons.

This is part of the magic of off-grid living: The role of the PV array is to provide energy to fill the batteries. Once the batteries are full, the charge controller turns off the power from the array, as there's nowhere else for it to go. At this point, any energy not used is energy wasted. But as the investment in the power system has been made already and the sun's energy is free, it might as well be used.

A discretionary load is any power-using device that may be turned off or left unused when cloudy weather hits and/or the batteries are depleted. This is a normal and valuable aspect of the initial system design process. By identifying certain household loads as discretionary, the size and cost of the power system can be substantially reduced.

Common household loads identified as discretionary include toaster ovens, coffee makers, clothes dryers, and cordless phones. A microwave oven is a discretionary load, although most modern off-grid homes have one. It uses much less energy than a toaster oven, mainly because it runs for only a few minutes at a time. But because most microwaves have phantom-load clock-timers, they should be installed on a plug strip. When batteries have a low state of charge, use of these appliances should be curtailed.

Phantom loads like home audio/video equipment, chargers for cordless tools, and the like also may be considered discretionary: Put on a plug strip, they can be left on nine months of the year and turned off when not in use during the shorter days of winter. A modern large-screen TV and home theater system is discretionary if there's a smaller TV for use during winter. "Discretionary" also means that the appliance may be used during cloudy periods, but may mean using the generator a bit to supplement solar charging.

On a typical morning in my off-grid home, I will toast a bagel for breakfast. For me and for most people, toast is an important part of breakfast, a toaster is a basic tool of daily life, and toast is difficult to make any other way. And while a toaster draws a fair amount of power, its run time is just a few minutes.

During most of the year, I know that I can toast my bagel and do all of the other energy-using activities of daily life with the confidence that my batteries will be full by day's end—or, if that day is cloudy, within a day or two. In winter, though, I will check the weather report (and look out the window) in the morning, then check my system monitor to note how full the batteries are. On a typical winter morning when my batteries are at, say, 85% full, and I expect them to be at 100% by day's end, I enjoy my toasted bagel. If it looks bright and sunny outside, and I know I'll fill my batteries by 3 p.m., I may get out the electric waffle iron, knowing that the half-hour use of the electric iron will be easily handled by the day's solar input. But if it has been stormy for the last three days, my system monitor shows the batteries to be about 60%, and it's still cloudy, I'll make pancakes on the gas stove.

Toast, waffles, or pancakes: Off-grid living means not that we go without the energy that we need, but that we live more in tune with the natural rhythms around us. Appreciating that our electricity comes from the sun, we let our habits be defined by the daily and seasonal cycles of the sun's patterns where we live. By paying attention to such natural cycles, we greatly reduce our dependence on a fossil-fueled backup generator. In my home, we raised our kids for seven years with no generator (and, yes, a larger-than-usual PV array and battery bank). While we never ran out of stored energy, the kids knew that a few times each winter we needed to go into "conservation mode," using fewer lights, keeping the computer off, and eating pancakes more than usual.

Access

Allan Sindelar (allan@positiveenergysolar.com) installed his first off-grid PV system in 1988, founded Positive Energy Inc. of Santa Fe in 1997, and has lived off-grid since 1999. He is a licensed commercial electrician and a NABCEP-certified PV installer.

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