A MOTHER EARTH NEWS E-book exclusive

Solarize Your Home

A practical guide to solar design, building and power.



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Navigation Bar

Table of Contents



SOLAR DESIGN AND BUILDING

Build a Solar Home and Let the Sunshine In.....5
Learn the basic principles of building a passive solar house.

Go Solar and Save Big!.....8
Passive solar design results in huge savings on energy bills.

Super Solar Homes Everyone can Afford.....12
Superefficient solar homes are just the beginning. The ultimate goal is "net-zero-energy" homes.

Solar in the City.....16
This solar-powered green dream home presents a shining example of what every new house can be.



SOLAR HEATING AND COOLING

Simple Solar Heating & Cooling.....18
Even when you're remodeling, these energy-saving options should be your first choice.

Build a Simple Solar Heater.....20
This low-cost plan lets you turn any south wall into a source of free solar heat.

Buyer's Guide to Solar Heating.....24
Tap free heat from the sun with these solar hot-air collectors.



SOLAR HOT WATER

Save with Solar Hot Water.....27
Learn all about solar hot water heating and slash your water heating costs.

Go Solar for FREE Hot Water.....31
Solar water heaters are the easiest entry into renewable energy.



SOLAR ELECTRICITY

8 Compelling Reasons to Buy a Solar Roof.....35
Eight reasons why you should install your own solar electric roof.

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Table of Contents, Continued

Simpler Solar Power.....36
Grid-tied solar systems make choosing clean, renewable electricity easier and more affordable than ever.

Easy Solar Power.....40
Try new thin-film photovoltaic (PV) laminates to start generating solar electricity.

You Can Afford Solar Power.....43
Here's how to calculate the payback period for a photovoltaic (PV) system.

Eliminate Your Electric Bill: Go Solar and Be Secure.....45
You can install a solar photovoltaic (PV) roof, which will generate your electricity from the free, unlimited supply of sunshine.

A Simple Solar Solution.....48
Living off the grid is a cost-effective option when you have to pay big bucks to connect to utilities.

Easy DIY Solar Lighting.....51
Learn renewable energy basics and generate serious solar excitement!



SOLAR WATER DISTILLER

Water Wise Solar Stills.....55
Passive solar distillation is an inexpensive, low-tech alternative for pure drinking water.

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Build a SOLAR Home and Let the Sunshine In

By Dan Chiras



CATHERINE WANEK

If you're planning to build your dream home someday, this article could save you thousands of dollars.

Millions of homes easily could be designed to capture free heat directly from the sun. But instead we are burning — wasting — huge amounts of oil and natural gas every winter. The missed opportunities to tap into solar energy are so fantastic they boggle the mind, and nowhere is our blindness to the potential of solar more troublesome than in the home-heating arena.

You can incorporate passive-solar heating in any style home. Or you can add solar features when remodeling an existing home, as long as the south side of the house receives full sun most of the day. When correctly designed, solar homes provide unrivaled comfort in winter and summer. They offer large, south-facing windows, generous views, sunny interiors and open floor plans.

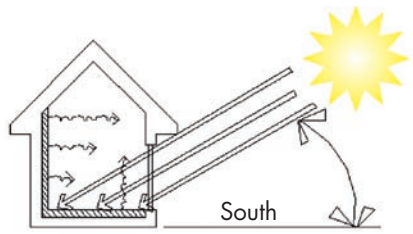
Architect Debbie Rucker Coleman, who has been designing solar homes since 1985, says her clients are impressed with how spacious the sunlight makes the home feel. "In addition to low heating bills, passive-solar homes are cool in summer. They are delightful places to live," she says.

Coleman's drawings (Page 6) show how two conventional house styles could easily become passive-solar homes.

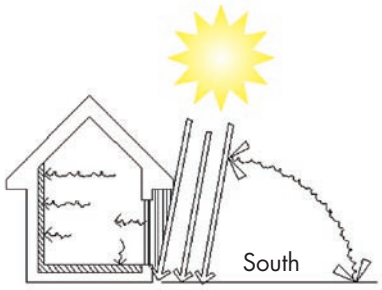
HOW IT WORKS

Heating homes with sunlight, known as passive-solar heating, is based on the simple idea of using south-facing windows to admit low-angled winter sun. Sunlight streaming into the home warms the interior space. Thermal mass, such as tile floors and interior masonry walls, stores the sun's heat and releases it when room temperatures fall at night or during cloudy weather. Choose a house design that accommodates the right amounts of south-facing glass and thermal mass. Add careful caulking and ample insulation (usually slightly higher than building codes currently require), and you'll have a solar heated home that requires little or no heat from any nonrenewable fuel source. In the summer, a solar home's thermal mass and insulation, together with properly sized overhangs to shade the windows, keep the home comfortable and reduce cooling requirements.

Simply orienting a conventional house to the south will cut annual energy bills by at least 10 percent, saving thousands of dollars over a home's lifetime. Add a long south-facing wall of windows and some thermal mass and you easily can tap sunshine's free energy to meet 50 percent to 70 percent of a home's heating requirements. Do your homework or hire a solar architect to create a rigorous passive-solar design and you can reduce your energy bills by 80 percent to 100 percent. Given the probability energy costs will increase steadily in the coming



Low Winter Sun Shines Deep into Home



High Summer Sun Blocked by Overhang

ADAPTED FROM *ENERGETIC DESIGN*

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DEBBIE COLEMAN

To harvest free energy from the sun, just orient the long side of the house to the south, add more windows to the south side and pay attention to overhangs, as we've shown for this conventional ranch house and colonial-style home.

years, the long-term savings from a passive solar home could become very substantial.

UP-FRONT COSTS

According to Ron Judkoff, director of the Buildings and Thermal Systems Center at the National Renewable Energy Lab in Golden, Colorado, passive-solar features increase the cost of building a new home by anywhere from nothing to about 3 percent. (On a $200,000 home, for example, the maximum additional cost of incorporating passive solar heating might be only another $6,000.) Since many building codes now require much more energy-efficient windows, walls, ceilings and foundations than in the past, and you'll need a much smaller furnace or other backup heat source, passive solar frequently adds very little or nothing to the cost of a new home.

Judkoff bases his cost estimates in part on a series of case studies sponsored by NREL and the American Solar Energy Society, headquartered in Boulder, Colorado. Data on passive-solar homes were collected from a variety of locations across the United States. The study found the addition at cost of building a passive-solar home ranged from nothing to 3 percent, while the annual savings from passive-solar heating in the homes ranged from $220 in New Mexico to $2,255 in New Hampshire. Based on recent energy prices, a passive-solar home in a northern location could save you as much as $67,000 on heating and cooling costs over a 30-year period.

We all know energy prices are only going to rise. Some regions already have experienced sudden 100-percent spikes in natural gas prices. Major increases in natural gas and oil prices seem inevitable. Without an inexpensive, reliable fuel source, millions of homeowners who rely on natural gas and oil may suffer enormous economic hardship. So let's take another look at those estimated cost savings from the NREL and the American Solar Energy Society (ASES) case studies. If we assume a 5 percent annual increase in energy costs, the potential 30-year savings from a passive solar home jump to $141,400, quite a return on a maximum investment of just 3 percent of your construction costs. If energy prices increase 10 percent per year, the estimated 30-year savings in cold climates could be **more than $400,000.**

No one knows for sure how fast fuel prices will increase. But whatever happens, passive solar clearly makes fantastic sense from a financial standpoint. And the bonus is the environmental benefit of reduced air pollution. Coleman estimates that compared to the average home, her 2,100-square-foot solar home—with its average heating or cooling costs of $12 per month will save 574,410 pounds of carbon dioxide emissions over 30 years.

SOLAR DESIGN BASICS

Here are the basic principles to follow in designing a new or remodeled passive solar home:

1. Choose a site that receives south sun during winter. Obstructions to the south of the site, such as tall evergreen trees, buildings or hillsides, need to be kept at least 1.7 times their height away from the home. When in doubt, visit the site around December 21, when the sun is the lowest in the sky. The site should receive full sun from 9 a.m. to 3 p.m.

If you're choosing to build on a small lot, select one that is deep from north to south, to ensure good solar access. Locating the house's septic drainage field within the solar access zone is another strategy for maintaining good solar access, since that area will need to be kept clear of trees and shrubs, which would otherwise block the southern sun.

2. Choose a home design with few projections below the roof line and no porches on the south. Projections shade adjacent windows; porches on the south prevent the sun from entering. Porches on the east and west can be beneficial by shading windows from the hot summer sun.

3. Orient the longest wall of the house so it faces true south. Rectangular floor plans minimize the exposure of east and west walls to summer sun, which is especially helpful in hot climates. The front, back, or side of the house can be the south wall. (True south is not the same as the magnetic south shown by compasses. Check with a local surveyor's office to find out how many degrees to adjust from magnetic south.)

Can you deviate from a due south orientation? Sure, but you'll pay a price in dollars and thermal comfort. Straying from a solar-south design reduces wintertime heat gain and may increase summertime solar gain, leading to overheating.

The more rooms that have some south windows, the better. This helps eliminate the need for fans or ducts to move warm air from one area to another. Place rooms that require less heat, such as workshops, bedrooms and kitchens, on the north side of the house.

4. Maximize windows on the south side. South glass should be a minimum of 7 percent of the house's square footage for a sun-tempered home and a maximum of 12 percent for fully passive-solar designs. Don't go wild on windows. North, east and west windows should follow the "Window Allocation Guidelines." Exceeding the 12 percent guideline for south windows may cause the home to overheat in summer, and may allow excess heat loss from the windows during the night and during long, cold, cloudy periods.

Coleman recommends choosing south glass carefully for your climate. Many of the new low-emissivity (low-e) coatings reduce heat loss and gain, but for south windows you do not want glass that keeps out the solar heat. She recommends south glass that has a Solar Heat Gain Coefficient (SHGC) of at least 0.5. In warmer climates with properly designed south overhangs, uncoated double-pane glass is preferred.

5. Design the roof overhangs to shade windows properly from the high summer sun. Overhangs are key to successful solar homes. Judkoff says the exact geometry of overhangs is critical for balancing the need to admit maximum sunlight in winter and minimize solar heat gain in summer. Generally, the warmer and sunnier the climate, the deeper the overhang should be. A 2-foot overhang nicely shades an 8- to 9-foot wall in most locations. If overhangs aren't possible, use insulated shutters to keep out the summer sun.

6. Provide thermal mass (tile floors and brick or masonry walls) in the south side of the house. Mass absorbs and stores heat when sunlight strikes it or when its temperature is lower than the air temperature. As the room's air temperature drops below the mass' surface temperature, heat is released and the air is warmed. Temperatures indoors remain relatively stable and comfortable, despite dramatic oscillations in outdoor temperatures.

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The mass in floors, framing, wallboard and furniture is usually sufficient to accommodate the solar heat in sun-tempered homes. But when you build a full passive solar design with up to 12 percent south glass, you need to add extra thermal mass in the form of tile, concrete floors, or masonry walls or planters. For optimal results, some mass should be in direct contact with the incoming sunlight throughout the day. The mass also should be distributed throughout the house. Add about 7 square feet of 4-inch-thick mass for every 1 square foot of south glass above the 7 percent minimum. One easy, inexpensive way to add this mass is to choose a concrete slab-on-grade foundation.

In addition to these solar design factors, follow these two principles that apply to all energy efficient homes:

7. Insulate and seal the structure well. Careful attention to detail is essential. Insulation should not be compressed and air should not leak in. If you can't get as much south glass as you would like, adding extra insulation can result in the same overall lower energy consumption. Judkoff recommends insulating at least to the level prescribed by the International Energy Conservation Code or ASHRAE 90.2, which are region-specific recommendations for the building-envelope elements and mechanical systems. Choose energy-efficient windows and consider using insulated shades to keep heat from escaping at night (and to keep the heat out in the summer), especially in cold climates. Entryways separated from the main living space by an, inner door are especially helpful in preventing cold air from rushing in whenever the outside door is opened.

8. Correctly size the heating and cooling system. Many solar homes require almost no additional heat, so you will need a much smaller, less expensive heating system. A woodstove or natural gas wall heater may be sufficient, or you can connect baseboard radiators to your hot water heater. The insulation and thermal mass features of a solar home make it more resistant to summer overheating, and in some climates you may get by with using ceiling fans instead of air-conditioning.

HELPFUL DESIGN TOOLS

Many professional solar designers use powerful software like Energy-10, a computer program that allows designers to predict the energy performance of various building-design strategies, permitting a fine tuning of designs to achieve optimal comfort, performance and economy. (Energy-10 is available from the Sustainable Buildings Industry Council. See "organizations" right.) Designers also use a Solar Pathfinder, a device that allows a builder or architect to fully assess the year-round solar potential of a site in about 15 minutes.

Debbie Rucker Coleman prefers a simpler approach using *Passive Solar Design Strategies: Guidelines for Home Building* by the Sustainable Buildings Industry Council (see "Organizations"). "Most homeowners would be able to follow these guidelines, as the notebook is put together very well. I like the program because it tells you the percentage of your heating needs the sun is providing and lets you compare strategies such as adding insulation or increasing south glass. You can complete the work sheets manually or with the computer software version."

SIMPLE SOLAR SOLUTIONS

So what are the worst-case consequences if you follow the basic principles, but don't want to perform your own detailed energy analysis or hire a professional to do it for you? Less-than-optimal amounts of south-facing windows may require running an auxiliary heating system more, or may necessitate adding another log to the woodstove or putting on a sweater. Undersized mass will cause winter daytime overheating, which is easily remedied by opening windows.

A less-than-perfect passive-solar design can be remedied after construction. What you cannot easily change later is the basic shape, design and orientation of the house. That's why a well-insulated, south-facing structure is the essential foundation for a comfortable passive-solar home.

BOOKS AND PLANS

The Solar House: Passive Heating & Cooling by Dan Chiras

Sun-inspired Home Plans by Debbie Rucker Coleman Available from Energetic Design

The Best of Fine Homebuilding: Energy Efficient Building by Fine Homebuilding

Solar Energy: Today's Technologies for a Sustainable Future by Burke Miller

VIDEOS

The Solar-Powered Home with Rob Roy. An 84-minute video examining basic principles, components, set up and system planning for an off-grid home. Features tips from America's leading experts in the field of home power. Available from Earthwood Building School

ORGANIZATIONS

American Solar Energy Society Publishes Solar Today magazine and sponsors an annual national meeting. Also publishes an online catalog of publications and sponsors the National Tour of Solar Homes.

Center for Renewable Energy and Sustainable Technologies (CREST) Online source of renewable energy solutions.

Florida Solar Energy Center Offers design guidelines for building homes in hot, humid climates.

Alliance to Save Energy Excellent information on saving energy and money.

Northeast Sustainable Energy Association Green-building, clean-energy and sustainable transportation site.

National Renewable Energy Laboratory, Center for Buildings and Thermal Systems Key players in research and education on energy efficiency and passive-solar heating and cooling.

Sustainable Buildings Industry Council This organization has a terrific Web site with information on workshops, books and publications, and links to many other international, national and state solar-energy organizations.

Windows in Passive Solar Design

For optimum passive solar design, window placement should follow the guidelines below as closely as possible:

SOUTH-FACING WALLS: At least 7 percent to 12 percent glass

NORTH-FACING WALLS: No more than 4 percent glass

WEST-FACING WALLS: No more than 4 percent glass

EAST-FACING WALLS: No more than 4 percent glass

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Go SOLAR and Save Big!

By Clarke Snell



CATHERINE WANEK

Every homeowner needs to know that passive solar design results in huge savings on energy bills.

Great news! You have free access to a source of energy that can save you thousands of dollars on your home's heating and cooling bills. You can harness this eco-friendly energy source using inexpensive, readily available technology, and it comes with a lifetime guarantee.

The energy source is the sun, and the technology is *passive solar design*—the conscious manipulation of building temperature by using the sun's direct energy. If you are planning to buy a new home or remodel your current residence, put passive solar design on your "must-have" list.

Everyone is already aware of some of the advantages of solar design: We all appreciate the coolness of a shady porch or patio in the summer, or the warmth of a sunny window in the winter. But most people are not aware of the huge difference solar design can make in the amount of energy needed to heat and cool our homes. In most situations, a well-designed passive solar home stays cool in the summer without air conditioning, and in the winter it requires much less energy to heat. The combination of a woodstove and solar design is often enough to keep a house comfortably warm, even in very cold climates.

The best aspect of solar design is that if you're building or remodeling a home, you can incorporate it at little or no extra expense. With oil and natural gas prices rising, and power blackouts becoming more common, it now makes more sense than ever to take advantage of natural heating and cooling rather than depending on fossil fuels.

After all, we already heat and cool our homes with solar energy. That's because the fossil fuels we burn today are nothing more than stored solar energy. Plants captured that solar energy through photosynthesis, and then—over millions of years—heat and pressure transformed dead plants and animals into deposits of coal, oil and natural gas. I wish I had the biggest bullhorn ever made (solar-powered, of course) to broadcast this message: *There's a better way! Everyone should use solar design to save energy, save money and reduce pollution.*

LOCATION, LOCATION

In nearly every kind of climate, heating and cooling a building is a challenge. Maintaining a stable temperature for a tiny air mass (the inside of your house) is a difficult undertaking because of the constantly fluctuating temperature of a much larger surrounding air mass (the great outdoors). Unlike most other approaches, though, solar design makes the sun an ally rather than an adversary in this task; the key is adapting the design to the specific location where you live.

Building site. Two facts about the sun make solar design possible. First, the sun's path through the sky changes throughout the year. Second, this path repeats the same cycle every year. That's why for any given building site we

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know exactly where the sun will be during every season, so we can design our homes to capture the sun's heat in the winter and block it during the summer.

In northern climates where winter heating is necessary, the winter sun is conveniently lower in the sky, so we can point the majority of the building's windows toward that free heat source. The low angle of the sun allows a maximum of solar heat into the building through windows, which will then be absorbed by the floor and walls. In the summer, the sun will be higher overhead, so the roof can be designed to block much of the unwanted solar heat. (See "Solar Design for Cold Climates.")

In southern climates, where cooling is the main concern, the sun is higher in the sky year-round. This makes it even easier to use building elements such as roof overhangs or porches to block the sun and keep the building cooler. If you are choosing a piece of property to build on, you also can take advantage of hills, trees and other buildings to block unwanted summer sun and winter winds.

Building shape. The right shape also is important. In a climate with cold winters, houses that are long and thin on their east-west axis are best because they expose more wall surface to the south, where it will be warmed by the sun in winter. This building shape also helps houses stay cool in the summer, when the sun is higher in the sky, because it has little wall surface on the east or west sides, which will be most exposed to the sun's heat at this time of year.

But in a warm climate where summer cooling is the main concern, houses that are compact in shape are easier to cool than long, thin houses, because they expose less interior area to direct sun from any direction. (See "Solar Design for Warm Climates".) In the absence of natural features such as hills or shade trees, you also can use the shape of the house to shade living space by building an interior courtyard or covered north veranda.

THERMAL MASS AND GLASS

Designing to take advantage of the sun's position during the year has a huge effect on a building's temperature while the sun is out, but you'll also benefit from building a house with materials that store solar energy effectively.

Thermal Mass. Everything stores temperature, but some things store it better than others. Dense materials—such as stone, concrete, bricks and earth—are known as thermal mass, and they excel at heat storage. Walls and floors built with these materials act as heat sinks that help maintain a comfortable interior temperature throughout the year. This works because in any environment, heat will move from warmer to cooler objects.

In the winter, thermal mass located inside the house in front of south-facing windows will absorb and store the direct heat of the sun. After sunset, the mass slowly releases heat into the air to warm the building. During the summer, that same mass stays cooler because it is shaded by the roof and overhangs, and it pulls heat out of the interior air during the day. At night, when windows are open to allow cooler air inside, the mass releases that heat back to the air. A 4-inch thick concrete slab floor is a good option for thermal mass if you don't cover it with insulating materials such as carpet. Earthen floors also work well. Additional mass also can be added to interior

Solar Design for Cold Climates

These solar design strategies can be effective in a climate with cold winters and moderate summers. The greatest need here is winter heating, and the building will be oriented to the south.

1. Choose a building site with **no obstructions to the south** for complete access to the low angle of the winter sun. Another plus is a site with trees that can block prevailing winter winds, which are usually from the north.
2. Chose a design with **a long south wall** facing within 15 degrees of true south.
3. The house should include **ample thermal mass** (dense, heat-storing materials such as concrete or earthen floors). Consider building an **earth berm** on the north side for more thermal mass.
4. **Most of the windows should be to the south** for access to the winter sun. Minimize windows on the east and west sides and place very few in north walls.
5. Use **shorter overhangs over south windows** for better winter heat gain and ample overhangs over other windows for shading.
6. Cover windows and glass doors at night with **insulating shutters or insulated drapes** to prevent heat loss.
7. **Maximize insulation** in walls and ceiling. Use rigid insulation under the floor and around its edges.
8. Consider using a **dark roof surface** to pick up solar gain in winter.
9. **Mechanical ventilation** will probably be needed in winter; a heat recovery ventilator, which preheats incoming air, is a good option.
10. Consider a **porch or plantings to the west** to block afternoon sun in summer.



OLIVIER ROLLIN (2)

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walls, with the first 2 inches in depth from the surface doing the most good. Interior brick or cob walls, thick plaster on straw bales, or plastered drywall are all possibilities for interior thermal mass.

In some warm climates, thermal mass also can be used as a kind of dynamic insulation in exterior walls. In the desert, where it is very hot during the day and significantly cooler at night, many homes are built from adobe, cob, rammed earth or concrete. Heat absorbed by the dense walls of these homes slowly moves inward during the day. But before it has a chance to reach the interior, the sun goes down, and exterior temperatures begin to drop. When the outside temperature drops below the inside temperature, the heat stops pushing inward. This happens because heat always moves toward cold. The heat then moves back toward the outside, causing the wall to cool down.

On the other hand, thermal mass isn't always useful. For example, in a tropical climate where it is breezy, humid and shaded by forests, direct sunlight isn't the issue, so thermal mass wouldn't be an effective way to cool your home. In this case, solar design would focus on ventilation.

Windows and glass doors. The careful placement of glass doors and windows is the next step in tapping solar energy. To capture heat, you'll want to place windows and glass doors along the long south wall to allow the low winter sun to shine in. Be conscious that glass on the east, west and north sides will let more heat escape than it will collect from the sun during the winter. The most common passive solar design mistake is to use too much southern glass and not enough mass. Fortunately, a lot of information is available about how to compensate for variations of climate and design. Do your research and enlist the help of experts.

NATURAL COOLING

For summer cooling, you'll want to block direct sunlight, but open doors and windows to let in wind. Using air movement for cooling can be difficult to fine-tune because wind is the natural element that varies most from site to site. The most effective research you can do when building a home is to spend a lot of time on-site during different seasons to understand how the wind moves there, then place windows and doors accordingly. Still, many generalities apply. For example, window screens reduce air flow by up to 50 percent!

In the summer, the more shade you can create, the cooler your breezes will be. Large porches and roof overhangs over windows and doors are a good way to create shade. Of course, trees and other vegetation also create shade.

Plants around the house also provide evaporative cooling, a process by which hot air is cooled by taking on water vapor, in this case from the constant transpiration of water by plants. Various studies have shown that a large hardwood tree can evaporate 100 or more gallons of water a day, creating a cooling effect equivalent to 10 window-unit air conditioners running for 20 hours. This, too, is tapping solar power, which is fueling photosynthesis in the tree.

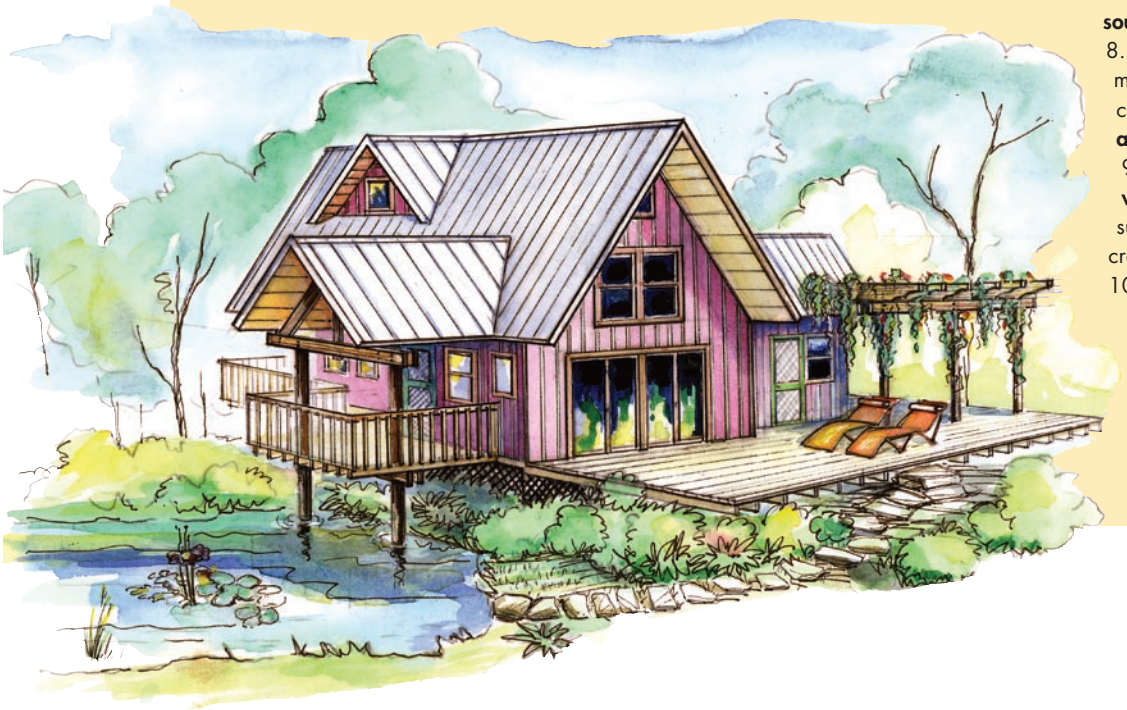
SLOWING HEAT MOVEMENT

To maintain temperature, we have to slow the inevitable movement of heat. Materi-

Solar Design for Warm Climates

These solar design strategies can be effective in a climate with mild winters and hot summers. Cooling is the main need, and more of the living space should be oriented to the north.

1. Look for a site where the house can be positioned with plenty of **outdoor living space to the north**. Another plus is a site with **trees to the east and west** to block morning and afternoon sun.
2. The house should be **compact in shape**, with less wall area exposed to the sun. Build shaded porches and patios.
3. Focus on outdoor living space to the north and east for cooking, sleeping and relaxing. Comfortable **shaded verandas** are inexpensive additions that make a house feel luxurious.
4. Take advantage of the cooling effects of vegetation by planning for **plenty of trees**, vines and garden space. Established shade trees are an invaluable resource — protect them!
5. Maximize **insulation** in the walls and in the ceiling.
6. For the roof, use a radiant barrier and **reflective metal or light-colored roof tile** and create air space between the roof surface and the sheathing.
7. If some winter heating is required, thermal mass, such as a concrete floor, and **windows to the south** can be used.
8. If using south-facing thermal mass for winter heating, use deciduous trees or a **vine-covered arbor** to shade it in summer.
9. **In arid climates, use thick walls** as a buffer against the sun. Minimize windows to increase this effect.
10. **In hot, humid climates with no winter, don't worry about thermal mass.** Lift the building off the ground over open crawl space to encourage air flow. Maximize window and door openings on all sides.



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als placed to slow the movement of heat are generically called insulation. However, heat moves in different ways, so insulation needs to be chosen based on the type of heat movement you're trying to prevent.

Light, airy materials such as fiberglass and straw bales slow conduction. Conduction is the transfer of heat from molecule to molecule through a material, such as the metal in a pot on a stove. It is best slowed by materials that form a complicated web that the heat must traverse. This is the principle behind most materials we normally label as insulation, including fiberglass, polystyrene foam and forms of organic cellulose such as cotton, straw bales and shredded newspapers.

Stopping air leaks slows convection. Convection is the transfer of heat by physically moving molecules from one place to another, such as the air that rises in a fireplace chimney. Many materials won't let air move through them: Wood, concrete and plaster, to name a few, allow basically no convective heat loss through their volume. Problems often arise, however, at joints between and breaks in these and other materials. Windows, doors, plumbing vents and electrical boxes are all potential convective weak points. Once identified, though, they can be sealed effectively. One huge source of convective air loss is opening the front door. This can be greatly reduced by creating an entry room, sometimes called an airlock or mudroom, that isolates the living space from the outside.

Reflective surfaces slow radiation. Radiation is the direct transfer of heat by means of electromagnetic energy: The sun heats the Earth through space with radiant energy. Heat absorption from radiation is best slowed by using reflective materials. How reflective a surface is depends on its color. A white surface is an effective reflector of light, but a poor reflector of heat. On the other hand, a shiny metallic surface is a good reflector of light and heat, but a poor emitter of heat. If you're trying to cool a home in the summer, a shiny metal roof does a good job of reflecting the light and heat of a sunny summer day away from the building, but at night a white roof will release the heat trapped in the attic more rapidly than a shiny metal roof.

MORE BENEFITS OF PASSIVE SOLAR

We've quickly outlined some of the basics of solar design, but they only begin to describe the benefits of living in a passive solar home. Here are a few other advantages of using solar design strategies.

Long-term savings. Ron Judkoff, director of the Center for Buildings and Thermal Systems at the National Renewable Energy Laboratory, says, "There is nothing intrinsically more expensive about passive solar construction. In fact, basically the same materials used to construct many modern homes can simply be rearranged to make a passive solar building."

Once built, passive solar buildings are cheaper to operate, so they will save you money—and lots of it—over the life of the building. "It's relatively easy in most climates to create a passive solar building that will use 30 percent to 70 percent less energy than a comparable nonsolar design," Judkoff says.

Attractive home designs. A common misconception about passive solar homes is that they are designed like space-aged cubicles. Older books on passive solar homes are full of wild, complex designs, including such things as retractable exterior walls and roof pond storage masses with movable nighttime covers. *Forget that stuff!* Passive solar homes can be designed to fit almost any style or aesthetic.

"Far from being limiting, passive solar design gives you a wealth of building elements to work with," says Greg Jackson, an architect and adjunct professor of sustainable design at the University of Kentucky. "Overhangs, roof articulation and a focus on the relationship between sunlight and glass all add visual interest to a building."

Buildings can be retrofitted. You don't need to have the perfect site or the opportunity to build a new home to take advantage of passive solar design, because you can make meaningful adjustments to an existing building. Any of the following can have significant effects on the thermal performance of your house: major work such as a complete solar retrofit; intermediate actions such as adding windows and an interior mass wall facing the winter sun; or simple do-it-yourself changes such as adding arbors with deciduous vines over windows and doors.

"Passive solar additions to existing buildings bring an excellent return on your initial investment," says builder and educator Marcus Renner of Appropriate Building Solutions. "A well-designed sunspace addition, for example, will cut energy bills by providing both solar heat and illumination. It will also create a cozy room that increases floor space and provides a great environment for plants. As if that weren't enough, all of these features add value to your house."

The bottom line. As heating and cooling costs rise and the scramble for dwindling fossil fuels escalates, it's time to tap the elegant, common-sense principles of passive solar. As corny as it may sound, we really can build a better world. The sun is shining down on us with the answer; all we have to do is soak it up.

Clarke Snell is a builder, consultant, writer and educator. He is the author of *The Good House Book: A Common-Sense Guide to Alternative Homebuilding*, and, with contractor and master builder Tim Callahan, *Building Green: A Complete How-to Guide to Alternative Building Methods*. You can contact him through his Web site, www.thinkgreenbuilding.com.

BOOKS

The Good House Book
By Clarke Snell

The Passive Solar House
By James Kachadorian

The Solar House
By Dan Chiras

WEB RESOURCES

Passive Solar Design
An overview of passive solar design strategies from the California Energy Commission.

Sustainable by Design
Advanced tools for calculating sun position, the impact of window overhangs and more.

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Super SOLAR Homes Everyone Can Afford

By Amanda Griscom Little



MARTIN PHOTOGRAPHY

Superefficient solar homes are just the beginning. The ultimate goal is "net-zero-energy" homes.

Superefficient solar homes are now available that reduce monthly energy bills 50 percent to 70 percent compared to comparable conventional homes, thanks to the design innovations of private-sector pioneers and the U.S. government's energy gurus. But these trendsetters won't be satisfied until they've perfected "net-zero-energy" home designs.

Net-zero-energy means the homes are superefficient, with much of their electricity produced by rooftop solar panels; they draw electricity from the grid at night or on cloudy days, but overall they generate at least as much energy as they consume each year. It's just a matter of time before such homes are truly affordable for the masses, according to Lew Pratsch, Zero Energy Homes project manager for the U.S. Department of Energy (DOE). Pratsch says that within the next decade, zero-energy homes could cost no more than comparable conventional homes. By 2020, he predicts, they could become the building-industry standard.

That's the exciting news emerging from the DOE-sponsored Building America program, which has built more than 26,000 homes as research projects. Zero-energy homes will incorporate the best energy-efficient strategies and renewable energy systems, and home designs will be keyed to regional climates. Right now, more than a third of total U.S. electrical use goes to heat and cool our houses and power the appliances within. Through the groundbreaking work of the DOE and commercial innovators, we can move steadily toward "energy independence" one home at a time.

"My feeling is we — and the leaders in Washington — should put zero-energy living up there with putting a man on the moon," says Jeff Christian, director of the Buildings Technology Center, which participates in the Building America homes program through the DOE's Oak Ridge National Laboratory (ORNL) in Tennessee. "Let's make it the grand challenge."

Today, anyone can have a zero-energy home by paying, upfront, roughly 10 percent to 20 percent more than the cost of a traditional home for renewable energy technology, which generally has a payback in energy bill savings of about 20 to 30 years. But the grand challenge is making solar homes affordable enough on the front end to become the norm in U.S. neighborhoods, rather than the exception. The goal, Pratsch says, is to lower the cost of such homes across the nation to the point that the expense of the zero-energy technology will be no higher than the monthly energy bill savings — therefore the added initial costs will cancel out. Over the long term, there will be additional savings once the mortgage is paid and the lower energy bills keep coming.

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ALLAN B. HUNT (2)

Above: Bethel Drive in Lenoir City, Tenn., where four solar homes are paving the way for energy-independent living. At right, two residents, Cotton Duncan and Becky Clark, show off their lowest-ever monthly energy bill: $11.90.

VOLKSWAGENS & CADILLACS

Net-zero-energy test homes have been built in dozens of cities along the East and West Coasts, where air pollution and electricity demands are the most intense, and where many states offer incentives for green building and renewable energy.

Steven Winter Associates, an East Coast-based green-building consulting firm, is overseeing solar home developments in Connecticut, Illinois, Maryland, Massachusetts, New York and Texas.

In San Diego, more than 100 large homes in the city's San Angelo subdivision are rigged with solar panels and a wide array of energy-efficient building technologies. Just up the coast on the shores of Clear Lake, Calif., a development known as Grand View Estates — composed of 90 solar homes — is under construction. At $230,000 to $330,000 each, the 1,400- to 1,900-square-foot homes are remarkably affordable considering that 10 years ago they would have cost at least 25 percent more to build in that location. Their affordability is largely due to the steady decline in the costs of energy-efficiency and solar technology.

The four homes Jeff Christian has built, on Bethel Drive in Lenoir City, Tenn., are much more modest in size — just 1,000 to 1,200 square feet — but they might offer the most convincing evidence to date that the dream of affordable net-zero-energy homes is on a fast track to reality. Collectively dubbed "Harmony Heights," the homes were constructed by Habitat for Humanity volunteers for about $100,000 each. That includes the cost of the photovoltaic solar system and factors in the labor provided by the Habitat volunteers.

At first glance, nothing about the homes, located just a few minutes from Christian's office, seems out of the ordinary. The houses are pleasant colonials with porches and shutters, and the lawns are strewn with bikes and soccer balls. Christian reveals, though, what makes them extraordinary: Each of these homes' total energy bills averages less than $25 per month!

"What we're trying to do is come up with the Volkswagen of net-zero-energy homes," Christian says. "All too frequently, the typical solar home is something more akin to a customized Cadillac." In other words, it features whiz-bang technologies, it simply isn't affordable for most of us.

Designing the "people's car" of solar homes, though, comes with challenges. "Because these are Habitat for Humanity houses, which are by definition no-frills, simple and affordable, we have to take minimum risks," Christian says. "We would love to use fancy controls and a lot more aggressive technologies, but we have to be disciplined and work within the realm of financial reason that makes sense for our occupants."

To find out exactly how well each technology they incorporate functions, the houses are equipped with dozens of sensors that monitor electricity consumption, temperature, humidity, carbon dioxide and hot-water usage. Christian regularly visits with the owners to learn about their experiences and perspectives on their homes, and updates his database daily with automatically collected data that chronicles the flow of electricity to appliances such as refrigerators, air-handler units, water heaters, compressors and inverters.

HIGHER-QUALITY HOMES

The Harmony Heights homes gain their ultra-low $25-a-month utility bills with the help of a long list of proven energy-saving features: airtight envelopes, Energy Star appliances, compact fluorescent light bulbs, HVAC distribution systems and low-emissivity windows, for starters. Christian's team also designed all the homes with passive solar principles in mind: Though they weren't able to position the front or back of the homes to face south, they put at least 70 percent of the windows in each house on the south-facing side. They also included extended overhangs above the south-facing windows to block light during the hottest hours of the summer, when the sun is directly overhead.

All the houses were built with structural insulated panels (SIPs), which are made of rigid foam sandwiched between two structural layers made of wood. SIPs are highly energy-efficient and cost-effective for walls and roofs, Christian says. He also is testing precast concrete walls that absorb and sequester heat to help keep the houses cooler in the summer and warmer in the winter, cutting down on cooling and heating demands.

The prefabricated SIPs have superior insulation value and are tightly joined, to form an airtight building envelope (for maximum energy efficiency). The houses all have a relatively simple ventilation system that maintains indoor air-quality to the high standards recently mandated by the American Society of Heating, Refrigerating and Air-conditioning Engineers. These ventilation systems filter outside air into the houses throughout the day and condition it in response to interior carbon dioxide, humidity and temperature measurements.

The homes also have "cool roofs" made of light-colored reflective materials or infrared reflecting pigments that allow darker colors to reflect heat like lighter colors. That keeps heat from being absorbed by the roof and conducted into the house, and can provide a 30-percent reduction in peak heat gain into the building during summer afternoons. Exterior wall panels also have special coatings to reflect heat.

"The result is not just energy-efficient homes, but higher-quality homes," Christian says. "They are healthier and more durable, with fresher air and more stable thermal comfort. They also have more natural lighting than you find in conventional homes today."

One of the biggest energy-saving features is the geothermal heating and cooling system. "It's hard to find much better energy savings than those from geothermal," Christian says. Over a roughly 20-year life span, a geothermal system would save a homeowner about 25 percent annually compared to fuel costs for a typical gas furnace. That estimate is based on current natural gas prices; as

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prices increase, the benefits of geothermal will be even greater.

Geothermal systems include a heat pump that taps the solar energy stored underground, where the temperature is relatively constant year-round. In the winter, using a heat-transfer fluid pumped through a labyrinth of pipes buried about 5 feet underground, the system warms the house. In the summer, the earth is colder than the air, and the system helps cool the house.

Geothermal technology is relatively new, and right now systems cost more up front than a gas furnace and air conditioner. So builders tend to install minimum-efficient furnaces, air conditioners and heat pumps to keep the initial costs of new homes down. But those systems will use more energy for the next couple of decades than geothermal would. In fact, the energy savings from geothermal systems are so substantial that even now the cost of the technology can be recouped in less than 10 years through lower energy bills.

According to Pratsch, geothermal markets are developing in more than a dozen states, including Kentucky, Missouri, New Jersey, Ohio, Oklahoma, Pennsylvania and Texas. In good markets, a basic geothermal system for a standard four-person home sells for roughly $8,000. Communities can help create markets for geothermal by organizing bulk purchases. "Once you have schools, office buildings or groups of homes making large-scale purchases — you have competitive bids, which lowers the [upfront] cost," Pratsch says.

Eventually, he adds, the economies of scale will kick in and the time it takes to recoup the initial cost of geothermal systems will become shorter and shorter — Pratsch predicts that by the end of the decade, geothermal will be much more affordable and common in markets nationwide.

ZERO-ENERGY SOLAR HOME KITS

The walls and roof on Christian's Harmony Heights homes were constructed with SIPs, which cut construction costs because they are so quick to erect. The envelope of the newest house was built in just two days. The bottom floor, a walkout basement, took only six hours and was assembled with premanufactured insulated concrete panels. The walls on the main floor are made of SIPs and were installed in five hours, and the insulated roof was up in just three hours. The solar system was installed in just one day. The final product totals 1,100 square feet with three bedrooms.

Christian's vision is a market-ready solar home kit, customized for each region: "We want to package the best-tested features and appliances, and make the whole home package available commercially to contractors and owner-builders."

He says these kits could be adapted to any style of home, be it a Cape Cod, ranch or colonial: "We're basically talking about bundling the concepts — airtight construction, panelization, mechanical ventilation, dehumidification and so on. These are all generic ideas that can fit into any style of home." These bundled concepts could even be applied to straw bale homes, he says, though it would require extra effort to assure durable airtight construction.

Different kits will be needed for different climate zones, Christian says. You can't put a home designed for Tennessee humidity levels and air conditioning demands in northern Maine, for instance. Different climates also justify different expenses — in northern climates, it is more reasonable to invest in a high-tech geothermal heat pump because it will yield more savings in heat bills; likewise in southern climes, it is more practical to invest in state-of-the-art central air for the savings in cooling and dehumidifying expenses.

LEARNING TO CONSERVE

Before Kim Charles moved into her net-zero-energy home at the end of the Bethel Drive cul-de-sac, she had seen solar panels only once — at Dollywood, Dolly Parton's theme park in Pigeon Forge, Tenn. They were mounted on the parking lot canopy to power its lights.

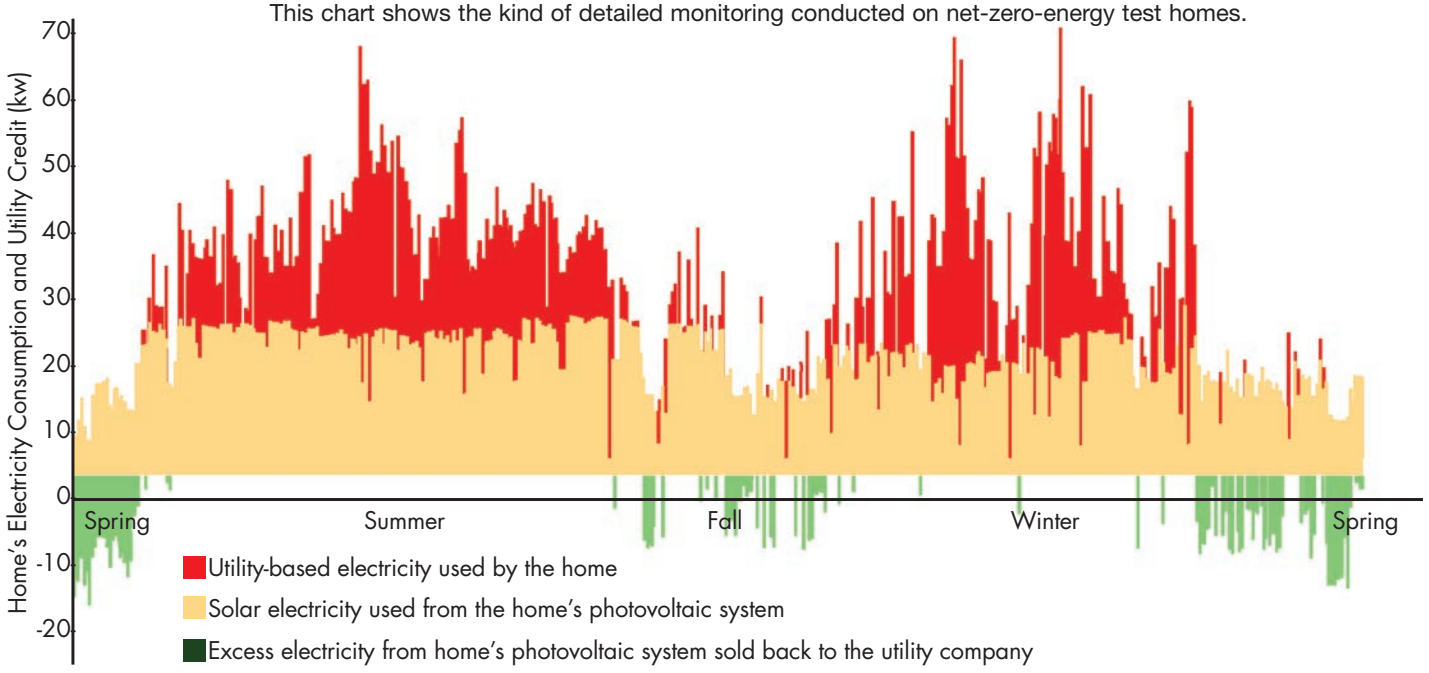
"I felt totally clueless going into this," Charles says. "At first, when we were getting all this attention with the media, I'm going, 'What is the big deal? What is so great about all this?' I didn't get the big picture. It took me a couple weeks to realize, wow, it's the first one of its kind."

Another fantastic first for Charles was studying her utility meter. As gratifying as it was to see it spin backwards on sunny days when her son and daughter weren't home and there was little energy demand on the house, Charles says it was even more riveting when she saw it hurtle forward, making her think about her family's energy usage.

"I'll never forget, I was on the back porch one evening, and I heard the clothes washer and dryer start," she says. "I looked at the utility meter and all of a sudden it started flying, but not backwards." It made her realize that laundry is one of her most energy-intensive chores. Charles admits she wasn't exactly mindful of energy efficiency before moving to Harmony Heights. "I used to think that electricity is like air — it's a given," Charles says. "I never really spent much time thinking about it."

Christian says there are advantages to working with people like Charles, who are previously unfamiliar with green building — it gives a realistic picture of mainstream habits — but no mat-

This chart shows the kind of detailed monitoring conducted on net-zero-energy test homes.



COURTESY NAHB RESEARCH CENTER, 2004

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Zero-sum Details

For more info on the Building America program's net-zero-energy homes, including building partners, contact:

ORNL Buildings Technology Center
www.ornl.gov/btc

Building America
www.buildingamerica.gov

For more info on the products and technologies discussed in this article, contact:

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ALLAN B.. HUNT

ter how technologically savvy a person becomes, mindfulness will always have to be a part of energy-independent living.

"To really get to net-zero, a certain amount of prudent practice in everyday habits is going to have to be a part of it," Christian says. "Lights being left on when nobody is home during daylight hours is sacrilege. This has to be about the best utilization of resources." Living in these homes, he says, will instinctively teach families to become more mindful. "It's just like when we garden — you're more in tune with what the sun is giving today."

THE UTILITY COMPANY PAYS YOU

In the case of Harmony Heights, the sun translates not into flowers or food, but into direct financial return: The homes have rooftop solar electric panels that create electricity whenever the sun is shining. When Charles' neighbor Becky Clark received her first electricity bill there, it showed a credit of $35 in one month. "We got paid!" she says, beaming. "It's like we're our own little power plant." At her old apartment, Clark paid nearly $200 per month for her combined utilities.

Price signals, Pratsch says, are a good way to change consumer behavior: "We're working with utilities on ways to give consumers good indications of time-of-use-pricing." It's much more expensive for consumers to use electricity at peak load times, which occur during the work day when businesses are buzzing, air conditioners are humming and energy demand is at its highest.

"We're trying to come up with user-friendly meters that could go in every home so consumers could have a real-time read-out of the cost of their electricity use," Pratsch says. "I can't imagine a better reminder to conserve." Even better, he adds, appliances and heating and cooling systems should be computerized, with "smart economizers," so that they automatically run at optimum times of the day to keep electricity costs down.

THE ZERO-ENERGY REVOLUTION

Why, you may wonder, would utility companies have any interest in cooperating with zero-energy home programs, thereby encouraging consumers to use less of their product? Because the demand for electricity over the past decade has grown faster than the utilities' capacity to produce it. That situation was dramatically illustrated by the August 2003 blackout: The largest ever in North America, it affected 50 million people in eight states and southeastern Canada.

"It's very expensive for utilities to invest in greater transmission line capacity to carry the growing electricity loads," Christian says. "And it's becoming increasingly difficult, especially in condensed urban areas, to find sites for new substations and transformers to generate extra capacity. So, investing in on-site generation that goes directly into the home without all that infrastructure makes good economic sense." Rooftop solar panels produce power during the afternoon and, along with other features of these homes such as continuous fresh-air ventilation and thermal mass, help reduce the utilities' peak demand.

That's one of the main reasons why the Tennessee Valley Authority (TVA), the local utility in the Tennessee Valley (which includes Lenoir City), agreed to help fund the ORNL project and has offered to pay a premium price for the solar energy from the Harmony Heights homeowners. In the last two years, TVA has initiated its own "Green Power Switch" program, which offers customers the option of paying a monthly premium for solar- and wind-generated electricity; more than 7,000 residential customers are now enrolled. The strong response encouraged TVA to launch another program called "Generation Partners," which offers homeowners the option of installing their own rooftop solar system or windmill, and selling the electricity generated back to TVA for 15 cents per kWh, more than twice the rate that TVA customers pay for traditionally generated electricity, but less than it costs the utility to install new, renewable generating capacity.

The more interest TVA detects among consumers, the more large-scale projects it — and other utilities — will want to finance, Christian says. This means if all goes well, we won't be moving toward energy independence just one home at a time — it will be one subdivision, one community, maybe even entire cities at a time.

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SOLAR in the City



Story and Photos by Catherine Wanek

This solar-powered green dream home presents a shining example of what every new house can be.

On a narrow lot in Capitola, Calif., stands a modest and inviting craftsman-style home. This not-so-big house fits into the quiet neighborhood, yet it is anything but ordinary. Its energy-efficient design features and solar technologies make this home a cutting-edge model of sustainability.

Stroll by this attractive house and the gleam of a rooftop photovoltaic (PV) solar system and solar hot-water collector will catch your eye. These systems, combined with passive solar design and superinsulated walls and ceilings, translate to rock-bottom energy bills. The home's 2004 average monthly energy bill from Pacific Gas and Electric Co. (which includes natural gas use and numerous administrative fees) was just $13.22. According to the company, the average monthly energy bill for customers in the same area is $83.

Homeowners Mark and Kristin Sullivan took full advantage of California's renewable energy incentives — namely net metering and generous rebates for grid-tied solar electric systems. The Sullivans paid $11,563 for their PV system, but after state rebates and tax credits, the net cost was reduced to $6,710. And because the house is grid-tied, the Sullivans did not need to buy costly batteries — the grid essentially functions as their backup power source. (For more information about grid-tied PV, see "Simpler Solar Power," Page 36. — Mother)

PASSIVE SOLAR, ACTIVE OWNERS

The home's primary means of saving energy is its passive solar design—specifically the concepts of "orientation, insulation, glass and mass." By orienting the main living areas of the house to the south, the low winter sun shines in and its heat is absorbed by the thermal mass of the floors and wall plasters. In the summer, roof overhangs and deciduous vines block sunlight from entering the house. The home's airtight straw bale walls and recycled cellulose insulation create a building envelope that helps the thermal mass retain heat or coolness, which releases over time, keeping the house at a comfortable temperature.

Passive solar design requires active owners — people who understand when to open and close windows and curtains for maximum comfort and energy conservation — and the Sullivans are prime examples. "When you live in a home that's run by nature, you're constantly aware of what is going on outside," Kristin says.

Mark and Kristin enjoy savings from energy-efficient appliances such as their clothes washer, dishwasher, stove and refrigerator. What's more, all their lighting fixtures have efficient compact fluorescent bulbs. Their entertainment appliances are plugged into power strips, so they can be completely turned off when not in use. This eliminates the "phantom loads" created by devices with remote controls and constant displays (such as a digital clock) even when they are turned "off." And instead of buying a clothes dryer, the Sullivans installed a retractable clothesline in the back yard. "Honestly, hanging laundry is fun, and it gives me an excuse to be outdoors," Kristin says.

BUILDING A DREAM WITH BALES

When Mark and Kristin met in 1983, they both dreamed of having a solar homestead in the country. But when the time came to build,

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The front door was a bargain find at a salvage yard.


The long, narrow plan of the home utilizes passive solar design.

they were quite happy in the city. They decided to look for a lot in Capitola, a quiet beach community near Santa Cruz, where they could walk to restaurants and bicycle to the grocery store. "It's energy-efficient to live close by the amenities you need," Kristin says. "We wanted to build in the city to show that you can bring sustainability there."

After searching for nearly two years, the Sullivans finally found their prize — a run-down bungalow on a narrow lot just blocks from the beach. The existing cottage was taken down, and the materials were set aside to be used for the new house.

Initially, the Sullivans were hesitant about straw bales — they had been told that bales are too bulky for urban building. They also had other common concerns about straw bale building — fire, bugs, mold and earthquakes. But after investigating their questions, they said, "Why not?" "With all my initial skepticism about straw bale, I never thought I would become a proponent of it," Mark says. "But straw bales covered with earthen plaster make a wonderful natural interior space."

They interviewed five architects with straw bale experience and eventually chose Kelly Lerner of One World Design. For the general contractor, the Sullivans chose Boa Constructor Building and Design, consisting of Michele Landegger and Debrae Lopes. The Sullivans also employed longtime friend Frank Schiavo to design their solar system.

Lerner asked the Sullivans to fill out a questionnaire before she began the design and floor plan. Then Lerner, Landegger and Lopes worked with the Sullivans to refine the two-bedroom, two-bath, two-story floor plan and the craftsman exterior.

Even though straw bales were not in Capitola's building codes, the local officials were immediately receptive to the proposal, Mark says. The Sullivans had a structural engineer evaluate the home's design; they also gave the city officials the state of California's model for straw-bale building codes. After that, the Sullivans were approved and on their way to building Capitola's first straw bale home.

By siting the house along the north side of the 45-by-100-foot lot, all the living space is oriented to the south, for maximum daylight and solar heat in the winter. To keep the scale of the home modest, they designed the line of the gabled roof to cascade back from a front porch, to a slightly higher first-floor roof, then to the taller second-floor roof.

Inside, the 1,460-square-foot home feels spacious, in large part due to the expanse of south- and east-facing windows that extend the view. Built-in design features such as arched doorways, a vaulted ceiling, *nichos* (recessed niches) and wall "see-throughs" add elegance without clutter. Everywhere there is a consciously efficient use of space.

Luscious earthen plasters adorn the interior bale walls, hand applied with natural clay from New Mexico. Ferrous sulfate, a benign and inexpensive agricultural fertilizer, was used to stain the exterior lime/cement stucco and cement floors. Other handcrafted details include built-in window seats, a recycled tile mosaic and the requisite "truth window" — a small, decorated hole in a wall that reveals a straw bale.

The 10-month construction process involved more than 200 friends, family members and subcontractors who joined the Sullivans' straw bale and plastering parties. All the wood used in construction was salvaged or sustainably harvested.

The Sullivans' landscape incorporates fruit trees and vegetables among other native California plants. Rainwater is collected off the roof and used to sustain the landscape. The front yard is a mix of native flowers, bunch grasses and low bushes that are drought-tolerant.

The Sullivans' biggest challenge was balancing their ecological ideals with budgetary concerns. "We knew the result that we wanted, but the most challenging part was determining the best sustainable materials at each step along the way," Mark says. "When building a house, you have to make a hundred decisions a day — it's not cut and dried which choice is the best."

At $200 per square foot, the Sullivans' home was more expensive than conventionally built stick-frame houses. "The slightly higher price per square foot reflects the extra-careful design and small engineering details — we squeezed a lot of features onto a small urban lot," Landegger says. "The PV and solar hot-water systems were reasonably priced, and the FSC-certified [Forest Stewardship Council] wood only added about 10 percent more to the wood cost. But when you build a smaller house, it will generally cost more per square foot than a larger home, with larger rooms. There is less material cost, but more labor cost relative to the finishing details."

But the Sullivans regard their home as an investment rather than an expense. "It's not just about the cost up front, but overall life-cycle costs, of which energy is the biggest piece in the average home," Kristin says. "We couldn't be happier with how the house turned out." Mark concurs, "One of the first mornings I woke up in the house, I watched the different tones and shades of the wall as the sun moved across the sky. I'm still amazed and in awe of all that."

PLANTING SEEDS

Kristin teaches environmental studies at De Anza Community College in Cupertino, Calif., and her students visit the house to experience its eco-friendly features. Mark teaches the same subject there, but on a part-time basis; he works full time as an environmental engineer. The Sullivans also open their home to monthly tours. "We're planting seeds," Mark says. The Sullivans' experience has made them local green building authorities. Kristin now is an environmental commissioner for Capitola, and she serves on several environmental committees at De Anza College.

The Sullivans walk their talk in other ways, too. When they need to, they hit the road in hybrid cars — Kristin drives a Honda Insight (about 60 miles per gallon), and Mark drives a Toyota Prius (about 50 mpg). They also buy their produce from a local all-organic farmer's market and belong to a community-supported agriculture co-op in nearby Watsonville. "Part of being a leader is showing change is possible," Kristin says. "It's not about perfection; I tell my students it's the things you do 90 percent of the time that matter."

Kristin describes the semester's final assignment for her students — a 10-year environmental action plan. "Some say 'I want to build a passive solar straw bale home within 10 years.' It gives you hope."

Author and photographer Catherine Wanek has been at the forefront of the straw-bale building movement for more than 13 years.

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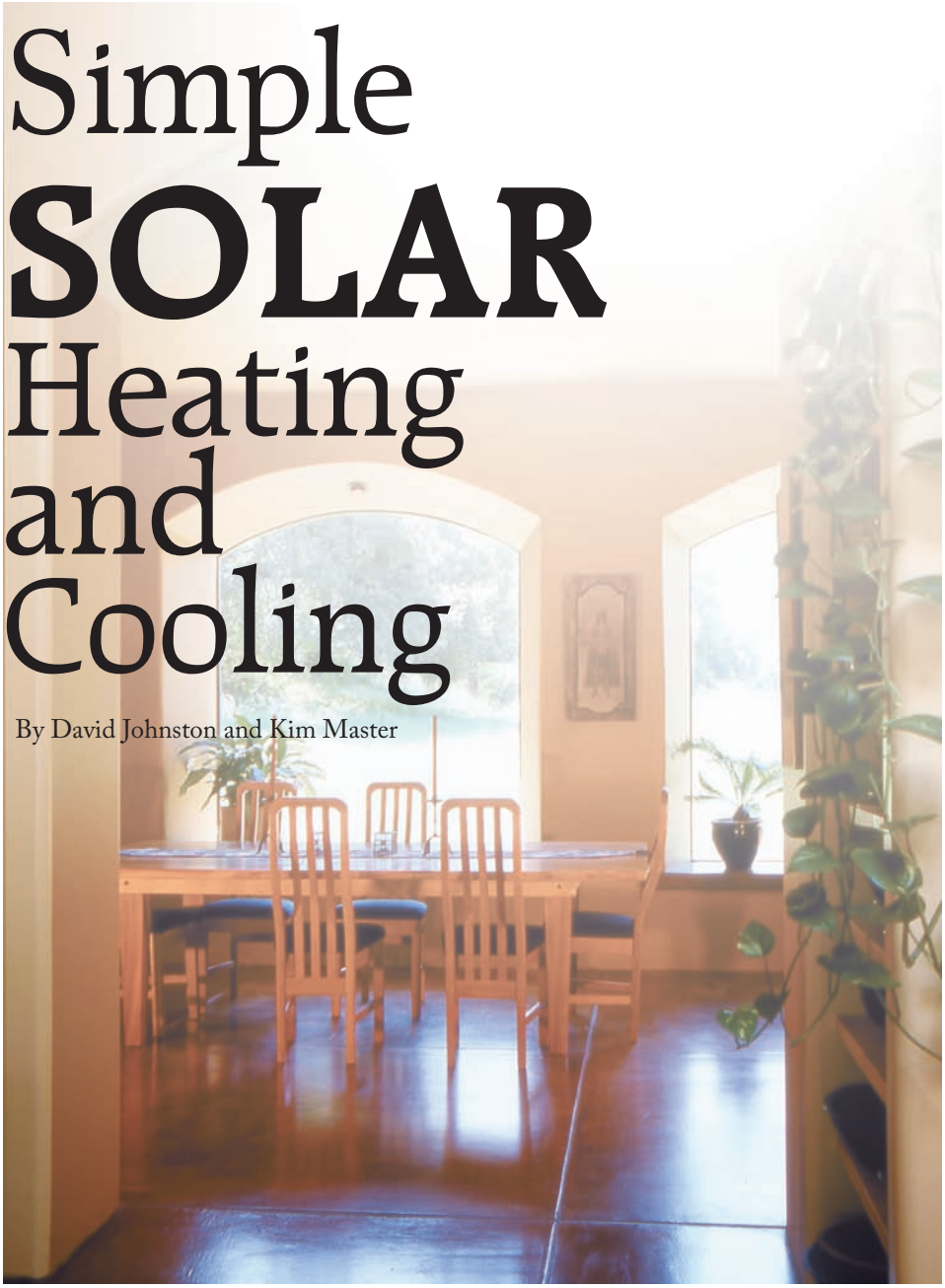
Simple SOLAR Heating and Cooling

By David Johnston and Kim Master



CATHERINE WANEK

When remodeling, these energy-saving options should be your first choice.

Remodeling is the perfect time to improve energy efficiency in your home using both active and passive solar designs. *Passive* solar design is both environmentally friendly and cost effective, and can cut your heating costs by up to 50 percent. It involves placing large windows on south-facing walls and locating thermal mass, such as a concrete slab floor or a heat-absorbing wall, close to the windows. Passive cooling involves using overhangs, windows with reflective coatings and other natural cooling approaches. *Active* solar retrofits include collectors to capture heat from the sun and use pumps to distribute it throughout your home. If the sun shines on your home for most of the day in the winter, it is a good candidate for an active solar-heating retrofit.

THE ROLE OF WINDOWS

Windows play a big role in passive solar design and in the energy efficiency of homes. In the summer, windows can allow unwanted heat into your house, and in the winter, windows can account for as much as 25 percent of a house's total heat loss, equaling more than $20 billion in electricity costs nationwide. The cost of replacing faulty windows in an existing house is high, but replacing them will make a substantial difference in the comfort of your home and likely will be well worth the cost. Upgraded windows typically add to the value and salability of your home because of their energy efficiency and resistance to outdoor noise.

Install multipane windows for efficient heating and cooling. Windows can be constructed with one, two or three panes of glass. Typically, the more panes of glass, the better your windows will insulate your home. Good double-pane windows add to the value of your home because they insulate almost twice as well as single-pane windows. Better-quality double-pane windows have inert gases, such as argon or krypton, installed inside the air space to further slow heat transfer from the sun.

In addition to creating savings on energy bills, multipane windows also make the whole house quieter and more comfortable during all seasons. Upgrading from single-pane windows to energy-efficient multipane windows can save up to 15 percent of your heating costs. Depending on where you live, this can add up to $100 per year, and over time, the savings can reach thousands of dollars. You can get a savings estimate more specific to your home by using the Lawrence Berkeley National Laboratory online energy calculator. Check with your local utility company for rebate programs.

Install low-emissivity (low-e) windows. Low-e coatings—virtually unnoticeable to the eye—are installed inside the air space of double-pane windows. One kind helps prevent heat from escaping through the glass in winter by reflecting it back inside. Another type of low-e coating blocks heat from entering the home during the summer by reflecting sunlight out of the structure. In some areas, the 10-percent to 15-percent higher cost for low-e glass can pay for itself in a few years. Many window manufacturers now include it as standard in their products.

Choose one of three types of e-coatings according to your climate:

- High-transmission, low-e: These windows are best suited for use in cold climates.
- Selective-transmission, low-e: These products are ideal for homes in mixed climates that have both significant winter heating and summer cooling requirements. Low-e qualities ensure winter performance by allowing sunlight to penetrate. The selective properties block most solar infrared energy, keeping the home cooler during summer months.

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• Tinted, low-e: This glass provides glare control along with a high level of solar heat rejection, which helps to control solar gains in hot climates especially on east- and west-facing windows.

Install superwindows. These are windows with one or two thin, plastic films suspended between the glass panes, effectively making them triple- or quadruple-pane windows. They can reduce ultraviolet rays that can fade fabric, rugs and art. The larger the window, the more effective superwindows are in providing a comfortable temperature.

Install windows tuned to solar orientation. East-, west- and south-facing windows work best if you choose glass with the right characteristics. Glass with a low solar heat-gain coefficient (SHGC) has built-in shading that reduces the amount of solar energy that shines into your home.

On the west and east facades, windows with a low SHGC should be used to minimize heat gain that will contribute to overheating or higher cooling loads. Also, check the visible light transmittance (often referred to as VLT) so that you don't block solar heat at the expense of the light and view you want to achieve from the window. On south-facing windows, use a high SHGC to increase the amount of solar heat that can warm your home. In most climates, the north-side solar heat gain is minimal, so SHGC values are not significant. Work with your window supplier to choose the right combination for your climate.

Choose low-conductivity frames. Most window frames and sashes are made of wood, vinyl, fiberglass or aluminum. Wood, vinyl and fiberglass generally insulate better than aluminum or steel frames because they conduct less heat.

THERMAL MASS

Thermal mass (usually a floor or wall) works in conjunction with south-facing windows to capture and store the sun's heat for passive solar heating. Choose materials such as brick, masonry, poured concrete or tile to soak up most of the heat that hits them. They will gradually release heat when the sun goes down, which in turn will moderate the interior temperature of the house. Thermal mass in properly designed passive solar homes will prevent high midday interior temperatures in the summer or on sunny days in the winter, and help keep the home from becoming uncomfortably cool on winter nights.

The thermal mass should be about six times the area of your direct-gain, south-facing glass. For most thermal mass materials, their cost and energy effectiveness increases with thicknesses up to about 4 inches. At a minimum, your drywall should be one-half to five-eighths of an inch thick to increase the thermal capacity on walls in sunlit rooms.

WINDOW SHADING

Carefully designed shading blocks unwanted sunshine (typically in summer and early fall), but does not block sun that is desirable for heating (typically in the spring, late fall or winter). Keep in mind that when sunlight strikes any surface it turns into heat: Interior roll-down shades don't keep out much heat because the light is already through the glass. However, if you can't afford to upgrade your windows or are looking for additional ways to conserve energy, shading windows or installing exterior blinds can be cost-effective ways of reducing solar heat gain and cooling load costs. Overhangs are most effective at shading when they are 2 feet wide and positioned 1 to 2 feet above windows within 30 degrees of true south.

In the winter, do not shade south-facing windows between 10 a.m. and 2 p.m. For east- and west-facing windows, it is best to use vertical louvers to prevent overheating. Tight-fitting, insulated window shades help keep heat inside at night. As a minimum in the summer, install white window shades, drapes or blinds to reflect heat away from the house. Close curtains on south- and west-facing windows during summer days.

LANDSCAPE SHADING

A well-placed tree, shrub or vine can provide effective shade and reduce energy bills. Trees are amazing in their ability to change the local microclimate: Not only do they create shade, but they evapotranspire (or "sweat"), cooling the air in the process. A mature tree with a crown of 30 feet can release up to 40 gallons of water in a day — that's comparable to removing the heat produced in four hours by a small, electric space heater. Mature tree canopies reduce the average temperature in suburban areas about 3 degrees, compared to areas with no trees.

Locate deciduous trees to the east and west sides of the house, but only those areas more than 60 degrees east or west of due south from the house. In particular, west and southwest facades should be shaded from low-angle sun that can cause overheating. It is not recommended that you place deciduous trees on the south side of a home because, even with their bare branches, these trees can block as much as 30 percent of the available winter solar energy.

ACTIVE SOLAR OPTIONS

Adding a solar heating system to your home is another way to combat increasing energy costs and to raise your home's market value. If the sun shines on your home for most of the day in the winter, it is a candidate for a solar-heating retrofit. The two major types of active solar retrofits are solar collectors that heat a fluid circulated within them and air collectors that capture solar heat and distribute the air current throughout the house with fans.

Solar collectors are the basic component of both systems. The most common collector for residential water and space heating is a flat-plate collector, which is basically an insulated metal box with a glass or plastic cover — called the glazing — and a dark-colored absorber plate. The sides and bottom of the collector are usually insulated to minimize heat loss. Sunlight passes through the glazing and strikes the highly conductive absorber plate, which heats up. The heat is then transferred to the air or the liquid passing through the collector.

CHOOSE A SOLAR SPACE HEATER

Active solar space heating uses solar collectors to heat liquid or air, which then heats a space. Solar space-heating systems are usually designed to provide 30 percent to 80 percent of heating needs, depending on geographical location, system type and size. Solar air heaters that directly heat interior air do not require a heat storage component and can complement most existing heating systems. They are the least expensive and simplest solar technology to install. Active solar space-heating systems are most economical in cold climates that have extended heating seasons with many sunny days and/or high utility rates.

Solar collectors are usually installed on the roof, which means the roof must be in good condition and be capable of supporting the collectors. You also can mount collectors on ground racks, vertically on a south-facing wall or on an adjacent structure such as a garage. Pipes (for liquid systems) or ducts (for air systems) that transfer heat from the collector(s) to the interior require a roof or wall penetration. You can increase the effectiveness of liquid solar space-heating systems by storing the solar heat in a large, well-insulated tank during the day for use at night or on cloudy days.

Windows in Passive Solar Design

For optimum passive solar design, window placement should follow the guidelines below as closely as possible:

SOUTH-FACING WALLS:
At least 7 percent to 12 percent glass

NORTH-FACING WALLS:
No more than 4 percent glass

WEST-FACING WALLS:
No more than 4 percent glass

EAST-FACING WALLS:
No more than 4 percent glass

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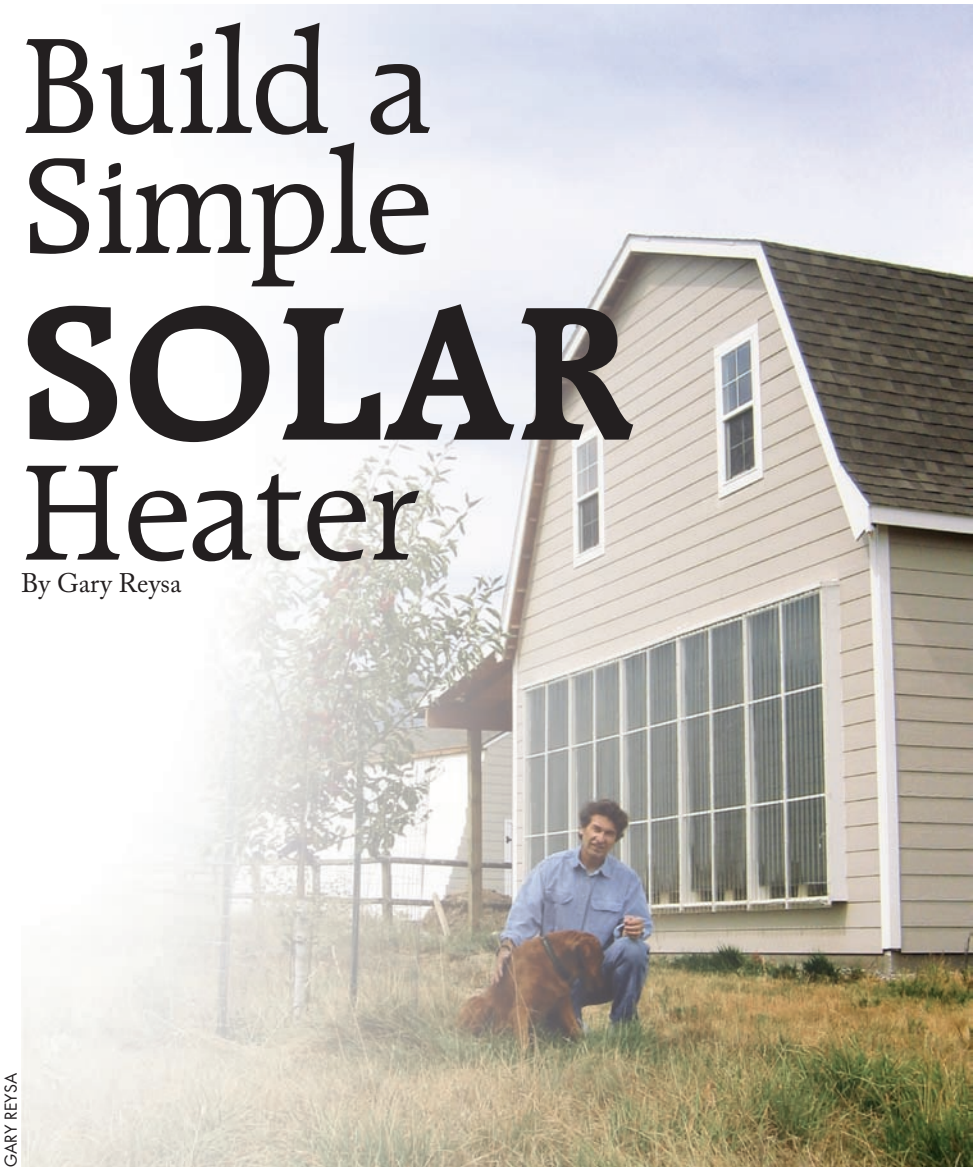
Build a Simple SOLAR Heater

By Gary Reysa



GARY REYSA

This low-cost plan lets you turn any south wall into a source of free solar heat.

After walking into my workshop one December morning and feeling a bone-chilling 10 degrees, I decided to install a heating system. Given the rising costs of propane and my family's environmental concerns about using nonrenewable fossil fuels, a solar solution seemed fitting.

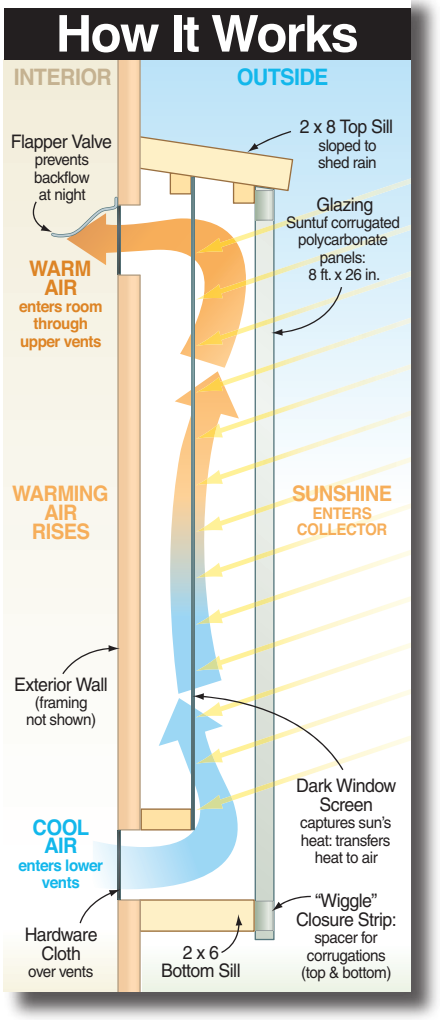
I'm a retired aircraft engineer, but you don't need a similar background to tackle this project. In fact, a solar hot-air collector built into new construction or added to an existing building can be an easy and inexpensive heating solution. Following the simple principles and plan outlined here, you can heat your workshop, barn or even your home with free heat from the sun. If it works here in Bozeman, Mont., it's bound to work wherever you are.

I reviewed many solar collector concepts and decided to install a thermosiphon air collector on the south wall of the workshop. The elegant, simple thermosiphon design uses only the buoyancy of heated air to create circulation through the collector, eliminating the cost, maintenance and power consumption of fans, sensors and controllers commonly used in other collector designs. On a sunny day, in a cold climate like ours, this simple system can produce heat equivalent to burning about $2 worth of propane (equivalent to about $3 for natural gas).

To minimize costs, I integrated the collector with the structure and used readily available materials. It cost me about $350 and took only one trip to the hardware store. I built and installed it in about three working days. Follow the suggestions below, and you may be able to do it faster!!

HOW IT WORKS

The thermosiphon collector consists of clear, corrugated polycarbonate panels fastened to 2-by-6-inch studs. The clear panels admit sunlight, and an absorber suspended inside the collector captures the sun's heat energy. The air around the absorber warms, expands and rises, creating a convection current. Vents at the top and bottom of the collector allow air to circulate through it. Cool air enters the lower vents from the interior, is heated by the absorber, rises to the upper vents and returns to the interior. Air circulation continues as long as the sun shines on the collector.



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GARY REYSA



The author checks airflow. Left: The collector is built from these simple materials.

JOAN REYSA

At night, airflow reverses as air in the collector cools to outside temperatures. Simple flapper valves on the top vents stop this reverse circulation and keep the heat inside.

PERFORMANCE AND ECONOMICS

On sunny winter days, the collector raises interior temperatures to between 60 and 75 degrees. In my neck of the woods, that's 25 to 35 degrees above outside temperatures. Overnight, the building typically cools to 8 to 15 degrees above the outside temperature. On heavily overcast days, the collector does little heating, but on partly cloudy days or with a thin overcast it provides useful heat. It usually takes about three hours to warm the workshop from 35 to 65 degrees — a good excuse to sleep in! If you're determined to start work early, more insulation, more thermal mass or an early morning blast from a backup heater would be in order.

Be sure to install adequate insulation and to control air infiltration. No solar collector — or any other kind of heating system — will heat a drafty, uninsulated area effectively. The walls and roof of my 700-square-foot workshop are insulated to R-19, as good as many houses.

According to my measurements, the heat output per square foot of panel compares favorably to that of most commercial panels — at less than one-tenth the cost! (See "Heat Gain: Running the Numbers," Page 23, for more details.) Our only alternative would have been to heat the workshop with propane. Although a propane heater would have cost a bit less than building the solar collector, paying $2 per gallon for propane over our five-month heating season would have cost $300 to $400 per year. The simple payback period of the collector is a year or two on materials cost. I haven't needed a backup heater, which is an additional savings.

Collector Materials

This list shows what I used and my costs, and should help you figure totals for your installation:

2" x 6" lumber (verticals, bottom sill)	68 ft.	$42
2" x 8" lumber (top sill)	22 ft.	$18
1" x 1" lumber (glazing supports)	130 ft.	$15
Suntuf 8' x 26" corrugated polycarbonate panels*	10	$160
Foam closure molding*	40 ft.	$10
Screws w/EPDM washers*	200	$10
Black metal window screen	4 x 70 ft.	$70
Paint, caulk, lag screws, hardware cloth, etc.		$25
Light plastic sheet (vent flappers)		free
Total		**$350**

*Your hardware store may need to special-order these items from the manufacturer, Palram Americas, (800) 999-9459, ***www.suntuf.com.***

SIZING THE SOLAR COLLECTOR

Usually, the bigger the collector, the better. Most outbuildings suffer high heat losses because of high infiltration rates and inadequate insulation, so the heat a large collector generates can be put to good use. More collector area provides some allowance for partly cloudy and thinly overcast days. With this collector design, overheating usually isn't a problem. You can easily close off upper vents or add thermal mass, such as water containers. Increased thermal mass also reduces nighttime interior temperature swings.

The added time and material cost is small to build a collector that uses the full south wall versus only part of it. Exceptions to using the full wall include locations with mild climates, well insulated and well sealed buildings, or buildings that are much longer along their east-west axis than their north-south axis. Even if the entire south wall is not available, using a portion still pays off.

NUTS & BOLTS

The collector frame is built of common dimension lumber and consists of vertical members, a bottom sill and a top sill. In mine, the six vertical 2-by-6-inch members divide the collector into five 4-foot-wide bays. The bottom sill is a 2-by-6, and a 2-by-8 is used for the top sill. The collector frame components are attached to the building with lag screws driven into them from the inside.

The collector is glazed with clear Suntuf corrugated polycarbonate panels. The manufacturer applies an ultraviolet-resistant coating to the panels' sun-facing side to extend their life. I used 10 panels, each 26 inches wide by 8 feet high. Pairs of panels are overlapped and joined over a 1-by-1-inch vertical wood strip to make the 4-foot-wide panels for each bay. Two 1-by-1-inch horizontal members provide additional support for the glazing.

The absorber, a black metal window screen, is installed on battens fastened vertically to the uprights and across the top and bottom of the bays, about halfway between the glazing and siding. After measuring thermal performance with one, two and three layers of screen, I found that two layers work best. The top and bottom vents are simply holes cut through the building's sheathing and siding. Simple light plastic flapper valves prevent back flow through the upper vents at night.

In summer, the vertical orientation of the panels and the high sun angle minimize overheating, but you should block the top vent openings to prevent the collector from delivering heat. I just staple a piece of cardboard over each top vent, but you could install hinged vent doors. Shading or covering the panels also would work, but is probably unnecessary. In the spring and fall, you can close some vents and leave others open to control the heat output.

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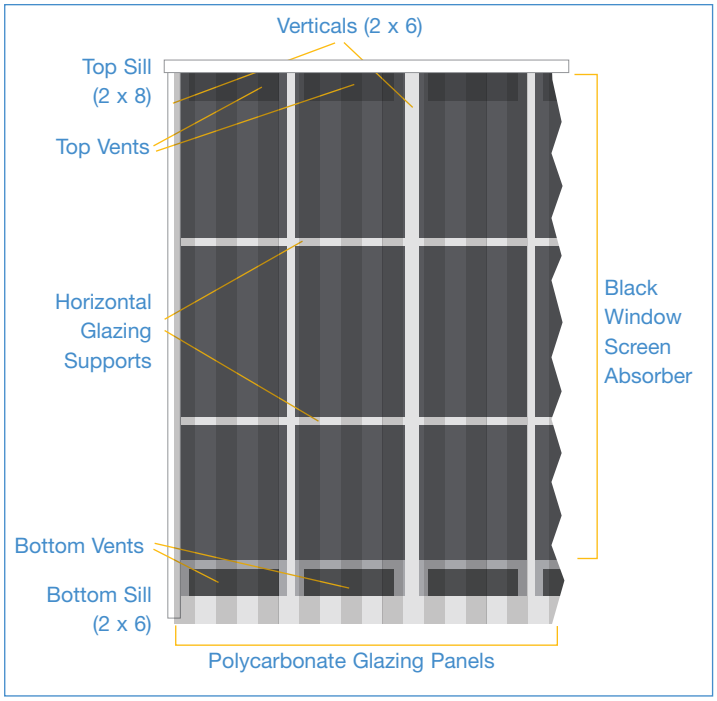


CONSTRUCTION TIPS

First, measure your building's south wall to determine how you'll need to adjust the collector design. Pay particular attention to available height and to stud spacing. Next, lay out the vents. Offset them from the wall studs enough to leave room for the vertical frames to be placed away from studs and lag-screwed from inside the building. Mark the vent locations on the inside and outside of the building to ensure you have no conflicts with electrical wiring. After you're certain the layout is correct, take a deep breath and cut the vents.

Cut the top sill long enough to lap over the end verticals by at least 1 inch. To shed rain, bevel the back edge of the top sill so that it slopes about 10 degrees when fitted against the siding. Next, cut the verticals, angling their tops to match the slope of the top sill. Line them up and cut notches for the two 1-by-1-inch horizontal glazing supports.

Next, prime and paint everything. You don't have to repaint the siding that will be behind the collector, but painting it a dark color will improve the efficiency slightly. Keep in mind that a muted version of this color will show through the collector screen, so be sure it meets your aesthetic sensibilities.

After the paint has cured, mount the verticals to the siding. I fastened them from the inside using 5 inch lag screws, with washers, through the wall sheathing and siding. If your siding is not strong enough to support the weight, align the verticals with the wall studs and drive lag screws from the outside through them and into the studs. Take care to keep everything level, plumb and straight — this will save you a lot of four-letter words later.

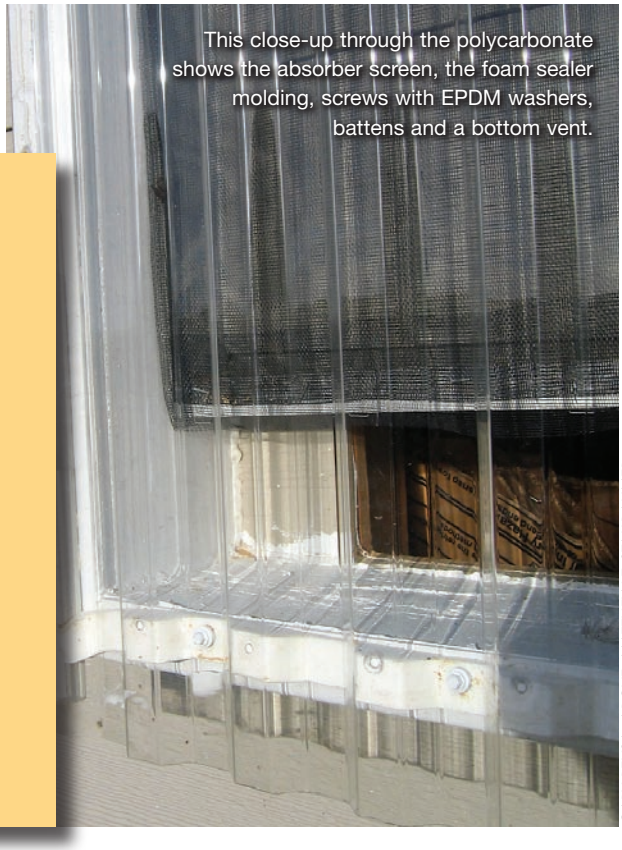
Now, attach the top and bottom sills. If desired, install sheet-metal flashing above the top sill to repel rain. Then, seal the perimeter of the collector frame with silicone caulk. Mount the battens and staple the window screen absorber onto them. Fold over the edges of the screen to fit in the bays, which are slightly less than 48 inches wide.

Make your 4-by-8-foot glazing panels by joining pairs of the 26-inch-by-8-foot corrugated panels. Overlap the panels by one corrugation, applying a light bead of silicone caulk between the overlapped sheets. Reinforce the joint by fastening a 1-by-1-inch wood strip on the inside of the overlapped corrugations using screws with washers made of EPDM, a synthetic rubber that stands up to sunlight and high and low temperatures.

Install the horizontal 1-by-1-inch glazing support strips in the notches cut into the collector frame. The surface of the strips should sit flush with the surface of the frame. Do any cleanup, caulking or other work inside the collector frame now. You won't be able to reach inside after the glazing is attached.

Next, mount the glazing panels. Install foam sealing strips, which are molded to fit the contours of the corrugated panels, on the top and bottom sills. Run caulk beads on the first set of verticals and mount the first glazing panel section. (You'll quickly find out how square your frame is.) Fasten the panel sections to the frame using screws with EPDM washers. Install the rest of the sections in the same way. Overlap each new section over the previous one by one corrugation, using a bead of caulk in the overlap.

For the flapper valves on the inside top vents, I went high-tech and used two thicknesses of plastic garbage bag. Before adding these, attach half-inch mesh hardware cloth over each vent to keep the flappers from being sucked into the vent. Then, staple the flappers along the top edge of the vent, just above the vent opening.



This close-up through the polycarbonate shows the absorber screen, the foam sealer molding, screws with EPDM washers, battens and a bottom vent.

GARY REYSA; ABOVE: MATTHEW T. STALLBAUMER

Solar Collector Pros & Cons

PROS:

- Simple (not much to go wrong or watch over)
- Easy to build and does not require changes to the building structure
- Long life and little maintenance (so far)
- Very low initial cost (less than one-tenth the cost of most commercial panels)
- Good economic return on the initial investment
- Reduces our greenhouse gas production by about 1,800 pounds per year
- Output can be adjusted by opening and closing vents — summer output can be reduced to zero
- Does not affect use of building (I can still pile stuff against the wall, but now it's not junk — it's thermal mass)
- It's not ugly (or at least not too ugly!)

CONS:

- It hurts a bit to cut holes in the wall (but you'll get over it)
- The building might require additional thermal mass and insulation to keep inside temperatures from dropping too much at night

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COLLECTOR VARIATIONS

A couple of variations could improve the system's performance. Substituting dual-wall polycarbonate glazing for the single corrugated sheet would reduce thermal losses through the glazing (although some loss in energy absorption also will occur). This type of glazing, which consists of two sheets of polycarbonate separated by support webs, also simplifies installation, since it requires less support and doesn't have corrugated edges that require sealing. Buildings in cold climates will benefit the most from this change, which would increase the cost by about $100.

Another option is alternating collector panels and windows on the south wall. This approach would admit more light and some direct heat gain through the windows, without the glare, high losses and overheating that accompany full window walls.

You can use the same concept to heat a house or cabin. With some refinement to integrate the vents with the interior wall, the same basic design can provide daytime heat to living spaces. One caveat — the National Mechanical Code prohibits circulation of conditioned air warmer than 120 degrees in wooden stud spaces. While this may not pose a problem for outbuildings, in buildings used for human habitation, consider constructing the collector with metal, rather than wood studs. As an extra measure of safety, wood areas immediately surrounding exit vents also could be flashed with sheet metal.

In altering the collector design, make sure you don't violate these guidelines:

- The collector's depth should be at least 1/15 of its height.
- The absorber must offer low resistance to airflow.
- The vent area should be at least 50 percent of the collector's horizontal cross-sectional area.
- The air path through the collector should be as shown in the "How It Works" diagram, Page 20.

OTHER WAYS TO BUILD IT

This collector could be built with less material and lower cost if it were integrated with the wall during initial construction. It also could be built on the outer surface of the wall, omitting the exterior siding behind it. This might save up to $2 per square foot. For a more finished appearance, you could install a higher grade of sheathing in the collector area.

For a more integrated approach, the wall stud cavities could be used for the collector itself. Using standard 2-by-6 studs at 24-inch spacing, inlet and exit vents could be incorporated in the inside finished wall, with the absorber screen mounted about halfway back in each stud cavity. The collector side of the inside finished wall could be lined with polyisocyanurate foam board insulation, which withstands high temperatures and provides high R-value at modest cost. The R-value of the insulated collector wall would be comparable to that of a standard wall. The glazing could be mounted on 2-by-2-inch members extending along the top and bottom of the collector, and over each of the vertical studs in the collector area.

The difference in materials cost between such a collector and a conventional wall would be close to zero! With a large collector, diagonal bracing or a shear-resistant inside wall may be required to maintain the wall's shear strength. Be sure to work out an agreement with your building department on the details.

Other approaches surely are possible. If you work out a good one, I'd love to hear about it. Meantime, here's to your warmth and comfort!

Gary Reysa worked for Boeing Aircraft. Since 2000, he has lived in Montana, where cold winters, high heating bills and ample sunlight sparked his interest in solar heating. Send your questions about this article or project to gary@BuildItSolar.com. He has posted many other DIY solar projects at his Web site, www.BuildItSolar.com.

Heat Gain: Running the Numbers

In a recent test I did at midday, under typical sunny winter conditions, the collector produced a 50- to 60-degree temperature rise between the lower vent and the upper vent, and an average air velocity at the upper vent of 110 to 120 feet/minute. Peak output was 25,000 Btu/hour, and the total daily heat gain was about 130,000 Btu (38 kWh). This is equivalent to burning about 2 gallons of propane (about $4 worth) at 70 percent efficiency.

Heat gain estimates are based on measurements of the temperature rise and the vent exit velocity. Combining these with the specific heat of air and the density of air gives the collector heat output. I estimated the rate of heat gain using the following equation:

$$G = A \times V \times D \times (T_u - T_l) \times H$$

G is heat gain rate; A is vent area; V is velocity of air through the vent; D is air density at prevailing temperature and altitude (you'll have to look this up); T_u is air temperature at the upper vent; T_l is air temperature at the lower vent; and H is the specific heat of air (a measure of the heat required to raise the temperature of a pound of air one degree Fahrenheit; it varies with temperature and pressure but is about 0.24 Btu/lb-F° under everyday conditions).

I measured the temperatures with several $2 Taylor thermometers from the hardware store. The vent exit velocity was taken using a Kestrel wind meter. Although this instrumentation might not meet Sandia National Laboratories' standards, I believe it does provide a solid estimate of the collector's performance.

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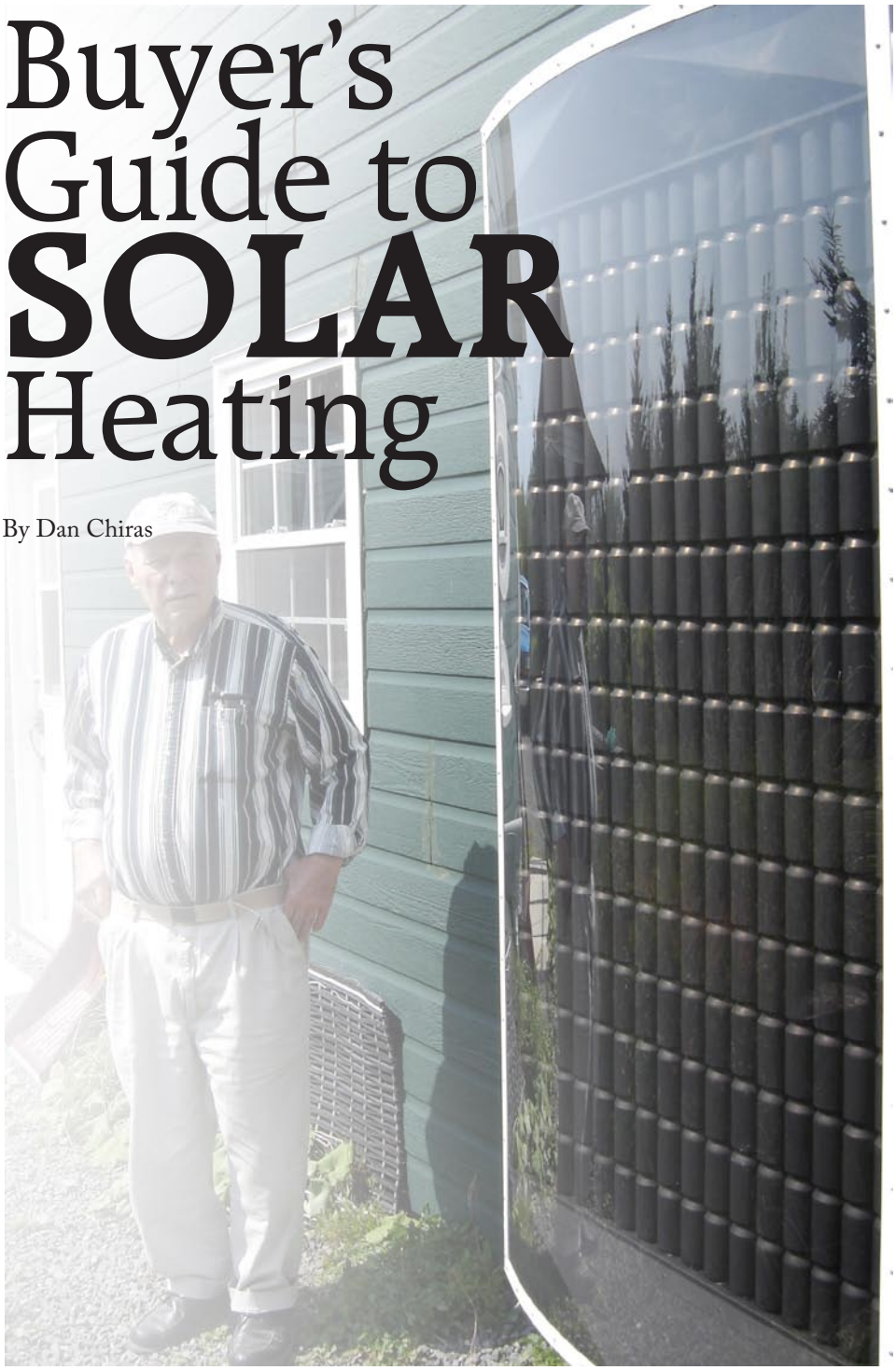
Buyer's Guide to SOLAR Heating

By Dan Chiras



CANSOLAIR

Tap free heat from the sun with these solar hot-air collectors.

Are you freezing in the winter to keep your fuel bill down? Or paying an arm and a leg to stay warm? Either way, it's probably time to consider installing a solar hot-air system. There are several options, and these systems are a hot commodity right now — in recent months several suppliers have reported increased consumer interest.

Solar hot-air systems capture sunlight energy and use it to heat incoming air. Heated air is then transferred into your home, often with a small electric fan. The solar energy costs what it always has cost — nothing. Solar hot-air systems can help alleviate homeowners' worries about rising fuel costs and provide years of inexpensive, maintenance-free comfort. They can heat homes, offices, workshops, garages and barns.

SOLAR SIMPLICITY

All solar hot-air systems rely on hot-air panels or collectors. Collectors are typically mounted on south-facing walls, roofs or even on the ground, if it's unshaded during the heating season.

Some commercial systems are simple thermosiphon collectors that rely entirely on convection to distribute hot air, but most use fans or blowers controlled by relatively simple electronics. A temperature sensor mounted inside the collector monitors internal temperature. When it reaches 110 degrees, it sends a signal to a thermostat mounted inside the home, which turns on the fan if room temperature is below the desired level. When the temperature inside the collector drops to 90 degrees, or the room reaches its setting, the thermostat turns the fan off.

Solar hot-air systems actively produce heat only in the daytime, but some of that heat is absorbed by the building's thermal mass: drywall, tile, framing lumber, etc. At night, the heat stored in the thermal mass radiates into the rooms. The more thermal mass, the greater the nighttime benefit.

HOT AIR VS. HOT WATER

Solar hot-air systems are simpler and easier to install than solar heating systems that circulate water as the heat-transfer medium. They're also less expensive, and don't use troublesome chemicals or require complicated electronic controls. You can even build a solar hot-air system yourself (see "Build a Simple Solar Heater," Page 20).

Solar hot-air systems also produce heat earlier and later in the day than water-based systems. As a result, they may produce more usable energy over a heating season than water-based systems of the same size, according to the U.S. Department of Energy's online publication, *Consumer Guide to Energy Efficiency and Renewable Energy.* Moreover, air systems do not freeze. Minor leaks in the collector or distribution ducts, which cause significant

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Construction continues around two SolarSheat 1500G panels installed in the wall.

problems in water-based systems, also are less troublesome in hot-air systems. (Water-based heating systems do have one major advantage: They can store heat for use at night in water tanks inside the home.)

TWO KINDS OF HEATERS

Solar hot-air systems fall into two categories: open-loop and closed-loop. The difference lies in the source of air entering the system.

In open-loop systems, collectors draw in cold outdoor air, heat it and transfer the heated air into buildings. Collectors used in open-loop systems, known as transpired air collectors, incorporate a dark-colored, perforated metal facing, called the absorber plate. There's no glazing over the plate; the sides and back are insulated to reduce heat loss. Sunlight striking the absorber plate of a transpired collector heats it. Air is drawn through the plate by a blower and is piped to the interior of the building.

Closed-loop systems, the most popular option today, draw cool air from the house, heat it and return the heated air to the interior. These collectors include glass or other clear glazing over an absorber plate, typically made of dark-colored metal. Its surface is roughened to increase air turbulence so that air absorbs heat from it more effectively. The collector's back and sides are insulated.

Air from the home enters the bottom of the panel and moves up, either behind the absorber plate (back-pass collectors) or in front of it (front-pass collectors). Air moves in and out of the collector through ductwork running through the wall or roof — the shorter the better. Small registers are mounted inside on the air intake and outlet openings.

Of the two types of glazed closed-loop collectors, back-pass collectors are more common. Back-pass designs use single panes of glass; front-pass designs are double-glazed to reduce heat loss. That makes back-pass collectors somewhat less expensive to manufacture and about 50 pounds lighter than front-pass collectors and, therefore, a little easier to install.

Most systems are thermostatically controlled and include backdraft dampers on the outlets to prevent reverse convective airflow at night, which would suck heat out of a building.

HEAT OUTPUT

Closed-loop solar hot-air panels can substantially boost the temperature of air flowing through them. According to the U.S. Department of Energy, air entering a glazed collector at 70 degrees is typically warmed an additional 70 to 90 degrees. Open-loop transpired air collectors may provide considerably less heat than glazed collectors. Chuck Marken, president of AAA Solar and solar thermal editor of *Home Power* magazine, says transpired air collectors increase the temperature of the air flowing through them only about 20 degrees, which is probably of little value to residential structures. However, manufacturers report considerably larger temperature increases, achieved by restricting airflow through the collector.

Closed-loop residential solar hot-air systems can produce impressive results. Steve Andrews, a residential energy expert based in Denver, Colo., for example, installed a collector to heat the bottom 500 square feet of his tri-level home, which was usually 5 to 6 degrees colder than the rest of his house. He found the collector made a big difference during sunny winter days and the following evenings. "Overall, the comfort improvement was dramatic," he says.

As part of my research for this article, I tested the SolarSheat 1500G, a closed-loop collector, and found it consistently raised the temperature of 68-degree indoor air that entered it by 40 degrees on sunny but cold winter days. (For more information about the SolarSheat and other commercially available panels, see "Seven Solar Heaters at a Glance," Page 26.)

Marken recommends one 4-by-8-foot collector per 500 to 1,000 square feet of heated space, depending on the location and energy efficiency of your home. A 2,000-square-foot home with unobstructed southern exposure might require two to four collectors. Separate collectors may be required for each room. For larger rooms, two or more collectors may be needed, with a more powerful fan to ensure adequate air flow. If collectors are shaded during part of the day, more will be needed.

MAKING CENTS OF SOLAR HOT AIR

How much can a solar hot-air system save you? Greater savings will be achievable in cold areas that receive more sunlight. As a rule, active solar heating systems are most cost-effective in cold climates with good solar resources, but they make sense in other locations as well.

One way is to calculate payback — or how long it will take to reclaim the cost of the system, plus installation, through annual fuel savings. Divide the cost of the system plus installation by the anticipated annual fuel savings. If a $2,100 system will save $300 per year in heating bills, simple payback is seven years.

To calculate payback accurately, consider rising fuel costs, interest paid on money borrowed to buy the system (or lost interest, if you withdraw money from savings to buy it), and maintenance costs. Fortunately, these systems have just two moving parts, a fan and a backdraft damper, and both should give many years of trouble-free service.

When calculating payback, don't forget financial incentives from utilities and state and local governments.

SHOPPER'S GUIDE

Before you buy a solar collector, make your home as energy-efficient as possible, because efficiency enables the system to meet a higher percentage of your heat requirements. Beef up insulation in ceilings and add insulation to walls, if they're uninsulated. Cover windows at night with insulating shades, and seal cracks in the building envelope with caulk and weatherstripping. Install foam gaskets in electrical outlets and light switches. Seal ducts in forced air systems.

Be sure to investigate local building codes and zoning ordinances before purchasing a solar hot-air system. You may need a building permit. Check out neighborhood or subdivision covenants as well. They may prohibit solar systems, although many homeowners have successfully challenged their neighborhood associations.

You can buy solar hot-air collectors online or through a growing list of solar suppliers, companies that also often install other solar systems such as hot water or electric systems.

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When shopping, watch out for too-good-to-be-true claims.

"Marketing departments can make anything look good," Hurrle says. "One panel won't heat a home, despite what some salespeople may tell you."

I personally prefer closed-loop systems — collectors with glazed panels. I think they look nicer than transpired collectors, and they produce lots more heat. Moreover, open-loop transpired collectors are designed primarily for commercial and industrial buildings and are generally not a good choice for home heating.

Although transpired collectors usually are not suitable for homes in colder climates, they are designed to work well in barns, garages, workshops and commercial buildings that need large amounts of fresh air.

INSTALLATION

Installing solar hot-air panels is not a job for a beginner. Solar energy expert Marken says a seasoned crew of two can install a solar hot-air system in a few hours, but it's more realistic to set aside a full day. "If this is your first time, plan on a weekend, even with help," he says. Because collectors are fairly heavy and measure around 4 by 7 feet, you'll need a brawny assistant or two.

The panel should face as close to due south as possible. The most common place to mount a solar hot-air collector is a roof, where shade is least likely. Unfortunately, roof mounts are usually more complicated and more costly than wall mounts. In homes with attics, installation requires flexible insulated ducts to transport air to and from the collector. Outdoor runs of duct are protected from the elements by galvanized pipe. Much shorter duct runs suffice in homes with closed ceiling cavities and for wall mounts. Like roof mounts, ground-mounted systems require considerable ductwork, and both require much heftier fans to ensure adequate air flow.

To install a glazed collector, you'll need to cut two 5- to 7-inch holes in the wall or roof and ceiling. Transpired air collectors require only one hole, albeit a rather large one (up to 9 inches in diameter). When cutting holes in a wall or roof, be certain not to damage water pipes or electrical wires.

You'll also need to hook up the thermostat, temperature sensor and fan. Wiring diagrams can be difficult to understand for the electrically illiterate. To make life easier, two manufacturers have provided rather ingenious alternatives to wiring. Your Solar Home sells my favorite solar hot-air collector, the SolarSheat 1500 series, which comes with its own supply of electricity: a small solar electric module that powers the unit's fan. To install, simply mount the panel on the wall or roof and then attach two wires from the panel to the thermostat inside the house. It's affordable, a snap to wire and very attractive.

Cansolair provides another simplified wiring solution. Its Solar Max is a glazed collector made from 240 empty aluminum cans, painted black and arranged in 15 vertical columns. Air flows through the solar-heated cans, pulled by an indoor fan in an attractive console that plugs into a 120-volt wall outlet. The fan unit also has a washable filter that helps keep indoor air clean. (To read about a DIY solar heater that utilized aluminum cans, see A Solar-Heated Church in our Archive. — Mother)

Solar hot-air collectors are often attached to existing walls or roofs, but DeSoto Solar sells collectors designed to be integrated into walls, reducing their profile. Such installations work especially well in new construction or when building an addition to a house, so the panel can be installed into the wall as the structure is framed.

SOLAR COMFORT

If a solar hot-air system makes sense for your home or your business, you'll be rewarded many times over. Once you've paid off your investment, you'll get free heat for the life of the system. And perhaps best of all, you'll be doing something positive to create a cleaner, healthier future.

Contributing editor Dan Chiras lives in Evergreen, Colo., in a state-of-the-art environmental home. He's written numerous books on green building and renewable energy — several are available here. Visit Dan and his company, Sustainable Systems Design, at www.danchiras.com.

Seven Solar Heaters at a Glance

Company	Model	Type	Estimated Peak Output (Btu/hr)	Airflow (cfm/min)	Cost	Comments
AAA Solar Supply Inc.; 2021 Zearing NW, Albuquerque, NM 87104; (800) 245-0311; ***www.aaasolar.com***	Sun Aire (2 sizes)	closed	5,000 to 6,000	362 to 488	$864 to $1,273	Wiring hookup required; ships assembled
Cansolair Inc.; Box 100, Colliers R.H., NL, Canada A0A 1Y0; (709) 229-4387; ***www.cansolair.com***	RA 240 SolarMax	closed	9,500	90	$1,649	Wiring hookup required; uses 240 aluminum cans in collector; washable air filter; ships assembled
ClearDome Solar Thermal; 3368 Governor Dr., 153-F, San Diego, CA 92122; (888) 227-7547 ext. 3427; ***www.cleardomesolar.com***	Low Profile UB Solar	closed or open	2,048	100	int., $395 ext., $449	Interior model intended for use inside a large window; plugs into standard outlet; units connect in series; ships assembled
DeSoto Solar; 1410 20th St. #20, West Des Moines, IA 50265; ***www.iedu.com/DeSoto***	on-wall (4 sizes)	closed	variable	variable	$240 to $1,280	On-wall model meant for agricultural structures, warehouses, shops, etc.; in-wall installs much like manufactured windows. No wiring required (thermosiphon, uses no fan); both types available in economy or high-efficiency models; ships assembled
	in-wall (3 sizes)	closed	variable	variable	$200 to $840	
Sunsiaray; 4414 N. Washburn Rd., Davison, MI 48423; (810) 653-3502; ***www.sunsiaray.com***	Northern Comfort	closed	3,000 winter; 4,000 summer	237	$1,150 to $1,400	The only SRCC-certified solar hot-air panel; also heats water; dual use qualifies it for federal credit; wiring hookup required; assembly by professional installer
Your Solar Home, Inc.; 299 Applewood Crescent, Unit 4, Vaughan, ON Canada L4K 4E7; (866) 556-5504; ***www.yoursolarhome.com***	SolarSheat 1500G, GS	closed	5,118	90	$1,655 (G); $979 (GS)	No wiring required (uses integral PV panel); ships assembled; 1500GS is an auxiliary panel
Conserval Engineering Inc.; 4242 Ridge Lea Rd. Unit 28, Buffalo, NY 14226; (716) 835-4903; ***www.solarwall.com***	SolarWall (3 sizes)	open	7,800 to 15,600	70 to 135	$1,959 to $2,788	Wiring hookup required; several colors available; 100 percent recycled materials; ships unassembled

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Save with SOLAR Hot Water

By Greg Pahl



JOHN IVANKO

Solar doesn't have to be unsightly: At Inn Serendipity, a bed-and-breakfast in Browntown, Wis., three 4-by-8-foot flat-plate collectors sit comfortably on the south-facing rooftop. They provide up to 70 percent of the homes' domestic hot water needs.

Slash your hot water heating costs.

Hot water heating is one of the most efficient and cost-effective ways of harnessing solar energy. According to the Department of Energy's Office of Energy Efficiency and Renewable Energy, hot water heating accounts for one-fifth to one-quarter of an average U.S. household's energy usage. Installing a solar domestic hot water system can reduce your hot water heating bill by 60 percent to 95 percent, potentially saving you hundreds of dollars a year. Invest in a solar hot water system for $3,000 to $6,000 and, in some cases, you might recoup the costs within only four to six years.

"If someone is really interested in renewable energy, and they want to get involved somewhere, a solar hot water system is probably the best place to start," says Rod Hyatt, owner of In Hot Water Heat & Power in Eden, Utah. "It makes the biggest impact at the lowest investment." Many states, municipalities and some local utilities now offer tax incentives and rebates, significantly sweetening the solar deal.

Fueled by the sun (think *free energy!*), instead of fossil fuels, solar hot water systems emit none of the pollutants and greenhouse gases — carbon dioxide, nitrous oxides, sulfur oxides — produced when natural gas or oil is burned. And solar hot water systems can be used wherever the sun shines. (Of course, generally the sunnier your location, the more hot water you'll reap.)

HOT HOUSEHOLD WATER

In most homes, domestic hot water (water for washing dishes and clothes, for bathing or cooking) usually is provided by an electric or gas-fired water heater, or boiler or furnace that also heats the home. Heating water with electricity is expensive and will become even more costly as the price of fossil fuels used to generate it continues to climb. And, although heating water with gas is less expensive than heating with electricity, burning gas still contributes to pollution and global warming.

In concert with an electric or gas-fired backup unit, solar domestic hot water can reduce the requirement for conventional water heating by two-thirds or more. The total amount the solar hot water system can contribute depends on your household's hot water consumption, and the amount of sunshine the collectors receive daily and throughout the year. In general, most solar systems are designed to meet one-half to three-quarters of a family's domestic hot water need. During the summertime, the system may usually meet all of their hot water needs. On average, an efficient collector in good weather will heat between 1 and 2 gallons of water per square foot per day. (A solar contractor can help you correctly size the collectors, storage tank and backup system.)

SMART SOLAR SHOPPING

If you're haunted by horror stories of the '70s and '80s, when fly-by-night installers, more interested in selling tax credits than reliable systems, left unwitting homeowners with poorly designed, difficult-to-maintain systems — it's time to shed those fears. Today, performance standards govern most active solar components, making comparisons between products possible (see Sources, Page 30), so when you shop, you can shop smart.

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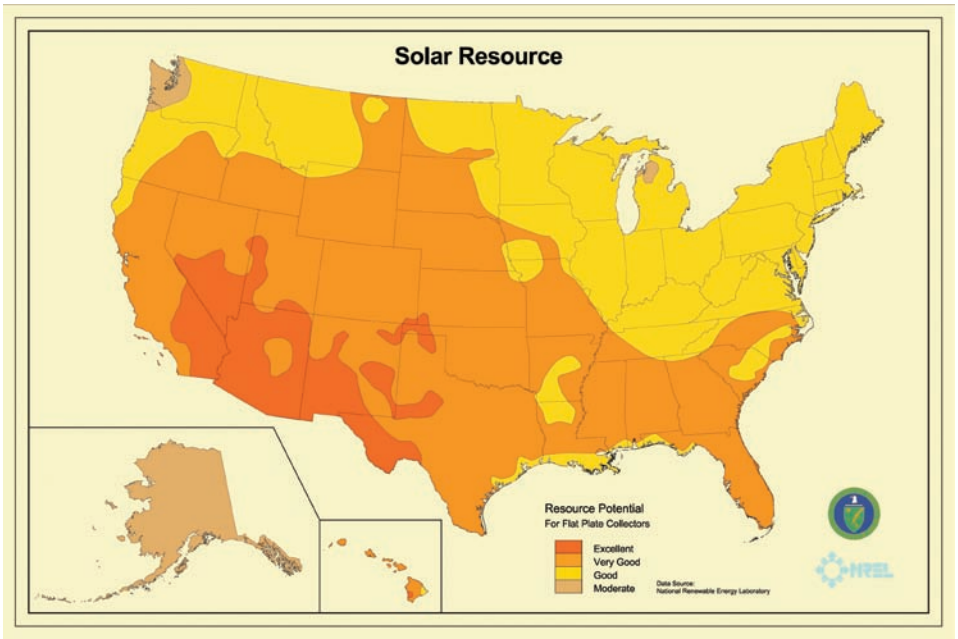


NREL

Solar hot water systems can be used wherever the sun shines, although their efficiency depends on the amount of solar energy received

Most manufacturers warrant their systems for at least 10 years; in many cases, the collectors and insulated piping may last as long as your house. Since it tends to degrade over time, the circulating fluid should be inspected every few years by a qualified technician.

SYSTEM COMPONENTS

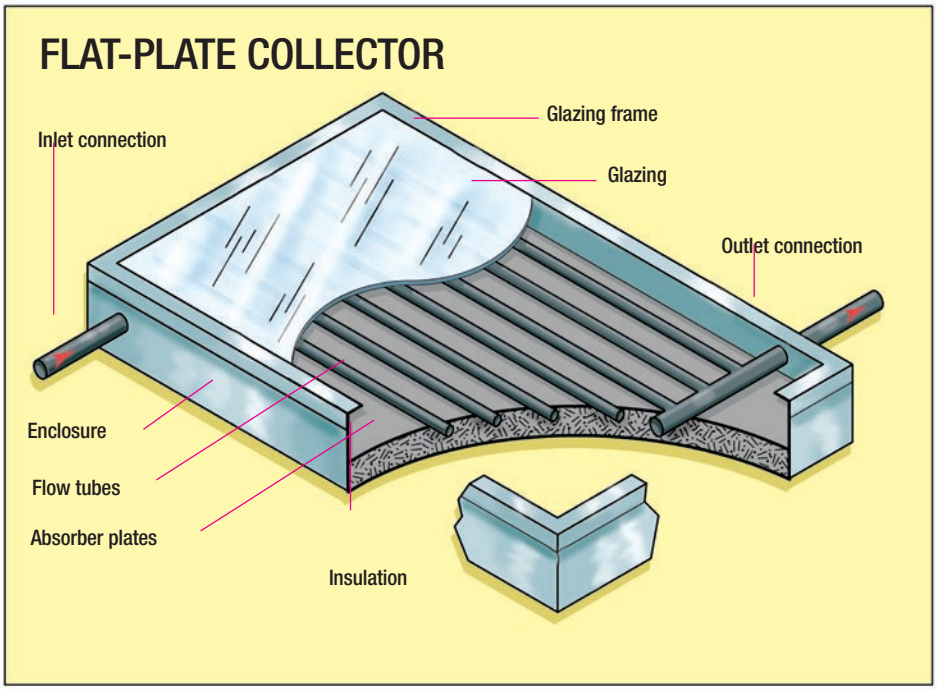
Solar hot water systems consist of collectors connected to one or more storage tanks by piping. For active systems, pumps, sensors and controllers may be added.

Flat-plate, evacuated-tube and batch collectors are all common collectors; each is suited to different needs. Flat-plate collectors (see illustration below), with a "black chrome" or a similar selective-surface coating, which absorbs the maximum amount of solar heat while minimizing radiant cooling, are the most common. Small tubes inside an insulated aluminum box with a tempered glass face contain either potable water or a heat-transfer fluid; the collector absorbs and transfers heat energy to the fluid in the tubes, which is then carried to the heat storage tank by insulated piping.

Evacuated-tube collectors use rows of parallel, transparent glass tubes, which are coated with a selective finish. A vacuum inside the tubes helps the collectors achieve temperatures between 170 and 350 degrees, which makes evacuated tube collectors ideal for high temperature water applications. Batch collectors are simple systems that use one or more black-painted tanks enclosed in a well-insulated, glass-topped box. In this design, the collector and storage tank are combined.

Flat-plate collectors generally perform most consistently for residential applications, yielding temperatures in a range of 140 to 160 degrees. Thermal performance ratings can be used to compare the efficiency and economics of various flat-plate solar collectors (see Sources, Page 30).

To maximize their efficiency, collectors need unobstructed southern solar exposure between the hours of 9 a.m. and 3 p.m., so site them accordingly. The collectors can be mounted on a building's roof or walls or set on a frame on the ground.



U.S. DEPARTMENT OF ENERGY

Flat-plate collectors are most commonly used in residential solar hot water systems.

TYPES OF SYSTEMS

Water heated by the collectors may be moved through the house with pumps (active systems) or by natural convection (passive systems). Batch and passive open-loop systems (which use natural convection to circulate fluid) require little maintenance but are vulnerable to freezing. More common active systems that use pumps and sensors to regulate fluid flow are generally more efficient and freeze-resistant, but require more maintenance.

In a direct or open-loop active system, a pump (regulated by an electronic controller, an appliance timer or photovoltaic panel) circulates heated domestic water throughout the entire system, from the collectors to the heat-storage tanks. With fewer components and no heat exchanger to lose heat, direct active systems tend to be more efficient. They can be powered by photovoltaic modules or a simple AC pump and controller. However, because these systems circulate water instead of antifreeze, they are vulnerable to freezing and are not recommended in climates that experience freezing temperatures.

Indirect or closed-loop active systems are the most freeze-resistant. They circulate a heat-transfer fluid (most commonly a non-toxic propylene glycol and water mixture) that transfers heat from the collectors to potable water held in storage tanks (the antifreeze also keeps the collectors and exterior piping from freezing). Like direct active systems, they can be powered by photovoltaics, too. They have more components and are more complex.

In cold climates where freezing is a concern, solar contractor Tom Lane, owner of Energy Conservation Services of North Florida, in Gainsville, Fla., recommends consumers choose from one of two closed-loop, active systems: unpressurized drainback systems or pressurized glycol systems.

"The most important criterion for both is that they won't freeze and burst."

An unpressurized drainback system uses a closed-loop of unpressurized water separate

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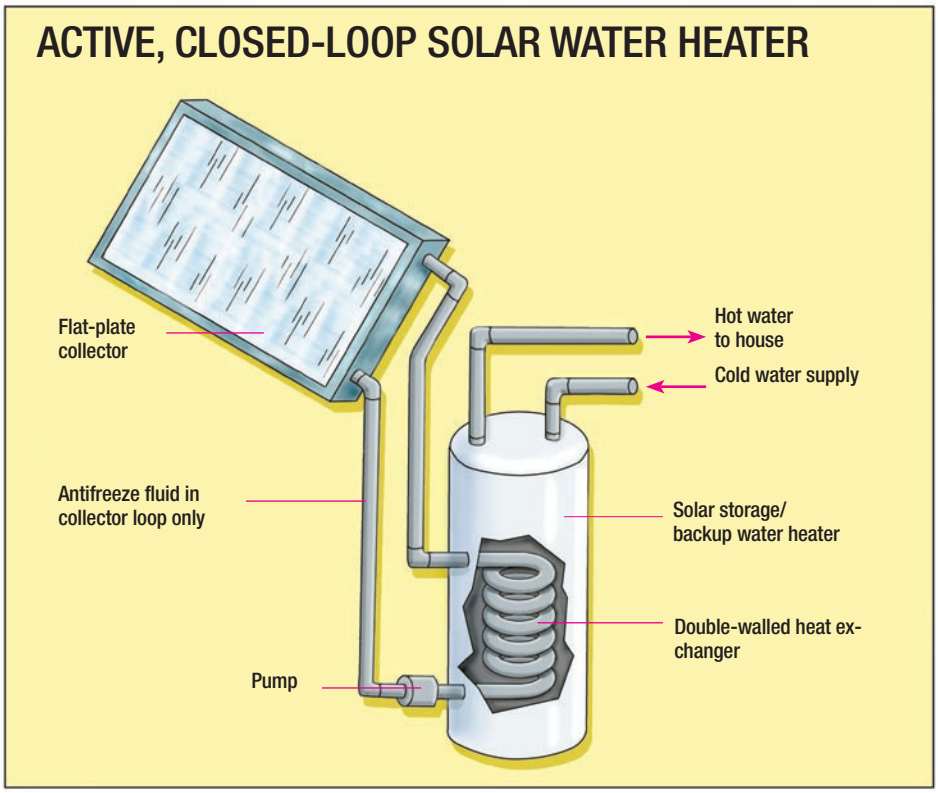

U.S. DEPARTMENT OF ENERGY

Active, closed-loop solar hot water systems use a heat-transfer fluid, like antifreeze, to absorb heat. Pipes carry the warmed fluid to the storage tank, where a double-walled heat exchanger allows the transfer of the heat from the fluid to the stored domestic water.

from domestic pressurized water. When solar heat can be collected, a differential control, which measures the difference in temperature between two sensors and turns equipment on and off, turns the AC circulating pump on, and water circulates through the solar collectors. When the pump stops, the collectors and pipes drain automatically into a drainback tank. Hot water from the drainback tank is pumped through a heat exchanger located in (or sometimes outside) the main potable water storage tank. Almost all drainback systems use a differential control and sensors to automatically drain the water from the collector when the temperature drops to freezing. In very cold climates, a propylene glycol solution can be added to the unpressurized solar loop for added freeze protection. Drainback systems typically have the least maintenance and are the highest performing, closed-loop solar hot water systems available.

Closed-loop glycol systems are the preferred option for extremely cold climates, but can be installed anywhere. Instead of using a drainback system, closed-loop, pressurized glycol systems rely on a continuous supply of antifreeze that remains in the pipes and collector, whether the circulating pump is operating or not. Closed-loop glycol systems often rely on a differential controller, sensors and an AC pump. A small PV panel can be used to operate a DC circulating pump, which runs while the sun shines and automatically shuts itself off when night falls or cloudy weather prevails.

Double-walled heat exchangers prevent contamination of household water with antifreeze or other heat-exchange fluids. Heat exchangers can be mounted outside the storage tank or located inside the tank. Because antifreeze tends to degrade over time, however, these systems need regular inspections to ensure that the antifreeze solution is still viable.

Whatever system you choose, locate the storage tank (and if practical, the collectors) as close as possible to the household distribution and backup system to minimize heat loss from the pipes, and insulate the pipes well.

REAL LIFE APPLICATIONS

Jay Mead and his wife, Edie Farwell, recently installed a closed-loop glycol solar hot water system in their home in Hartland, Vermont. "We live in an environmentally based cohousing community that has a centralized wood-fired boiler for all the units," he says, "and we wanted to have some kind of non-fossil-fueled augmentation for the boiler." A solar hot water system seemed like an obvious choice.

So far, their solar domestic hot water system has performed flawlessly. "It's really quite amazing," Mead says. "On a cold winter day, when the temperature outside is around zero, the temperature of the tank registers between 130 and 150 degrees. We've been very impressed." The system's operation is so subtle that Mead says the only way he can tell that it's running is the faint sound of the circulating pump.

Val Roberts and his wife, Rosalie, retired recently to a remote home in Bancroft, Idaho, where winter temperatures of 40 degrees below zero are not unusual. But Roberts didn't hesitate to install a solar hot water system. The glycol in the solar system offers freeze protection down to 50 below zero.

Besides offsetting a substantial portion of their domestic hot water needs, the system provides some space heating. "There are days when we get water as hot as 200 degrees out of the solar panels, and we can heat the water tanks up to 180 degrees, which act as a heat sink for the times when the sun isn't shining,"

Solar Swings in History

The first commercial solar water heater was patented in 1891; within five years, about 30 percent of the homes in Pasadena, California, had solar domestic hot water systems installed.

Although the solar hot water heating industry had spread to Florida by the 1930s, copper shortages during World War II (coupled with economic incentives offered by electric companies to switch to their hot water heaters) crippled the burgeoning solar hot water industry.

It was almost more than a half century later when solar hit the mainstream market again, revitalized by the OPEC oil embargo and skyrocketing fossil fuel prices. Federal and state tax credits of the early 1980s for renewable energy systems gave the solar industry a major, if short-lived, boost. Almost overnight, a huge number of companies sprang up all across the nation to serve a seemingly insatiable demand for a wide array of solar installations. Then, in 1986, the Reagan Administration pulled the plug on solar incentives.

"It almost entirely killed the industry and stopped virtually all [renewable energy] technological development in this country," says Christel Bieri, the vice president of marketing at Heliodyne, Inc., in Richmond, California. Heliodyne was one of a handful of U.S. solar manufacturers that survived the industry crash.

Today, motivated by consumer demand for environmentally friendly and economically sound technologies, the solar industry is witnessing what many hope will be a full-fledged energy revolution — a switch from a fossil-fuel based economy to a one powered by the sun, wind and water.

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Ten 4-by-10-foot flat-plate collectors heat a straw bale greenhouse at Inn Serendipity in Browntown, Wisconsin. The panels provide 240,000 BTUs of heat each day, heating 700 gallons of water contained in storage tanks. Coupled with R-43 straw bale walls, the solar hot water heating system keeps the greenhouse toasty warm, even in the depths of a Midwestern winter.

he says. The Roberts have a valve on their domestic hot water line so they don't get scalded. "We're very satisfied with the system," he says. "We would definitely recommend it to other homeowners."

Since 1979, more than 16,000 solar hot water heaters have been installed in Oregon — certainly not the sunniest spot in the country! — for domestic hot water, swimming pools and spas (and many of those early systems are still working). A typical solar hot water heater there provides between 50 percent and 60 percent of a home's water heating needs. Oregon currently offers a residential energy tax credit (based on the system's performance) of up to $1,500 on certified systems. Linking tax credits or other incentives to system performance is an important new strategy to minimize tax credit abuses, and has widespread support in the solar industry.

THE FUTURE OF SOLAR

If solar hot water systems are so popular with their owners, even with those who live in extreme climates, why aren't they found in more homes across the United States?

The problem isn't technical, Lane says; the technology is time-tested and works well. Part of the problem is the need to rebuild the industry's support infrastructure and to strengthen educational and promotional efforts. The other part is political.

"We could sure use more vocal support from our politicians," Lane says. "It would be extremely helpful if they would encourage people to adopt solar energy."

Nevertheless, he is optimistic about the future of solar hot water. "It's the best product the solar industry has to offer, and it's going to grow in the future," he says. "It's affordable, and from an environmental standpoint, it's the responsible thing to do."

Sources for Solar Domestic Hot Water Systems

American Solar Energy Society (ASES)
The ASES can help you find solar contractors and suppliers in your area. They also publish *Solar Today* magazine, which often has articles on solar hot water systems.

The Database of State Incentives for Renewable Energy (DSIRE)
A comprehensive Web-based source of information on state, local, utility and selected federal incentives that promote renewable energy, including tax credits, sales and property tax exemptions, rebates and loans.

Florida Solar Energy Center (FSEC)
Hosts the Solar Rating and Certification Corporation (SRCC), a nonprofit organization with the primary purpose of developing and implementing certification programs and national rating standards for solar energy equipment.

Solar Energy Industries Association (SEIA)
Solar contractors and suppliers can be located through the SEIA Web site.

Tom Lane, Energy Conservation Services of North Florida, Inc.
Offers a comprehensive, spiral-bound book, *Solar Hot Water Systems: Lessons Learned, 1977 to Today*, available in a black and white edition for homeowners ($35), and a color edition for contractors ($55).

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Go SOLAR for Free Hot Water

By Bob Ramlow



JOHN INVANKO

The author's Wisconsin straw bale home incorporates both a solar water-heating system (upper roof) and a photovoltaic solar-electric system.

Solar water heaters are the easiest entry into renewable energy.

How would you like to have free hot water for the next 40 years? That should sound pretty good — about 15 percent to 20 percent of a typical household's energy outlay goes to make sure the "H" tap means what it says. If energy prices increase by 6 percent annually, the average family would save thousands of dollars over the coming decades by installing a solar water-heating system that supplies just 65 percent of their hot water.

I mean "free" literally. Yes, you'll spend money up front to install the heating system, but your home equity will increase instantly, often enough to offset the cost of installation. You'll also pay reduced utility bills — saving more money every time rates rise. Within a few years, you'll recover the initial expense. Experts agree, a solar water heater is far and away the easiest initial investment in renewable energy. Perhaps best of all, you'll enjoy hot baths or showers with the satisfaction of knowing the energy comes directly from the sun.

A GOOD DEAL, GETTING BETTER

Solar water heaters vary in their details, but they all do the same basic things: gather heat in a solar collector; transfer the heat, directly or indirectly, to the water supply; and store the heated water until it's used. They use relatively simple, time-tested technology, which is one reason they are a best bet in renewable energy.

It's important to understand that solar water-heating systems have very low — sometimes zero — operating costs, and maintenance amounts to only about $2 per month. Say you might spend $7,000 to install a solar water heater, when you could install a conventional gas or electric heater for considerably less. But it's so much less expensive to operate the solar heater that, at some point, you'll make up the initial difference. When all costs for purchase, installation, maintenance and operation are taken into account, a solar water heater usually equals an electric heater after just eight and a half years, and equals a gas heater in just less than 15 years. From then on, through the expected 40-year life of the solar system, you've got free hot water (see "Gas vs. Solar: Compare Costs," Page 32).

Consider the positive environmental benefits of a solar water heater, and the deal just gets better. A typical residential solar water heater will offset greenhouse gas emissions by about 1,500 pounds of carbon dioxide (CO_2) per year. That's equal to the amount of CO_2 released by an average vehicle every 1,685 miles (based on 19.6 pounds of CO_2 per gallon at 22 mpg).

It's cheaper to conserve energy than to purchase it, so the first thing you'll want to do is reduce your hot water needs to the minimum. Start by reducing waste; then minimize consumption. Reducing your usage ensures that your solar heating system will provide the maximum possible portion of your hot water. Even if you don't go solar, using the minimum necessary hot water is good for your wallet and good for the environment.

The next step is to choose a solar water heater to supplement your fossil-fueled heater. Here are the first things you need to consider about a solar water heater:

Siting. Solar collectors must be in full or nearly full sunlight all year, so have a solar

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Gas vs. Solar: Compare

	65-gal. gas water heater	solar water heater
Life expectancy	12 years (buy in year 1; replace in years 13, 25, 37)	40 years (buy in year 1; replace storage tank & 30-gal. backup heater in years 16, 31)
Initial purchase price Installed	$590	$7,000
Total equipment costs 40 years @ 3.5% inflation	$4,275	$12,781
Fuel costs 40 years @ 6% inflation	$46,428	$16,250
Maintenance 40 years @ 3.5% inflation	$1,000	$2,033
Total	$52,293	$38,064

Solar saves you $14,229!

Assumptions: The solar water-heating system initially uses the existing water heater as backup and provides 65 percent of hot water; the average family currently spends $300 annually to heat water; maintenance of the solar system currently costs $24 annually; fuel costs will increase by 6 percent annually; other costs will increase by 3.5 percent annually.

professional assess your site to find the best location for the collector. The optimum collector mounting angle, measured from horizontal, equals the latitude of the collector location. Ideal direction is true south, but in most cases, solar collectors for water heating can be mounted within 30 degrees of true south and will tolerate a small amount of shading.

Collectors are typically mounted on roofs, but also can be mounted on the ground near homes. Wind can create strong lift under collectors, so they must be securely fastened to the building or to the ground. They're not heavy, even when filled with fluid, but make sure the roof structure is in good shape.

Sizing. Solar water heaters are rarely designed to provide 100 percent of your hot water — there are just too many cloudy days over the course of a year. Nevertheless, a typical solar water heater will provide between 50 percent and 75 percent of your annual load. In hot climates or during the sunniest times of the year, you can expect to get nearly 100 percent of your hot water from solar. During the cloudiest periods you may only get 50 percent, depending on your climate.

In cool climates, a system is sized with 20 square feet of collector and 20 gallons of storage capacity for each person in the household. For large families, this can be reduced by 10 percent for each person over four members in the household. In warm climates, a system is sized with 15 square feet of collector and 25 gallons of storage for each person in the household, with the same reductions for larger families. These sizing methods will give the best return on investment. Systems smaller than these will work well, but your savings will be less.

SOLAR HOT WATER: WARM CLIMATES

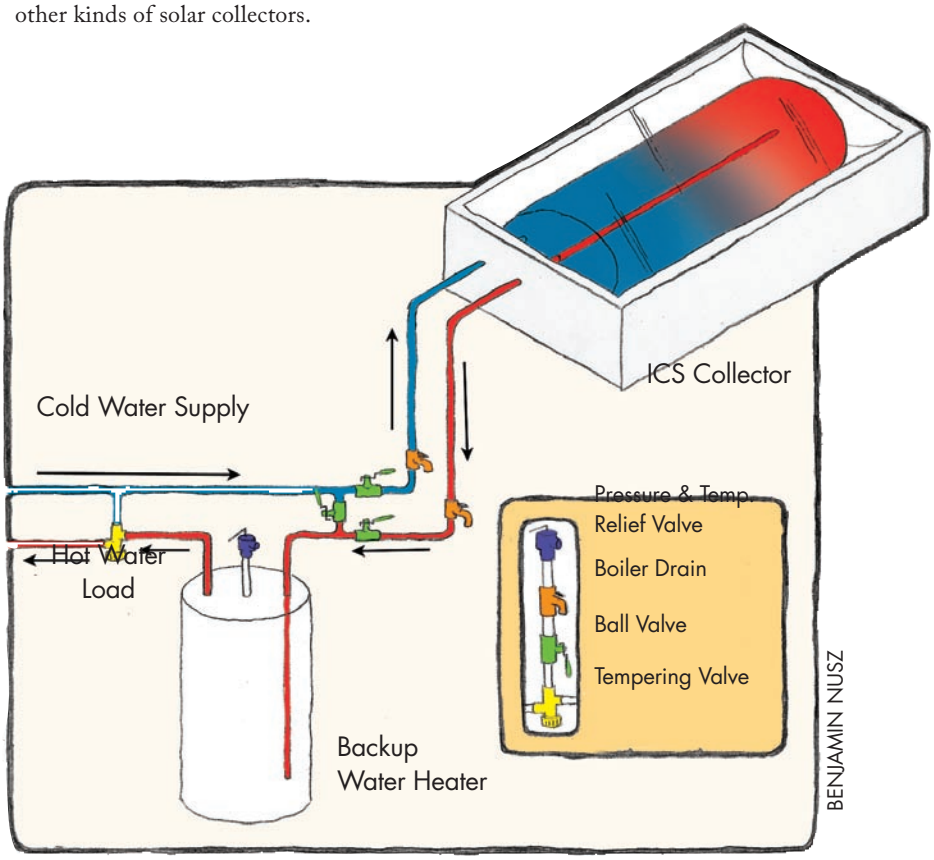
The choice of the right type of solar water-heating system depends primarily on the climate where you live. The crucial fact is that if a water-filled pipe is exposed to freezing conditions, the water inside the pipe will freeze and the pipe will burst. In any climate that experiences freezing temperatures, some precautions must be taken to prevent pipes from freezing.

In climates that never experience freezing conditions, or for systems that operate only in summer, such as those for summer homes and campgrounds, water in the solar collector and piping presents no such threat. The best type of solar water heater for these applications is an integral collector storage (ICS) system, often called a batch heater. ICS systems are simply water tanks exposed to the sun. Commercial ICS collectors have one or multiple tanks inside an insulated box with glass on one side. The glass side is set facing the sun, and the tanks are painted black or have a special coating that absorbs the sun's energy. This system has no pumps or controls and is plumbed directly into a home's water system. It is the simplest, least expensive solar water heater and is popular in all areas surrounding the equator. ICS systems heat domestic water directly. Other systems heat the water indirectly, using a heat-transfer fluid that is kept separate from the water supply, because most water supplies contain dissolved minerals that will clog the small passages in other kinds of solar collectors.

SOLAR HOT WATER: COOL AND MODERATE CLIMATES

In areas that experience freezing conditions, two kinds of solar water-heating systems are appropriate, closed-loop antifreeze systems and drainback systems.

Closed-loop antifreeze systems are the most popular and versatile type of system installed worldwide. They consist of one or more collectors, insulated piping, a circulating pump, an expansion tank, a hot-water storage tank, a heat exchanger, solar fluid (usually a solution of water and nontoxic propylene glycol antifreeze), a controller, and some valves and gauges. The piping loops from the collectors to the heat exchanger and back again. This closed loop is filled with the antifreeze solution, which stays inside the collectors and piping at all times. Whenever the sun shines on the collectors, the circulating pump comes on, and the solar fluid circulates within the closed loop. The fluid gets hot inside the collectors and travels through the piping to the heat exchanger. The heat exchanger transfers the heat from the fluid to the water inside the storage tank, which stores the heated water for your use. As the fluid heats, it expands, so the expansion tank is included to relieve pressure in the system. When the sun is not shining, the circulating pump simply turns off, and the fluid stops circulating.



Best for warm climates or seasonal use, integrated collector storage (ICS) systems are the simplest solar water heaters.

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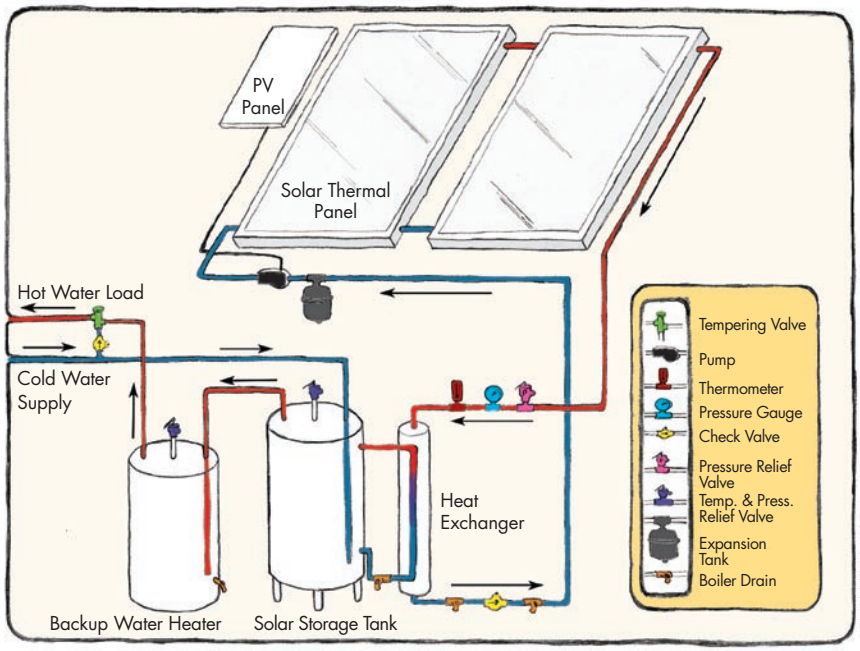
Advantages and Disadvantages of Solar Water-heating Systems

System type	Integral Collector Storage	Closed-loop Antifreeze	Drainback
Best for	Hot climates or seasonal use	All climates	Moderate/hot climates
Advantages	• Proven design • Low maintenance • High efficiency • Simplicity	• Proven design • Low maintenance • High efficiency • Usable in any climate, including extreme freezing • Pumps can be PV-powered • Can place collectors in any position relative to storage tank • Piping can be installed in a variety of ways	• Proven design • Low maintenance • High efficiency • Freeze protection in all but coldest conditions • Fluid drains when idle, preventing degradation of antifreeze solution
Disadvantages	• Weight • Best where freezing *never* occurs; where freezing is infrequent, use only with freeze-protection valves	• Antifreeze solution degrades, especially in hot climates or when system is idle, and must be replaced every 10 to 15 years	• Collectors must be mounted above drainback tank, limiting options • Installation requires care to ensure quick, complete drainage • Pumps usually not PV-powered • Vulnerable to freezing in extreme cold

The circulating pump in these systems can be powered by either AC or DC current. If AC-powered, the pump gets its energy from your home's 120-volt electrical power system. In this case, a controller is necessary to turn the pump on and off at the appropriate times. The controller is connected to temperature sensors in the collectors and on the storage tank. Whenever it's hotter in the collectors than it is in the storage tank, the controller turns on the pump. When it's warmer in the storage tank than in the collectors, the controller turns the pump off.

If the circulating pump is DC-powered, it's wired directly to a small photovoltaic (PV) panel mounted outside. Whenever the sun shines on the PV panel, electricity flows to the circulating pump, and it starts running. When the sun stops shining, the pump turns off. DC-powered systems are becoming the most popular kind of closed-loop antifreeze system on the market. The PV supplies free power to the pump; the pump runs whenever the sun is out, preventing stagnation and overheating; and it runs at variable speeds depending on the amount of sunlight, so it automatically matches the collector's heat output. These pumps have limited power, but it's sufficient to move the fluid through a piping system that's always full. The absence of a pump controller, the component most prone to failure, makes PV-powered systems quite reliable.



Ideal for all climates, closed-loop antifreeze systems use heat exchangers to transfer heat from the antifreeze mixture to the water, which remains in the storage tank until used.

Drainback systems are popular in moderate and hot climates. They're similar to closed-loop antifreeze systems, but the big difference is that they include an additional tank, the drainback tank. When the system is off, the fluid is stored in the drainback tank and the pipes and collectors are empty. The fluid can be pure water or a weak solution of antifreeze in water. These fluids don't resist freezing as well as those used in closed-loop antifreeze systems, which makes drainback systems vulnerable to freezing in extreme or extended cold.

Drainback systems usually use a controller and an AC pump. The pump is a special high-head pump because it has to lift the fluid to fill the piping and collectors every time the system turns on. This requires more power than in antifreeze systems, where the pump just circulates fluid through piping that's always full. Otherwise, drainback systems operate similarly to an antifreeze system: When the sun warms the collectors, the high-head pump comes on and circulates the fluid into and throughout the system, and a heat exchanger transfers the heat from the fluid into the storage tank. There is no expansion tank and fewer valves and gauges than in an antifreeze system, but the piping must be carefully installed to facilitate proper drainage.

ADDITIONAL CONSIDERATIONS

A few other factors will influence your choice of a solar water heater. If you find a system that is substantially cheaper than others, there's

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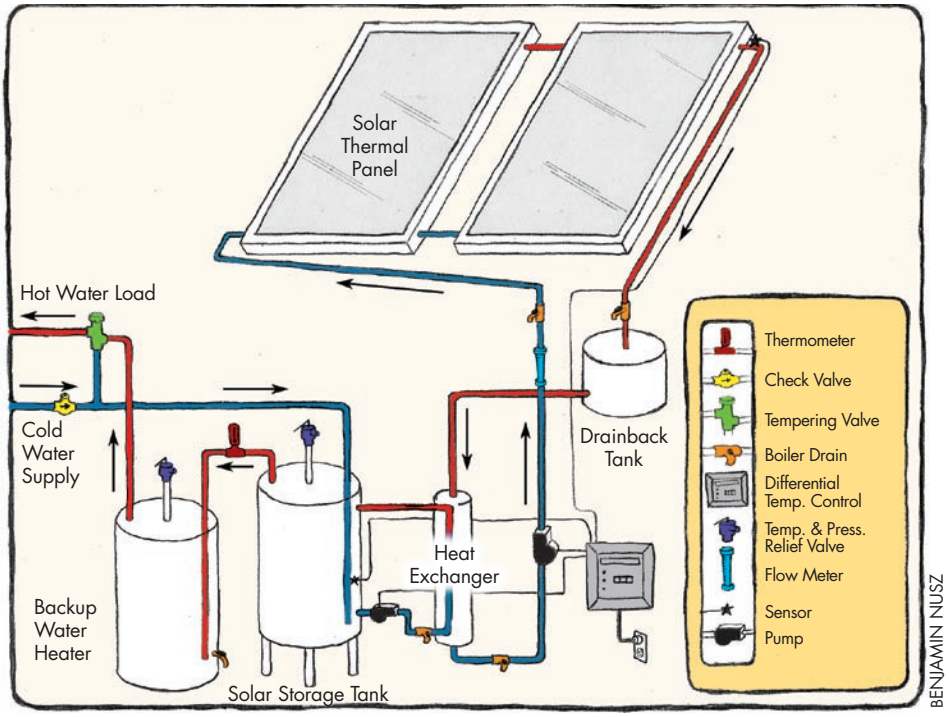

Best suited to moderate/hot climates, drainback systems include a tank that holds the antifreeze solution when the system is off.

Solar Sources

Solar Water Heating
By Bob Ramlow

LOCATE DEALERS/INSTALLERS

FindSolar

North American Board of Certified Energy Practitioners

***Home Power* magazine**

LEARN MORE ABOUT SOLAR

American Solar Energy Society

Energy Efficiency and Renewable Energy, click "solar energy technologies"

probably a reason, such as lower quality components. There is no substitute for quality — don't take shortcuts with an investment like this.

A solar water-heating system often can be expanded to include space heating as well. The collector array and other components will need to be larger. There are numerous options for storing and distributing heat in combination systems. Discuss your ideas with a solar professional (see "Solar Sources").

Closed-loop and drainback systems should always have a separate storage tank for solar-heated water and a backup water heater. The same tank can't do both jobs efficiently. Typically, the output of the storage tank runs to the input of the backup heater. When solar output is sufficient, the backup heater doesn't come on.

COLLECTIVELY SPEAKING

There are two popular kinds of solar collectors, flat-plate and evacuated-tube.

Flat-plate collectors are by far the most popular kind of collector and work well in all climates. They have been around the longest and are efficient and competitively priced. They are shallow rectangular boxes with glazed tops and insulated backs and sides. An absorber plate inside gathers solar heat and transfers it to a network of copper tubing, through which the solar fluid flows. They are the only collector that sheds snow and frost well. They also operate precisely within the temperature range needed to heat domestic water — below zero to about 180 degrees — and rarely overheat.

Evacuated-tube collectors from different manufacturers vary significantly, but all use rows of glass tubes, each containing a heat absorber. A vacuum sealed inside the tubes insulates the absorbers. These collectors overheat more readily than flat-plate collectors, so care must be taken never to oversize the collector array or undersize the storage tank. They tend to cost more than flat-plate collectors for equivalent heating capacity, but prices for high-quality evacuated-tube collectors are falling. They also are more fragile than flat-plate collectors and don't shed snow or frost well. On the other hand, they work well when there is a consistent year-round, daily load on the system. In addition, they're less susceptible to the forces of wind, because there are spaces between the tubes, unlike the large closed surface of a flat-plate collector.

Solar water heaters can last 40 years or more if the design is appropriate to the climate and the system incorporates high-quality materials and workmanship. Investing in a solar energy system could even be considered patriotic, because solar keeps our energy dollars at home and reduces our dependency on others. You will spend a certain amount of money to heat water in any case, so why not choose to do it with solar energy? Your pocketbook, and the environment, will appreciate it.

Bob Ramlow has more than 30 years of experience with solar energy systems. He currently owns a renewable energy consulting company, and he is a co-founder and member of the board of directors for the Midwest Renewable Energy Association. This article was adapted from Solar Water Heating, a MOTHER EARTH NEWS Book for Wiser Living from New Society Publishers.

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Eight Compelling Reasons to Buy a SOLAR Roof

By Terri Suess and Cheryl Long



CHERYL LONG

Thin-film photovoltaic laminates adorn MOTHER EARTH NEWS Editor Cheryl Long's barn.

Eight reasons why you should install your own solar electric roof.

1. Personal and national security. The more we tap solar and other renewable energy sources, the less dependent we are on utility giants and nonrenewable fossil fuels. Solar roofs can even be used to charge electric vehicles, which will reduce pollution and decrease our need for foreign oil.

2. Protection against price increases. Electricity prices in many states are increasing. In California a combination of deregulation, population growth, increased consumer demand and construction of fewer new power plants caused electricity costs to skyrocket. Other states are watching similar trends and expect prices to increase in the coming years. With nuclear power plants being decommissioned or phased out because of the high costs and high risks related to nuclear waste disposal, and with the best hydroelectric sources tapped, new sources of electricity are needed. Even though many new gas-fired power plants have been constructed, some analysts see natural gas shortages emerging that will require expensive drilling and pipeline construction. This points to higher natural gas prices rippling across to electricity prices.

3. Rebates . Some states are finally getting serious about supporting renewable energy options. Government rebates, tax credits and grants can cut the cost of your solar roof by up to 60 percent in some areas. To learn what's available in your state, go to the Database of State Incentives for Renewable Energy (DSIRE), www.dsireusa.org.

4. Selling back peak power to the grid via net-metering. Net-metering rules and regulations are in place in many states, allowing homeowners to run their electrical meters backward when they send electricity to the grid from a solar-electric rooftop. When the homeowner uses electricity from the grid at night or on cloudy days, the meter runs forward. The monthly bill is based on the net difference.

5. Global warming reductions. According to the Department of Energy (DOE), electric power plants emitted 40 percent of all carbon dioxide (CO 2) emissions in the United States in 1999, making them the largest single-source contributor to global warming. Fifty-one percent of all the electricity produced in the United States in 1999 was generated by coal-fired plants, yet these plants produced 80 percent of all the C0 2 emissions resulting from electricity power generation. DOE also reports one-quarter of all types of air pollution emissions nationwide are caused by burning fossil fuels (coal, natural gas and oil) to generate electricity.

6. A response to "Not in my back yard" Conventional power plants and transmission lines take years to plan, site and build — and most people do not want them in their back yards. Power distribution systems feeding metropolitan areas are operating near capacity during peak demand periods. Onsite power production via home solar-electric installations, part of a "distributed generation" scenario, offers a positive solution for elected officials seeking to prevent blackouts and brownouts, improve air quality and enhance the economy by producing jobs.

7. A beautiful, distinctive, high-tech, home design element. Technological developments have resulted in more appealing and affordable systems, designed to complement a home's architecture. With Building-Integrated Photovoltaics (BIPV), the solar-electric system is the roof.

8. Supporting the future of solar power. The PV market is expected to grow to $10 billion by 2010. The annual growth rate of solar PV products has increased by 20 percent annually and is expected to double every three years for the next 20 years. This growth should spur additional investment, contribute to economies of scale in the industry and help make systems even more affordable.

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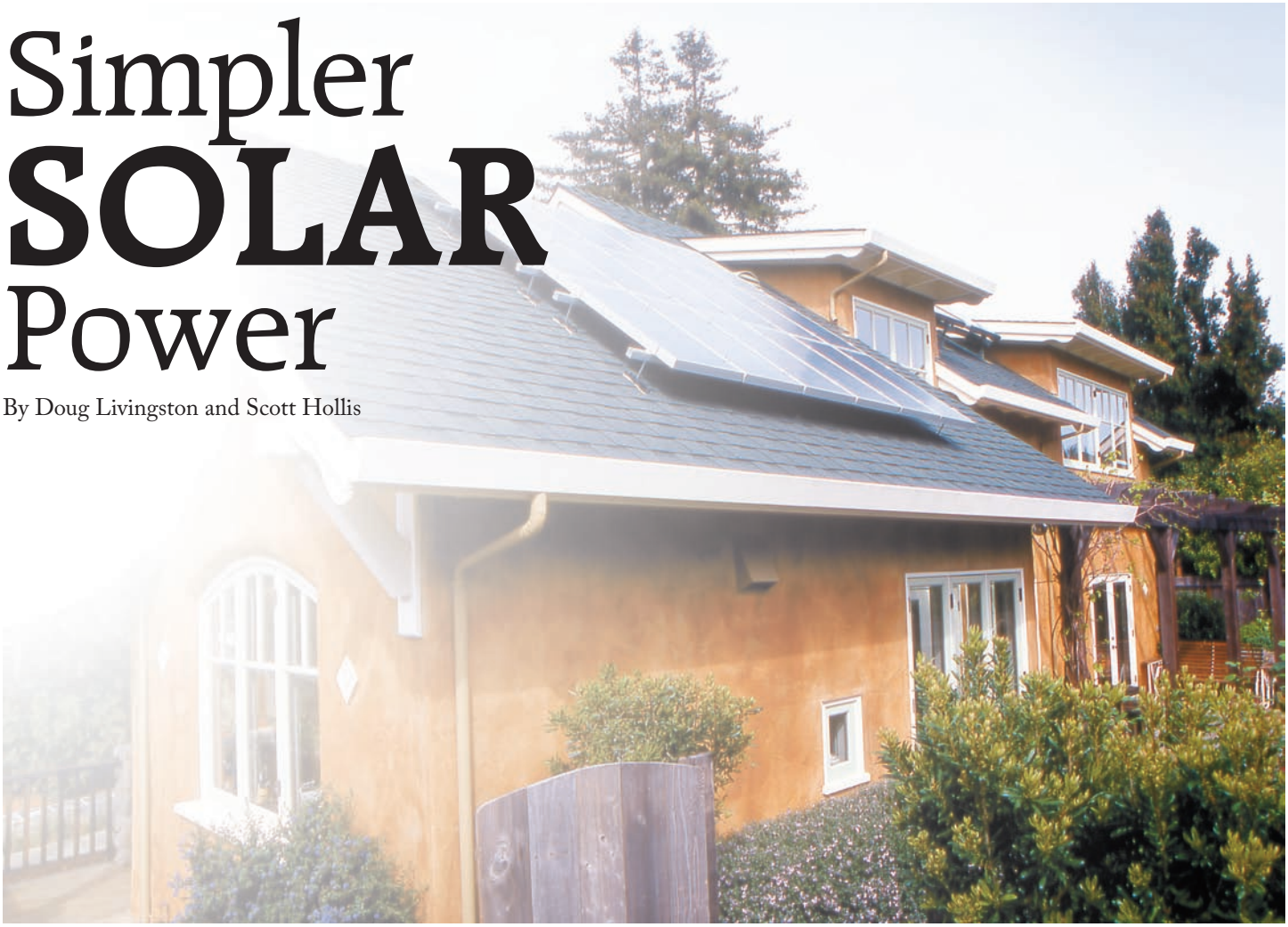
Simpler SOLAR Power

By Doug Livingston and Scott Hollis



CATHERINE WANEK

Grid-tied solar systems make choosing clean, renewable electricity easier and more affordable than ever.

Many of us dream of tapping alternative energy sources so we can live "off the grid." But you don't need to unplug from the utility grid in order to use solar panels to produce your own power. For most of us, a simpler grid-tied system is a better choice than an off-the-grid setup. Instead of costly batteries, you can use the grid to "store" your excess solar power. In most states, net metering laws require your utility to credit you whenever your system produces more power than you use. This means that when the sun is shining, your electric meter may spin backwards!

What follows is a guide to grid-tied solar systems — the simplest way to switch to renewable energy for your home.

NET METERING

The most important factor in deciding to install a grid-tied solar system is whether your state or area has net metering. Net metering means the utility will trade electricity with you, giving you credit for any excess power your renewable energy system produces for the grid. When your grid-tied system is producing more than you use, the excess power automatically flows back to the grid, literally spinning your electricity meter backward and adding credits to your account. Net metering is so important that you probably don't want to consider a residential grid-tied system in a location that doesn't offer it, unless you aren't concerned with saving money.

If your area doesn't have net metering, write your state policymakers urging them to change the regulations.

Many states (37 and counting) do offer net metering. Not all locations have the same regulations, though; go to www.dsireusa.org to learn more about net metering policies in your area. This Web site also is a great source for information about renewable energy rebates and other incentives available in your area.

You should pay close attention to your local net metering regulations because they will affect the sizing of your system. Some states calculate net metering *monthly,* while others figure it annually. Most home solar systems produce a surplus of power in the summer and

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People Worry too much about . . .

PHOTOVOLTAIC ORIENTATION

Changing the PV angle is uncommon — it's usually restricted to off-the-grid systems in which every little bit of winter sun is more precious than summer sun. For the lower 48 states, any inclination between 5 and 45 degrees will work fairly well. In the absence of shading problems, pointing your PV at any orientation between southeast and southwest also will work nearly as well as due south. Solar-tracking mounts, which automatically follow the daily movement of the sun, rarely are used on grid-tied residential systems.

BACKUP POWER FROM BATTERIES

Batteries reduce the amount of useable electricity your system will produce, as well as make your system more expensive and complicated to install and maintain. "Store" your excess electricity by sending it back into the utility grid for a credit, and if you need power during an outage, buy a generator — they're cost-effective and probably more environmentally friendly than batteries.

People Don't Worry Enough about . . .

SHADING

Crystalline modules usually consist of 36 or 72 cells wired together in a series. If just one cell becomes covered by a shadow, perhaps from a vent pipe or tree branch, it can block the flow of the entire module. Built-in bypass diodes help minimize loss, but a shadow covering just 3 percent of a module can equal up to a 50-percent power loss. If you can't avoid partial shading, consider amorphous PV because it is not as affected by shading as crystalline modules.

The Size of Your System Relates to Energy Efficiency

The first step in sizing your solar system is to reduce any unnecessary power usage in your home. By doing so, you can purchase a smaller, less expensive system that will save money on the up-front cost and still make your home more energy efficient. Your local utility can be a good resource for energy efficiency tips, and it often gives rebates for replacing major energy-wasting appliances with more efficient ones such as Energy Star-rated appliances (www.energystar.gov). To reduce your consumption by half is just as good for the Earth as providing half of your energy needs with a solar system — and it's easier on your pocketbook.

How Much Electricity can you Create?

To estimate paybacks or returns on investment, first you need to predict the amount of electricity your PV system will generate. For the simplest systems with fixed PV, minimal shading, reasonably good orientation, inclination and annual net metering, this is easy to estimate. Multiply your local annual "noon sun hours per day" (keep reading) by your PV wattage. Reduce that figure by 15 percent to 30 percent to compensate for less-than-perfect system efficiency. Now divide this total by 1,000 for the total kilowatt-hours produced by your system.

A typical value for "noon sun hours per day" in the Midwest is 4.5. In the Sun Belt, this value is slightly higher (above 6 in some areas of the desert) and in the extreme Pacific Northwest to the Upper Midwest and through New England, the value is about 4 or slightly lower. To find the average amount of sunshine in your area, click here.

In some locations (California, for example), the electric rates vary with the season. For details and examples on how to calculate other PV production scenarios like this, go to *www.MotherEarthNews.com/downloads/simplesolar*.

run a deficit in the winter, so an annual billing period usually is a better deal.

In many states, any net excess electricity credits you accumulate during your billing cycle can be sold to the utility — but usually at a significantly lower price than the retail rate. So it probably wouldn't be cost-effective to produce more electricity than you use; the goal is to choose a system sized to produce only the power you think you will use in a given net metering period.

GO WITHOUT BATTERIES

One of the greatest advantages of a grid-tied system is that you can avoid buying a large battery bank. Batteries in a grid-tied system only provide backup power during utility outages. This may seem like a good idea in theory, but the batteries make the system unnecessarily complex, less efficient and substantially more expensive. Batteries also contain hazardous heavy metals and last only for a limited time (they will need replacement about every five years). What's more, battery-based grid-tied systems take up more space and require more equipment.

A much better tool exists for backup power — a gas or diesel generator. If you expect long power outages in your area, you would want a generator just to avoid having to maintain a large battery bank. And once you have a generator, why have batteries at all?

PHOTOVOLTAIC OPTIONS

Photovoltaic (PV) modules (the panels that collect the sun's energy) come in two main types: crystalline and amorphous (also called "thin-film"). Both cost about the same for quality modules ($8 to $12 per installed watt), but they differ in the way they look and work.

Crystalline modules come in two types: mono and poly. Monocrystalline PV has blue or gray-black cells that don't completely cover the module face. A white backing usually shows at each cell's rounded corner, producing a visible pattern that some homeowners find unappealing. Polycrystalline cells are cut into rectangles that completely cover the white background, providing a more uniform appearance. They usually are a sparkly blue color. Both mono and polycrystalline modules are covered with tempered glass in an aluminum frame. Mono and polycrystalline PV perform similarly — your choice likely will be decided on availability, price and personal aesthetics.

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Amorphous PV has not been on the market as long as crystalline PV, and the first generation or two did not prove to be durable. Even now, most amorphous modules only carry a five-year warranty, although United Solar Systems' UniSolar amorphous PV carries at least a 20-year warranty and has maintained good performance after decades of operation. UniSolar's standing-seam thin-film laminates can be bonded directly onto a metal roof, creating a durable, uniformly dark surface that also is pleasing to the eye. Usually, the thin-film PV can be connected invisibly to its wiring under the roof's ridge cap.

Amorphous PV requires more space per generated watt than crystalline PV, but it has two significant advantages: High temperatures and partial shading do not affect amorphous PV as much as crystalline. For crystalline PV, electricity production is more affected by shadows; when just one cell is shaded, it blocks the flow of all electricity in that series. UniSolar amorphous PV transfers electricity using a weblike series of connections that bypasses shaded areas.

All PV modules produce less electricity the hotter they become, but the output reduction for amorphous PV is about half as much as it is for crystalline PV. If you use framed crystalline PV, mount the array 3 to 6 inches off the roof so it stays cooler.

The upfront cost for UniSolar's amorphous PV is high because of the roofing to which it is bonded. But if you are putting amorphous PV on a new structure or are re-roofing an existing structure, then UniSolar standing-seam modules probably are a good choice. As PV production increases, the price of amorphous should decrease to less than crystalline modules.

THE REST OF THE SYSTEM

The only other major component of your grid-tied nonbattery system is the inverter. The inverter changes the direct current (DC) created by the PV into the alternating current (AC) we use in North America. In a battery system, the inverter usually is sized for the maximum potential demand of your home during a power outage — and that typically makes it much larger and more expensive than nonbattery inverters that only have to be sized to handle the power produced by the PV system. The new generation of certified grid-tied, or "grid-interactive," inverters seems reliable, but you probably should choose a *high-voltage* DC inverter because they are less expensive to wire. (Low-voltage inverters only are necessary under a couple of specialized conditions, where you have more than three solar arrays, persistent shade or batteries.)

Inverter power ratings refer to the maximum continuous output. As a rule of thumb, the most cost-effective nonbattery grid-tied inverters are in the 2- to 6-kilowatt range.

THE SOLAR PAYOFF

The time it will take for your system to pay for itself depends on the amount of sunshine in your area; the cost of the system; local electric rates and future inflation; your state's metering laws; your system's type and size; and rebates and tax credits. A good installer should be able to work out all these variables for you on paper. Or once you have a system price quote, you can download the spreadsheets at here to calculate your approximate payback period and return on investment (see "Grid-tied Solar Money Management," Page 39, for examples). "Payback" is the number of years it takes for your electricity savings to equal the system's cost and maintenance.

If you live in an area where net metering is not available, a solar electric system for your home probably won't pay for itself during your lifetime, unless the declining supply of coal and oil causes unprecedented increases in the cost of electricity. Your money may be better spent on energy-efficient home improvements (see "The Size of Your System Relates to Energy Efficiency," Page 37).

Once you've estimated your system's kilowatt-hour production, you need to determine the cost of your utility electricity. This usually is a flat rate (the national average cost for electricity is almost 10 cents a kilowatt-hour) but some areas, such as California, have penalty-pricing structures in which high-usage households pay more for their electricity. A long-term financial analysis should include an estimated inflation factor for the cost of electricity (see "Solar Energy as an Investment," Page 39). The more expensive electricity becomes in the future, the faster your system will pay for itself.

The savings on your electric bill, unlike a stock market investment, will not be taxed. By investing in a solar system, you may get a higher rate of return on your investment than with an average stock market investment. If you are lucky enough to have Time Of Use metering (rates are lower for nights, weekends and off-season usage — available in parts of California, for example), your rate of return will be even better.

Doug Livingston is a former physics instructor who has designed renewable energy systems for a decade. He also is an instructor for the Solar Living Institute in Hopland, Calif. Scott Hollis is an associate editor at MOTHER EARTH NEWS.

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Grid-tied Solar Money Management

Calculate your payback period and return on investment.

Before you decide that a solar system is right for you, it helps to calculate the payback period of a potential system. For two examples, let's look at Mark and Kristin Sullivan's home in Capitola, Calif. (See the Sullivans' home specs, below; learn more about the Sullivan home, Page 16.)

Because the Sullivans' home is designed so efficiently, the couple's total energy use is so low that the house uses less power than most American homes — on average, less than 7 kilowatt-hours a day (kWh/day). In fact, the Sullivans' power consumption stays within California's first tier of the penalty-pricing bracket, which means they only pay 11.4 cents per kilowatt-hour for electricity — the lowest possible rate from their utility. In the Sullivans' region, the second penalty-pricing tier doesn't apply until their monthly consumption of grid power reaches 19.1 kWh/day in the winter and 10.4 kWh/day in the summer. Because of this, their system payback period will be longer than for a California home with more typical electricity consumption. (Go here for details on calculating seasonal production.)

The following payback analysis assumes a 5-percent annual increase in the price of electricity after the first year. The Sullivans produce about 4.7 kWh/day of photovoltaic power and use about 1.7 kWh/day of grid power sold to them at 11.4 cents a kilowatt-hour. This means the Sullivans' solar system earns about $196 in the first year [0.114 cents (grid price) x 4.7 kWh/day (PV production) x 365 days (year)].

Now let's calculate how long it will take the Sullivans to pay off their grid-tied solar system.

The total installed cost of the Sullivans' system was $11,563. Without rebates, tax incentives and grants, the system would pay for itself in the 34th year. But with a $3,992 rebate from the California Energy Commission and an $861 state tax credit, the couple paid only $6,710 for the system, which reduces the payback period to 22 years. A similar system with batteries would cost about $12,000 *after* rebates and incentives, and would have a payback of 41 years.

Let's calculate the payback period for an average California home that consumes 20 kWh/day (almost three times as much electricity as the Sullivans' home), using the same Sullivan system assumptions, including rebates and system cost. In this case, the average home would rarely step out of the lowest-priced tier during winter (19.1 kWh/day), but would regularly step into the second and third pricing tiers during summer (10.4 kWh/day).

In winter, the average home's daily PV production is about 3.8 kWh, which corresponds to 688 kWh over 181 days of winter (short days). Assuming the cost of first-tier grid electricity still is 11.4 cents, the total seasonal savings equals $78 for all winter PV production in the first year.

In summer, the average home's daily PV production is 5.5 kWh, which corresponds to 1,012 kWh total over 184 days of summer (long days). Because the cost of electricity increases to 17.6 cents per kilowatt-hour for electricity usage from 13.5 to 20.8 kWh/day, the total summer PV production equals $178. This translates into a payback period of about 18 years.

CALCULATING RETURN ON INVESTMENT (ROI)

So, how does investing in a solar power system compare with other investment options (such as the stock market)? I find the easiest way to calculate investment returns is on an accounting spreadsheet so I can change economic factors such as system cost, inflation, interest rates and the natural decline in the efficiency of PV panels, which we call the "degradation rate." (Download my Excel spreadsheet here)

Let's look again at the Sullivans' house, using the system cost and payback figures from the previous section; I have chosen to replace the inverter every 25 years and replace the PV every 50 years. First, let's assume a reasonable 5-percent electricity inflation rate (national oil prices have increased 4.2 percent annually since the Arab oil embargo of 1973) and an average annual system degradation of 0.5 percent. The Sullivans' 50-year investment will return a tax-free average profit of 7.5 percent per year. But if we plug in an estimated annual increase in electric rates of 8 percent, instead of 5 percent, then the system will return an annual profit of almost 25 percent. If electric rates rise as much as 20 percent a year, the value of a photovoltaic system skyrockets.

In theory, you are buying 50-plus years worth of electricity. The above calculations assume you didn't borrow the money to pay for your solar system, but borrowed money comes with an interest rate. Generally, the financial picture for debt-financed PV is unattractive because of high upfront system costs. Remember you have to subtract any loan interest costs from your electric savings.

— Doug Livingston

Solar Energy as an Investment

SULLIVAN HOME SPECS

- Array: 18 modules (12 volt/60 watt)
- Solar inclination: 37 degrees
- Inverter: 2,500-watt SMA-America SunnyBoy
- Total rated PV production: 1,080 watts
- Annual output: 1,700 kWh (4.7 kWh/day)
- Average daily power consumption: 6.4 kWh/day or about 2,300 kWh/yr.
- Grid power consumption: 1.7 kWh/day
- Gross installed cost: $11,563
- Rebates and tax deduction: $3,992; $861
- Adjusted installed cost: $6,710

50-YEAR RETURN ON INVESTMENT (ROI)

The main unanswered question in any investment analysis of solar power is how much the cost of grid electricity will increase in the future. Here are four scenarios that assume electricity costs will increase at different rates, from 5 percent to 20 percent per year. No one knows how fast electric rates will climb in response to the declining supply of fossil fuels and increasing environmental controls, but it's worth noting that the average cost of residential electricity increased 8.8 percent per year in California from 2000 to 2002.

Assumptions for Mark and Kristin Sullivan's house in Capitola, Calif.:

- Initial expense of $6,710 (after incentives)
- System output of 4.7 kWh/day with a decline in efficiency of 0.5 percent per year
- Initial electricity rate of 11.4 cents/kWh

If electricity cost increases at 5 percent annually, their ROI will be 7.5 percent.

If electricity cost increases at 8 percent annually, their ROI will be 25 percent.

If electricity cost increases at 10 percent annually, their ROI will be 53 percent.

If electricity cost increases at 20 percent annually, their ROI will be 2,130 percent.

Easy SOLAR Power

By Cheryl Long



Try new thin-film photovoltaic laminates and start generating solar electricity.

Installing clean, reliable, inflation-proof solar power is easier than ever, thanks to the invention of thin-film photovoltaic (PV) laminates that can be bonded directly onto metal roofing panels. Unlike crystalline PV material, there's no need for obtrusive racks and heavy, expensive glass. Instead, unbreakable thin-film PV is produced using amorphous silicon, encapsulated in Teflon and other polymers.

Thanks to pioneering work by Steve Heckeroth, a MOTHER EARTH NEWS contributing editor and the director of building-integrated photovoltaics for Energy Conversion Devices (ECD) Ovonics, this thin-film PV is now available in easily shippable, 16-inch-wide rolls. It's a peel-and-stick laminate. You just unroll the sheet, lay it face up on a flat metal roofing panel and press it onto the panel while your assistant pulls the protective sheet off the sticky backing.

Invented by ECD Ovonics co-founder Stan Ovshinsky, thin-film laminates offer several advantages over crystalline PV panels. Thin-film sheets perform better in high temperatures and in partly shaded conditions, and they require 100 times less silicon, which means thin-film PV is expected to become less expensive than crystalline as production capacity expands over the next few years.

We had a chance to get a firsthand look at this exciting new PV option after Heckeroth offered to install it on the new metal roof I was putting on my small barn last summer. We invited the public, and Heckeroth led a workshop about solar power. Nearly 50 folks spent an unusually hot, 100 degree May day watching and helping as Heckeroth showed volunteers how to bond the thin-film PV laminates to the metal roof panels. Then local architect and builder Kenton Knowles and his Global Homes crew installed the panels on the barn. As the photos on the following pages show, it's hard to imagine a simpler way to install grid-tied, solar-electric power on a new or replacement metal roof. It took only five to 10 minutes to apply each PV sheet to a roof panel.

Our new metal roof was 24-gauge Galvalume steel from Englert, Inc. It should last at least 50 years, and the steel can be recycled, making it an excellent sustainable choice for any building. After the roofing panels were installed, Heckeroth danced briefly along the ridge to snap the connecting wires together, and then our electrician, Robert Gore, wired the direct-current output from the thin-film PV into a Fronius inverter. The inverter converts the direct-current power generated by the solar panels to standard 110-volt alternating current. Then the power flows through the new meters installed by the utility company (at no charge!) and into my home.

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1 Peel off the backing of the PV strip and stick it onto the roof panel.


2 Raise the solar roof.


3 Snap one edge of the roof panel into place, with help from the rubber mallet.

The sun was blazing, and the roofers were really sweaty, but as soon as Gore flipped the switch, everyone smiled as the inverter kicked on and the digital readout quickly climbed to "1,530 watts," showing exactly how much electricity the new system was delivering to the house. Anytime the house needs more power than the PV is producing, the system draws from the utility grid.

WHAT'S IT GONNA COST?

The only hard thing about grid-tied solar power is paying for it, but it makes more economic sense every time the rising cost of oil pushes up energy prices. Now, ECD Ovonics' thin-film PV costs about the same as crystalline PV with glass covers and frames, $4 to $5 per watt, but it requires less labor to install.

In addition to the PV, you'll need an inverter (ours cost about $2,500), cables and switches, plus the services of an electrician and roofers. Then you subtract all tax credits, rebates and other incentives available in your state. The final cost will vary greatly depending upon where you live.

Two major variables will determine the long-term value of your PV system: 1) Your utility's electric rates and how much they increase over the 25-year life of your system and 2) State and federal incentive programs to promote renewable energy. Here in Kansas, a small system such as our grid-tied 1.8 kW setup would cost about $7,200 for the PV, plus $2,500 for the inverter and switches, plus labor. We can reduce this amount by claiming a federal income tax credit of about $2,000. Kansas unfortunately has no state incentives to encourage solar power development, nor has it passed a net-metering law that would require our utility company to pay us a retail rate for any electricity our system sends back to its grid. Kansas is lagging behind the rest of the country — 40 states have now passed net-metering laws and most have enacted incentives to support further development of solar, wind and other renewable energy options.

In nearby Colorado, for example, some utilities are paying rebates of up to $6 per watt to homeowners who install PV systems, thanks to a state law requiring utilities to generate 10 percent of their power from renewable sources by 2015. So in Colorado and dozens of other states that offer generous rebates and credits, solar power has become a very attractive option.

It's hard to predict exactly how fast a PV system will pay for itself, since nobody really knows how high the cost of grid electricity will climb as oil and gas prices rise (along with growing concerns about global warming) and how much the prices for PV will shift as demand and production capacity increase. But in the dozens of states that have decided it's wise to offer generous renewable energy incentives, investing in solar power already makes great sense. To find out what incentives are available in your state, go to www.dsireusa.org. For more about how to cal-

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CHERYL LONG; MATTHEW T. STALLBAUMER (5)

culate the payback period, see "You Can Afford Solar Power," Page 43.

A straight cost/benefit analysis is not the only factor to consider. If you choose to go solar, you will be supporting an industry that is poised to make a major contribution to the looming energy crisis and our global warming predicament. Buying a solar-electric system is one of the best things you can do to help protect our environment and to give your family some protection from skyrocketing energy prices and the uncertainties caused by climate change. Every homeowner who opts for clean, renewable solar power is taking us one more step toward a wiser, more sustainable human presence on Earth.

Cheryl Long is the editor in chief of Mother Earth News. She lives south of Topeka, Kan., on an eight-acre homestead and loves hearing her PV inverter hum every time she walks into her barn.

Learn More About Easy Solar Power

WATCH THE VIDEO

Online at www.MotherEarthNews.com, solar expert Steve Heckeroth explains how building-integrated thin-film solar power works. Heckeroth is a Mother Earth News contributing editor and the director of building-integrated photovoltaics for ECD Ovonics.

RECOMMENDED WEB SITES

www.dsireusa.org
Spells out the state rebates, loans and other incentives available for all renewable energy categories and for energy conservation.

www.homepower.com
Home Power magazine is an excellent resource for anyone who wants to learn more about solar or other renewable energy options. The Web site includes a directory of renewable energy dealers and installers.

www.nabcep.org
Find certified solar installers listed with the North American Board of Certified Energy Practitioners.

www.pvwatts.org
Determines how much power a PV system will produce at your location and lists local utility electric rates.

www.uni-solar.com
Through this site you can locate a solar installer who can give you a price quote on a building-integrated ECD Ovonics solar project.

RECOMMENDED READING

Got Sun? Go Solar
By Rex A. Ewing and Doug Pratt
This new book by two veteran solar experts provides a clear discussion of all the basic information homeowners need in order to choose a simple, grid-tied solar or wind system.

Basic Solar Power Stats

Average home electricity use:
Typical home: 900 kWh per month; 10,800 kWh per year
Energy-efficient home: as little as 420 kWh per month; 5,000 kWh per year

Estimated annual production per 1.0 kW of PV:
Amounts vary depending upon climate, latitude, local rates and PV system specifics; to calculate production for your location, go to www.pvwatts.org.

	Annual kWh AC production	Value of the PV production (current local rate per kWh)
Phoenix, Ariz.	1,617	$137 (8.5 cents)
Colorado Springs, Colo.	1,519	$128 (8.4 cents)
Miami, Fla.	1,339	$121 (9.0 cents)
Topeka, Kan.	1,310	$101 (7.7 cents)
Albany, N.Y.	1,159	$168 (14.5 cents)
Seattle, Wash.	970	$62 (6.4 cents)

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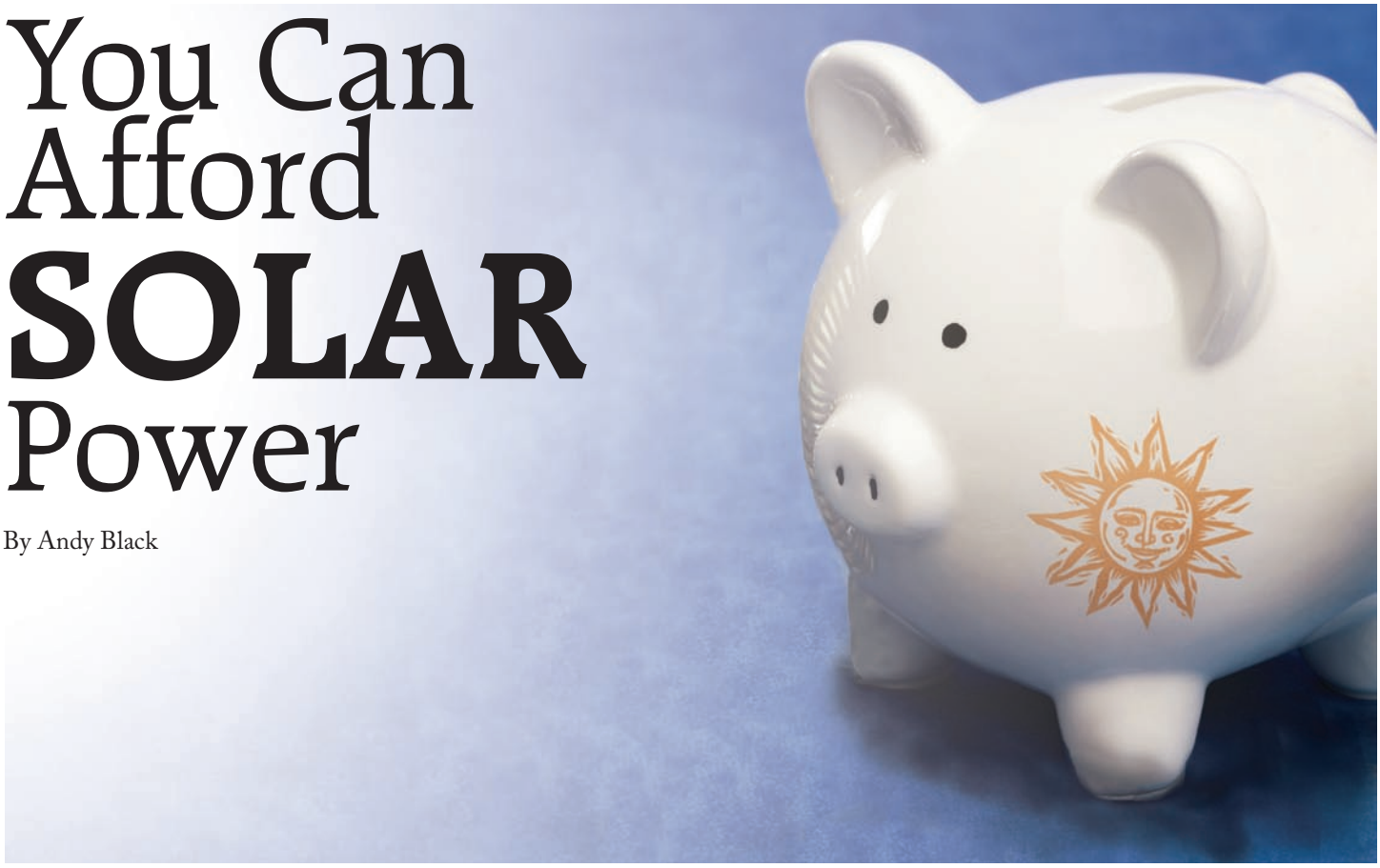
You Can Afford SOLAR Power

By Andy Black



Here's how to calculate the payback period for a PV.

For years, questions about returns on the expensive investment in a solar-electric system were dismissed with the analogy, "What's the payback on your swimming pool?" That sentiment might speak to the converted, but for most people considering solar power, the financial case is a major deciding factor.

Fortunately, photovoltaic (PV) technology has matured such that we now can offer serious answers to the payback question, backed by solid math and accounting. Answers vary significantly by local climate, utility rates and incentives, but in the best cases, the returns will be more than 10 percent, the cash flow positive and the increase in property value greater than the system cost. In other parts of the country where electric rates are low and incentives may be less, a grid-tied system may barely cover its maintenance costs.

WHAT FACTORS IMPROVE PAYBACK?

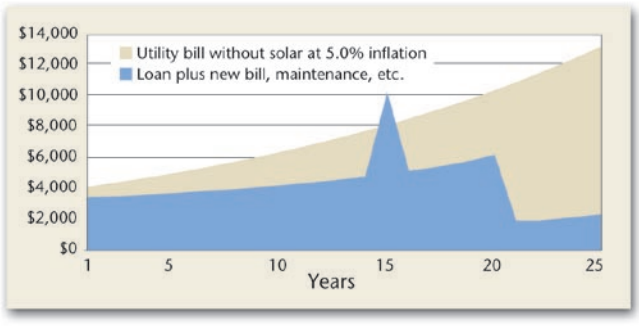
The most important factors for making solar an attractive investment include high electric rates, net-metering policies, financial incentives and good sunlight. Unlike the other factors, sunlight is available in almost all of the continental United States.

High electric rates can take various forms. California, Hawaii, New York and other states have average rates well above 15 cents per kilowatt-hour (kWh). California's tiered pricing system penalizes large residential users with prices as high as 33 cents per kWh. Solar energy offsets highest-tier usage first, making the customer look like a smaller net user.

Under most net-metering laws, which vary by state or utility, solar energy generated by users offsets the retail cost of the electricity they use. Even better, in California, solar systems are allowed to operate on a time-of-use rate schedule, which enables users to sell electricity back to the utility at peak rates, which can be even more

Figure 1. Power Costs Compared

This chart compares costs of utility bills without a solar system to costs of the solar system (loan, lower utility bill and maintenance). It assumes the PV system inverter is replaced at 15 years. The major drop at 20 years represents payoff of the loan.



ANDY BLACK/ONGRID SOLAR

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valuable. These high rates are the most important factor in improving the payback.

Direct incentives can include tax benefits such as credits or depreciation. A federal tax credit went into effect Jan. 1, 2006, for 30 percent of the cost of a solar system, up to $2,000 for residential systems (there's no cap on commercial credits). For PV systems, that typically means a $2,000 credit on your tax return for the year the system was installed. Then there are state incentives, including rebates, which can discount up to 60 percent of a system's cost. Some states also offer tax credits, which can further reduce the upfront cost of a system. Consult a certified tax adviser to check the applicability of such incentives to your situation.

A big factor in some calculations is inflation in electric rates. Solar power is an inflation-protected investment, because it offsets electricity costs at the current prevailing retail rate. As rates rise, the owner saves even more. New forms of incentives, including renewable energy credits, or "green tags," can be combined with net metering and other incentives. With these, a PV system can garner substantial revenue per kWh generated.

DETERMINING PAYBACK

There are several ways to measure the economic value of a solar system: compound annual rate of return, cash flow or increase in property resale value. In the best cases — California and New Jersey — common results are a rate of return well over 10 percent, positive cash flow and an increase in property value that more than covers the cost of the PV system.

Compound annual rate of return. This is another term for interest-rate yield, which is a way of comparing one investment to another. For example, a savings account might pay 1 percent interest, and the long-term stock market has paid about 10.5 percent. Solar systems in California, New Jersey and a few other locations can often produce a pretax compound rate of return of 10 percent or more.

Cash flow. The cash flow will be positive, either immediately or within the first few years, for many homeowners who finance their solar systems using home equity loans.

This calculation compares the estimated savings on the electric bill to the cost of the loan. Monthly loan cost is the principal-plus-interest payment required to pay off the loan, less any tax savings. In the case of "deductible" loans, such as home equity-based loans, the interest is usually tax-deductible, and thus the loan effectively costs less. Home equity loans often are excellent sources of funds because interest rates on real estate-secured loans are relatively low and payment terms can be long.

Inflation plays an important part. Inflation affects electric rates and thus effectively increases the savings from a solar system over time. Inflation doesn't affect loan rates, particularly with fixed-rate loans. Hence, as electric rates rise, the savings grow, but the cost of the loan stays relatively constant (it rises a little over time as the interest portion of the payment falls, which cuts the tax deductibility). See Figure 1, Page 43, for an example. Note that this is an ideal case in a state with the best incentives.

The accumulation of net annual savings is free and clear with no initial outlay of cash, because that was covered by the loan. The savings are small though significant in the first years, but really jump when the loan payments stop.

Increased property resale value. Homes with solar-electric systems increase in value because the systems decrease utility operating costs. According to a 1998 article by Rick Nevin and Gregory Watson in The Appraisal Journal, a home's value increases $20,000 for every $1,000 reduction in annual operating costs from energy efficiency.

The rationale is that the money from the reduction in operating costs can go toward a larger mortgage with no net change in monthly cost of ownership. Nevin and Watson state that historic mortgage costs have an after-tax effective interest rate of about 5 percent. If $1,000 of reduced operating costs is redirected toward debt service at 5 percent, it can support an additional $20,000 of debt. Instead of paying the utility, the homeowner pays the bank, but total monthly cost of home ownership is identical.

This increase can effectively reduce the payback period to zero years if the owner chooses to sell the property immediately, and it removes the purchase risk. It could even lead to a profit on immediate resale in some cases.

Currently, this increase in property value is theoretical. Many of the existing grid-tied solar-electric systems have been installed since 2001. Most of these homes have not been sold, so no broad studies of comparable resale values are available. However, emerging evidence suggests that some solar homes are seeing significant jumps in resale value.

For example, a 2004 National Renewable Energy Laboratory (NREL) study demonstrated that San Diego zero-energy homes with solar features increased in value faster than comparable conventional homes in a nearby community. On average, the homes increased in value $40,000 more than the conventional homes, at a higher rate of appreciation and with a shorter length of ownership.

PV systems will appreciate, rather than depreciate, for several years. Appreciation comes from the increasing annual savings the system will yield as electric rates and bill savings rise. It cannot continue forever, however, as the increase in resale value reaches a limit determined by the savings potential during the system's remaining life. For these analyses, the system is assumed to be worthless at the end of 25 years. (This estimate is conservative, since panels typically are warranted to work at 80 percent of their as-new capability when 25 years old.) If the system is worthless after 25 years, its only value as it nears that time is the savings it can generate before the end of the 25th year. The remaining-value limitation takes over in about the 11th year. (See Figure 2, above, for an example.) As the NREL resale study suggests, however, actual resale value could be much higher depending on the market mood for solar.

MARKETS REWARD INVESTMENT

For more information on calculating PV system payback, go to www.ongrid.net/payback. Be aware that some tools don't account for tiered or time-of-use electric rates in interaction with PV production, and therefore their results may over- or underestimate the value of a PV system in a particular situation.

Going solar, like any other major purchase, is a "buyer beware" situation. In addition to avoiding oversimplified estimates, be cautious of aggressive sales pitches and overly optimistic financial analyses.

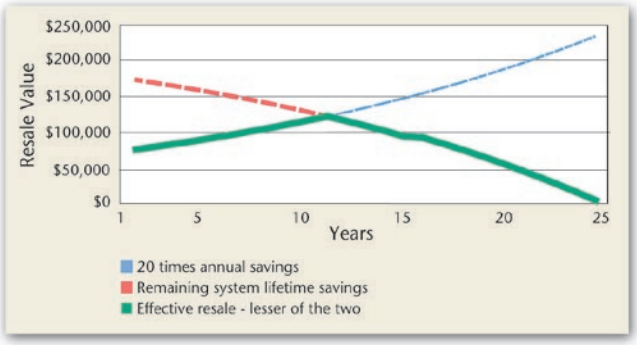
Solar has finally come into its own in certain markets, which are exploding because individuals are discovering the financial benefits of owning PV systems in those regions. To encourage widespread adoption of solar energy, we need to empower everyone with this knowledge and expand the components that make it possible — tiered rates, time-of-use net metering and renewable energy credits. Market forces will take it from there.

Andy Black owns OnGrid Solar, which provides solar financial analysis tools and consultation. He is a board member of the American Solar Energy Society (ASES). He teaches and consults regularly on the payback of solar electricity. Contact him at (408) 428-0808 or www.ongrid.net.

This article was reprinted from Solar Today, the excellent magazine published by ASES. A year's subscription is only $29, a bargain for anyone interested in the latest news on solar and other renewable energy technologies.

Figure 2. Solar and Property Value

This chart shows changes in value of a property with a solar system. It appreciates until about year 11, then is limited by the savings the system will provide in its remaining lifetime.



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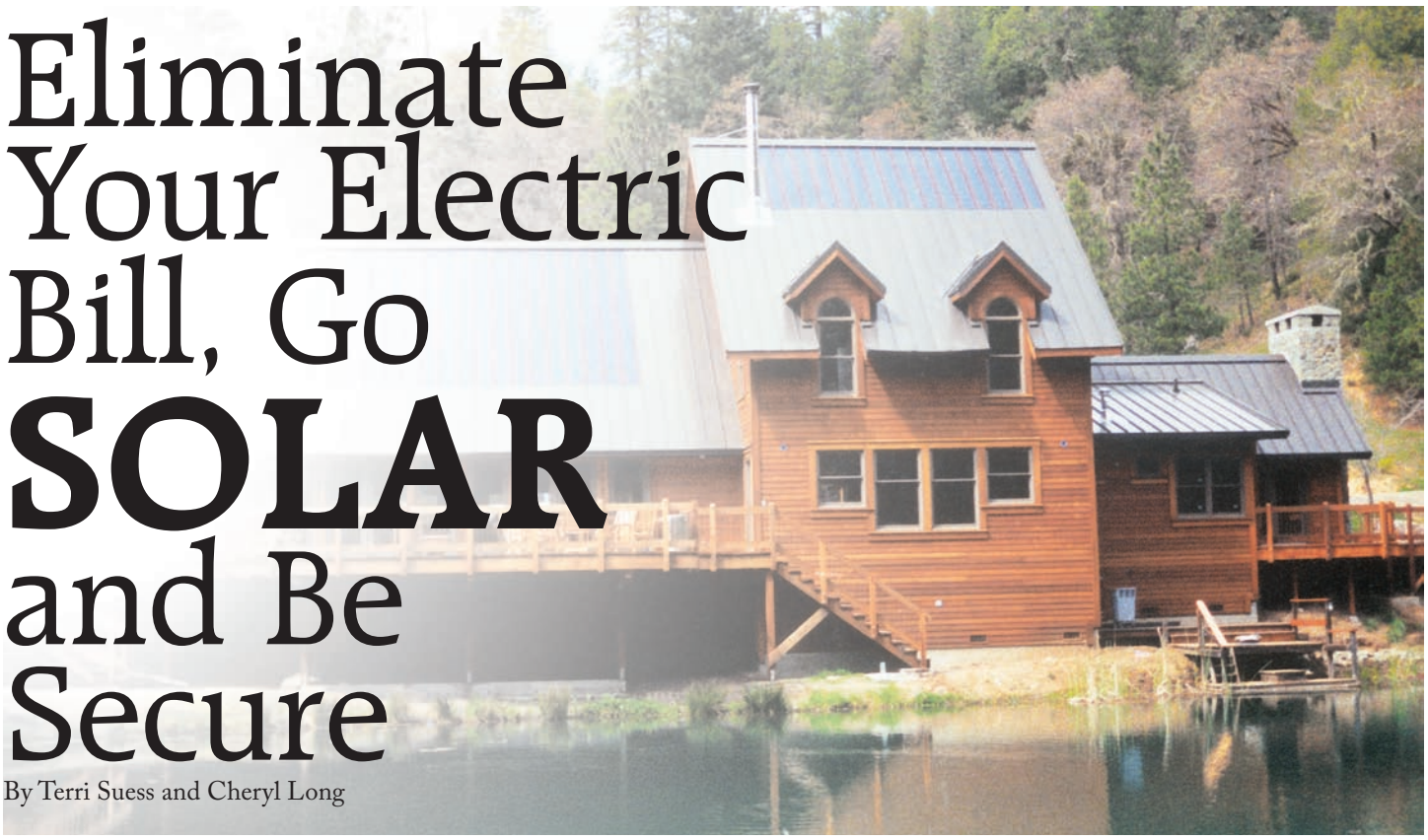
Eliminate Your Electric Bill, Go SOLAR and Be Secure



DANIEL MARINO

By Terri Suess and Cheryl Long

You can install a solar photovoltaic roof, which will generate your electricity from the free, unlimited supply of sunshine.

This story is about a choice that can make you, and the world, more secure. With your very own solar-electric roof, you'll be protected from rising electricity prices. You'll also take a major step away from our national dependence on polluting, unsustainable fossil fuels and dangerous nuclear reactors.

"Solar PV is too expensive," you're probably thinking. Or maybe, "Our neighbors might think solar panels are ugly." Well, advances in solar PV technology are rapidly resolving both of those concerns.

A new kind of PV panel, called thin-film amorphous silicon, is dramatically bringing costs down. Government rebate programs are also cutting homeowners' costs by as much as 60 percent in some states. And in some cases your solar roof can generate excess power during peak daylight hours that you can sell back to your utility company (or use to recharge an electric car or bike). Regarding aesthetics, the thin-film PV panels are now being produced as shingles and standing-seam roofing panels that closely resemble regular roofing materials, so you don't even realize the home's roof is actually a solar-electric power plant!

These new solar-electric systems are called building-integrated photovoltaics (BIPV), because the photovoltaic panels become the roof itself. BIPV installations eliminate the need for expensive racks and trackers, as well as the additional labor costs associated with them.

Ready to sign up? To get started, all you need is a few hundred square feet of south-facing roof that receives full sun all day. You can start small if you want and add more panels later. A solar roof system is actually simple — the right number of panels to produce the number of watts you want, wired to an instrument called an inverter. The inverter changes the solar direct current (DC) into the alternating current (AC) used by most household appliances.

Unless you already know a lot about electricity, you will want to find a local solar dealer or contractor to install your system. If possible, obtain bids like you would for any other home construction project. If you want to install the system yourself, or just want to learn as much as possible before you choose a system, we highly recommend the magazine *Home Power;* (800) 707-6585. The Home Power Web site also lists renewable energy dealers in a database that can be searched by state.

CURRENT COSTS

Heckeroth says a basic PV system in a net-metered grid-connected system (see "Types of PV System," Page 47), costs about $8 to $12 per installed watt, so a two kw system would come to $16,000 to $24,000. But if you are lucky enough to live in a state that offers rebates that cost can be cut in half to just $8,000 to $12,000.

So there it is: Right now it can cost as little as $8,000 to install enough solar roofing to meet the long-term electricity needs of a small, efficient home. (By the way, "long-term" means a 20- to 25-year warranty; there are no moving parts and these solar PV panels are very durable.) And the great thing is, the more of us who buy solar roofs, the faster the costs of production and prices will come down. All new technologies become less expensive as

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UNI-SOLAR

Uni-Solar's breakthrough solar electric roofing comes in rolls or shingles and can be applied directly over plywood. A thin layer of amorphous silicon generates the electricity. The silicon is applied to a stainless steel foil and then coated with a flexible, weatherproof polymer.

demand grows and production costs improve. Within the next two to three years, Heckeroth predicts the installed costs of thin-film BIPV roofs (see "Advantages of Thin-Film Solar PV Panels") will drop to as little as $6 per installed watt for reroofing projects, and costs could fall to $5 or less per watt in new homes designed specifically to maximize the advantages of this exciting new technology.

In areas where electric rates are already high, solar PV systems are a pretty good bet at $8 per installed watt, even without a rebate and without adjusting for future electricity rate hikes or declining costs per PV watt.

GOVERNMENT INCENTIVES

Some states need solar electricity so badly they're not waiting for the costs to come down naturally. They are offering cash rebates and other incentives that will slash the price tag for residential solar roofs by up to 60 percent. More states may join in this year, as policy-makers work to meet increased electricity demand by promoting clean renewables and distributed generation-installing many small power-generating systems close to where the energy is needed. These officials understand people don't want polluting coal plants or dangerous nuclear plants near their homes, and people do not much like living next door to high-tension wires or natural gas pipelines, either.

For information about rebates, loans and grants available in your state, consult the Database of State Incentives for Renewable Energy (DSIRE), or call your local utility or state energy office. (If your state isn't yet offering rebates, we strongly suggest you get on the phone and make an appointment to have a chat with your state legislators.)

Here are summaries of solar energy incentives available in three leading states: New York, New Jersey and California.

NEW YORK

"In New York state, we are facing an energy crisis that is not going to go away simply because demand is exceeding supply," says Linda Anne Burris, director of NY Shines, an organization dedicated to educating homeowners about solar and renewable energy systems. "There is a thirst for energy that is difficult to meet, particularly in New York City and Long Island, where the electricity infrastructure is old and pushed to its capacity."

Burris says New York currently offers some of the best rebates in the country when homeowners purchase residential solar, grid-connected solar-electric systems. "Most people in the industry will tell you that it costs about $10 per watt to install a solar-electric system on your home without batteries," she said. "In New York State, when homeowners tap into an array of rebate programs, they can cut that price by almost one half."

NEW JERSEY'S CLEAN ENERGY PROGRAM

In New Jersey, small solar-electric systems of fewer than 10 kilowatts qualify for a rebate of $5 per watt. The rebate covers up to 60 percent of the system costs under a program

Advantages of Thin-Film Solar PV Panels

Most people know solar photovoltaic (PV) panels as large, heavy, rectangular panels mounted onto a roof or sometimes on a special rack with a tracking system that turns the panels to keep them facing the sun. These older style panels are made of crystalline or polycrystalline silicon modules. In contrast, a new kind of PV panel is now available, called thin-film amorphous silicon. Here's how the new thin-film panels compare to the crystalline modules:

- The older crystalline and polycrystalline modules are fragile and need to be mounted in an aluminum frame between a layer of glass and a stiff-bottom material. In contrast, the newer thin-film amorphous PV panels use a thin stainless steel foil and a weatherproof plastic "elastomer polymer" coating. As a result, thin-film panels are unbreakable, much lighter and less expensive than the crystalline products, since they don't require glass covers and metal framing.
- The crystalline panels lose efficiency and produce less electricity when temperatures rise, while thin-film panels are not bothered by hot, sunny conditions.
- Crystalline panels stop producing electricity when even one portion of a panel is shaded, while thin-film panels still produce energy when partially shaded. Thin-film panels are also more efficient than crystalline in indirect or diffuse light, making expensive tracking systems unnecessary.
- The production process for the thin-film panels requires much less energy (and costs less) than crystalline panels.
- When used as roofing shingles, thin-film panels actually are the roof, so you can save the otherwise additional cost of regular roofing. New quick-connect features and large panels are making thin-film roofing faster, and thus less expensive, to install.

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About Net Metering

Net-metering is a "win-win" for utilities and homeowners. The utility adds more clean power to its network from a power source located close to demand centers, reducing not only the need to build new plants to meet peak demands but also the load on distribution lines.

The process is a win for the homeowner, who doesn't need a bank of batteries to store electricity to power the household at night or during overcast days. Instead the system uses the utility grid as a storage battery.

When the solar-electric rooftop produces more electricity than the household needs (at midday, when the family is away at work and school), electricity is sent to the utility grid and the home's meter runs backward. When the household needs more electricity than the system produces (at night), it is drawn from the utility grid and the electrical meter runs forward.

The net difference between electricity exported to the grid and grid-electricity used forms the basis for the homeowner's electric bill. In many states, net metering is annualized. The utility credits solar electricity produced by the rooftop system during the summer against electricity needed from the grid during the winter.

funded by the state and administered by utility companies. New Jersey also provides a sales tax credit for solar-electric system installations.

By fall 2001, there had been little publicity about this program, with most applicants finding out about it by word-of-mouth. One of the major utilities in the state reported in late August only 16 applications had been processed. Some of the impediments to the program included lack of publicity and early difficulties homeowners had locating solar contractors. Now a short list of utility-qualified contractors is provided to interested homeowners.

CALIFORNIA'S REBATE PROGRAMS

California has myriad state, local and utility-sponsored rebate programs, state property tax exemptions and other incentives to help homeowners install solar electric rooftops — and they are being used. Some solar programs in California reported receiving 250 inquiries a week.

The "Emerging Renewable Buy-Down Program" and "Self-Generation Program" both offer rebates of up to $4.50 per watt or 50 percent off the price of purchasing the system, whichever is less.

The Los Angeles Department of Water and Power (LADWP) offers even more generous rebates as part of an effort to install 100,000 solar root tops in the city of Los Angeles by 2010. Under the LADWP program, financial incentives include a maximum $3 per watt for systems manufactured outside of Los Angeles, and a maximum of $5 per watt for systems manufactured within the city.

TO FIND A SOLAR ROOF DEALER

The fastest way to learn what rebates are available in your area is to contact a local solar roof dealer. The dealer will know what's currently available and probably will know if any additional legislation is pending in your state. The dealer can explain, in detail, various solar roofing options and give you a bid on whatever system you choose.

To find a dealer check your yellow pages, state energy office, electricity regulatory agency or local utility. Or check *Home Power* magazine's dealer Web page at www.homepower.org.

MAKING A DIFFERENCE

"Each of us can decide how to make our own contribution to reduce our impact on the Earth," says Bill Lord, who lives with his wife, Debbi, in a custom-built solar house in southern Maine.

"Ours happens to have been investing in a solar house. We have found that there can be a free lunch and dinner, but you need to pay for breakfast," he says, referring to the initial planning and investment needed to integrate solar technologies into one's home.

The Lords integrated passive solar design principles, solar thermal and solar electric technologies into their custom-built home in Maine more than five years ago. Since then they have been reaping the benefits of free sunlight that falls on their roof every day, reducing their utility bills to zero.

Working with Solar Design Associates of Harvard, Massachusetts, the Lords built their home to include super insulation, energy-efficient appliances, and a passive-solar design that welcomes the warm sun in the winter and shades the interior of the house in the summer. This reduced the energy load of the home while offering comfort levels exceeding those found in a comparable conventional home.

With a full south-facing solar rooftop comprised of a solar thermal system for radiant heating and hot water, and a solar electric system to produce electricity, the home's solar systems provide nearly all the energy the Lords need.

"It takes some planning, but it is possible to make these investments incrementally to reduce the cost of living on Earth," says Lord. "The beauty of solar electricity is it is modular, so you can install some to meet a portion of your electricity needs and then expand the system as your budget allows."

Types of PV Systems

There are several ways a solar photovoltaic (PV) roof system can be designed:

Grid Connected, without battery backup. In this system, the PV roof is connected directly into the commercial utility grid. When the PV roof generates more electricity than the house needs, the electric meter spins backward, and the power flows into the utility grid. At night or on cloudy days when the PV roof can't produce enough power for the home, the system draws electricity from the grid. (See "About Net Metering," left.) Without batteries, these systems do not provide power to homeowners when grid power goes down.

Grid Connected, with battery backup. This is identical to the system above, except it includes a bank of batteries that can be used when the utility grid power goes down. Special switches must be included to assure the home is completely disconnected when the grid power goes down and battery backup is used. While batteries can be installed to supply power when the grid is down, they are expensive and require more maintenance than a simple grid-connected system.

Stand-Alone, Independent or Off-Grid System. In this design, surplus power from the PV roof is stored in a group of batteries, and the system is not connected to the grid. Although the battery component of this system increases the cost and requires more maintenance, a complete off-grid system is usually a competitive choice in remote locations where new and extremely expensive power lines would need to be installed.

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A Simple SOLAR Solution

By Laurie Guevara-Stone



SOLAR ENERGY INTERNATIONAL

Living off the grid is a cost-effective option when you have to pay big bucks to connect to utilities.

Chris Banks and Paula Minucci were faced with a decision. Just bringing electric service to their beautiful mesa homesite near Carbondale, Colo., was going to cost thousands even though the site was less than a mile from the nearest utility line. They wanted to have all the modern-day comforts, but couldn't convince themselves that forking over $8,000 to connect to the utility — and then to be burdened with a lifetime of electric bills — was a wise investment. Instead, they decided to put their money where they could reap a return: in a photovoltaic (PV) system.

Even before he was faced with the sticker shock of connecting to the utility grid, Chris was interested in using solar energy. "[Resources] are going away faster than [they are] being replaced," Chris says, "so any way to conserve helps out in the big picture."

SIZING THE SYSTEM

Chris and Paula visited Sunsense, Inc., a local PV dealer and installation company in the Roaring Fork Valley of Colorado, to discuss their energy requirements. Sunsense owner Scott Ely showed them different equipment

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The Power of PV

A single PV cell is made of highly purified silicon that is doped to create a voltage difference on each side of the cell. Sunlight striking a PV cell knocks electrons loose, which frees them to flow in a current. Metal contact points on the top and bottom of the cell draw the current off for whatever external use is intended.

On a bright, sunny day, the sun shines about 1,000 watts of energy per square meter of the Earth's surface; if we can just collect part of that energy economically, we can easily power our homes and offices with sunlight instead of oil. (For more amazing science, visit Howstuffworks).

System Components

- 8 75-watt Siemens photovoltaic (PV) modules
- 4 100-watt Siemens PV modules*
- Ananda Powercenter 3
- Trace 4024 Inverter
- 8 Trojan L-16 Batteries

System costs

8 75-watt Siemens modules	$2,400
Mounting	$400
APT Powercenter	$1,700
Trace 4024 Inverter	$3,200
8 Trojan L-16 Batteries	$1,500
Miscellaneous materials	$650
Shipping	$100
Tax	$250
Labor	$850
Total	**$11,050**

*Four 100-watt panels were added later, at a cost of $1,800.

options, and explained what they could expect from a PV system. Ely and his associates also visited the Banks-Minucci building site to determine the best placement of the system and help them calculate their electric loads.

Chris and Paula have many of the typical electric needs of a U.S. family: lights, toaster, blender, hair dryer, juicer, stereo, television, refrigerator and washing machine. Along with lighting needs, refrigerators, washing machines, electric heaters, air conditioners and electric ovens usually are the biggest electrical loads in a house. Thanks to their lower consumption of energy, high efficiency refrigerators and horizontal-axis washers are easy to run on solar electricity. (Appliances that use electricity to generate heat such as electric stoves and heaters are relatively inefficient and not well-suited to solar electric.) Chris and Paula bought a Sunfrost refrigerator and a Staber washing machine, which both retain their warranties even connected to a PV system. Highly insulated Sunfrost refrigerators use about one-quarter of the energy of conventional refrigerators. Their Staber washer, besides saving about two-thirds of the water typically used, also cuts energy usage in half, compared to vertical-axis washers. Chris and Paula also chose energy-efficient compact fluorescent light bulbs, which require one-quarter of the energy used by incandescent light bulbs. Just this simple switch — investing in 10 15-watt compact fluorescent lights, instead of 10 60-watt incandescent lights — can make the difference in buying three to four fewer 100-watt PV panels — a savings of thousands of dollars.

Using the calculations the couple provided to him, Ely designed an eight-panel "starter" system that could be expanded to 12 panels as the budget allowed. A backup propane-powered generator, says Ely, was the ace in the hole that enabled the initial implementation of a smaller, more inexpensive system. (You can calculate your own household's energy loads by using the Electric Load Estimation chart below and the Wattage Chart on Page 50.)

SITING THE SYSTEM

Because even a small amount of shade can drastically reduce output, multicrystalline PV panels generally are installed in a "solar window" — an outside area that receives no shade from 9 a.m. to 3 p.m. To effectively access this solar window, PV modules can be mounted on a roof or a pole, or on a rack that is set on the ground. Another option is to use newer building-integrated PV (BIPV) arrays, which are integrated into the roof or applied to the existing building's exterior. These thin-film panels are less sensitive to shading.

Ely advised Chris and Paula as to how far the panels could practically be mounted from the house, and together the three of them figured out the best location. Paula was adamant about keeping the house's appearance streamlined, which meant leaving the panels off the roof. They also wanted to preserve the home's attractive entryway and didn't want panels visible from the house or the driveway. Eventually, they found a perfect sunny spot behind the house to place the array.

Pole-mounted PV systems have the advantage of being able to be connected to a tracking mechanism that follows the sun from east to west (and, in the case of dual-axis trackers, from horizon to sky). Tracking systems can increase the amount of power a multicrystalline PV system annually produces by up to 25 percent. Although trackers are well-suited for applications such

Electric Load Estimation

Load	Qty	x	Volts	x	Amps	=	Watts AC	Watts DC	x	Use (hrs/day)	x	Use (days/wk)	÷	7 days	=	Watt-hours AC	Watt-hours DC
		x		x		=			x		x		÷	7	=		
		x		x		=			x		x		÷	7	=		
		x		x		=			x		x		÷	7	=		
		x		x		=			x		x		÷	7	=		
		x		x		=			x		x		÷	7	=		
		x		x		=			x		x		÷	7	=		
AC: Total Connected Watts										AC: Average Daily Load							
DC: Total Connected Watts										DC: Average Daily Load							

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as a batteryless water pumping system, which can use solar energy the second the sun comes up, for many applications it's more economical to add another panel or two than to invest in a tracker. The Banks-Minucci system is the best of both worlds: a pole-mounted system that can be manually adjusted throughout the day and year. To capture the most from the sun, Chris adjusts the tilt of his panels to different sun angles throughout the year. To follow the sun's arc through the sky, Chris daily repositions the panels. He doesn't think of it as work or an inconvenience, but takes a special enjoyment in what he considers "farming" the sun.

SYSTEM COMPONENTS

PV panels are only one part of a solar-electric system. For the Banks-Minucci off-grid application, eight deep-cycle batteries store electricity for nighttime and cloudy-day use. A controller keeps the batteries from being overcharged, and an inverter converts DC electricity produced by the solar panels into AC electricity typically used by home appliances. A 4,000-watt inverter, oversized for their initial system, provides expansion possibilities if Chris and Paula want to add more energy production.

Wattage Chart for Typical Appliances

Description	Watts
Refrigerator* (22 cu. ft. auto defrost)	300
Dishwasher (cool dry)	700
Microwave*	300
Coffee maker (warming)	600
Toaster (2-slice)	1,200
Blender	350
Television (25-inch)	170
CD player	25
Stereo, AC-powered (avg. volume)	55
Fluorescent Light (60-watt equivalent)	15
Electric Clock	4
Clothes Washer* (vertical-axis)	650
Clothes Washer (horizontal-axis)	250
Vacuum Cleaner	900
Computer (Modem/desktop)	55
Inkjet Printer	35
Hair dryer	1,500

*Does not include startup power

LIVING WITH THE SYSTEM

Unlike grid-connected systems, stand-alone photovoltaic systems require more owner involvement, and maintenance is essential to keep a system functioning properly. But in the past seven years since the system was installed, Chris and Paula have called Sunsense only a few times with questions or problems.

Both feel that living with solar hasn't dramatically changed their lifestyle. "Conserving energy is not a sacrifice, but more of an awareness," says Chris. Although he and Paula considered themselves "environmentally conscious," they both admit they now are much more aware of the instant payoff of their energy conservation — and the almost instantaneous repercussions of being neglectful: If you leave the lights on, the PV system runs low, the generator goes on and the propane bill goes up.

Chris and Paula do use their backup generator in the winter more than they would prefer. Two years ago, when they realized they needed more power and had a few extra dollars to invest in their system, they decided to add four 100-watt panels, bringing their entire system's energy production capabilities to 1 kilowatt. Instead of hiring out the job, Chris made a couple of calls to Solar Energy International, a renewable energy education center. With SEI's advice and Ely's previous work, he integrated the four new panels himself.

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Easy DIY SOLAR Lighting

Learn renewable energy basics and generate serious solar excitement!

By Charles Higginson



Lights! Camera! Solar! The lights on our demo unit came on the first time we flipped the switches.

CHERYL LONG

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Navigation Bar

Many people dream of solar-electric power for their homes, but can't afford whole-house systems. Here's an affordable, entry-level system with which you can have fun and get to know the basics of solar power. This setup, built with a small photovoltaic (PV) panel, one battery and low-power direct current (DC) lighting fixtures, can bring solar lighting into your home or remote locations. If you can turn a screwdriver, you can install it yourself.

This project can augment your existing 110-volt lighting circuits. It's a great introduction to simple solar circuitry, it's easy to build, and it produces useful light for several hours a day. Not only will it impress your friends and neighbors, but you'll also enjoy the satisfaction of using clean, renewable energy.

In most home settings, it probably won't save you money, but in other circumstances this system could save you a bundle. If you want lights in a cabin, garage, barn or garden shed that's far from installed power lines, this project could be far less expensive than hiring professionals to extend standard power to the building.

Our friends at Gaiam Real Goods, the pioneering retailer of renewable energy products, helped us design the Mother Earth News Low-Voltage Solar Light System (to order it as a kit, see Page 53). The key is its use of energy-efficient loads and low-voltage, DC components and circuitry. That combination keeps total power demand low and simplifies installation. Compact fluorescent light bulbs (CFLs) and light-emitting diodes (LEDs) are available in 12-volt DC forms, and they're ideal components for a small, off-grid supplemental lighting system. You can easily build a system that will run, say, two or three CFLs for two hours each evening and an LED for five hours — all powered by a small battery charged by a small solar panel.

We spent about $760 on solar components and about $80 on other parts. For ideas on reducing costs, see "Ways to Save on a Solar Light Setup," Page 54.

Once installed, the system has no operating cost and needs little maintenance. The light bulbs are rated to operate for thousands of hours, so they will survive for years when lit for a few hours a day. Both kinds of bulbs cost more than regular incandescent bulbs, but prices are dropping, and they will save you money over the long term. Plus, with this system you won't pay a penny for electricity. The PV panel in our kit is warranted to produce at least 80 percent of its rated output for 25 years. The battery has the shortest life of all the components; the type we used will typically last three to five years. (For specifications on components, see Page 53.)

EASY SOLAR POWER

The generating and storage system has three major parts: a small PV panel, a battery and a charge controller. The PV panel generates electricity whenever sunlight strikes it. The battery stores the electricity, so the lights can be operated at night. Since most cars use 12-volt DC circuitry, it's tempting to use a car battery, but this would work only for a short time. Car batteries provide large current flows in brief bursts and don't respond well to being discharged deeply. Here, the battery provides small current flows for long periods and may be discharged fairly completely, so you must use a deep-cycle battery. Several deep-cycle technologies exist; we chose a gel type, which is maintenance-free.

On its way from the PV to the battery, the electricity is routed through a charge controller, which ensures that the battery gets all the power it needs to stay fully charged. It also prevents over-charging.



A 15-watt compact fluorescent produces as much light as a 60-watt conventional bulb while using a quarter of the energy.

How big a battery and panel do you need? To answer these questions, work backward from your desired end result: how much light you want for how many hours a day. We settled on three 15-watt CFLs, which could be distributed around the house for general lighting, each one operating for an hour a day (each CFL's light output roughly equals that of a 60-watt incandescent bulb). We added an LED light bulb and assumed it would operate for five hours a day, pulling the modest total of about 3 watts. LEDs tend to provide very directional light. In the home, this means they're not the best choice for general ambient lighting, but they're great for focused task lighting. (If you want more light than this, the tech folks at Real Goods can help you choose the right components.)

CAUTION: MATH AHEAD

Here's a summary of the process of sizing your system. Once you've chosen lights and estimated daily usage, calculate watt-hours (Wh). In our case, it goes like this:

(3 CFL bulbs x 15 watts) x 1 hour/day
+
(1 LED bulb x 3 watts) x 5 hours/day
= 60 Wh/day

Having figured daily watt-hours, you can calculate the necessary battery capacity, measured in ampere-hours (Ah). This involves several factors. First, Norman Franks, renewable energy technician at Real Goods, says battery life is determined by depth of discharge and the number of times the battery is discharged. Franks likes to specify a battery that could power the system for three days without being recharged, to cover cloudy days. Second, he says these batteries should not frequently be discharged below 50 percent of capacity. Third, in practice you'll get about 80 percent of the rated Ah from a battery before its voltage drops below a useful level.

Taking all this into account, Franks recommended a battery for our system rated at 50 Ah. This is a little overcapacity but would allow expansion in the future.

PICK A PV PANEL

How much PV will you need to keep the power flowing? We already know we need 60 Wh per day. To account for various inefficiencies in the system, multiply that by two, yielding 120 Wh. In a typical U.S. location, you've got five hours a day of good sun with which to generate watts, so dividing 120 Wh by five hours yields 24 W. That's the minimum generating capacity of a PV panel that will drive this system.

But there are several reasons to upsize from the minimum. Climate is one; in cloudier areas, you'll need more PV to get the same power. Seasons are another; a panel that's adequate in optimum conditions may let you down in mid-winter. Economics also enters the picture. Franks says the cost per watt rises sharply with PV panels below about 40 watts. We chose a 50-watt panel, in part because it was in stock and well priced, and in part to get excess capacity to allow for low winter sunlight and perhaps for system expansion.

Having chosen a battery and panel, it's time to consider the charge controller and safety disconnect. You need to ensure that your total loads don't exceed the charge controller's capacity. In our case, a 10-amp charge controller would have ample capacity. However, if you anticipate expansion, you might as well get a bigger charge controller from the start. We settled on a 20-amp model that would accommodate the addition of another similar PV panel and/or extension of our lighting circuits.

Safety disconnects are heavy-duty switches used to isolate the battery from all other components for maintenance or in emergencies. They're not necessary for operation, but even in a small, low-voltage system like ours, they are highly recommended for safety.

We also picked up a fuse block. It functions like the breaker panel in standard home wiring: The main power source (battery) feeds to positive and negative main terminals, and the individual lighting circuits, protected by fuses, connect to charged secondary terminals.

Solar panels require solidly anchored mounts. Since our panel is so small, we opted for a simple set of feet designed for mounting panels on recreational vehicles. You could easily fabricate an adequate mounting system of your own.

MISCELLANEOUS PARTS

Standard, widely available AC components complete the system — wire, cable, switches and

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The Mother Earth News Low-voltage Solar Light System

(Designed by Gaiam Real Goods renewable energy technician Norman Franks)

Our system is about as simple as solar electricity gets, because of the low-voltage lights and grid-independent DC circuitry. Staying grid-independent means you don't interact with the alternating current (AC) standard in home wiring, so there's no need for the inverter and meter usually associated with grid-tied systems.

CAUTION: Lightning is a hazard if you mount your panel high on a frame or roof. Because we intended to use this system as a portable demonstrator, we didn't include lightning protection, but it must be considered in a permanent installation. Real Goods can provide adequate guidance and protective components.



MATTHEW T. STALLBAUMER

Kyocera photo-voltaic panel: $345
- Generates electricity from sunlight.
- 50-watt, 36 cell, polycrystalline silicon.
- 25"x26"; weighs just 11 pounds.
- Warranted to remain within 80 percent of rated output for 25 years.



CFLs: $19 each
12-volt, 15-watt.

LED bulb: $45
12-volt, 3-watt.

Bulbs and switches installed on board for demonstration purposes only; you can distribute lights anywhere in your home.

Power in from PV panel

Power out to switches/lights

Phocos charge controller: $55
- Monitors battery charge, directing power from PV to battery when needed; prevents overcharging.
- 12-volt, 20-amp.
- Three LEDs show charge status.

MK Power battery: $122
- Stores electricity from PV panel.
- 12-volt, 50 amp-hour.
- Sealed lead-acid.
- Gel electrolyte means no spills or fumes; can operate in any position.

Eaton Cutler/Hammer safety disconnect: $45
- Main switch, disconnects all components from battery for maintenance or emergency.
- Two 30-amp fuses, $5 each.

Blue Sea Systems fusebox/load center: $39
- Distributes power to circuits.
- Up to six circuits.
- Uses ATC-type fuses: $2.95 for five (5-amp for our system).

Available as a kit from Gaiam Real Goods:
(800) 919-2400; www.realgoods.com
Item #53-0123
Discounted price: $699 plus shipping & handling;
we spent about $80 for additional parts.

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sockets. Interior wiring can be speaker wire, its gauge determined by the device's amperage and the length of run. Measure your planned installation before buying wire. It may be surprising how quickly the distance adds up. (Real Goods can determine the appropriate gauge.) Use stranded rather than solid wire—it's more flexible.

Our DC bulbs have standard Edison bases and will screw into any common light fixture. They can't handle dimmers, so get simple switches. Remember to pick up switch boxes, switchplates and junction boxes to mount your socket fixtures.


The safety disconnect holds two 30-amp fuses.


Five-amp fuses protect each circuit.

LET'S GET IT TOGETHER

The ideal spot for a solar collector of any kind is a shade-free area, facing south, and tilted at an angle from horizontal that is equal to the location's latitude. A roof often provides an angle close to ideal. You also can build a simple frame to mount the panel on the ground or a south wall.

Also consider the location of the battery, which should be in conditioned space—batteries don't like extreme temperatures. For efficiency, it's best to keep the battery as close as possible to the PV, so you may have to balance several factors to design your system. It makes sense as well to keep the charge controller, safety disconnect and fuse block near the battery. A common approach is to mount all components to a sheet of plywood, then attach it to the wall. Make sure the battery's exposed terminals are not accessible to a casual passerby; you may need to place it in a lidded box. If you build a shelf for the battery, make it stout: Even a small deep-cycle battery like this one weighs almost 40 pounds.

NOTES ON ASSEMBLY

We built this system as a portable demonstration setup, creating some complications you wouldn't encounter in a permanent domestic installation. Even so, it took one person only about seven hours to put it together, including a trip to the hardware store.

The kit went together easily, using just three screwdrivers, a wire stripper, an adjustable wrench, and a hand drill with two bits. Mount your devices with sufficient room between them for convenient routing. Wiring could hardly be easier—cut wires to length, strip the tips, twist the strands together tightly and screw them into the proper terminals. The wiring diagram provided by Real Goods was crystal-clear.

It's critical to maintain polarity—all LEDs, and CFLs made for DC, are unidirectional. We used outdoor extension cord to connect the PV panel, and we were lucky that the conductors in the cord had color-coded insulation. The rest of the wire was inexpensive zip-cord type, which had words embossed along one conductor only. We arbitrarily designated that side as positive. Some wire has a ridge molded along one conductor only, and some speaker wire has clear insulation with conductors of different colors. Just make sure you connect positive to positive and negative to negative throughout.

You don't have to tin the wire ends with solder, but it's never a bad idea with stranded wire, and it would make some connections easier to secure. We suggest soldering spade lug terminals onto the tips of the two battery cables, to allow more reliable connections and easier disconnects.

It was distinctly odd to run circuits with no provision for grounding, but that's part of the simplicity of this setup. In general, grounding is optional for PV systems under 50 volts, but it's a good idea on larger systems and essential anywhere lightning protection is needed.

Two things surprised us the first time we flipped the switches. We expected at least one poor connection, but lo and behold, the lights came right on. And we did not expect them to be as bright as they are—even the LED puts out a nice, bluish gleam. No question about it, this is a genuinely useful solar lighting system.

Associate Editor Charles Higginson has not had this much fun since he rebuilt the manual transmission of an old Volvo station wagon.

Ways to Save on a Solar Light Setup

We purchased our components new at retail for about $760, and some were oversized for the immediate need. With a bit of time and energy, you could build a similar system for less money. (Real Goods is offering the kit for $699—see Page 53.)

The PV panel is the most expensive item in the system. There's a market for used solar panels, which could provide distinct savings. A solar panel that hasn't been damaged should operate for 25 years without significant degradation, so a panel just a few years old should work for quite a while. Norman Franks of Real Goods says you generally can't get a warranty on a used panel, but PV is so reliable that the savings are worth the risk.

Batteries also are expensive, and also can be found used, but their life expectancy is considerably less. A used battery would be a way to get started, but anything more than two years old is likely to fail within a couple of years.

Two sources for used equipment are *Home Power* magazine (*www.homepower.com*; under "magazine" click "marketplace") and Oasis Montana (*www.oasismt.com/usedsolar.html*). The latter also posts worksheets to calculate electrical loads, power requirements and more.

You also could save about $20 by building your own panel mounts from scratch. And you could replace the safety disconnect unit with fuses in a simple in-line fuse block, saving perhaps $25. Don't be tempted to omit this protective component altogether.

How Solar Power Works

Photovoltaic (PV) panels convert light energy to electrical energy. In a nutshell — keeping in mind there's a lot more to modern PV than this — here's what happens: PV takes advantage of the different characteristics of silicon crystals with different impurities. Pure silicon is not electrically active, because its atoms are locked into a solid crystal structure. There are no "spare" electrons running around, and no spots "seeking" electrons. But certain impurities added to silicon create crystal with a slight tendency to lose electrons, and other impurities create crystal with a slight tendency to attract electrons. When the two kinds of silicon are placed close together and exposed to sunlight, photons (particles of light) knock electrons loose on the "losing" side. These electrons travel across the junction to the "attracting" side. That's an electrical current.

Light-emitting diodes (LEDs) are made of similar materials and take advantage of the same physical principles, but in reverse. Powering LEDs with a PV panel is satisfyingly symmetrical: photons in, electrons out; electrons in, photons out.

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Water Wise SOLAR Stills

By Claire Anderson



EYEWIRE

Passive solar distillation is an inexpensive, low-tech alternative for pure drinking water without bottles, including types of distillers, cost comparisons, going automatic or electric.

Americans worried about the purity of their well or tap water often end up spending a small fortune on bottled water just to be safe. But bottles aren't the only solution. For those who want to produce their own pure drinking water, passive-solar distillation is an inexpensive, low-tech option.

SOLAR SOLUTIONS

Distilling and reverse-osmosis filtering are the two best methods for purifying water. Both approaches remove more contaminants than activated carbon filters do. The U.S. Environmental Protection Agency says only reverse-osmosis systems and distillers may be called water "purifiers." All other systems are water "treatment" devices, in spite of the performance claims many manufacturers make. But reverse-osmosis filtration wastes water: For every gallon of purified drinking water produced, the process consumes 2 to 4 gallons of water. In contrast, solar distillation wastes no water and is powered by the sun.

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H_2Oh-No! What's in Your Water?

Although the U.S. Environmental Protection Agency requires water utilities to monitor and keep the levels of 80 potential contaminants below legal limits, there are more than 70,000 synthetic chemicals in production today.

Lead, nitrate, mercury, asbestos, arsenic and volatile organic compounds top the EPA's list of the most common public drinking-water contaminants. Other pollutants also are making their way into our water: carcinogens, pesticides like atrazine and aldicarb, industrial chemicals such as nonylphenol (from shampoos and other detergents), pharmaceutical steroids and antibiotics, and chlorine byproducts, especially trihalomethanes (THMs), which are suspected reproductive toxicants that adversely affect male and female reproductive systems.

If you're concerned about the quality of your drinking water, do some sleuthing at your local public water utility, and request their latest report, often called a Consumer Confidence Report. Public water-supply organizations are required by federal law to provide consumers with information about their drinking-water supplies. This report will tell you where your water comes from, and whether your water exceeds the limits for any of the 80 contaminants regulated by the EPA. You can also request a printout of the levels of all the contaminants. The National Environmental Education and Training Foundation's Web site at www.waterqualityreports.org/waterquality gives advice on how to interpret the Consumer Confidence Reports and what to test for, and publishes fact sheets on the 40 most common drinking-water contaminants.

If your water comes from a well, you'll need to get it tested yourself. The EPA's Safe Drinking Water Hotline [(800) 426-4791; www.epa.gov/safewater] provides information on how to obtain a list of certified labs. To get a preliminary picture of your water's quality, inexpensive test kits also are available. For $20, you can test your water for E. coli, lead, two common pesticides, chlorine, nitrite, nitrate, pH and hardness [Silver Lake Research; (888) 438-1942; www.watersafetestkits.com].

Instead of removing specific contaminants, as filtration systems are designed to do, solar distillation purifies water by removing only one thing: water.

Distillation takes advantage of the principle that chemicals vaporize at different temperatures. Most potential chemical contaminants in drinking water have vaporization points higher than water. When untreated water is heated in a solar distiller, pure water vaporizes first, leaving contaminants behind.

A simple solar distiller removes salts, heavy metals and bacteria, as well as arsenic and many other contaminants. According to a paper by Horace McCracken, a leader in solar distiller design, laboratory tests show distillers can remove trichloroethylene (a dry-cleaning chemical) and nitrates. Both are common pollutants and suspected carcinogens. A simple solar distiller paired with a carbon finish filter which removes any residual chlorine byproducts, will give you the cleanest drinking water for the least expense.

SIMPLE SOLAR

Solar distillers work by mimicking the natural water cycle: The sun provides energy to warm the water, the water evaporates (forms clouds) and condenses (makes rain) when it meets a cooler surface. Unlike electric distillation, boiling is not required for solar distillation. Some people believe water from a solar distiller is purer than boiled water. Florida Solar Energy Center principal research scientist W.R. McCluney, Ph.D., says vigorous boiling "can force unwanted residue into the distillate (distilled water), defeating purification."

TYPES OF DISTILLERS

The simplest solar distiller is a single basin distiller — a rectangular, black box fitted with a piece of angled glass sealed to the top. The basin is filled with untreated water; as the sunlight penetrates the glass, the water warms and evaporates, leaving most contaminants behind. The temperature difference between the cover, which does not absorb much heat, and the water surface causes the water vapor to condense, forming a thin film on the underside of the cover. When enough water condenses, it runs down the cover to a collection trough. Simple single-basin distillers work best on flat, level surfaces, and can be constructed fairly easily.

The other common type of solar distiller is the multibasin distiller. Also known as inclined solar distillers, multibasin distillers use numerous small basins to produce a greater amount of distillate during the day. These distillers generally can be transported easily and may be more suitable for temporary dwellings. Due to the amount of latent heat stored in one large basin of water, single-basin distillers continue producing distilled water at night, and thus are as efficient as multibasin distillers.

All basin distillers have four major components: a basin, a support structure, a clear cover (usually tempered glass) and a distiller trough. Most distillers also include insulation, sealants, piping and valves. Volunteers in Technical Assistance's booklet Understanding Solar Distillers offers a wealth of recommendations for building your own distiller.

The total amount of surface area determines the yield of the solar distiller. Dennis Lemon, author of Pure Water Nature's Way (see "Distiller Sources," Page 57), says on a sunny day, for every 1,000 square inches of cover surface, the solar distiller will produce about 1 gallon of pure water. An efficient 4-by-8-foot distiller should yield 2 to 4 gallons

With the sun's energy, this simple single-basin, passive-solar distiller can produce up to 4 gallons of purified drinking water per day of pure water on a sunny day. A solar water distiller will make potable water day after day, season after season.

COST COMPARISONS

A study by New Mexico State University shows solar-distilled water costs less than 7 cents



SOLAQUA

With the sun's energy, this simple single-basin, passive-solar distiller can produce up to 4 gallons of purified drinking water per day.

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per gallon, based on the conservative estimate of a 10-year distiller life span. Quality bottled water can cost as much or more than gasoline. Many American families spend more than $250 per year on bottled water, says Michael Cormier of SolAqua, a solar distiller distributor. Electric distillers, which consume about 3 kilowatt hours per gallon of water, will yield good water, albeit energy intensive and more expensive, at about 30 cents per gallon.

About $400 will buy a small solar distiller that will produce 2 to 6 quarts of drinking water per day, depending on weather conditions. A larger solar distiller, selling for about $800, will produce up to 2 gallons per day, or 770 gallons per year. After just one year of production, that's only a little more than a dollar per gallon. The cost will drop every subsequent year of operation. With no mechanical parts to wear out, a solar distiller is long-lived. A little cleaning maintenance is all that's needed to provide potable water for decades.

GOING AUTOMATIC

Unless you've automated your system (discussed below), you'll have to fill your distiller with source water and collect the distilled water on a daily basis. This can be an enjoyable routine or a confounding chore, depending on your lifestyle and time constraints.

Many people use subsystems to automate filling the distiller and storing the distilled water. A simple cyclical timer and solenoid-actuated valve can be set to automatically fill the distiller. To reduce the amount of electricity needed to power the subsystem, use a valve with a normally closed actuator. Without power supplied to the solenoid, the valve remains closed to water flow.

Besides automatic filling, it's handy to have pure water delivered to your tap. A gravity-fed system, in concert with a rooftop-mounted distiller and a storage tank, can serve this function. If your roof is unable to support a distiller's weight, you can place your distiller on a ground-mounted frame, and a small pressure pump can route water directly to your kitchen faucet.

CARE AND MAINTENANCE

As water evaporates in the distiller it leaves minerals and other contaminants in the basins. To ensure optimal performance, flush the system out periodically and keep the glass cover clean.

If you live in a climate where freezing is a concern, you will need to take some extra precautions to protect your distiller and subsystems. Insulate your inlet and outlet lines. Besides insulation, Lemon says gravity is the best protection against freezing. Locate your water-distribution system components and automatic-fill system below the distiller to avert potential freeze disasters. When there's no more sunlight to warm the distiller, an automatic controller can turn off the circulating pump, allowing the water to drain back into an indoor storage tank.

WATER STORAGE

Distilled water is a strong solvent, so choose your storage containers carefully. Stainless steel containers, and glass bottles and carboys are best. Avoid storing distilled water in soft plastic containers. Many plastics give off toxins, such as methyl chloride, a carcinogen that can leach into water. Design your storage capacity to contain four to five times the average output of the distiller, so you'll always have clean water on hand.

GOING ELECTRIC

Although solar distillers are best from an energy and economic standpoint, some situations may not accommodate solar distillers: You may be an apartment dweller or have a perennially shaded yard. Those who still want pure, distilled water can choose from a variety of electric distillers on the market.

Electric distillers work similarly to solar distillers, but rely on electricity rather than solar power. Small countertop distillers, which cost $150 to $350, can produce about 1 gallon of distilled water in four to six hours. Larger floor models, which can cost $1,000 or more, produce about 9 gallons of pure water per day. These units can be connected directly to your water system to provide pure drinking water on demand, eliminating the need for manual filling.

Waterwise (see "Distiller Sources") also makes a distiller that can be used over an open fire, or on a woodstove, gas grill or stove top. At $379, it can provide up to 16 gallons of drinking water in a 24-hour period.

Distiller Sources

SOLAR DISTILLER DEALERS

Agua del Sol
P.O. Box 651
Safford, AZ 85546
(928) 348-7512
Products: ADS Flat Distiller;
TSS Leaner Distiller

DMD Products
P.O. Box 799
Longmont, CO 80501
(866) 253-7087
Products: Solar distiller subsystem components (pumps, solenoid valves, filters)

Gaiam Real Goods
360 Interlocken Blvd,
Suite 300
Broomfield, CO 80021
(800) 919-2400
Products: Sunwater Solar Distiller

SolAqua
P.O.Box 4976
El Paso,TX 79914
(877) 483-2980
Products: Rainmaker 550 single-basin distiller;
SolAqua DIY Solar Distiller Kit

SOLAR DISTILLER PLANS

El Paso Solar Energy Association
P.O. Box 26384
El Paso, Texas 79926
(915) 772-7657
Solar distiller plans available for $15

ELECTRIC DISTILLER DEALERS

Durastill Export Inc.
(888) 434-7845
www.durastill.com

Glacier Water Systems
(877) 717-5700
distilled-water.com

Polar Bear Water Group Limited
(800) 363-7845
www.polarbearwater.com

Precision Water
(877) 935-0505
www.precisionwater.com

Waterwise
(800) 874-9028
www.waterwise.com

West Bend Co.
(262) 334-6949
www.westbend.com/water/product.html

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