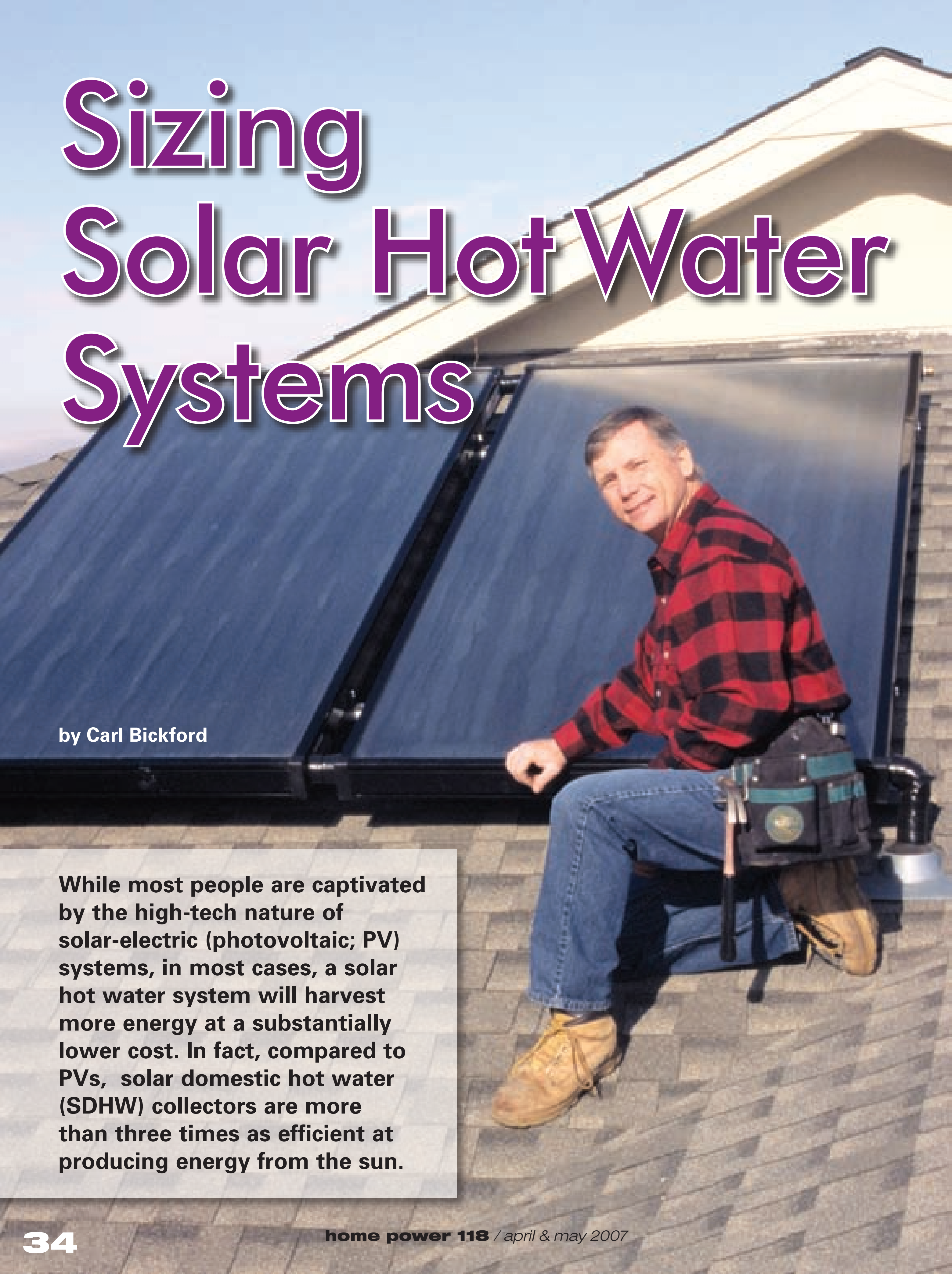
Sizing Solar Hot Water Systems

by Carl Bickford



While most people are captivated by the high-tech nature of solar-electric (photovoltaic; PV) systems, in most cases, a solar hot water system will harvest more energy at a substantially lower cost. In fact, compared to PVs, solar domestic hot water (SDHW) collectors are more than three times as efficient at producing energy from the sun.

Daily Hot Water Usage for a Family of Four

Hot Water Use	Efficient Household: Avg. Gallons Per Usage	x Times Per Day	= Gallons Per Day	Typical American Household: Avg. Gallons Per Usage	x Times Per Day	= Gallons Per Day
Showering	10.0	4.0	40.0	20.0	4.0	80.0
Automatic dishwashing	4.0	1.0	4.0	12.0	1.0	12.0
Preparing food	2.0	2.0	4.0	5.0	2.0	10.0
Automatic clothes washing, hot cycle (4 loads per week)	18.0	0.6	10.8	32.0	0.6	19.2
Hot Water Usage Per Day (Gal.)			58.8			121.2

Investing in a solar domestic hot water (SDHW) system is a smart solar solution for most homeowners. This proven and reliable technology offers long-term performance with low maintenance. And with federal, state, and utility incentives available, these systems offer a quick payback—in some cases, only four to eight years.

A thoughtfully designed SDHW system could provide *all*, or at least a significant amount, of your household hot water needs for some portion of the year. The California Energy Commission estimates that installing an SDHW system in a typical household using electric water heating can shave 60 to 70 percent off water heating costs. To get the most for your money, you'll want a properly sized system that offers the best performance in your climate. Here's what you need to know to size right—before you buy.

Efficiency First, Then Loads

Before you install a solar hot water system, insulate pipes and storage tanks, install high-quality, restricted- or low-flow faucets and showerheads, and lower your water heater's thermostat setting if possible. Making these improvements and repairing plumbing leaks will minimize losses, reduce your hot water demand, and make your solar hot water system both smaller and less expensive.

To size your solar hot water system, start by estimating your household's hot water use—its loads. Calculating a household's actual hot water load can be a social science exercise (people have very different water use habits), but a

SDHW Advantages

- Year-round usage
- Relatively low installed cost (often less than $5,000)
- Federal and state rebates or tax credits available (see Access)
- Small area required for collector mounting (usually less than 80 sq. ft., and sometimes less than 40 sq. ft.)
- High efficiency—more than three times that of PV systems
- Integrates with existing plumbing systems
- Variety of system types to meet specific needs
- Proven technology and system designs
- Quality components widely available
- Expandable (with proper design)
- Long system life
- Low maintenance
- Large energy displacement
- Significant utility bill savings possible

Shower Power

After bathing, showering generally is the highest hot water consumer. If you really want to get a handle on your hot water use, you can measure the flow rate of your showerhead with a bucket and a timer, in gallons per minute (gpm). You will also need to measure the temperature of your shower water (fill a cup while you're showering) and that of the cold water supply (preferably while you're not).

Measuring the water temperature and timing the length of your showers will allow you to calculate energy consumed. For example, a 10-minute shower at 110°F (heated from a 50°F supply) with a flow rate of 1.5 gpm (a high-quality, low-flow showerhead) would result in an energy consumption of roughly 7,500 Btu.

Volume (gallons) x Temperature rise (°F) x 8.33 (the density of water multiplied by its specific heat) = Energy (Btu)

1.5 gpm x 10 min. x 60°F x 8.33 = 7,497 Btu

Even though the energy use is relatively low, it must be supplied at a high rate (power). That rate of energy usage (45,000 Btu per hour) would have to be matched by the input of an on-demand water heater, but with sufficient storage, we can do the job with low-power solar collection.

Another helpful conversion factor is: 1 watt equals 3.412 Btu per hour. With this, you can convert your shower power from 45,000 Btu per hour to 13,190 watts, which would require 55 amps from a 240-volt electric element—that's what an on-demand electric water heater would have to supply to keep you in hot water!

Load & Collector Sizing Calculations

Some up-front number-crunching can help you size your SDHW system appropriately for your household, saving you money from the get-go. The example below sizes a system for an efficient household in Des Moines, Iowa, that uses about 60 gallons of hot water daily.

1. Calculate your daily household water heating load. Two formulas are particularly important to calculating hot water loads:

Volume (gallons) x Temperature rise (°F) x 8.33 (the density of water multiplied by its specific heat) = Energy (Btu)

Suppose you heat 1 gallon of water from 50°F to 130°F. The temperature rise is 80°F, so the energy formula would tell you that 666 Btu (1 x 80 x 8.33) are required. A family of four, using 15 gallons of hot water each, would require:

60 gal. x 80 (temperature rise) x 8.33 (lbs./gal.) = 39,984 Btu

2. Determine your site's average daily insolation and equivalent SRCC "Sky Type." Use the PVWatts online calculator, or an equivalent source (see Access), and convert the KWH/m^2/day figure to Btu/ft.^{2}/day, using the following:

1 KWH/m^2/day = 317.1 Btu/ft.^{2}/day

Des Moines receives an average of 4.83 KWH/m^2/day (collector at a 41.5 degree tilt angle). Applying the conversion factor:

4.83 KWH/m^2/day x 317.1 Btu/ft.^{2}/day = 1,531.6 Btu/ft.^{2}/day

This available solar resource most closely matches the SRCC's "Mildly Cloudy" (1,500 Btu/ft.^{2} per day) sky-type category.

3. Categorize your climate. For all but the coldest locations in the United States, using the "C" category will give you a reasonable estimate. (For more tips on improving your estimate's accuracy, see the SRCC Collector Ratings sidebar.)

4. Obtain collector performance output data from the SRCC Web site (see Access). One popular 4- by 8-foot, flat-plate collector produces about 24,000 Btu per day in Category C and "mildly cloudy" conditions. If we assume system losses of about 20 percent (80 percent efficiency), one collector can be expected to produce about 19,200 Btu (24,000 Btu x .80) per day—almost half of the family's hot water needs.

To take advantage of the federal tax credits, this family would need to install two collectors and have at least 64 gallons of storage capacity, which would provide most of their annual hot water requirements.

You can find an Excel spreadsheet to help you through the process of estimating a collector's output at www.homepower.com/promisedfiles. SRCC also provides comparisons and ratings of prepackaged SDHW systems. See their Web site (www.solar-rating.org) for details.

Example Collector Data*

	Thousands of Btu/Sq. Ft./Day		
Category (T_i–T_a)	Clear (2,000 Btu/ ft.^{2} per day)	Mildly Cloudy (1,500 Btu/ ft.^{2} per day)	Cloudy (1,000 Btu/ ft.^{2} per day)
A (-9°F)	43	32	21
B (9°F)	39	28	18
C (36°F)	33	24	13
D (90°F)	23	13	4
E (144°F)	13	4	negligible

*Black chrome, flat-plate collector, 32 sq. ft. nominal

rough rule is to estimate 30 gallons of hot water per day, per person. A family of four typical Americans would result in a load of about 120 gallons of hot water every day. (If you have a water-wise household, this figure results in overestimating hot water consumption.) You can estimate your household water heating loads using the Daily Hot Water Usage table on the previous page. If you use natural gas for space and water heating, you can also look at your summertime utility bills to estimate your water heating needs.

After you've determined your household load, you can estimate your energy needs for heating water (see Load & Collector Sizing sidebar). An "average" American household requires about 80,000 Btu each day for water heating, but an efficient household uses *half* this amount.

Choosing the Right Collector

Once you have a good understanding of how much hot water your household uses and the amount of energy required, it's time to choose your collectors, which convert the sun's radiant energy to heat energy and warm your water. Whether you choose flat-plate or evacuated tube collectors, focus on how much energy a collector will produce on an average day at your site.

One piece of the solar puzzle is knowing how much insolation (average daily peak sun-hours) your site receives. You'll need this number to figure out how much output to expect from your collectors. For a quick estimate, you can convert the average yearly insolation data from the online solar resource calculator PVWatts (see Access). Next, choose your collector make and model, and determine how many you'll need to offset your water heating needs. The Solar Rating and Certification Corporation (SRCC) maintains a Web site that provides thermal output performance estimates on many commonly available collectors. The examples and equations above and the SRCC Collector Ratings sidebar will help guide you through these steps.

Most SDHW experts recommend installing enough collectors to cover 40 to 70 percent of the annual load. To qualify for federal tax credits, an SDHW system must supply at least 50 percent of the household's water heating. A system that is sized to supply 100 percent of the annual load will produce very hot water in the summertime, which is unnecessary and potentially problematic.

Courtesy www.solarthermal.com

Evacuated tube collectors are more efficient than flat-plate collectors in cloudy or colder conditions, but can be more expensive.

Storage Sizing

Electric and natural gas-fired tank-style water heaters can minimize their storage capacity because energy is typically always available. This isn't the case with solar water heaters, because the weather affects their output. A solar water heater can be slower to recover after hot water usage, so greater storage capacity is required. A backup heating source for extended periods of cloudy weather is typically included.

Your climate and the total area of the collectors will determine the storage tank capacity that's needed. Storage tanks are available in a range of sizes—from 30 to 120 gallons. A tank's capacity should be equal to or greater than that required by the daily loads. (For more climate-specific recommendations for sizing a solar storage tank, see "Solar Hot Water: A Primer" in *HP84*.) Systems installed in sunny, warm climates can accommodate more storage volume than systems in cloudy and cold ones, since more energy can be collected.

In general, more storage volume leads to lower collector operating temperatures, which improves the collector's performance. If possible, the storage tank should be dedicated to its task, and be separate from the backup tank. Any backup heating system (tank or tankless) should be sized for 100 percent of the load to guarantee sufficient hot water in any weather.

Solar Savings

Tax credits and other financial incentives can sweeten the deal for solar water heating systems. Through December 31, 2008, you can claim up to 30 percent (to a maximum of $2,000) of your system costs as a tax credit for a residential installation that provides at least 50 percent of your water heating needs. Businesses can receive a 30 percent tax credit—with no cap.

Using the SRCC Collector Ratings

Solar thermal collector output depends on four main criteria: 1) size, type, and construction materials of the collector; 2) solar energy available at the site; 3) difference between the collector inlet temperature and the ambient air temperature; and 4) the application of the collector(s).

Using the SRCC's online performance tables for individual collectors (OG-100) can help you correctly size your solar hot water system (see Access). The SRCC boils down the relatively complex test results to a user-friendly table or matrix, which dovetails two of the four factors governing collector output (see Example Collector Data table on opposite page).

Three columns in the matrix classify available solar energy into sunny, clear day; mildly cloudy day; and cloudy day. Five rows describe temperature ratings derived from the simple formula ($T_i - T_a$), the difference of the collector temperature inlet minus the temperature ambient.

All collectors lose some of their heat to the outside (ambient) air. The higher the collector inlet temperature is above the ambient temperature, the more heat lost and consequently the lower the collector's output. As the temperature difference ($T_i - T_a$) gets larger, the collector's output drops accordingly. Output also decreases as the solar energy available drops.

SDHW use is year-round and collector output varies significantly with changing seasons. Most locations cannot be classified into a single cell in the matrix. To more accurately predict the output, an average between two, and sometimes more, cells is required. When using the SRCC data to predict performance at any location, keep in mind that the daytime temperature is the important factor. You can closely approximate daytime temperatures by knowing the lows and highs for a given period.

Typical SDHW systems can have large temperature variations throughout the day. This is due to the changing relationship between the inlet temperature and the daytime ambient temperature. Collectors will typically operate in the B and C categories in the morning, when cooler ambient temperatures are closer to the inlet temperatures. As a typical day progresses, SDHW inlet temperature outpaces the ambient temperature, and the collector operates in the C and D categories.

As a general rule, if you must pick a single category of operation in any location, the C category will be most accurate year-round in all but the very coldest climates in the United States. Many systems will operate closer to the D category in the winter, but will predominately be closer to the C category in the spring, summer, and fall.

Using the SRCC collector matrix to estimate a solar collector's performance is only an approximate science—with a little art in the mix. The art is being familiar with the nuances of local climate conditions, prevailing weather patterns, and educated guessing.

—Chuck Marken

Maximizing Efficiency

Heat losses typically occur through the plumbing and the solar storage tank walls. Properly insulating pipes and the storage tank can reduce these losses to less than 5 percent per day. Use 3/4-inch-thick, closed-cell foam pipe insulation, and wrap tanks with insulating blankets. Select solar storage tanks with insulation levels greater than R-15, or with more than 2 inches of foam insulation.

Many states and local utilities also offer rebates, shortening the payback period significantly. (See Access to find more information on SDHW rebates and incentives.)

Besides having a positive effect on your pocketbook, SDHW systems are also good for the planet. According to the U.S. Department of Energy, over a twenty-year period, one solar water heater can prevent more than 50 tons of carbon dioxide, a notorious greenhouse gas associated with global warming, from being emitted.

Access

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Database of State Incentives for Renewables & Efficiency (DSIRE) • www.dsireusa.org • Federal, state, and local incentives

U.S. DOE, Office of Energy Efficiency & Renewable Energy • www.eere.energy.gov/consumer/your_home/water_heating/index.cfm/mytopic=12760 • Hot water savings tips

PVWatts • http://rredc.nrel.gov/solar/codes_algs/PVWATTS • Web-based software for solar energy data

Solar Rating and Certification Corporation (SRCC) • www.solar-rating.org

Further Reading:

"Solar Hot Water: A Primer," Ken Olson, *HP84*

"Solar Hot Water Simplified," John Patterson, *HP107*

"Solar Hot Water for Cold Climates: Closed-Loop Antifreeze System Components," Ken Olson, *HP85*

"Solar Hot Water for Cold Climates, Part 2: Drainback Systems," Tom Lane & Ken Olson, *HP86*

"Installation Basics for Solar Domestic Water Heating Systems," Chuck Marken & Ken Olsen, *HP94*

"SDHW Basics, Part 2: Closed-Loop Antifreeze," Chuck Marken & Ken Olson, *HP95*

"Heat Exchangers for Solar Water Heating," Chuck Marken, *HP92*