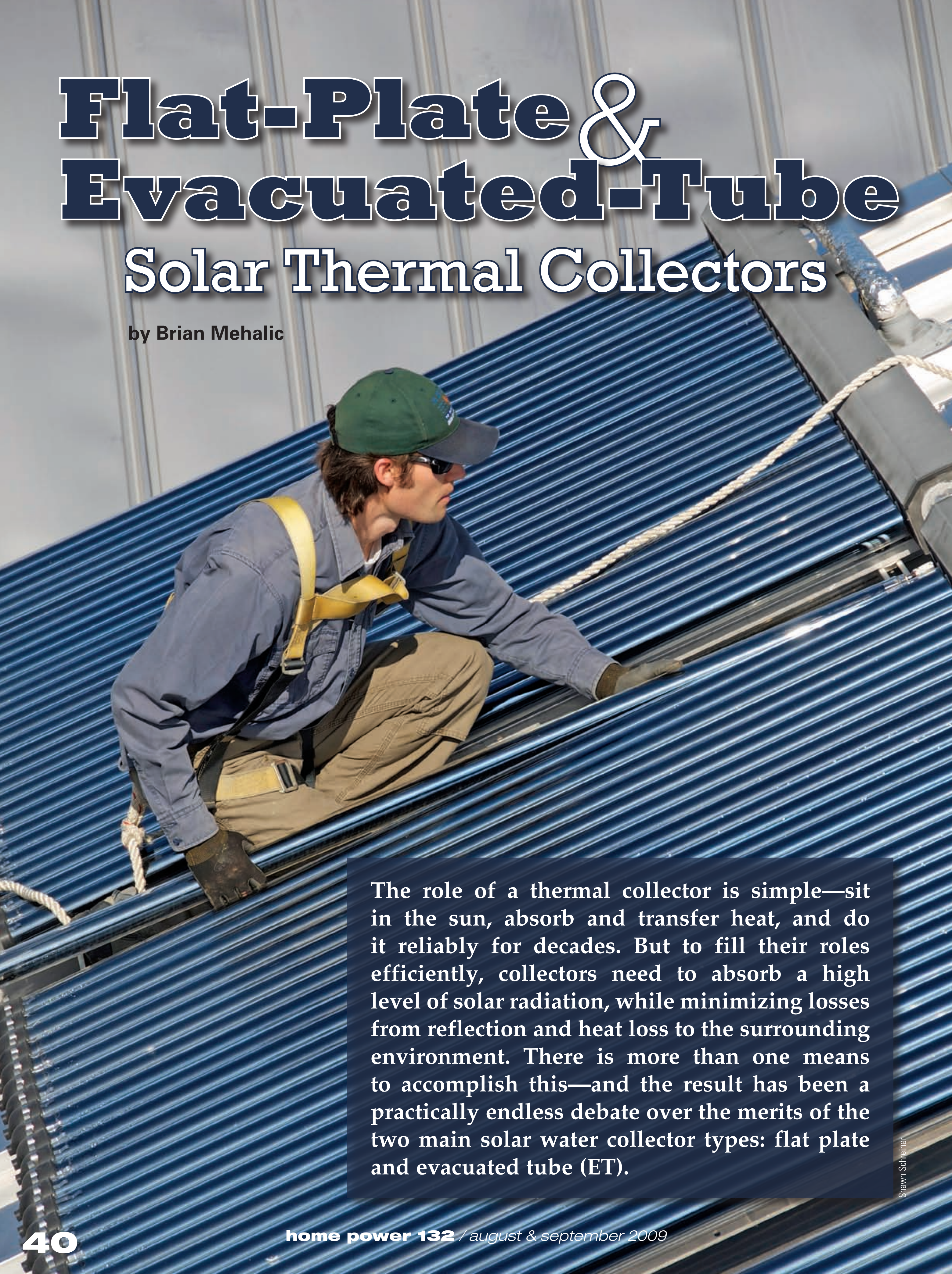
Flat-Plate & Evacuated-Tube

Solar Thermal Collectors

by Brian Mehalic



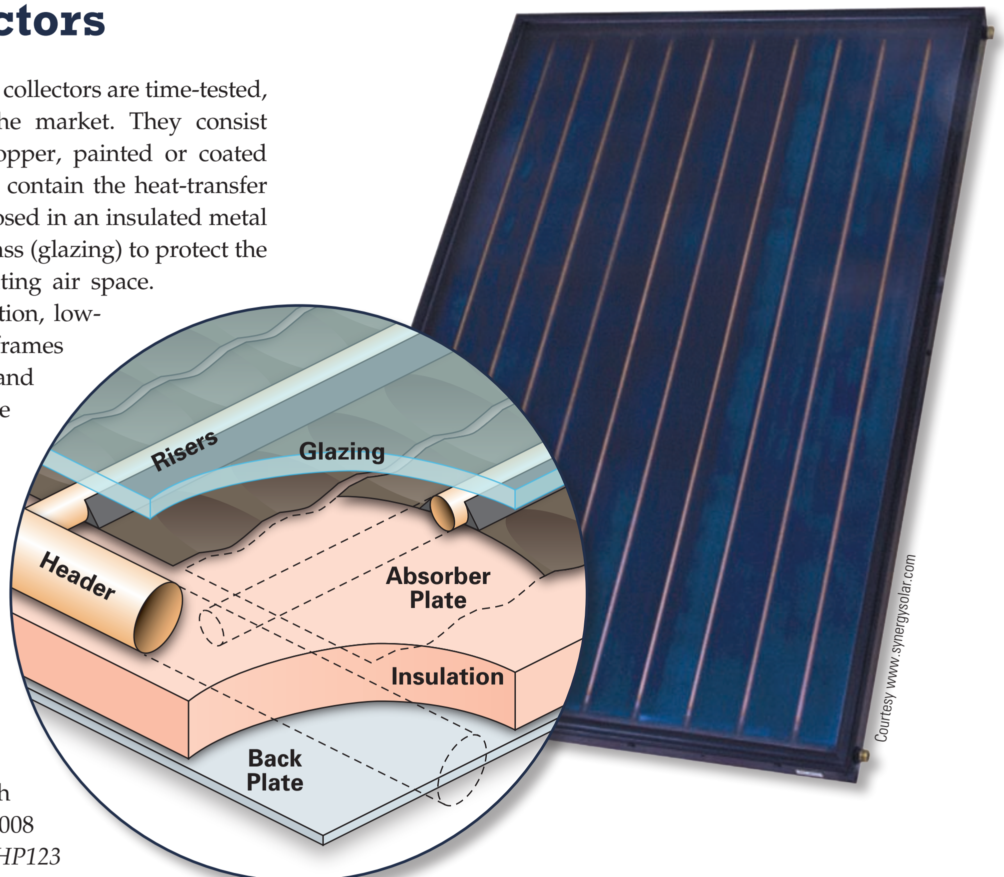
Shawn Schreiner

The role of a thermal collector is simple—sit in the sun, absorb and transfer heat, and do it reliably for decades. But to fill their roles efficiently, collectors need to absorb a high level of solar radiation, while minimizing losses from reflection and heat loss to the surrounding environment. There is more than one means to accomplish this—and the result has been a practically endless debate over the merits of the two main solar water collector types: flat plate and evacuated tube (ET).

Flat-Plate Collectors

In use since the early 1900s, flat-plate collectors are time-tested, reliable, and currently dominate the market. They consist of an absorber plate—a sheet of copper, painted or coated black—bonded to pipes (risers) that contain the heat-transfer fluid. The pipes and copper are enclosed in an insulated metal frame, and topped with a sheet of glass (glazing) to protect the absorber plate and create an insulating air space. High-temperature rigid-foam insulation, low-iron tempered glass, and aluminum frames are the most common materials, and different absorber plate coatings are available, ranging from black paint to proprietary selective-surface coatings designed to maximize heat absorption and retention.

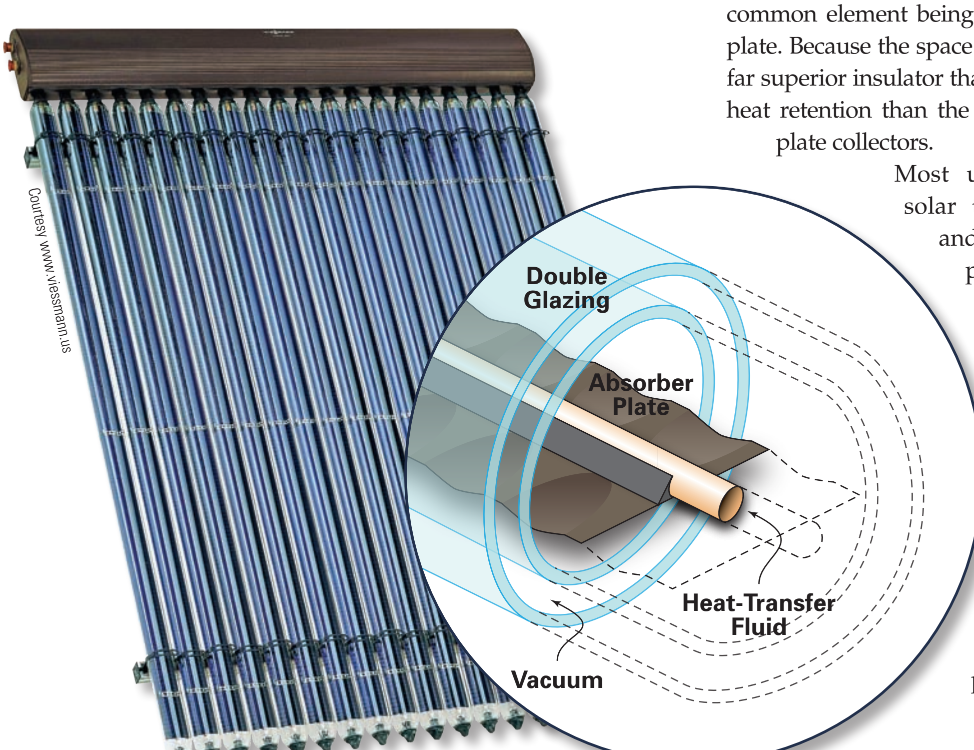
Flat-plate collectors usually range in size from 24 square feet (3 x 8 ft.) to 48 square feet (4 x 12 ft.) or more, and can weigh more than 150 pounds each. They hold a small volume of fluid, typically less than 3 gallons even in large collectors, which is circulated through for heating. See "*Home Power*'s 2008 Solar Thermal Collector Guide" in *HP123* for detailed specs on both types of collectors.



Evacuated-Tube Collectors

Evacuated-tube collectors are a more recent technology, introduced in the late 1970s. Several types are available, with the common element being a glass tube surrounding an absorber plate. Because the space inside the tube is a vacuum, which is a far superior insulator than air, these collectors have much better heat retention than the glazing/air space (R-7) design of flat-plate collectors.

Most use borosilicate glass to maximize solar transmission to the absorber plate, and use similar absorber coatings to flat-plate collectors. Frames and manifolds for paralleling multiple tubes are available and can hold 4 to 20 tubes or more. As with flat-plate collectors, multiple banks can be plumbed together to increase system capacity. While overall weights and dimensions are similar between the two types, evacuated tubes usually have an advantage in that individual tubes can be carried to the location and then assembled in place, rather than lifting an entire collector.



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Individual evacuated tubes connect into a manifold.

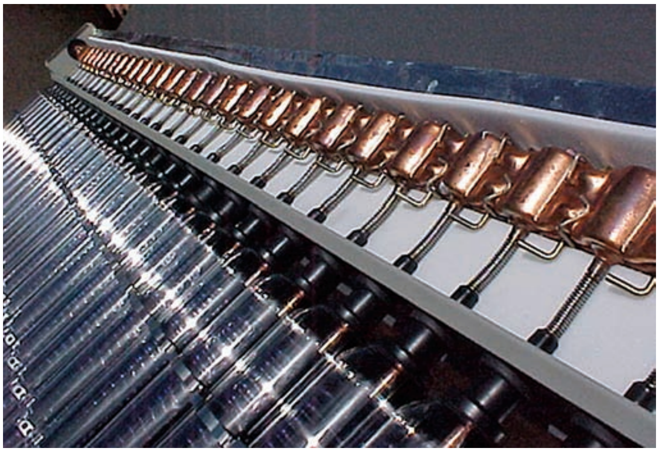
Selecting a Collector Type

Wading through the glut of conflicting collector information can be a big chore—unless you first prepare for the task. Each type of collector has its advantages and disadvantages, and in many cases either may be suitable for the same application.

As with any system, improper sizing, design, component selection, or installation can easily trump the performance of even the most efficient collector. (See "Sizing Solar Hot Water Systems" in *HP118* for a detailed discussion on sizing; and "Solar Hot Water Simplified" in *HP107* and "Certified Solar" in *HP125* for more information on the types of hot water systems.)

Cost

Cost is often the primary consideration, especially if performance is comparable. While ETs may cost 1.2 to 2 times more, flat-plate collectors use considerably more copper and can be subject to greater price fluctuations due to resource prices. Local availability and shipping costs may also affect price differences and, in some cases, ETs may be less expensive.



Courtesy www.thermomax.com

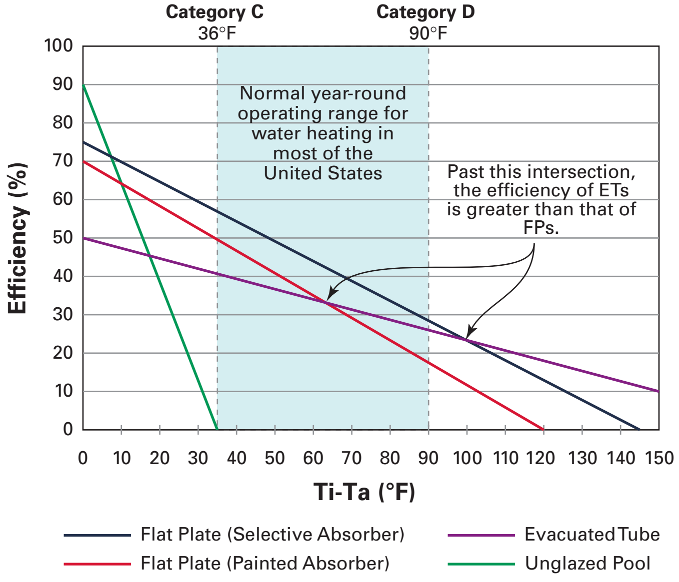
The heat-exchanger manifold with the cover removed.

Pros, Cons & Conventional Wisdom

Efficiency. Collectors operate most efficiently when the temperature of the inlet fluid (Ti) is the same as or less than the ambient temperature (Ta) of the air. When Ti equals Ta, flat-plate collectors tend to be about 75% efficient, while evacuated tubes have an efficiency of about 50%. However, collectors rarely operate under these conditions.

In most systems, collectors operate 30°F to 80°F above ambient temperatures to produce end-use temperatures from 100°F to 130°F. As the inlet temperature increases, the potential for heat transfer from the absorber to the surrounding air increases—heat lost to the atmosphere is heat not transferred to the fluid in the collector, and the result is less efficiency. Because of the superior insulation in ETs, their efficiency curve, which shows the loss in efficiency as the difference between inlet and ambient temperature (Ti–Ta) increases, is less steep compared to flat plates. Flat plates are more efficient when Ti equals Ta, but

Collector Efficiency



the efficiency curves of each, which decrease at different rates, intersect at some point. Past this junction, as Ti continues to rise, ETs are more efficient than their flat-plate counterparts.

When comparing ET and flat plates having similar-quality absorber plate coatings, this intersection typically occurs when the inlet temperature exceeds the ambient by 90 to 100°F or more—conditions that most systems do not typically experience. However, it does mean that ET collectors are capable of producing higher temperatures overall and can produce more heat in cold weather. ETs also perform much better under cloudy and windy conditions, again a result of the improved insulation keeping more heat "in the collector."

Unfortunately, the superb insulation that otherwise helps evacuated-tube collectors can undermine their efficiency in areas that receive a lot of snow or heavy frost. Light passing through frost or snow will heat the absorber plate of flat-plate collectors. Some of this heat radiates out and warms the glass, melting frost and creating a layer of water that allows snow to slide off. However, in ET collectors, the more effective vacuum insulation prevents the heated absorber from warming the surrounding glass, resulting in much longer "melt-off" times. Additionally, snow can pass through the spaces between the tubes and accumulate underneath, resulting in snow buildup. In some cases, evacuated-tube collectors may take half the day or more to melt snow or frost, reducing their operational time and offsetting their increased cold-weather efficiency.

Design Differences. Typically designed with an unsealed enclosure, flat-plate collectors can be prone to condensation buildup on the inside of the glass as they age. Cosmetically, this may be an issue, but the impact on performance is minimal—an increased possibility of corrosion on the collector materials and mounting components is the most serious long-term effect.

On the other hand, sealing and maintaining a vacuum is difficult, and an evacuated tube without a vacuum performs very poorly. This was a common problem that plagued early designs that relied on seals, but today the majority of ETs use a continuous piece of glass to minimize the risk of vacuum loss.

Flat-plate collectors tend to have stronger glass than ETs. If the glazing breaks, though, replacing it can be challenge. Due to the modular design of ET collectors, individual tubes can easily be replaced if they become damaged.

Siting & Other Considerations. Evacuated tubes are less sensitive to sun angle and orientation than flat-plate collectors—some tubes can even be individually rotated within the rack system to favor late or early sun. Their circular design allows sunlight to pass at a right angle through the same thickness of glass throughout the day, whereas the changing sun angle relative to a fixed flat-plate collector results in increased reflection due to the angle of incidence.

Because of aesthetics or other constraints, collectors are often mounted parallel to the roof surface. While a steeper pitch may favor winter production, many roof angles are 35° or less, and a parallel-to-roof installation can lead to collectors overheating in the summertime and under-producing during the winter. Again, for the reasons mentioned above, this has less of an impact on ET collectors than for flat plates.

In general, ET collectors are best suited for areas with low winter temperatures and/or a below-average solar resource, or when high-temperature water is required (such as in some commercial applications). Realistically, either type will work for most applications, with flat plates usually a more economical choice in Sunbelt climates. Your local solar pros should have a handle on what works best in your particular climate.

Brian Mehalic

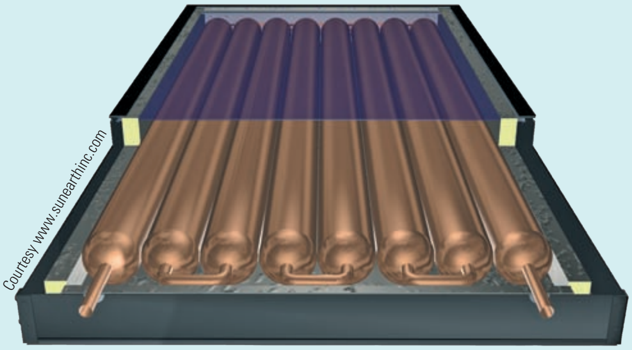
A flat-plate collector tilted to optimize winter performance.

Ben Root

While evacuated-tube collectors are less affected by angle and orientation, mounting them parallel to a steeply pitched roof will improve their wintertime production.

A Collector for Mild Climates

A third type of collector, integrated collector storage (ICS), is worth mentioning. As the name suggests, these collectors hold a comparatively large volume of fluid (40 gallons or more). Usually, though not always, this fluid is the domestic—or end-use—water, rather than a separate heat-transfer fluid. However, many ICS collectors are appropriate only for installation in areas that have record-low freeze temperatures above the single digits, and less than 30 to 40 freezes per year. While the volume of water in the collector is frequently able to hold enough heat to resist freezing, the piping to and from the collector, if not installed and insulated properly, is most likely to freeze and burst. Furthermore, cold nighttime temperatures result in heat loss, since the end-use water is stored outside in the collector.



SunEarth's CopperHeart progressive tube is one of several types of ICS collectors that work well in nonfreezing climes.

Characteristic	Flat Plate	Evacuated Tube
Proven technology	✔	✔
Typically less expensive	✔	
Less affected by collector orientation		✔
More efficient at high temperatures		✔
More easily sheds snow	✔	
More efficient in cloudy weather		✔
Suitable for drainback systems	✔	

Performance & Collector Ratings

The independent nonprofit Solar Rating and Certification Corp. (SRCC) helps consumers make educated SHW choices with its voluntary certification, labeling, and rating programs for collectors (Standard OG-100) and also for complete systems (OG-300).

For OG-100 certification, collectors from a manufacturer's production lines are randomly selected and then tested by independent, accredited labs using procedures and standards specified by the SRCC. Collectors are tested for both performance and durability, and energy output is measured over the course of the day to even out the peaks and valleys of fluctuating minute-to-minute performance. Since testing is standardized, the resulting performance ratings allow direct comparison between different collectors. (Note that not all collectors are OG-100 rated—some are only sold integrated into complete systems, which are certified under the OG-300 standard.)

Collectors are first tested for durability, including the quality of the materials and construction, the potential for leaks, and expansion and contraction due to temperature changes. They also undergo pressure, exposure, thermal shock, and post-shock pressure testing.

Thermal performance testing is only undertaken after collectors have passed the durability testing. Instantaneous collector efficiency is measured over a wide range of operating conditions, with incoming fluid ranging from near ambient temperature to 126°F over ambient. These tests are performed with sunlight within 30° of perpendicular to the collector surface. Because performance can change dramatically with sun angle, the efficiency curve is modified to account for performance based on a changing sun angle. Once the collectors have undergone these tests, they are partially disassembled to check for internal or hidden problems that may have arisen during use.

The "Directory of SRCC-Certified Solar Collector Ratings" is available at www.solar-rating.org, and is updated regularly. Collectors are listed by manufacturer and model. General information includes the supplier, model, and type; the dimensions, weight, and fluid capacity; and the materials used for the frame, cover, absorber, and absorber coating. Dimensions are provided for both the gross area, which is the full surface area of the collector including the frame, and the net aperture area, which includes only the absorber surface.

To account for different applications of the same collector, operation categories are used to distinguish performance under various conditions, and are further qualified based on sunlight conditions.

The categories (as in the example ratings table on the opposite page, top right) are based on the inlet fluid temperature minus the ambient temperature (Ti – Ta). Two categories are applicable to domestic water and space heating:

C—Water heating (warm climate); inlet temperature: 36°F above ambient
D—Water heating (cool climate); inlet temperature: 90°F above ambient

The columns show performance based on available sunlight for a standardized "type" of day:

Clear day: 2,000 Btu/ft.^{2} per day = 23 MJ/m^2 per day = 6.3 kWh/m^2 per day
Mildly cloudy: 1,500 Btu/ft.^{2} per day = 17 MJ/m^2 per day = 4.7 kWh/m^2 per day
Cloudy day: 1,000 Btu/ft.^{2} per day = 11 MJ/m^2 per day = 3.2 kWh/m^2 per day

Example SRCC Performance Data

COLLECTOR THERMAL PERFORMANCE RATING							
Megajoules Per Panel* Per Day				Thousands of Btu Per Panel* Per Day			
CATEGORY (Ti-Ta)	CLEAR DAY 23 MJ/m²•d	MILDLY CLOUDY 17 MJ/m²•d	CLOUDY DAY 11 MJ/m²•d	CATEGORY (Ti-Ta)	CLEAR DAY 2,000 Btu/ft²•d	MILDLY CLOUDY 1,500 Btu/ft²•d	CLOUDY DAY 1,000 Btu/ft²•d
A (-5°C)	47	35	24	A (-9°F)	45	34	23
B (5°C)	43	32	20	B (9°F)	41	30	19
C (20°C)	37	26	15	C (36°F)	35	25	14
D (50°C)	24	14	4	D (90°F)	23	13	4
E (80°C)	12	3		E (144°F)	11	3	

A-Pool Heating (Warm Climate); **B**-Pool Heating (Cool Climate); **C**-Water Heating (Warm Climate); **D**-Water heating (Cool Climate); **E**-Air Conditioning

*Based on a flat-plate collector gross panel area of 32.84 ft.²

Original Certification Date: December 18, 2007

TECHNICAL INFORMATION

Efficiency Equation [NOTE: Based on gross area and (P) = Ti-Ta]

	Equation			Y-Intercept	Slope	
SI Units:	$\eta = 0.7447$	-3.0285 (P)/I	-0.0198 $(P)^2/I$	0.7525	-4.1062	W/m²•°C
IP Units:	$\eta = 0.7447$	-0.5337 (P)/I	-0.0019 $(P)^2/I$	0.7525	-0.7240	Btu/hr•ft²•°F

You can use PVWatts (http://www.nrel.gov/rredc/pvwatts/) or other resources to find out the average solar resource for a specific location in kWh/m² per day, on a monthly and annual basis. (To convert, 1 kWh/m² per day = 317.1 Btu/ft.² per day.) For example, Prescott, Arizona, receives an average of 6.22 kWh/m² per day, ranging from 5 kWh/m² per day in the winter to 7 kWh/m² per day in the summer. This places this location in the "Clear" category, though overall performance in the winter is closer to "Mildly cloudy." Detailed, city-by-city data used for PVWatts can be found in the Solar Radiation Data Manual, also known as the "Redbook," available online at http://rredc.nrel.gov/solar/pubs/redbook/.

The performance rating of the collector is given per panel, per day, in both thousands of Btu and megajoules (MJ), and for each combination of operation category and type of day. This information can then be used to estimate system output (how much water will be heated) or to size systems based on heat load requirements. Information for creating a graph of collector efficiency is also provided.

Systems usually operate with the solar fluid at much higher temperatures than ambient. Because efficiency decreases as fluid temperature rises, the slope of the efficiency curve is negative, and this value is provided for the collector. The more negative the number, the steeper the curve; the steeper the curve, the quicker collector efficiency decreases relative to the increased temperature differential. Typical slopes range from -0.2 Btu/hr/ft.² per °F (a more gradual curve, typical of ETs) to -0.8 Btu/hr/ft.² per °F (a steeper curve, representing the more rapid loss in efficiency of flat-plate collectors). The slope value means that for each

Evacuated tubes are easily moved onto the roof, where they can then be inserted into the manifold and clipped into place on the rack.

Shawn Schreiner

degree Fahrenheit that the inlet fluid temperature exceeds the ambient temperature, the collector will produce "X" fewer Btu per square foot per hour.

Both the efficiency equations of the collector and the daily thermal performance rating are based on the gross area—the total collector size, including the frame and manifold (if one is required). Flat-plate collectors tend to have a higher gross-to-net collector area ratio, because less space is taken up by the frame and there aren't the airspaces that typically exist between tubes that are banked together. The standardized ratings based on gross area allow for easy comparison between collector types.

The SRCC also provides a simple methodology for comparing the value of different collectors. The assumption is that all other things in the systems are equal—the cost of the remaining components, the energy used by pumps and controllers, heat loss from piping and tanks, the system operating category, the available solar resource, and system demand. Once these potential variables are removed from the equation, it becomes a simple matter of comparing the dollars per rated Btu of the collectors in question:

Performance rating (Btu) ÷ Collector cost ($) = Btu per dollar

The more Btu per dollar, the better the value of the collector.

Making the Choice

For most residential hot water and space-heating applications, flat-plate collectors tend to be more cost-effective and more than capable of delivering the necessary temperatures. However, evacuated tubes can offer performance increases and other advantages due to their design. To further add to the confusion, not all evacuated tubes or flat plates have the same design, so generalizing about advantages can be a mistake. And while the collector usually only constitutes 10% to 20% of the full system price, different collectors may require different components in the rest of the system, and mounting requirements can vary considerably. These factors can significantly influence the overall system price, meaning that simply comparing the prices between the two types of collectors will not tell the whole story.

Access

Brian Mehalic (brian@solarenergy.org) is a NABCEP-certified PV installer with experience designing, installing, and servicing PV, thermal, wind, and water-pumping systems. He instructs and develops curricula for Solar Energy International and lives in Prescott, Arizona. Dedicated to Charles Michael Mehalic.

Further Reading:

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

Solar Radiation Data Manual "Redbook" • http://rredc.nrel.gov/solar/pubs/redbook/