Solar Collectors

…Behind the Glass

by Chuck Marken

Solar collectors are the engines that drive all solar energy heating systems. If variety is the spice of life, then the full lineup of solar thermal collectors is a flavorful dish indeed. Although solar heating collectors have settled upon a few basic designs, they are still manufactured in an array of configurations. We'll look at the different classifications and types of collectors, and briefly examine the construction differences, which can affect system performance. For in-depth coverage of Solar Rating and Certification Corporation (SRCC) certified collectors, see the 2008 buyer's guide in *HP123*.

Solar collectors are classified by the temperatures that can be produced under normal amounts of solar radiation. The collector's end-use application can be determined by the temperature classification. Low-temperature collectors (which typically produce temperatures lower than 110°F) are used for applications such as swimming pool heating. Medium-temperature collectors (up to 200°F) are used for space heating and heating domestic hot water. High-temperature concentrators (greater than 250°F) track the sun and are capable of producing the high temperatures required to drive Stirling-cycle heat engines and steam turbines. Let's start low and work our way up.

Courtesy www.solarexpert.com

Simple unglazed solar pool collectors offer great energy savings over conventionally heated pools and spas.

Low-Temp Collectors

First in the collector lineup are unglazed collectors, which include swimming pool collectors—the most popular solar thermal system in the United States. The collectors are simple and inexpensive, and the systems follow suit.

Early pool collectors were made from copper tubing and plates—essentially the absorber of a classic flat-plate collector with larger header tubes to accommodate the flow rates associated with swimming pool pumps. But copper swimming pool collectors gave up the market long ago to black plastic polymer collectors, especially polypropylene, a relatively high-temperature plastic. With no insulation or other protection from the weather, these systems are only for seasonal use in most climates. Solar pool heating systems have such a high benefit-to-cost ratio that they are routinely excluded from incentives for solar energy heating equipment.

Cutaway of a polypropylene solar pool heating collector.

Chuck Marken

Flat-plate collectors are most commonly used to supply hot water for domestic and space heating uses.

Medium-Temp Collectors

For all but the mildest climates, two main types of medium-temperature collectors are available: **flat-plate** and **evacuated-tube**. Flat-plate collectors have a history going back at least 100 years; evacuated tubes have been available for about three decades. Flat-plate collectors are less expensive per square foot of collector—and this has made market penetration tough for evacuated-tube collectors, except in colder, cloudier climates where tube collectors may outperform flat plates. The cost difference between the collectors fluctuates with the price of copper, a primary material used in most flat-plate collectors. Both tubes and plates are used in applications such as domestic hot water systems, space heating, and indoor pool heating. To be eligible for the federal government's residential solar investment tax credits, collectors must be certified by the SRCC. Commercial and industrial scale projects don't require the certification to be eligible for the 30% credit.

Flat-Plate Collectors

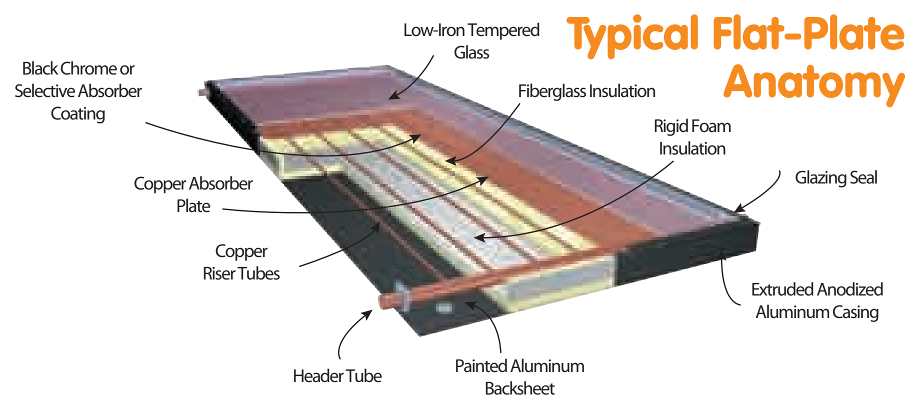
Flat-plate collectors are named after their flat absorber plate. These collectors are made with a metal enclosure (usually aluminum) and high-temperature insulation, and usually are covered with a sheet of low-iron tempered glass. Low-iron glass is important in collector design because, compared to typical window glass, it passes about 7% more light to the absorber inside the collector. The tempering of the glass makes it tough enough to withstand all but the largest hailstones.

Absorbers can be configured in a couple of ways. One design—a grid—uses multiple small riser tubes spaced a few inches apart. Each riser is brazed to the headers—the horizontal tubes that allow collectors to be connected together quickly. The entire tube assembly is then bonded to the absorber plate. Multiple riser tubes allow even flow through the collector with minimal restrictions.

Another design uses a single tube to bend back and forth in a serpentine pattern between two headers, a strategy for antifreeze-based systems. A downside to this design is that, in a drainback system, the single, bent riser tube can retain water and possibly freeze.

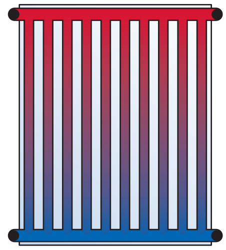
Besides differences in absorber configuration, collectors may locate headers inside or outside of the frame. Collectors with internal headers are designed to be connected together. With two inlets and two outlets, connections between collectors can be accomplished with minimal materials and labor. A classic internal-header collector has headers that are

Typical Flat-Plate Anatomy

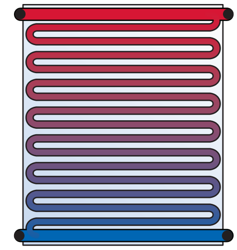


Courtesy www.sunearthinc.com

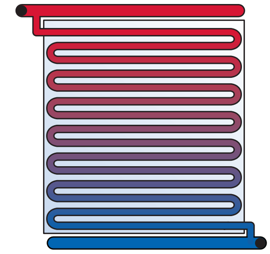
Flat-Plate Configurations



Grid-Style Absorber with Internal Headers



Serpentine-Style Absorber with Internal Headers



Serpentine-Style Absorber with External Headers

large enough not to impede the flow when a row of eight to 10 collectors are installed in parallel.

E**xternal header** collectors have a single inlet and outlet, and a simple serpentine bend tube. External header collectors require extra materials and labor in parallel-collector configurations.

An option to the external header is connecting multiple collectors in series. A series connection requires that each collector's outlet is connected to the next collector's inlet. Each collector in series is hotter than the preceding one and the system experiences more heat loss. While an appreciable drop in production doesn't occur with just a couple of collectors in series—the more that are connected, the worse the heat loss becomes.

Regardless of the design, the riser tubes through which the collector-loop fluid flows must be soldered, brazed, or welded to the absorber plate, or bonded to the absorber plate with a high-temperature, thermally conductive adhesive. Bonding of the plate to the tubes is critical to the collector's performance—a poor bond can cut the collector's heat production by 50% or more.

Integrated Collector/ Storage Units

The oldest design for a medium-temperature collector is the batch water heater. At its simplest, it is an insulated box with a black-painted tank inside and a glass cover that faces the sun. The use of batch heaters in mild climates transcends more than a century of fairly wide popularity. In places where freezing temperatures are common, batch heaters can be used seasonally, and bypassed and drained when winter weather comes.

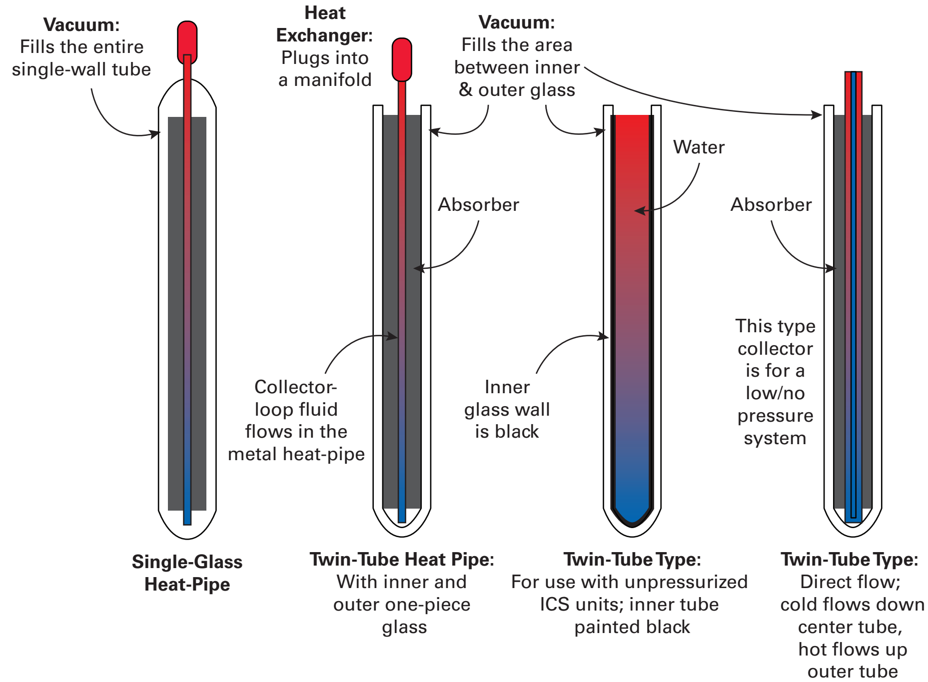
Progressive-tube batch water heaters are a more recent development. Instead of a single, large tank, the water is contained in several 4-inch-diameter tubes. The tubes are piped in series, with the cold water entering at the bottom of the collector and the hot exiting at the top. The progressive-tube design allows the water to stratify more, limiting the mixing of the incoming cold water with the exiting hot water. Both the tank-type and progressive-tube batch heaters are classified as integrated collector/storage (ICS) units.

Flat-plate and twin-tube evacuated collectors that are designed with the tank attached are also classified as ICS units. These designs depend upon thermosyphoning, where hotter liquids "rise" and colder "fall" as long as the storage tank is higher than the collector. ICS units are completely passive and don't depend on any moving parts or electricity to operate, though some contain electric water-heating elements for backup.

The flat-plate ICS designs use a classic flat-plate collector. The hot exit pipe of the collector is piped to the top port of the storage tank. The cold (or bottom) port of the storage tank is piped to the cold inlet at the bottom of the collector. As long as the sun is shining, water circulates through the collector and tank.

The twin-tube evacuated tube design is similar, although these heaters are only for use with unpressurized water systems. The inner tube of the twin tube is painted black and acts as an absorber. Each tube is "plugged in" at the bottom of a special stainless steel tank with gasketed ports the same diameter of the twin tube, one port for each tube. When the tank is filled with water, the inner tube is also filled with water. When the sun heats the inner tube through the black-painted absorber, the water moves by thermosyphon into the tank. The evacuated tube ICS has a freeze-tolerance advantage over the flat-plate thermosyphon unit due to the high insulation value of the vacuum.

Evacuated-Tube Collectors



Evacuated-tube collectors depend on vacuum technology for superior heat retention—a vacuum is an excellent thermal insulator. Even a relatively small space filled with a vacuum provides much better insulation than the foam, fiberglass, and glass cover of a flat-plate collector. With superior heat retention, evacuated tubes are often preferred in colder climates and cloudy regions where flat-plate collectors have lower performance.

Many early evacuated tubes had design flaws that caused the loss of the vacuum after only a few years. When the vacuum is gone, the heat retention advantage is also eliminated. But the past problems with vacuum loss have been addressed, and vacuum tube collectors are enjoying a renaissance throughout many countries in the world. Because of their popularity in China and Europe, the tubes have an increasing share of the world market in SHW collectors.

Tubes can be configured differently for various applications. The largest difference is where the all-important vacuum is contained.

In a **single-glass** tube, the vacuum fills the entire space inside the glass tube. These were the first type of evacuated-tube collectors manufactured, and experienced problems with the vacuum escaping at the top of the tube, where the glass was sealed to the absorber tubing. These early collectors also were made of inferior glass that was very fragile, and many fell victim to hailstones. Today, all the tubes are made with more-durable borosilicate glass or soda-lime glass. Older designs with single-glass tubes have a copper waterway bonded to a flat copper absorber inside the tube. The collector-loop fluid enters the tube at the top and exits at the bottom. Another direct-flow design locates both the supply and return tubing at the top of the tube. However, this design—where the collector loop fluid directly flows through the tube—has fallen out of favor because trapped fluid limits the tubes to an antifreeze system. Plus, broken tubes are not easily replaced.

The most popular evacuated-tube design incorporates a heat exchanger in each tube. In these designs, the heat exchanger consists of a single tube—a “heat pipe”—bonded to the absorber plate. The solar radiation heats the tube absorber, which heats the heat pipe, boiling and vaporizing the fluid (typically alcohol or purified water with special additives) inside it. At the top of the tube, a heat exchanger transfers the heat from the vapor to a manifold, through which collector-loop fluid circulates. The heat-pipe design allows each evacuated tube to be a separate collector and makes the entire system modular. This is popular with some installers since the collector can be assembled on the roof. Plus, since there is a “dry” connection between the absorber and the header, installation is much easier than with direct-flow collectors. Individual tubes can also be exchanged without draining the entire system of its fluid. Finally, should one tube break, there is little impact on the complete system.

Twin-tube collectors are built similarly to the popular vacuum bottles that keep drinks warm or cold. Two separate tubes, one inner and one outer, contain a vacuum between them. Most twin tubes use the heat-pipe design described above, but can be used in direct-flow and integrated collector/storage units (see “Integrated Collector/Storage Systems” sidebar, previous page). The heat-pipe design in a twin-tube collector is the same as in a single-glass collector and they enjoy the same benefit of superior insulation.

Absorber Coatings

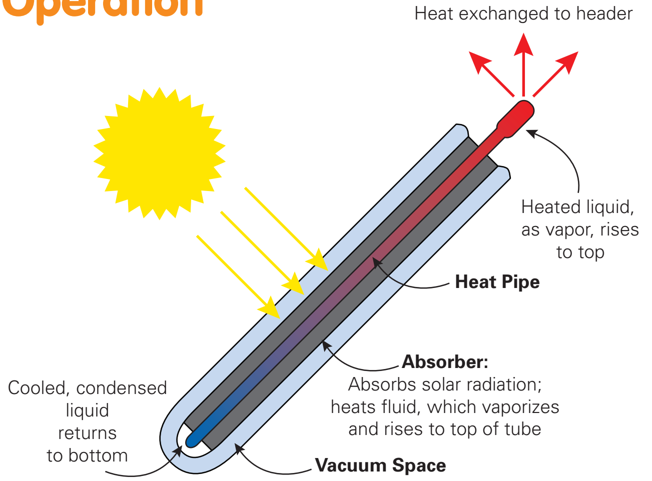
Flat-black paint was used on all solar collectors up to the late 1970s. Although this coating has high absorption (about 95% of solar radiation), it also has high emissivity (also about 95%), resulting in efficiency losses.

A significant improvement in collector performance came from the advent of selective-surface coatings, which absorb about as much radiation as flat-black paint but emit only 10% to 20%. This amounts to a gain of a few percentage points in collector performance. A selective coating is a complex and expensive process compared to simply painting an absorber—but it is worthwhile in many cases, such as installations in colder climates. Some selective-surface coatings are called black chrome, black crystal, and sputtered aluminum.

Courtesy www.thermomax.com

A modern evacuated-tube collector, showing the heat exchanger at the top of the tube and its connection to the manifold.

Evacuated Tube Operation



Air Collectors

Least known in the medium-temperature category, air collectors are used for space heating. They are similar to liquid flat-plate collectors and are difficult to differentiate from a distance. The only differences from SHW collectors is that air collectors don't have any tubing bonded to the absorber plate and use round ducts on the back, instead of tubing on the side, as the collectors' inlets and outlets.

Air from any room or building is ducted to the collector, where it passes over its aluminum absorber, gaining 30°F to 60°F depending on the room air temperature and amount of sunshine available. Then the heated air is circulated back into the room/building. The collectors can use passive air circulation but most often include a blower to force circulation and increase efficiency. The efficiency of air collectors is about 10% lower than liquid collectors due to the lower density and heat-carrying capacity of air.

Air collectors can also be configured as transpired air collectors, which have thousands of tiny holes in the absorber. Heat is transferred from the absorber to the air as it moves from one side of the absorber sheet to the other.

High-Temperature Concentrating Collectors

Solar concentrators are capable of making high-pressure steam (400°F to 750°F) and have limited residential applications. With few exceptions, the niche for concentrators is utility-scale electrical generation. Concentrators compete economically with hydro, wind, biomass, and photovoltaics.

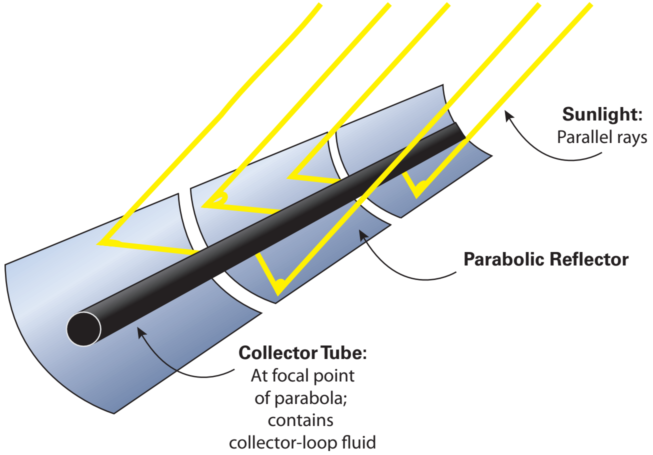
Concentrators must track the sun throughout the day to maximize their potential. The concentration of the sun's rays requires direct-beam solar radiation (primarily desert sun) and this need is a limiting factor in their deployment.

Concentrators come in two types: line-focus and point-focus collectors. A parabolic trough reflector is the collection part of a line-focus collector. A black target tube runs the length of the trough and is mounted at the focal point of the mirrored, curved surface. The trough reflects about 90% to 95% of the direct-beam radiation onto the target tube, heating the circulating collector-loop fluid within it. Typical systems run synthetic oil through the target tubes and exchange the heat to a water loop, creating steam to drive a turbine that generates electricity.

Courtesy Greg Kolb, Sandia National Laboratories

A large array of parabolic trough concentrating collectors at Kramer Junction, California.

Parabolic Trough Reflector



Point-focus collectors typically resemble satellite dishes. Instead of focusing on a tube, the collectors focus on a point. The dishes that collect the solar radiation are also parabolic mirrors, only round. These systems are used to heat buildings and make hot water in desert climates, although the market is limited. The piping to and from the collector is usually underground. In freezing climates, antifreeze is used as the collector fluid. The dishes are also used as the heat source for a Stirling engine. A single, large mirror or several smaller mirrors focus the solar radiation on the cylinder of a Stirling-cycle heat engine, which is coupled to a generator to make a stand-alone electric power plant. The units have been built in 5 to 30 kW capacities.

A central receiver system is another type of point-focus collector. It consists of a receiver tower surrounded by large mirrors called heliostats. The heliostats are computer-controlled and track the sun in concert to reflect the solar radiation onto the receiver. The collector-loop fluid is piped to a heat exchanger and steam is used to drive a turbine to produce electricity. These large point-focus collectors can concentrate enough solar energy on the receiver to create temperatures in the thousands of degrees. Few large central receivers are in operation—they are still considered to be in the research-and-development phase. They also have high initial costs and other issues surrounding the high temperatures they produce. The only application for central receivers is the utility-scale generation of electricity.

What's Best for You?

The classification of the collectors by their effective end-use temperatures is a helpful method of differentiation. The residential uses of solar heating collectors eliminate high-temperature collectors for consideration by most people.

Medium-temperature collectors apply to residential applications, and can effectively heat domestic water and assist in space heating throughout most of North America. Commercial or industrial applications not requiring high temperatures are also good candidates for medium-temperature collectors. ICS units are popular in many southern states with mild climates. Flat plates are the choice throughout most of the United States for heating water, but evacuated tubes have become popular in some northern climes.

Point focus parabolic dish with Stirling engine at Plataforma Solar de Almería in Spain. Note the parabolic troughs in the background, turned out of the sun to stop heat production.

Courtesy: Schlaich Bergermann und Partner

Courtesy Thomas Mancini, Sandia National Laboratories

A Stirling engine driven by heat from focused mirrors can produce up to 30 kW of electricity.

Low-temperature collectors are used almost exclusively for heating pools and hot tubs, with the season dictated by the local climate. They can also be used for heating domestic water in very mild climates, but these systems are rare and have questionable performance in medium to cold climates in the winter.

The SRCC publishes catalogs of the collectors and systems certified under their program, which is recognized in many federal, state, local, and utility incentive programs for solar thermal systems. The catalogs are updated a few times per year and are available at www.solar-rating.org.

Access

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