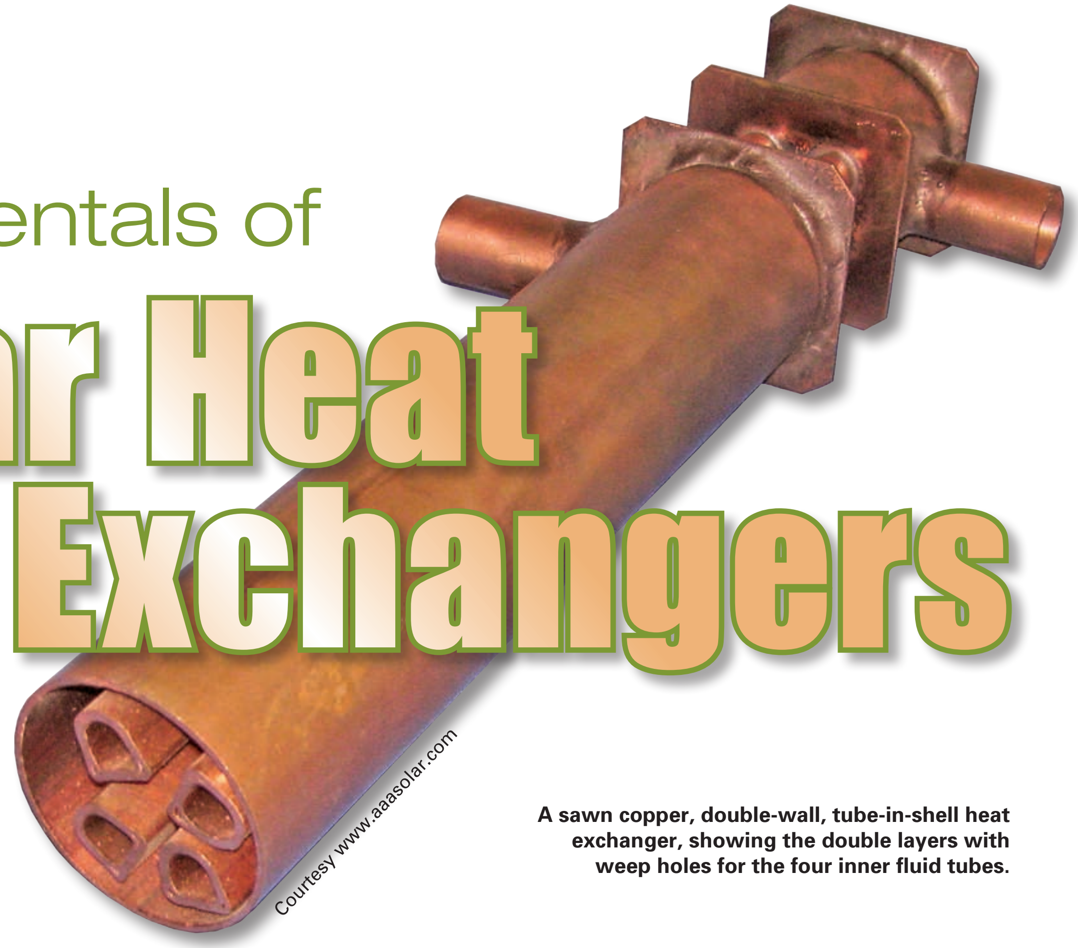
Fundamentals of

Solar Heat Exchangers



A sawn copper, double-wall, tube-in-shell heat exchanger, showing the double layers with weep holes for the four inner fluid tubes.

by Chuck Marken

You might not realize it, but heat exchangers are a part of everyday modern life. Every car has two or three of them; most homes have three or more. Wood heaters and baseboard radiators are heat exchangers. Refrigerators have a couple tucked away. And all drainback and antifreeze solar hot water systems—among the most common SHW types—need a heat exchanger for freeze protection.

Heat exchangers can be air to air (forced-air furnace), air to liquid (car radiator), or liquid to liquid (most SHW heat exchangers). This article covers liquid-to-liquid exchangers exclusively, although most of the rules for good heat exchange are applicable to all configurations.

Heat exchangers in SHW systems are used to transfer heat from one fluid (the heated collector fluid) to another (usually stored water), with heat flowing from the hotter fluid to the cooler fluid. By definition, no contact between the two fluids occurs within a heat exchanger. Instead, heat transfer is accomplished by conduction through the metal walls in the exchanger that separate the two fluids.

Exchanger Design Factors

Wall materials, exchange surface area, and construction all impact heat-exchanger performance. Here are the most important parameters.

Material conductivity. The thermal conductivity of the heat exchanger material is an important factor in system performance, but it is often overlooked. Make a heat exchanger out of glass and you'll learn the game—it will work, but you'll be disappointed by its poor efficiency. The more insulative the material, the worse it will perform as a conductor of heat. I've never seen a SHW heat exchanger worth a nickel that wasn't made out of metal.

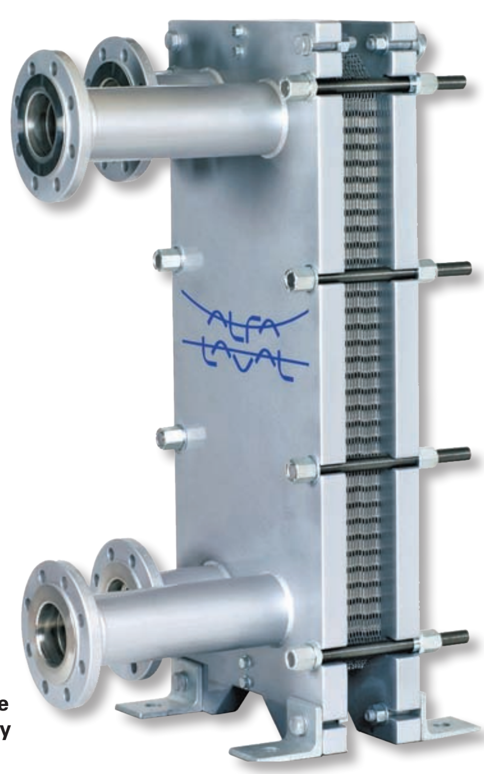
A major water heater manufacturer once made a tank with an internal, coiled double-wall heat exchanger—copper tubing covered with a high-temperature PEX (high-density, cross-linked polyethylene)—but the product was discontinued after a couple of years. The bottom line: All metals have good-to-excellent thermal conductivity. Plastics and other thermal insulators typically have poor conductivity, making for less effective heat exchangers.

Surface area. An exchanger's heat-transfer surface area is very often the most important design parameter. It must be large enough to transfer the heat to where it's needed. Too small a heat exchanger will simply give unsatisfactory performance.

A high ratio of the exchanger surface area to the volume of liquid within the inner tubes makes for better heat transfer. A good example can be demonstrated if you have a thermometer. Take a few ice cubes, crush them into small pieces, and place them in a glass. Take an equal number of cubes and place them in another glass of equal size without crushing them. Fill both glasses with an equal measure of water from the kitchen tap. Wait a couple of minutes and measure the temperature of both glasses of water. Although both have an equal volume of ice and the temperature of the ice and water are the same when the glasses are filled, the glass with the crushed ice will be colder. What's at work? The surface-area-to-volume ratio of the crushed ice is greater and serves to better exchange the heat.

While the surface-area-to-volume ratio is important, sacrificing total surface area for a higher surface-to-volume ratio can result in less heat exchange. For example, using a smaller-diameter tube increases surface-to-volume ratio but decreases the total surface area and can be detrimental. The surface area decreases less than the volume. This is true for all cylinders (tubes)—very large tubes have much less surface area compared to the volume of liquid in the tube—and results in less heat exchanged. Although the heat exchange is better with the smaller tube, the design needs to ensure the volume is large enough to not impede the flow.

Physical configuration. A solar heat exchanger is usually designed in one of three ways—with coiled tubing, plates, or tube in shell. Coiled heat exchangers are used inside of or wrapped around storage tanks. Plate heat exchangers are generally preferred when single-wall heat exchangers are acceptable. Tube-in-shell heat exchangers are the design used for most double-wall external heat exchangers.



Courtesy www.alfalaval.com

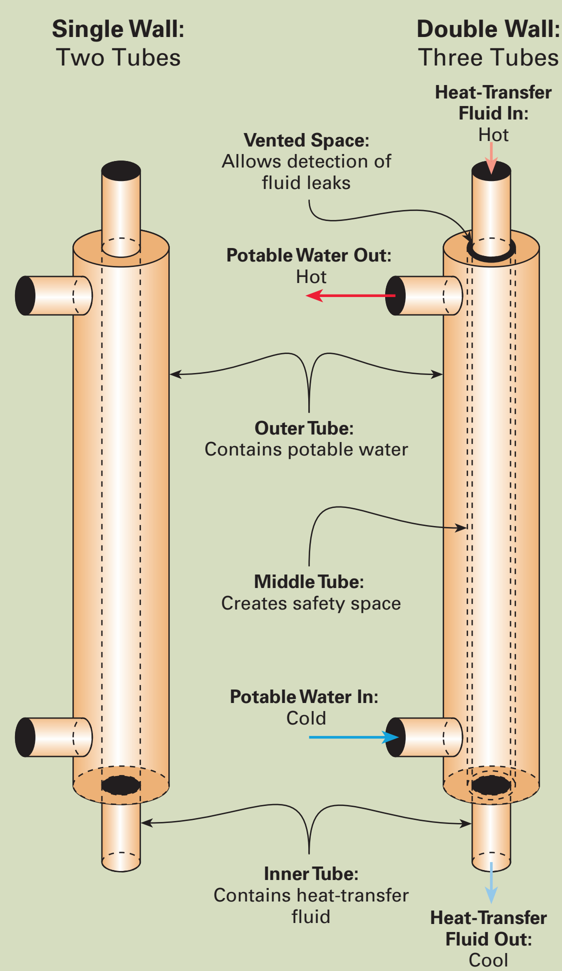
A large plate-style heat exchanger by Alfa Laval.

Regulations: Avoiding a Red Tag

The 2006 Uniform Solar Energy Code specifies that heat exchangers in SHW systems transferring heat to potable water must be double-walled—no exceptions—to prevent possible mixing from occurring in the event of a leak. I've always thought this rule was excessive when nontoxic propylene glycol is used and even debated a local inspector about it once (do so at your own peril).

His logic was this: Even if *I* always used nontoxic glycol as the system antifreeze, how could he or I ever prevent someone else from filling the system with toxic—potentially lethal—ethylene glycol in the future? Unless your local building department approves of single-wall heat exchangers in SHW systems or your favorite tag color is red, stick with the double-wall design.

Single Wall vs. Double Wall



Courtesy www.rheemsolar.com

The Rheem Solaraide HE is a storage tank with an integrated, wraparound heat-exchange coil.

Heat exchangers are either external to the tank or housed inside the tank (internal). I've read a couple of well-respected books that claim that external heat exchangers are more "efficient" than internal heat exchangers. The books don't give a reason why. Perhaps the reference is to the difference in external *plate* heat exchangers and internal *coil* exchangers. Since it is almost impossible to make an apples-to-apples comparison of the two designs, I still question this blanket claim.

Bonding. The design of a double-wall heat exchanger calls for the two walls to be thermally bonded together and also have a path to the atmosphere so leaks can be detected. A heat exchanger's effectiveness depends on this bond. In most cases, a simple, press-fit mechanical bond is not sufficient. The mechanical bond must be augmented with heat-transfer paste to ensure good conductivity between the two walls of the heat exchanger.

System Design Factors

Besides the exchanger's design and construction, how well it works within the system is critical. These factors all influence system efficiency.

Delta T (ΔT, temperature difference). The larger the temperature difference between the fluid in the heat exchanger and the water in the tank, the better the heat exchange will be. When the difference in temperature is only a few degrees (a low ΔT), less heat is transferred in the exchanger.

Flow rate. Generally, the higher the flow rate through the SHW system, the better the heat exchange. More flow means that more liquid volume is available for its heat to be exchanged. More powerful pumps and larger-diameter pipes help improve flow rate.

Fluid type. Water has the highest heat-content capacity (specific heat) of common fluids. Antifreeze (propylene glycol) solutions have about 70% of the heat-content capacity of water and this affects the heat-exchange efficiency in the system. However, fluid-type efficiency is less of a factor than the efficiency and surface area of the exchanger itself.

An inefficient heat exchanger will have a high ΔT between the two fluids. While this normally makes the heat exchange more efficient, the overall system efficiency suffers because the collectors operate at higher-than-necessary temperatures.

Courtesy www.aaasolar.com

An external, tube-in-shell heat exchanger (far right) with other balance of system components, like circulator pumps (far left) and an expansion tank (center).

The high ΔT can be caused by many factors. Low flow rates, small heat-exchange surface areas, and low surface-to-volume ratios, or a combination of these factors can all affect the heat-exchange efficiency and overall system efficiency.

System Designs

SHW heat exchangers can be internal, external, or wraparound. All of the systems can be configured as either single- or double-wall designs, except the wraparound, which by its nature is a double wall, since the tank is one wall and the wall of the tubing is the other.

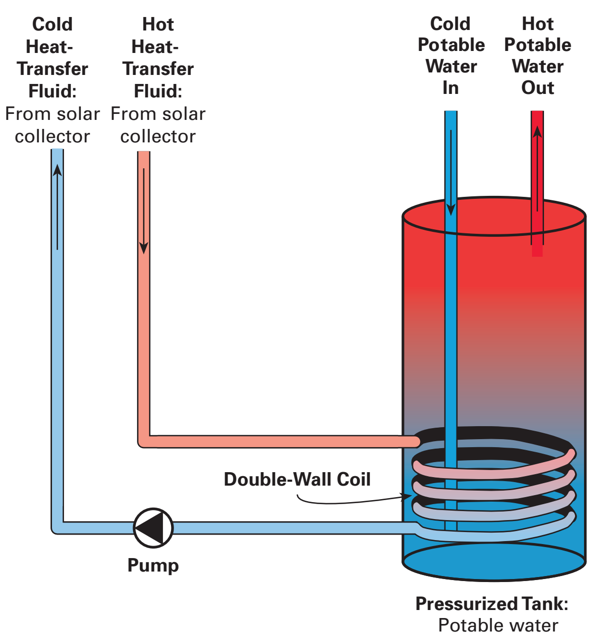
Internal Exchangers

Immersed exchanger in a pressurized tank. This efficient design puts the domestic hot water in contact with the outer wall of the heat exchanger. The efficiency of the double-wall design used in antifreeze/glycol systems depends a great deal on the bonding between the two walls.

These tank/exchanger designs are usually the most expensive. However, one design (the Solar Wand; see Access) lends itself to insertion into the tank, screwing into a 3/4-inch port at the top of the tank. This design is useful when you need to use an existing water heater as the solar storage tank.

Be aware that copper heat exchangers placed in glass-lined steel tanks are predisposed to causing premature tank failure—after the large mass of copper has devoured the tank's sacrificial anode rod, it then attacks through the imperfections in the tank lining to eventually corrode the tank itself.

Immersed, Bonded, Double-Wall Heat Exchanger



Area, Volume & Performance

A good example of heat-exchange effectiveness is shown by comparing the surface area and surface-area-to-volume ratio of the two heat exchangers pictured below. The large copper tube-in-tube exchanger was originally installed on a solar thermal system heating an indoor swimming pool. It has a total heat-exchange surface area of 65 square inches. The five 1/2-inch-diameter inner tubes total a volume of 36 fluid ounces, for a ratio of 1.8 to 1. The plate-type stainless-steel heat exchanger shown in front of the copper exchanger has a total exchange surface area of 720 square inches and total volume of only 15 fluid ounces, a 48:1 ratio—offering both a higher surface area and a higher surface-to-volume ratio.

The proof was in exchanging the exchangers. The tube-in-tube heat exchanger was unable to heat the pool successfully, while the plate exchanger allowed the system to perform as designed and heat the pool without any other modifications.

The original tube-in-tube heat exchanger and the more efficient plate-type heat exchanger.

Courtesy www.aaasolar.com

The Solar Wand from Butler Sun Solutions is an internal heat exchanger that fits into any standard water heater port.

Immersed exchanger in an unpressurized tank. Any material that will withstand 212°F is suitable for an unpressurized storage tank. Steel, stainless steel, concrete, fiberglass, polypropylene, and EPDM rubber have all been used successfully as unpressurized tanks.

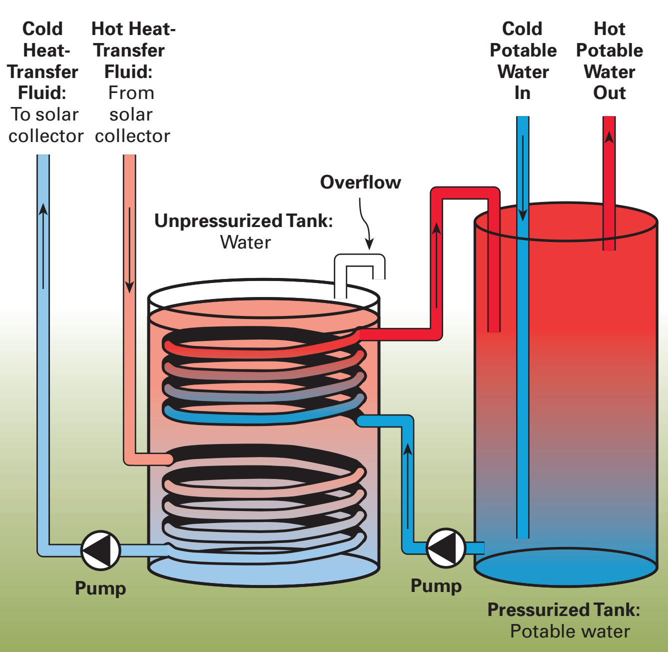
Most drainback systems use the potable water in the tank as the collector-loop fluid, but for antifreeze systems, a coil circulating the antifreeze solution can be inserted in the tank. Since the potable domestic water is circulating simultaneously through a similar immersed coil, the two walls of the coils effectively make a double-wall exchanger. The unpressurized tank system is a great choice for SHW systems performing more than one job. For instance, a domestic water heating and radiant floor system would each have a separate coiled heat exchanger.

External Exchangers

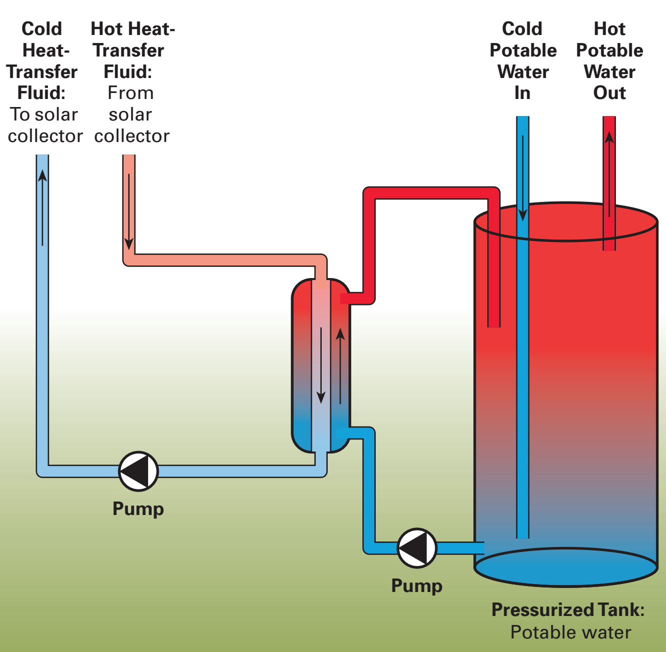
External heat exchanger. This design offers the flexibility of using any type of pressurized tank in the system. Slightly modified electric water heaters make excellent solar storage tanks when used with external heat exchangers. Typically, two pumps are required for external exchanger systems—one to circulate potable water from the tank to the exchanger and another to circulate the heat-exchange fluid from the collector to the exchanger—but some external exchangers can avoid one pump by thermosyphoning on the tank side. The shell or tube (waterway of the DHW) of a good thermosyphoning heat exchanger is fairly large to cut down on frictional head loss.

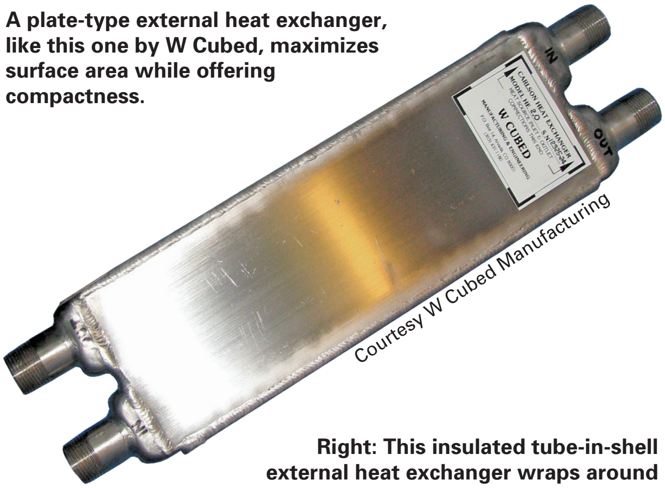
The external exchanger can be single or double wall depending on the collector-loop fluid or the fluid to be heated. (See *HP97* for an article on how to build a single-wall, tube-in-tube exchanger for a drainback system.) Stainless-steel plate heat exchangers are the most popular for heating radiant floors and other applications not heating potable water.

Immersed, Double-Wall, Double-Coil Heat Exchanger (Multiple Pass)



Exterior, Vented, Double-Wall Heat Exchanger





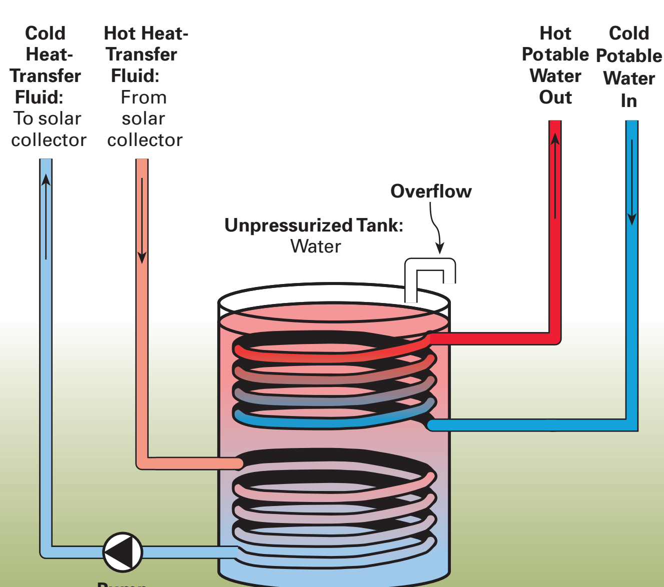
A plate-type external heat exchanger, like this one by W Cubed, maximizes surface area while offering compactness.

Right: This insulated tube-in-shell external heat exchanger wraps around the expansion tank to save space.

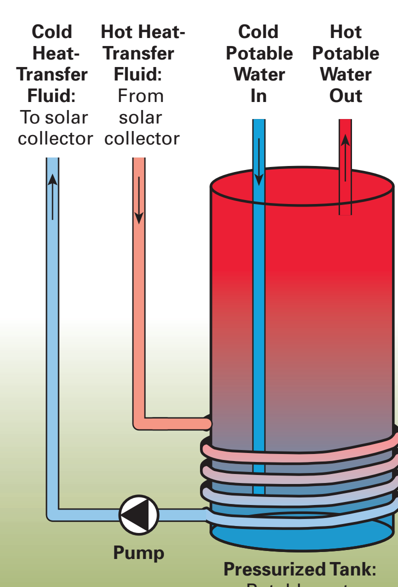
Instantaneous (a.k.a. single-pass) exchangers. These exchangers are designed for use with potable domestic water. The water is not circulated into storage but makes a single pass though the exchanger on its way to the point of use. For this exchanger to be effective beyond very modest use patterns, its surface area and surface-to-volume ratio need to be very high.

Single-pass heat exchangers have a reputation of disappointing their users. Typically, the only way you can have sustained hot water with a single-pass exchanger is to have hundreds of feet of exchanger tubing and enough of them in parallel to handle the needed flow.

Instantaneous Immersed, Double-Wall, Double-Coil Heat Exchanger



Wraparound, Double-Wall Heat Exchanger



Wraparound heat exchangers. This design is probably the most widely used in systems using Solar Rating & Certification Corporation-certified SHW collectors. (This certification is required for residential solar water heaters to be eligible for the federal tax credit). The system requires a single pump and is easy to adapt to drainback and antifreeze designs. While the tank is costly, it reduces labor costs because it is simpler to install. These tanks are equipped with a backup electric heating element in the top of the tank.

The design of a heat exchanger is very important in the efficiency of any freeze-protected solar water heating system. Less costly heat exchanger designs usually require more labor and materials for installation. The costlier designs are easier to install but offer less flexibility, and tank replacement will warrant a higher repair bill.

Access

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Heat Exchanger Manufacturers:

AAA Solar Supply Inc. • www.aaasolar.com • External double-wall exchangers

Alfa Laval Inc. • www.alfalaval.com • Small plate exchangers & large double-wall exchangers

Butler Sun Solutions • www.butlersunsolutions.com • Double-wall exchanger

Doucette Industries Inc. • www.doucetteindustries.com • Double-wall & plate exchangers

W. Cubed Manufacturing & Engineering • Phone/Fax: 303-431-1180 • Flat-plate exchangers

Tank & Exchanger Combination Manufacturers:

Rheem Water Heaters • www.rheem.com • Wraparound double-wall exchangers

Vaughn Manufacturing Corp. • www.vaughncorp.com • Double-wall exchangers bonded in a pressure vessel