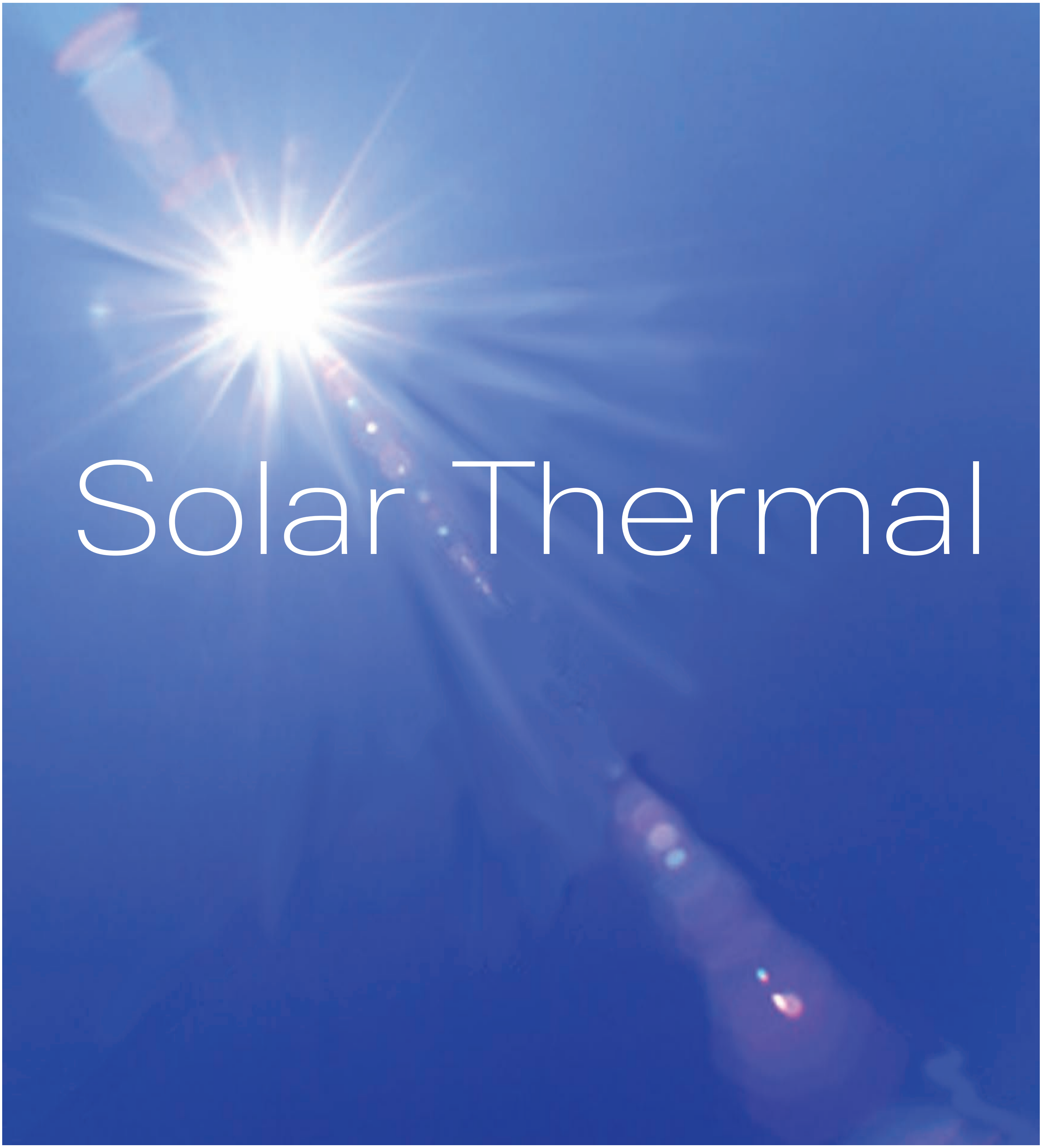
Solar Thermal

System Design

Part 3: System Design

BY W. HOLLIS FITCH III

The first article of this series (in the January/February 2011 issue) discussed some advances in solar thermal system design techniques, especially software, and the differences between evacuated tube and flat plate collectors. The second article (in the March 2011 issue) focused on freezing and overheating issues. This last article wraps up the series with a look at some other aspects of a complete solar thermal system design.

Since the solar collectors are the most visible part of a solar system, many people tend to focus on them and ignore the other system components. In fact, the collectors represent less than 30 percent of the installed cost of a system, and sometimes less than 10 percent. Aside from cost, every component in a solar thermal system must be designed to complement not only the array, but also the facility itself and the pressures and temperatures common in solar systems. It also must be designed to last for decades.

SYSTEM COMPONENTS

What other equipment is part of a solar thermal system? Depending on the application, it may be necessary for the engineer to address or specify, at the very least, the following:

- Structural steel supports
- Storage tanks
- Mixing valves
- Control and balance valves
- Solar controllers and instrumentation
- Pumps
- Piping systems

While none of the design requirements are difficult, it is important to recognize how a solar system operates and to take this into account in the installation. The two most important considerations are the temperature of the water commonly generated by solar systems and the longevity of the system, and the impact of these will become apparent as each of the above items is discussed.

Structural Steel Supports

While a structural analysis is beyond the scope of this article, the plumbing engineer typically is responsible for forwarding structural load information to the other engineers or architects on the project. The

Figure 1 Example of structural steel supports
Source: Cinco Solar

TABLE 1 HEAT CAPACITIES OF COMMON LIQUIDS

Liquid	Btu/lb°F
Acetone	0.51
Alcohol, propyl	0.57
Ammonia, 104°F	1.16
Calcium chloride	0.73
Ethylene glycol	0.56
Freon R-12 saturated, 120°F	0.244
Gasoline	0.53
Glycerine	0.576
Mercury	0.03
Oil, vegetable	0.4
Paraffin	0.51
Potassium hydrate	0.88
Propylene glycol	0.6
Sodium, 1000°F	0.3
Sodium chloride	0.79
Water, fresh	1

actual weight of a collector usually is insignificant (say, 200 pounds), but the wind loads can be extreme. Once wind loads are calculated and the appropriate safety factors are met, the forces acting in an upward or downward direction can exceed 5,000 pounds, which is far in excess of the simple weight of the collector.

It is important to convey this information early in the design phase so steps can be taken to support the collector array. Many times the wind loads make fitting the collectors to existing buildings difficult, and even on new construction extra steel will be required (see Figure 1).

One more interface is the roof penetrations. Any large system will require numerous penetrations for the supporting steel and the piping, and involving roofing contractors early on will make the process smoother.

Solar Storage Tanks

Storage tanks act as the heart and battery of most solar systems. While the world is still looking for the ideal electrical storage battery, the solar thermal industry already has it in the form of a water tank. Water has the highest heat capacity of any common liquid (only ammonia is higher, see Table 1), so it makes an ideal and inexpensive medium for storing energy.

While water itself may be almost free, the storage tank will not be so simple. Since a modern solar thermal system quite easily will produce water in temperatures up to 200°F, storage tanks should be designed with this in mind. At such temperatures, epoxy- or glass-lined carbon steel tanks will be unsuitable, and using them will cause premature failure. Other options should be used, such as cement, stainless steel, or specialty linings able to handle elevated temperatures. If such options are not available (such as when a preexisting tank is present), then the solar system must have temperature-limiting controls to prevent the tanks from being damaged. Since solar storage tanks most often are pressurized and have a heat source, they should be designed and built to ASME standards.

Storage tanks may be separate from the water heater or part of a combined water heater/storage unit. In the latter case, solar efficiency will decrease slightly, since the water heater will maintain a set point (say, 140°F), while ideally you would want the solar system to use cooler water. This loss of efficiency is countered by the simplicity and ease of installing just one combined heating and storage unit, which often is the preferred option. If a combined unit is used, it is good practice to place the heat source near the top of the tank and consider the top one-third of the tank as the recovery volume, as well as increase the thermostat deadband up to 20°F if possible. Both of these techniques will help improve the overall efficiency of the system.

Figure 2 Mixing valve
Source: Armstrong International

Figure 3 Modern solar controller
Source: Resol

Multiple tanks are commonly specified for several reasons. In many cases, the mechanical room, outside slab, or access door is simply not big enough for one large tank, and several may have to be used. (Similarly, sometimes in confined spaces a horizontal orientation must be used instead of the preferred vertical orientation.) Multiple tanks also allow the system to take advantage of tank prioritizing routines, which will improve overall efficiency.

Mixing Valves

Mixing valves are commonly specified in domestic hot water systems to protect users from scalding. Many types and brands are available, and choosing the correct mixing valve is critical. Most mixing valves are set at the factory for a certain narrow input range of temperatures and also may require a minimum and maximum flow rate.

However, when a solar system is installed in conjunction with a water heating system, most mixing valves will not work. This is because the temperature of the water feeding the water heater from the solar storage tanks will range from as low as 80°F to as high as 210°F. Most mixing valves simply cannot handle such a broad input temperature range and still hold set point.

Similarly, during periods of low water use, the building recirculation system may allow temperature creep to occur, but again, much higher temperatures than normally encountered in DHW systems may be present in the solar storage tanks, making this creep especially insidious. In most cases, it is best to specify a digital mixing valve, which will be able to operate correctly under any temperature or flow rate (see Figure 2).

Control and Balance Valves

Every piping system needs valves for isolation, control, and balance, and solar thermal systems are no different. Any valves used in the solar loop should be specified for the temperatures expected during service, which may range from 200–300°F. If the loop is potable water, then the valves should be NSF 61-Certified, or at least made from NSF 61-approved materials, such as 316L stainless steel and EPDM seals. Most valves able to take the elevated temperatures common in solar loops will be made from these materials anyway, so this should not be an issue.

If more than one row of collectors is used, it will be important to use balance valves at the end of each row to ensure an even flow across the entire array. Balance valves are made in several types, including constant-volume flow, pressure-independent constant-volume flow, temperature-compensated flow, and modulating. Any of the constant flow-volume valves are poor choices for solar arrays, not because they are of inferior quality, but because better operation is achieved if the flow can vary in relation to the temperature. That leaves electronic modulating valves and thermostatic balance valves as the best options.

Electronic modulating valves offer the best in flexibility and efficiency, but they are quite costly to install because each needs a power source and an input/output control. Thermostatic balance valves are nearly as efficient as electronic valves, and they do not require any wiring. This type of valve is set at the factory to modulate flow volumes to maintain a desired set point. For example, if the set point is 155°F, the thermostatic balance valve will adjust the valve flow rate continuously to hold this temperature. If the sun goes behind a cloud, the thermostatic element will close the valve, allowing water to remain in the collector bank longer and thus reach the set point. When the sun comes back out, the element will open the valve wide to allow water less time in the collector bank.

Solar Controllers and Instrumentation

For many years, solar systems were controlled by very simplistic controllers, and hence often failed. Recently several companies have introduced increasingly sophisticated controls, and this has been a great benefit to the solar thermal industry. The best controls offer numerous temperature inputs; logic to control solar pumps, freeze conditions, over-temperature conditions, tank prioritizing, and energy production; and some form of communication inter-

Figure 4 Common solar pump
Source: Cinco Solar

Figure 5 Flexible stainless solar pipe
Source: SolarTrac

face. (See Figure 3 for an example of a mid-level controller.)

The solar professional should consider using one temperature sensor for each bank of collectors, two in each storage tank, and one on both the array supply and return piping. In addition, using an outside air temperature sensor, an irradiation meter, and a flow meter will allow very precise measurements of system performance.

Communication is important, and the controller should be able to communicate to proprietary software so that data and alarms can be seen and heard, but a better option is a controller that can interface with a building management system.

Solar Pumps

Just as with valves, pumps are common in the plumbing industry, and innumerable types and manufacturers are available. For a solar system, pumps should be selected on the basis of service (e.g., hot potable water), efficiency, ease of maintenance, and longevity. In general, a stainless steel housing and impeller are considered important for durability, along with high-temperature pump seals (see Figure 4).

Pump size varies from ¼-horsepower pumps for small commercial systems up to 10 horsepower or more for very large systems. The more advanced models have built-in temperature sensors and speed control.

Piping Systems

Piping for solar thermal systems traditionally has been sweated copper, usually type L, but occasionally type M and type K are specified. Copper makes an ideal material for solar piping, since it has a low heat capacity, can withstand fairly high temperatures, and is commonly available. However, copper is expensive, and alternatives are available.

One of the best alternatives is stainless steel pipe or tubing. In addition to rigid stainless steel, several companies produce a corrugated flexible stainless steel pipe (see Figure 5) that is suitable for solar systems, and it may come pre-insulated to save time in the field.

Since water can be up to 200°F in solar array supply piping and 250°F (or more after a stagnation period) in return pipe and at pressures up to 80 pounds per square inch, non-metallic pipe typically is not suitable for solar systems because manufacturers do not allow the use of PEX or CPVC pipe where temperatures exceed 180°F, except on a very limited basis. It is hoped that these limitations will be overcome in the future to allow more choices to the solar installer.

SUMMARY

Interest in solar thermal systems has increased dramatically in the past few years. Because of this interest, the plumbing engineer is advised to understand how the industry has changed over the last few decades and how to overcome some of the challenges that arise in designing a robust system.

Advances in technology and tools allow for high-quality and efficient installations. These advances include improvements in solar thermal collector design, such as well-made flat panels and high-performing evacuated tube collectors. Developments in software now allow very detailed energy analysis models to be made, providing for more detailed specification of system size and performance.

Since evacuated tube collectors are so resistant to freezing, options are available to the engineer when choosing a heat-transfer fluid. Whereas glycol historically has been the only option available for flat panel systems, direct water, in addition to glycol, is an option when specifying evacuated tube systems.

Just as important as the collector are the system components discussed above. Again, none of these components are difficult to specify or obtain. It just takes an understanding of how solar thermal systems operate and the use of common sense in selecting the highest quality equipment and materials.

With the right approach and careful study, a solar thermal system can be a pleasure to design and specify and will benefit your clients for decades to come. When done correctly, such installations can save up to 70–80 percent of the fossil fuel demand in a facility, which will mean reductions in both operating expenses and emissions, as well as free up high-quality fuels such as natural gas for more important uses such as transportation and electrical energy generation. **PSD**

Hollis Fitch is Chief Executive Officer of Cinco Solar Inc. in Spring Branch, Texas. For more information or to comment on this article, e-mail **articles@psdmagazine.org**.