# Solar Thermal

# System Design

## Part 2: How to Overcome Freezing and Stagnation

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Part 1 of this series on solar thermal system design in the January/February 2011 issue of *Plumbing Systems & Design* discussed solar thermal system applications and compared flat plate collectors and evacuated tube collectors. This article discusses two of the most important considerations for solar thermal system design: freezing and stagnation.

Solar thermal systems have been used for centuries. However, in the mid-1970s, U.S. government incentives provided a much-needed boost to solar thermal systems and generated a great deal of interest, research, and review of large-scale test installations. When the incentives ended in the early 1980s, the solar thermal industry came to a standstill in the United States, and advances in technology and understanding also stagnated. Today, solar thermal engineers have to dust off the white papers and books of the 1970s to get back up to speed, since little new information has been published since then.

One area that needs review is consideration of the detrimental effects of extreme weather conditions—freezing and high-temperature stagnation—on solar collectors. While freezing has been addressed in the past, the new evacuated tube collectors offer a different opportunity that should be explored. On the other hand, stagnation conditions largely have been ignored by the industry, which has led to many premature failures.

### FREEZE PREVENTION METHODS

Since flat panel collectors by design incorporate a large, flat sheet of glass as a cover, they exhibit an inherently low R value, or thermal resistance. This means that flat panel collectors are quite susceptible to freezing as temperatures decrease. In fact, freeze-related damage has been the single largest problem the solar thermal industry has faced, and it is the cause of the majority of system damage, loss of service, poor reputation, and loss of investment to date.

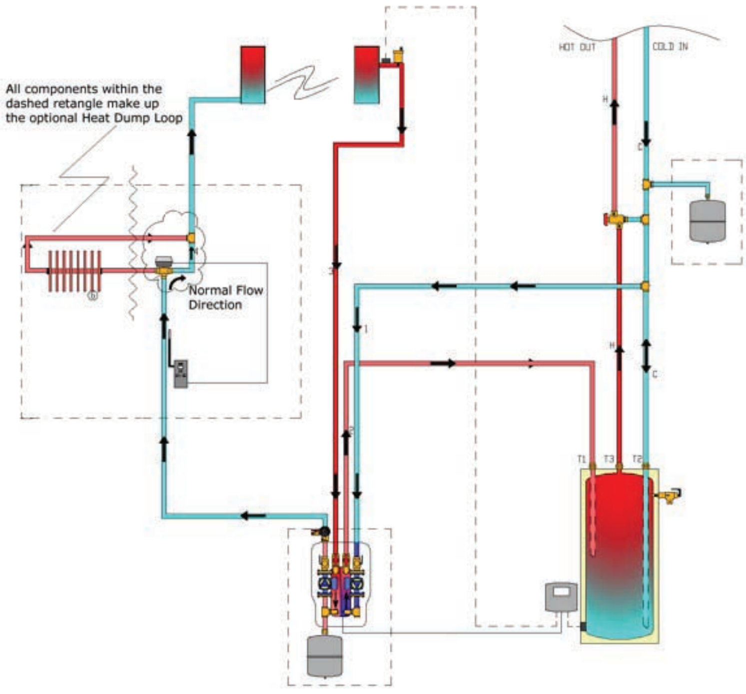


Figure 1 Glycol loop with heat exchanger

Source: Solarhot USA

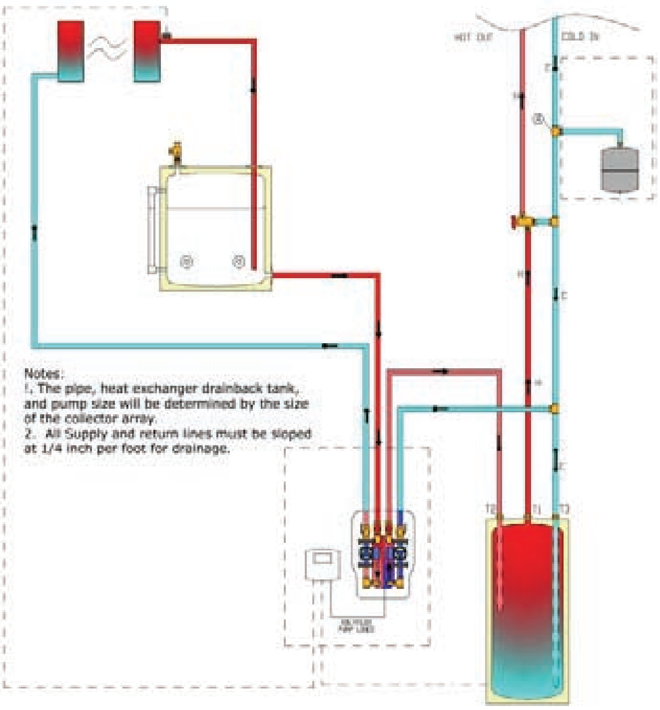


Figure 2 Drainback system

Source: Solarhot USA

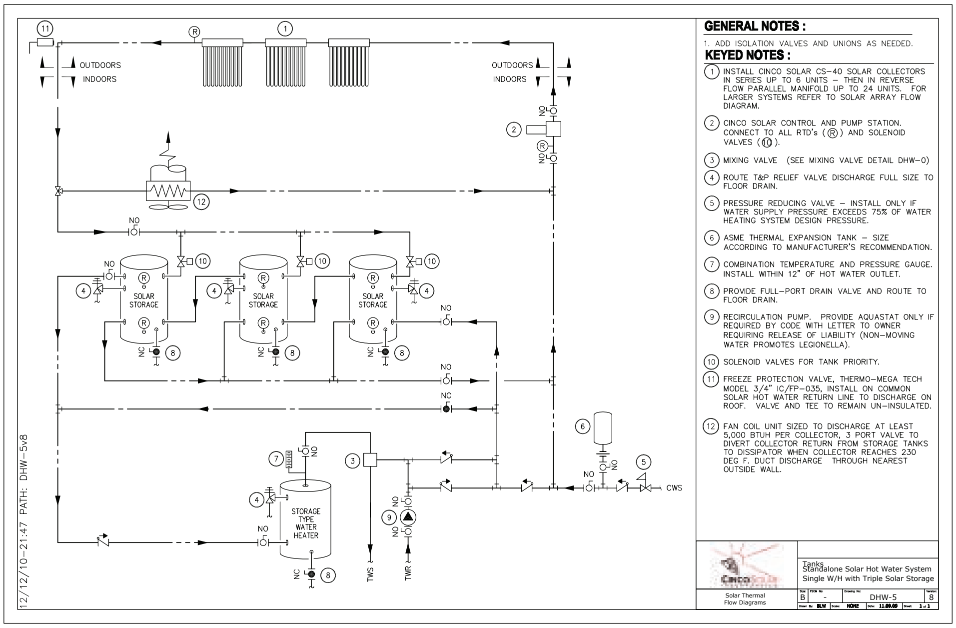
In an effort to combat the damage caused to flat plate collectors by freezing, the industry adopted two solutions: using glycol antifreeze as the heat-transfer fluid (see Figure 1) or installing drainback systems to drain the exposed panels and piping of water during cold weather. It is essential to use one of these options when installing flat panel collectors, or the system inevitably will freeze at some point (unless the project is located in the tropics, of course). It is not practical to circulate hot water through such systems, since the heat loss from flat panels is prohibitive and would extend the payback beyond the design life of the collectors.

It is important to note that while both options help reduce the possibility of freezing, they both also present a host of other problems that need to be addressed as part of the design, operation, and maintenance of the system.

## Glycol Antifreeze

In the case of glycol antifreeze as the heat-transfer medium, the problems are as follows:

- Glycol is not stable at elevated temperatures; it breaks down over time and must be replaced. If a solar thermal system stagnates, which happens from time to time, the higher temperatures cause much faster breakdown. As a side effect of this breakdown, glycolic acid is produced, which can etch copper piping, collector components, heat exchangers, pumps, and valves. A preventative maintenance program should be put in place when glycol is used to ensure that the pH is measured regularly and that the glycol/water solution is replaced every one to three years. Even the safe propylene glycols used in solar systems are considered controlled substances and should not be disposed into sanitary drains, but taken to proper recycling stations.
- Glycol fluids require closed-loop piping systems (see Figure 1). This means that the heat from the solar loop must be transferred to the potable water system, usually through a double-wall heat exchanger and dual pumps or through double-wall heat exchanger bundles in storage tanks. Besides the higher costs associated with the extra components, the biggest issue is maintaining pressure in the closed loop. If any leak occurs in the glycol loop, then the pressure soon will drop to zero, which will cause overheating at the collectors, pump failure from cavitation, and overheating of the glycol. If a glycol system is used, low-pressure alarms should be installed to notify operations personnel of loss of pressure so immediate action can be taken. Maintenance personnel also should receive training on using the correct proportions when refilling the system with the glycol/water mix, so an accurate base pressure is built up again.
- If a closed-loop glycol system loses pump flow, overheating will occur at the collectors, and in most cases temperatures will increase high enough to allow the formation of steam. All closed-loop systems must have both expansion tanks to allow for normal increases in system volume as temperatures rise as well as pressure-relieving devices to handle steam buildup. If accidental discharge occurs, then the system must be recharged immediately, and many authorities having jurisdiction and plumbing codes do not allow relief valve discharge of glycol to either the roof surface or city drains. Instead, special capture tanks must be installed. Such systems also should have high-pressure and high-temperature alarms installed to alert personnel of possible problems.
- Another concern in very cold climates is the viscosity of glycol mixes. As the coldest outside air temperatures decrease region to region, a higher and higher percentage of glycol must be used in the solar loop. Ultimately the percentage is so high that viscosity becomes a factor. In normal operation, a glycol-based system is stopped during times of heavy cloud cover and at night. If conditions are also very



**GENERAL NOTES :**

1. ADD ISOLATION VALVES AND UNIONS AS NEEDED.

**KEYED NOTES :**

① INSTALL CINCO SOLAR CS–40 SOLAR COLLECTORS IN SERIES UP TO 6 UNITS – THEN IN REVERSE FLOW PARALLEL MANIFOLD UP TO 24 UNITS. FOR LARGER SYSTEMS REFER TO SOLAR ARRAY FLOW DIAGRAM.

② CINCO SOLAR CONTROL AND PUMP STATION. CONNECT TO ALL RTD's (Ⓡ) AND SOLENOID VALVES (⑩).

③ MIXING VALVE (SEE MIXING VALVE DETAIL DHW–0)

④ ROUTE T&P RELIEF VALVE DISCHARGE FULL SIZE TO FLOOR DRAIN.

⑤ PRESSURE REDUCING VALVE – INSTALL ONLY IF WATER SUPPLY PRESSURE EXCEEDS 75% OF WATER HEATING SYSTEM DESIGN PRESSURE.

⑥ ASME THERMAL EXPANSION TANK – SIZE ACCORDING TO MANUFACTURER'S RECOMMENDATION.

⑦ COMBINATION TEMPERATURE AND PRESSURE GAUGE. INSTALL WITHIN 12" OF HOT WATER OUTLET.

⑧ PROVIDE FULL–PORT DRAIN VALVE AND ROUTE TO FLOOR DRAIN.

⑨ RECIRCULATION PUMP. PROVIDE AQUASTAT ONLY IF REQUIRED BY CODE WITH LETTER TO OWNER REQUIRING RELEASE OF LIABILITY (NON–MOVING WATER PROMOTES LEGIONELLA).

⑩ SOLENOID VALVES FOR TANK PRIORITY.

⑪ FREEZE PROTECTION VALVE, THERMO–MEGA TECH MODEL 3/4" IC/FP–035, INSTALL ON COMMON SOLAR HOT WATER RETURN LINE TO DISCHARGE ON ROOF. VALVE AND TEE TO REMAIN UN–INSULATED.

⑫ FAN COIL UNIT SIZED TO DISCHARGE AT LEAST 5,000 BTUH PER COLLECTOR, 3 PORT VALVE TO DIVERT COLLECTOR RETURN FROM STORAGE TANKS TO DISSIPATOR WHEN COLLECTOR REACHES 230 DEG F. DUCT DISCHARGE THROUGH NEAREST OUTSIDE WALL.

Tanks
Standalone Solar Hot Water System
Single W/H with Triple Solar Storage

Figure 3 Direct water system

cold, the glycol will prevent freezing, but the temperature of the glycol will approach the outside air temperature. When the sun eventually comes out, the glycol may be so viscous that it will resist pumping, and it may be several hours before the very low flow rates allow the fluid to heat sufficiently. In northern areas of the United States, solar systems are designed to circulate the glycol during these cold periods to try to minimize this problem, with the understanding that stored heat will be lost from the system.

## Drainback Systems

Due to the issues regarding the use of glycol, many solar installers favor drainback systems (see Figure 2). However, it is considered impractical to use drainback systems when the array size is more than 10 collectors due to the mounting difficulties.

Drainback systems are also closed loop, but they are maintained at atmospheric pressure. All piping and collectors are mounted so that water will completely drain from the exposed piping and collectors when the solar pumps stop. If freezing occurs, the solar pumps stop, and the system drains to a small tank located inside the building.

When using this type of system, the following should be kept in mind:

- Usually distilled or treated water is used in the loop, but since the system is exposed to atmosphere (and must be vented at all times), evaporation loss occurs daily. The facility should have readily available means for adding this treated water to the system, or scale will become a problem. Scaling is accelerated in drainback systems since the dry collectors become quite hot when the sun comes out until the system is completely filled.
- Drainback systems rely on the sloping components to drain, and complete drainage provides the only freeze protection. Thus, the engineer and installer must eliminate low spots where water can collect, since water in a low spot may freeze in low-temperature conditions. Also, correct drainage must be ensured by installing at least one vacuum breaker in each row of collectors and perhaps a few more if exposed piping is extensive. The facility maintenance crew should inspect these vacuum breakers for correct operation each fall and replace any that have sticky operation.
- Drainback systems rely on a temperature sensor to signal the pumps to stop in cold conditions. Since so much depends on this sensor, the engineer should consider redundant sources, and these should be inspected, calibrated, and tested after each cold spell.

## Direct Water Systems

These two freeze-protection choices have become so ingrained in the body of knowledge that many engineers don't even consider using a direct potable water system. However, a look at the history of solar thermal systems shows that despite the implementation of glycol or drainback strategies, the failure rate of solar systems due to freezing has been widespread. The reasons vary from the installer not understanding the importance of overall system design to a lack of proper monitoring and control systems or because facility operations personnel assumed that the use of glycol or drainback options made them invincible against freeze failure, when in fact such options present an even larger oversight and maintenance burden.

Evacuated tube collectors change this entire paradigm. Evacuated tube collectors, by their very design, do not contain any water in the absorber, and the absorber itself can freeze without any damage to the collector. The water in the header piping is subject to freezing temperatures, but it is enclosed completely by insulation. While heat loss from a flat panel collector is significant in freezing conditions, heat loss from evacuated tube collectors is nearly zero in the exposed tubes and minimal (200–500 British thermal units per hour) in the header. This means that the engineer now has a third option besides glycol and drainback: circulation of water during freeze conditions, or a direct water system (see Figure 3).

Using direct water in the solar loop obviates all of the issues described above for glycol and drainback systems. The engineer must be concerned with only two issues: scaling and ensuring circulation during freeze conditions. Both of these are easily addressed. Scaling can be prevented using softened water or can be corrected by descaling, and due to the low delta T between the water and the heat source, scaling forms quite slowly (in years). Freezing can be prevented by sensing outdoor temperatures and circulating water through the solar loop at low flow rates.

It is true that the sensors may fail; however, with correct design and redundancy, multiple sensors can be monitored by the control system and activate circulation. It is also possible that a power failure may accompany very cold conditions, and the engineer is advised to connect the solar pumps to emergency power sources whenever using a direct water system. A small amount of heat is lost during circulation, but this is usually less than 5 to 10 percent of what can be produced by the system during an average day. In all cases, a direct water system should incorporate both a freeze

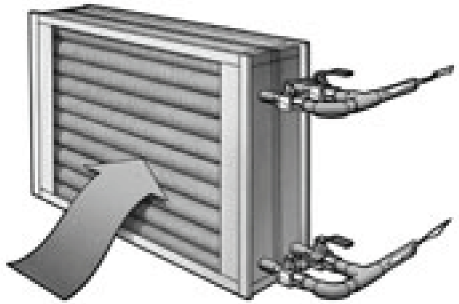


Figure 4 Heat dissipater

Source: Armstrong International

dribble valve and automatic and manual draindown provisions as a last resort option.

No antifreeze option is foolproof. The engineer must compare the pros and cons of each choice, and make an informed decision based on the location and application. In most cases, the direct water system, when correctly designed and built, presents the least risk of failure and the lowest operations and maintenance burden.

## DEALING WITH STAGNATION

Stagnation occurs when the solar loop fluid stops circulating. When that occurs, the collectors have no way to relieve the heat gain and quickly rise to the maximum temperature associated with their design and R value. These temperatures range from more than 300°F for well-made flat plate collectors to 430°F for uncontrolled evacuated tube collectors.

Following are the most common reasons for stagnation conditions, listed in order of frequency:

- Purposeful solar pump shutdown to prevent overheating in the rest of the solar system
- Solar pump failure (loss of power or mechanical failure)
- Solar loop blockage (incorrect valve position, foreign material in piping, etc.)

Whatever the cause, stagnation should be avoided as much as possible due to the thermal stress damage that occurs to collectors, piping and components, and glycol fluids.

Solar pump failure and solar loop blockage can be overcome by careful tagging of valves, using high-temperature alarms, and using duplex pumps connected to emergency power sources to minimize accidental conditions.

### Preventing Overheating

Solar thermal systems are designed to provide just enough heat in the summertime to satisfy the facility demand. However, from time to time there may be too much solar gain and/or too little load needed by the facility, and in these cases the solar storage tanks will eventually reach their high-temperature limit, typically between 180 and 200°F. At this point, steps must be taken to prevent more energy from entering the solar system. These can include:

- Stopping the pumps—a cheap option that can damage the pumps (and unfortunately is a common choice today)
- Circulating fluid through a heat dissipater (see Figure 4)—a good, but potentially expensive, engineering solution
- Installing larger storage tanks—a somewhat inexpensive option, but effective for only one or two days of low facility loads
- Dumping the heat to a secondary load such as a swimming pool or HVAC system—another somewhat inexpensive option, but requires careful planning during design and not always possible
- Dumping the heat by draining the water—an inexpensive option, but wastes water
- Covering the collectors—sometimes used for seasonal installations

Each of the above options prevents the system from overheating, and each has its pros and cons. The solar engineer is advised to examine the options early in the design process to select the best overall design.

## CONCLUSION

Freezing and stagnation are damaging conditions lurking at opposite ends of the thermometer. Like most engineering challenges, they can be overcome by a thorough understanding of solar components, system design, and operating conditions. A number of recognized solutions are available, and each project will lend itself to a particular combination that balances both initial cost and overall life-cycle costs.

The last article in this series will discuss solar thermal system design and best practices.

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