COUNCIL NOTES

G 5.7 SOLAR WATER HEATERS
Like people, solar water heating systems come in a variety of shapes and sizes. No one system outperforms the rest under all conditions. If a decision is made to purchase a solar water heating system, there are several choices. This circular describes the basic components of a variety of solar water heating systems and how they are used to heat a home's water.

**SOLAR SYSTEMS**

Solar water heating systems have five basic parts:

- A *collector* which absorbs the sun's heat and transfers it to a heat transfer medium (usually a liquid, sometimes air).
- A *storage device* which retains the heat until there is a need for hot water.
- A *circulation system* which controls the flow of heat from the collector to a storage system, from storage to the conventional water heater, and, ultimately, to points of hot water usage.
- A *safety system* which alleviates dangers to humans and the system associated with high temperatures and pressure.
- A *freeze-protection* system which prevents damage to the system due to freezing of liquid heat transfer fluids in the collectors and piping.

In a typical system, (see schematic, above right) a fluid enters the collector array (1); is heated and returned to the storage area (2); where it is kept until needed at the tap, shower or appliance (3). If the stored water is not warm enough for direct use, additional heat is provided by the conventional water heater. So long as the collectors remain warmer than the water in storage, the fluid continues to circulate, transferring heat from the collectors to storage.

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Schematic solar water heating system shows collector (1), storage area (2), and the end use (3).

**Collectors**

Collectors have five basic parts, shown in the drawing below. Incoming solar radiation strikes the absorber surface (1) where it is converted to heat. The backing (2) for that surface conducts the heat away to a fluid (3) which in turn carries the heat to locations where hot water is stored or used. Two types of insulation, the collector cover (4) and back and side insulation (5), help prevent loss of the collected heat along its path to the fluid.

**Absorber Surfaces and Backings.** Flat black (or other dark color) paint is a typical absorber surface coating. Dark surfaces absorb solar radiation, but tend to lose the heat that has been absorbed by re-radiating it. "Selective coatings" such as black chrome and nickel black have equally high absorption but do not re-radiate as much heat.

In most collectors, the high-absorption surface coating is applied to a material that conducts heat readily (usually copper, steel, or aluminum). Heat absorbed at the surface is conducted through the metal to a fluid flowing behind it or in tubes attached to it at intervals.

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Composition of flat plate collectors
### Collector Glazing Materials

<table>
<thead>
<tr>
<th>MATERIAL</th>
<th>ADVANTAGES</th>
<th>DISADVANTAGES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Glass</td>
<td>excellent solar transmission; no UV degradation; does not warp or buckle</td>
<td>more costly; heavy; breaks easily</td>
</tr>
<tr>
<td>Fiberglass-reinforced Polyester (flat)</td>
<td>lightweight; do-it-yourself installation; break resistant</td>
<td>yellows with age; may warp or wrinkle; some UV degradation</td>
</tr>
<tr>
<td>Fiberglass-reinforced Polyester (corrugated)</td>
<td>strong; lightweight; do-it-yourself installation; good solar transmission; less expensive than glass</td>
<td>may warp or wrinkle; some UV degradation; yellows with age</td>
</tr>
<tr>
<td>Polycarbonate</td>
<td>good solar transmission; very strong; lightweight; do-it-yourself installation</td>
<td>10% transmission loss over 20 years; 30% loss of strength; expensive</td>
</tr>
<tr>
<td>Acrylic</td>
<td>high solar transmission; very strong</td>
<td>scratches easily; can be permanently deformed</td>
</tr>
</tbody>
</table>

**Heat Transfer Fluid.** The heat transfer fluid in some systems is a solution of water, antifreeze, and rust inhibitors in a closed loop, with a heat exchanger to the consumable water. Other systems are designed to use the consumable water itself in an open loop. A few systems, generally ones that combine space heating and water heating, use air as the transfer fluid.

**Collector Covers.** Clear collector covers (or glazings) are located on the side of the collector facing the sun. They allow solar radiation to enter the collector and strike the absorber surface, but prevent the longer-wave heat radiation produced from escaping. Materials used for this purpose are glass (low-iron varieties work best) and some types of plastics (acrylic outlasts other plastics).

For water heating systems in all but the warmest parts of the United States, it is advisable to use double glazing rather than single as the collector cover. This minimizes heat loss when a large temperature difference exists between the absorber surface and the outdoor air.

**Back and Side Insulation.** Back and side insulation lines the collector frame to prevent loss of the collected heat. Foil-faced foam-board insulation (polyurethane or polyisocyanurate) is generally used for side insulation. These materials or fiberglass batts are used for back insulation, which is enclosed between the absorber and the frame.

Frames for commercially-made collectors are generally aluminum or coated steel. For home-built collectors, pressure-treated lumber or heartwood cedar may also be used, but wood loses strength when exposed to high temperatures.

**Collector Types.** Collector types used in solar water heating systems are illustrated. The flat plate collector, which is the most common, is so named because the absorber surface forms a flat plate, with channels or tubes carrying the fluid to be heated. The plate area between tubes increases the absorber area serving each fluid channel.

The breadbox water heater combines the collector and storage components of the system into one. It consists of a water tank, to which an absorbent coating has been applied, laid horizontally in an insulated box with a glazed cover.

Evacuated tube collectors employ a different approach. The absorber and fluid channel are combined in the form of a metal tube with an absorbent coating applied to it. The tube is surrounded by two glass cylinders, one nested inside the other, and the space between them evacuated of air. The vacuum greatly reduces heat loss from the glass cylinders, so it forms an "invisible insulation." In addition, a reflective surface on the underside of the glass tube reflects and focuses the sun's energy on the metal tube, effectively increasing the absorber area.

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The flat plate collector has channels or tubes that carry the fluid to be heated.

Evacuated tube collectors use a metal tube surrounded by a glass cylinder.
The breadbox water heater consists of a water tank laid horizontally in an insulated box.

Parabolic collectors use a shaped reflective surface to concentrate the heat from the sun on a collector tube running the length of the collector. Because the solar energy is concentrated, the heat transfer fluid can become much hotter than in flat-plate collectors. Parabolic systems usually use an antifreeze system and a heat exchanger in a tank, which can supply domestic hot water or heated water to a coil in the ductwork for space heating.

Parabolic collectors are often connected to a tracking device, which follows the movement of the sun to collect the maximum amount of energy through the day. The tracking device is controlled electronically, and a motorized linkage keeps the collectors constantly turned toward the sun. The electronic systems can fail, and the mechanical linkage can be damaged by corrosion and icing conditions. Maintenance and repairs to the tracking collectors may be more frequent than with systems using fixed collectors. It is important to buy such a system from a reliable, established firm so that maintenance service will be available in the future.

If a conventional water heater is already in place, a "solar storage tank" (a tank without a heating element), can be connected in series with a water heater.

A thermosiphon system requires a tank at least one foot higher than the top of the collector.
Storage Systems

Storage is needed to keep hot water on hand until it is needed. For all but the breadbox system, this takes the form of one or two well-insulated water tanks, with a capacity of approximately 1.25 to 2 gallons per square foot of collector face. Since it is uneconomical to install a solar-heated system large enough to provide 100% of the hot water during periods of cloudiness or unusually high demand for hot water, a conventional or an instantaneous water heater must also be included in the system.

Water Tank Storage. Research has shown that systems using one large storage tank operate more efficiently than those with two smaller tanks. However, if one small tank (e.g. a conventional water heater) is already in place, the plumber can connect a “solar storage” tank (without a heating element) in series with the existing water heater.

In this case, cold water enters the bottom of the solar storage tank and is heated as it circulates through the collector array or to a heat exchanger containing heated fluid from the collectors. As hot water is called for in the household, water is drawn from the tank of the conventional water heater. This, in turn, is replaced by water from the top of the “solar storage” tank, which is replenished from the cold water supply. If the water transferred from solar storage to the conventional water heater is not warm enough to satisfy the thermostat setting (usually 120-140°F), the conventional heating element (gas burner, oil burner, electric coil, etc.) switches on and raises the water to the desired temperature.

Rock Storage Systems. In the case of an air collector system, the water tank is set into a bed of rocks, through which hot air from the collector flows. These are larger than liquid-based systems because the materials used to store heat in an air system have a much lower heat capacity per unit volume than does water. Also, the heat transfer from air to rock to water is less efficient than the heat transfer from collector fluid to water. On the other hand, air systems are less vulnerable to leakage, freezing, and corrosion problems.

In systems using one large tank, cold water enters at the bottom, is heated by passing through the collector or over a heat exchanger carrying fluid from the collector, and rises to the top of the tank. As hot water is used in the household, it is drawn from the top of the tank, and the tank is replenished by the cold supply at the bottom. An auxiliary heating coil is installed at the top of the tank to boost the water temperature if it is not warm enough for use.

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A pumped system compares the temperatures at the collector and in the tank. When the sun shines on the collector, raising the temperature, the controller turns the pump on. On cloudy days the pump does not turn on. When the temperature in the collector drops below 40°F, the collector system drains.

**Circulation System**

The circulation system connects the collector array and storage in all but the breadbox model, where the two are combined. The simplest circulation system consists only of insulated pipes. The heat-transfer fluid circulates due to its own buoyancy when heated. This thermosiphon system requires that the bottom of the storage tank be located at least one foot above the top of the collector and that a back-flow preventer be installed to prevent reverse thermosiphoning when the collector is cold. Thermosiphoning is an efficient means of transferring heat from collector to storage. Its main disadvantage is that, if the collectors are mounted on the roof, the water tanks may be too heavy to be installed there or in attics.

Alternatively, fluid can be moved through the circulation system with pumps. The use of pumps allows the storage tank to be located below the collectors. A pump controller which compares the temperatures of the collector and the bottom of the storage tank is needed. When the collector is 10°F warmer than the storage tank, the controller turns the pump on. When the temperature of the fluid leaving the collector falls below the tank temperature, the controller switches the pump off.

In systems using anything other than potable water as the heat transfer fluid, a heat exchanger can be located inside the storage tank; it can surround the storage tank inside its insulated covering; or can be within an expansion or other holding tank.

The optimal flow rate of the heat transfer fluid through the collector is specified by manufacturers. Recommended rates fall within the range of 0.02 to 0.03 gallons per minute per square foot of collector area.

**Freeze Protection**

A freeze protection system is essential for solar water heating systems in virtually every part of North America. Even areas such as Florida encounter occasional freezing conditions. Freeze damage to collectors and plumbing is usually difficult and expensive to repair. It can occur at air temperatures as high as 40°F due to the additional cooling effect of radiant heat loss.

The simplest approach to freeze protection is to use the system only during warm seasons. This involves draining all parts exposed to outdoor temperatures before the first frost and refilling the system after the last frost of the year. This approach is more reliable and less expensive than more complex methods of freeze protection. In most parts of the United States, warm season systems produce almost as much heat during the warm season as year-round systems produce annually. This occurs for several reasons.
ANTIFREEZE SYSTEMS

When the sun is shining, pumps move both the antifreeze solution and the water through the system in their respective circuits. When there is insufficient sunlight for heating, the system is shut down and neither pump cycles.

The intensity of solar radiation drops off substantially in winter due to more frequent cloud cover, so there is less energy available to be collected. Also, collectors operate less efficiently in winter because the greater temperature difference between the collector plate and the outdoor air causes large losses of collected heat back to the atmosphere. Furthermore, freeze protection systems involving heat exchangers reduce the system efficiency by an additional 3 to 4 percent.

Drainback System. A second type of freeze protection system drains the exterior portions of the water heating system whenever it is not actively collecting heat. This is a drainback freeze protection system. When the temperature of the collector falls below that of the storage tank, the controller switches off the circulating pump. At the same time, it signals a valve to open and drain the fluid from the exterior parts (even if the air temperature is well above freezing) to the indoor storage tank or a separate holding tank. Such a system would drain every night and during cloudy periods. Most systems of this sort drain by gravity, so the collectors must be designed for self-draining, and all piping from collector to tank must be sloped to drain freely into the tank. When the collector again reaches a useful temperature, the pump refills the exterior parts of the system while a bleed valve clears it of air.

Drainout System. Another drainage-based freeze protection system is the drain-out arrangement, in which exterior parts of the system drain whenever their temperature approaches the freezing point. The fluid drains onto the ground or into a sewer, and the collector is refilled with fresh water when its temperature again rises above the freeze-danger range. Drainout systems are considered less reliable than drainback systems. Because their drain valve is operated less often, malfunction is less likely to be detected. Since they are designed only to open under critical conditions, any malfunctions which do occur are more likely to be serious. Like the drainback systems, drainout arrangements must include collectors designed for self-draining, plumbing appropriately sloped to the drainage point, and a bleed valve to allow refilling. In addition, in both of these types of systems the frequent change of cycle (collection cycle to drain cycle) can lead to more frequent maintenance and repair.

Antifreeze System. A fourth means of providing freeze protection is to replace water as the heat transfer fluid with an antifreeze solution. In order to isolate the antifreeze from the potable water supply, a separate, closed loop is created which circulates the antifreeze solution between the collector array and the heat exchanger. There, the collected heat is transferred from the antifreeze solution to the potable water. If a toxic antifreeze solution is used, a double-walled heat exchanger is required as a protective measure against possible leakage of antifreeze solutions. The local plumbing code should be consulted whenever an antifreeze-loop, or indirect collection system, is being considered.

Indirect collection systems require an additional pump if the heat exchanger is separate from the storage tank. Thus, any non-thermosiphon system operating with an antifreeze loop and a "free standing" heat exchanger would have two pumps.

Most antifreeze systems require periodic monitoring of the antifreeze concentration and the pH level. Gradual loss of antifreeze due to leakage, evaporation, or absorption can leave the
system vulnerable to freezing. If allowed to stagnate (heat up without circulating the heat transfer fluid), many antifreeze compounds become acidic and can corrode collectors and plumbing.

**Reverse Heating System.** Yet another freeze protection alternative is to circulate hot water from the storage tank through the collector whenever the collector temperature drops near the freezing point. Clearly this mode of operation is not desirable for extended periods, as the storage is heating the collector rather than vice versa and the heat is lost. It is only recommended for use in climates where freezing conditions are quite rare.

**Safety System**
The safety system in solar water heating installations is intended to prevent damage due to pressure buildup, overheating, and abrupt temperature change. A pressure-temperature relief valve (PRV) should be located at the highest point on each plumbing loop containing a heat source. Conventional water heaters have PRV's attached as a standard feature. A solar storage tank should also be equipped with a PRV.

In systems using potable water as the heat transfer fluid, valves are usually installed so that the collector array can be isolated (for repair, etc.) from the storage and distribution system. In this case, a PRV should be installed in-line near the collector array outlet. In installations using a closed, antifreeze loop for freeze protection, a PRV is essential in the antifreeze loop, as well as on storage tanks. An expansion tank is provided in the antifreeze loop so that the antifreeze solution can expand as it is heated without activating the PRV, unless critical pressures are reached. Care should be taken that each PRV is set to open at a pressure below the critical level for the component or loop it serves.

A second safety hazard is overheating of the stored water to a temperature dangerous to humans and damaging to appliances. A thermostatic mixing valve installed at the point of connection with the household hot water system will protect against overheated water. Another solution is to supply a high limit thermostat which switches off the pump circulating fluid to the collectors if the storage temperature exceeds 140°F. Since such a pump shut-down would occur during periods of high solar radiation, collectors should be provided with a venting mechanism or an emergency heat sink to prevent damage due to overheating during shut-down conditions.

**System Efficiency**
All components chosen for a given system must be compatible in material, size, fittings and function. Some manufacturers market packaged systems which include collector and storage along with the appropriate distribution lines, controls, safety and antifreeze subsystems. Other manufacturers make only components, and it is up to the solar equipment distributor, installer, or consumer to choose the proper combination of parts.

Materials compatibility is essential to controlling corrosion, which can cause leaks, clogging, loss of efficiency, and potentially dangerous pressure build-up. To the extent possible, the same metal should be used throughout the path of the heat transfer fluid. If this is not possible, a dielectric union should be used where two dissimilar metals meet in order to prevent galvanic corrosion. Compatibility between the metal used for heat transfer fluid channels and the fluid itself should be checked. Corrosion inhibitors are often added to the heat transfer fluid used in collectors having steel or aluminum tubing.

For maximum system efficiency, the size of the collector array, heat exchanger, and storage tank must be properly matched. The proper proportions depend on the efficiencies of the particular collector and heat exchanger being used. If improperly matched, the stored water may not heat up enough to be used without auxiliary heating or, at the other extreme, may be heated more than necessary, causing inefficient operation of the collectors and potential scalding hazards to users of the hot water. For most systems using flat plate collectors, an appropriate proportioning of storage volume to collector area is 1.25 to 2 gallons of storage per square foot of collector face.

Compatibility of connections and pipe sizes must also be checked, although it is often possible to correct problems in this area by the addition of conversion fittings. In thermosiphon systems, fluid flow is hampered if pipes or connections anywhere in the system are smaller in diameter than the collector tubing.

**Summary**
This circular is meant to be an introduction to the basic types of solar water heating systems that are in use today. Before purchasing or installing a solar water heating system, it is recommended that the consumer consult with reputable solar equipment distributors, installers, and owners about systems availability. Another very important step in the selection is to make sure you check local service and support for these systems. For additional information on sun angles and collector placement in various parts of the country, you may wish to review Council Notes C 3.2, Solar Orientation.