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Solar Domestic Water Heating:
Selecting Equipment

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A present-day solar domestic water heating system represents a sizable investment. 1981 installed costs for a well designed, manufactured active system will run from $2,000 to $3,000. To most families an expenditure of this magnitude will fall in the "major" category requiring considerable thought and comparison before making a selection. The aim of this guide is to present an overview of state-of-the-art solar domestic water heating equipment along with some suggestions that a potential solar consumer might follow in making a wise decision. This guide will not deal with do-it-yourself, home-made water heating equipment but will look instead at manufactured, active, liquid systems.

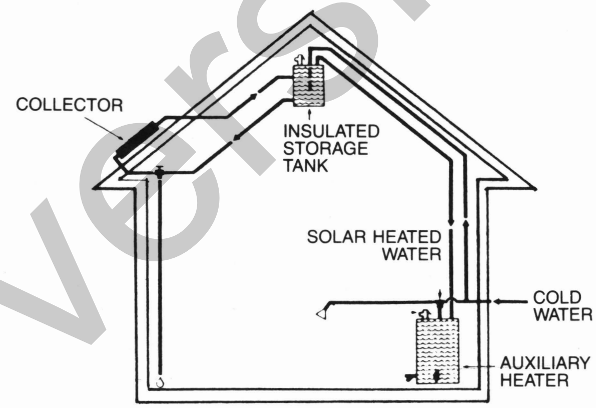

Figure 1—In a thermosiphoning system, cold water flows from the bottom of the tank to the bottom of the collector, and returns to the tank when warmed.

Common System Types

All solar water heating systems can be characterized as either **direct** or **indirect** depending on whether potable (drinkable) water is heated directly in a collector or picks up the sun's heat indirectly through a heat exchanger/transfer fluid arrangement.

With direct systems, the water flows from the main to the collector, to storage, to your faucet. It is circulated either by natural convection and gravity (called thermosiphoning), or by a small circulating pump.

A thermosiphoning direct system (Fig. 1) is simple and inexpensive to operate but a potential disadvantage is that the storage tank must be located some 2 feet or more above the collectors.

In many cases, this means finding a location for a heavy storage tank on an upper floor or somewhere in the attic.

Direct systems, whether pumped or thermosiphoning, possess a number of other shortcomings. The water being circulated should be neither hard nor acidic. Under the elevated temperatures experienced in the solar system, scale deposits from hard water would rapidly clog the inside of collector tubing. Acidic water, on the other hand, can quickly render a system inoperable as a result of corrosion.

Perhaps the greatest liability with a direct system rests in its vulnerability to freezing. A frozen system can not only wreck havoc with a collector, but assorted fittings such as piping and valves can also be damaged. Freeze protection in a direct system should be considered essential and usually relies on what is termed **draindown**. During freezing weather or with insufficient collector temperature, a draindown valve opens allowing water in exposed sections of the system to escape, usually to the sanitary sewer (Fig. 2).

The best choice for hard water and freeze-prone areas is an indirect, closed-loop system (Fig. 3). The heat transfer fluid, water or otherwise, never comes in direct contact with the potable water. It instead circulates

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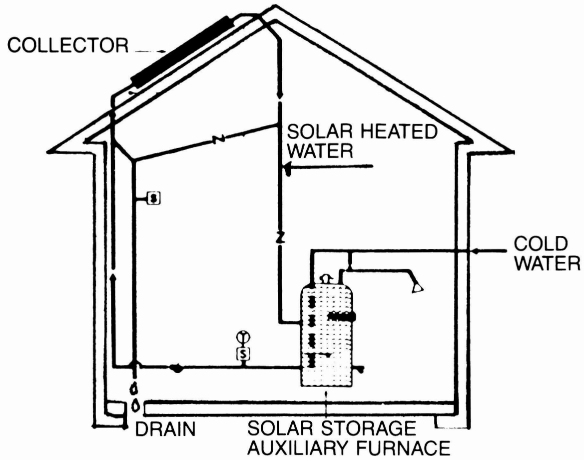

Figure 2—In a pumped draindown unit, solar heated water flows to the storage tank for direct use by the household. When the pump shuts off, whatever water remains in the collector drains away by gravity flow.

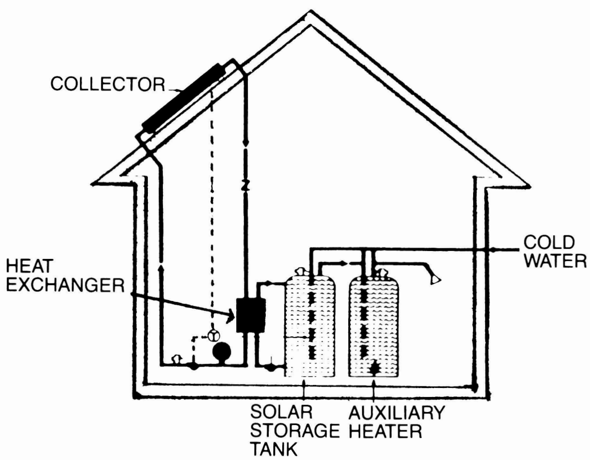

Figure 3—In an indirect (or closed-loop) system, a heat transfer solution is pumped through a heat exchanger, where it gives up its heat to the house water supply.

through a heat exchanger often immersed in the storage tank. **Closed-loop** indicates a circuitous flow of fluid isolated from the atmosphere. Such an arrangement permits the circulation of inhibitors or anti-freezes, for corrosion and freeze protection, respectively, or even a special heat transfer oil.

Some closed-loop systems circulate water as the transfer fluid using a "drainback' (as opposed to draindown) technique for freeze protection. In this approach, the water is allowed to drain back into a holding tank (usually located in or near the storage tank) while replacement water is prevented from refilling the array by an electrically controlled drain/dump valve.

In general, closed loop systems permit more flexible layouts and installations than open-loop systems, but are more expensive to purchase, install, and operate.

Typical System Components

In a practical sense, a solar water heater is no different than a conventional water heater. Both elevate cool incoming water temperatures to a preselected temperature. What is unique about a solar unit is it's heat source, the sun. In order to harness this source a number of historically little used and/or here-to-fore unusual pieces of hardware are employed.

Collectors—The heart of an active liquid solar system is the collector (Fig. 4). Practically all conventional systems use a series of "flat-plate" collectors or "panels" mounted together in what is called an array. A typical water heating collector consists of the absorber, glazing, insulation, case, and plumbing connections. An absorber plate can be made of copper, steel, aluminum or any of a variety of non-metallic ("plastic") compounds. Selection by the manufacturer of absorber material depends on application, desired performance and economics as reflected in the final system cost.

Copper, the most durable as well as expensive absorber metal, has a proven track record. Years of use in plumbing and hydronic systems leaves little doubt as to copper's durability in almost any solar environment.

Aluminum is also a durable material. But under certain conditions (not unlike those found in solar applications), aluminum is susceptible to corrosion. When compared to copper, aluminum is thermally less conductive and as an absorber should be on the order of twice as thick for comparable performance.[1]

Steel absorbers are being used by some manufacturers

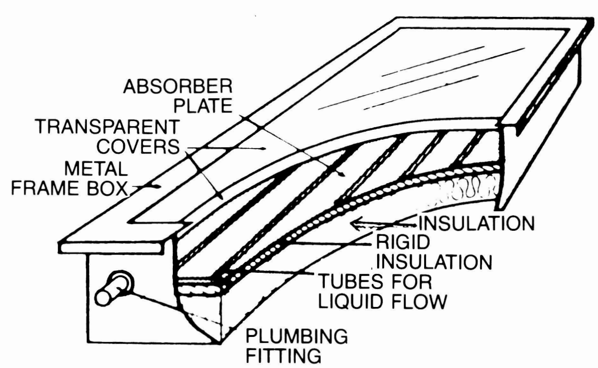

Figure 4—Flat-plate solar collector.

and appear to be performing well. Steel's primary manufacturing advantage over copper and aluminum is its cheaper cost (both initial and end) and ease of fabrication with fairly conventional equipment. On the liability side is steel's weight, its susceptibility to rust, and its comparatively low thermal conductance. This last characteristic almost automatically dictates a larger (than copper or aluminum) array in achieving comparable performance although installed system cost is usually still quite competitive. The rust problem can be curtailed most easily by circulating a fluid such as oil that is compatible with the ferrous absorber.

Non-metallic absorbers reportedly dominate the low temperature applications market.[2] For such uses as pool heating, plastic absorbers are an excellent choice. However, additional research appears in order before wholesale application of non-metallics to domestic water heating becomes commonplace.

For maximum efficiency, an absorber must be dark in color. The hue normally selected is black with little if any sheen. Special coatings called "selective surfaces" have been developed to improve the performance of an absorber plate. Collectors with selective absorber surfaces attain higher collection efficiencies at *higher than normal* temperatures. However, in view of selective surface costs and short life expectancy, the improved performance is only occasionally justified. Flat black paint is still the most practical absorber coating material (author's opinion).

Every effort should be taken to thermally insulate the collector from excessive heat loss. Insulation typically used in a solar collector will be of fiberglass (un-bonded is preferred), or rigid urethane foam. The former is perhaps the wisest choice in view of the less than satisfactory performance record of the latter. "Outgassing", that is, the release at elevated temperatures of gasses used in the manufacture of the foam, has been a problem. On escape, the gasses deposit a film or residue inside the collector, under the glazing. The effect is to block or screen radiation from the absorber thereby reducing system performance. Outgassing has also been reported as a problem when bonded fiberglass has been used as collector insulation.

A final thought concerns collector glazing. Materials typically used fall into two broad categories: 1) plastic; and 2) glass. Even though they are "cheaper", in the opinion of the author, the selection of any of the contemporary plastics as a collector glazing is false economy. Today's plastics simply do not chemically possess the properties necessary to give them *longterm* weatherability, durability, and reliability. A single layer of low iron, textured, tempered glass is the only sensible choice. Tempered glass will last the life of the system and will survive unscathed the worst of hail storms and most vandal's stones. In Missouri's climate, the minimal improvement in performance resulting from double glazed collectors does not justify the added cost of the double glaze.

Storage—The storage of domestic solar heated water will take two approaches. In a new installation the practical choice is one large tank. In a retrofit situation in which the existing, conventional water heater is "getting along in years", a new, single storage tank might also be chosen. Again in retro-fit, should the present heater be fairly new with a number of useful years remaining, the most economical route will usually be to keep the present tank and add an additional storage tank, space permitting.

Obviously, the quantity of water to be stored will dictate the size of the storage tank. As a rule of thumb, storage on the order of 1.2 to 1.8 gallons/net square foot (48.42 to 73.17 liter per square meter) of collector is recommended. Depending on collector efficiency and required solar contribution, a single storage tank can easily fall into the 80-160 gallon size. (303-606 liters). The physical dimensions of such a container are sufficient to call for an investigation, by the homeowner or dealer, of stairwell and door widths and supporting member size. Remember, water weighs 8.3 lbs./gallon (.99 kg/liter).

The reader will recall that in a closed-loop, indirect system, the domestic water does not circulate through the array. Instead, some type of heat transfer fluid collects the sun's heat and transports it to storage whereupon the heat is "transferred" to the cold water in storage. This transfer of heat from one fluid to another is accomplished through the use of a heat exchanger.

While it is a recognized fact that a heat exchanger decreases overall system efficiency by some 10%, the advantages of same are still considered worth the loss. Especially the advantage of freeze protection.

For health-safety reasons, a double-wall heat exchanger is recommended. With this device, the potable water is separated from the heat transfer fluid by two concentric metal tubes (usually copper or brass) separated by a thin cavity of air. Both tube walls must fail before contamination of the water supply occurs.

Manufacturers are using either a storage tank with integral heat exchanger (preferably replaceable) or an external heat exchanger located in close proximity to the storage tank. As might be expected, each technique possesses advantages and disadvantages which a potential consumer should investigate.

In single tank storage, the tank must possess the backup heat source which must be large enough to meet the load demand when sufficient solar heat is unavailable.

The tank itself should provide long life while being constantly subjected to the corrosive effects of water. So called "glass" or "stone" lined tanks have traditionally provided excellent service. The tank exterior should be insulated to as high of an "R" value as is possible. Two inches of fiberglass insulation factory installed in some tanks should be considered a minimum insulation level.

Some manufacturers are now using a urethane foam jacket around the tank exterior. Urethane's superior insulating qualities combined with its seamless installation make it a good choice when installed in sufficient (2-3 inch) thickness.

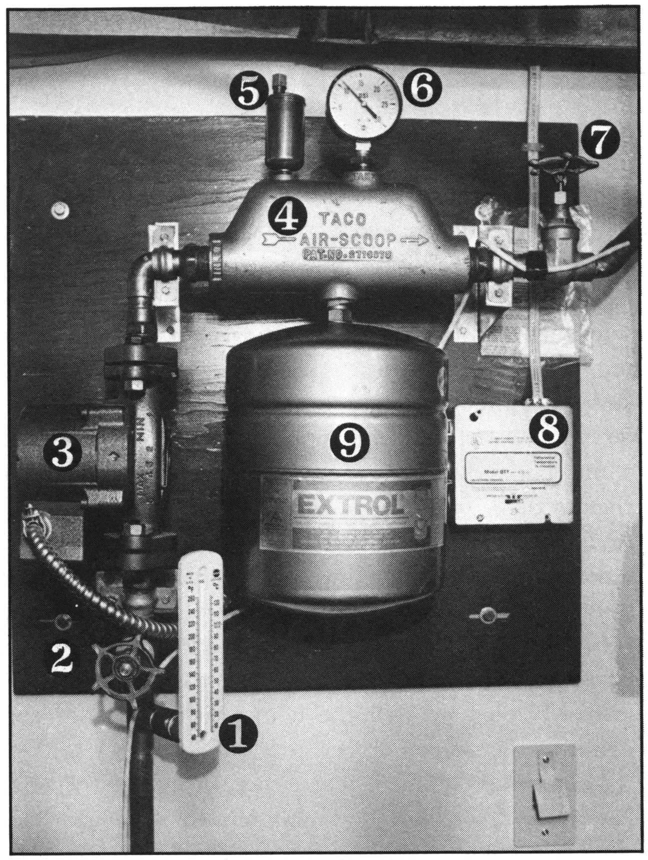

Fig. 5—Water heater control panel—(1) monitoring thermometer, (2) isolation valve (3) circulating pump, (4) air eliminator, (5) air vent, (6) pressure gauge, (7) isolation valve, (8) differential thermostat, (9) expansion tank.

Control/Regulation—The control and regulation of a solar domestic water heating system takes many forms with the physical arrangement of parts as varied as the number of manufacturers. Some control centers (modules) come replete with components encased in streamlined, space-age enclosures. Others are less elaborate with components mounted on plywood back boards. Whatever the case, the systems will usually include similar parts (Fig. 5)

All active indirect systems will require a pump (or pumps) to move the heat transfer medium through the collector array. If the system utilizes an external heat exchanger, an additional pump will be needed to circulate domestic water through the exchanger. In most instances, pumps used for the preceding tasks will be very small, low-head centrifugal devices with fractional (1/20 - 1/12 H.P.) ratings requiring minimal operating current. Pumps used in today's solar systems were used in the past in hydronic heating systems and their reliability is proven. Pump bodies and impellers will usually be made of either cast iron or bronze and stainless steel, respectively. Obviously, if water or an anti-freeze/water solution is circulated, the best choices from a rust/corrosion standpoint are bronze and stainless steel.

To turn the pump on and off automatically requires the services of a differential controller (thermostat) and companion sensors, usually thermistors. The sensors are installed at two primary locations: 1) at the array; and 2) at the base of the storage tank. Additional sensors may be used to report temperatures for freeze protection and maximum storage temperature. Wire leads connect the controller to the sensors completing that part of the circuitry. The controller is wired to line voltage and in series with the pump(s).

Other control apparatus will normally include: an expansion tank providing a cushion for the increased volume of fluid that develops on heating; a pressure gauge to monitor fluid loop pressure; some system for trapping and venting "air" residing in the fluid loop; a fluid loop pressure relief valve; a fluid loop check valve to prevent night-time "reverse thermosiphoning"; a standard temperature/pressure relief valve on the storage tank; and, system drain/fill valve(s).

Two additional items are viewed as convenient but not essential. They are isolation valves and fluid line thermometers. An isolation valve's job is as its name implies; that of providing a means of controlling flow at a particular point in the system. A well designed system will include isolation valves on either side of major components such as the pump, heat exchanger, etc. The valves combined with pipe unions simplify and greatly reduce service time if parts replacement becomes necessary.

Monitoring thermometers, installed in the fluid lines running to and from the array are perhaps the simplest and most economical method of assessing daily system performance. An ordinary well-mount, alcohol thermometer will provide reasonably accurate temperature readings as the fluid passes through the array and the storage tank heat exchanger. As one grows accustomed to a solar water heater's personality, the readings from line thermometers become excellent diagnostic tools.

Alternate flow monitoring accessories include either an in-line "pinwheel" flowmeter, or a float type flowmeter. Either device will economically indicate if the pump is on thereby generating flow, but operating temperatures would remain pure speculation.

Heat Transfer Fluids—In addition to a fluid's heat capacity and its freezing and boiling (or flash) points, a number of other criteria should be evaluated.[3] Included in the list are viscosity and volume change with temperature; thermal and oxidative stability; corrosiveness toward common metals; chemical compatibility with materials other than metal, e.g., plastics, rubbers, etc.; toxicity; and price.

Fluids commonly used for solar system heat transfer include water, water/glycol solutions, hydrocarbon oils, and silicone oils. While it is beyond the scope of this guide to present an indepth look at each fluid, a brief review is in order.

To prevent freezing, some systems utilize water in solution with ethylene glycol (ordinary auto anti-freeze) or propylene glycol. Because of its toxicity, the former, in the author's opinion, should not even be considered in a domestic water heating application. Propylene glycol while not toxic does not possess the heat transfer characteristics of its cousin. Glycol solutions will boil and when overheated become highly corrosive. These acids, unless immediately drained and replaced with fresh solution, will deteriorate metals, rapidly shortening the life of the system. In the final analysis, the reliability and durability of a glycol charged solar system depends primarily on how well the homeowner maintains and monitors the system.

Hydrocarbon oils may be either natural or synthetic. Natural hydrocarbons are highly refined petroleum fractions selected for their heat transfer characteristics. They are relatively low in cost, non-toxic, and not subject to freezing or boiling. On the negative side, petroleum based oils attack a number of rubber hose and gasket materials, roof spills on asphalt shingles can be costly, and some oils have a low flash point raising the possibility of fire.

Synthetic hydrocarbons are products of controlled polymerization reactions designed to yield a product with specific properties. These properties include, in general, low freezing and high flash point temperatures, low if any toxicity, and, unfortunately, high cost.

Silicone fluids are chemically inert, do not freeze or boil at normal solar system temperatures, are non-toxic, and don't corrode or attack metals or other system materials. At first glance, silicone appears to be the premier transfer fluid, and perhaps time and experience will reward it accordingly. However, silicone fluids, like all previously mentioned fluids, are not without their disadvantages. Silicones possess very low surface tension causing unusual flow characteristics and creating the need for a special heat exchanger. Additionally, warm silicone will seep through invisible "air tight" cracks such as in a sweat joint or a valve packing. And silicone fluids are expensive-on the order of three to ten times the price of other heat transfer fluids just described.

Plumbing Lines—Solar system array supply and return lines could be viewed as merely conduit required to transport a fluid from "point A" to "point B". When viewed in this context, a number of common piping materials are available. Included are galvanized or black steel pipe w/threaded connections; CPVC and polybutylene plastics w/solvent, threaded or mechanical connections; and copper w/soldered and threaded connections. There are perhaps others, but from the author's experience only one, copper, should presently be considered. As an all-around best conduit, the qualities of copper are void of competition.

As in the case of the absorber and storage tank, all fluid lines from storage to array should be insulated. Ordinary fiberglass pipe wrap is one rather unattractive but economical option; a pre-formed foam insulation is another. The latter is available in varying wall thicknesses and for different pipe sizes. In the past this reasonably priced, closed-cell foam has been used to insulate refrigeration tubing.

One note of caution—Neither of these insulators should be used on fluid lines located outside the structure. If unprotected, fiberglass will immediately become water-soaked. Refrigerant-line foam insulation is susceptible to ultra-violet degradation.

A fairly recent foam insulation, also pre-formed, is urethane. To retard outgassing and protect from abuse and weather, manufacturers of this insulation are wrapping the foam with a PVC plastic sheath. As might be expected, the end result is an excellent but expensive product.

All fluid lines, the heat exchanger and the array should be equipped with appropriately located drain and fill valves to help changing and draining of the system.

Choosing the Right System

Let's now briefly look at the second aim of this guide. That is, the offering of some suggestions that a potential solar user might consider in choosing the "right" system.[4]

Though still a very much developing industry, the solar marketplace offers dozens of brand-name, packaged water heating systems. Let it be said at the outset that there is no "best" system! The right system for any buyer is quite simply the one that will most adequately meet his needs at an acceptable price. In most cases, an *experienced* dealer or installer is probably the most qualified person to evaluate a particular family's needs and then match his equipment to those needs. To be sure, systems can be designed to supply 100% of a family's needs. However, in Missouri (and most of the mid-West) the investment vs: return of such a system is completely out of all proportion, at least at present utility rates. On the other hand, an undersized system is little more than an expensive conversation piece taking up space on the lawn or roof.

Should you buy and install a system capable of providing say 65-70% of your needs, a legitimate question is, "How do I know if the thing is producing as it's supposed to"? In all honesty, the fact of the matter is, you don't!

In sizing a system initially, a number of educated guesses will normally be made concerning a family's water consuming practices. Verifying the accuracy of these guesses requires monitoring equipment not normally a part of a standard solar water heating package. Once again the integrity of the dealer becomes important unless the consumer is willing to purchase and have installed the additional monitoring aparatus.

In choosing a brand and model of packaged system, you will be weighing the total installed cost of competitive systems against each system's stated performance and probable quality. When comparing two apparently similar systems on the basis of price, be sure that they are alike in *all specifics* (same type, same size and capacity, comparable components, etc.).

Probably no single system can offer all desired features at an affordable cost. Trade-offs will almost certainly have to be made. Some of the factors that should enter into your decision are:

- **System efficiency**—How well does the unit heat water?
- **System durability**—How long can it be expected to last?
- **Manufacturer's commitment**—What position does the manufacturer assume in "backing up" the dealer?
- **Warranty**—If the system breaks down, what is warranted and who is responsible for replacing it? Is labor and transportation extra?
- **Proven workability**—Has the system under consideration a respectable track record?
- **Working system**—A chance to see the same model in operation and speak with the owner can be very beneficial and educational.
- **Maintenance**—How much effort and expense will be needed to keep the system performing well?
- **Owner's information package**—For your protection, it is vital that you be given complete, concise, written information describing your particular installation.
- **Safety**—As with any heating system, consider potential hazards and built-in safety features.
- **Tax incentives**—investigate thoroughly all Federal and state (and local?) solar tax credits for their applicability in your situation.

Want More Information?

Additional information on solar water heating can be found in Home Economics Guides:

GH 5996 - Solar Domestic Hot Water Heating Systems

GH 5252 - Solar Domestic Water Heating: A Case Study

Solar enthusiasts should also be aware of the Conservation and Renewable Energy Inquiry and Referral Service (CAREIRS), P.O. Box 8900, Silver Springs, MD 20907 or Call toll-free, (800) 523-2929.

And, if you would like to be placed on the mailing list to receive periodic updates on the CEDAR RIDGE system, contact the author at the following address: Bob Cusick, Housing Specialist, UMC Extension Center, Courthouse-4th Floor, Mexico, Missouri 65265, phone (314) 581-3231.

References:

1) Anderson, Bruce, *The Solar Home Book* (Harrisville, NH: Cheshire Books, 1976), p. 157.
2) Madsen, P. & Goss, K., "Report on Non-Metallic Solar Collectors," *Solar Age*, (January, 1981), pp. 28-32.
3) Sullivan, Tom, "Solar Heat Transfer Fluids," *Solar Age*, (December, 1980), pp. 33-36.
4) U.S. Department of Housing and Urban Development, *Hot Water From The Sun*, (Washington: Government Printing Office, 1980 HUD-PDR-548), pp. 57-59.
   U.S. Department of Housing and Urban Development, *Solar Energy And Your Home*, (Washington: Government Printing Office, 1980 HUD-PDR-183(13)).

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