Passive Solar Thermosiphon

Domestic water is heated in a collector and stored under the roof

by Stephen Lasar

The concepts involved in collecting and storing energy from the sun are easy to understand, yet there can be an infinite variety of applications as far as architectural design is concerned. My interest has focused on passive heat gain because passive systems require very few (if any) motors or controls to make them work. Based on research I began in 1974, I developed a thermosiphon for domestic hot-water heating. Initial installations—including one in my own house—were followed by slight changes in layout or specifications, as I modified the design to make it work more effectively. The results of this process are described here. My design for a solar-based thermosiphon for heating domestic water offers several advantages. It can be built and installed on-site by the owner or builder. Special skills, equipment and materials aren't required. The finished system needs no mechanical assistance to perform its function; consequently, it is maintenance-free and works independently of electrical power. The thermosiphon is inexpensive to install when compared to other heat-gain systems, and it is effective. Assuming a hot-water use of 15 gal. per day per occupant, about 80% of wintertime hot water needs can be met and 100% of summertime hot water demand.

How a solar thermosiphon works—Radiant energy from the sun excites water molecules, and this heated water becomes less dense (therefore less heavy) than an equal volume of cold water. The heated water rises, just as the warm air in your house naturally rises above the colder air mass near the floor. As the water cools, it sinks, eventually finding the lowest possible level until it is heated again. The thermosiphon effect allows the hottest water to collect at the highest point in the system. Consequently, the highest point is the best place to store the heated water.

The general layout for my solar-based thermosiphon for heating water consists of three parts: the *collector*, where cool water in the thermosiphon is warmed by radiant energy, the *storage tank*, which holds the hottest water ready for use, and the *piping*, which connects the tank to the collector. Many water-heating thermosiphons also incorporate a heat exchanger, since they are closed loops relying on an antifreeze solution to prevent freeze-ups. Heat exchangers, however, tend to be expensive and less efficient at translating the sun's energy into hot water for domestic use. My design is an open system that is directly linked to the home's water supply; freeze-ups are eliminated because all parts of the system are inside the house, where they are protected from low temperatures. Eliminating the heat exchanger and hooking up the thermosiphon directly to the water supply make the system inexpensive and effective. An electric water heater acts as a backup on cloudy days, at night or when demand is high.

Constraints—Incorporating a water-heating thermosiphon in a building creates a number of design constraints. The storage tank has to be located above the collector; ideally, it should be as close to the collector as possible, and positioned so that the bottom of the tank is 1 ft. to 2 ft. above the top of the collector. The weight of the storage tank also must be considered. Supplementary bracing is needed, since the tank weighs close to 1,000 lb. when filled with water.

A second constraint concerns the piping that connects the collector to the tank. I use 1-in. diameter type-L (heavy wall) copper pipe, carefully laid out with a minimum of bends. The pressure created by the thermosiphon is low, and unnecessary bends in piping sections will impede the flow of water. Ideally, the pipe sections between collector and tank should be as short and straight as possible.

Another important design consideration has to do with the fact that the solar panel will be filled with water rather than antifreeze. Insulating the roof area around the panel and allowing warm interior air to circulate in the skylight space are necessary in order to keep the water from freezing. The system has to be set up within the warm house space. Some heat will be lost through the skylight, but the ceiling vents specified for my system minimize the loss. Positioned horizontally along the top and bottom of the skylight well, these vents limit convective air currents against the cold skylight, allowing just enough warm air circulation to keep the water in the collector from freezing.

During the summer, temperatures in the skylight will rise considerably, but this presents no hazard as long as the system is in daily use and there is some input of fresh, cold water. Opening the vents allows warm air to escape. If the system is left unused, the panels should be shaded in some way to prevent excessive heat buildup.

The collector—The collector module in the thermosiphon must be located on a south-facing roof. We have designed systems for roofs with slopes ranging from 30° to 60°. A 30° system will be more efficient in summer, while a 60° system will take better advantage of winter sunlight. We've found that the optimum roof slope for all-season operation at latitude 41° 40'N (southern Connecticut) is between 40° and 45°.

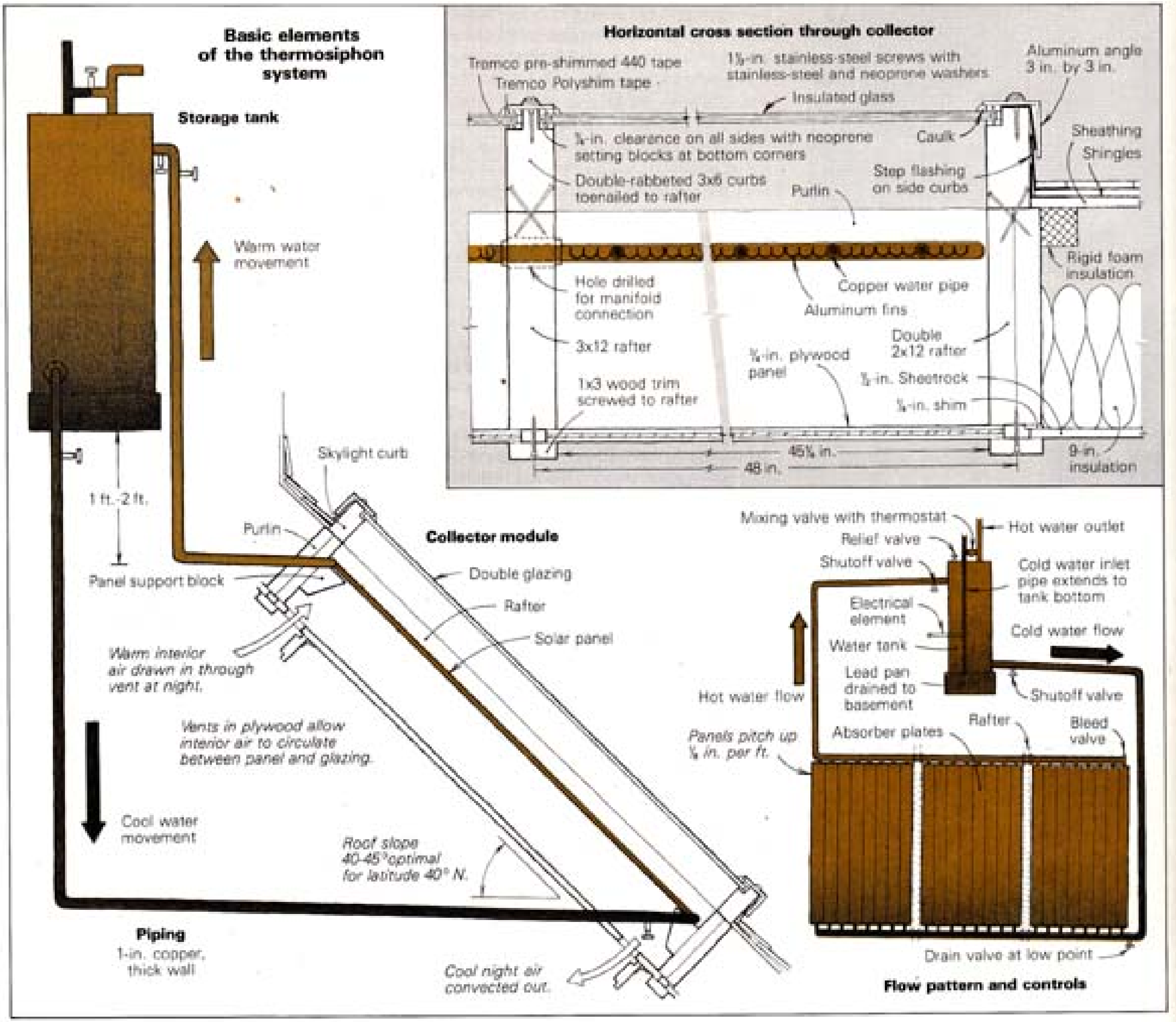
South-facing skylights, solar absorbers set between rafters, and interior venting make up the collector module in the thermosiphon. For new construction we always install the skylight first. Panel installation, plumbing and interior finishing then follow.

Although I have used mainly ⅝-in. thick low-iron glass in standard sizes (34 in. by 76 in. or 46 in. by 76 in.) for the skylight, clear acrylic panels are also suitable for glazing this type of solar collector. A different curb glazing detail would be required for acrylic, however, due to the increased expansion characteristics of this material. Insulated glass is a must, and the builder should keep in mind that standard sizes are far less expensive than cut-to-order panels.

We kept the skylight design simple to allow for on-site construction and to avoid the extra cost of prefabricated units. The glass sits in a rabbeted curb of 3x4 or 3x6 Douglas fir. Corner joints are butted, with the top horizontal curb overlapping the two side pieces to protect their end grain. We used liberal amounts of caulking for all joints and curb-to-rafter contact points to keep out moisture and cold air. Caulking is cheap, it is a good sealer and adhesive, and it is also flexible enough to allow for temperature-induced fluctuations in size. We have found that Tremco Mono sealant or an equivalent caulking compound is best for wood-to-wood or metal-to-wood joints.

We lay the skylight curb directly on top of the exposed rafters and butted against the roof sheathing before toenailing it in place. Aluminum flashing follows around the outside of the curb to cover the sheathing-curb corner joint. Step flashing is necessary on the sides to keep water from getting under the shingles. To allow for expansion of the glazing material, the rabbet should be ¼ in. wider than the glazing on all four sides.

Before setting the glass panels in place (a heavy, unwieldy job that requires at least two people), we lay a strip of ¼-in. by ½-in. Tremco pre-shimmed 440 tape in the rabbeted depression. This specially designed strip glazing material (available from Tremco, 10701 Shaker Blvd., Cleveland, Ohio 44104) is sticky on both sides and contains a continuous spacer-rod shim that limits its compressibility, so that airspaces as



a result of settling will not occur. Once the tape is in place, we position two neoprene setting blocks (¼ in. by ½ in. by 4 in.) one-fourth of the way in from the bottom corners of the skylight rabbet to hold the glass panel ¼ in. away from the bottom edge.

With the glass covering on the skylight, a layer of Tremco Polyshim tape is stuck down along all four edges. This should fill the rabbet to a point ⅛ in. above the top edge of the curb. Then a 3-in. by 3-in. by ⅛-in. anodized aluminum angle is secured over the curb edge, covering and compressing the strip glazing to lock the skylight glass in place. We use 1½-in. stainless-steel wood screws (roundhead) through neoprene and stainless-steel washers to fasten the aluminum angle to the curb. The final step in weatherproofing the skylight is to lay a bead of caulk along the edge of the glass where the aluminum angle overlaps it. It's important to use a good weatherproof caulk here, and one that can adhere to both metal and glass.

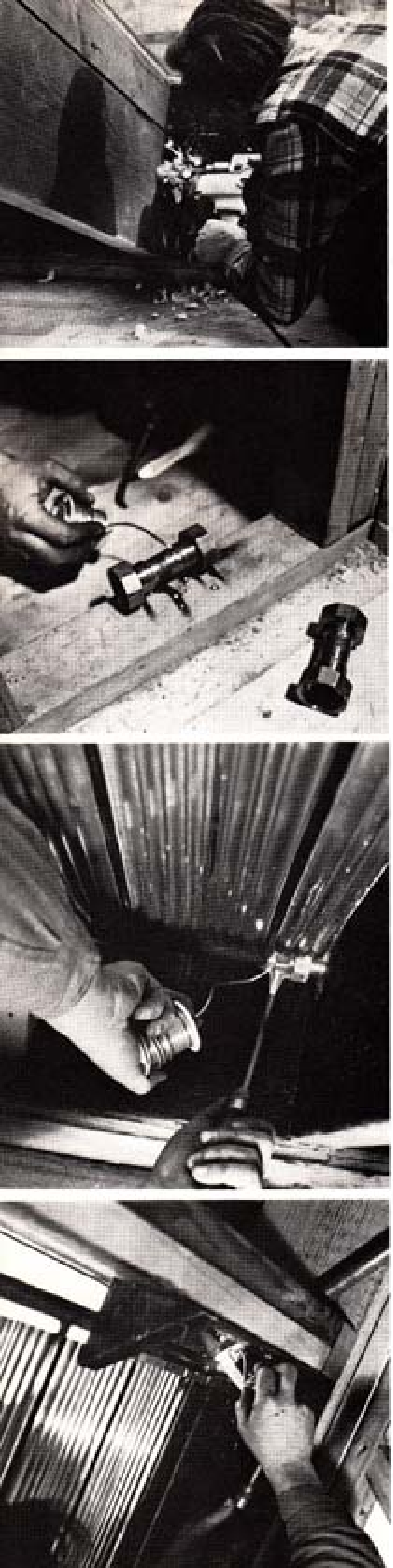
We are currently designing insulated shades that will be installed between the top of the solar panel and the skylight glazing. Although not crucial to the performance of the system, these manually adjustable shades will help reduce heat loss during winter nights, and prevent excessive heat buildup in the skylight well during sunny summer days.

The solar panel—Although my initial designs specified Sunworks copper absorbers tucked up under 34-in. by 76-in. skylights, we now use Sun-Ray absorber plates, which are a combined copper/aluminum fin construction. The fins capture radiant energy and conduct the resultant heat to the copper tubing that conveys the water through the system (see horizontal cross section above). A special mechanical conductive bond ensures effective heat transfer between the two metals and also reduces corrosive activity.

Sun-Ray absorbers consist of 5½-in. wide individual plates joined at top and bottom with copper connecting pipe to form panels of various widths. This system works best with 24 sq. ft. of panel surface per occupant, and a minimum total of 48 sq. ft. We have found that this recommendation minimizes auxiliary heating requirements and is the most economical arrangement in terms of installation costs and payback schedule.

The width of your panels depends on the roof framing in your house and the size of skylight glazing available. The system shown here uses 46-in. by 76-in. glass set above 3x12 rafters located on 48-in. centers. With these specifications in mind, we had Sun-Ray connect eight solar plates, giving us panels 44¾ in. wide and 71 in. long. The advantage of the Sun-Ray collector is that it can be cut to any length (up to 96 in.); width is also adjustable, based on the 5½-in. module for individual plates. Sun-Ray will provide assembled panels, but connections between panels must be done on site. (For information, contact Sun-Ray Solar Equipment Co., 4 Pines Bridge Rd., Beacon Falls, Conn. 06403.)

The first step in panel installation involves drilling holes in the rafters for panel-to-panel



With the skylight built, the first step in installing the solar panels is marking and drilling holes in the rafters (top) so that panel-to-panel manifold connections can be made. To assemble the manifold connections, a short length of pipe is soldered to threaded connecting hardware. The length of the pipe depends on the width of the rafter and the distance between panels. Supports nailed to rafters and roof blocking hold the panel in position while the elbow piping connection is made. This links the top part of the panel to the water tank, allowing solar-heated water to rise into the tank. Once all soldering has been done, the panel supports can be permanently fastened. Manifold hardware is inserted in rafter holes, mated to panel piping (bottom), and soldered to connect neighboring panels. Connections have to be made to pipe sections at the top and bottom of each panel.

connections. The easiest way to do this is to position the panels temporarily, mark the rafters where connecting manifolds must go, and then remove the panels and bore the holes. We use a 2-in. diameter bit to give the 1-in. manifolds plenty of clearance. These soldered manifold connections are the weakest part of the absorber assembly, so they can't carry any weight once the absorbers are installed. Crosspieces of 2x4s nailed between the rafters or block supports under top and bottom connecting pipes hold the absorber panels in position. A panel installation sequence is shown in the photos at left.

Interior finish beneath the collector plates consists of ¾-in. thick plywood panels held flush with the surrounding ceiling by 1x3 wood trim. The trim is screwed in place so that the absorber is easy to get at in the unlikely event that repairs or adjustments have to be made. We installed continuous metal floor registers (4 in. wide) at the top and bottom of the covering plywood; this also corresponds with the top and bottom of the solar panel. In the winter these vents are kept open, allowing heated interior air to circulate between absorbers and skylight. This is especially important on winter nights, when the water in the collector cools and the temperature in the space between the panel and skylight glazing drops. Cooler air will exit by convection through the bottom vent, drawing warm interior air in through the top vent to protect the collector from freeze-ups. On sunny winter days, the convection pattern is reversed: Air in the skylight well is heated by the solar panel and enters the room through the top register. In summer, the vents can be closed to isolate the warm skylight air.

The storage tank—Actually, you could also call this the hot-water tank, since in my system no separate backup hot-water tank is needed. Instead, we install a standard 4-kw electric water-heating element in the middle of the tank to provide auxiliary heating when necessary. In my first installation, we connected the storage tank to a separate electric hot-water tank located in a first-floor closet. This was a more costly route that we abandoned in later designs. It could, however, serve as a model for refitting an existing active water-heating system with the thermosiphon heater. If you're building a new house, you won't need a second hot-water tank if you have an active backup.

We use a 120-gal. Rheem Solaraide tank. This is a further modification on the initial design, which called for an 80-gal. tank. The extra capacity allows more hot-water storage and makes the thermosiphon more efficient. The tank has a standard pressure-relief valve. We install a lead pan under the tank. The pan protects the house from water damage; draining it to the basement rather than to the wastewater system will alert the owner when a leak occurs.

Piping—As I mentioned earlier, we use type-L copper tubing for all piping in the thermosiphon; it lasts longer than the conventional soft copper pipe specified for domestic hot-water plumbing. There is a drain valve at the bottom end of the solar collector; this is the lowest point in the thermosiphon system. We also install shutoff valves at inlet and outlet fittings near the storage tank and a manually-operated bleed valve at an upper corner of the solar panel. The hot-water pipe goes from the top of the solar panel to the top part of the storage tank. As water in the tank cools, it sinks to the bottom of the tank and is eventually thermosiphoned out through the cold-water exit pipe that runs to the bottom of the solar panel. The cold-water inlet pipe links the thermosiphon to the water supply, and must run to the bottom of the tank. Hot-water piping connects the tank with tap outlets throughout the house. To prevent extremely hot water from reaching the tap, we install a thermostat-governed mixing valve between hot-water outlet and cold-water inlet pipes.

Piping to and from the collector must be made as short and straight as possible to allow the thermosiphon to function at optimum levels. If piping must run between roof rafters or near exterior walls for any distance, then it should be protected by R-19 roof insulation. To further reduce heat loss in the system, we cover all piping between the panel and the tank with wrap-around insulation.

Cost and performance—Though I've developed several different prototypes for a passive solar water heater, the basic system outlined here seems to offer both value and satisfactory performance. There are certain to be modifications due to design or construction variations in different houses, but I am convinced that the thermosiphon principle can be used effectively as a primary source of hot water for domestic use during the greater part of the year. Periodic temperature readings at the tap at one installation have ranged from 116°F to over 140°F; after three rainy, overcast days the temperature dropped to 100°F.

A solar thermosiphon like the one described here will cost about half as much to install as a comparable active system for heating water. Given the efficiency of the passive system and the fact that it requires neither maintenance nor auxiliary power to operate, I feel that it offers excellent value to the homeowner. If the costs of oil and electric heat continue to rise, the system should pay for itself in less than five years. Federal and state tax credits for domestic solar systems can further offset the installation cost. ☐

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