**SUN ON TAP

The Best We Know
by Frederic S. Langa**

**You Can Cut Hot Water Bill By Two-Thirds...
With A Fine-Tuned Passive Solar Heater**

 

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| I 'm going to tell you a secret. I've never told this to any one before -- not even my wife -- because it's something I'm really embarrassed about.  When I was young, I had a wildly irrational fear of the cellar. When some household chore forced me to go downstairs, I'd become utterly, insanely terrified. My heart would race, my legs would feel weak, and I'd get goose bumps. Sometimes I'd breathe so hard I'd almost black out.To me, the cellar was a place where strange machines and nameless horrors lurked in the shadows, a place of creatures whose sole purpose was to terrorize (and maybe eat) young boys. All too often, the furnace or water heater suddenly would roar to life just as I walked by, scaring me silly. The tongues of flame visible through the air intakes seemed hungry and menacing, like some evil from the nether world. No amount of whistling in the dark or rabbit's-foot rubbing could make me feel any better.In time, I grew out of my fears. Today, I know my cellar is inhabited only by my home's mundane mechanical systems: the furnace, the duct work, the plumbing. While it's a relief to know I'll never become an hors d'oeuvre for a hungry water heater, as an adult I've found a new and entirely rational reason for disliking the cellar's mechanical denizens.It's not me they're after, it's my paycheck.According to the Department of Energy, you and I now spend more than $1,100 a year on the energy it takes to run our homes. After the furnace, the single greatest energy-eater is the water heater. It costs hundreds of dollars a year to run. But you probably don't think about its operating costs because they are lumped in with other appliances that use the same fuel. As long as you get hot water when you turn the tap, everything seems to be fine. But everything isn't fine. Chances are, at least one out of every three dollars you now spend on water heating buys you absolutely nothing: It's simply wasted by the built-in inefficiencies of your system. To make matters worse, another third of your present water heating bill is a sort of hidden penalty for the "convenience" of using oil, gas, or electricity, because the sun easily could provide this much water heating energy for free. In other words, at least two-thirds of your present water heating expense is money down the drain.It's this needless 66 per cent waste that our "Sun On Tap" series is aimed at. During the last year, we examined all sorts of solar and non-solar water heating systems to see which offered the best combination of performance and price. Wherever possible, we concentrated on do-it-yourself options to keep down the cost.The full test results were reported in the last issue, but the highlights are worth repeating. No system we looked at, regardless of type, cost, or size, could beat this combination:  | First, upgrade your home's existing water heating system for maximum energy efficiency, then add a "batch" solar water heater to deliver the sun's free heat.The batch heater itself is a masterpiece of simplicity, with no moving parts or high-tech gadgetry. Likewise, our energy-efficiency upgrading is extremely simple and very, very effective. Both jobs require only ordinary hand tools and basic construction skills, yet the combined performance rivals that of some complex solar systems costing two or three times as much. How well does it work? If you live in the South or West, where there's plenty of sun and a generally mild climate, our retrofit can save you around 18.2 million Btus per year, equivalent to about 5,333 kwh of electricity, 200 gallons of fuel oil, or 24,300 cubic feet of natural gas (multiply by your present fuel costs for a ballpark estimate of monetary savings). In colder, cloudier climates, the performance is only a little lower. Here in Pennsylvania, for example, our batch heater must be drained during the below-freezing months of December, January, and February, yet the total annual savings are still almost 14 million Btus, equivalent to roughly 4,000 kwh of electricity, or 150 gallons of fuel oil, or 18,200 cubic feet of natural gas. Of course, your local climate and the care with which you do the job will determine exactly how many millions of Btus you can save each year, but you will save. And chances are, you'll save a bundle. Right now, one of our test families is saving almost $300 a year, based on local electric water heating rates of about six cents per kwh.As for costs, the entire job -- everything from insulating the home's existing pipes to building and installing the solar water heater -- totals just $450, not including state and local solar tax credits. (We've already deducted the 40 per cent federal credit: The full, pre-credit price is about $750.) To put this in perspective, our test retrofit will pay for itself in about a year and a half, and then will go on to generate pure profits for the rest of its 10- to 20-year life. We don't know of any solar, do- it-yourself retrofit that will give you a better return on your investment. In fact, the job is so straightforward (taking only about five comfortably paced weekends), the cost is so reasonable, and the savings so spectacular, you can hardly afford not to do it.The next few pages contain the information you need to perform your own batch heater/efficiency retrofit. First, we'll tell you more about solar batch heaters so you'll understand how they work, and so you can choose the variation that's right for your home. Then we'll show you, step by step, how to build and install it. When you've finished, you'll have taken a giant step closer to energy independence. And who knows? Maybe you'll even start enjoying trips to the cellar.   |

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| http://www.green-trust.org/2000/solar/sunontap/page2.1_small.gifJust what is a batch heater, anyway?Ask a solar engineer, and he'll tell you it's an "integrated storage/collector unit."Ask an historian, and he'll say it's the oldest kind of solar water heater there is.Ask a home owner who owns one, and he'll say it's money in the bank. We'd like to add our own definition: Batch heaters are simplicity itself.All four definitions are correct. A batch heater is an "integrated storage/collector," because one tank simultaneously stores and heats the water. It certainly qualifies as historical, because the first batch heater was built around 1890 by Clarence Kemp, an ingenious Baltimore businessman. People who own batch heaters swear by them be cause they're effective, they're extremely reliable, they don't cost a lot, and they quickly pay for themselves. Coupled with an energy-efficiency retrofit of a home's existing hot water system, our own batch heater design can pay for itself in as little as 18 months.Batch heaters are really nothing more than insulated, weather-tight enclosures containing one or more black-painted water tanks. The south wall of the en closure is clear glass or plastic, and is tilted at an angle approximately equal to the geographic latitude of the site, so the sun shines directly on the tank and warms the "batch" of water within. The design is uncomplicated because batch heaters need no pumps, blowers, differential thermostats, or other externally powered devices. Instead, they're powered solely by the sun and by water pressure in the home's plumbing: As the sun-warmed water is fed directly to the home's taps, or to the existing water heater, cold water automatically enters the tank at its bottom.Because batch heaters are so straightforward, you could probably build a serviceable unit with instructions as general as these: Build a south-facing, weatherproof, insulated wooden box; insert a black-painted water tank; add glazing; connect the tank to the supply line leading to your existing water heater; and install valves so you can fill and drain the system as needed. In fact, thousands of batch heaters have been built with instructions just that basic.  | Thousands more have been assembled by handymen using only their common sense to guide them. On the other hand, with a little more attention to detail you can build a batch heater that will rank among the very best, and rival the performance of more complex systems costing two or three times as much. Surprisingly, only a handful of factors separate the winners from the also-rans.**The Water Tank**The water tank is the heart of any batch heater. Its size, shape, and positioning within the heater's enclosure determines how well it does its job. A useful rule of thumb for sizing batch heaters suggests that the tank should hold from one to two-and-one-quarter gallons of water for every square foot of glazing on the batch heater enclosure.This insures that the tank is large enough to provide a reasonable amount of hot water, but not so large that it requires many hours of solar heating before reaching the desired temperature of 110 -- 120 Degrees F. Our own batch design uses a 40-gallon tank with 28 square feet of collection area -- about 1.4 gallons per square foot. This seems to be nearly ideal for providing both adequate storage and high delivery temperatures. Regardless of the gallonage, long, narrow tanks are best because they have a large surface area relative to their volume, and thus effectively get the sun's heat into the water, where it belongs. Our batch heater utilizes a tank five feet tall but just 14 inches in diameter. This, too, seems nearly ideal.Some batch heaters use one tank; others use two, three, or even more. (See Illustrations A through D.) Single-tank systems are usually cost-effective for average families (and our design is a single-tank model), while the multiple- tank systems' greater storage capacity works well for larger families.In multiple-tank designs, there are two very different ways of plumbing the tanks. In the first, the tanks are connected to a shared inlet and outlet (parallel flow). In the second, the outlet of one tank is connected to the inlet of the next (series flow). The series flow produces slightly higher outlet temperatures, and usually is preferred for that reason. | Regardless of the number of tanks, you have a choice of how they're mounted. Illustrations A and B show horizontal mounts, with the tanks on their sides; C and D show vertical units, with the tanks on end. From a performance standpoint, the vertical mount seems better because it encourages "stratification"; that is, the hottest water tends to rise to the top of the tank where it easily can be drawn off. Stratification is much less pronounced in  horizontal tanks, and lower outlet temperatures can result from the mixing of the cold incoming water with the tank's stored hot water. Because of this, the design of a horizontal tank's inlet and outlet pipes is crucial. Illustration A's plumbing schematic shows one way to arrange the plumbing to minimize the harmful effects of mixing the tank's water in a horizontal single-tank design; Illustration B's schematic shows the correct technique for multi-tank units.**Preventing Heat Loss**If you used hot water only while the sun was shining, then you simply could insulate the walls of the batch heater's enclosure, and that would be that. But most families use large amounts of hot water twice a day: first around breakfast time, and again after supper. So a batch heater must be constructed to hold the day's solar heat through the evening and into the following morning. At night (assuming the walls of the heater's enclosure are thoroughly insulated), the glazing will be the principal cause of heat loss. Because of this, a batch heater should be double-glazed to minimize this loss. In cool climates, it's also a good idea to add some form of movable insulation (see Illustration A) that can be opened in the morning and closed at night. Movable insulation is highly effective, but it has a drawback because the owner must schedule twice-daily trips to the heater in order to operate it. If you forget to open the insulation, you'll get no heat for the day. Also, though the work involved in opening or closing insulation doors is hardly major, it's not really in keeping with the purely passive concept of hatch heating. A more elegant solution is to use triple glazing on the enclosure to minimize convective heat loss, and a "selective surface" on the tank to minimize radiant heat losses. (A selective surface is a special product that absorbs large amounts of solar energy, but reradiates very little, keeping the heat inside where |

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| **Illustration A Horizontal One-Tank System**wpe71566.gif (241197 bytes) **Above** *If you have (or plan to add) a sunspace or greenhouse to your home, a horizontal one-tank batch heater can be ideal. Mounted high on the sun-space's rear wall, it takes up very little room, and the sunspace's inherently mild interior climate means that the batch heater's enclosure can be as simple as the hinged boards of rigid insulation shown here. The insulation is closed manually at night to help keep the water warm.*wpe02397.gif (80299 bytes)**Above** *Because they lie on their sides, horizontal tanks have difficulty taking  advantage of warm water's natural tendency to rise. For maximum efficiency, the inlet and outlet tubes must be very carefully designed and installed (as shown) to minimize unwanted mixing of the tank's thin layers of hot and cold water.***Illustration C Vertical Two-Tank System****Below** *Two-tank systems work even better in a vertical orientation because the warmest water is allowed to rise to the top of the upper tank, where it easily can be drawn off without mixing with the incoming cold water. In addition, this freestanding ground-mount avoids any structural problems posed by the wall mounts of the first two systems we've seen. The pipes connecting this batch heater to the home's existing water heater are in an underground trench for heat retention and aesthetics. (In cold climates, the relatively long pipe run means that electric heat-tapes are mandatory to prevent freezing of the underground pipes during sudden, unexpected cold snaps.) This particular design uses double glazing and a cusp-shaped reflector to increase the collection efficiency. A cutaway view of a cusp is on page 26.*wpe53986.gif (225685 bytes) | it belongs.) Together, triple glazing plus a selective surface work virtually as well as movable insulation, but without the bother.There's another heat-loss problem that affects batch heaters in the snow belt: freezing. Because water expands as it freezes, burst tanks and pipes are a very real danger. Good bye, hundreds of bucks.There are two basic approaches to solving the problems of freezing. One is to mount the batch heater in a sheltered location such as a sunspace or a green- house. (See Illustration A.) Because the sunspace or greenhouse provides both temperature moderation and weather-proofing, this type of batch heater canbe simpler and less expensive than designs that must face the elements alone.The second method of freezeproofing is for batch heaters in their own enclosures, whether freestanding or built as part of a home's exterior wall: You simply drain the tank in early winter, and let it stand idle during the coldest months. (A rule of thumb: Hatch heaters should be shut down during any month that racks up more than 1,000 degree- http://www.green-trust.org/2000/solar/sunontap/page3.5.gif**Above** *Vertical two-tank systems are plumbed much like their horizontal cousins. Drain valves must be located at the lowest point of the system's plumbing, and all pipes should maintain a steady downward slope to that point.*  |

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| ays in your area.) Winter clouds and cold temperatures mean that there isn't all that much solar energy to be had anyway, and winter shutdowns of, say, three months reduce the heater's annual Btu output by only 15 per cent or so. We feel winter shutdowns are the most practical solution to freezeproofing:Make sure your tank and all exterior plumbing can be drained completely.**Glazing**The best glazing material for batch heaters seems to be one of the specially designed solar plastics. (Kalwall, Filon, 7410, etc.) They're less expensive than glass, they're much easier to work with, they offer good resistance to breakage, and they have good optical and thermal properties.**Collection Efficiency**In the simplest batch heater designs, the entire inner surface of the enclosure is painted flat black to absorb solar heat. This technique works, but it's not ideal because using the box's inner surface as a collector raises the temperature of the ([next page](http://www.green-trust.org/2000/solar/sunontap/page5.htm)) wpe20100.gif (108042 bytes)**Above** *There are only two ways in which this plumbing differs from the previous designs. First, a "vacuum breaker" insures rapid and complete drainage of the tank. Second, the inner tube, which carries hot water out of the tank, is insulated inside the tank with a loose-fitting jacket of CPVC pipe. (Full plumbing details for this design appear in the following article.)* | **Illustration B Horizontal Two-Tank System**wpe88228.gif (230298 bytes) **Above** *Here, a horizontal two-tank system forms a canopy for the home's patio doors and is housed in a double-glazed, heavily insulated enclosure of its own. Wall-mounted systems such as this and the previous one-tank version must be braced securely to carry the tank's considerable weight: Two 40-gallon tanks, for example, weigh over 750 pounds when filled with water. If you live in earthquake-prone areas, check your building codes before attempting this type of mount, or look into one of the ground mounts shown in the next two illustrations.*wpe49297.gif (77717 bytes)**Above** *Two-tank horizontal systems, if properly interconnected, can achieve higher output temperatures than single-tank designs because the incoming cold water is kept away from the hot outlet. Even so, these tanks still cannot take full advantage of warm water's tendency to rise. In this system, provision has been made for convenient draining of both tanks (for freezing-weather shutdowns or for maintenance) by the additions of a drain valve and a one-way valve.* **Illustration D Vertical One-Tank System****Below** *This design combines the good temperature stratification inside vertical tanks with the simplicity of a single-tank design. The enclosure is mounted close to the house to minimize heat loss, and its sheathing matches the home's original siding to provide a "built-in" appearance. Our batch heater shown on the cover is based on this type of single-tank, vertical system. It uses a "selective surface" absorber coating on the tank, triple glazing on the enclosure, and a cusp reflector to provide superior thermal performance.*wpe16895.gif (223916 bytes) |

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| box as a whole and increases heat loss. The resulting higher temperatures alsomay cause glues, plastics, or other heat-sensitive components to deteriorate.Better batch heaters use some sort of shiny surface to reflect the incoming sunlight onto the tank. For example, it's a simple matter to line the enclosure with aluminum foil or other shiny metal. And if the heater is equipped with movable insulating doors, the backs of the doors should also be covered with reflective materials so they can be angled during the day to reflect additional sunlight onto the tank.Flat reflective surfaces like these help raise the collection efficiency of batch heaters, but have some built-in limitations. Hold a pencil up to a mirror (an excellent flat reflector) and you'll see why: The image of the pencil occupies only a small fraction of the mirror's surface, and you can see a reflected view of you and the room to either side of the pencil. A flat reflector in a batch heater works the same way. A large amount of the reflected solar energy simply misses the cylindrical water tank altogether and is bounced right back out through the glazing.The best batch heaters use a curved reflector to collect and accurately focus sunlight on the tank. In our design, the reflector is made from two intersecting curves, the point of which is called a "cusp." (See Illustration E.) A cusp reflector keeps the incoming solar energyfocused on the tank all day long as the sun moves across the sky, and can even gather diffuse energy that's been scattered by clouds or haze. In fact, this type of reflector offers many of the same advantages provided by a high-tech sun-tracking collector, but without the added costs and complexity.**Long Life**A batch heater should be constructed carefully from high-quality materials to insure a long life and minimal maintenance. Cheap caulking, for instance, may save a dollar or two now, but laterwpe56506.gif (152347 bytes) | compromise the enclosure's weather-tightness -- hardly a bargain. Likewise, all plumbing components should be selected for resistance to corrosion. We recommend glass-lined, stone-lined, or heavily galvanized tanks, coupled withlow-cost plastic plumbing.**Proper Siting**In order to work properly, a batch heater needs a good location. First of all, it should be located as close as possible to your existing water heater to minimize heat losses from the connecting pipes. Second (and more obviously), it needs plenty of sunlight.It's easy to find a good solar site. You start by determining where true or "solar" south is. (It's usually different from magnetic south as shown by a compass.) The fastest way to find true south is to drive a stake into the ground and observe its shadow at solar noon, when the shadow forms a precise north-south line. (South is toward the sun.) Solar noon is the time exactly halfway between sunrise and sunset, and may or may not coincide with 12 p.m. on the clock. You can find the times of sunrise and sunset in any almanac or daily newspaper.Ideally, a solar heater should face due south. But if your home is off the mark, don't give up. Any location that lets you mount your batch heater so that it faces within about 20 degrees east or west of due south will provide upwards of 90 percent of the energy available at a due-south orientation, and that's still prettydecent performance.Of course, shadows will ruin the performance of even a perfectly oriented solar system, so you need to be sure your south-facing location will remain essentially shade-free during the prime solar collection hours of 9 a.m. to 3 p.m. You can estimate sun and shadow at your site with an ingenious method developed by New York's Energy Task Force:Stand where you want to place your collectors and face true south. Hold your left arm out straight, level with your  | **Illustration E Cusp Reflector Cross Section**wpe97921.gif (87527 bytes)**Above***A cusp is a point where two curves intersect. A cusp-shaped reflector accurately focuses sunlight, onto a batch heater's water tank regardless of the direction from which the sunlight is coming.*eyes, and point at the horizon. Place your right hand, in a fist, on top of your left hand and "stack" your fists one on top of the other in succession, moving upward, the number of times listed in Table One. Do this three times, following the Table: Once for true south, next for 30 degrees east of south, and last for 30 degrees west of south. Any object you can see above your fists in these directions will cast a shadow on your collectors; any object below yourfists in these directions is of no concern.**Energy Efficiency**A batch heater will work on almost any home, but will work best on a home with an efficient standard water heating system. To put it another way, it really makes no sense to invest in a solar water heater if the rest of your home's plumbing merely throws away most of the delivered energy."Most" isn't an exaggeration. The waste in standard systems is incredible. In one of our test homes, for example, we performed a simple, basic energy-efficiency retrofit of the existing standard water heating system. The entire retrofit took less than eight hours, and cost just $80. We turned down the water heater thermostat from 150 Degrees F. to 120 Degrees F., insulated the water heater tank and hot water pipes, installed an automatic timer on the tank's electric heating elements, and put on flow-restricting shower heads and faucet aerators throughout the house. When we were done, the energy used for water heating dropped by an incredible 50 per cent, saving the family over 3,600 kwh ofelectricity each year, worth $218 at local |

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| rates. Those energy savings are equivalent to about 136 gallons of fuel oil, or 165 therms of natural gas.Chances are your present system is now wasting a similar amount of fuel. No batch heater -- or any other solar hot water system -- will work to its full capacity until this enormous waste has been dealt with.**Your Batch Heater** | As you no doubt noticed when you read through this list of design considerations, the batch heater we've designed is unusually sophisticated. It employs a single, vertical tank for simplicity and good stratification of the water, triple glazing and a selective surface to avoid the complications of a movable insulation system, and a cusp-shaped reflector to boost collection efficiency. |  It's a flexible design that can be adapted to any one of the mounting options shown in the diagrams: in a greenhouse, on an exterior wall, or freestanding. Among the do- it-yourself systems available, we believe our design offers an unbeatable combination of cost, performance, and foolproof reliability. Best of it all, it's not hard to build.The next few pages show you how. |

**Here's How to Build Ours**

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| In preparing these step-by-step instructions, we've divided the construction and installation of our batch heater into essential and non-essential procedures. The essential procedures (and the ones we'll be spending most of our time dealing with) are: plumbing and mounting the batch heater's tank (including installation of a "selective surface" absorber coating); constructing the sophisticated cusp-shaped curved reflector frame; building the supporting frames that house the reflector; constructing our special, low-cost triple-glazing system; and connecting the hatch heater to your existing water supply. | When you've completed these essential steps, you'll have a working batch heater like the one shown in Illustration A, plus the additional subassemblies as shown in Illustrations E, F, G, and H. The only thing your batch heater will lack is its outer "skin," that is, its exterior enclosure. From a technical standpoint, the exterior enclosure is the least important part of the batch heater. Most of the decisions regarding the enclosure are aesthetic, and have more to do with your taste, budget, and imagination, than with any element of the batch heater's performance. For example, if low cost is your primary objective, you can sheathe the assembly | shown in Illustration A with plywood, and mount it on a simple, angled frame of two by fours or pressure-treated posts. (This type of freestanding mount was shown in Illustration C in the previous article.) The total mounting costs could be as low as $50. Or, if you prefer, you can mount the batch heater in a custom enclosure much like the one shown on our front cover, matching your home's existing siding and trim for an eye-pleasing "built-in" appearance. Or, by enlarging the enclosure, you can build the batch heater as a freestanding tool shed, and use the space beneath the batch heater for storage. Or you can add it to a garage, or a workshop... the list of options is almost endless. |



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| Because the design of the enclosure is non-essential to the proper functioning of your batch heater, we'll limit our discussion of this step to a general run-through of the major concepts and procedures. Only you know what type ofexterior enclosure will work best at your home, so we'll leave the specific detailsof this one step to you.Building a batch heater isn't very difficult, and if you know how to hammer, saw, and solder, the entire job should take about five weekends, tops. Your best bet is, first, to read through the following pages to get a feel for the scope of the project. As you read through the step-by-step procedures, you'll find numerous terms in italics, such as *tank support bracket* and *involute center cleat*. The italics mean that these specialized ([Continued page 29](http://www.green-trust.org/2000/solar/sunontap/page8.htm))wpe65057.gif (131611 bytes)**Photo Three** *The mirrorlike Mylar should be handled carefully and protected with newspapers to avoid scratches. Here, one of the plywood involute patterns is about to be used as a template to cut out a section of the Mylar. Each component of the reflector should be fitted with its own individually cut piece of Mylar to allow for slight differences in size and shape.*wpe18876.gif (137452 bytes) | wpe75467.gif (130696 bytes)**Photo One** *Following the instructions in the text, it's easy to draw the correct involute and cusp for any tank using only a length of wire and a pencil. Here you can see how the curve is formed automatically as you move the pencil away from the tank. The plywood will be cut along this line to create the "involute patterns" shown in the next steps.*wpe23287.gif (134481 bytes)**Photo Six** *When the reflector subassembly is complete, it's enclosed in a simple but sturdy framework of 2 X 4s. Truss plates (the worker is nailing one in place), joist hangers, and plumber's straps help reinforce the frame's joints, making sure it safely can carry the full 500-plus-pound weight of the filled water tank.* | wpe82822.gif (110445 bytes)**Photo Two** *The "flashing layout line" will help you mount aluminum flashingto form the sharp point of the cusp. Simply place a scrap of flashing at thepoint of the cusp, bend it slightly to follow the curve of the involute, andmake a pencil mark where the flashing ends. We'll refer to this mark in a laterstep.*wpe29310.gif (59357 bytes)**Photo Four** *The involute pattern is the keystone of the reflector assembly. Here, auxiliary fittings are added: A top cleat (the long board) provides a place to fasten other pieces of the reflector frame. Two bracket cleats (the identical short boards) help support the water tank in a later step. And the center cleat (the triangular board) will help hold the reflector center support in place.***Photo Five** *After the cleats are added,the reflector side boards are nailed tothe plywood patterns, forming therectangular assembly shown, on thefloor. The workers are setting a "V"shaped assembly of hardboard sheetsand a 2 X 2-inch, center support into thepoints of the involute pattern's cusps.In the next step, the hardboard sheetswill be bent downward to follow thecurves of the involute patterns, finishing the reflector subassembly.* |

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| parts are clearly shown in illustration A, and that you should turn to that illustration to see exactly what the component is, where it goes, and what it does.Next, you should obtain any necessary permits and gather together the materials you'll need. We've listed all the components and their dimensions in one place (at the end of the article) for use both as a "shopping list" and for the dimensions you'll need as you build your batch heater.That done, you're ready to build and install your passive solar water heater, using the following step-by-step procedure as a guide.**Drawing The Cusp**The cusp reflector is constructed from two specially curved plywood involute patterns, two sheets of thin hardboard (such as Masonite), and a reflective surface of aluminized Mylar. Construction begins with the layout and cutting of the two involute patterns, which create the special curve of the cusp reflector when the hardboard sheets are bent and attached to them. Photos One through Six provide an overview of this process and will help you visualize the next few steps.Start by cutting the two involute pattern blanks to size. (Again, see the parts list for complete material specifications and dimensions.) Next, lay one of these blanks lengthwise on a level, flat surface with its smooth side up and with the smoothest edge (the edge cut at the factory) facing toward you. Locate and mark the midpoint of this factory edge, and use a carpenter's square to draw a perpendicular line all the way across the width of the plywood. Your line should divide the plywood into equal right and left 'halves, each 25% inches long by 20 inches wide. The water tank will rest squarely on this center line.To help center the water tank, (which measures 14 inches in diameter), draw two parallel lines each seven inches to either side of the center line. Lift your (empty) water tank and place it on the plywood's center line, between the two lines you just drew. Now, keeping the tank squarely on the center line, position it so that it's set back one inch from the factory edge. (See Illustration B.) When the tank is properly positioned, run a pencil around its circumference to trace its outline on the plywood.Now you're ready to draw the actual cusp. You'll need three feet of thin, flexible wire (don't use string, which could stretch and deform the shape of your cusp), and a heavy, black pencil. Tightly tie one end of the wire to the pencil near its point, and then position the pencil's point as shown in the illustration. Wind the rest of the wire around the tank in a clockwise direction, and | firmly tape the wire's loose end to the tank.Next, as shown in Photo One, swing the pencil away from the center line, keeping an even tension on the wire at all times, and you'll automatically draw the curve that's just right for your tank. Run the pencil's point right off the factory edge.Now, reposition the wire and pencil to draw the mirror image of the curve you've just created: When you're done, you'll have drawn an "involute curve" shaped like a rounded letter W. The central point of the involute is the "cusp" from which the reflector assembly gets its name and its characteristic shape. You can now remove the tank from the plywood and set it aside for later use.The involute you've drawn is an ideal form, and must be slightly modified to meet real-life conditions. First, you should "open up" the curves to admit the maximum amount of sunlight. It's easy: Make a pencil mark on the factory edge exactly 25'/4 inches to the right of the center line. Next, take a straightedge and draw a line between this point and the original involute curve, so that the line just grazes (is tangent to) the curve. (See Illustration C.) Repeat the same procedure at the other end of the plywood. In effect, you're opening the original involute almost to the outer corners of the plywood sheet.Illustration D and Photo Five are both for later steps, but they show why the next modification is needed. A 2 X 2 will span the distance between the "points" of the cusp to provide the necessary support for the two thin hard-board sheets. Because 2 X 2s are cut square, the curve of the cusp must be changed from its original narrowly pointed shape to a squarer shape that matches the 2 X 2's right angles. This only takes a minute: Use a carpenter's square to redraw the point of the cusp to a precise 90-degree angle.By examining Illustration D closely, you'll see how the original, sharply pointed curve of the cusp will be recreated in a later step with strips of aluminum flashing. You now should draw a reference mark to help mount the flashing accurately in that later step. Photo Two shows how: Cut a short piece of four-inch aluminum flashing, and position it at the intersection of the plywood's center line and the tank's circle. Bend the flashing slightly to follow the actual involute pattern, and make a pencil mark where the flashing ends on the involute pattern. This mark is the "flashing layout line" that will be used in a later step.The last step before actually cutting out the involute pattern is to mark the location where the tank support | **Illustration B Drawing The Involute And Cusp**wpe19485.gif (117151 bytes)**Above** *The involute is the spiraling curve, and the cusp is the point where the two halves of the involute meet. To draw these complex curves, all you need is a length of wire and a pencil: Take a bird's eye view of your tank as it rests on the plywood sheet and pretend that its circumference is divided like the face of a clock. The center line of the plywood should bisect the tank from 12 o'clock to six o'clock; and the six o'clock position of the tank should be recessed one inch away from the plywood's factory edge. Tie one end of a three-foot length of wire to a pencil, and place the pencil's point on the plywood's center line at the 12 o'clock position. Wind the wire clockwise around the tank and tape the wire's loose end to about the 9 o'clock position. Now swing the pencil away from the center line, as shown, and you'll automatically draw the proper curve. Then simply reverse this process to draw an identical curve on the other side of the tank, and your basic involute and cusp is complete.* ILLUSTRATION BY SALLY ONOPA**Illustration C Altering The InvoluteFor Top Performance**wpe74344.gif (89314 bytes)**Above** *The involute and cusp must be altered slightly for construction ease and for optimum solar performance. Following the dimensions given in the text, use a carpenter's square to "open up" the involute nearly to the edges of the plywood sheet, as shown. Next, use the square to reduce the original sharp point of the cusp to a 90-degree angle. This will make fabrication of other parts of the reflector assembly much simpler in later steps.*ILLUSTRATION BY MARY WEST |

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| rackets will be mounted: Take one of the four tank support brackets and center it five inches to the right of the plywood's center line; place another one five inches to the left. Position the brackets so that they're square to the plywood's factory edge, with their inner corners just touching the tank's circle. Mark this location for future reference. That's it. Now you're ready to put your pencil marks to use.**Cutting The Involutes**Take the sheet of plywood you've been working on, and place it on top of the duplicate piece you cut earlier. Clamp or lightly nail the two sheets together (rough side to rough side), and use a saber saw to cut along the modified involute curve. Because you're cutting through both sheets of plywood at once, you'll end up with two virtually identical involute patterns, and that's just what you want. (Save the pieces of scrap plywood. They can be used later on.) Drill one 3/8-inch hole at each of the support bracket mounting locations, making sure you drill through both sheets of plywood. Then unclamp and separate the involute patterns. Later on, these patterns and the entire reflector assembly will be covered with a mirrorlike layer of "aluminized Mylar" (a plastic). Cutting the Mylar to fit these complex curves would be very difficult to do when the reflector is completely assembled. Instead, it makes much more sense to cut the Mylar now, and set it aside for later use. Photo Three shows how: Cover an area of the floor with newspaper and unroll the Mylar so that the side with the aluminized coating is facing up and the clear plastic side is down. (To determine which side is which, take a pencil eraser or a rag covered with a small amount of white toothpaste and rub one side of the Mylar. If the eraser or the cloth turns black, you have rubbed the side that has the thin, shiny coat of aluminum.) Place one of the involute patterns on the Mylar, kneel on the pattern, and using a utility knife, cut through the Mylar along the perimeter of the plywood. When you're done, use a felt-tipped pen to mark the letter "A" on both the pattern and the Mylar. Next, repeat the entire operation and cut a second piece of Mylar, this time using the second involute pattern as a template. Mark both these second pieces "B," then set the Mylar aside.    | wpe91672.gif (376353 bytes)**Above** *The cusp's original sharp angle must be altered to 90 degrees so that a square 2 X 2-inch "reflector center support" can be used as the backbone of the assembly. In later steps, aluminum flashing will be added to recreate the initial shape of the cusp.***Building The Reflector**Now (at last) you're ready to begin some actual construction, adding the top cleats, center cleats, and tank support bracket cleats onto the involute patterns.Photo Four illustrates this step. First, cut out all the cleats to the correct dimensions. Next, using wood glue and one-inch nails, fasten one top cleat to each of the plywood involute patterns. The cleat should be mounted on the rough side of the plywood, flush with the factory edge, and with an equal amount of overhang to either side of the pattern. (Nail in from the plywood.) Next, cut and mount the two center cleats. (These cleats can be cut from corners of the scrap plywood left over from cutting the involute patterns.) The "point" of the cleat should extend about 2'/4 inches into the space between the involute halves, as shown in Photo Four. (A precise measurement is unnecessary.) Again, use wood glue and nails to secure the cleats. The tank support bracket cleats are the last to be mounted. They should be positioned flush against the top cleat and spaced so that they fall squarely over the 3/8-inch bracket mounting holes you drilled earlier into the plywood. Once the bracket cleats are mounted, use the bracket holes as a guide, and drill through the cleats at the same location. (The 3/8-inch bracket holes must extend through both the plywood and the cleat.)With the addition of the two reflector side boards, the assembly begins to take on a recognizable form. First, cut the side boards to length. Then stand the two involute patterns on their factory ends (as shown in Photo Five) and glue and nail the side boards into the top cleats. Use 8d nails, two per joint. Photo Five also shows the addition of the reflector center support and two sheets of hardboard reflector backing: | Cut the center support and both sheets of hardboard to length. Because each hardboard sheet will form half of the curved reflector area, the width of each sheet must equal half the perimeter of the involute curve. However, as Illustration D shows, one of the hardboard sheets will overlap the other by 1/8 inch, so one of the sheets must be trimmed by this amount. Use a tape measure or a length of wire to measure the length of one half of the involute curve (the distance along the perimeter between the point of the cusp and the furthest corner of the factory edge). Subtract 1/8 inch from this measurement, and cut one sheet of hardboard to this length. Mark this sheet "C." Then repeat the procedure for the other half of the involute, but don't subtract the 1/8 inch. Instead, cut the hardboard to the full measure, and mark this sheet "D." Now measure the distance from the point of the cusp to the flashing layout line you marked earlier. Transfer this measurement to both of the hardboard sheets and snap a chalk line across the full length of the hardboard. (The distance between the chalk line and the edge of the hardboard should equal the distance between the point of the cusp and the flashing layout line. See Illustration D.) Just as with the involute patterns, it's much easier to cut the Mylar for the hardboard sheets now than to try to do it later, when they're mounted. Following the same procedure as before, use each hardboard sheet as a template and cut out pieces of Mylar to fit. Mark the Mylar "C" or "D," to identify which hardboard sheet goes with which piece of Mylar. Set the Mylar aside. Now, using one-inch underlayment nails, nail both sheets of hardboard to the reflector center support so that they form a "V" shape, with the center support at the tip. Refer to Illustration D: The smooth sides of the hardboard should face out, and one hardboard    |

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| sheet should overlap the other, as shown. Next, pick up the hardboard assembly and gently lower it into the notch formed by the cusps in the plywood involute patterns, as shown in Photo Five. Nail through the center cleats to secure the center support in place. Next, some fun: Gently bend the hardboard sheets downward so that they take on the shape of the curved end pieces, and tuck the loose end of each sheet down inside the 2 X 4 frame. The hardboard is springy, and you may feel that you're wrestling with a large, flat snake. (If you have a helper, you can heat the hardboard into submission in no time.) Once it's in position, nail and glue the edges of the hardboard to the plywood end pieces. (Use one-inch panel nails and white glue.) Seal the entire reflector subassembly, except the smooth side of the hardboard, with polyurethane varnish. While you're waiting for it to dry, build the framework that surrounds the reflector.  **Building The Framework**  Assembling the frame is a snap. As you can see in Illustration A, and in Photo Six, there's nothing fancy at all. First, cut the end-frame studs to length. Then using two 12d common nails per joint, assemble two identical end frames, exactly as shown in the photo and drawing. One of the end frames will be at the bottom of the batch heater when it's finally installed, so it should be reinforced with metal joist hangers. Again, simply follow the photo and drawing. Lay flat the end frame with the joist hangers, and stand the reflector subassembly on top of it, so that the factory edge of the plywood involute pattern is flush with the top of the end frame. Nail the involute pattern to the end frame with 8d nails. Repeat the same process for the other end frame, attaching it to the opposite end of the reflector subassembly. There are only five boards left to add: two long side frame studs and an identical back frame stud; plus two short side frame studs. Assemble them as shown in Illustration A and Photo Five, and then reinforce the joints of the assembly with metal truss plates and plumber's straps, as shown.  **The Tank Assembly**Assembling the batch heater's tank involves (1) adding a selective surface to the tank's exterior, (2) installing the necessary pipes and fittings, and (3) mounting the tank in the reflector frame. A selective surface is a special coating designed to absorb large amounts of solar energy while reradiating very little.     | **Photo Seven** *The selective surface is a metal foil coated on one side with black chemicals, and on the other with pre- pasted adhesive. It's applied like con- tact paper and pressed into place with one-inch overlaps at the seams. The outer protective backing is peeled back far enough to allow the next sheet to be applied, but is then left in place until the batch heater is mounted and ready  to use.* PHOTOS BY JIM FREEMAN  The type we chose is supplied as sheets of thin metal foil. One side of the foil is coated with special sun-catching black chemicals; the other side is prepasted with an adhesive. Both sides are protected with peel-off plastic backings. To install the foil, you first must be sure the tank is smooth and clean. Re- move any rough  spots on the tank's surface with sandpaper, and then wipe it down with denatured alcohol. When the surface is dry, cut a sheet of foil large enough to wrap around the tank once, with a one-inch overlap. Peel the protective sheet from the foil's adhesive, and gently press the foil to the tank, starting at the bottom edge and working your way up. (The first sheet of foil will cover about the lower third of the tank.) Press out any air bubbles trapped beneath the foil with a soft rag or a wall- paper roller, and use a utility knife to remove the foil from any plumbing connections on the tank that get covered over. The second and third sheets of foil are applied in the same way, until the entire tank is covered. (Trim off the third sheet's excess.) As Photo Seven illustrates, each successive sheet should overlap the previous one by about an inch: Simply peel back the outer protective sheet, as shown, and apply the edge of one sheet directly over the other. (Leave the rest of the outer protective sheets in place to prevent damage to the thin foil. They'll be removed in a later step.) The top of the tank is convex; the bottom concave. Rather than struggle to apply the foil to these complex shapes, simply paint them with black graphite paint, which acts much like a selective surface. While you're waiting for the graphite paint to dry, build the tank support by cutting slotted angle iron to the specified lengths, and assembling the four pieces as shown in Illustration A. It's as simple as it looks: Just bolt everything together. When it's assembled, paint the support with the rest of the black graphite paint. Lay the assembled support across a pair of sawhorses, and place the tank on top of the support. (Photo Eight, though for a later step, clearly shows how the tank nestles within the support.) Bolt  | wpe28971.gif (216071 bytes)the tank to the support, using heavy pipe strap wrapped around the tank's middle. Now you can plumb the tank; that is, add the pipes and fittings that will transform it into the heart of your solar water heater. Illustration E shows a cutaway view of the tank with all subassemblies labeled and in place; the five exploded views show how every part of every fitting should be assembled. Simply follow the captions and diagrams, and you can't go wrong.  When assembling the plumbing, wrap the threads of every screw-in fitting with three to four layers of Teflon plumbing tape. (The Teflon tape provides a permanent, waterproof seal.) All other fittings should be carefully soldered. Photo Eight shows how the base of the tank will look when you're finished. When the plumbing's done, temporarily install the four tank support brackets in the holes you drilled earlier in the plywood involute patterns. Lift the tank (on its support) and lower it onto the brackets for a test fit. With a pencil, mark the locations where the tank's plumbing connections will have to pass through the reflector assembly.  wpe87535.gif (272211 bytes)**Photo Eight** *Here's what the base of the tank looks like when the plumbing is nearly complete. The tank has already been coated with the selective surface and the black graphite paint, and it's securely nestled in its framework of slotted angle irons. As soon as the reflector frame is ready, the tank can be mounted.* |

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| wpe27888.gif (2691784 bytes)wpe10978.gif (133516 bytes) | **Left** *This cutaway view shows the batch heater's water tank as it actually appears when installed,  including the four major subassemblies: A vacuum breaker allows air to enter the tank during maintenance or freezeproofing drain downs; a pressure/temperature relief valve protects the plumbing against extreme operating conditions; a cold inlet tube delivers the incoming water to the base of the tank; and a hot outlet tube draws the sun-warmed water from the top of the tank. The five exploded views show where every part of every subassembly goes. (Note that the hot outlet tube is actually a copper pipe within a loose-fitting CPVC jacket. The CPVC provides in- the-tank insulation to help keep the hot water hot. The tank itself should be "extra heavy galvanized" to minimize corrosion. In areas with acidic or otherwise unusually corrosive water, we recommend installation of a "sacrificial anode" in one of the tank's unused threaded openings. The anode is made of a material that corrodes more easily than the tank's steel, and thus "sacrifices" itself to protect the tank.*(Illustration A shows the approximate locations of these holes. Use your own plumbing for the exact locations.) Remove the tank and support assembly from the reflector frame, and drill the holes whose locations you just marked: The hot outlet hole should be 2 1/2 inches in diameter, the cold inlet hole should be 2 inches in diameter, and the temperature/pressure valve drain hole should be 3/4 inch in diameter. Finally, remove the tank support brackets.  **Installing The Reflective Mylar**In one of the first steps you performed, you altered the cusp from its sharply pointed shape to a square 90 degree angle. Now it's time to restore the cusp's original shape, in preparation for adding reflective Mylar to the cusp assembly. Illustration D shows how: Two strips of slightly curved aluminum flashing are mounted back-to-back where the two sheets of hardboard meet. A strip of aluminum duct tape seals the "point" of the cusp and keeps the flashing together. Mounting the flashing is easy. First, cut two strips of flashing to length. Then, using a length of pipe or a rolling pin as a template, form the flashing so    |

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| that it's slightly curved across its 4-inch width. Using the flashing layout lines you drew in an earlier step, attach the flashing by stapling through the hardboard into the center support with 1/4 inch staples. (Photo Nine, though for a later step, shows the flashing in place.) Finally, tape the two pieces of flashing together at their peaks with the duct tape, as shown. Once the flashing is in place, install the Mylar, starting with the large sheet marked "D." Place this sheet, aluminized side down, on the "D" piece of hardboard, and check that the fit is correct. (If it isn't, trim the Mylar accordingly.) Each piece of Mylar is fastened in sections, rather than all at once, and you'll find it helpful to have a friend ready to assist. Photo Nine shows the correct procedure: Lift the edge of the sheet of Mylar away from the point of the cusp, and apply a uniform coating of spray adhesive over an area about 1 1/2 feet wide across the full length of the hardboard. Immediately (and carefully) press the Mylar into place on the adhesive, smoothing out trapped air bubbles with a soft, clean rag. Then fold back the other, unglued edge of the Mylar, spray the exposed portion of the hardboard with adhesive, and press the Mylar into place. When you've pressed out all the air bubbles, protect the mounted Mylar with newspapers. Repeat the entire procedure for the "C" Mylar sheet, and then stand the reflector frame assembly on end to mount the "B" and "A" Mylar sheets on the plywood involute patterns. Use a utility knife to trim the Mylar where it covers the holes for the plumbing and the tank support brackets. **Insulation**When the Mylar is completely in- stalled, turn the reflector frame assembly face down and staple R-11, 3 1/2" thick fiber glass insulation on the back of the hardboard sheets and within the end frames. (Additional insulation should be added to the exterior enclosure, when built, to bring the total insulation to at least R-15.) Finally, add the two plywood back panels to the insulated frame.  | **Glazing**Illustration F shows how we made our triple-glazing frames, and Illustration G shows the method we used to wrap the frames with different types of clear plastic to achieve an optimum combination of good solar performance and structural strength. Although we give you the dimensions we used, the final size of your glazing frames depends on your exterior enclosure. We suggest you use our materials and wrapping techniques as a general guide and alter the dimensions to suit whatever enclosure you elect to build.wpe08158.gif (912725 bytes) **Above** *Our triple-glazing system uses two identical frames. (One frame is illustrated.) They're assembled with brass screws and wood glue and painted with an oil-based porch and deck paint, which should be allowed to dry for about four days. One of the frames is then wrapped with two layers of solar plastic; the other with only one layer. (See Illustration G for the exact technique.) Then the turbo frames are mounted, one atop the other, and screwed to the batch heater's framework. Caulking and batten strips are added as the rest of the heater's enclosure is constructed.*wpe90822.gif (127000 bytes) | wpe96616.gif (348045 bytes)**Photo Nine** *Once the point of the cusp has been recreated with aluminum flashing, as shown, the entire reflector assembly is ready for its surface of mirrorlike Mylar. Spray adhesive simplifies the mounting. Apply the Mylar one section at a time, working carefully to press out any trapped air  bubbles as you go.* PHOTO BY JIM FREEMAN wpe43053.gif (143313 bytes)**Photo Ten** *We used a three-sided concrete foundation for the built-in batch heater shown on our cover, al though a slab foundation would work as well. A freestanding batch heater could use pressure-treated posts or a simple cross-braced frame of 2 X 4s. Your mounting options are limited only by your budget, imagination, and taste.*PHOTO BY ED LANDROCK |

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| **Installation**As mentioned earlier, the specific details of installation vary from site to site. In general, though, the first step is to prepare a suitable foundation. (Refer to the previous article for information on proper site selection.) Photo Ten shows how we built a three-sided concrete foundation to support the batch heater shown on the cover. A slab foundation would also work for this type of built-in installation, while pressure-treated posts would be perfectly adequate for a freestanding mount (see Illustration C in the previous article). In cold climates, the foundation must extend below the frost line. If your batch heater will be built against your home, you can run the plumbing straight from the batch heater's tank, through the home's exterior wall or foundation, on to the existing water heater. (We drilled a four-inch hole in the home's concrete foundation and lined the hole with a piece of PVC drainage pipe. Wherever you drill, be sure to seal the penetration and stuff any gaps with insulation.) If your batch heater is mounted some distance away from the house, it's best to run the pipes in a small, underground trench to minimize heat loss. Whether freestanding or built-in, your batch heater should be mounted in an insulated enclosure whose tilt approximately equals the geographical latitude of your home. If you opt for a freestanding mount, you should sheathe the batch heater frame with exterior- grade plywood, creating a weatherproof box. Then simply mount the box on the foundation: A cross-braced frame of 2 X 4s is fine. Built-in mounts can also be very simple: Photo Eleven shows the simple lean-to framework we used to  | **Right** *Connecting the batch heater to the existing plumbing is a matter of adding the six valves and the associated fittings as shown in color. Of course, you should turn off the water and the power to the water heater before making your alterations. Otherwise, it's a straightforward matter of soldering the parts in place, just as you see them here.*wpe56581.gif (303432 bytes)mount our built-in batch heater. To allow for any movement or settling of either the house or the heater, the frame leans against the home's siding but is not directly attached. In both cases, extrafiber glass or rigid insulation should be added to bring the enclosure's total R- value to at least 16. **Photo Eleven** *A batch heater's enclosure doesn't have to be elaborate, as you can see from the simple framing we used on ours. This framework was covered first with insulating sheathing and then with exterior siding chosen to match the home's original finish.*wpe33623.gif (596956 bytes) | wpe82453.gif (117023 bytes)While mounting the batch heater's frame (when everything is still accessible), reinstall the tank support brackets and mount the water tank inside the reflector frame. Run 1/2" CPVC supply-and-return pipes from the existing water heater to the batch heater, and connect the batch heater to the CPVC, using the fittings marked "site assembled" in Illustration E. Then connect the CPVC to your existing plumbing. Illustration H shows the proper plumbing layout for homes in which the water heater is in the basement: The drain valves, as shown, are at the lowest point of the solar loop's plumbing. This insures that the solar system will drain properly. But if your water heater is in a location higher than your batch heater's, plumb your system exactly as shown, and then add two more drain valves (one in the hot line, one in the cold) at the solar plumbing's lowest point. These two additional valves should be opened in conjunction with the valves shown in Illustration H when you wish to empty the batch heater. When your system is plumbed, turn on the water and fill the system, then continue with the finish work on your enclosure. From time to time, inspect every fitting in your solar plumbing for leaks.  |

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| If no leaks have appeared after 24 hours, install electric heat cables and 3/4 -inch closed-cell foam insulation on all exterior plumbing. (The heat cables are insurance against an unexpected freeze. They can be omitted in very warm climates.) Next, clean the Mylar reflector of any accumulated dirt, and remove the plastic protective sheeting from the tank's selective surface. Install the glazing frames and complete any remaining work on the enclosure. Every seam in the hatch heater's enclosure should be thoroughly sealed with a | high-quality silicone caulk. Next, install 3/4-inch, closed-cell foam insulation on all your home's interior hot water lines; insulate your existing water heater with at least six inches of fiber glass; install flow restrictors on all faucets and shower heads; and (if you have an electric water heater) install a timer to eliminate unnecessary nighttime heating of your water supply. (Full details of an energy-efficiency retrofit of a home's water heating system appeared in our September, 1980 issue.) All that's left is to go inside and take your first solar-heated shower.  | The People Behind Sun On TapAlthough each installment of Sun On Tap showed only one name as the author, there were actually dozens of people involved in the research and design. My thanks especially to: Jim Eldon, Director Of Design; Diana Branch, former Product Testing Director; Bob Flower, Product Testing Engineer; Dave Sellers, Product Testing Engineer; Keith Marks, Design Prototyper; Phil Gehret, Design Prototyper; and Harry Wohlbach, Product Testing Technician.  |

**References**

Parts And Sizes

