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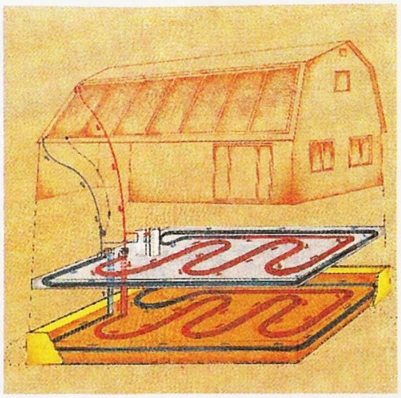

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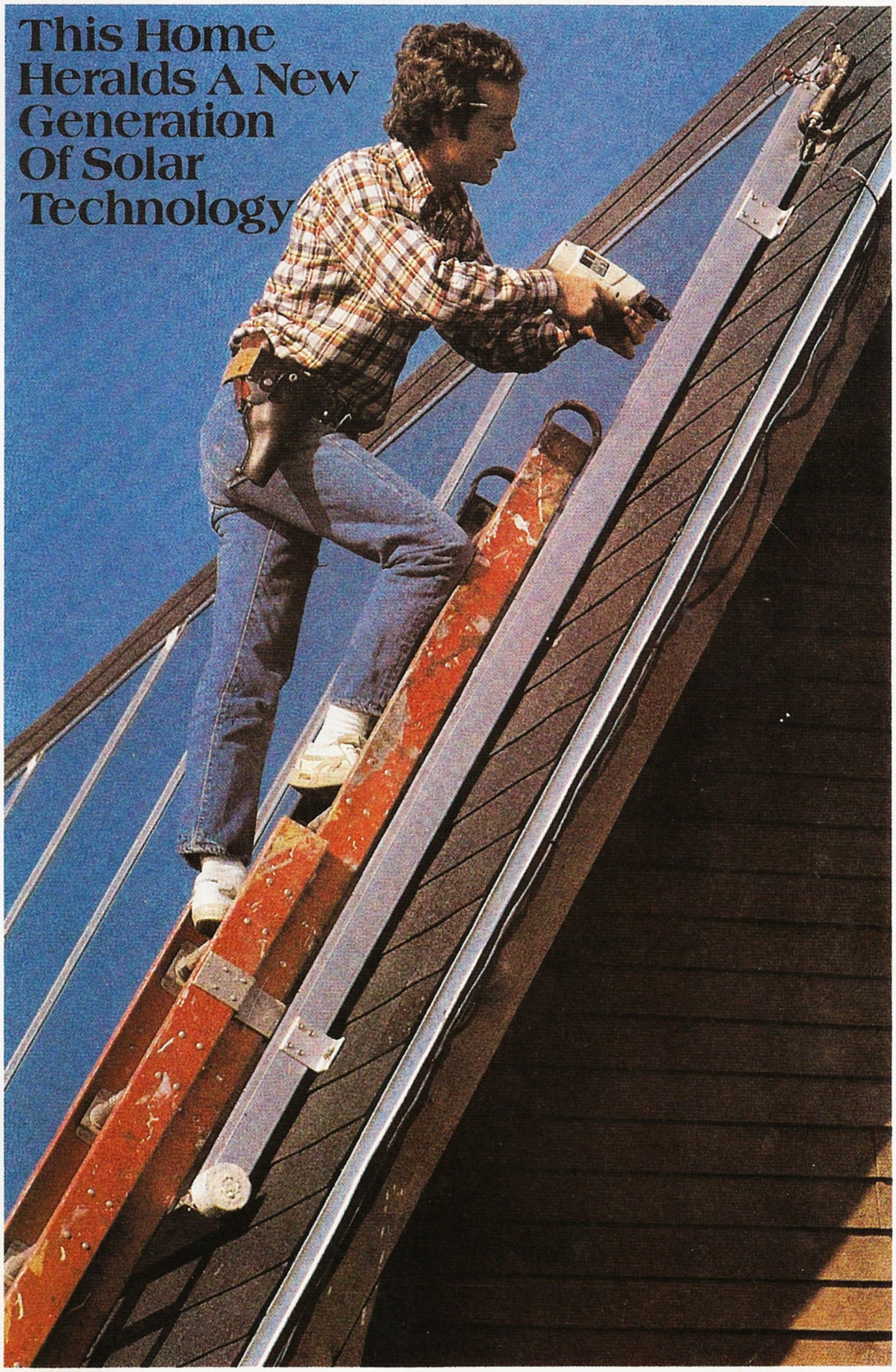

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ACTIVE SOLAR:

Sure-fire success has been boiled down to five rules.

by Frederic S. Langa

Lyndonville, Vermont, is about the last place on earth you'd expect to find the future of solar heating.

Lyndonville is a postcard-perfect New England town located only a few dozen miles from the Canadian border. With its white clapboard houses and narrow, twisting main street, the whole town looks like a Norman Rockwell tribute to the past.

But the future *has* arrived on a sunny hilltop at the edge of town. It's Bob Starr's home, and it's a visual landmark: Seven rooftop solar collectors stand on the shingled roof in sharp contrast to the corrugated steel roofs of neighbors' houses. It's a symbolic landmark, too, because Bob's home incorporates some startling new ideas in solar design, ideas that are a radical break with the traditional ways of building active solar homes.

Bob's home is an exciting blend of active (electrically operated) and passive (self-powered) design strategies – a *hybrid solar home* – that provides essentially 100 percent solar space and water heating in a severe 8000-degree-day climate. The solar system is almost unbelievably simple, and offers a unique combination of reliability, low cost, ease of installation, architectural flexibility, comfort control, and best of all, truly outstanding thermal efficiency. In many ways, it leaves conventional active and passive solar systems in the dust.

Hybrid Solar

Bob's not alone. Over the last decade, hundreds of researchers have spent innumerable man-hours studying all kinds of active solar homes to learn why some succeed and others fail. Their research has paid off in spades: From the morass of information they've collected, five vital rules of thumb have emerged. These rules provide a solid framework for success by pointing the way to a new kind of "second generation" active solar design that's a quantum leap ahead of previous designs.

Here and there, in locations scattered across America, builders and designers are beginning to construct active solar systems that incorporate these five rules of thumb. The details vary from system to system and site to site – but that's the beauty of rules of thumb. They're a guide, not a straitjacket; they point you in the right direction.

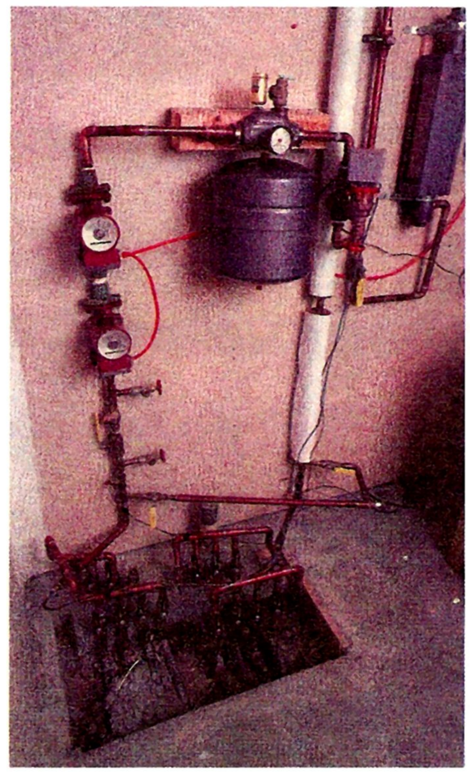
Bob Starr's home, for example, has a number of unique elements specific to its location, but it still embodies the five principles that spell success in active solar heating. And as such, I'll be using Bob's system as a case study. First, I'll show you how his specific system works. Then we'll run through the rules of thumb. Along the way, we'll hear from a number of notable solar professionals whose work is helping to shape this new generation of solar homes. With Bob's home and the experts as a guide, you'll learn the general principles that will help you build or buy an active solar system that's certain to succeed.

The Starr System

Bob's system is a hybrid of both active and passive design elements. "I tried to be eclectic," he says. "I wanted to take the best elements of electrically powered and unpowered designs, and unite them into a single system. I guess I wanted the best of both worlds."

It looks as though he's achieved it. (See Figure 1.) The passive elements of Bob's design include an extremely tight, well-insulated building shell, with the windows concentrated on the south and east sides of the building. (The east windows encourage quick heating of the home on cold winter mornings, the south ones allow the sun to shine in during the rest of the day.) A 6-inch concrete slab and insulated 2-foot-deep "earth box" provide a massive heat-storage system for the solar BTUs.

The active portion of the system has just four moving parts – a pump, an air



Above *The heart of Bob Starr's solar system is this plumbing array, shown here with most of the pipe insulation removed. The eight supply and eight return headers entering the concrete slab and earth box are clearly visible, as are the pumps, expansion tank, air valves, and control circuitry. The Department of Energy (DOE) is currently performing an intense, year-long monitoring of Bob's house. (Normally, there's just one pump; the DOE's monitoring equipment necessitated the installation of a second pump on the plumbing.)*

The Second Generation

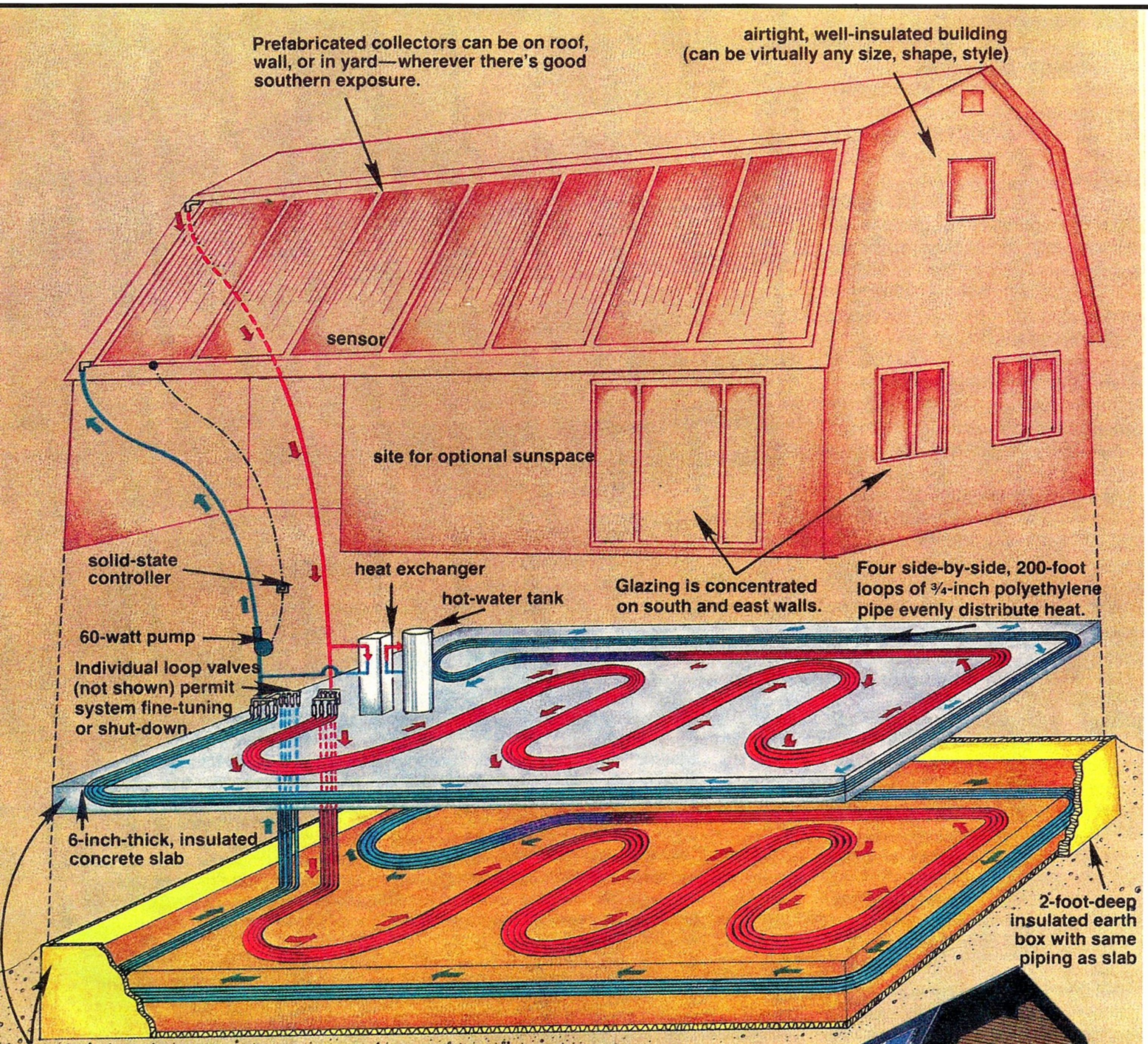
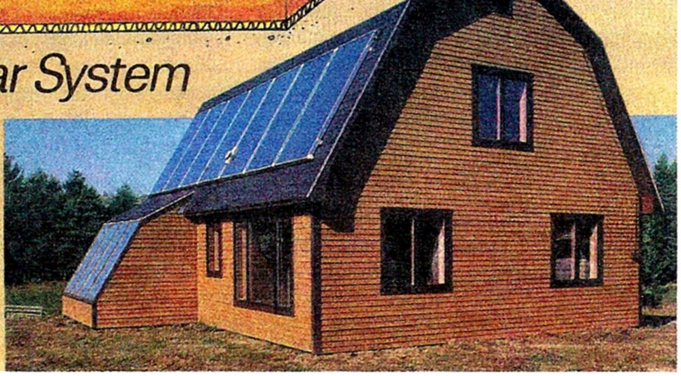


***Figure 1.** A Hybrid Solar System*

Above *Bob Starr's solar home belongs to a new breed of high-efficiency, low-energy dwellings that combine the simplicity of passive design with the architectural flexibility and enhanced comfort control of active designs.*

Inset *Bob Starr's home as it appeared newly built.*



purging valve, a one-way check valve, and an ordinary ball valve. Of these, only the pump consumes electrical power. Other components include seven Grumman Sunstream collectors on the roof, a heat exchanger for hot tap water, and 1600 feet of 3/4-inch polyethylene pipe. The polyethylene pipe is divided into eight serpentine loops, each loop 200 feet long. Four of the loops are embedded in the concrete slab. (They're laid in place when the slab is half-poured.) The other four loops are similarly embedded midway in the earth box.

Whenever there's sun, an electric controller switches on the pump, which pushes a water-antifreeze solution into the collectors for heating. The warmed antifreeze solution is then fed into three pipes. One runs to the heat exchanger, which preheats the hot tap water supply. The second pipe runs to a "header," which feeds the sun-warmed liquid to the four serpentine pipes embedded in the concrete slab. A second header sends the remaining antifreeze through the four serpentine loops in the earth box.

As the antifreeze circulates through the loops, it gives up its heat to the concrete and earth, and then returns to the pump, where it is joined by the antifreeze that went to the heat exchanger. The pump then sends the antifreeze back to the collectors for reheating.

Bob defines his system as active charge, passive discharge. By this he means that the storage mass is charged with heat by the actively pumped, circulating antifreeze. However, there are no controls, electrical components, or other devises to modify the discharge, or release of heat from storage. Instead, the heat simply comes out on its own. It's pretty unusual for an active solar system to be connected to a passive-discharge thermal mass, but Bob's hybrid system is also unique in other respects. For one thing, the mass is *very* massive, weighing more than 175,000 pounds. Unlike conventional systems that raise a small amount of mass to a relatively high temperature. Bob's system raises a huge amount of mass to modest temperatures. Typically, the slab temperature averages between 65° and 70°F: the earth-box temperatures are sometimes lower. These temperatures are already in the comfort range, and that's why the heat can be allowed to come out on its own. It's already at the level you want.

The low storage temperatures also have another extremely important benefit. They keep the collector temperatures very low, typically under 90°F and often in the 75° to 80°F range. By contrast, collector temperatures in conventional active systems usually range between 120° and 180°F. Because Bob's collectors run cool, they lose less energy to the environment. Lower thermal losses, in turn, help boost the overall thermal efficiency of the system into the 60 to 70 percent range – roughly *double* that of conventional active systems!

Each of the eight serpentine loops can be controlled individually by manual valves. These controls allow the system to be fine-tuned to meet the preferences and lifestyles of the occupants, or for any other reason. In the mild weather of fall, for example, the slab can be shut off to avoid overheating the home's living spaces, and all the available solar energy delivered to the earth box to precharge it with heat for the coming winter. In summer, the slab and earth box both can be shut off, turning the system into a giant-sized water heater.

Clearly, this is a remarkable system. But again, it's only one example of the new, extremely simple, hybrid solar designs cropping up. For instance, we're hearing more and more reports of people vastly improving the comfort level of their purely passive solar homes by installing one or more tiny, 30- or 60-watt fans to move the air around to avoid cold spots in the home, and make better use of the home's ability to store solar heat. A fan or two might spoil the "passive purity" of the design, but it pays off handsomely in terms of personal comfort and thermal efficiency. Similarly, many sunspace manufactures are now offering small fans as part of their kits. So you see, hybrid solar can be approached from either end of the solar design spectrum: You can take an essentially passive design and add a few very simple active elements to enhance the performance; or, you can take a basically active design and make it as simple as possible, *à la* Bob Starr.

How do you arrive at this happy combination of simplicity and effectiveness? With five rules of thumb:

1. Get Your Priorities Straight

Solar heating should *never* be your first priority. Not ever. Putting a solar system on a house that's inherently inefficient is a virtual waste of money and time. It's like pouring high-grade gasoline into a car with four flat tires and a gummed-up engine.

Instead, the essential first step in the solarizing of any building, new or old is to get the basic structure as air-tight and well insulated as possible, and to make sure that the nonsolar space and water-heating systems operate at peak efficien-

Left *Bob Starr artfully disguises the concrete slabs in his solar home by covering them with wood floor tiles. Bedded in mastic, and only 5/16 inch thick, the wood has a negligible effect on heat transfer out of the slab, yet enormously improves the home's aesthetics.*

cy. (In new homes, this means using state-of-the-art conventional heating equipment; in older homes, tuning or upgrading existing equipment.) Energy-saving measures such as these almost always pay for themselves in a matter of months. And they pay off again in terms of solar design because an efficient home can get by with a smaller, less expensive solar system.

All this may seem obvious, yet it's one of the most common reasons why solar installations fail. Larry Zarker of The National Association Of Home Builders Research Foundation says, "I can't tell you how many homes I've heard about where an otherwise excellent solar system is hooked up to uninsulated pipes and tanks in the basement. The homeowner wonders why the solar energy isn't doing more, when most of it is simply being bled away into the basement air."

Gaspar DeGaetano of the Tennessee Valley Authority Solar Applications Branch agrees: "You have to look at the complete system, and not just think about the individual components."

Bob Starr got his priorities straight by paying attention to detail in ensuring his home's thermal integrity. The walls of the building are studded with 2 x 6s, allowing for $5^1/_2$ inches of fiberglass insulation. Another inch of tongue-and-groove Styrofoam sheathing brings the walls to an R-value of over 22. The building's concrete slab and earth box are snugly wrapped in an unbroken layer of Styrofoam, and a full foot of fiberglass insulates the ceiling. Large voids in the building shell around windows, doors, and other penetrations are filled with an expanding urethane foam, and small cracks and imperfections are thoroughly caulked. The windows and doors themselves are insulated and heavily weather-stripped. The list goes on – but you get the idea.

2. Keep It Simple

In the abstract, active solar heating is a wonderfully simple idea. But making it work in the real world is a little more complex. Figure 2 shows a traditional active solar system, with five separate components or groups of components: *collectors* turn the sun's energy into heat; a *control system* senses when solar heat is available and transfers energy (via warm air or warm water) to an *insulated storage* tank or bin; a *second control system* senses the home's need for heat and transfers energy from the storage bin or tank to the *distribution system*, which actually carries the heat into the home. The problem is, this simple, five-part concept almost never appears in its pristine form. Take a look at Figure 3. Believe it or not, it's for real, based on a drawing we found in a government booklet on active solar heating published just seven years ago. Instead of a simple, five-part system, you end up with hundreds of individual components that tend to be expensive, eat up an inordinate amount of space inside your house, and pose major reliability problems as Murphy's Law goes wild with each of the system's many parts.

That's why the second rule of thumb in designing or buying a solar heating system is "keep it simple." The more streamlined and uncomplicated a solar system is, the more effective and reliable it is apt to be.

How can you evaluate systems for simplicity and reliability? "It's tough on the consumers," says Ross McCluney of the Florida Solar Energy Center. "You can pick up any one of the solar magazines and read about some really crazy kinds of designs. Some of these systems work, some don't. There's still an awful lot of experimentation going on. It's becoming more and more essential to rely on objective tests to tell the effective designs from the ineffective ones."

Several agencies including the Florida Solar Energy Center, the Solar Rating and Certification Corporation, and the Tennessee Valley Authority are beginning to perform such objective tests of entire, working, active solar heating systems.

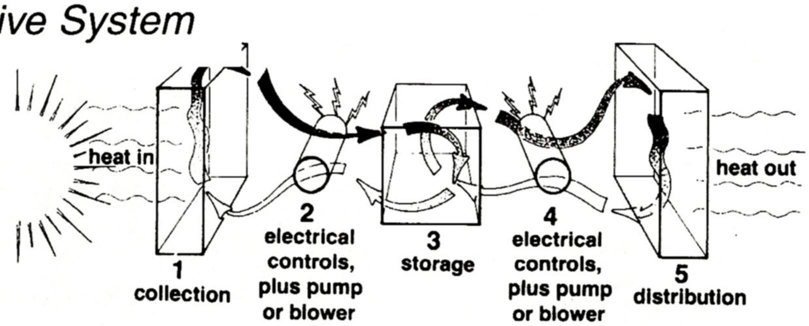
If you're interested in a system that hasn't been tested, or if you're thinking of building your own system, there's still plenty of solid, general information you can use to perform your own armchair evaluation of just about any active design. For example, a report entitled *Guide to Effective Solar heating And Cooling Practice* published by the National Solar Data network (NSDN) (available from the National Technical Information Service lists the most common design errors discovered through long-term monitoring of hundreds of solar systems around the country. Here are some highlights.

Look for systems that rely on as few "field connections" (site-built or site-assembled components) as possible. Such systems suffer fewer breakdowns and often have superior thermal performance. One reason this is so, says the NSDN, is that factory-assembly can be done in a controlled environment with proper tools, while site work is often performed under adverse conditions with whatever tools are at hand. Several manufacturers have taken this information to heart, and are offering entire, prepackaged solar systems, usually in the form of several preassembled modules (prefab collectors, prefab air handlers or pump-header assemblies, and so on). For example, Bob Starr chose prefabricated collector assemblies that simply bolt to the roof, and require two plumbing connections. "They're an incredible time saver," he says. "They outperform anything you can put together yourself, and if you shop carefully, you can get a cost-per-But that's close to scratch-built."

Avoid systems that use exotic or hard-to-find components. A system that requires a unique kind of glazing or a one-of-a-kind pump, for example

ILLUSTRATION BY ED WACHTER

Figure 2. *An Idealized Active System*



Right *Most traditional active systems have the five major subsystems shown here. Bob Starr's hybrid solar design combines "storage" and "distribution" into one element (the slab and earth box), and eliminates the second set of electrical controls. As the number of components goes down, reliability goes up.*

may be shut down for weeks if the specialized component fails and you have to wait for the factory to ship you a new one. On the other hand, a system that uses standardized, off-the-shelf components is much easier to maintain and service, and should have a longer, more reliable lifetime. Everything in Bob Starr's system, for example, except the collectors and the pump's electrical controller, can be purchased at any well-stocked plumbing-supply store. And the system isn't fussy about what controller or what collectors it's hooked to, so substitutions can be made there as well, if needed.

Systems must be designed to cope with extremes of heat and cold. The NSDN says that at some point in their lives all solar systems experience "stagnation" – when the system fails or is inoperative even though there's full sunlight. During stagnation, the collectors go on collecting even though no heat is being removed from them. Stagnating collectors easily can reach temperatures in excess of 400°F, which can cause plastics to break down or release gases that condense on the glazing, causing it to fog. Or, the physical structure of exposed wooden components may slowly change with exposure to high heat so that the ignition point of the wood becomes dangerously low. Stagnating collectors actually can begin to smolder or even burst into flame.

Cold temperatures aren't much easier on the system. Ice is the natural enemy of all water-filled solar systems because an ice blockage will at least impede the flow through the system, and may even burst the pipes. Severe cold also causes metal components to contract, possibly pulling free of their nails, screws, or other fasteners.

Systems should use two means of dealing with temperature extremes. First, the system should be designed so that extremes are avoided as much as possible. Second, the system should be designed so that occasional overheating or a cold snap won't faze it. For example, overheating problems usually can be avoided with a simple system of bimetallic automatic vents that open at around 160° to 180°F, allowing a small amount of fresh air to flow (by thermosiphoning) through the collector box for the duration of the overheating condition. Low-temperature plastic fittings can be avoided, and all the wooden parts of the collector can be completely isolated (by heavy insulation) from the sunward portion of the collector where high temperatures may occur.

Freezeproofing is usually simpler. Air-filled systems can't freeze at all, so there's no problem. Water-filled systems should be designed to drain completely with no pockets or pools of water left anywhere in the exposed plumbing. Alternatively, the pipes can be filled with antifreeze, or they may be made of one of the new, durable plastics, such as EPDM, which can withstand repeated freeze-and-thaw cycles without damage.

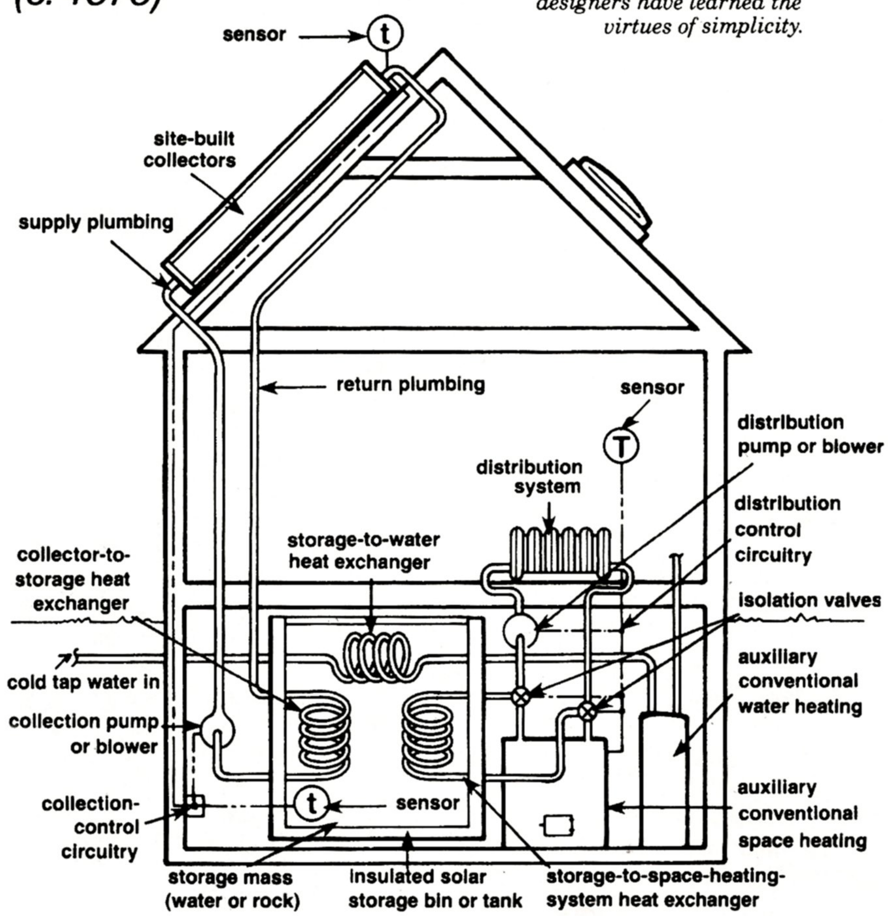
Bob Starr's design uses a variety of strategies to cope with temperature extremes. In the first place, the huge amount of thermal mass ensures that the system routinely operates at very mild temperatures, far below stagnation temperatures. These low temperatures give the system a considerable safety margin – it takes that much longer to heat up to dangerous temperatures in the event of a transient (short-duration) shutdown. Also, during transient shutdowns, the high quality of the Grumman Sunstream collectors and the high boiling point of the antifreeze solution add even more of a safety margin. For extremely rare extended shutdowns, Bob simply covers the collectors with shade cloth.

At the other end of the thermal environment, cold temperatures are no problem at all for Bob's system, because it's filled with antifreeze.

Other highlights from the NSDN report: Collector mounts should be designed to cope with the worst expected snow and wind loads; the entire system should be protected from corrosion through the use of high-quality paints, sealant, or chemical additives; all components that require periodic servicing should be in accessible locations. (The NSDN report actually goes on for over 50 pages, and is well worth reading.) These design criteria might seem imposing, but the underlying concept is quite straight-forward: Such desirable

Figure 3.
The Bad Old Days (c. 1976)

Active solar space heating reached the peak of Rube Goldberg complexity in the 1970s. This illustration is adapted from a 1976 government publication. Since then, solar designers have learned the virtues of simplicity.



characteristics must be incorporated into solar systems, and the best way to do it is to build them into the system, right from scratch, rather than add them on in the form of piecemeal control subsystems. Bob's system shows how simply and elegantly this can be done.

3. Accept No Substitutes

Here's where we get into the nitty-gritty of successful solar design, dealing with the individual components – the nuts and bolts – that make up a system. As you might expect, the ideal of simplicity is also paramount here: Individual components should be designed to do their job as simply as possible. Fortunately, the task of finding simple, reliable, high-quality components has become much easier over the last few years.

For example, the Florida Solar Energy Center has been testing solar collectors for over five years. Jim Roland, who handles some of the testing, says, "Five years ago, collectors were a conglomeration of separate parts: The separate tubes in a liquid absorber, for instance, would be spot-soldered or simply friction-fitted to the absorber plate. Now, many manufacturers are going for one-piece absorber plates with the tubes integrally designed into the plate, or are using continuous brazing and soldering to connect the pipes and plate into a single, solid assembly, It may not sound like much, but if you come up with six or seven small improvements like that, you can turn a pretty ordinary collector into something outstanding. And a lot of manufacturers are doing just that. There's a lot of good equipment out there." In fact, Jim says that on average, today's collectors produce *33 percent more* BTUs per square foot than the designs of just five years ago.

The good news isn't limited to a few Florida systems, either. Barry Graves of ESG, an energy systems group located in Georgia, is currently involved in the testing of 160 state-of-the-art active solar systems. Fully 90 percent of the systems have experienced *no* component failures at all, and the majority of the problems that occurred in the remaining 10 percent of the systems were quite minor, causing the systems to be shut down only for a day or two. "Most of the problems happened within the first couple weeks of operation," Graves says. "It's really part of the normal shakedown period, and no big deal. This represents a really tremendous increase in component reliability compared with the systems of, say, ten years ago."

The one weak area in solar components seems to be in the electrical control systems and electrically operated valves. In the ESG tests, while the overall number of failures was small, half the problems that did occur happened in these critical components. Manufacturers are responding with solid-state technology, innovative design, and an unusually high degree of industrial cooperation.

For example, the Sunspool Corporation (a manufacturer of drain valves and sensors) worked together with Heliotrope General and Independent Energy Inc. (which manufacture controllers) to produce a new kind of *one-piece* collector sensor module that is designed to replace most of the usual rat's nest of temperature and freeze sensors scattered throughout an active system; it connects to a controller with only four wires. This greatly increases reliability, and also helps to keep the amount of site work to a minimum.

The same simplification and improvement in reliability extend beyond electronics. For example, you can now buy pre-engineered plumbing packages that include a controller, a pump, and the critical pipe assemblies already mated and mounted. Likewise, manufacturers of air heating systems offer complete "air handling packages" that incorporate sensors, blowers, valves, and ductwork to properly shunt a solar system's air to where it is needed.

The net result is that solar components you buy today will probably work the way they're supposed to – if you buy legitimate solar components.

"Take something as simple as an air vent used to let air in and out of the system that periodically drains and fills," says Sunspool's Michael Kast. "Air vents are common on almost all hydronic heating systems, and they've been around for dozens of years. But most of the ones on the market are meant for use in indoor boiler rooms or in other protected locations. Put one of these vents outside on a solar collector, and stagnation temperatures may cause the vent's delicate internal components to melt or become distorted. At night, residual water vapor may freeze in the tiny air passage, causing the valve to stay open or shut. Either way, a failed air valve can lead to catastrophic stagnation or freezing of the solar system."

On the other hand, an air valve specifically designed for solar systems will have extra-large air passages that resist ice clogging, and rugged internal components with special coatings to keep them from sticking at high temperatures and to prevent ice crystals from clinging at cold temperatures. (Sunspool makes such a valve.) The bottom line is, "Accept no substitutes." Don't ask nonsolar components to pinch-hit in a solar system's critical assemblies.

In Bob Starr's system, for example, the only component problem he's had was a collector that showed signs of minor outgassing. (The glazing fogged up a bit in one corner.) Bob called the manufacturer, and they identified the problem as a seal made from the wrong kind of plastic. They immediately sent a free replacement. "They were great about it," Bob told me. "They really want their components to work, and they'll do almost anything they can to see that they do."

4. Install With Care

The world's finest solar system can be torpedoed by a sloppy installation. Ross McCluney told me, "I've seen collectors plumbed backwards, installed without any insulation at all, pipes blocked with excess solder or flux, and collectors installed smack in the shade."

For too long, the record on installation was pretty dismal. The NSDN, for instance, looked at a number of active air-heating systems and found that air leaks in the ductwork typically amounted to 30 to 40 percent of the total volume of air intended to flow through the system. In one memorable case, the leaks equaled the volume of the air flowing through the collectors.

The good news is that there's no need for these kinds of installation errors, because correct, proven, reliable installation techniques are available, and information about these techniques is rapidly spreading throughout the solar industry. The

Florida Solar Energy Center, for instance, conduct workshops for professional installers to teach them the very best methods for hanging pipes, penetrating roofs, mounting collectors, and so on. In addition, several excellent handbooks have been written on the subject allowing anyone (including do-it-yourselfers) to learn the proper installation techniques.

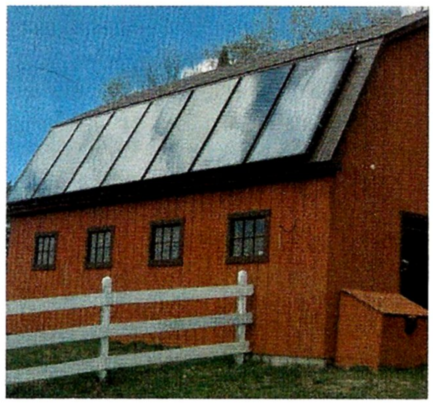
As the new information on installation techniques spreads, the effects are already becoming visible. Tim Merigan of the Florida Solar Energy Center told me, "Most of the installation horror stories you hear about thankfully, are receding into the past. A lot of people were guinea pigs for the first generation of solar systems, and a lot of bad installers made a quick buck and disappeared. But most of the ones who are left take their business seriously, and are very concerned about the quality of their work. Some have even been trained and licensed by the manufacturers of the systems they sell; others have simply learned the best ways to do things, through on-the-job training. Either way, it's not that hard to find competent installers now."

You've probably noticed by now that these rules of thumb have fallen into an orderly sequence: If you have the right priorities, you can get by with a simpler system. Simpler systems have fewer components. By making sure that those components are well designed and of high quality, the job of installation becomes simpler. Then, it's a relatively simple matter to use state-of-the-art installation techniques to ensure that everything goes together properly. With the successful completion of each stage in this process, the probability of success of the solar system goes up. It's like a jigsaw puzzle, and all the pieces are fitting together. In fact, there's just one more.

5. Owner Maintenance

There's one vital component in every solar system that no manufacturer, designer, or installer has any control over. It's the owner—you. The way a system is used or abused goes a long way toward determining its final performance. William Stoney of ESG summed up the feelings of many other solar experts with whom I spoke: "The user of a solar system is at least as important as, and maybe more important than, any other factor in the success or failure of the system."

A Long Island study really drives home this point. Long Island's electrical utility installed 632 identical solar hot-water systems on area homes. The same two contractors performed all installations. Yet the annual solar contributions to the homes' hot-water loads ranged from a low of 20 percent to a high of 80 percent. An incredible difference that must be attributed largely to the way each homeowner used and maintained his system.



All solar systems, no matter how simple, no matter how high the quality, require some maintenance.

John Avery of Los Alamos National Laboratories told me, "Solar-system lifetimes of 20, 30 years, or even longer, are entirely possible. But you hear about premature failures all the time. Most of them are directly attributable to someone's not taking the time to do preventive maintenance. An owner of a solar system has to be involved, and has to pay attention to what the system is doing. All too often, people want their solar system to just sit there and run for 15 years, like a refrigerator. They end up simply ignoring it until there's not heat coming out, or until there's a puddle on the floor."

It's a shame, because solar system maintenance need not be difficult. Generally, it's simply a matter of checking for leaks, making sure that there's enough fluid in the system, making sure the fluid is neither acidic nor alkaline (you use inexpensive pH strips you can buy at the drugstore). You should also make sure that the glazing is clear and unobstructed, that the insulation on pipes and tanks is still in place and intact, and so on.

The owner plays a major part in the *daily* efficiency of an active solar system, too. For example, you can boost efficiency of a solar water heater by scheduling your heaviest hot-water use for late afternoon and early evening, when the solar storage tanks are hottest. (If you wait, the water cools off, and you end up using more auxiliary fuel.)

Bob Starr goes one step further: When he needs a lot of hot water for washing clothes or for other purposes, he waits for a sunny day and then shuts off the flow of sun-warmed antifreeze to the slab, sending it instead to the tap-water heat exchanger. For as long as the slab is shut off, his solar system acts as a water heater of enormous capacity, giving him virtually all the hot water he can use. Meanwhile, the house stays comfortable because of the heat previously stored in the slab and earth box. Of course, this strategy is unique to his system, but the principle applies to all solar systems: Make the most of the sun while it shines, and don't place extra thermal loads on the system during sunless periods. Common sense, really.

If you don't want to attend to maintenance yourself, you can buy a service contract to have professional come out and service your system and correct any problems that develop. Better, you can rely on an owner's manual to explicitly detail the routine servicing and trouble-shooting a system may need. (Not all manufacturers provide manuals. If you're buying a solar system, a system with an owner's manual may be a better buy than one without.) ■