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HARNESSING SOLAR ENERGY FOR HEATING AND HOT WATER: THE KEY IS STORAGE, STORAGE, STORAGE!

By Rob Spence

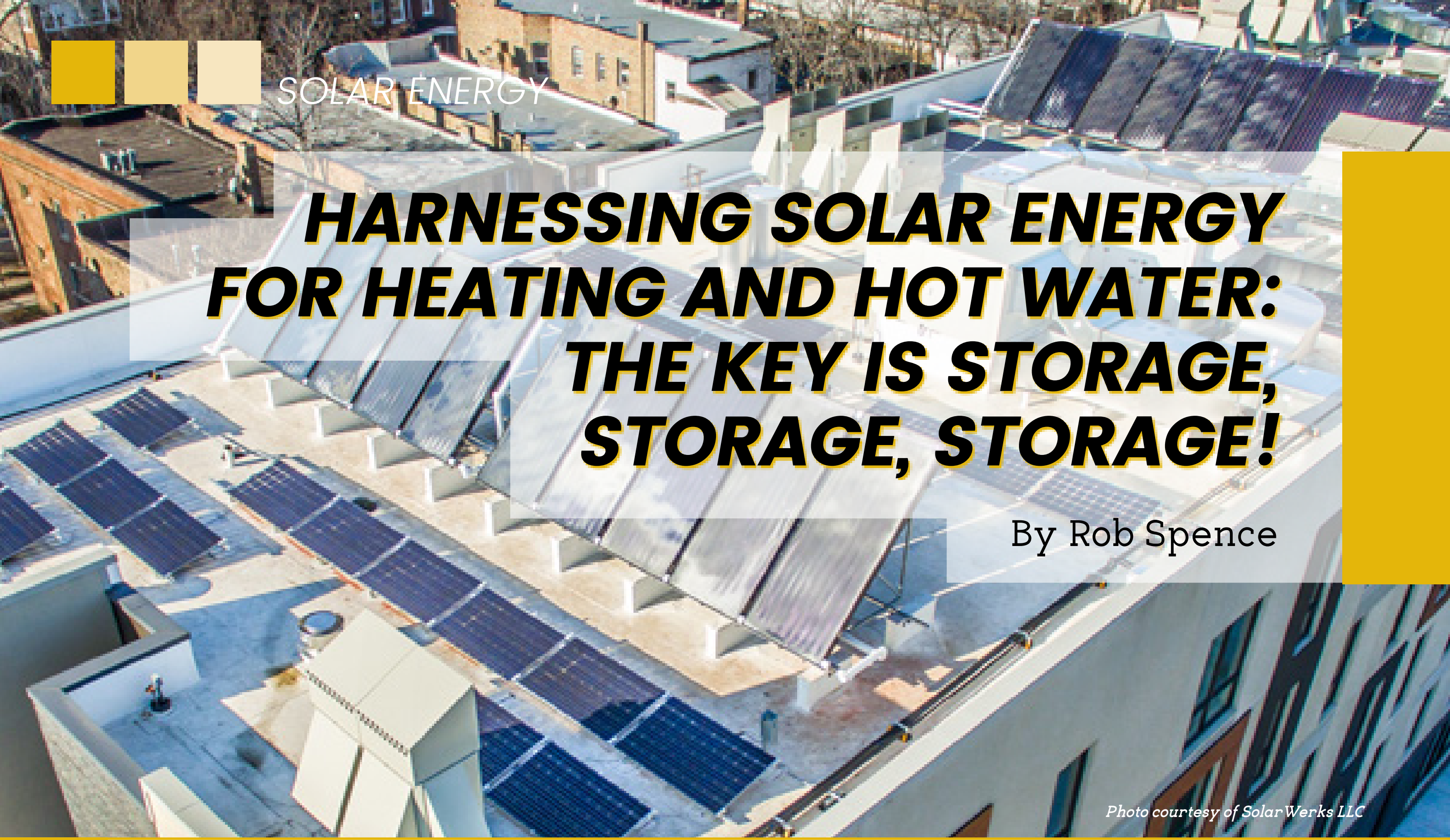

Photo courtesy of SolarWerks LLC

When asked to write an article on harnessing solar energy for heating and hot water, my first thought was, that should be easy. Unfortunately my second thought was, what new information can I provide that hasn't been said in the pages of this publication or others like it? Most of those previous articles did a good job describing the difference between PV and solar thermal; drainback and draindown vs. pressurized systems; flat plate vs. evacuated tubes; and some insight into what works here in Wisconsin. This invariably steers the reader toward domestic hot water (DHW) production applications.

To provide you with some new information, this article will focus on when and how to take advantage of solar for space heating. Don't get me wrong; DHW is still the low-hanging fruit for solar thermal and will remain the easiest to justify. However, almost every time I get involved with a hydronic heating job where the customer wants to add solar, the next question is, "How many panels do I need to offset all or most of my heating?"

This article will attempt to clarify how much heating load can realistically be offset with solar in a typical heating application, and identify applications where solar can be used to offset a substantial portion of a structure's heat load with simple, cost-effective systems. I will also provide a brief summary with some of those solar definitions. For anyone wanting a more in-depth resource on solar thermal systems, I suggest you look up a periodic journal called "idronics™" published by Caleffi, specifically volumes 3 and 6, which are dedicated to solar energy.

DEFINITIONS AND BACKGROUND

There are two distinct types of solar energy collection methods.

Photovoltaic (PV) panels convert the sun's solar radiation directly into electrical energy. Most of the commercially available panels output a relatively low DC voltage. Multiple panels are then wired together to achieve the desired voltage. The system usually incorporates a DC to AC power invertor, so the current can easily be used in the home or fed back onto the power grid.

Solar thermal systems convert solar radiation directly into usable heat. The most basic form is a passive solar thermal system, designed to add solar energy directly to the structure without pumps, fans or other moving parts. For a structure with many south-facing windows and a high-mass (stone or concrete) floor, it is actually very effective. However, it is difficult to control and it requires you to design the building architecture to take advantage of the sun at the correct time of the year.

The active solar thermal system is by far the most common **(fig. 1)**, it circulates either water or air to a solar collector outside and then back to the load. While the air-based system can be used effectively to supplement some of the space heating requirements of the structure, it has control and thermal storage limitations. The water-based systems are more flexible since they can directly heat either DHW or hydronic heating water and then easily store it for later use. These systems use a controller that turns the pumps on and off to maximize the heat collection.

If the PV panels make electricity directly and you can easily make hot water with electricity, why do we need solar thermal? The answer is cost and efficiency. Since the PV panel is converting the solar radiation directly into electricity, it is relatively inefficient; actually about 15%.

In contrast, the solar thermal panels simply collect the solar radiation as heat, which ends up being pretty efficient. On average they convert about 65% of the solar radiation that falls on them to heat. Therefore, to collect the same amount of energy you would require over four times the area of PV panels. In addition, there is a decent price advantage. Currently, the going rate for PV panels averages $1/watt, compared to about $.40/watt for flat plate collectors. To collect the same amount of energy you would spend 2.4 times more to purchase PV panels.

Even with these handicaps, the PV panel market is still strong due to their flexibility. Every home or business uses electricity and in most cases the system can be tied into the power grid and the utility will buy back extra energy. Currently, Focus on Energy is providing incentives for solar PV systems and they qualify for the 30% federal tax credit as well.

However in our part of the country, space heating and DHW production make up the largest portion of any homes energy needs and the solar thermal panels are the clear winner for those applications. That's why we continue to see a big market for these types of systems. While they don't qualify for the Focus on Energy incentives anymore, they still qualify for the 30% federal tax credit. For those reasons and the fact that this is the PHC magazine and most of you are either plumbers or hydronic heating guys, we will focus the remainder of this article on solar thermal systems.

SOLAR THERMAL

At a minimum, a typical system **(fig. 1)** will consist of solar panels, storage tank, circulator, expansion tank, heat exchanger, heat transfer fluid (water or glycol mix) and a differential controller. The differential controller measures and compares the solar collector temperature and the tank temperature and if it's greater, the circulator is turned on. Simple!

Solar collectors: The two types are flat panels and evacuated tube collectors. The flat panel is the most common and simplest in design. They are less expensive and simpler to install. The evacuated tube collectors will typically have higher efficiencies in colder weather and diffused light conditions. In general, either type of collector can be used in any of these designs with one exception. There are some collectors that aren't compatible with draindown and drainback systems, so please check with the manufacturer before use in those applications.

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FIG. 1

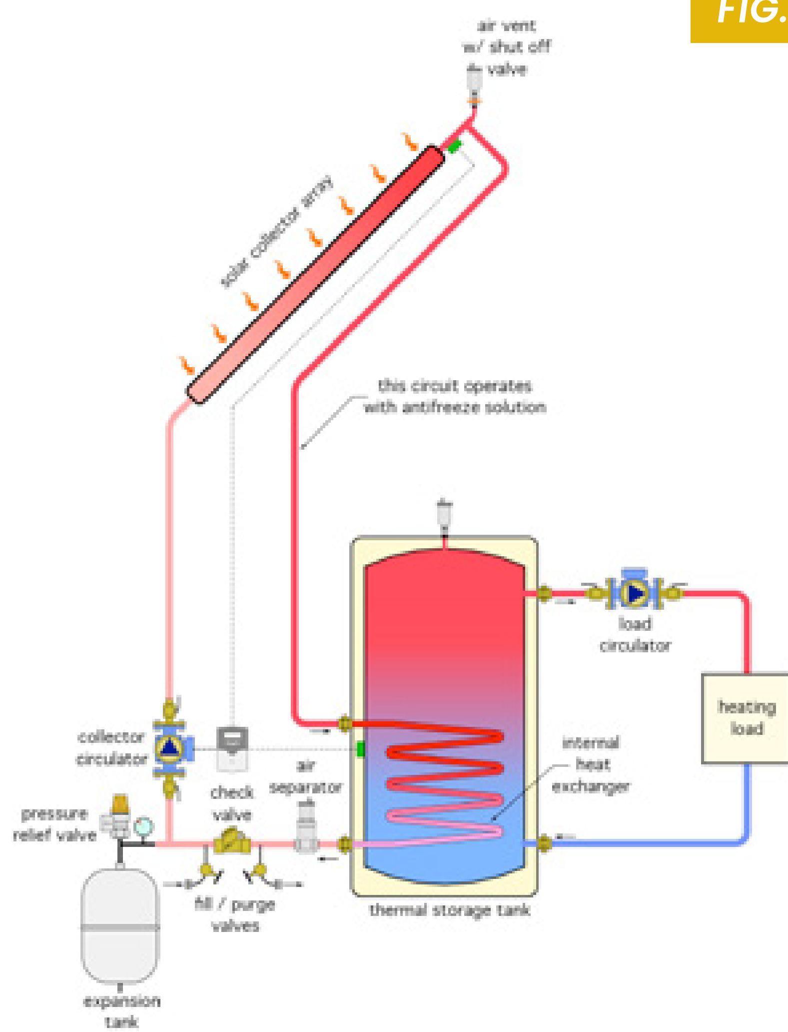

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FIG. 2

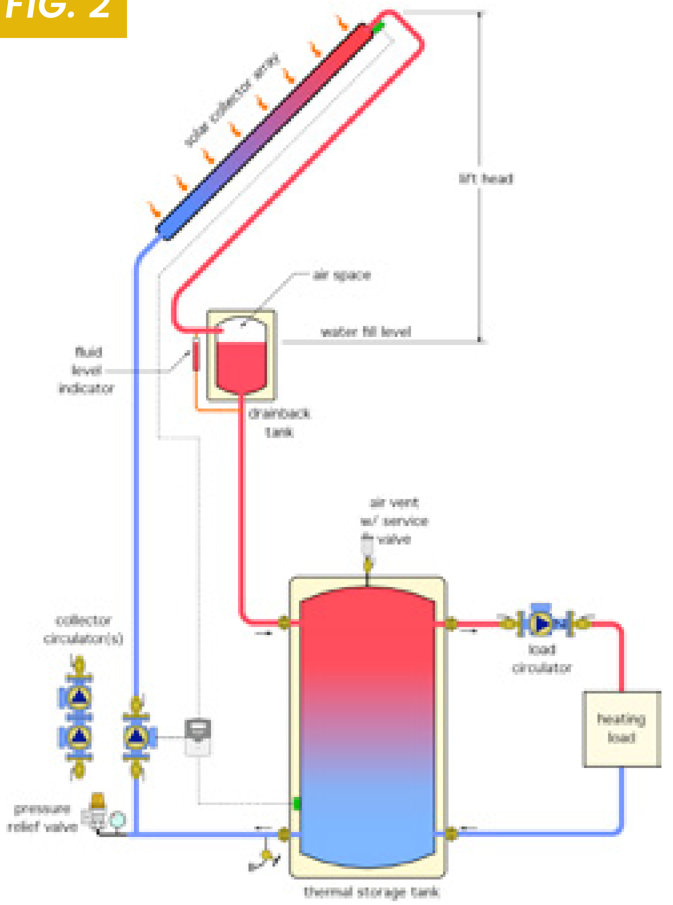

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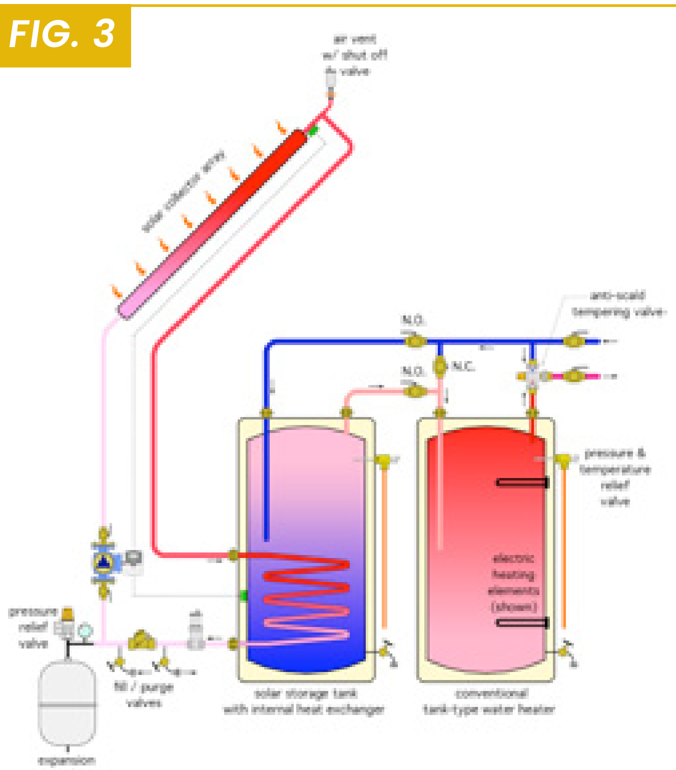
FIG. 3



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SYSTEM TYPE

The three main types of systems are pressurized, drainback and draindown. The pressurized system **(fig. 1)** is very similar to a hydronic heating system in which the entire circuit is filled and pressurized at all times. An expansion tank must be used to account for the thermal expansion and an air separator is used to help remove any air. In this type of system, a water glycol mixture is a must to provide freeze protection. Because of this, it almost always requires a heat exchanger to separate solar fluid from the DHW or boiler system water.

The drainback system **(fig. 2)** incorporates a separate drainback tank. While the system can still be sealed, it is normally not pressurized and the system is not completely filled. When the system is turned off, the panels and piping are designed to let the fluid drain back into the tank to provide proper freeze protection. The placement of this drainback tank, other components, pipe routing and pitch are very critical in this design. The controls have an added feature that will turn the pump off if it senses a freezing condition or the solar tank is too hot.

The draindown system is the same as a pressurized system, except when it senses a freezing condition, valves are opened to let a portion of the water be dumped to drain. Once the freeze event is over, the system is either automatically or manually refilled. This system is designed to be used in a warm climate, where a freezing event is a rare occurrence.

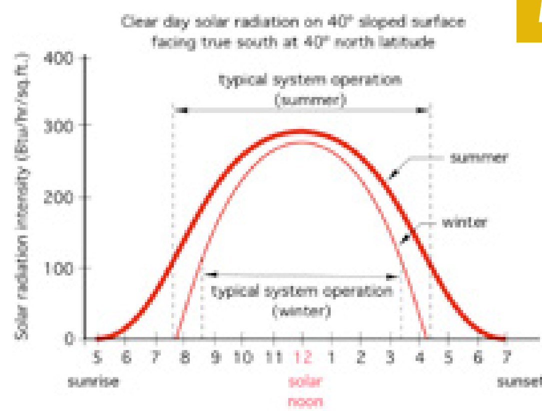
DOMESTIC HOT WATER (DHW) PRODUCTION

The most common DHW solar system **(fig. 3.)** has at least two tanks. The one on the left is the preheat tank, which is only heated by solar. The incoming domestic water always flows into this tank first and then flows into a conventional hot water heater, which will maintain itself at 120°F. The solar tank always starts with water at 50°F, which is the beauty of the two tank system. Even early in the day or on cloudy days when the pre-heat tank may only be at 80°F, you are still reducing the cost to make hot water, since the conventional heater only needs to heat the water from 80°F to 120°F. Once the preheat tanks get above 120°F then the conventional heater won't come on. Note: an anti-scald valve must always be installed to limit the actual water temperature to the fixtures.

As noted earlier, in this area the most easily justified application for thermal solar is to make hot water. Why is this? Well, typically you have the need for DHW every day, so the investment in solar pays back all year long. In addition, it is easier to store a day's worth of DHW than a day's worth of heat for space heating. To understand this better, let's discuss how we determine the amount of solar energy that can be stored in a tank of water. It depends on the gallons in the tank and the temperature difference between the starting point and end point. The practical upper limit for domestic hot water is 200°F (keep below P&T). The lower limit is the incoming water temperature, typically around 50°F. Therefore, our useable temperature difference (deltaT) is 150°F. A very easy to remember formula can be derived from the definition of the British Thermal Unit (Btu). It says, "A Btu is the amount of energy required to raise 1 lb. of water 1°F. The weight of a gallon of water is 8.34 lbs., therefore the formula for energy stored in pure water is: Btu (stored) = 8.34 x deltaT x gallon. It should be noted at this point, the above formula and calculation to follow are simplified for this article to demonstrate general concepts.

Let's use an 80-gallon storage tank for our example: If we plug 80 and 150 into that formula we see the tank can accept 100,080 Btus. Assume we have 4 ft. x 10 ft. flat panel collectors. This panel has an SRCC (category C, clear day) daily output rating of 40,000 Btu. This rating takes into consideration that the sun's intensity on the panel changes throughout day **(fig. 4)**. Therefore, two panels would give a total of 80,000 Btu. This is well below the 100,080 Btu capacity, thereby minimizing the chance of overheating the tank. It should be noted that an 80 gallon tank at 180°F will provide substantially more than 80 gallons of DHW since you are mixing it down to 120°F as you use it. A typical family of four on average uses 70 gallons of hot water per day, so this relatively reasonable system can produce and store more than enough DHW for a complete household on a day with full sun.

FIG. 4



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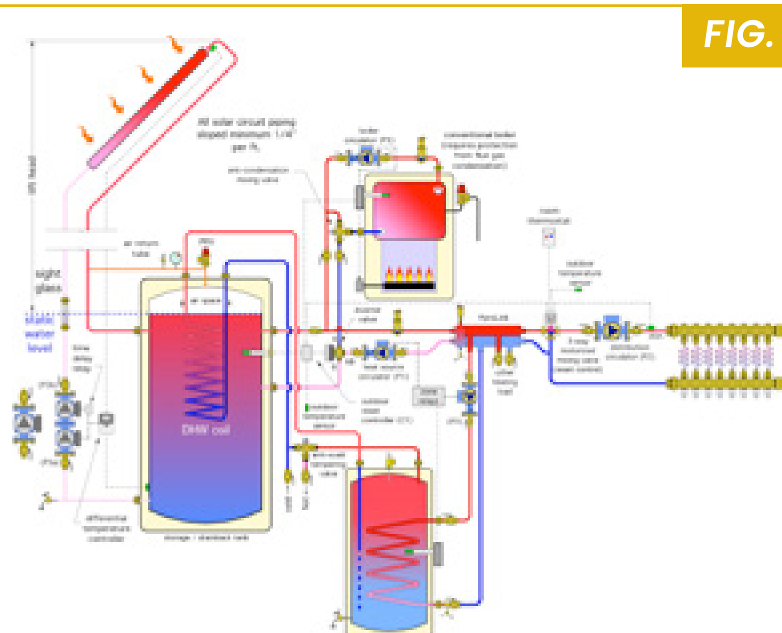
SPACE HEATING COMBI SYSTEM

Let's look at an example of a combination system **(fig. 5)**. This is a drainback system where the boiler and solar fluid are common. The conventional water heater is an indirect, which utilizes boiler water to keep the tank hot at all times. The incoming potable water is routed through a pre-heat coil in the solar drainback tank. This is a very simple system to control – the solar control adds heat to the drainback tank just like it did in the all-DHW system. Once the fluid in the solar tank is warm enough, a control valve opens to let the fluid from this tank provide heat to the house or to the DHW indirect tank. There are many variations of this system, but all will incorporate a large storage tank or tanks and a control to determine when it's hot enough to provide heat to the system.

FIG. 5



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Now back to the question at hand, how many panels and storage tanks do we need to take care of our space heating needs? Utilizing solar for heating provides us with a unique challenge. During a clear, sunny day when the output of the panels is the highest, we will require the least amount of heat! Practically, this is why a typical combi system is designed to only offset the structure's daylight heat loss. But, let's see what it takes to supersize things, so we can collect and store enough energy to carry us through the night, similar to what we can achieve with the DHW system. Our example house is a typical 3,000-sq.-ft. home and has a design heat loss of 60,000 Btu/hr (-10 design day). This is the peak load that the heating system will be designed to; however, the majority of the time the actual requirement is much less. On a typical winter day (20°F) with the sun shining it will need 22,500 Btu/hr (for 8 hrs) for a total of 180,000 Btu. At night the load would be 37,500 Btu/hr (for 16 hrs) for a total of 600,000 Btu. This equates to a daily total of 780,000 Btu. If we use 4 ft. x 10 ft. panels, their SRCC (category D, clear day) daily output is 26,000 Btu. This reduced output is due to winter sun conditions **(fig. 4)**. Divide that into our total daily requirement and the result is 30 panels required to yield 780,000 Btu, but only seven required to handle just the daytime requirement of 180,000 Btu.

Let's look at how much energy can be stored in a solar tank for use later as space heat. For the same size tank it will be less than it was for a purely DHW system. This is because the practical limits are much different; the lower limit is more like 120°F. Once the stored water drops below the required water temp to heat the structure, it is useless for heating. Therefore heating systems that utilize very low water temperatures are ideal. The upper limit is still 200°F so the deltaT for this application is 80°F. If we used that same 80-gallon tank and formula, we find that only 53,376 Btu are available for use in heating vs. the 100,080 Btu available for the DHW application. If you divide the 53,376 into a nighttime requirement (600,000) it yields 12 80-gallon tanks or a total of 900 gallons. To summarize: by adding 30 solar panels and 900 gallons of storage to your heating system, on a sunny day you can offset the full day's energy requirement. While this is technically possible, it is very difficult to economically justify. The added cost of the solar equipment and labor for a system like this could easily reach $80K and you really can't downsize the conventional heating system. In addition, finding the space for 30 panels and the storage tanks is a real problem. In contrast, only seven panels are required to offset just the daytime load and the tank drops to 200 gallons. As noted earlier, this becomes the typical target for a combination system.

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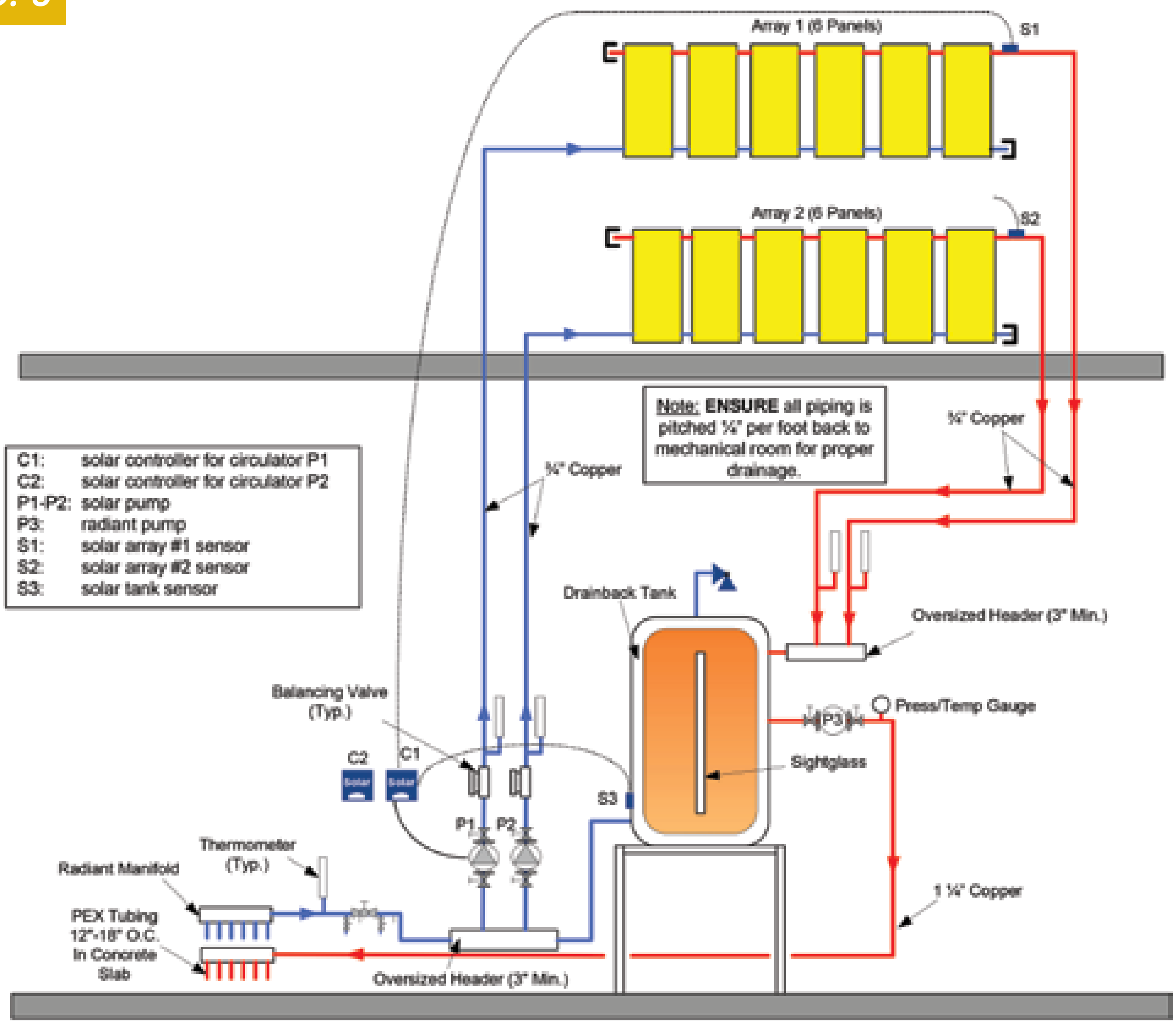
SPACE HEATING (DIRECT TRANSFER TO THERMAL MASS)

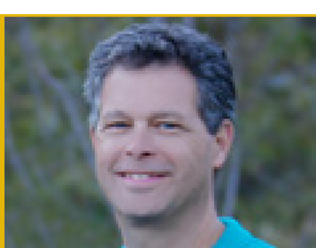
Based upon what we just saw in the combination system it seems impossible to economically offset a majority of the heating load, not to mention all of it! On the contrary, it can be done if we have the right project. Slab-on-grade (high thermal mass) projects with radiant heat (low water temperature) and one other key ingredient – the customer must be ok with a range of ambient temperatures. These are storage facilities, car washes, hangers, farm storage, etc. A simple drainback system **(fig. 6)** with many panels and no storage tanks can maintain a structure at 40-60°F without a backup boiler. The solar fluid flows directly into the in-floor system and directly heats up the slab. The concrete slab provides almost unlimited thermal storage, which will get you through a cloudy stretch. The system drains back in the summer to prevent overheating.

A future article will address practical design criteria for this type of system.

FIG. 6



Courtesy of Rundle-Spence



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