Photo 1a (left): Small commercial solar combisystem. **Photo 1b (right):** Residential solar combisystem.

Integrating Solar & Hydronic Heating In Residential and Small Commercial Systems

By Bristol Stickney

This article and the following companion article, "Advantages of Integrated Control in Solar Combisystems," share our field experience in the solar heating industry for those seeking better ways to apply solar thermal technology in their heating system designs. This article discusses applications where hot water produced by solar collectors can be easily allocated to multiple uses with a simple piping configuration and straightforward control strategies. The detailed control of these systems is more thoroughly described in the companion article.

After a solar heating professional becomes proficient with solar water heaters, the next logical step is to delve into solar combisystems. In these systems, the collector arrays become larger, and the heat is distributed to multiple end-uses, not just a single water tank. In a combisystem, it is typical for a large group of collectors to provide heat for space heating, water heating, and other uses such as boiler preheat, pools, spas, ice melt, and heat storage. The piping involved in these systems can seem complex, and the control systems formidable. But the technology has matured and the energy savings can be significant, so solar heating should not be overlooked.

The information presented here is essentially a report from the field, drawing upon the experience of more than 100 solar-heated combisystems installed and operating over the past five to six years. We have focused on pres-

About the Author

Bristol Stickney is chief technical officer at SolarLogic in Santa Fe, N.M.

surized, closed loop glycol/hydronic solar collector systems, since these systems can be applied in a variety of building geometries and orientations with few limitations. Our results and observations have helped to formulate our own recommended best practices, presented here, which can be applied directly to solar heating installations in residential and small commercial buildings (see examples in *Photos 1a* and *1b*). The discussion presented here targets new and retrofit heating systems in small buildings (less than 10,000 ft^2 [929 m^2]) using hydronic heating systems. We have found that a standardized and modular approach to the design, installation and control of solar combisystems can greatly improve the speed and reliability with which they are deployed.

Why Active Solar Hydronics?

Closed loop hydronic solar heating collector systems are seamlessly compatible with hydronic boilers, hot water radiators, domestic hot water and radiant-heated mass floors. Both the solar equipment and the conventional systems operate along the same principles, using similar fluids and fluid pressure, and have compatible temperature ranges. Conventional building construction practices for hydronic heat distribution systems do not need to be altered or relearned in most cases when solar heat is to be included.

Closed loop, pressurized solar collectors can be mounted in a variety of ways, including ground mounting, roof mounts and wall mounts, allowing for flexibility in their application, and, therefore, compatibility with existing and new buildings without any further technical development. Closed loop active solar heating systems are assembled, operated and maintained in much the same way hydronic boiler systems are, making them compatible with the skills of our existing hydronic installers.

Solar Heating Opportunity

Hundreds of thousands of hot water boilers are installed in the U.S. every year.

Even if only a small fraction of them could easily benefit from supplemental solar hydronic heat collectors, that still represents thousands of solar thermal installations each year. Also, the backlog of hydronic heating systems installed over the past 20 years represents an enormous opportunity for practical solar thermal retrofits. Clearly, millions of homes and other buildings use hydronic (hot water) heating systems that could benefit from the fuel offset that solar heating can easily provide.

Typical Solar Heating Design Thought Process

Anytime someone starts thinking about adding solar heat collectors to a small building project, the thought process invariably proceeds along the same lines. First, he thinks about a solar water heater with one or two collectors. Next, he wonders if some of that heat could be connected to the floors or to other space heating jobs. If so, then maybe a few more collectors would be worthwhile. Finally, he wonders how hard it would be to hook up some other heating jobs to get additional benefit from larger collectors. The design process can be surprisingly predictable and typically includes the following items:

- Solar collectors;
- Solar hot water tanks;
- Solar heated floors;
- Hot water baseboards or radiators;
- Hydronic boiler (conventional fuel or other on-demand heat sources); and
- Intermittent heat sources like a wood burner or waste heat from an electric generator.

Then, we need to answer some questions:

- Can we connect them all together?
- Can we send extra heat to: the pool, spa, ice melt, hot air fan coils, etc.?
- Do we need big water tanks for heat storage?
- How do we control solar overheating?

Every new choice represents a change in the design, different piping connections, additional components, various temperature requirements and different controls.

Solar Combisystem Dilemma

Multiple heat sources and multiple heating loads can be connected in a bewildering variety of different ways. In our region (Northern New Mexico), the most typical solar-hydronic combisystem includes:

- A solar heat collector array;
- A gas or propane hydronic boiler;
- A domestic water heater with in-tank heat exchanger; and
- A radiant heated floor typically divided into several heating zones.

I call this application "Solar Combisystem 101" because these basic features have been duplicated so many times for small buildings in recent years.[1] This includes only four items, two heat sources and two heat loads. Yet, if you present these requirements to three different heating equipment suppliers, you will likely get three different piping and wiring plans with tees, motorized valves and pumps in different locations, as well as some often cryptic control strategies (or none at all), which will complete the confusion.

This is what happened in the unfortunate installation seen in *Photo 2a*. Several equipment suppliers and three different installers made a valiant attempt to install a Combi 101 system in a small residence in Santa Fe, N.M. Each supplier had its own idea about plumbing connections and controls, and each installer eventually gave up in confusion. The result was an unfinished heating system, and the plumbing nightmare seen in the photo.

Proper design and control can be a daunting challenge to any mechanical installer. The makers and suppliers of the components, to their credit, have put a lot of thought into all the different ways their equipment might be installed, and generally provide plenty of choices, suggestions and alternatives so as not to limit the installer. But, all these choices can (and do) serve as barriers to rapid and reliable deployment of solar thermal combisystems. Each alternative plumbing configuration represents a slightly different operating sequence (and a different control strategy to go with it) that the installer must understand explicitly if it is to start-up and operate successfully over the long term.

Solution by Design

Let's pause for a moment to reflect on what we are ideally trying to accomplish with a combisystem piping configuration.

We have multiple heat sources feeding multiple heat loads. Some of the heat sources are only available intermittently, but those are typically the most desirable with the lowest fuel cost. Not all the heating loads require the same temperature, and some have intrinsic heat storage capacity. Water heat-storage tanks can act both as heat sources and heat loads, so the piping configuration needs to allow for this.

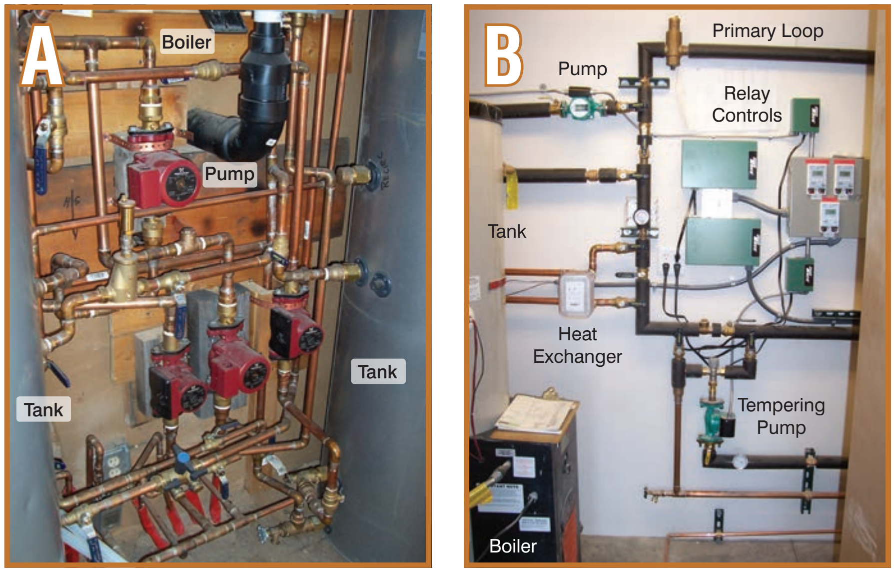

Photo 2a (left): The dilemma: chaos. **Photo 2b (right):** The solution: elegance.

We want to deliver solar heat to any job that needs heat, giving it top priority whenever it is available because of the lower fuel cost. If solar heat is used directly (instead of stored) as soon as it arrives, the delivered solar thermal efficiency is maximized when the energy loss associated with heat storage, extra pumping and multiple heat exchangers is eliminated. The same capability is needed for any other intermittent source of heat when they are connected.

So, a piping configuration is needed that allows any heat source to connect to any heat load whenever the temperature is useful, and allow heat to bypass any heating load when the temperature is not a proper match or it is not needed.

Also, we need a piping configuration that can be modified easily, so that heat sources and heat loads can be added or deleted more easily in a standard way so installers can plug and play solar heat, storage tanks, or other equipment without a major redesign.

It may seem like a tall order to meet all these requirements in a single standard piping configuration, but one solution stands out, having been in popular use for decades. The primary loop configuration has been more popular in commercial buildings than in residential in the past, but it can be applied to solar combisystems as well. After many solar combi installations in small commercial and residential buildings, the primary loop approach seems to fill the bill nicely. A system can be seen just like this in *Photo 2b*, which is located inside the residence in *Photo 1b*. It is a Combi 101 primary loop configuration that performs exactly the same functions as the system in *Photo 2a* was supposed to do.

Primary Loop "Flow Center" Concept

To connect all heating sources to all heating loads, a flow center is needed to allow the supply and return fluid from all the circulator pumps to join together without interfering with one another. This can be accomplished with primary/secondary piping using closely spaced tees to attach the secondary loops, which plug into the primary loop with a two-pipe connection.

Figure 1 illustrates this concept as it applies to a small solar heating system. This diagram is typical of many smaller solar-heated homes in Northern New Mexico, where the glycol boiler fluid circulates in a pressurized, closed system, directly from the solar collectors into the floors, the boiler, and other heating equipment. This eliminates the need for a primary heat exchanger (separating the outdoor fluid from the indoor fluid), which lowers the cost of these small installations, and improves the solar thermal system efficiency. Solar-direct glycol systems are typically used on smaller projects of less than 2,000 ft^2 (186 m^2).

Notice that the piping transition from copper to the PEX in the floor always includes a thermal tempering valve to protect the plastic tubing from possible solar overheat. Notice also, that if the solar collectors are sized, mounted and controlled properly with respect for the heat storage capacity of the radiant mass floor and the water heater tank, no other heat-storage water tanks are needed. There are many systems like this installed in our region that employ only the domestic hot water (DHW) tank and the mass of the floors for heat storage.

Temperature Sequencing

Heat sources should be sequenced along the primary loop in order of increasing temperature production, and heat loads are placed in order of declining temperature requirements. This is important in any simple primary loop because the cool return fluid mixes with the hot supply fluid at every secondary connection that has flow. So, for example, the DHW gets higher temperature heat before continuing around the loop to the radiant mass floor. The tees for a baseboard secondary would be

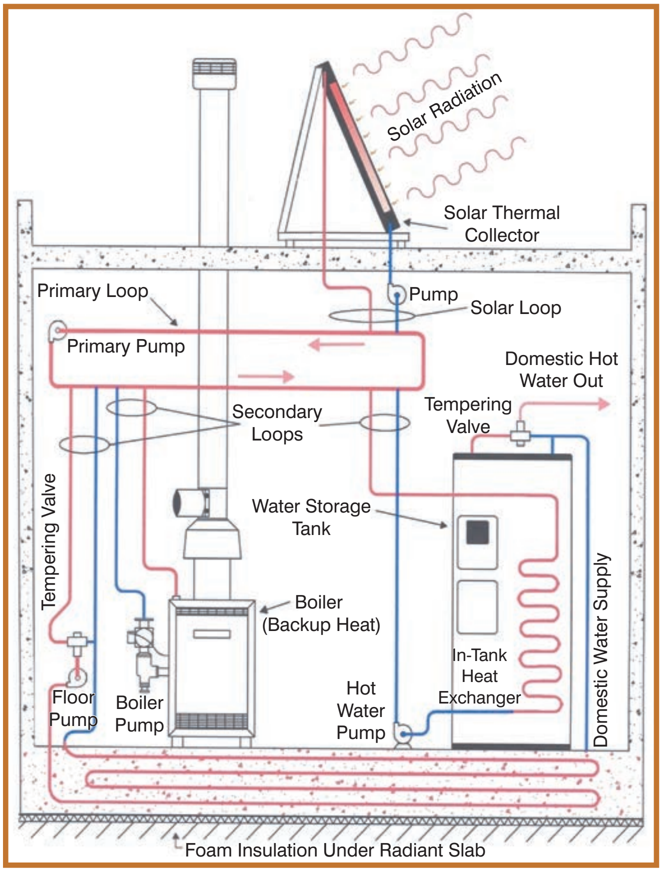

Figure 1: Primary loop flow center.

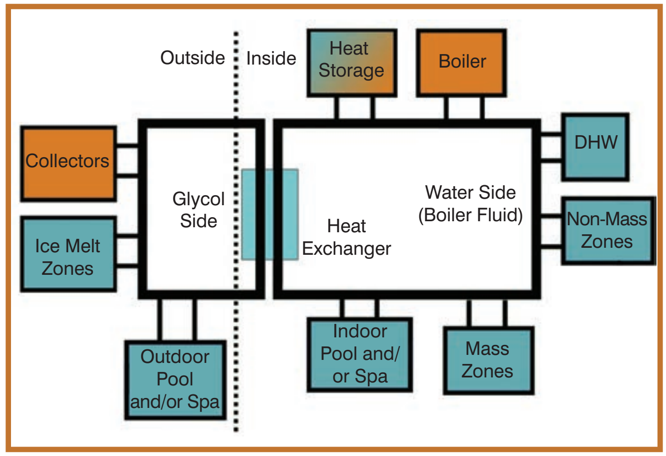

Figure 2: Dual primary loop system block diagram.

placed before the radiant floor tees, and swimming pool heat should be taken after the radiant floor connection.

Dual Primary Loop Heat Exchanger System

Figure 2 shows a block diagram of what has become our standard plumbing configuration for solar combisystems in recent years. It provides all the pipe connections to deliver comprehensive solar hydronic heating to even our larger building projects and solar retrofits (typically up to 10,000 ft^2 [929 m^2]). The piping connections are divided into the outdoor components using glycol, and the indoor components using water as boiler fluid. A primary heat exchanger provides a thermal pathway to deliver heat into or out of the building as required by the control system. The proper thermal sequencing is shown on the diagram in the order that the components are placed around the primary loop. In projects where some of the components are not included, or will be added later, the tees can be included, deleted or capped to match the needs of the job.

Primary Loop Configuration Provides Plug & Play Design

The piping configuration seen in *Figure 2* provides everything on our wish list mentioned earlier. Any heat source may be connected to any load or bypassed easily by the control system by simply turning secondary circulators (and zone valves) on or off. Any heating component can provide direct heat, preheat or no heat to any other device mounted on the primary loop.

Each component can be added or deleted, during initial installation or at any time in the future using a two-pipe connection to the primary loop. Modular pump stations can be used with this two-pipe standard to speed up assembly on the job. Using this modular configuration for pipe connections also allows for modular controls. Both the components and the controls can then plug and play together.

Solar Heat Storage in Masonry Floors

Direct active solar heating of masonry warm floors has been done in our region dating back at least to the 1950s.[2] This technique has enjoyed renewed popularity in recent years, thanks to the widespread use of PEX tubing in concrete radiant heated floors. The idea is to pump heat directly from a solar heat collector into the heat storage capacity of a masonry floor. The floor warms up slowly and stays warm well into the evening on cold sunny days. The challenge is to size the collectors and tilt them so that the floor is provided with a quantity of heat that does not cause overheating at any time of the year. This has a lot to do with the specific heat storage capacity of the masonry material in the floor, which has about one-half to one-third of the heat storage capacity of the same volume of water.

Fortunately, there is an enormous volume in the radiant mass floors in a typical home construction, capable of storing about five times as much heat as a properly sized heat-storage water tank system. Another way of saying this is that the masonry warm floors will operate with temperature fluctuations about five times lower than a typical water tank heat-storage system (when solar heated directly using common design strategies). This puts the floor temperature within the range of human comfort, and the lower temperatures result in lower rates of heat loss and higher thermal efficiency. This temperature performance has been observed and confirmed in many field installations. By some estimates, a 25% bonus can be realized in fuel savings by bypassing the storage tanks and heat exchangers whenever possible.

If you take this into account and control the heat in the floor within the comfort range, you realize that you can often elimi-

nate the need for large additional heat-storage water tanks that have been the backbone of big solar heating systems past and present. The floor acts as the solar accumulator instead of the more traditional, costly and complex water tank systems. The floor had to be there anyway, so does not contribute much to the added cost of solar equipment.

In our climate, a well-insulated mass floor can be heated with about 10% to 15% of the floor area in collectors, and the collectors work quite well for winter heating when mounted vertically on a south facing wall as seen in *Photo 1b*. The low winter sun angle provides maximum solar heat to a vertical collector during the cold season. In *Photo 1b*, the roof overhang was designed to partially shade the collectors in summer when all the solar heat is not needed. The collectors can be tilted more toward vertical if heat is not needed in summer, because the high summer sun angle inhibits the collectors from gaining heat. They can be tilted back more if there is a big water heater load or a heated swimming pool.

Two-Stage Room Thermostats

In a typical solar combisystem, we use two-stage room thermostats to allow the solar heat to provide a slightly higher setpoint than the boiler heat in rooms having heat storage in the floors.[4] And we use the primary loop and the existing zone valves to send the solar heat to where ever it is needed most (e.g., the cooler rooms first). Solar heat is delivered to the thermal mass of the floor until the room temperature reaches the limit of the upper differential temperature range. By raising the temperature of a masonry floor just 1°F (0.6°C), we have stored thousands of Btus (Joules) in the thermal mass, which will radiate into the room over a period of many hours, delaying the boiler from turning on.

In this way we are putting the thermal flywheel effect of the mass floor to good use, by prolonging the delivery of solar heat well into the evening. The backup boiler will not fire until the room thermostat drops all the way through its entire differential range and the second stage low limit is triggered.

Solar Combisystem Control, From Relays to Software

In the final analysis, the high efficiencies, fuel savings, comfort temperatures, and all other potential benefits of a solar combisystem cannot be accomplished without reliable and effective controls. Even if all the right equipment is installed and all the piping is correct, there will be no solar savings unless the control system shuts off the boiler and turns on the right pumps and valves in the correct sequence. The building must act much like a hybrid car, sensing when to choose one fuel over another, with consistent, reliable and logical precision.

The most common way this is done, even today, is to use thermostats, setpoint and differential controls that sense temperature changes that activate a relay in response. Each relay can turn a pump or other device on or off. Controls such as this can be seen in *Photo 2b* with temperature controls and green relay boxes strung together in a specific arrangement of wiring.[5] The thermostats are usually digital and have useful programmable functions for tuning the heating performance. But much of the programming of the whole system and the switching logic is in the wiring.

In our most recent solar combisystem installations, the old temperature-actuated relays have been replaced with sensors and computer software. This has proven to deliver a much higher level of control, communication and intelligent logic that was not possible with the hard-wired relays.[6]

For a detailed discussion of the proper control of these systems and the benefits of using software instead of hardware, see the companion article by Fred Milder, "Advantages of Integrated Control in Solar Combisystems."

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