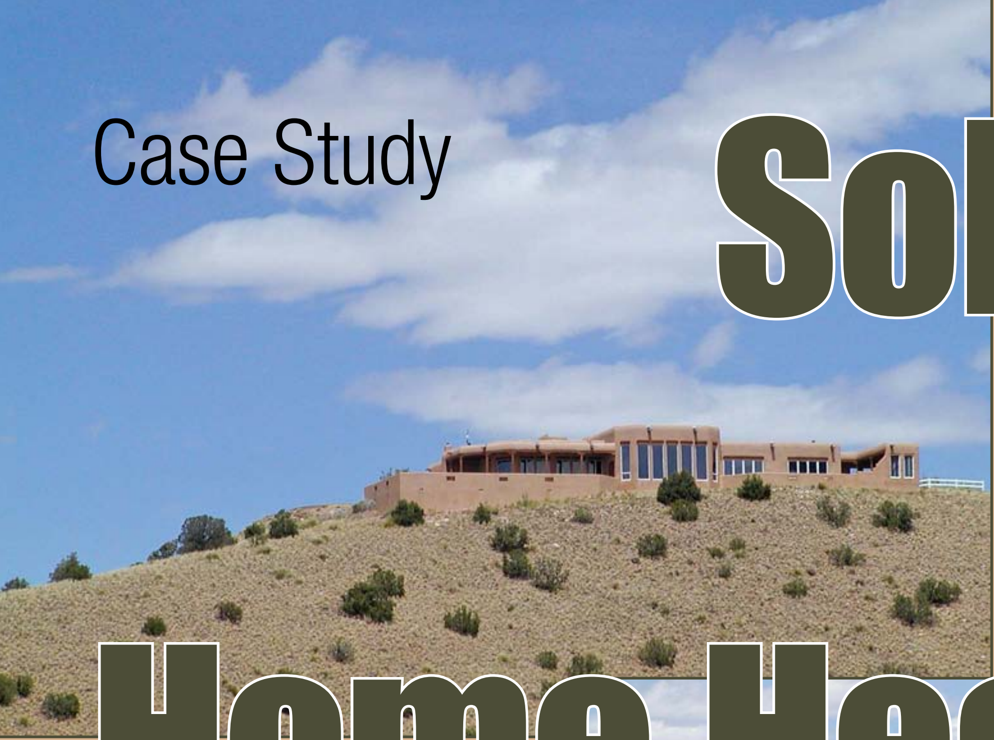
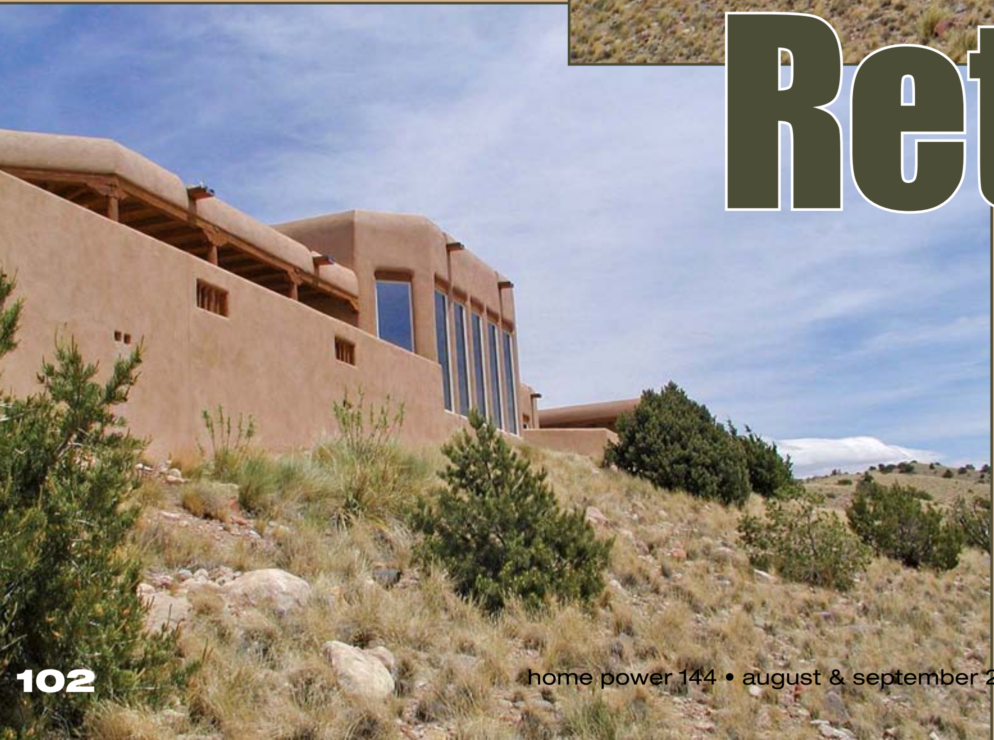
Case Study

Solar Home Heating Retrofit



Bristol Stickney



Courtesy Jeff Stampfer/Eldorado Solar (2)

by Bristol L. Stickney

In June 2009, my former company, Cedar Mountain Solar, began designing a solar heating retrofit for a residence in the foothills in Placitas, New Mexico, near Albuquerque. This house has approximately 5,000 square feet of living space, which was heated by a propane boiler and a hydronic system embedded in the concrete floors. The building is well-constructed, with good heat retention. It is in a high altitude mountain climate where freezing temperatures and snowstorms are common in winter.

This solar heating retrofit is typical of what I call "Combi 101," which includes several specific heating system functions (connected with a primary loop): solar heat in combination with a boiler, a domestic water heater (DHW), and radiant-heated floors throughout the house.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Solar thermal collectors provide the majority of domestic hot water and space heating for this Southwestern home.

By October 2009, 12 SHW collectors had been installed on the roof and the heating system was converted into a solar "combisystem," with all of the heat sources connected to all of the heat loads. Even though much of the roof is covered with solar collectors, they are mounted in low-profile to reduce their visual impact. The system has been showing good fuel savings for two heating seasons to date. Heating fuel consumption has been reduced by more than half, with the savings estimated at more than $3,000 per year.

What's a Combisystem?

The idea of adding solar collectors to a home often proceeds along the same lines: First, homeowners consider a solar water heater with one or two collectors for domestic water heating. Then, they may consider adding heating to a chilly room—maybe more collectors would be worthwhile. Then they consider hydronic baseboards or make connections to heat other rooms. Then, they wonder about solar heating the spa or pool, an ice-melt zone, or some future addition.

Thermal Mass in Hydronic Floors

Thermal mass is any dense material used to store heat—water and masonry are the most common. In passive solar houses, for example, interior masonry walls and floors store solar heat gained through south-facing windows.

This solar heat-storage can also use active solar hydronic collectors to feed heat directly into hydronic tubing embedded in masonry floors. Under proper control, the floors warm by day and discharge heat by night—to keep the home within the comfort range, thereby delaying or preventing the backup boiler from operating. It helps when the floors are well-insulated, both around the perimeter and underneath, to slow heat loss into the ground.

Common slab-on-grade radiant floor construction practices will work quite well as solar heat-storage floors. But they should be insulated underneath, between the warm concrete and the ground. Two to 3 inches of waterproof rigid insulation ("blue board") is reasonable for improved heat storage, but more than 3 inches is probably overkill. Common slab thickness of around 4 inches works very well, and up to 8 inches is reasonable for extra heat storage. While thicker slabs will store more heat, they will operate at lower temperatures (possibly below the range for human comfort) and have a longer lag time.

Placing the tubing in the center of the slab usually works well. In Southwestern climates, that means spacing the PEX tubing typically 8 to 12 inches apart, and locating it near the center or below the center of the concrete with an approximate 4-inch thickness.

This is also used for solar heating in concrete swimming pools and spa tubs. When hydronic tubing is embedded in the floors and walls of a concrete pool, solar heat can be delivered in a controlled way, independent of the filter pump system.

In the Southwest, large heat-storage water tanks are only necessary when hot water baseboards or fan coils require it—but not when the house has hydronically heated masonry floors. Typical slab floors contain a tremendous amount of heat storage capacity—up to five times as much as a properly sized water storage tank. When the solar heat is delivered directly to the floor, the heat loss associated with the water storage tank and its pipes and heat exchangers is eliminated. This results in about 25% more solar heating available on a typical winter day. This makes the most efficient use of the heat provided by the solar collectors, which can be sized slightly smaller.

The home's thermal mass floors are ideal for heat storage and temperature regulation.


Courtesy Jeff Stampfer

When multiple sources of heat are connected to multiple heating jobs, we call them combisystems, since it is a single heating system made up of a combination of different kinds of equipment. When one of the heat sources is solar heat, we call it a "solar combisystem."

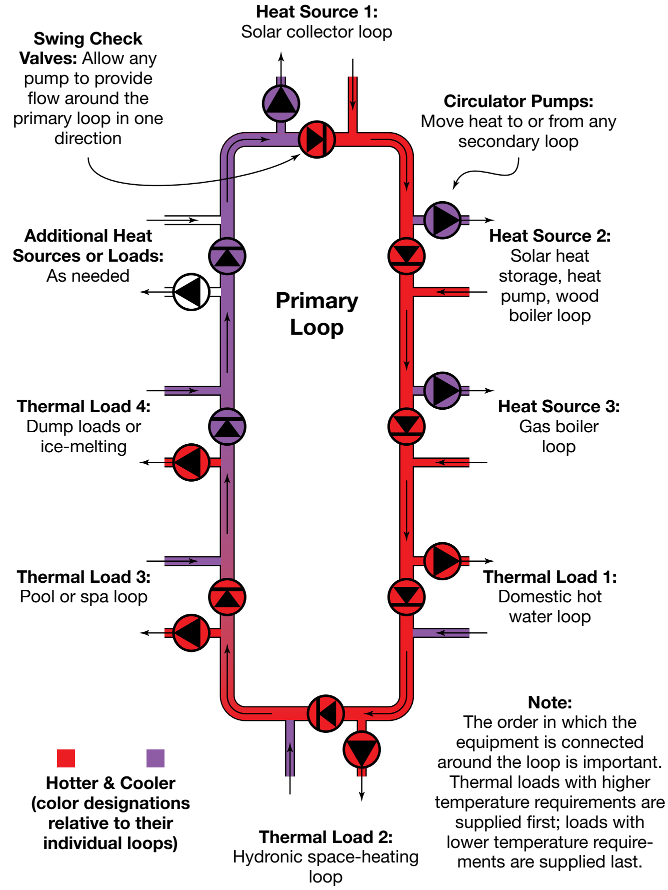
System Details

Multiple heat sources and heating loads can be connected in many ways. In the Southwest, the most typical solar-hydronic combisystem includes solar collectors, a gas boiler backup, a domestic water heater, and a hydronic floor. This most basic variant includes only four items: two heat sources and two heat loads. Yet, if you present these requirements to three different solar heating suppliers, you will get three very different designs with heat exchangers, water tanks, tees, motorized valves, and pumps in different locations—and some often cryptic control strategies (or none at all) to complete the confusion. Adding features or changing the heating system requires a redesign with different piping connections, different components, different temperatures, and different controls.

After going through this same design process with many different projects, I decided to standardize the design, making it easier to add, remove, and change components. The key is to make the system modular so that things can be added or removed as the project develops, without requiring re-engineering. I began building all my designs around a "flow center" where all the circulation pumps plug into a "primary loop" with two pipe connections, which can just as easily be unplugged. Making such major alterations with such simplicity is actually a minor revolution for water-heating systems.

The primary loop using closely spaced tees has been popular in commercial buildings for decades, and has proven its worth in residential systems. The schematic shows the basic configuration for both simple and larger systems. This system allows extending the primary loop through attic or crawl spaces to remote areas of a building to pick up or deliver heat from other mechanical rooms—especially useful in many retrofit situations when combining existing and remote heating equipment under one control system. It also allows expansion for additional heating sources and jobs by adding additional double-tee connection points.

Basic Solar Combisystem Primary Loop Flow Center



The combisystem may look complex, but to a professional, it's a simple combination of independent source and load loops.

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Solar Heating without Large Tanks

Solar hydronic heating systems are commonly designed as if they are very large solar water heaters. Several solar collectors are connected to large heat-storage tanks, and all of the solar heat is put into the water tanks, and then drawn out to meet heating needs.

Courtesy Jeff Stampfer

The domestic hot water tank does not have a heat source, but heats through internal exchangers from the primary loop and directly from the backup boiler.

A Triangle Tube propane boiler makes up for what the solar collectors don't supply.

Top: The Caleffi 2+2 flow control acts receives and distributes heat from multiple sources.

Bottom: Expansion tanks allow fluids to expand as they heat.

But most (or all) large heat-storage tanks can be eliminated when the heat distribution is from radiant-heated masonry floors (see "Thermal Mass in Hydronic Floors" sidebar). High thermal storage in the existing concrete floors allowed a relatively large solar heating system without any additional heat-storage tanks, except for a single 115-gallon domestic hot water (DHW) tank.

The Details

Temperature regulation. Because the thermal mass of a concrete slab is so large, its temperature can be easily regulated within the range for human comfort. The room temperature can be allowed to drift as much as 8°F from day to night while staying reasonably comfortable. However, comfort range is a personal preference and therefore needs to be controllable room-by-room.

The easiest way to do this, especially in retrofits, is to replace each room's single-stage thermostat with a two-stage thermostat. As the temperature drops, the first stage calls for heat, but it only delivers solar heat when solar is available. If the room temperature continues to drop, the second stage will then call for heat, which causes the backup boiler to fire (along with solar preheating from storage tanks, if available). The advantage of individual room heat controls is that, for some rooms, a wider daily temperature swing can be tolerated, and this will result in higher heating savings in those rooms.

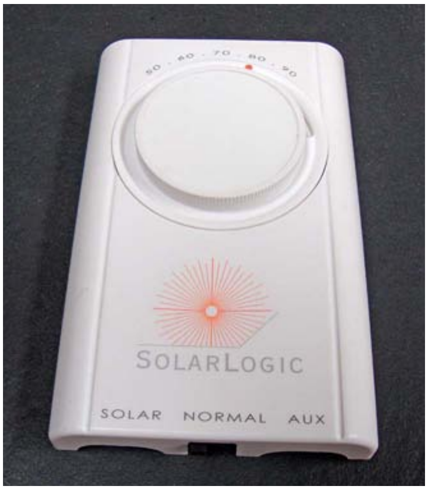
Two-stage thermostats are adjustable in many ways, and the owner or installer can choose an allowable temperature swing and a low limit to suit the comfort needs of the occupants, zone by zone, to achieve the necessary balance between comfort and energy savings. The room temperatures can be adjusted to drift up and down as little as 1°F or as much as 8°F, depending on how the room is used. The more the room temperature is allowed to drift, the more solar heat is stored and released in the mass floor, resulting in more fuel savings.

If the first stage of a room thermostat has not kicked on, the system sends the solar heat to any other room where stage one *is* activated. If none of the rooms require stage one heating, then the heat is sent to the water heater, water storage, or pool. If the water from the solar collectors is hot but there's no use for it, then the heat dissipation cycle is activated (see below).

The key to success with this approach is the substitution of more intelligent controls in place of large water tanks. If done effectively, this can lower the cost of a solar heating installation, while improving the solar thermal system's efficiency. In our Placitas retrofit, there are eight room thermostats, and all of them include two-stage switching (solar first; boiler second) and programmable temperature swing capability.

For the Placitas system, a hydraulic separator—a "flow center" device that eliminates the need for a primary loop—was used instead of a Combi 101-style primary loop. These devices can be purchased from various plumbing equipment manufacturers. They provide a large, open container that is filled with "boiler fluid" and receives the heat and then provides heat to the other equipment. The Caleffi Hydrolink eliminated the need to assemble a primary loop piece by piece. As seen in the piping diagram, a primary loop consists of tees, valves, elbows and connective piping. A prefabricated hydraulic separator comes from the manufacturer with many of these parts built in.

The Hydrolink 2+2 model was configured to provide the same heating functions and advantages of a primary loop system. The result is a piping system that resembles a Combi 101 system with very compact central piping, incorporating a substantial number of collectors (12) and heating zones (8).



Courtesy SolarLogic

Two-stage thermostats allow custom tuning of the zones to optimize the solar versus boiler heat balance.

System Control & Monitoring

This retrofit's controls were originally designed with common equipment such as conventional room thermostats, mechanical relays for switching pumps and zone valves using several differential thermostats, and set-point temperature controls. This is the conventional way solar/boiler heating systems have been controlled. For the Placitas retrofit, the technically proficient owner was willing to test a control system that included a solar logic integrated control (SLIC)—a computer- and Web-based control of our own design.

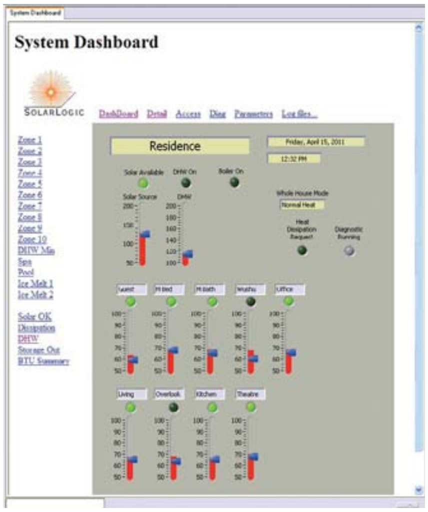
The SLIC control system replaces all of the relays and temperature controls with a single box. It is easy to operate using familiar room thermostats and allows both the installers and the owners to monitor and record the heating system's performance and data, and adjust settings locally or remotely over the Internet. This is great for fine-tuning the balance between comfort and efficiency.

The fuel efficiency and comfort provided by a solar combisystem is only as good as the control system. There are many ways to save energy through the control system. Features that are not needed are simply turned off at the time of installation. The internal software controls have many functions, such as solar-only and backup-only settings, heat dissipation, and room target-temperature control, plus many other settings subtle and not so subtle that affect system performance and monitoring.

Fuel-Saving Strategies for Heating

Each 4- by 10-foot collector can produce enough heat to offset up to 0.5 gallons of propane per day. But the savings are not entirely from solar heat gain—other factors include a high-efficiency condensing boiler and heat-saving control strategies. Solar priority over the boiler is guaranteed both by the piping configuration and the control logic. Solar heat for the floors has an adjustable priority over heat storage in the water tank, and is controlled by the SLIC using virtual two-stage room thermostats. (The room thermostats transmit the room temperature and the user's setpoints to the central control, which implements the two-stage functions.)

Heat storage is also optimized in the DHW tank and DHW recirculator by software control. The SLIC controller is programmed to save heating fuel in every way possible, such as stranded heat recovery—routing hot fluid left in the pipes after a heating cycle is completed to a water-heater tank



Courtesy SolarLogic

The solar home-heating system's "dashboard" shows vital system information and allows changing the settings to tweak system performance.

Overview

System type: Closed-loop antifreeze SHW with single heat exchanger feeding hot water flow center. Solar combisystem provides both space heating and domestic hot water

Location: Placitas, New Mexico

Solar resource: 6.7 average daily peak sun-hours

Production: 9,333 kBtu per month, average

Domestic hot water produced annually: 91%

Hot water (boiler fluid) produced annually: 60% fuel savings

Solar Equipment

Collectors: 12 Solar Skies SS-40 , 480 sq. ft. nominal area

Collector installation: Low-profile, roof-mounted at a 75° tilt

Heat-transfer fluid: 50/50 propylene glycol/water

Circulation pumps: 2 Laing D5

Pump power supply: 2 BP350J 50 W PV modules (one for each D5 pump)

Storage

Domestic hot water storage tanks: Oventrop 115-gal., dual-coil, in-tank heat exchangers

Heat exchanger: Triangle Tube TTP3-40 flat-plate

Backup DHW: No other tanks installed. Boiler backup for Oventrop tank

Performance Monitoring

Dial thermometer: 3 probe-type, in brass wells

Pressure & temperature dial gauge: 2 generic P&T gauges in brass wells

Data logging, diagnostic & control package: Solar Logic Integrated Control (SLIC) Gen1 (The SLIC controller monitors and operates all sensors, pumps, and valves)

Room sensors: 10 standard 10 kOhm thermistors in thermostats

System sensors: 6 standard 10 kOhm thermistors on heat system piping and tank

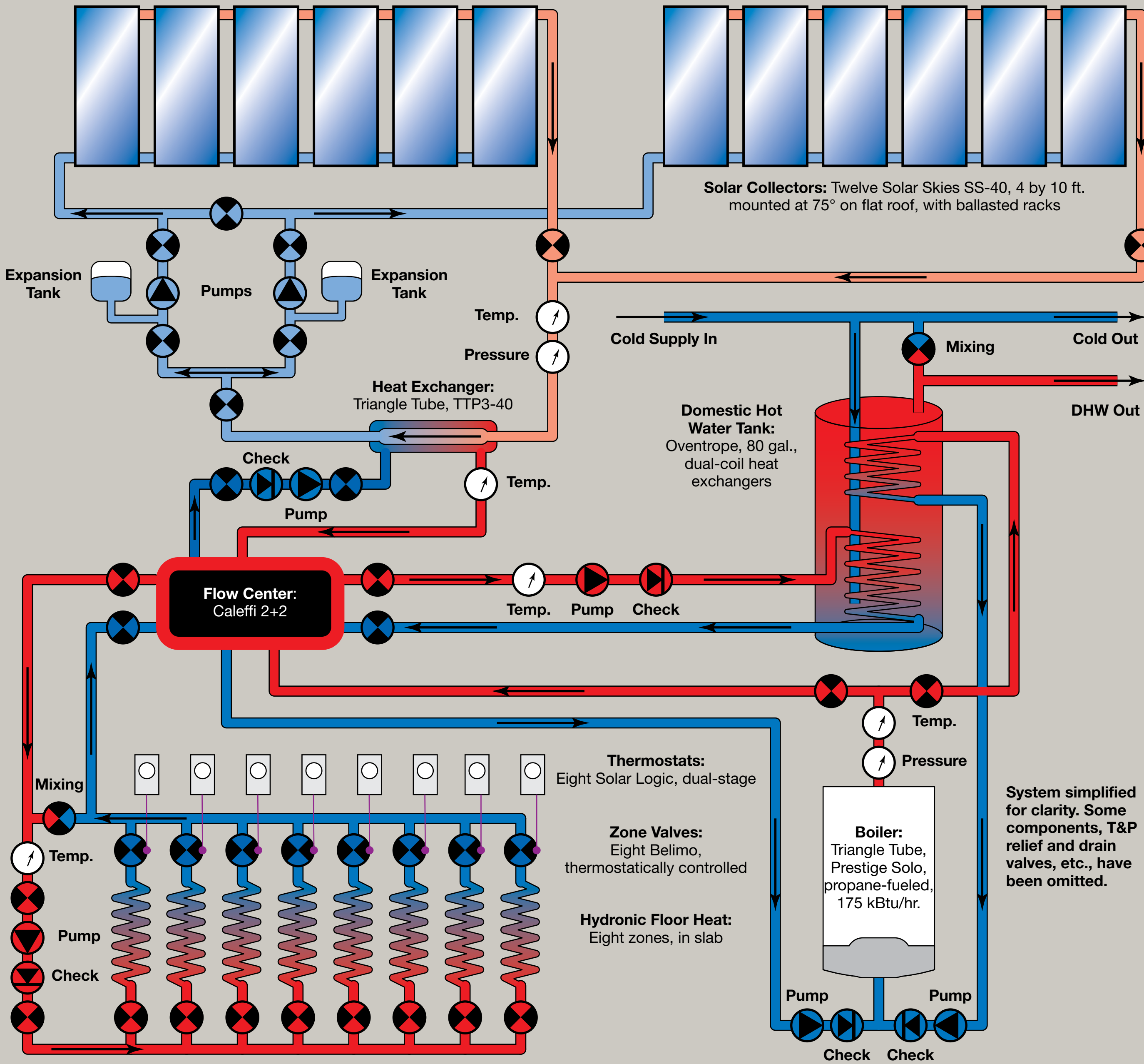
Radiant Floor System

Floor tubing: Wirsbo (Uponor) 1/2-inch HePEX

Boiler: Triangle Tube Prestige Solo (LP); 175 kBtu/hr.

Length of tubing: 5,000 ft.

Placitas Solar Combisystem Retrofit



Number of zones: 8

Circulation pump: 5 Grundfos UPS15-58 (three-speed)

Pump Controller: SLIC Gen1 operates all circulator pumps

Zone valves: 8 Belimo 3/4 in., latching valves, 24 VDC, LRB24-3-S

Tempering valve: Honeywell 1 in., AM102R-US-1; set to between 70°F and 180°F

Auxiliary Heat Source(s) to Solar Storage

Source: Same boiler used for zone heat (listed above) is used for DHW backup

Circulation pump: Listed previously; one of five circulators, all identical

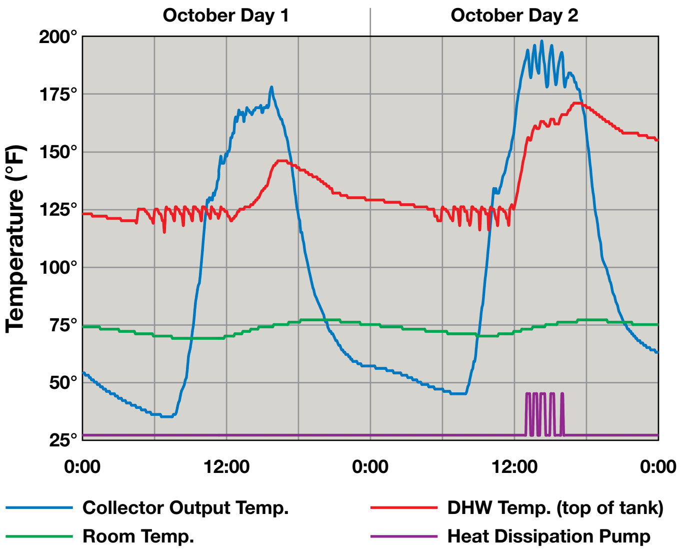
Pump controller: SLIC Gen1 operates all pumps

Other Equipment

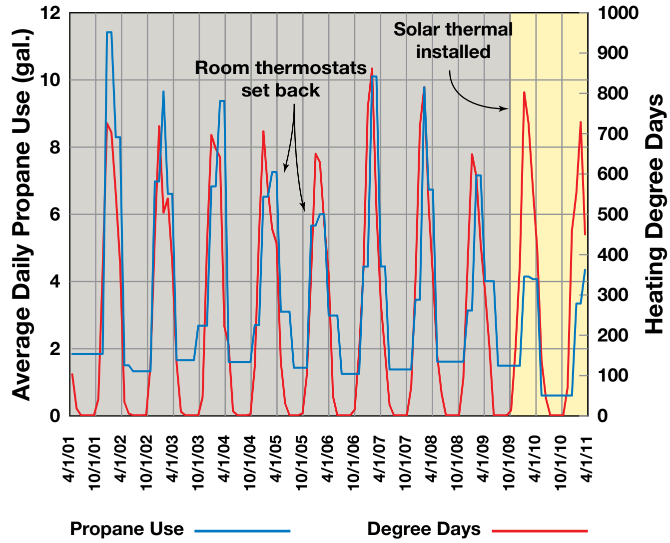
Overtemperature dump valve: All zone valves and all circulators listed previously can be used by the SLIC control system to dissipate extra heat into the concrete floors by day and through the solar collectors by night

Overtemperature dump-valve controller: Heat dissipation is controlled by the SLIC Gen1

Example Combisystem Performance



Propane Use vs. Heating Degree Days



or some other useful load—and intelligent priority control based on temperatures and critical loads.

Past and current performance can be reviewed and analyzed at any time. The graph shows an example from two days in October 2009. On Day 1, the room temperature is kept within a comfortable range, and the solar heat is diverted to the water tank after the room warms up in the morning. On Day 2, the weather is even warmer and sunnier, so the room warms up, the water heat gets very hot, and the intelligent heat dissipation kicks in to cool the collectors all afternoon, typically routing heat to the concrete floor in the garage. This verifies that the control system is set correctly; data like this can be viewed at the house or remotely at any time.

Electricity-Saving Strategies

The opportunities for saving electricity in a heating system are sometimes small but worth considering. In this system, circulator pumps are disabled when they are not needed. Multispeed circulators are used and set to the lowest speed that is effective for each job. The number of transformers are limited to eliminate their "phantom load." "Latching" zone valves are used, which only require power when they change their state. There is no "primary pump"—all circulation through the flow center is provided by the secondary pumps that are smaller and thus require less energy. Solar circulation for collectors using closed glycol loops is achieved with very small pumps that were energized by PV power.

Overheating Control

The SLIC controller is programmed to prevent solar overheating and to maintain safe high limits and comfortable temperatures. Keeping the collectors below 230°F prevents the propylene glycol from breaking down and becoming acidic, corroding the pipes over time.

When the solar heat is not needed and the collector temperature approaches 200°F, several mass floor zones are opened automatically to cool the collectors by 5°F or so. The cooling cycle only takes a few minutes and does not typically contribute any noticeable heat to the floor. (See the graph on day 2 when the cooling cycle occurs five times.) It is most common to use a garage floor, outdoor ice-melt zone, or swimming pool as heat sinks.

When heat in the house is not wanted, the flat-plate solar collectors are used to radiate heat to the night sky. The DHW tank is used as a heat accumulator by day, and can be cooled through the solar collectors by night. This can be very useful when the house is unoccupied and hot water is accumulating in the storage tank. The floors in the warmest rooms in summer can be cooled by night circulation through the collectors as well.

Final Analysis

The homeowner carefully recorded heating fuel consumption, both before and after the solar heating retrofit. Between 2004 and 2006, some fuel savings came from using thermostat setbacks with the old boiler. But, because some of the rooms became uncomfortably cold, the thermostats were raised to around 65°F between 2006 and 2009.

The owner's analysis of this data includes some interesting highlights. Propane use has been reduced from about 2 to 3 heating degree-days (HDD) per gallon before the retrofit to about 5 to 7 HDD per gallon after the retrofit. For HDD determinations, an outdoor baseline temperature is established (65°F) where it is assumed that no space heating is used. Whenever the outdoor temperature drops below this baseline, it is assumed that the house will need some heat. If the average outdoor temperature drops 1°F (to 64°F) for 24 hours, that condition is defined as "1 HDD." If you know how cold it is in HDDs over a given period of time, and you know how much fuel you used (e.g., in gallons), then you can calculate gallons per HDD, or the inverse: HDD/

gallon. This is a good way to compare the fuel efficiency of your house over any period of time, much the same way automobiles are compared using mpg.

For domestic hot water, propane use is down to an average of 0.6 gallons a day versus 1.5 gallons per day previously. This past winter, the house netted 273 to 375 kBtu per day of solar heat (80 to 110 kWh per day). Annual propane consumption has dropped by about two-thirds, saving about 1,300 gallons a year. At current local prices, this translates into saving $3,000 per year. The total cost of the retrofit was $57,315. After state and federal tax credits totalling $21,459, the net system cost was $35,856, resulting in a simple return on investment of 10 years.

Access

Bristol Stickney has been designing, manufacturing, repairing, and installing solar hydronic heating systems for more than 30 years. He holds a B.S. in mechanical engineering and is a licensed mechanical contractor in New Mexico. He holds several patents related to solar/hydronic heating and control and is the Chief Technical Officer for SolarLogic, where he develops solar heating control systems and design tools.