Solar Solutions

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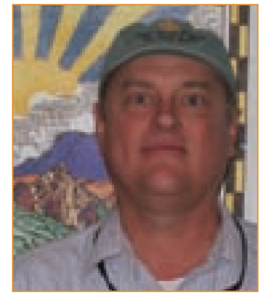

Bristol's six principles of good solar hydronic design

Thermal mass for space heating – water vs. concrete

In this series of articles, I have been making the case that the key ingredients for solar/hydronic design and installation can be divided into six categories, listed below, roughly in order of their importance.

1. RELIABILITY
2. EFFECTIVENESS
3. COMPATIBILITY
4. ELEGANCE
5. SERVICEABILITY
6. EFFICIENCY

The success of any solar hydronic home heating installation depends on the often-conflicting balance between any of these six principles. Finding the balance between them defines the art of solar heating design.

In previous columns I have mentioned thermal mass and its application in solar hydronic heating systems many times. Thermal mass is any dense material that is used to store heat. Water and masonry materials are the most common. It has long been standard practice in the solar heating industry to store all the solar heat in insulated water tanks before sending it out in response to a call for space heat. In our region we have found that large heat-storage water tanks are only necessary when hot water baseboards or fan coils require it but not when the house is all-mass-floor hydronic heat. Insulated hydronic slab floors contain a tremendous amount of heat storage capacity, and when controlled properly this can reduce or eliminate the need for water tank solar heat-storage. Fewer tanks mean simpler plumbing, simpler controls and a lower cost solar heating installation.

Because water has a higher heat storage capacity than concrete, but has a lower density, while the concrete is often available in a much higher volume, the comparison between the two heat storage systems is not obvious. It is no wonder that people have trouble visualizing how much heat is involved and at what temperatures. Let's look at the difference in performance of direct solar heated concrete compared to the more common solar heated water tanks by comparing two hypothetical heating systems in our climate (Santa Fe, N.M.).

The following simplified analysis is intended to establish the general magnitude of the solar heat storage effects to allow the reader to get a realistic feeling for the amount of heating energy involved. I round off the numbers and make assumptions based on my own experience in order to get us into the "ballpark" for a reasonable comparison.

Please review the previous columns in the *Plumbing Engineer.com* archives for more details regarding the many other factors that make up a complete solar heating design.

Water and concrete by the numbers

A good snapshot of these two heat-storage systems must include the storage capacity as well as the heat loss from the different configurations. The storage capacity is defined by the specific heat capacity and the density of the heat storage material. The heat loss is driven by the temperature difference between the warm mass material and the environment, the insulating value, and the surface area. Table 15-1 lists a summary of the key conditions needed to make a comparison.

Continued on page 34

Table 15-1Physical Properties and Conditions Assumed for Comparison

Property	Water	Concrete	Units	Comments
Specific Heat Capacity	1.0	0.2	Btu/lb.-F	Heat stored in one pound when the temperature rises 1 degree F.
Density	62	120	Lb./cubic ft.	Weight per unit volume. Water is 8.3 lb./gallon.
Earth Temp.	50	50	F degrees	Earth temperature 6 feet below the house is similar to the average annual temperature.
Heat Load	7	7	Btu/square foot floor	Average hourly heat load on a cold day in a well-constructed house.
R Value	15	15	Ft2-F-Hr./Btu	Insulation value surrounding the tank and under the slab foor.
Room Temp	70	70	F degrees	Typical Average Daily Room Air
Slab Temp	73	73	F degrees	Typical Average Daily Slab Surface

Continued from page 32

Heat loss is calculated by multiplying the surface area by the temperature difference and dividing by the "R" value. Heat storage is calculated by multiplying the specific heat by the density and then by the temperature rise (or drop) in the material.

vide 2 gallons for each 1 square foot of collector, or 640 gallons. Setting aside the other obvious design issues such as integrated DHW, room temperature control strategies and over-heat protection, let's focus on how much heat is involved and how the thermal storage systems react to it.

Table 15-2 Specifications: Sample 3,200-Square-Foot Solar Heated House

Item	Tanks	Floor	Comments
Size	640 Gallons	3200 Sq. Ft.	Assume cylindrical tanks containing boiler fluid (low pressure water).
Weight	5312 Pounds	128000 Pounds	Weight of slab 4" thick.
Heat Capacity	5312 Btu/F	25600 Btu/F	Heat stored when average temperature rises 1 degree F.
Heat Loss	1693 Btu/hr	4907 Btu/hr	Tanks lose heat to the mechanical room. Floor loses heat to the ground.
Solar Panel	320 Ft2	320 Ft2	Eight flat plate panels, 4' x 10' each.
Solar Heat	320000 Btu/Day	320000 Btu/Day	Useful solar heat delivered to the house on a clear day. (1000 Btus per square foot per day)
Boiler	80000 Btu/hr	80000 Btu/hr	Minimum hydronic boiler output size typical for this type of house.

A sample solar heated house

Let's consider a residential house with 3,200 square feet of heated living space that is well constructed with the energy use and performance temperatures as seen in Table 15-1. The owner decides to include eight large (4×10 flat plate) solar heat panels to supplement the heat from a hot water heating system using a hydronic boiler. One plan proposes storing all the solar space heat in water tanks and another plan uses "direct" heat storage using insulated "slab on grade" hydronic radiant concrete floors. The size of the collectors is typical of systems installed in our area, using about 10% of the floor area in collectors. A water tank system would be typically sized in our climate to pro-

It is interesting to note that even though the concrete floor weighs 24 times as much as the water, its total heat storage capacity is only about 5 times that of the water. The backup boiler is capable of burning the equivalent of about 1 gallon of propane per hour at full output. The solar collectors deliver about 4 times this amount of heat per day.

Thermal response of water vs. concrete heat storage

Using the data shown in Table 15-2, we can calculate the temperature rise in the thermal mass driven by the available solar heat. We also can calculate the heat loss from the tanks, the heat loss from the floor, and the heat

Continued on page 36

TABLE 15-3 Daily Solar Heat Response: Sample 3,200-Square-Foot Solar Heated House

Item	Tanks	Floor	Comments
Temp. Gain	60.2 F rise	12.5 F rise	Maximum average temperature rise in storage possible in one sunny day.
Temp. Loss	7.7 F drop	4.6 F drop	Typical temperature drops in the storage. mass due to heat loss through the insulation per day
Temp. Net Gain	52.5 F rise	7.9 F rise	Useful temperature rise available per sunny day for space heating.
Net Solar Heat Delivered	161120 Btu/Day	202240 Btu/Day	Floor loses heat to the ground. Tanks lose heat to the mechanical room and also to the ground when heat is finally delivered to the floor.
Boiler Run-time Saved	2.01 Hours/Day	2.53 Hours/Day	Boiler running at full output (80000 Btu/hr).
Boiler Run-time No Solar	6.72 Hours/Day	6.72 Hours/Day	Boiler runtime with no solar at full output on a cold day.
Solar Percent	29.9%	37.6%	Solar heat contribution expressed as a percent of the normal boiler routine.

Continued from page 34

needed by the building. The net solar heat delivered can then be determined and the solar savings compared. These results are summarized in Table 15-3. Note that the water tanks must operate at a much higher temperature range than the concrete floors in order to store the daily ration of solar heat. The tanks can gain over 50 degrees of net temperature rise while the floors gain less than 8 degrees. If the tank begins the day at 100ºF, it will be 150ºF at the end of a sunny day. The concrete floor surfaces will typically stay below 80ºF. Lower temperatures are generally associated with higher solar thermal efficiencies.

The direct floor system is capable of providing over 25% more solar savings than the storage tank system with the same solar collectors in this example, based on the daily heating summary.

When the thermal mass of the concrete floors is used directly, the concrete becomes the solar heat accumulator. Even though the concrete has a lower specific heat storage capacity, because there is so much of it, the temperatures can be maintained easily within the range of human comfort. The room temperature can be allowed to drift as much as 8 degrees from day to night without exceeding the limits of the human comfort range. Using programmable 2-stage thermostats, this comfort range can be controlled to the user's needs on a room by room basis. In some rooms, a wider temperature fluctuation can be tolerated, and this will result in higher solar savings in those rooms.

Keep in mind that a solar heated house must be well constructed to achieve a high solar heating fraction. The solar collectors provide a finite amount of heat each sunny day. In this example, the solar heating fraction does not exceed 40% on this cold hypothetical day. During milder cold weather, the solar contribution will be higher. It is possible to design buildings with solar collectors where the heating energy balance is engineered to provide a high solar contribution.

Regional Results Will Vary

This example is intended only to illustrate the concepts involved in solar heat and thermal mass when used for solar space heating. Tables 15-1 and 15-2 show only a short summary of all the variables that can affect the performance of a solar heated building. These and other variables will change in different regions, resulting in different solar performance results.

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