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A Low-Energy Home Goes Solar

Winter Heating with the Sun

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Leading architects describe the latest in energy-efficient design.

Warm, Radiant Comfort in the Sand

Floor heating systems that store the sun's energy in sand offer warmth through the cloudy winter.

By Bob Ramlow

Imagine slashing your heating bills by at least half and heating your home with the sun. But, you ask, what about the extended cloudy periods so common when and where space heating typically is most needed?

The secret to effective solar heating in such environments is a system with good heat storage. In regions where heat storage is needed, active solar space-heating systems use water or sand to store heat gathered in collectors usually located on a building's roof. This article describes the basics of water- and sand-based heating systems and why, for well-insulated buildings having a footprint of at least 1,000 square feet (93 square meters), systems that use a sand bed for heat storage offer the best performance and comfort.

Assessing the Benefits, Limits of Water Storage

Traditional active solar space-heating systems use large water tanks to store heat gathered by solar thermal collectors. This heat is then extracted from the storage tank and delivered to the building in any of various ways as needed. Sizing solar space-heating systems is always a compromise, because if we size the system to heat the building on the coldest day of the year, then every other day the system will be producing more heat than we can use. To minimize cost and overheating, a good compromise is to size such systems to heat the building on an average winter day. In most climates it is possible to get up to half of your annual space-heating needs with this sizing strategy.

Water is one of the best heat-storage mediums, because it can store a large amount of heat in a relatively small area. It is also fast and relatively easy to add or extract heat from water, and the heat dissipates rather quickly throughout the water. In a solar storage tank, the heat is delivered near the bottom of the tank, which enhances the mixing. Under traditional designs this aspect is a benefit because if the storage tank is designed to hold a day's worth of the output of a solar array, then the storage tank can heat sufficiently in that day at a high enough temperature to heat the house for a day. The key here is "at a high enough temperature." In order to deliver stored heat to the home, the difference in temperature (delta-T) between the building and the storage must be at least 20˚F or more. But the quick dissipation of solar heat in the storage tank can be a detriment if the storage tank is too large, because it may take days of sunny weather to get the tank hot enough to deliver meaningful heat to the building.

Here in Wisconsin where winters tend to be long and cold, we size traditional solar-heating storage tanks at a ratio of approximately 1.25 gallons (4.7 liters) of storage for every 1 square foot (0.1 square meter) of flat-plate collector or equivalent in evacuated-tube collectors. Our rule of thumb for sizing collector arrays is to have 2 square feet (0.2 square meter) of flat plate collector or equivalent in evacuated tube collectors for every 10 square feet (1 square meter) of the footprint of the building. Systems sized this way have been installed for more than 25 years, providing up to one-half of the annual space-heating requirements of a well insulated home. This type of system often is the first choice in active solar space-heating systems and the *only* choice for retrofitting an existing home with a solar heating system having storage.

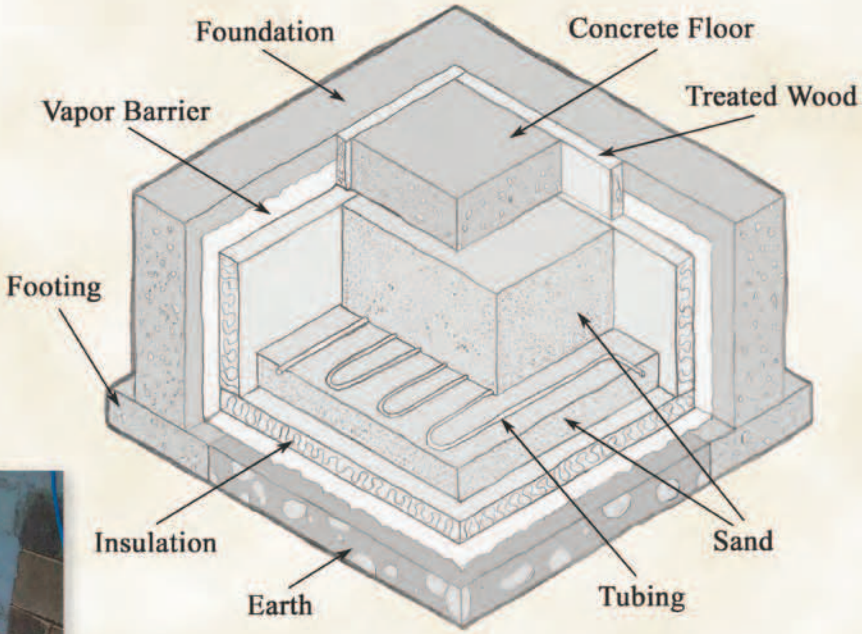
But many people would like to achieve an even higher solar contribution to their annual space-heating loads. Designers over the years have tried to devise a practical, affordable solar heating system able to store a large amount of heat and to deliver the stored

> A radiant system with sand-based heat storage can provide 75 percent of a home's annual heating needs.

Sand-Bed, or High-Mass, Solar Heating System

Photos by Marguerite Ramlow • Illustration by Benjamin Nusz

In a sand-bed, or "high-mass" solar heating system, the sand bed typically is 2 feet (0.6 meter) deep and covers the building's entire footprint. The sand bed is lined on the bottom and sides with high-density extruded foam insulation and a vapor barrier. A concrete slab is poured over the compacted sand.



A gridwork of PEX tubing is installed in the lower portions of the sand bed. Solar-heated fluid pumped through the gridwork of tubing heats the sand. Heat then radiates from the sand through the floor and into the building.

heat in a timely manner. One tactic is to oversize the water-storage tank in relation to the collector array in order to increase the heat-storage system's capacity. However, as the ratio of storage capacity to array size increases, the system's ability to deliver meaningful heat decreases.

Achieving Greater Heat Storage with Sand

During the 1980s, some innovative solar contractors developed a solar heat-storage system using a bed of compacted sand in an insulated box, which was located under the building. Primarily designed for new construction, these systems performed well. This type of solar heating system is akin to passive solar-heating systems, and in fact, it works best when incorporated into a building that also has some passive solar-heating characteristics. Systems using sand-bed storage have resulted in annual solar heating contributions exceeding 75 percent.

This system might be described as a high-mass radiant solar-heating system. Common names include "high-mass" and "sand-bed" solar heating systems. The sand bed in this system is typically 2 feet (0.6 meter) deep and covers the building's entire footprint. The sand bed is lined on the bottom and sides with high-density extruded foam insulation and a vapor barrier. A concrete slab is poured over the compacted sand. A gridwork of PEX tubing is installed in the lower portions of the sand bed. Solar-heated fluid pumped through the gridwork of tubing heats the sand. Heat then radiates from the sand through the floor and into the building.

The solar array for these systems is sized the same way as for a system using a water-storage tank. In our 8,500+ heating degree-day climate, our rule of thumb is to have 2 square feet (0.2 square meter) of flat-plate collector or equivalent in evacuated tube collectors for every 10 square feet of building footprint (1 square meter) (2/10 = 0.2/1). A solar heating system sized according to this ratio will provide up to 50 percent of the annual heating load for a system that uses water storage and up to 75 percent when using sand-bed heat storage. In well-insulated, highly efficient buildings, the percentage can be even greater. The reason the sand-bed system can give a higher annual solar contribution than a water-storage system when both systems have the same collector array size is because the sand-bed system can retain heat gathered during the late summer and early fall. The water-storage system has no such long-term storage capacity.

What Makes Sand Good for Storage?

The following examples illustrate the differences between sand-bed storage and water-storage systems. Let us assume that the model building is a well-insulated, single-story building with a 2,000-square-foot (186-square-meter) footprint. Using our rule of thumb to size the collector array (2,000 square feet x 0.2), we get a 400-square-foot (37-square-meter) array. If using water as a

Getting Started

Resources

Solar Water Heating, A Comprehensive Guide to Solar Water & Space Heating Systems by Bob Ramlow with Benjamin Nusz, New Society Publishers, 2006. Order at **www.arthaonline.com**.

Solar Hot Water Systems – Lessons Learned 1977 to Today by Tom Lane. Order at **www.ecs-solar.com**.

Incentives

Database of State Incentives for Renewables and Efficiency: **www.dsireusa.org**

Solar Estimators and Local Pros

FindSolar.com: **www.findsolar.com**

Building Design

Arkin Tilt Architects
Ecological Planning & Design
David Arkin, AIA, Architect
LEED Accredited Professional
www.arkintilt.com

CHAMOMILE NUSZ

Primarily designed for new construction, solar heating systems with sand-bed heat storage can provide 75 percent or more of a home's annual heating needs. Here, collectors on the south-facing roof capture solar radiation for water and space heating. The lower collectors are the thermal collectors, with photovoltaic (PV) collectors above. This building was designed with rooflines to accommodate proper collector-mounting angles, steep for the solar thermal system because it is for space heating and a less severe angle for year-round production of the PV panels. The collectors in this photo are mounted on the detached garage and the heat is piped underground to the home. The system was designed by Bob Ramlow of Artha Sustainable Living Center.

heat-storage medium, the water-storage tank must have a capacity of 400–500 gallons (1.5–1.9 kiloliters). This tank would weigh between 1.67 tons and 2.08 tons (1.51–1.89 metric tons). If using a sand bed as a heat-storage medium, the sand bed must contain 2 cubic feet (0.06 cubic meter) of sand for every square foot (0.09 square meter) of the building's footprint. A cubic foot of dry, compacted sand weighs approximately 100 pounds (45.4 kilograms), so for every square foot of the building footprint the sand bed would have 200 pounds (90.7 kg) of storage, resulting in 200 tons (181.4 metric tons) of storage for a 2,000-square-foot building. You can see that the sand-bed storage system has 100 times the weight of the water-storage system.

The reason the sand-bed system can give a higher annual solar contribution than a water-storage system is because it can retain heat gathered during the late summer and early fall.

Heat dissipates quickly in a water tank because water is uniform and has no spaces between water molecules. Sand, on the other hand, has spaces between the granules, so heat transfer is much slower. However, heat can travel in a concentrated path rather quickly through a sand bed toward cold.

If we return to the example of the 2,000-square-foot home with a 400-square-foot collector array, and instead of having a 400- to 500-gallon water-storage tank, we had a water-storage tank equivalent to the size (by weight) of the sand bed, the system would work poorly, if at all. The reason is that the collector array is not big enough to heat the water tank sufficiently in one day to achieve a delta-T large enough to efficiently extract the heat from the tank and deliver it to the building. If the building used a sand-bed system, after an extended cloudy period during the heating season, the sand bed would cool as it delivered heat to the building. When the sun again shined, the heat delivered to the sand bed could travel directly through the sand to the floor surface to provide immediate heating without being dissipated throughout the whole sand bed. Sand's abilities to provide long-term heat storage and deliver heat quickly to the surface make it a good heat-storage medium in a solar heating system.

Sized according to the above-mentioned strategy, sand-bed solar heating systems provide the base-load heat to a building during the whole heating season. We can store a large amount of low-grade heat in the sand bed. Because the radiator (the whole floor of the building) is large, low-grade heat can effectively heat the building. In a well-insulated building, a sand-bed solar heating system can keep a building from freezing with no other heating source in the building. In fact, we have observed buildings that never got colder than 50˚F (10˚C) at any time during the winter using just a sand-bed solar heating system. That works only with buildings that are both well-insulated and have a footprint of at least 1,000 square feet. Smaller buildings require more auxiliary heat because of the large ratio of wall area to floor (or sand-bed) area.

Because this is a radiant floor-heating system, the type of floor covering is important, just as with traditional radiant floor-heating systems. The most conductive options are exposed concrete or tile floor coverings.

Living with Solar Heating

Sand-bed solar heating systems do require some owner involvement. As with most active solar heating systems, the collectors are set at an angle to maximize the winter sun, and that reduces the array's output during the summer. Nonetheless, the system will continue to produce heat during the summer that the building operator may need to deal with. One solution is to install a drainback system that simply turns off once the heating load is satisfied. If a drainback system is utilized, the building operator must switch some valves and/or a switch to eliminate the heat transfer to the sand bed in the early to mid-summer. If a pressurized system is utilized, the building operator will have to divert the excess heat to a shunt load during the same time frame.

Sand-bed solar heating systems are usually activated during the late summer. In my Wisconsin climate, the solar energy system begins to heat the sand bed in early to mid-August. During this part of the year, we like to see as much heat delivered into the sand bed as possible. It takes about a month to get the sand bed saturated with heat, and then the temperature inside the building is regulated by judicious opening and closing of windows. While this does require homeowner involvement, most people appreciate the opportunity to have their windows open much later in the fall than they would be able to do if they were paying for the heat.

Sand-bed (or high-mass) solar heating systems offer an opportunity to draw on the sun for a high fraction of the annual heating load of buildings, in climates from mild to severe. Although it can contribute more of the total heating load, this system's installed cost is similar to that of a traditional water-storage solar heating system. Unfortunately, no manufacturers currently offer this type of system as a package. These systems are custom-designed by either a solar thermal system designer or a solar thermal contractor.

I'm aware of a couple of dozen sand-bed systems installed in Wisconsin during the last decade or so, as well as numerous systems installed throughout the continental United States. All the feedback I have received about these systems has been very positive.

My own sand-bed system has been operating for the last two winters since we built the house. Our home was designed with high insulation levels, so it requires little auxiliary heat to maintain comfort. Even when outside temperatures fluctuate wildly, we enjoy stable temperatures and savings on our heating bills. Who says solar heating can't work in cloudy Wisconsin? ●

Bob Ramlow (artha@wi-net.com) is CEO of the Artha Sustainable Living Center in Amherst, Wis. Ramlow encountered his first solar-heating system in 1971 and built his first solar collector later that year. He has been active in the solar energy business for over 25 years, operating his own company for many of those years. Now the solar thermal technical lead for the Wisconsin Focus on Energy Program, Ramlow also conducts workshops nationwide about solar water- and space-heating systems and designs solar thermal systems and conducts solar thermal site assessments nationwide. Access www.arthaonline.com.