> PRO LEAGUES Target Solar for Stadiums *page 14*

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Passivhaus Design, Louisiana Style

Architect Corey Saft adapts Germany's rigorous energy-efficiency standard to the steamy South.

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Storing Summer Heat

for Winter

Before electric appliances came on the scene, we cut ice from frozen lakes and rivers and buried it to use for refrigeration long after the rivers had melted. What if there was a way to do the reverse, storing summer heat for warmth during the winter?

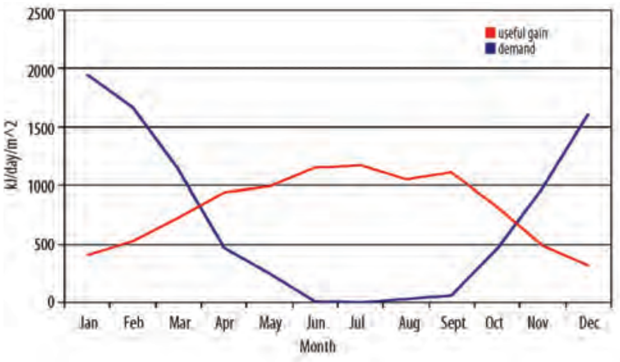
Space heating comprises nearly half of the energy used in a typical U.S. home. With retirement in mind, I became interested in high-mass solar heating — storing heat from solar thermal collectors in water or sand — as a means of reducing our monthly utility bills. A look at annual heating demand and solar energy supply overlaid in a single graph further underscores the need for effective long-term solar thermal storage (figure 1). I've also gotten interested in energy-efficient housing, in hopes that my grandchildren can avoid ever-increasing utility bills when they have their own homes.

Our house is like many built in Virginia, a one-story ranch built on a crawl space. I originally designed our home's solar energy system to provide both radiant space heating and domestic water heating using water tanks. I tried several variations to optimize space heating, but it seemed impossible to design a system big enough to reasonably heat the house without generating excessive hot water during the summer.

I first learned about high-mass solar heating while attending a solar hot water training presented by Bob Ramlow at the Midwest Renewable Energy Association (MREA, the-mrea.org). I later saw Bob's own system at his net-zero-energy home in Amherst, Wis. It was simple and it worked. Through a gridwork of radiant tubing, collected heat is delivered to and stored in a sand bed beneath the house; heat is provided through the home's floor by conduction. (See Ramlow's *SOLAR TODAY* article, "Solar-Heat Your Home," Nov./Dec. 2009: solartoday.org/ramlow.) But not a lot was known about the design of the high-mass sand bed; we know what was done but not why it works or how to optimize it.

Mechanical engineering colleagues at Virginia Commonwealth University joined me in solving this challenge. Associate Professor James T. McLeskey Jr. and master's candidate Marshall L. Sweet helped develop a system to retain summer's peak heat for solar thermal heating during the cold months. As a bonus, the storage system uses conventional building materials and techniques, making it easy for a builder to do.

Figure 1: **Annual Space-Heating Demand vs. Useful Solar Energy**



Designing the Virginia Heatstore

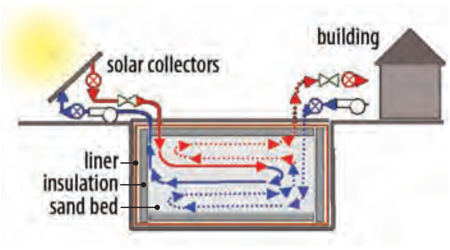
Most solar thermal heat-storage systems to date have used large water tanks. Large water tanks are expensive and structurally complex. High-mass systems avoid these problems, but they cannot be "turned off." Once heated by the solar collectors, the sand bed transfers its heat to the building's floor until the heat is gone. Inside temperatures can reach as high as 86°F (30°C).

The Virginia Heatstore was designed to take advantage of sand bed design but allows the user to store heat year-round in a sort of solar oven. We are researching the size, shape and construction of the heatstore. As shown in figure 2, the sand bed is isolated from the floor; it can even be located away from the house. Heated water from the solar panels is carried through PEX tubing in the bed, heating the sand. During the winter, a second set of PEX tubing removes heat from the bed to heat the house via a radiant floor. The water carrying heat from the bed to the house is activated and deactivated as needed by thermostats.

Simulating Performance

Modifying your home to include high-mass heat storage can be expensive and risky. In addition, building inspectors are reluctant to permit systems with which they are not familiar. In order to size and optimize the Virginia Heatstore, we needed to model the system.

Figure 2: **The Virginia Heatstore**



We simulated the performance of an underground heatstore for a single-story ranch-style home in Richmond, Va. To do so, we used software called TRNSYS ("tran-sis"), or TRaNsient SYstem Simulation program, designed to simulate the transient performance of thermal energy systems. The TRNSYS component library enables users to simulate complex energy systems by selecting system components and linking their inputs and outputs.

As shown in figure 3, our simulation used many components from the standard TRNSYS component library. The major components we used were Type 56 (Building), Type 701 (Basement) and Type 76 (Theoretical Flat Plate Collector). The heatstore bed itself was modeled using Type 342 (Multi-Flow Stratified Thermal Storage Model with Full-Mixed Layers), which we purchased from Transsolar Energietechnik, an engineering firm. Type 56 (Building) was

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Based on simulation results, the high-mass solar heating system being demonstrated in Virginia will provide 70 to 80 percent of a home's heating load.

By **DAVE STETS** with **JIM MCLESKEY** and **MARSHALL SWEET**

used to model our single-story ranch style home built on a crawl space. The crawl space was modeled using Type 701 (Basement). We used Type 76 (Theoretical Flat Plate Collector) to model solar thermal collectors that provide thermal energy to the heatstore bed (Type 342).

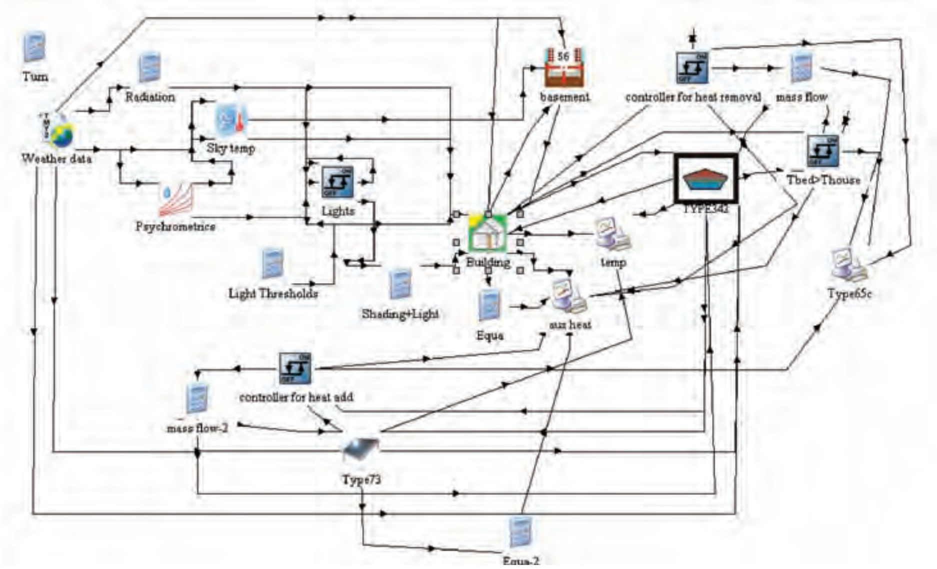
Our team modeled six different-sized houses: 800 square feet (74 square meters), 1,000 square feet (93 square meters), 1,400 square feet (130 square meters), 1,600 square feet (149 square meters), 2,000 square feet (186 square meters) and 2,400 square feet (223 square meters). Each house was modeled with and without a heatstore bed. The bed volume was varied for each house. All simulations were run using weather data for Richmond, Va. On models with a heatstore system, 80 percent of the south-facing roof was covered with solar thermal collectors.

Heat demand for each home was modeled with an idealized heating system to maintain a minimum temperature of 68°F (20°C) inside the house. The same system was used for auxiliary heating in models with heatstore. For homes with heatstore, the auxiliary heating system was designed only to keep the house from dropping below 19°C (66°F). In the model, if the temperature of the heatstore bed was less than the temperature of the home, then the radiant floor would not activate. Similarly, we modeled the system so that it's only possible to add heat to the system when the output temperature of the solar collectors exceeds the temperature of the storage medium. This avoids cooling the bed.

Results showed that the optimal size for a heatstore bed in Richmond, Va., is between 530 and 565 cubic feet (15 and 16 cubic meters) and the shape is square. This dimension varies for other geographic locations. The simulation showed that a bed of this size can provide 70 to 80 percent of the heating load for the modeled homes. We measured this effect as the amount of reduction in needed auxiliary heat (figure 4). Smaller homes having smaller heat demands saw the greatest reductions. However, larger homes have a higher internal volume-to-wall area ratio, which allowed them to achieve higher efficiencies. The higher efficiencies were evidenced by a decrease in heat loss from the home per square foot that was lower in larger houses.

We also optimized the flow rates through the size and number of solar thermal collectors used to charge the heatstore bed. We found that higher flow rates increased heating efficiency, with an optimal speed of 3 gallons per minute. Not surprisingly, results showed that we reduced needed auxiliary heating as we increased solar collector area. Even though using more collectors leads to greater reductions in auxiliary heat, we found the optimum collector area to be 75 percent of the total roof area, as long as all panels faced south at a 37-degree angle. These simulations involved many other variables, as well.

Figure 3. **TRNSYS Simulation System for a House with Seasonal Solar Heat Storage**



Initial calculations estimate a payback of approximately 25 years for the optimized system. The solar panels account for the bulk of the cost.

David Stets founded Richmond BySolar (bysolar.net) in 2007 and installed the first solar thermal system at Virginia Commonwealth University (VCU). He funded the original solar heatstore research at VCU. Contact him at dave.stets@bysolar.net.

James T. McLeskey Jr. is an associate professor of mechanical engineering at VCU. McLeskey holds a Ph.D. in mechanical engineering from the University of Virginia. He teaches courses in thermodynamics, fluid mechanics and energy conversion systems.

Marshall L. Sweet is completing a master of science degree in mechanical and nuclear engineering at VCU.

Step by Step

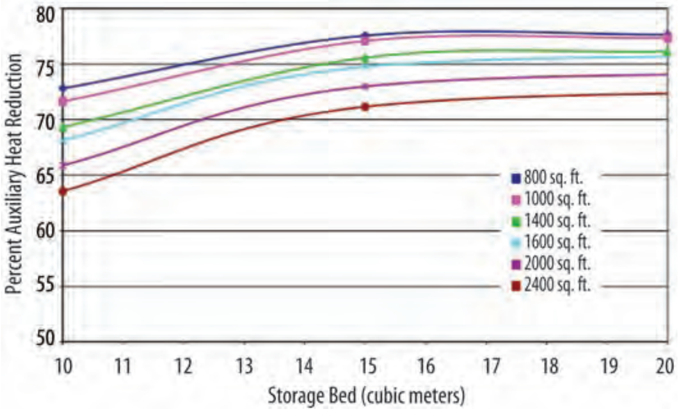
A, B, C - Workers dug the hole for the heatstore during the week of July 7. The authors had planned to dig 12 by 12 by 10 feet (3 by 3 by 2.4 m) and fill back 2 feet (0.6 m) on top of the 8-foot deep heatstore. But based on modeling results, they filled the sand to only 6 feet (1.8 m) deep.

C, D, E - Digging holes for retrofits costs more than during new construction because you have to haul dirt away. The authors lined the hole with 2-inch-thick, 4- by 8-foot polystyrene insulation. Then they laid a tarp over several extension ladders bridged across the opening, to keep it dry during construction.

Demonstrating the Heatstore

The first demonstration of the Virginia Heatstore was permitted Earth Day, April 22, 2010. It is located in Henrico County, just outside Richmond, Va. By building the heatstore at my home, we can easily track its performance. Initially we planned to divert the home's three existing solar thermal panels to the heatstore. However, after reviewing TRNSYS models, we decided to add eight new panels instead.

Figure 4. **Auxiliary Heat Reduction vs. Storage Bed Volume**



Workers dug the hole for the heatstore during the week of July 7. We had planned to dig 12 by 12 by 10 feet (3 by 3 by 2.4 m) and fill back 2 feet (0.6 m) on top of the 8-foot deep heatstore. But our TRNSYS model specified we use 15 cubic meters (8 by 8 by 8 feet), so instead, we filled the sand to only 6 feet (1.8 m) deep.

We lined the hole with a 6-mil (152-micrometer) liner and 2-inch-thick, 4- by 8-foot (5-cm-thick, 1.2- by 2.4-m) polystyrene insulation. We covered it with a tarp to keep it dry during construction. On sunny days, we opened it up to dry and help warm the sand. Business and family schedules limited the time we could work on the heatstore mostly to weekends.

We put in the solar panel ground mounts in one day, dug in a few hours with a power auger.

We spent another day trenching 2 feet deep under the mounts, for piping to the heatstore. The eight solar thermal panels were ground-mounted the next weekend.

We recycled the solar panel shipping pallets to build a 4- by 4-foot room on top of the heatstore bed for the controls, pump, valves, and pipe manifolds. We used two six-port copper manifolds for the PEX piping for the solar


F

F, G - The authors installed the solar panel ground mounts in one day, dug in a few hours with a power auger. They spent another day trenching 2 feet deep under the mounts, for piping to the heatstore. The eight solar thermal panels were ground-mounted the next weekend.


G


H


I

H, I - The authors recycled the solar panel shipping pallets to build a 4- by 4-foot room on top of the heatstore bed for the solar appliance and pipe manifolds. The week of Oct. 12, the authors measured 145°F (63°C) at 3 to 5 feet deep. The system's solar panel array was producing a maximum water temperature between 168°F and 178°F (76°C and 81°C) on days the sun shined. They were ready to fill the hole and put the heatstore in observation mode.

loop. We decided to use CPVC to connect the heatstore water loop to the home's radiant floor, since we don't expect temperatures over 160°F (71°C).

We got the solar loop running in late September, just before heading to the Solar Thermal '10 conference in Milwaukee to present on the heatstore. We found we needed to update the software in the solar appliance to get the monitoring software working correctly.

We put recording temperature sensors at 2, 3, 4 and 5 feet (0.6, 0.9, 1.2 and 1.5 m) deep at the center of the heatstore. We'll move one of the sensors to the hot water line once we activate flow to the floor. It's too early to tell what the results will be, but the sand is getting hotter. The week of Oct. 12, we measured a high temperature of 145°F (63°C) at 3 to 5 feet deep. Our solar panel array was producing a maximum water temperature between 168°F and 178°F (76°C and 81°C) on days the sun shined. We were ready to fill the hole and put the heatstore in observation mode.

Most of the thermal gain is expected to occur between March through the end of September. We expect solar gain from the other months to replace some of the heat used during the heating season. We average 3,963 heating-degree days in Richmond, with January peaking at an average of 908. Last year, before the heatstore addition, we ran the radiant floor from November through March. PEX piping carried 120°F (49°C) solar-heated water into the house, keeping the house very comfortable. Returning water from the floor cooled to around 85°F. A small electric hot water tank supplements the radiant floor (a tankless water heater would also work).

As mentioned, we modeled our TRNSYS simulation so that it was possible to add heat to the system only when the output temperature of the solar collectors exceeded the temperature of the storage medium. It was a good precaution, because, as the heatstore warms up, the panels have taken a few minutes more each day to heat up to the bed temperature and then transfer the stored heat to the heatstore.

In the first quarter of 2011, we'll demonstrate a second heatstore, at a house retrofit the Richmond Metropolitan Habitat for Humanity is undertaking. The lessons we're learning with the first heatstore will simplify and help us refine the Habitat heatstore. Look for updates on both systems in coming issues. **ST**