Efficient (and Cheap) Space Heating with a Solar Basement

By Susanna Gross, edited by Elaine Hebert

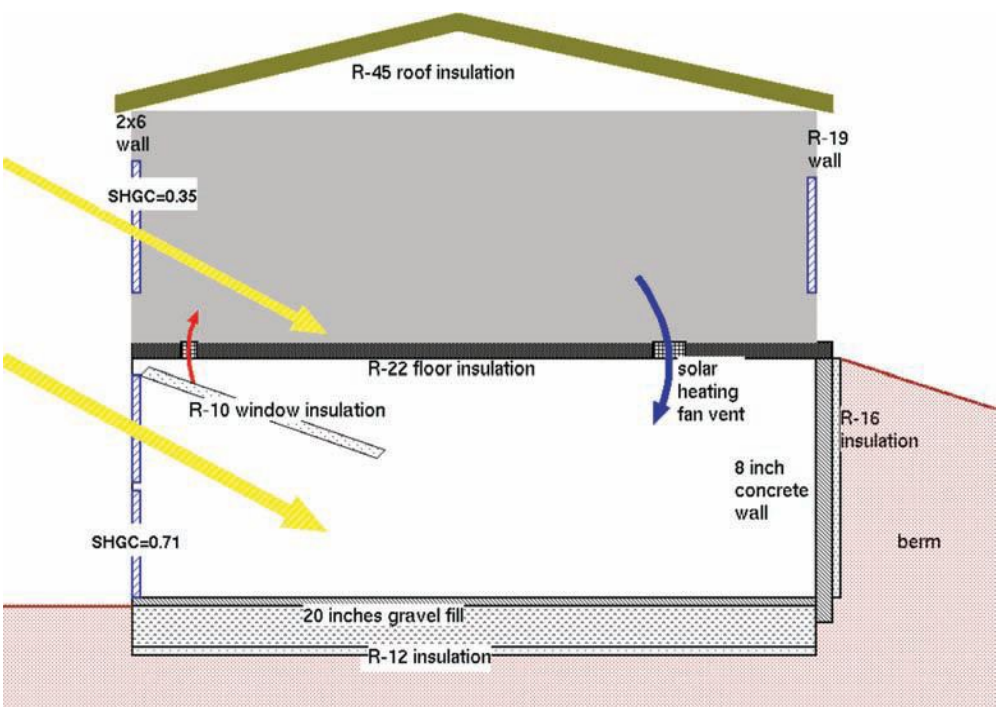
Do you live in a cold climate? Have you ever wanted to use much more solar to heat your house than you could afford, or had a client with that problem? If so, you might be interested in a design like our manufactured home with a customized solar basement!

About 15 years ago, while considering building a new home in the cold, sunny San Luis Valley of Colorado (8300 feet in elevation), efficiency was our first design goal, in the sense of low-cost housing, efficient use of energy, and reduced environmental impact. My husband Frank and I wanted to heat our home with solar energy.

In our experience, the most affordable housing that exists is built in a factory and shipped to the building site. Manufactured housing is particularly attractive if there is no general contractor and the buyers (like us) lack a background in construction.

We knew enough that in a colder climate, thermal mass would be a big help in heating with solar – but it is fairly impractical to include enough thermal mass in a manufactured house. We wanted to find a way.

And we did: by buying a manufactured home and installing it on a site-built custom solar basement.



Schematic of solar basement design, showing air circulation. The curved downward pointing blue arrow in the figure represents cool house air being blown into the basement by a single computer-controlled 800 CFM fan. The small red arrow pointing upward represents hot basement air returning to the house, through one of the 7 6x13 inch vents, distributing solar heat throughout the house.

Design and Construction Features

My husband Frank wrote a numerical model to help design the basement. His model was based on eight years of hourly weather data from Center, Colorado. The model included solar gain through windows, heat transfer in concrete and soil, conduction through house walls, air infiltration, heat transferred from the basement by the fan, and a backup furnace.

An important design element was that our land was on a south-facing slope. Our solar-capturing basement would face south and be bermed on the other three sides. US Department of Housing and Urban Development (HUD) manufactured houses built to code were appropriate for our purpose. Almost any floor plan could be used, but we knew it would be best if the footprint of the house were a simple rectangle with long sides that could face south; that way, both the house's and the basement's windows could let in solar heat, oriented toward the noon winter sun. We settled on a rather ordinary 1,508 square foot double-wide manufactured house that came with R19 wall insulation, R45 roof insulation, and additional insulation on the underside of the floor. Our house was built by Guerdon Homes of Idaho and set on the site-built basement in 2004.

We have backup heat via an ordinary forced-air propane furnace. There is no fireplace or wood-burning stove.

The basement window area is 22% of the floor area, which comes to 330 square feet of windows, all on the south side. The glazing fraction can be higher than normally found in solar houses because the basement is not living space. In a typical winter the basement air temperature exceeds 90°F.

We have about 260 tons of thermal mass, with reinforced concrete walls and gravel beneath the concrete slab floor.

We have moveable insulation (R10) in the solar basement, raised and lowered under computer control with a system of ropes and pulleys connected to a garage door opener. In the summer we lower the insulation partway and block what little light enters the basement, which drops the temperature dramatically. Our climate is cool enough that no air conditioning is needed. Air circulates passively and actively, rising through vents; very little electricity is needed, and there is no associated plumbing or ductwork.

The San Luis, Colorado residence of Susanna Gross and Frank Evans is 97% solar heated.

We placed reflectors on the ground in front of the basement windows to send more heat in, and their tilt is adjusted seasonally.

We have R16 insulation between the basement walls and berms, and R12 insulation buried 20 inches beneath the basement floor.

Our house's windows are also insulated with R10 in winter evenings.

The house is off-grid, and we have a photovoltaics (PV) array to provide electricity.

We have a solar hot water system, backed up by an ordinary propane-fired water heater.

Everything is monitored by our computer-linked control and monitoring system.

Monitoring and Performance

We have monitored our house for more than 12 years. We record temperatures at three locations in the basement and one in the house at 5 minute intervals. The monitoring system controls the basement fan, backup furnace, basement window insulation and heat recovery ventilator. An on-site weather station measures outdoor temperatures and solar fluxes. For plots of these measurements, please see our website (http://strike.coloradolinux.com/solar).

Our home automation control system uses 1990s hardware. The computer communicates over a two wire serial bus to boards with eight relays and sensors. A custom-written C program controls the heating system and logs hot water temperatures. Our computer runs other programs to download and process weather data and update our website. Home automation has important convenience benefits, but a major benefit for us is data gathered.

Estimating energy savings

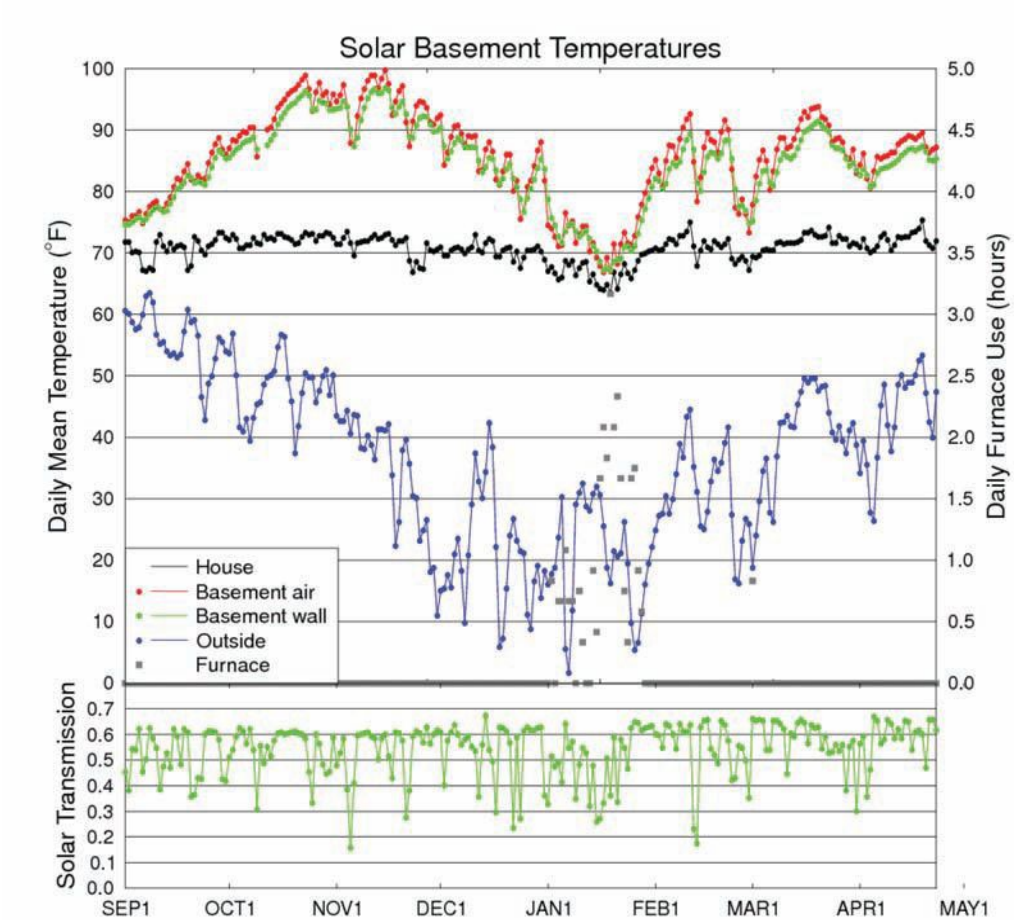
To estimate how much propane we would have used without the solar basement, I used the Home Energy Saver web application, http://homeenergysaver.lbl.gov. This model includes type of construction, orientation and geometry, solar heat gain coefficient of windows, R-value of insulation, and climate, but not for our exact location. I ran the Energy Saver for Alamosa, Colorado, and corrected the results for our actual heating degree days, getting an estimate of 930 gallons propane needed per year to heat a conventional house, compared to the 25.6 gallons per year actually used to run our furnace from 2006-2016, which suggests the house is 97% solar heated.

Long term monitoring is essential to evaluate the effectiveness of more efficient solar designs, because use of the backup heating system doesn't occur except during rather unusual cloudy and cold periods. During mild winters, our furnace is hardly needed; for example, during the mild winter of 2013-2014, it ran for a half hour, total. Although we have a 500 gallon propane tank, it has not been filled since August 2008. In January 2010 we installed 7 solar reflecting panels, each 4 by 8 feet, in front of the basement windows, and now we have a long enough observation period that we can estimate how effective they are. It appears they are saving us approximately 40 gallons of propane annually.

Our basement cost $30-40,000 more than a stem wall foundation, which we could have had built, but it saves roughly 905 gallons of propane annually according to the Home Energy Saver. The annual propane savings are worth about $2,100, and we prevent 5.7 tons of CO2 emissions annually. Another way to consider the savings is to compute a payback period, 17 years in this case. That payback period would be shorter if propane becomes more expensive than $2.33 per gallon, or longer if propane prices fall.

Disadvantages and Defects

Our house is very conventional looking, inside and out. It has no partic-ular style. This suits us, but it may not have wide appeal. The basement berming works best on building sites that slope toward the equator, to reduce the amount of excavation needed. Although the heating system works well, it needs a substantial difference in temperature between the basement and house to move heat efficiently. That is one reason we have a thermostat that depends on time of day, as the basement gets warmest in late afternoon. Also, our heating system is somewhat noisy, because effectively, we have built a solar forced-air heating system. Our house can overheat, especially in fall, when outdoor temperatures are still rather warm and we are starting to heat the basement to prepare for winter. We have dealt with the problem by closing vents and opening windows. The manual effort of insulating windows



Seasonal summary of solar basement temperatures and furnace use. The time axis starts in the fall of 2016 and ends in spring of 2017. An unusually cloudy period in January caused us to run the furnace for 30 hours last winter. The solar transmission in the bottom graph is the measured daily average solar flux on the horizontal divided by the top of atmosphere solar flux.

at night in the house is another drawback. An average homeowner would probably neglect that.

The concrete contractor who built the basement made some mistakes and omitted insulation around the footers. They also poured the slab so it goes completely under the south wall of the basement, and can conduct heat outside. We covered the exposed concrete with polyisocyanurate insulation, and protected the insulation with sheet metal. Also, the workmen who set the house onto the basement didn't realize how important it was to put it down on the sill plate at the top of the basement walls. They lifted it above the sill plate by a significant fraction of an inch when leveling the house. That left a gap which produces additional infiltration. We shimmed it and attempted to insulate with blown-in foam, but that wasn't entirely effective. We don't know exactly how much heat we lose, but the basement temperature falls on windy days in a way that must partly be due to that construction error.

Advantages

Our heating system has several important advantages, beyond cost. Without anything being burned to produce heat, our air quality is excellent. The heat recovery ventilator gives us plenty of fresh air. Our heating system is very simple and dependable, and uses little electricity. Much of the year we don't need to run the solar heating fan, because enough heat rises passively through the vents in the floor. We have a lot of excess room in the basement that can be used for storage. Costs to maintain our solar basement have been very modest. The garage door opener in our basement that opens and closes the window insulation requires lubrication every year or two, but has not been replaced. The basement floor is painted black and needs to be mopped once or twice a year to help it absorb sunlight. At monthly intervals in late winter and spring, we tilt the reflecting panels in front of our basement, sending noontime sun directly into the basement windows.

Final Thoughts

We are very pleased with how well our design is working. Although there were some defects, the real-world performance is excellent, and the operating costs have been much lower than a conventional heating system would have been. One area that could use improvement is the use of sustainable building materials. Our basement is of conventional steel-reinforced concrete, with considerable embodied energy. If you compute the amount of carbon dioxide emitted in producing the concrete, and divide that by the emissions saved annually, you can estimate an emissions pay back period, after which the environmental damage will have been offset. We have estimated that the embodied energy of the concrete in our basement is equivalent to 1,500 gallons of propane, and the pay back period was about 1.6 years. Much more pollution could be prevented if this design were commonly built. The affordability makes it practical for more families to purchase solar houses. We would be delighted to offer advice to anybody working toward that goal.

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