COST EFFECTIVE PASSIVE SOLAR FOR NEW HOME CONSTRUCTION

Steve Kawell
Durango Solar Homes, LLC
310 Craig Lane
Durango, CO 80303
E-mail: solar@stevekawell.com

ABSTRACT

As the owner of a design/ build firm that specializes in passive solar homes, I see clients come to us struggling to juggle a strong commitment to an energy-efficient home design with budgetary limitations**.** Our firm has put together what we consider to be one of the most cost-effective design programs to create simple, cost effective, high-performance solar homes.

We believe in keeping the design and construction details as simple and economical as possible.

Our design program utilizes a whole systems approach, encompassing everything from energy efficiency to water conservation to indoor air quality. For this paper I will focus on passive solar heating and cooling strategies.

The following is a description of the program we used to design and construct a 2800 sq. ft. solar home in southwest Colorado.

Fig. 1: East elevation of subject house.

1. INTRODUCTION

The building site is located at 7400 feet in elevation, with approximately 6900 heating degree-days and over 300 days of sunshine per year.

The subject site is north facing and fairly steep with large ponderosa pines. Fig. 1 shows east elevation with entry. The home was completed in the spring of 2011.

The basic concept of this design program is to combine a very energy efficient building envelope with direct gain passive solar heating and cooling elements.

With these two tactics we can provide 75% - 85% of the home's heating and 100% of cooling needs.

With the addition of a high efficiency boiler we most cost effectively supply the final 15% -25% of the heating load. Our final piece of this approach, budget allowing, is to integrate renewable energy generation, i.e., solar thermal and photovoltaic**.**

2. ENERGY CONSERVATION

Our primary objective, and best return on investment, is to reduce the heating and cooling loads. We achieve this objective with a tight and well-insulated building envelope. We build exterior walls with advanced framing techniques utilizing 2x6, 2 ft. o. c. framing. The wall cavity is insulated with open cell spray foam. We find the open cell foam to be a good R-value and an excellent air barrier. It's also less toxic and less expensive than closed-cell foam.

The entire exterior of the wall is covered with 2" expanded polystyrene above grade and 2" extruded polystyrene below grade. The exterior finish material is cement based stucco. The combined above grade wall insulation is rated at R-28.

The vaulted ceiling areas use open cell foam applied directly to the underside of the roof sheathing and is rated at R-43.
In the 2nd level flat ceiling area we first apply 3½" of open cell foam to the entire attic side of the dry-walled ceilings. This gives a continuous ceiling air-barrier. On top of the open cell foam we spray 14" of loose fill cellulose insulation to achieve R-68.
We think this is the most cost effective way to create a tight, high R-value ceiling insulation assembly for flat ceiling areas.
The concrete slabs on grade are insulated with 2" of extruded polystyrene, rated at R-10.
The blower door test recorded 1.0 ach50.
We further reduced the energy load by using CFL & LED lighting and Energy Star rated appliances and ceiling fans.

3. PASSIVE SOLAR

With our area of the country receiving over 300 days of sunshine a year, a solar design is a logical choice.
The simplest and most cost effective solar strategy is to start with a passive solar direct gain system, basically allowing the winter sun's rays to penetrate the building via south facing windows.

3.1 Orientation

This building's orientation is within 5 degrees of solar south. We feel that proper orientation is one of the most important keys to a successful passive solar design.
The general geometry of the building is a rectangle, with a long east-west axis. This gives us a large south-facing facade in which to place the direct gain solar windows.

3.2 South windows

The design has approximately 8% south window area to floor area. This percentage of window area seems to work well with the amount of thermal mass in this plan.
We find that it's important to size the south solar gain windows in each interior space proportionately to the size of the room, in other words, large room, large window area, smaller room, smaller window area. Fig. 2

This home also employs different types of low-E window glazing on different facades. The south exposure has low-E 179, which has a higher SHGC (solar heat gain coefficient) than the low-E 260 windows facing other directions.
This allows more solar heat gain through the south windows during the winter heating season.


Fig. 2: South elevation at winter solstice.

This site's solar exposure is slightly diminished by large Ponderosa pines casting shadows across the south windows. The shadows are constantly moving as the day progresses, reducing the solar radiation but still allowing adequate solar heat gain.

3.3 Thermal mass

We have incorporated into the design several forms of thermal mass.
The most prominent is the 5" thick concrete slab-on-grade that makes up more than half the main floor area.
This concrete slab serves several functions.
First**,** as the design's primary thermal mass element, it stores incoming direct gain solar heat.
Second, it is the heat distribution component of the hydronic heating system.
Third**,** we stained and sealed the concrete slab and it serves as a finished floor.
We really like the idea that a single piece of the design can serve several functions.

The framed floor areas are constructed with 3" concrete slab caps and are covered with either tile, hardwood or carpet. These thinner concrete floor areas also have heat tubing for hydronic heat distribution.

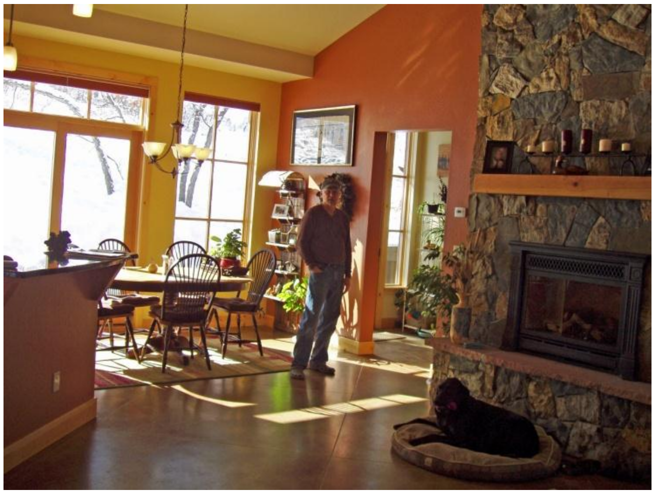
Fig. 3: Stained concrete finished floor.


Fig. 5: Sun & hydronic heated thermal mass floor.


Fig. 4: Vibrant living spaces.


Fig. 6: Sun rays on granite counter thermal mass.

The second form of thermal mass is the the large stone veneer fireplace in the great room area. The stone face is a 2” thick veneer attached to a wood frame with Portland based morter. Fig.3 & Fig. 10

Large granite kitchen counter tops work as additional mass. It is ideal that the tops are in direct line of the incoming winter solar radiation. Fig. 5 & Fig. 6

We also installed 5/8” thick drywall through-out the house, replacing the more standard ½” thickness and giving the house additional mass.

We find the best thermal mass is dense, not too thick (5/8”-6”) and with a large surface area to absorb and reradiate. The thermal mass helps stabilize the interior temperature as solar energy is added . The perfect battery to store excess heat during the winter heating season.

4. <u>SUMMER COOLING</u>

Cooling the structure during the summer months is an equal focus of this design.
Daytime summer temperatures in this part of Colorado can reach the upper 90’s. The home features
several approaches to reduce interior summer temperatures.

4.1 <u>Shading features</u>

The first strategy is to block the direct summer solar radiation from entering the building interior via South window openings.
We have designed the overhangs on the South side of the building to shade the window areas from the summer sun. The south eve overhang starts 18” above the top of window and extends out 24” from the face of the wall.

Fig. 7 photo taken at noon on June 21^{st}, the summer solstice, clearly shows the noon shadow line of the summer window shading.

Fig. 7: Summer solstice noon shading.

The second shading design element is a two story covered porch on the west face of the building.
This balcony structure is fabricated with raw tube steel.
The porch's shadow effectivly reduces the amount of afternoon summer sun directly striking the west windows and exterior building surfaces.
The west-side windows are also equiped with a low SHGC glazing to reflect summer solar radiation.
Fig. 8 shows this west side shade porch constructed with durable low maintainence materials .

Fig. 8: West side shade porch.

A good passive solar design synchronizes the building interior to the changing seasons, cool shaded summers, warm sunny winters.

The shading elements combined with proper orientation fine-tune the seasonal solar radiation contacting the building face and interior.

4.2 Ventilation

A unique weather factor of the inter-mountain west is the dramatic temperature swings between day and night.
It is not unusual to have a 30 – 40 degree temperature change.
We have used this day/night temperature differential to design natural air movement systems to cool the interior.
The key is to remove the warm air accumulated during the day and replace it with the cool night air and to do it passively.
We use small (2- 21"x 26") operable skylights for both day lighting and more importantly, to ventilate. The skylights are located in the 2^{nd} level ceiling directly above the stair well, creating a nice chimney effect. Fig. 9 & Fig. 7 show skylights from interior & exterior.
By opening the skylight after sundown, the warmest stratifying air collecting near the ceiling is vented out and cooler night air is drawn in through open lower floor windows. This utilization of the passive stack effect requires no electric fan, just a small motor to open and close the skylight.

Fig. 9: Skylights in second level ceiling.

The skylight is equipped with a rain sensor that automatically closes the skylight when a rain drop contacts it.

Operable windows are incorporated on all facades of the building to create cross ventilation throughout the interior. Occupants can create a comfortable interior temperature for most of the year, simply by adjusting window openings.

Ceiling fans are also installed in all bed rooms and the large great room area to move & mix air when needed.

When the interior mass is cooled with night air, the house can then be closed up during the heat of a summer day and the interior will remain cool until the sun sets and the house can again be flushed with cooler night air. This nighttime cooling of the mass allows the house to passively maintain a comfortable interior temperature through the hottest days of summer.

All four types of thermal mass can be seen in Fig 10, concrete floor, stone veneer fireplace, granite counter top and 5/8" thick drywall.

Fig. 10: Thermal mass elements.

5. INSULATING WINDOW BLINDS

Another important component of this passive solar strategy is the insulating window blinds. The window treatments are a simple double-cell honeycomb design with an inset mounting style that uses the window jamb to create a frame around the blind. Fig 11

The blinds almost double the insulating value of the windows. The window and insulating blind combined R-value is R-6 to R-7 (U-value .16 - .14).

The comfort level of the occupants on a cold winter's night is greatly increased compared to a window without insulating blinds.

Another important property of the blind is its ability to adjust the incoming sunlight through the south windows during the winter heating season. An example**:** Closing the blinds half way in the dining room windows to more comfortably enjoy lunch. The blinds enable the homeowner to adjust the intensity of the in-coming winter sunlight.

Fig. 11: Inset mounted insulated window blinds.

6. COMPLEMENTARY HEAT SYSTEM

To supply the last 15-25% of the heat load and compensate for cloudy days when the sun's heat contribution is minimal we use a high-efficiency gas boiler hydronic heating system. We think this is an excellent match with passive solar direct gain. It uses the thermal mass floor for its heat distribution component thus maintaining a consistent floor temperature range, giving the occupants a more comfortable experience.

The boiler is a sealed combustion high efficiency gas unit, rated at 95.0 AFUE. It has the ability to modulate, slowing the burn rate if only one zone requires heat. Fig.12

Fig. 12: High efficiency boiler and zone valves.

The in-floor hydronic heat tubing is designed with different zones on the north & south sides of the house. This zoning design complements the passive solar direct gain by enabling homeowners to separately add heat to the north areas of the house which benefit less from direct gain solar.

This house is equipped with programmable thermostats one for each of the seven zones.

We have the thermostats programmed to allow the thermal mass of the floor to be operated like a flywheel. Thermostats are programmed to turn on the boiler prior to the owners waking in the morning. This short input of heat from the boiler warms the floors in the morning, while the passive solar gain takes over warming the floors through the day. The thermal mass helps maintain a comfortable interior temperature even after the sun has set. The mass floors are allowed to cool during the night until the boiler starts the heat cycle all over again with an early morning shot of heat. This flywheel cycling creates a wonderfully comfortable interior space that coordinates the timing of the boiler input with the solar gain, getting the most out of both.

Fig. 13: Floor heat tubing ready for concrete

With a relatively tight building envelope, 1.0 ach50, we installed an air-to-air heat exchanger to provide the interior living space with fresh/filtered air. The HRV is set to run at a low constant speed and if needed can be adjusted to higher speeds with a wall mounted key pad.

7. <u>THIRD PARTY CERTIFIED</u>

The house was third party energy tested by Annadel Building Solutions LLC, a certified Energy Star rater. The Energy–Star, Home Energy Rating System was used and the house received a HERS index of 50.

Fig. 14: Blower door test, third party certified.

8. ACTIVE SOLAR

An important piece of the energy puzzle is a solar thermal system for domestic hot water. The solar hot water system has two- 3' x 6' panels and uses an 80 gal. storage tank. The storage tank has electric heating elements for cloudy days when solar collection is minimal. Fig.15
The initial $ 9,000.00 system price tag was reduced 2/3 by qualifying for federal tax credits and state rebates.

Fig. 15: Solar thermal collectors.

We also installed a circulation pump to efficiently supply solar heated hot water to a distant powder room and kitchen sink. It is activated with an occupancy switch in each room that turns the pump on when a person enters the room. It saves water by having almost instant hot water at the faucet, no need to let the water run down the drain waiting for it to get hot.

The upper south roof area is dedicated for a future photovoltaic array. The structure is prewired for a simplified PV system installation.

The building's orientation is ideal for passive solar as well as the solar thermal collectors and future P.V. array.

Fig. 16: Beautiful dynamic living spaces.

One important point that we have learned from working with passive solar is that the living space is the solar collector. Make sure that the occupants' comfort is the primary concern, not just maximizing solar BTU's.

A good passive solar home design creates beautiful dynamic living spaces that are synchronized with the changing seasons.

9. ACKNOWLEDGMENTS

Thanks Darrell & Eileen for sharing the vision.