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Some Considerations in Passive Solar Design

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A GOOD PASSIVE SOLAR DESIGN must combine five important components: site selecttion, climate, building materials, indoor-outdoor environment, and the sun and its travel patterns.

Site selection considerations include proper orientation of the home, solar access on the south side of the home between 9 a.m. and 3 p.m., and adequate vegetation to ensure a good windbreak.

The local climate and the indoor-outdoor environment are important. They dictate the design indoor and outdoor temperatures for both winter and summer, and they affect heat losses and/or gains throughout the year.

A proper selection of building materials is important. A thermal mass is needed in a solar home to store heat during warm winter days and release the stored heat at night. A thermal mass also helps temper the indoor temperatures throughout the year.

Understanding the sun's travel patterns is crucial because the sun, in Michigan latitudes, does not follow the seasons. Spring conditions do not begin in Michigan on March 21, the day on which the sun reaches the spring solstice. As a result, fixed overhangs used as shading devices generally do not work well in Michigan. Shading devices that keep the sun out on September 21 (when heat may not be needed) will also keep the sun out on March 21 (when heat may be needed). Factors such as this must be incorporated into a total passive solar design.

USE A GOOD DESIGN

A good design should do four basic things:

1: Eliminate the effects of daily temperature extremes — It must provide enough thermal mass of the right kind to absorb excess solar energy on a given warm sunny day to prevent overheating, and to release that heat into the home when the temperature falls below the comfort level.

2: Allow the house to modulate itself so seasonal extremes are not too noticeable — In effect, the house must behave like an earth-sheltered home—in which the stable earth temperatures allow the house to essentially experience the same temperature all year round. In a passive solar home, a similar effect can be achieved by proper selection and use of insulation, building materials and thermal mass.

3: Allow the home to open up on sunny winter days to absorb heat, and close up at night to hold the heat in.

4: Allow the home to close up on hot or sunny summer days to keep heat out, but open up on clear summer nights to allow coolness to come in.

All four of these items essentially express one important design objective: the building must interact with the climate. The importance of this concept cannot be overemphasized. The design must allow the house to be a solar collector—to let heat (or coolness) in and out when required. The house must be a solar storehouse, storing heat for cold periods, and coolness for undesirable warm or hot periods, and it must be a good trap for heat (or coolness).

SUGGESTED ORDER OF DESIGN STEPS

1. Calculate your heating requirement. The heating load should be based on the *average heating season temperature* rather than the ASHRAE* design temperature used for sizing furnaces. Some help is given on calculating the heating requirement later on.

2. Identify your need. Determine how much of the heating requirement can be obtained from solar enrgy. In Michigan, do not expect to depend entirely on a solar energy system. Such a system would be so oversized that for most of the year, it would overheat the home. A more realistic objective is to plan to have solar energy provide from 30 to 60% of your annual heating requirement. This might mean that the sun will supply almost all your space heating requirements in spring and fall, but only meet 10 to 20% of your needs in December through February.

3. Evaluate the solar potential of the home. How much **usable** solar energy will the home receive during a typical heating season? In Michigan only two stations—East Lansing and Sault Ste. Marie—have reliable long-term solar data. Several solar energy books have data for the 40°N latitude, providing a good approximation for design purposes.

4. Re-evaluate your expected contribution from solar energy, depending on how far your solar potential (Step 3) is from the answer you obtained in Step 2.

5. Design your system, using the information obtained from Steps 2 through 4.

*Amer. Soc. of Heating, Refrigeration and Air Conditioning Engineers.

An Example

Step 1: heating requirement

Assume that your heating load for October through March, based on the average heating season temperature, is 200 million Btus.

Step 2: identification of need

You would like to obtain 60% (or 120 million Btus) of this from the sun.

Step 3: evaluation of solar potential

Assume that the only solar data available is the total daily vertical clear-day sunlight for the 40°N latitude. From October through March, this amounts to almost 11,300 Btu/ft²-day. With a total of 212 days from October to March, the total amount of energy available is 2.4 million Btu/ft².

Since Michigan experiences a lot of cloud cover, you may further decide that only 50%, or 1.2 million Btu/ft², can be collected. If your solar system (including thermal mass, glazing and absorber surface) has an efficiency of 60%, then the amount of usable heat available is 720,000 Btu/ft². For this amount of heat to provide 60% of your heating needs, you will need 167 ft² of total window or collection area.

This is equivalent to a window size of 6 ft by 28 ft, or four windows of 7 ft by 6 ft.

Step 4: re-evaluation of need

Not having the necessary southern exposure to install that large a window area, you may then decide to reduce your expected solar contribution to 40%. Your required total window area is now 111 ft².

Step 5: system design

Now, you are ready to design your system, knowing that you would need 111 ft² of vertical glazing area.

Comments

As demonstrated by the above example, design is not always a cut-and-dry procedure. Depending on how much information is available to begin with, decisions have to be made on various factors. The better informed you are, the less painful the procedure.

DESIGN FACTORS AFFECTING EFFICIENCY

Floor plans — The location of rooms in a passive solar home affects the comfort level of the occupants. Locate heavily used rooms in the southern part of the house, so these can benefit from natural lighting. The garage location should provide a buffer against the prevailing winter winds. The garage and other windbreaks reduce inmfiltration heat loss. ASHRAE has information on the direction of the prevailing winter winds in many Michigan cities.

Location of windows — When possible, do not locate windows on the north side of the house. Unless well protected, windows lose a great deal of heat in the winter, especially on the north wall of the house. Most of the windows in a solar home **must** be located on the south side.

In 40°N and higher latitudes, the south side of the building receives almost twice as much solar energy in the winter as it does in the summer.

East and west windows absorb about 2½ times more solar energy in the summer months than in winter. Therefore, while windows on the east and west sides won't add very much to winter heating requirements, they add to the summer cooling load and thus increase air conditioning requirements. On the other hand, east and west windows help ventilate the home, providing an interesting design problem. A solution may be to put one window each on the east and west ends of the home, for ventilation. You may also install an air-to-air heat exchanger to provide ventilation.

Thermal mass — This is a crucial consideration. It is discussed later on.

Tightness of the building shell — A solar home must be designed tight. It must have adeqaute insulation in all walls, ceiling, and floor, and provide usable insulating devices for windows. Make sure that windows and doors fit properly, and install vapor barriers to keep infiltration at a minimum.

Orientation to the sun — Even though this may appear to be an obvious point, it is amazing the number of homes built without concern for orientation. Just walk down any street running north-south in your neighborhood, and see how homes are oriented. Proper orientation should have the long sides of the house facing north and south to allow for maximum solar gain. For homes on a north-south street, this may require putting the "front door" on the side of the house.

Siting: The site of the home should enable the home to benefit from as many natural windbreaks as possible, but it should not allow significant solid shade on the south side between 9 a.m. and 3 p.m. in winter. This can be done by planting (or saving) deciduous trees around the house. These lose their leaves in winter, allowing the sun to come in. In the summer months their fullness provides needed shading. The distance between a windbreak and a house must be 1½ to 2½ times the height of the home.

The shape of the house — The optimum shape loses the minimum amount of heat and gains the maximum amount of solar heat in the winter. It also gains and/or retains the minimum amount of solar heat in the summer. A solar gain analysis is required in order to determine the optimum shape. A square house is not optimum in any climate.

Heat recovery — It is usually cost-effective to include an air-to-air heat exchanger in your design. Air-to-air heat exchangers can recover up to 75% of the heat in exhausted air and transfer this heat to incoming fresh air. Less energy is then required to bring the incoming fresh air up to temperature. Air-to-air heat exchangers can also be used to transfer coolness from outgoing air to warm incoming air during the summer, to reduce air-conditioning requirements.

HEATING LOAD CALCULATION

Primarily the heat load of a home comprises the following losses:

1. Heat loss through exposed walls, ceiling and/or roof, and floors;
2. Heat loss through glass surfaces and doors; and
3. Heat loss due to infiltration of cold air.

The general heat loss equation is:

$$Q = U A (T_{in} - T_{avg})$$

where

Q is the heat loss in Btu/hr
U is the overall heat loss coefficient in Btu/hr-ft^2-F
A is the surface area normal to heat flow, ft^2
T_{in} is the inside temperature and
T_{avg} is the average outside heating season temperature, both in degrees F. U is related to the "R value" by this equation:

$$U = \frac{1}{R_{tot}}$$

where

R_{tot} is the sum of the R values of all the materials that make up the wall section, window or door, etc.

Infiltration Heat Loss

This refers to the heat required to warm cold air seeping into the home around windows and doors, electrical outlets, and through gaps and crasks in the thermal shell of the house. There are two ways to calculate it, depending on whether the air exchange rate is known or not.

If the air exchange rate is known, the formula is:

$$Q_I = 0.018 \times AC \times VOL$$

where

Q_I is the infiltration heat loss in Btu/hr
AC is the rate of air exchange in hr^{-1}
VOL is the volume of the home in ft^3
and
0.018 is the specific heat of the air in Btu/ft^3.

If the number of air exchanges is not known, then the relation is:

$$Q_I = 0.018 \times Q_a \times (T_{in} - T_{out})$$

where

Q_a is the air entering by infiltration in ft^3/hr.

This quantity is very sensitive to the air veolocity.

The air exchange rate should not be less than one-half air change per hour, unless an air-to-air heat exchanger is installed.

THERMAL MASS SELECTION

Thermal mass must be compared in terms of initial and/or operating costs, convenience and dependability, weight, heat storage capacity, and space requirements, among other factors. Thermal mass is used as a storage and/or collection system. It includes masonry walls, water walls, and "phase change" materials (also known as eutectic salts). The incorporation of thermal mass in passive design enables the home to become a container for storing heat.

General Comments

1. A thermal storage mass should be over-sized rather than undersized. This is because under-sizing the storage could lead to wide temperature fluctuations in the home. The alternative is to initially undersize the thermal storage, but make provision for additional thermal mass space, so more mass can be installed later, if necessary.

2. The tighter the home, the larger the thermal storage system needed. Since a tight home loses very little of the solar gain, more space is required to store the heat than in a less efficient home.

3. Every part of the home—walls, floors, roofs, and partitions—can be used as storage containers. Non-structural containers can also be used for storing heat. Water drums are often used for that purpose in solar greenhouses.

4. Floors being used as thermal mass **must not** be covered with carpets.

5. It is preferable for the thermal mass to have a dark surface (to enhance absorption of solar energy) and be in direct or reflected sunlight.

6. In general, indoor temperature fluctuations decrease with an increase in thermal mass wall thickness.

Sizing Thermal Masses

In general, the volume of water or masonry required for heat storage in a passive solar home can be computed by using the following relationship:

$$VR = \frac{HS}{C_p \times TD}$$

where:

VR is the volume of storage required, in ft^3

HS is the quantity of heat to be stored, in Btu

C_p is the heat capacity of the storage medium in Btu/ft^3-F

and

TD is the required temperature range.

An Example:

In the example before:

$$HS = 1.2 \text{ million } Btu/ft^2 \times 111 \ ft^2$$

or HS = 133.2 million Btu over the season. Using a water wall storage, the heat capacity of water, C_p, is 62.4 Btu/ft^2. If the heat is stored through a temperature change of 30°F, then:

$$VR = \frac{133.2 \text{ milliion}}{62.4 \times 40 \times 212} = 334 \ ft^3$$

If you put the water wall right behind the glazing, then it will have the same surface area as the glazing. The water wall thickness required is:

$$\text{Thickness} = \frac{\text{volume}}{\text{area}} = \frac{334}{111} = 3 \text{ ft}$$

Information on sizing other thermal mass patterns are provided in "The Thermal Mass Pattern Book."*

**Total Environmental Action, Inc., 105 Church Hill, Harrisville, N.H. 03450.*

Phase Change Materials

The basic principle of using phase-change materials as thermal mass is this: as a material changes phase (or state) from solid to a liquid, it stores a very large amount of heat. For example, it takes 1 Btu of heat to raise the temperature of 1 pound of water by 1°F. However, it takes 144 Btu to melt 1 poundof ice, even though the temperature only changes by 1°F, from 32°F to 33°F.

On changing back from liquid to solid, the material gives up all the heat that was required to melt it. Since water freezes at 32°F, it is not a good phase-change material for solar storage—most people like to keep their homes between 65°F and 72°F. However, phase-change materials like Glauber's salt which melt between 85°F and 120°F are ideal media for storing solar heat.

The major advantage of phase-change materials is that they require very little space. For example, to store 125 Btu through a temperature change of 30°F, it will take only 2 pounds of Glauber's salt. However, it would require about 4 pounds of water and 20 pounds of rock to store the same amount of energy.

Volume Requirements of Eutectic Salts

The following relationship can be used to calculate the volume of phase change material required:

$$VR = \frac{HS}{(HF + CP \times TD) \times DM}$$

where:

HF is the heat of fusion (the heat required to melt a pound of the material), in Btu/lb

CP is the amount of heat stored in a pound of the material for a 1ºF rise in temperature, in Btu/lb-F and

PM is the density of the material, in lb/ft³.

An Example

In the previous example, if you had decided to use Glauber's salt instead of water (under the same conditions), then HF = 104, C_p = 0.7 and DM = 97; TD is still 30. Then, the volume required will be:

$$VR = \frac{133.2 \text{ million}}{[104 + 0.7 \times 30] \times 97 \times 212} = 52 \text{ ft}^3$$

It is apparent that this provides for an immense savings in storage space requirements, compared to using water as storage. The Glauber's salt requires only 15.6% of the space.

SUMMARY

A passive solar system can be incorporated into plans for new homes, without significantly changing the original design. It can also be used effectively in existing homes. If the home (old or new) is reasonably well insulated and sealed against the harsh Michigan winters, the economic results of letting the sun in will be well worth the effort.

As already stated, the design process is hardly ever exact, especially when so little solar data is available in Michigan. It is important, therefore, to monitor the new or retrofitted home for several heating seasons, keeping good records. This allows one to compare actual performance to what the design had projected. The performance data may also suggest ways to improve the design.

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Further Reading

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