A DESIGN AND SIZING PROCEDURE FOR PASSIVE SOLAR HEATED BUILDINGS

by Edward Mazria AIA

INTRODUCTION

Passive solar heating systems are integral to the architecture of a building, or, to put it another way, the building or some element of it *is* the system. Whereas conventional or active solar heating systems can be somewhat independent of the conceptual organization of the building, it is extremely difficult to add a passive system to a building once it has been designed.

All acts of building, no matter how large or small, are based on rules-of-thumb. Architects, contractors, mechanical engineers and owner-builders, design and build buildings based on the rules-of-thumb they have developed through the years of their own or other people's experience. For example, a rule-of-thumb to determine the depth of 2-inch floor joists is given as *1/2 the span of the joists (feet) in inches, plus two*, or to span a 20 foot space one would need roughly 2 x 12 inch joists. Calculations are used to verify and modify these rules-of-thumb after the building has been designed.

THE PROCESS

Passive systems demand a skillful and total integration of all the architectural elements within each space—glazing, walls, floor, roof and in some cases, even interior surface colors.

Two concepts are critical to understanding the thermal performance of a passively heated space. They are:

1. That the quantity of south glazing, insulating properties of the space, and outdoor climatic conditions will determine the average temperature in a space over the day, and that the size, distribution, material, and in some cases (Direct Gain systems) surface color of thermal mass in the space will determine the daily fluctuation above and below the average indoor temperature.

In the process of storing and releasing heat, thermal mass in a space will fluctuate in temperature, yet the object of the heating system is to maintain a relatively constant interior temperature. In a Direct Gain system, with masonry thermal mass, the major determinant of indoor air temperature fluctuations is both the amount of exposed surface area of masonry in the space and the distribution of sunlight over the masonry surface; in a Thermal Storage Wall system, it is the thickness of the material used to construct the wall; and in a Roof Pond system, it is the quantity of water in the pond.

DIRECT GAIN

Direct Gain systems are characterized by daily fluctuations of indoor temperatures which range from only 10°F to as much as 30°F. The heating system cannot be turned on or off since there is little control of

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natural heat flows in the space. To prevent overheating, shading devices are used to reduce solar heat gain, or excess heat is vented by opening windows or activating an exhaust fan.

The major glass areas (collector) of each space must be oriented to the south for maximum solar heat gain in winter. However, these windows can serve other functions as well, such as openings for light and views.

Each space must also contain enough thermal mass for the storage of solar heat gain. This implies a heavy masonry building, however, the masonry can be as thin as four inches. If an interior water wall is used for heat storage, then light weight (wood frame) can be used.

A. South Glazing:

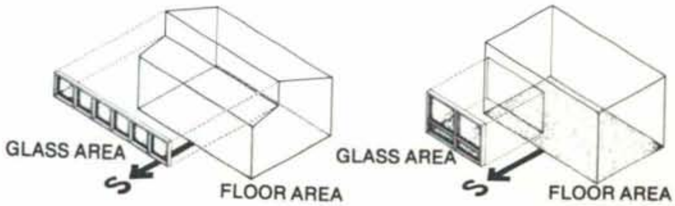
Our criterion for a well designed space is that it gain enough solar energy, on an average sunny day in winter, to maintain an average space temperature of 68°F ± over that 24 hour period. The following table lists ratios for various climates and locations that apply to a well-insulated residence:

TABLE 1

Average Winter (Clear-day) Outdoor Temperature[1]	Glazing/Floor Area[2] 36°NL	
Cold Climates		
20°F	.24	(w/night insul.)
25°F	.22	(w/night insul.)
30°F	.19	
Temperate Climates		
35°F	.16	
40°F	.13	
45°F	.10	

Notes: [1]Temperatures listed are for December and January, usually the coldest months.

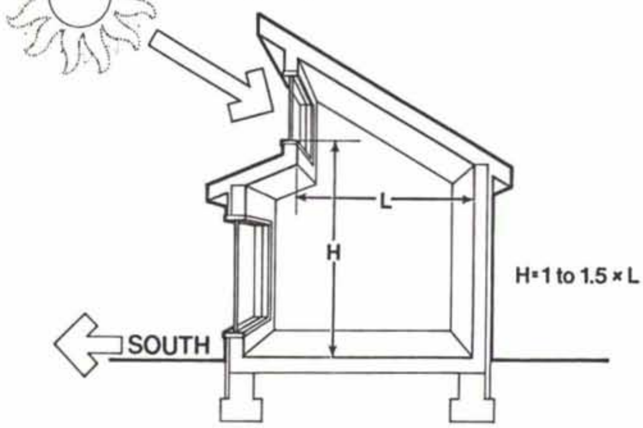
[2]These ratios apply to a well insulated space with a heat loss of 8 BTU/day/sq. ft. fl./°F. If space heat loss is more or less than this figure, adjust the ratios accordingly.



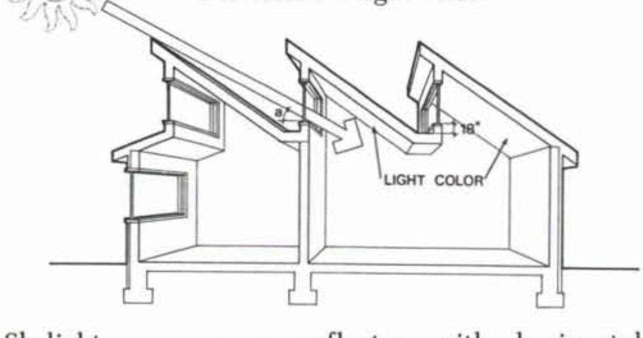
For example, in Denver, Colorado at 40°NL, with an average January temperature of 30°F, a well insulated space would need approximately 0.20 square feet of south-glazing for each one square foot of space floor area (i.e., a 200 square foot space needs 40 square feet of south-glazing).

In a Direct Gain System, sunlight can also be admitted into a space through clerestories and skylights, as well as through vertical south-facing windows. Use the following guidelines when designing clerestories and skylights:

Clerestory — locate the clerestory at a distance in front of an interior thermal storage wall of roughly 1 to 1.5 times the height of the thermal wall. Make the ceiling of the clerestory a light color to reflect and diffuse sunlight down into the space.



Sawtooth Clerestories — make the angle of each clerestory roof (as measured from horizontal) equal to, or less than the altitude of the sun at noon, on December 21, the winter solstice. Make the underside of the clerestories a light color.



Skylight — use a reflector with horizontal skylights to increase solar gain in winter and shade both horizontal and south-facing skylights in summer to prevent excessive solar gain.

B. Thermal Storage Mass:

The two most common materials used for storing heat are masonry and water. masonry materials transfer heat from their surface to interior at a slow rate. If direct sunlight is applied to the surface of a dark colored masonry material it will become uncomfortably hot, giving much of its heat to the air in the space rather than conducting it away from the surface for storage. This results in daytime overheating and large daily temperature fluctuations in the space. To reduce fluctuations, direct sunlight must be spread over a large surface area of masonry so that roughly 60% of the solar energy admitted into the space is stored as heat in ;the walls and/or floor and/or ceiling at sunset. To accomplish this:

Construct interior walls and floors of masonry at least 4 inches in thickness.

Diffuse direct sunlight over the surface area of the masonry by using either a translucent glazing material by placing a number of small windows so that they admit sunlight in patches, or by reflecting direct sunlight off a light colored interior surface first.

Use the following guidlines for selecting interior surface colors and finishes:

- masonry floors a dark color
- masonry walls any color
- lightweight construction (little thermal mass) a light color to reflect sunlight to masonry surfaces
- avoid direct sunlight on dark colored masonry surfaces for long periods of time
- do not use wall-to-wall carpeting over masonry floors

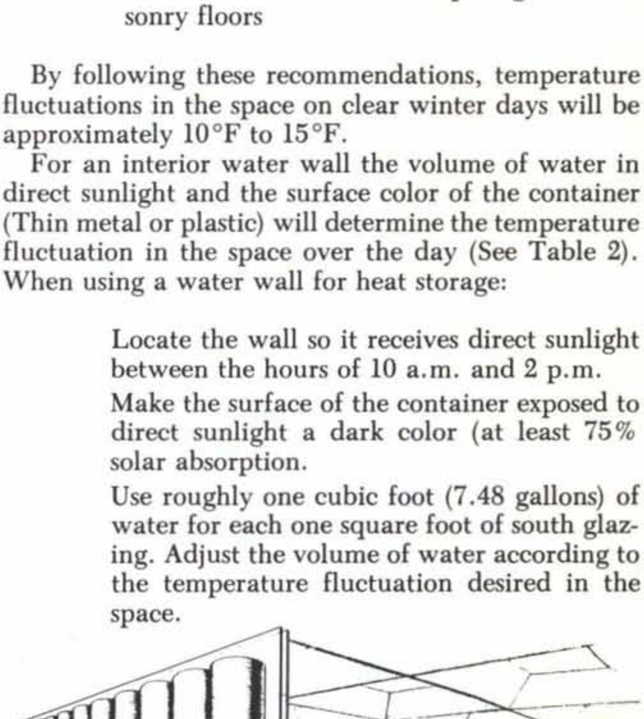
By following these recommendations, temperature fluctuations in the space on clear winter days will be approximately 10°F to 15°F.

For an interior water wall the volume of water in direct sunlight and the surface color of the container (Thin metal or plastic) will determine the temperature fluctuation in the space over the day (See Table 2). When using a water wall for heat storage:

Locate the wall so it receives direct sunlight between the hours of 10 a.m. and 2 p.m.

Make the surface of the container exposed to direct sunlight a dark color (at least 75% solar absorption.

Use roughly one cubic foot (7.48 gallons) of water for each one square foot of south glazing. Adjust the volume of water according to the temperature fluctuation desired in the space.



Note that when using an interior water wall there are few restrictions regarding other wall and floor materials and surface colors in the space. The water can be stored within an interior wall or in free standing containers, as long as the surface of the water wall is a thin material exposed to direct sunlight.

TABLE 2
DAILY SPACE AIR TEMPERATURE FLUCTUATIONS[1] FOR DIRECT GAIN WATER STORAGE WALL SYSTEMS[2]

Solar Absorption (Surface Color)	Volume[3] of Water Wall for Each One Square Foot South-Facing Glass: 1 cu. ft.	1.5 cu. ft.	2 cu. ft.	3 cu. ft.
75% (Dark Color)	17°F	15°F	13°F	12°F
90% (Black)	15°F	12°F	10°F	9°F

Notes: [1]Temperature fluctuations are for a clear winter day with approximately 3 square feet of exposed wall area for each one square foot of glass. If less wall area is exposed to the space, temperature fluctuations will be slightly higher. If additional mass is located in the space (such as masonry walls and/or floor) then fluctuations will be less than those listed and therefore less water can be used.

[2]Assumes 75% of the sunlight entering the space strikes the mass wall.

[3]One cubic foot of water = 62.4 lbs. or 7.48 gallons.

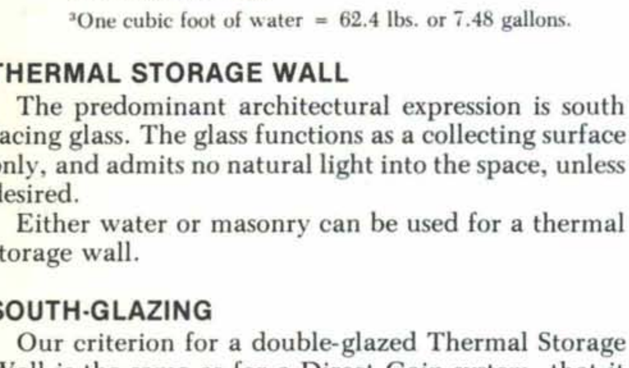
THERMAL STORAGE WALL

The predominant architectural expression is south facing glass. The glass functions as a collecting surface only, and admits no natural light into the space, unless desired.

Either water or masonry can be used for a thermal storage wall.

SOUTH-GLAZING

Our criterion for a double-glazed Thermal Storage Wall is the same as for a Direct Gain system, that it



DAY

transmit enough heat on an average sunny winter day to supply a space with all its heating needs for that day. To accomplish this use the following tables* as a guide for sizing the glazing of masonry or water wall:

*These tables apply to a well insulated space with a heat loss of 8 BTU/day/sq.ft. fl./°F. If space heat loss is more or less than this figure, adjust the ratios accordingly. The surface area of the wall is assumed to be the same size as the glazing.

TABLE 3

Average Winter (Clear-day) Outdoor Temperature	Masonry WALL/Space Floor Area[1] 36°NL
Cold Climates	
20°F	.71
25°F	.59
30°F	.50
Temperature Climates	
30°F	.40
40°F	.32
45°F	.25

Average Winter (Clear-day) Outdoor Temperature	Water Wall/Space Floor Area[1] 36°NL
Cold Climates	
20°F	.52
25°	.45
30°	.36
Temperate Climates	
35°	.28
40°	.23
45°	.17

Note: [1]For thermal walls with a horizontal specular reflector equal to the height of the wall in length, use 67% of the recommended rations. For thermal walls with night insulation (R-8), use 85% of the recommended rations. With both night insulation and reflectors, use 57% of the recommended rations.

For example, in Boston, Massachusetts, at 42°NL, with an average January temperature of 31.4°, a well insulated space will need approximately 0.41 square feet of double-glazed water wall for each one square foot of building floor area, (i.e., a 200 square foot space will need about 82 square feet of glazing).

WALL DETAILS

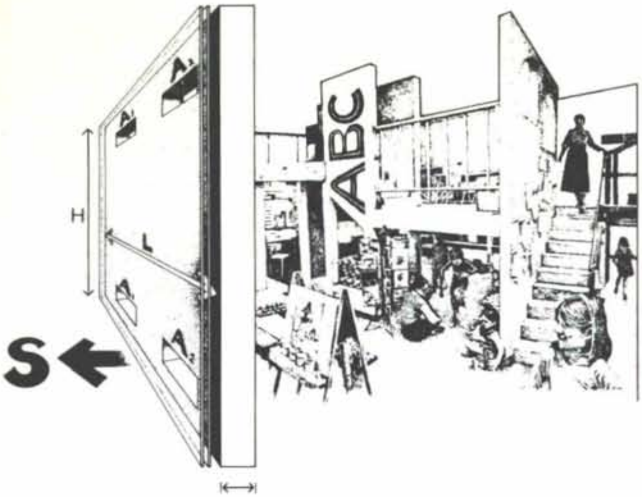
While the above procedure gives guidelines for the overall size (surface area) of a Thermal Storage Wall, the efficiency of the wall as a heating system depends mainly on its thickness, material and surface color.

Material	Recommended Thickness
Adobe	8 - 12 inches
Brick (common)	10 - 14 inches
Concrete (dense)	12 - 18 inches
Brick[1] (magnesium oxide additive)	16 - 24 inches
Water[2]	6 inches or more

Notes: [1]Magnesium oxide is commonly used as an additive to brick to darken its color. It also greatly increases the thermal conductivity of the material.

[2]When using water in tubes, cylinders, or other types of circular containers, use *at least* a 9½ inch diameter container or 1/2 cubic foot (31 lbs., 3.7 gallons) of water for each one square foot of glazing.

The choice of a wall thickness, within the range given for each material, will determine the air temperature fluctuation in the space over the day. Use the following table for selecting a wall thickness:



APPROXIMATE SPACE TEMPERATURE FLUCTUATIONS[1] AS A FUNCTION OF THERMAL STORAGE WALL MATERIAL AND THICKNESS

	Wall Thickness in Inches					
Material	4	8	12	16	20	24
Adobe	-	18	7	7	8	-
Brick (common)	-	24	11	7	-	-
Concrete (dense)	-	28	16	10	6	5
Water	31°F	18	13	11	10	9

Note: [1]Assumes a double-glazed thermal wall. If additional mass is located in the space, such as masonry walls and/or floors, then temperature fluctuations will be less than those listed. Values are given for clear winter days.

The greater the absorption of solar energy at the exterior face of a thermal wall, the greater the quantity of incident energy transferred through the wall into the building. Therefore:

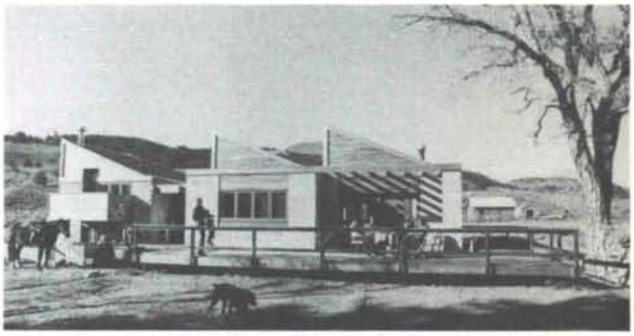
> Make the outside face of the wall a dark color (perferably black) with a solar absorption of at least 85%.

In cold climates, the addition of thermocirculation vents in a masonry wall will significantly increase the performance of the wall. In mild climates the vents are unnecessary since winter daytime temperatures are comfortable and heating is usually not needed at that time. To size the vents:

> Make the total area of each row of vents equal to approximately one square foot for each 100 square feet of wall surface area.
>
> Prevent reverse air flow at night by placing an operable damper over the inside face of the upper row of vents.

CONCLUSION

Since a building, or some element of it, *is* the passive system, the use of passive solar energy must be included in every step of a building's design. The format outlined here provides a method for including technical information in a way that can be applied by architects, builders and owner-builders. *E.M.*



A successful use of Sawtooth Clerestories.

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