THERMAL STORAGE WALL DESIGN MANUAL

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The purposes of this Association shall be to further solar and related arts, sciences, and technologies with concern for the ecologic, social, and economic fabric of the region. This shall be accomplished through exchange of ideas and information by means of meetings, publications, and information centers. The Association shall serve to inform public, institutional, and governmental bodies and seek to raise the level of public awareness of its purposes.

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Foreword

Interest in solar energy has been growing at an increasingly rapid rate over the past several years. Systems to heat and cool houses, heat water, distill water, dry food crops, and generate electricity are being shown to be feasible throughout the United States and world. The primary roadblock to expanded solar energy utilization is not the lack of technology, but the unavailability of easily understandable information. The purpose of this manual is to educate individuals about one method of heating a building with the sun's energy: through the use of a thermal storage wall.

This manual represents the combined and dedicated efforts of nearly the entire New Mexico Solar Energy Association staff. Particular credit is due to Tom Zeller for work on the heat loss section and help with coordination, Dennis Kensil for the glazing information and chart, Bristol Stickney, Lawrence Sherwood, Mary Beth Bliss and Ellen Morris for technical support, Stephanie Paladino for help with research and coordination, Karobi Kumalaugh for the graphics, Anne Cicero for the editing, and Florence Abersold for her hours spent typing.

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- A.T. Wilson

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Chapter 1

Introduction

In any solar energy system for space heating there are three functions performed: **collection** of solar energy, **storage,** and **distribution** of that energy (heat) from storage to living space. The two basic categories of solar systems for space heating - active and passive - perform these three functions, but in different ways. Active solar heating systems incorporate mechanical devices to circulate air or fluids through collectors and into thermal storage units such as water tanks or rockbeds. Additional fans or pumps are required to bring stored heat to areas where it is needed. Active systems can be quite complex and rely on external sources of energy to operate.

Passive solar heating systems, on the other hand, require no electrical or petroleum based energy to operate; they utilize natural methods of heat transfer - thermal conduction, natural convection, and thermal radiation.' **Thermal conduction** refers to heat transfer from warmer to cooler areas within or between objects by direct contact of particles within the objects.2 **Natural convection** transfers heat between two objects through a moving fluid such as air or water.3 Radiation is the transfer of heat through space by wave motion. In all three modes, heat moves from warmer to cooler objects. The greater the difference in temperature, the greater the heat flow.

Passive systems perform the three functions of collection, storage, and distribution of solar energy in the following way. Sunlight enters the clear or translucent section of a wall. This section (known as glazing) should be on the south side of a building (in the Northern Hemisphere) to collect the maximum amount of solar radiation available. Solar radiation is then absorbed by the storage medium behind the glazing. This stored heat is distributed into the living space by means of the three transfer mechanisms mentioned above.

There are five basic designs for passive solar space heating: direct gain, solar greenhouse, convective air loop, roof pond, and thermal storage walls. This manual focuses on the design and operation of the last system: thermal storage walls.

THERMAL STORAGE WALLS - AN OVERVIEW

Thermal storage walls fall into three general categories: those utilizing a massive wall to store heat - these are known as Trombe walls; those utilizing a water wall to store heat; and the more experimental type in which heat is stored in eutectic salts or salt hydrates. Because Trombe walls are the most used type of thermal storage wall, much of our discussion will focus on them. Five elements of a thermal storage wall can be identified: glazing, air space between glazing and wall, the mass or storage wall, vents (in some thermal storage walls), and roof overhang (especially in warm climates). These will be discussed in detail later in this manual; it is important here only to introduce how these elements enable a thermal storage wall to function in heating a building. (See Diagram A)

1 Systems utilizing both active and passive components are frequently termed "hybrid."

2 Thermal Conduction: Process of heat transfer through a material medium in which kinetic energy is transmitted by the particles of the material from particle to particle without gross displacement of the particles -ASHRAE 1977 Fundamentals 33.4.

3 Natural Convection: Circulation of gas or liquid (usually air or water) due to differences in density resulting from temperature differences - ASHRAE 1977 Fundamentals.

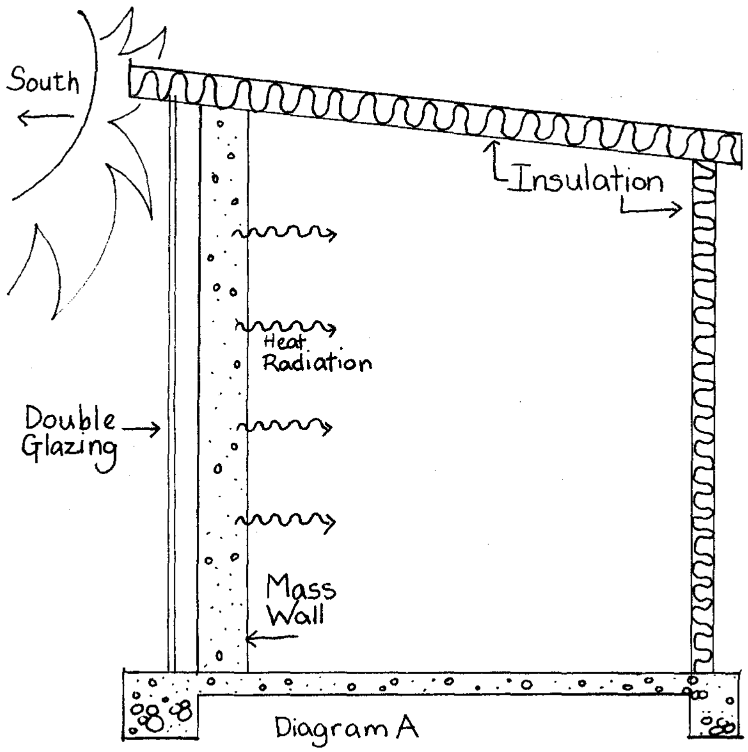

Diagram A. Unvented thermal storage wall showing double south glazing, thick mass wall, insulated roof and north wall. (Note: A thermal storage wall building does not have to be of this shape; the simplified design is used only to illustrate its functioning.)

During the day sunlight strikes the double glazing on the thermal storagewall (which is located on the **south** side of a house or building) and some percentage of that light (60% to 90% depending on the glazing materials) passes through the glazing. Most of the light penetrating the glazing is absorbed by the dark surface of the mass wall. In an unvented thermal storage wall (Diagram A) this heat goes into the mass wall. In a vented thermal storage wall (Diagram B). In addition to heat moving into the mass wall, air between the glazing and wall heats up and moves directly into the building in a convective loop.

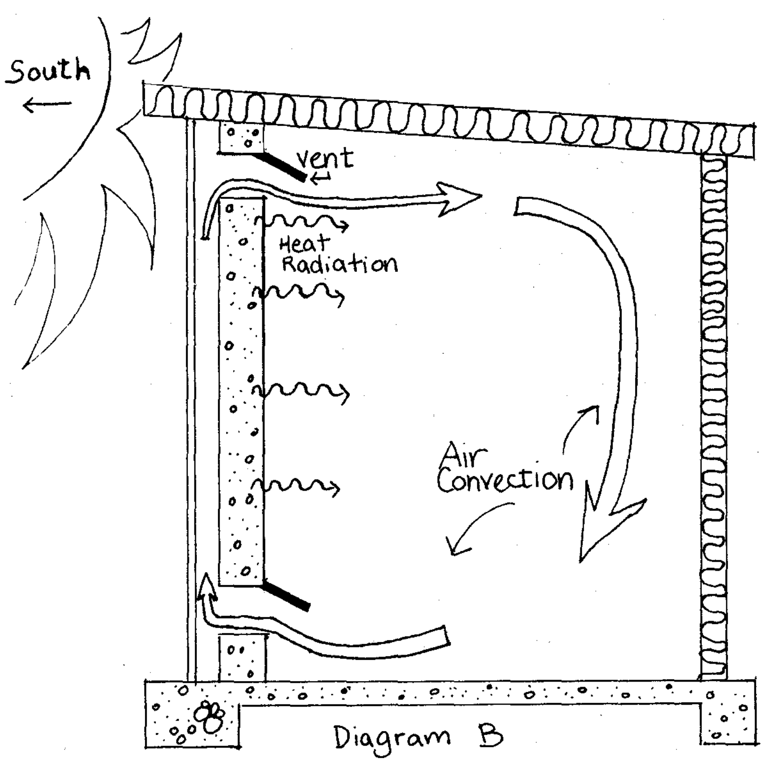

Diagram B. Vented thermal storage wall identical to Diagram A except that in addition to heat transfer through the mass wall, warm air moves into the building through upper vents by means of convection and cool air moves into the collector area from the building through lower vents. These vents should be closed at night to decrease heat loss from the building.

In either case (vented or unvented thermal storage walls), heat is absorbed into the mass wall where it is stored and slowly moves through the wall in a **conductive** wave. As will be shown later, the thicker the wall, the more heat it can store and the longer the conductive wave takes to move across it. For a very thick wall (around 24 inches), there will be almost no variation of temperature on the inside, while for a thinner wall (8 to 14 inches) the amplitude of the wave will be pronounced, the wave will move faster, and most of the heat will be provided to the living space in the evenings (when it is often most needed).

With vented thermal storage walls, the vents can provide an important control mechanism both in heating and cooling the building. They can facilitate heat transfer into the building during a winter day. The use of vents through the **glazing** while upper vents through the mass wall are closed reduces heat gain by the mass wall and thus keeps the building cool in the summer (see sections on venting and operation). A roof overhang can also reduce heat gain during the warm months when the sun is high by shading the thermal storage wall. And, as will be shown, there are many other ways to adapt thermal storage walls to increase or decrease solar gain and reduce heat loss.

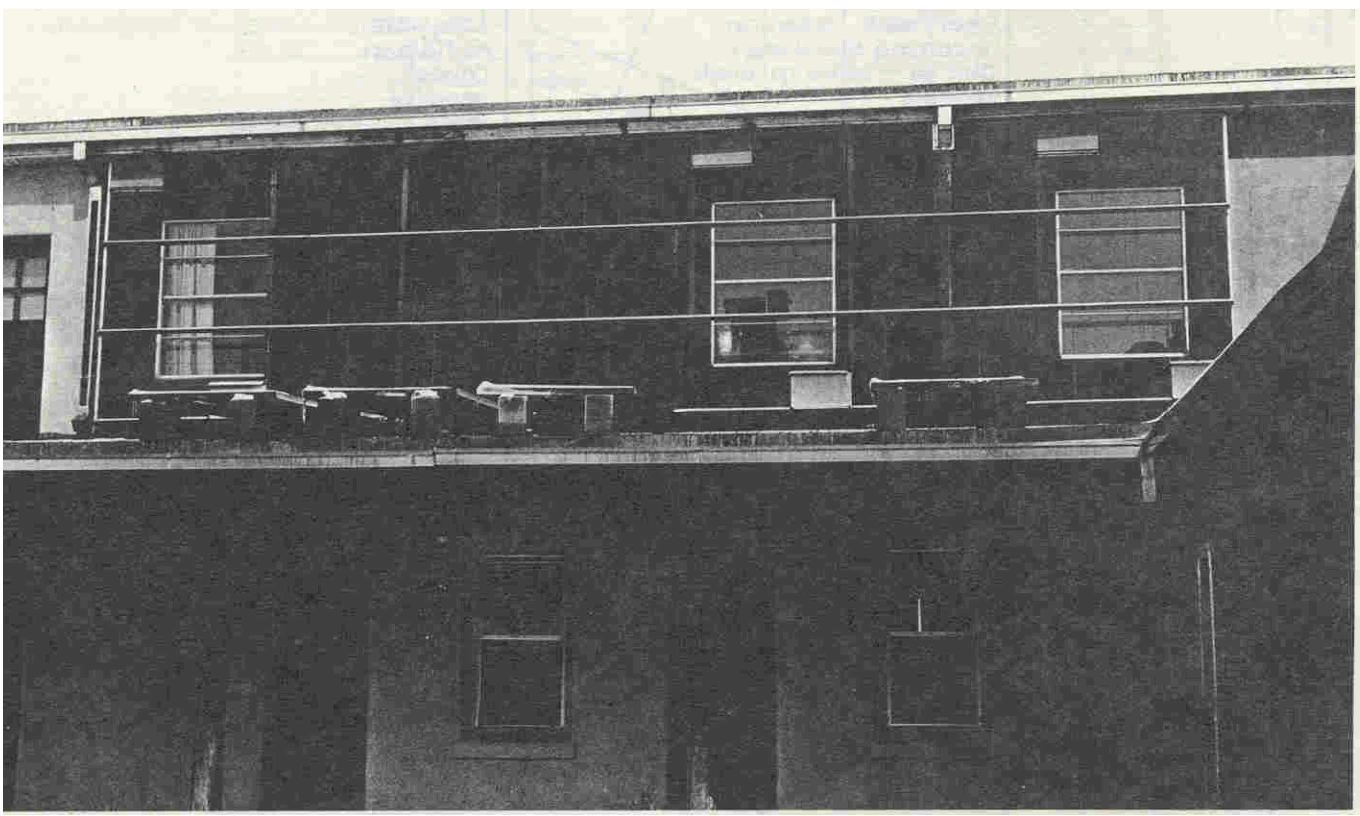

Photo: Bristol Stickney

Chapter 2

Thermal Storage Wall Components

GLAZING

Glazings are critical components of most solar collection systems. The purpose of the clear translucent coverings is to trap heat from the incoming solar radiation. The heat-trapping ability of glazings arises largely from their wavelength dependent transmission. That is, they allow radiation of certain wavelengths to pass through while blocking the passage of others.

A good glazing material should allow **maximum** transmission of solar (short wave) radiation (expressed as the percentage of incident light that passes through). And it should keep heat loss to a **minimum** by preventing long-wave transmission and by serving as a barrier to heat loss. Long wave radiation or heat is radiated out from surfaces that absorb light in any collector system. By preventing the escape of this long-wave radiation, the collector heats up. This process is the familiar "greenhouse effect" (see Diagram C). Additionally, an ideal solar glazing should possess resistance to ultraviolet ray deterioration, good thermal stability, a high resistance to abrasion and weather, low maintenance and purchase costs, high fracture and Impact resistance, and ease of handling.

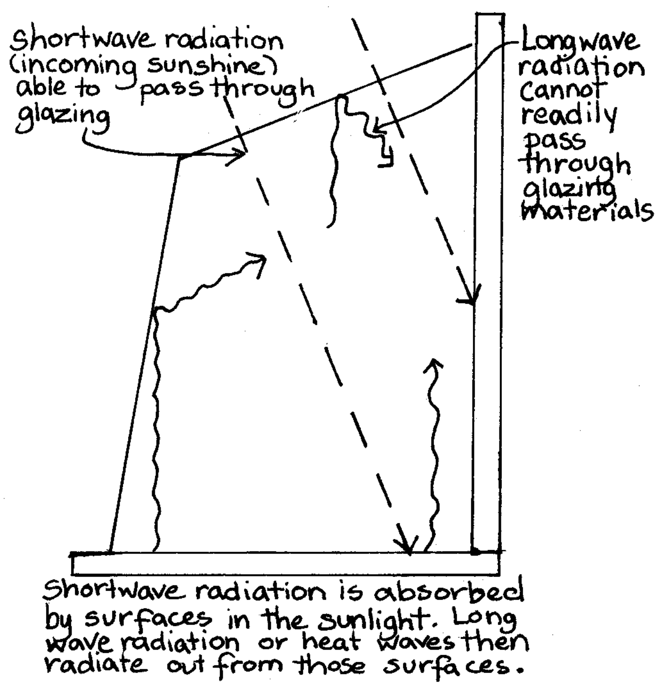

Diagram C. Greenhouse Effect

Commonly used glazing materials fall into two broad categories: glass and plastics. Glass, in a variety of forms and compositions is the proven performer against which other materials are usually judged. Table I summarizes the various types of glazings available. The information is based largely on manufacturers' ratings which cannot of course, always be accepted without qualification. The brands listed do not reflect a recommendation of any kind, but are chosen for

COMPARISON OF GLAZING MATERIALS

GENERAL TYPE	TRADE NAMES	COMMENTS	THICKNESS (inches)	SOLAR TRANSMITTANCE (%)	IR TRANSMITTANCE (%)	MAXIMUM OPERATING TEMPERATURE (°F)	ESTIMATED LIFETIME (years)	$ / SQUARE FOOT	TRANSPARENT	TRANSLUSCENT	POUNDS / SQUARE FOOT
GLASS	DOUBLE STRENGTH	ADVANTAGES	.125	84	<3	400+	25+	1.00	X		1.60
		• Excellent Transmissivity Characteristics									
		• Superior Resistance to Heat, U.V., Abrasions									
	INSULATED UNITS	• Low Thermal Expansion/Contraction	.625[1]	71	<3	200[2]	25+	3.50-7.00	X		5.
		• Easily Available									
		• Transparent									
	SUNADEX	DISADVANTAGES									
	LO-IRON	• Difficult to site fabricate	.187	91	<3	400	25	2.25		X	2.4
		• Low Impact Resistance									
		• Cost									
ACRYLIC	PLEXIGLAS	ADVANTAGES	.125	89	<5	180-200	20+	2.00	X		.73
	LUCITE	• Excellent Transmissivity Characteristics									
	ACRYLITE	• Superior U.V. & Weather Resistance									
		• Won't Yellow									
	DOUBLE WALL:	• Lightweight	.625	83	<5	160	20+	3.00-4.00		X	1.
	EXOLITE	• East to Site Fabricate									
	SOP	DISADVANTAGES									
		• Susceptible to Abrasions									
		• High Expansion/Contraction Rate									
		• Slight Embrittlement with Age									
		• Cost									
		• Relatively Low Service Temperatures									
POLYCARBONATE	LEXAN	ADVANTAGES	.125	87	6	270	10-15	3.25	X	X	.75
	MERLON	• Excellent Service Temperatures									
		• Highly Resistant to Impacts									
	DOUBLE WALL:	DISADVANTAGES									
	TUFFAK-	•Poor Weatherability & U.V. Resistance (Yellows)									
	TWINWALL	• Scratches Easily	.220	79	<8	270	5-7	1.75-3.00		X	.25
		• Not Easily Available									
	QUAALEX	• High Expansion/Contraction Rate									
FIBER REINFORCED POLYESTHER[3]	LASCOLITE	ADVANTAGES	.040	81	<10	160	15	.60		X	5 oz.
	FILON	• Low Cost	.040	82		160	15	.85		X	4 oz.
		• High Strength									
	KALWALL	• Superior Weatherability-Tedlar coated panels only	.040	85		200	12	.85		X	5 oz.
		• Easy to Fabricate and Install									
	DOUBLE WALL:	DISADVANTAGES	1.500	70		N/A	12	5.00		X	N/A
	KALWALL	• Susceptible to U.V., Dust & Pollution Degradation									
	ROOF PANELS	• Yellows with Age									
		• High Expansion/Contraction Rate									
LAMINATE: ACRYLIC/ POLYESTHER		ADVANTAGES									
	FLEXIGARD	• Combines Weatherability of Acrylic with High Service Temperature of Polyesther	.007	89	9.5	275	10	.40	X		5 oz.
		• Good Transmissivity Figures									
		DISADVANTAGES									
		• Non-Reversible									
		• Susceptible to Wind Flapping									
POLYETHYLENE	VISQUEEN	ADVANTAGES	.006	>85	>70	120	8 mos.	.02		X	.5 oz.
		• Inexpensive									
		• Easy to Install									
	MONSANTO 602	• Easily Available	.006	87		<160	2-3 yrs	.08		X	.5 oz.
	(U.V. REISISTANT)	DISADVANTAGES									
		• Poor U.V. and Weather Resistance									
		• Low Service Temperature									
		• Cats LOVE to climb on the stuff									

COMPARISON OF GLAZING MATERIALS

Material	Product	Advantages / Disadvantages	THICKNESS (inches)	SOLAR TRANSMITTANCE (%)	IR TRANSMITTANCE (%)	MAXIMUM OPERATING TEMPERATURE (°F)	ESTIMATED LIFETIME (years)	$ / SQUARE FOOT	TRANSPARENT	TRANSLUSCENT	POUNDS / SQUARE FOOT
POLYESTHER	MYLAR	ADVANTAGES • Low Cost, Clear Glazing • High Service Temperature DISADVANTAGES	.001-.035	85	>50	250	2	.08-.35	X		.25 oz.-10 oz.
	LLUMAR (U.V. RESISTANT)	• U.V. Degradable Unless Treated • Optical Clarity is Distorted due to Thinness of Material	.0005-.014	88	N/A	350	10	.50	X		
FLUROCARBONS	TEDLAR PVF	ADVANTAGES • Excellent Weatherability • Strong • High Solar Transmission DISADVANTAGES • High I.R. Transmission • Not Easily Available • Susceptible to Wind Flapping	.004	90	>50	300	10	.50		X	.5 oz.
	TEFLON FEP	ADVANTAGES • High Solar Transmission • High Service Temperatures • Long Life DISADVANTAGES • Same as Tedlar PVF • Poor Tear Resistance	.061	96	>50	400	25	.50	X		
SILICONE COATED CLOTH	DOW CORNING	ADVANTAGES • Good Transmissivity Characteristics • Excellent Service Temperature • Extremely Weatherable DISADVANTAGES • Susceptible to Wind Flapping and Tearing	.008	90	10	500+	15+	1.00		X	.5 oz.

FOOTNOTES:

1 2 panes of 3/16 inch tempered, float glass separated by l/4 inch air space.

2 Higher temperatures will damage edge sealants on insulated units.

3 Greenhouse quality or better (not the stuff available at hardware stores which is a 2-5 year economy grade.

SOURCES:

- **Thermal Storage Wall Manual, No. 1**
- **Solar Glazing: 1979 Topical Conference.** Mid-Atlantic Sea, 2233 Gray's Ferry Avenue, Philadelphia, Pennsylvania 19146
- **Modem Plastics Encyclopedia.** Vol. 54, No. 104. McGraw Hill, Inc., 1221 Avenue of the Americas, New York, New York 10020
- Manufacturers' Data

NOTE: Much of the technical information in this chart was gleaned from Manufacturers' data.
Actual field performance may be different.
Costs are accurate as of April 1980 from Southwest regional distributors. Local prices may vary.

the availability of their specifications and for their ability to illustrate different generic types of glazings. Definitive data on any particular glazing materials of interest can be extracted from detailed manufacturers' literature or from appropriate reference materials in a technical library.

MASS WALL

The mass wall is the most crucial component of a Trombe wall type thermal storage wall. In it the solar heat will be stored and transmitted to the inside of the building. The material used for a mass wall IS, therefore, very important and is discussed in some detail below. Also important with a mass wall is the surface exposed to the sun. It is necessary that the surface of the mass wall absorb nearly all the light energy passing through the glazing. To do this, the surface of the mass wall should be a **dark** color. If using paint on the mass wall, it should be black or a very dark color and should be able to withstand the high temperatures reached in a Trombe wall collector. Darkening agents other than paints may be used, depending on the wall material. Wood stains have been used to darken adobe and concrete block. Cement stucco can easily be darkened with added pigments. Counter to much previously published information, there is apparently very little difference in absorption between flat and glossy paints, glossy paints being, in fact. better as they tend to pick up less dirt and dust.[4]

In selecting the material for a mass wall, two considerations should be made: cost and thermal characteristics. Given the common materials for mass walls - concrete, brick, adobe and stone - one should research the availability and cost of each before making any decision. Such information can usually be obtained from local brickyards and building supply outlets. Also take into account additional expenses such as forming costs for concrete, the expense of an experienced bricklayer, etc. "Do-it-yourself" Trombe walls, of course, save a great deal of money.

With thermal characteristics, we are interested in 1) how much heat a material can store, and 2) how rapidly that heat can be transmitted (by conduction) through the material and released to the inside air. These characteristics are determined by four physical properties of a material: density, conductivity, specific heat, and heat capacity.

Density, p, is a measure of how heavy a given volume of a material is, expressed for our purposes In Ibslft3. In general, heavier (more dense) materials tend to absorb and store more heat than lighter ones.

Thermal conductivity is a measure of how rapidly and easily heat can move through a material. The movement of heat is always due to a difference in temperature - heat moves from warmer to cooler parts of any material. The British Thermal Unit (Btu)[5] is the commonly used measure of heat. A measure of conductivity is the number of Btu's able to pass through a given thickness of a square foot of a material in an hour if there is a 1 °F difference in temperature from one side to the other. Thermal conductivity, k, is expressed in Btu ft/ft^2 hr °F.

Specific heat Cp, is a measure of the amount of heat needed to raise the temperature of a given mass of material, and is expressed in Btu/lb °F.

Volumetric heat capacity is a measure of how much heat can be stored in a cubic foot of material when being raised in temperature 1°F. It can be found by multiplying the density (p) of a material by the specific heat (Cp) and is expressed in Btu/ft^3 °F.

4 NMSEA **Southwest BULLETIN,** January/February 1979, Volume 4, Number 1.

5 One British Thermal Unit (BTU) is defined as the amount of heat required to raise one pound of water one degree Farenheit

TABLE II

PROPERTIES OF COMMON BUILDING MATERIALS

Type of Material	Density p=lbs/ft³	Specific Heat Cp=Btu/lb°F	Conductivity K=Btu ft/ft²hr°F	Volumetric Heat Capacity Btu/ft³ °F
Concrete[1]	144	.16	.540	23.0
Concrete[2]	140	.20	1.000	28.0
Brick[1]	123	.20	.400	25.0
Limestone Rock[1]	103	.22	.540	23.0
Wood (Pine)[1]	27	.67	.063	20.8
Adobe[2]	106	.24	.30 [3]	25.0
Water[1]	62	1.00	.35 [4]	62.0

Sources:

1 **Handbook of Fundamentals,** 1977. American Society of Heating, Refrigerating and Air-Conditioning Engineers, New York, N.Y.

2. Mazria, Baker, Wessling, **Predicting the Performance of Passive Solar Heated Buildings,**

3. Reported values for the thermal conductivity of adobe range from .16 to more than .70 BTU ft/ft^2hr ° F. The conductivity IS largely dependent on moisture content-the hig her the moisture content. the higher the conductivity. For a complete discussion of this see B. T. Roger's article, "Effect of Moisture Content on the Thermal Properties of Sun Dried Adobe," in the NMSEA **Southwest BULLETIN,** September 1978, Volume 3, Number 9.

4. When **convection** is taken Into account. the *"effective* conductivity" IS much greater.

In addition to the massive building materials (concrete, brick, stone, adobe, etc.) there are other possibilities for a thermal storage wall. Water has been used extensively as a heat storage medium, and In fact IS In many applications superior to mass walls. Salt hydrates also have great potential in storing heat for solar applications.

Some properties of water are shown in Table II, Because it IS a fluid, convection currents distribute heat very quickly **(effective** conductivity close to Infinity. This property, together with the high volumetric heat capacity, allows a water wall to provide a greater **solar heating fraction** than a similar sized wall of concrete or some other massive material. Though often difficult to contain, water costs very little, so it can be very attractive to the solar designer/builder.

The properties of salt hydrates or eutectic salts are shown in Table III. The heat of fusion or **latent** heat absorbed and released with phase changes (i.e. melting or freezing) IS the property of most significance. A large amount of heat is absorbed by salt hydrates as they melt (when being heated up,) This heat is then released as the solutions freeze (when cold). The melting point is low, enabling this phase change to occur at temperatures reached in thermal storage wall-type collectors. One can see the tremendous potential of salt hydrates to store a great deal of heat in a small volume. Problems of cost containing the salts, and phase separation with continued cycles of freezing and thawing, however, have to date limited the use of salt hydrates for other than experimental systems. One can expect to see much research in this area and probably viable and cost effective use of salt hydrates in the near future.

In summary, the mass wall in Trombe wall collectors should be able to store a lot of heat (high heat capacity) and allow heat to readily move through (high thermal conductivity). Sizing the mass wall is covered in Chapter 3, "Design and Sizing."

TABLE III

TABLE PROPERTIES OF SALT HYDRATES

	Chemical Compound	Melting Point, (F)	Heat of Fusion, (Btu/lb)	Density, (lb/ft³)
Calcium chloride hexahydrate	$CaCl_2$ $6H_2O$	84-102	75	10-2
Sodium carbonate decahydrate	Na_2 CO_3 $10H_2O$	90-97	106	90
Disodium phosphate dodecahydrate	Na_2HPO_4 $12H_2O$	97	114	95
Sodium sulfate decahydrate	$Na_2So_4 10H_2O$	88-90	108	91
Sodium thiosulfate pentahydrate	$Na_2S_2O_3$ $5H_2O$	118-120	90	104

Source: Maria Telkes, 1975, "Thermal Storage for Solar Heating and Cooling," from Proceedings of the Workshop on SOLAR ENERY STORAGE for Heating and Cooling of Buildings, April 1975, Charlottesville, Virginia, NSF-RA-N-75-041.

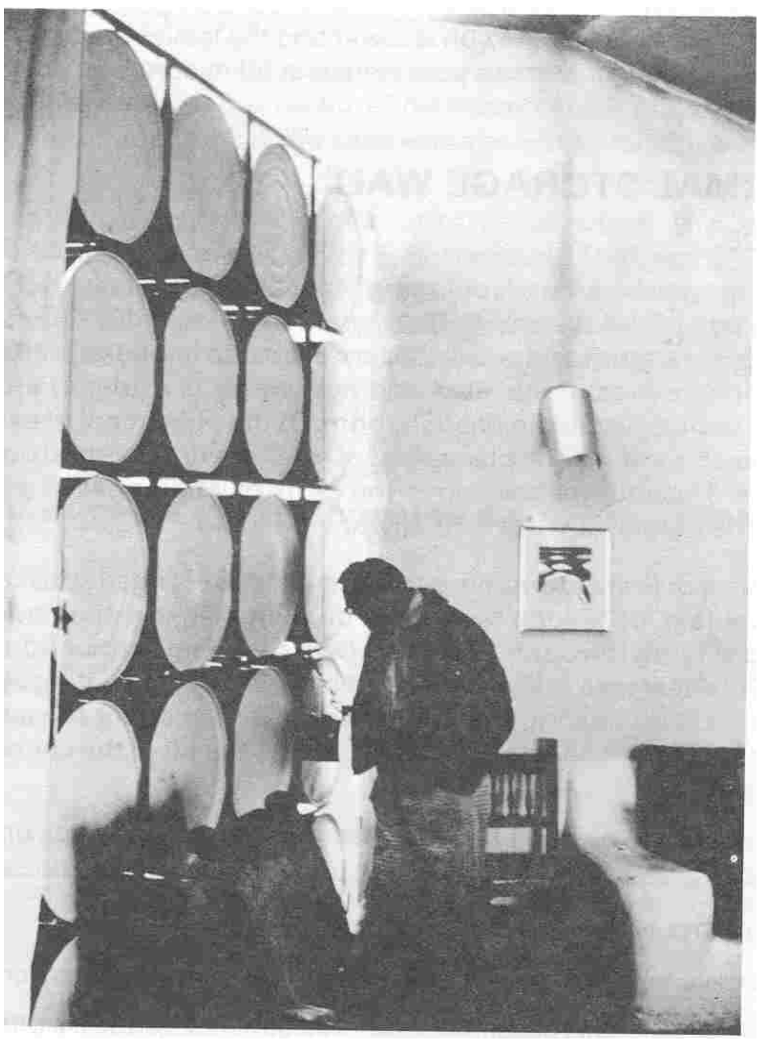

Photo: Bristol Stickney

Chapter 3

Designing and Sizing a Thermal Storage Wall

SITE SELECTION

For any solar collector to operate effectively, it must be placed in a good location. The most important criterion for selecting a site for a solar collector system (such as a Trombe wall) is access to the sun. To insure that the site will have enough solar gain, the following must be determined: 1) where south is, 2) the sun's changing position in the sky during the day and year, and 3) potential shading of the site by existing structures, trees, etc.

The best site is one that faces due south. Some variation is possible, however, in most climates. Data from the Los Alamos Solar Group, suggests that a Trombe wall can face up to 20° east or west of south and still perform with acceptable efficiency.[6]

The sun changes position in the sky both during the day and throughout the year with the winter sun being lower in the sky than the summer sun. In selecting a site for any type of solar collector, one must determine whether nearby buildings or trees will provide unwanted shade and when that shading will occur. A large cottonwood tree that shades part of one's house in the summer may not be a problem in winter when the sun is lower and the leaves are off the tree. On the other hand, a neighbor's house may not shade your house at all in summer, but in winter may block your south wall completely.[7]

SIZING A THERMAL STORAGE WALL

THE HEAT BALANCE

One of the most important parts of planning any heating system for a building is the determination of the size of the system. To do this, we must take into account the following: 1) weather conditions (temperature and wind) 2) desired inside temperature; 3)what the building is made of (wood frame, adobe, brick, etc.) and how well it is made; 4) areas of wall, ceiling, floors, windows, and doors; 5) volume of each room; 6) the placement of exterior windows and doors; 5) volume of each room; 6) the placement of exterior windows and doors, and 7) heating system specifications. This information forms the basis of what is called a heat balance which will help us size the heating system of virtually any building.

A heat balance consists of first determining the amount of heat needed to keep the building at a specified temperature (e.g. 65°F for a residential building). This is done by calculating the heat lost from a building directly through its "skin" (walls, ceiling, etc.) and through cracks and vents (infiltration). This heat loss is then balanced by designing a heating system to replace the losses. In the case of a solar heating system this takes into account the available energy from the sun, the orientation of the collector surface to south, the tilt of the collector surface and the efficiency of the system.

There is some calculation involved in this process but luckily it involves only basic arithmetic.

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6 NMSEA Southwest BULLETIN, February 1978, Volume 3, Number 2, page 2.

7 For more detailed information on the position of the sun in the sky at specific latitudes, consult sun angle charts in one of the following:
Bennett, Robert, 1978 SunAngles for Design.Available for $ 5.00 from Robert Bennett, 6 Snowden, Bala Cynwyd. Pennsylvania 19004.
Anderson. Bruce, 1976 The Solar Home Book, Cheshire Books, Harrisville, New Hampshire.

HEAT LOSS

We will use two ways of describing heat. The first is its intensity or temperature (measured for our purposes in degrees Fahrenheit. °F). The second is its quantity. This is measured in British Thermal Units. (BTU's). One BTU is defined as the amount of heat that must be added to one pound (approximately one pint) of water to raise its temperature one degree Fahrenheit. Ten BTU's of heat energy will raise the temperature of that same pound of water 10° or *five* pounds of water 2°F and so on.

We want to find out how many BTU's are lost per day for every degree Fahrenheit (°F) difference between inside and outside temperatures (BTU's/degree day). The **degree** day[8] is a very useful measurement for calculating heating demand. It is the number of degrees (°F) below 65°F for one day. For example, if on January 21 st. the **average** temperature was 25°F, 40 degree-days (65°-25°) would be calculated for the day. By adding up degree days, one can obtain monthly and annual degree days for a given area. Such figures are available from most weather stations around the country. Annual degree days for eighty-four cities are provided in Appendix A. Areas with a larger number of degree days require more heating. By calculating for a building the number of BTU's lost per degree day, it is very easy to calculate the total BTU's lost per month or year. This is done by multiplying the BTU/degree day figure by the number of degree days during the time period of interest.

We will now explain one method of doing heat loss calculations resulting in BTU's lost per degree day. Please note that there are other ways to calculate heat loss, resulting in different expressions for heat loss, but we will focus on BTU's/degree day because it is consistent with the sizing methods described in the section on "Solar Gain."

As described in the introduction, heat *moves* from warmer to cooler areas in one of three ways: radiation, thermal conduction, or convection. This *movement* or flow of heat can be retarded by placing something in its path. Such is the case with the walls, ceiling, windows, doors, etc. of a building.

Every building material resists the flow of heat to some extent. This ability can be given a numerical *value* which is called an R *value* (R for Resistance). The greater the ability of a material to resist heat flow, the greater the R value. These values are determined in laboratory tests done by organizations such as The American Society of Heating, Refrigeration and Air-Conditioning Engineers (ASHRAE). See Table IV for a list of R values for some common building materials.

TABLE IV

R-VALUES FOR A FEW COMMON BUILDING MATERIALS

Material	R-value
½″ gypsum Board	0.45
½″ Plywood	0.62
Asbestos-Cement shingles	0.21
3½″ Fiberglass insulation	11.00
Stucco	.20 per inch

Source: New Mexico Energy Conservation Code.
Other sources of R-value tables include: Anderson, B. **The Solar Home Book**; Leckie, et. al, **Other Homes and Garbage**; **Handbook of Fundamentals**, 1977, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., New York, N.Y.

8 Used here to mean **heating** degree day.

Knowing this Information will help us later to calculate the amount of heat lost through a building's "skin" To determine the total R value for a wall made of several materials we find the R value of each material in the wall, then add up these values. It must be noted here that even air has a resistance to heat flow. This applies to both "dead" air trapped in cavities In the building part, and to the thin films of air directly In contact with the surfaces of the building parts. (See examples 1 a and 1 b.)

Another way of looking at how a building part reacts to heat is to measure its ability to **transmit** heat. This ability can also be given a numerical value, which is called a U value, the inverse of an R_T value. Mathematically the U and R values are reciprocals of one another. In other words U= 1/Rt.
The lower the U value, the lower transmission of heat. Note: U values are determined from the total R value and cannot be added.

U values are expressed in terms of BTU per square foot of building part per degree Fahrenheit difference between Inside and outside temperatures per hour, or BTU/ft^2 of hr. Thus, if a wall has a U value of .27 this means that if we were to measure the flow of heat through one square foot of the wall for one hour during which the difference in temperature inside to outside was one degree Fahrenheit, we would measure a flow of .27 BTU's. This suggests a simple multiplication problem which will give us the amount of heat loss through any building part in one day for any given set of conditions. All we need to know are three quantities: 1) U value of the building part. 2) size of the building part, and 3) time: 24 hours/day. Our multiplication problem is the following:

U value (BTU/ft^2 of hr) x Building Part Size (ft^2) x 24 hours/day.

This gives us the heat loss through the building part in BTU's per degree day. (See examples 1a and 1b.)

By calculating the heat loss of each building part and adding them all together we can arrive at the total heat loss per degree day through the building skin. Note that areas of doors and windows should be subtracted from areas of the walls they perforate and be subjected to separate calculations.

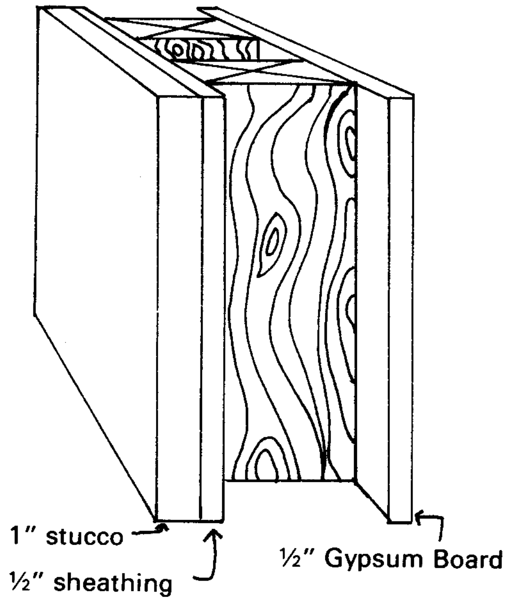
To calculate the infiltration heat loss we must know the volume of air in each room. Then we must estimate the amount of air that will infiltrate into each room from the outside. This IS usually expressed in terms of air changes per hour with one air change per hour meaning that all the original warm air in a room has been replaced by cold air over the period of an hour. This IS determined by a rule of thumb method based on the number of sides of the room which have doors and windows with outside exposed as shown in the following table.

Evaluating each room in this manner will give us the total volume of air we need to heat up. We now need to know how much heat is needed to raise the temperature of the air and how much we need to raise its temperature. It takes .018 BTU to raise one cubic foot of air one degree Fahrenheit. That doesn't sound like much, but as we will see, massive amounts of air can flow through a building in a day. The .018 figure is based on sea level. Thinner air at higher altitudes need less heat to raise its temperature. Altitude correction factors have been developed which must be multiplied by .018 if the building In question is above sea level.

EXAMPLE I

CONDUCTIVE HEAT LOSS

cross-section of wall



Ia. Find the amount of heat loss in Btu/DD of a 10′ by 10′ uninsulated wall.

Component	R-value
outside air film	.17
1" stucco	.20
½" sheathing	1.32
3½" dead air space	1.01
½" Gypsum Board	.45
inside air film	.68

Rtotal = 3.73

U =.27 BTU/ft² °F hr

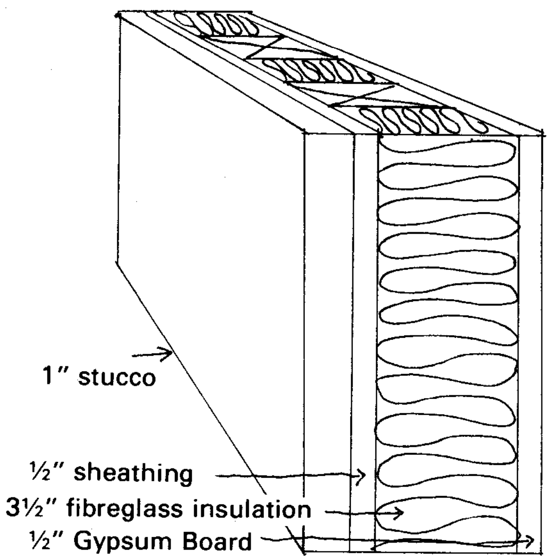
heat loss = Uvalue x Area x Time

$$\text{heat loss} = \frac{.27\ \text{BTU}}{\text{ft}^2\ °\text{F hr}} \times \frac{100\text{ft}^2}{1} \times \frac{24\ \text{hours}}{\text{day}}$$

heat loss = 648 BTU/°F day

or

648 BTU/degree day



Ib. Find the amount of heat loss of the same wall with fiberglass insulation.*

Component	R-value
outside air film	.17
1" stucco	.20
½" sheathing	1.32
3½" fibreglass ins.	11.00
½" Gypsum Board	.45
inside air film	.68

Rtotal = 13.72

U = .07

heat loss = Uvalue x Area x Time

$$\text{heat loss} = \frac{.07\ \text{BTU}}{\text{f}^2\ °\text{F hr}} \times \frac{100\text{ft}^2}{1} \times \frac{24\ \text{hours}}{\text{day}}$$

heat loss = 168 BTU/Degree Day

* It IS important to note that a more accurate heat loss calculation should separate heat loss through the Insulated wall sections and heat loss through the stud or wood areas off the wall. Wood is not as good an insulator as fiberglass batts (R value of softwoods = 1.25/inch), so in Example 1 b, more complex calculations are necessary. The Rt for wood areas of the stud wall (as calculated for Example lb) is 7.2 (U=.14), while for the rest of the wall, Rt=13.7 (U=07). I n a stud wall with 16 Inch on-center studs, wood (the studs) comprises about 20% of the wall area, and for a 24 inch o.c. stud wall, wood comprises about 10% (ASHRAE). Therefore, with a 161nch o·.c. stud wall, one would use the following equations to calculate actual heat loss in BTUS/degree day:

U value of Insulated wall section (BTU/ft^2 of hr) x Area of entire wall (ft^2) x .80 (percentage of total wall area without studs) x 24 hrs/day

plus Uvaueofwaseton(BTU/ft^2°Fhr)xAreaofentrewa(ft^2)x 20(percentageoftotal wall area comprised of studs) x 24 hrs/day

In reality, most people disregard the studs In doing heat loss calculations - producing slightly low heat loss totals

TABLE V

AIR CHANGES PER HOUR

Kind of Room	Number of Air changes per hour*
Rooms with no windows or exterior doors	0.5
Rooms with windows or exterior doors on one side	1.0
Rooms with windows or exterior doors on two sides	1.5
Rooms with windows or exterior doors on three sides	2.0
Entrance halls	2.0

*For rooms with weather-stripped windows or with storm sashes. use two-thirds these values.

Source: **Handbook of Fundamentals,** 1977, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc .. New York. N.Y.

TABLE VI

ALTITUDE CORRECTION FACTORS

Altitude (ft)	Correction Factor	Actual Btu's needed to raise the temperature of one cubic-foot of air one degree F.
Sea level	1.00	.018
100	.97	.017
2000	.93	.017
3000	.90	.016
4000	.86	.015
5000	.83	.015
6000	.80	.014
7000	.76	.014
8000	.73	.013

Source: Dr. Francis Wessling's classroom notes. Engineering Department, U.N.M., Albuquerque, N.M.

EXAMPLE II

INFILTRATION HEAT LOSS

How much heat is lost by infiltration per degree day by a 10' by 10' by 10' room with a door on one exterior side in Santa Fe. New Mexico (altitude 7.000 ft)?

Infiltration = Volume (ft^3) x Air changes per hour x heat

capacity of air (Btu/ft^3 OF) x time 24 hrs/day

Heat Loss

= 1000 ft^3 x 1.0 air changes/hr x 0.014 BTU /ft^3 °F x 24 hrs/day

Infiltration Heat Loss = 328 BTU/degree day

This process is repeated for each room. The results are added to give the total infiltration loss. Alternately, infiltration heat loss can be calculated for the entire building without separate calculations for each room. Calculated infiltration loss is usually 30-35% of the heating load. Recent studies by J. L. McGrew of Applied Science and Engineering of Littleton, Colorado indicate that in some cases infiltration losses can be 60% or more of the heating load.[9] This type of heat loss is often the easiest to cut down through weather stripping and other infiltration inhibitors.

The heat loss for a building is then added to the total infiltration loss to give the building's total heating load. This total heating load is what one must design a heating system to satisfy. In other words, this heat loss must be replaced by the heating system to maintain the desired comfort levels.

SOLAR GAIN

Once the total heating load of a building has been calculated, one can determine either: case a) for a given sized Trombe wall, what percentage of the total heating load can be obtained, or case bl how large a Trombe wall is necessary to provide the desired heating demand. There are a number of methods for determining these values and there is work being done to simplify and standardize the calculations. We are including here the method developed by J. Douglas Balcomb and Robert D. McFarland of the Los Alamos Scientific Laboratory.[10]

This method, of necessity, has been prepared for a specific thermal storage wall system (basically a double-glazed, 11/2 foot thick concrete wall). A complete list of assumptions is shown below:

Vertical, south-facing glass Wall
absorptance = 1.0 Ground
reflectance = 0.3 No shading
Thermal Storage = 45 BTU/°F ft2 of glazing Trombe wall
has vents with back draft dampers Double Glazing
(normal transmittance = 0.747) Temperature range in
building = 65 to 75° Other building mass is negligible
Night insulation (when used) is R9; 5 pm - 8 am Wall to
room conductance = 1.0 BTU/hr of ft^2 Trombe wall
properties:
thermal conductivity (K) = 1.0 BTU/ft hr °F
volumetric heat capacity = 30 BTU/ft^3 °F

Temperature data from eighty-four cities as well as performance efficiencies of Trombe walls and water walls, have been calculated into the load collector ratio figures (shown in Appendix A) to create an easy to use procedure. In the following section, "Designing a Thermal Storage Wall," we will describe how variations from the parameters or assumptions shown above will affect Trombe wall efficiency and performance.

Step 1

Calculate the Building Loss Coefficient in BTU/degree-day as described in the heat loss section (page 12).in this calculation, the collector /thermal storage wall should not be included in the load.

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9 J. L. Mcrew. 1978. "Heat Loss and Found," Applied Science and Engineering of Littleton, Colorado.

10 J. D. Balcomb and R. D. McFarland, 1978, "A Simple Empirical Method for Estimating the Performance of a Passive Solar Heated Building of the Thermal Storage Wall Type."

Step 2 - Case A

If working with a thermal storage wall of a certain size and interested in what fraction or percentage of your heating demand it will supply. calculate the Load Collector Ratio (LCR) as follows:

$$\text{Load Collector Ratio} = \frac{\text{Building Loss Coefficient (BTU/D-D)}}{\text{Solar Collection Area (ft}^2\text{)}}$$

In calculating the Load Collector Ratio, the solar collection area used should be the net glazed area (the actual solar collection aperture) and not the gross area of the thermal storage wall.

Step 3 - Case A

In Appendix A. locate the city of interest (or the one most closely representing the climate of the area of interest.) If the Load Collector Ratio determined in Step 2 corresponds exactly to one of the values of Solar Heating Fraction (SHF) listed in the table, then this Solar Heating Fraction is the fraction of your total heating load that will be supplied by the thermal storage wall. If not. one needs to interpolate the actual Solar Heating Fraction from the data in the table. As used in this method, the SHF is the fraction of the degree days for the area of interest times the Building Loss Coefficient (BTU's/degree day) which is supplied by the thermal storage wall. The wall is not credited with the heat used to supply its own steady-state load since a "normal" south wall would presumably have a much lower loss coefficient and would inevitably benefit from solar gains, even if they are unintentional.

One can see that once the solar heating fraction has been determined, it is easy to calculate how much supplemental or auxiliary energy is necessary during a year to maintain 65°F. The following equation can very simply be plugged into:

$$\underset{\text{(BTU/yr.)}}{\text{Auxiliary Energy}} = (1\text{-SHF}) \times \text{Annual Heating Degree Days} \times \underset{\text{(BTU/°F day)}}{\text{Building Loss Coefficient}}$$

Step 2 - Case B

Often when designing a passive solar building, it is important to know how large the thermal storage wall must be to provide a **desired solar heating** fraction. This calculation can easily be done using Load Collector Ratios provided in Appendix A and the following equation:

$$\text{Solar Collection Area (ft}^2\text{)} = \frac{\text{Bldg Loss Coefficient (BTU/Degree Day)}}{\text{Load Collector Ratio}}$$

Simply find in Appendix A the Load Collector Ratio for the desired Solar Heating Fraction and the location of interest. Plug that figure and the Building Loss Coefficient (from the heat loss calculations) into the above equation, and the solar collection area (in ft^2) for a thermal storage wall will be found. This will be the net glazed area of a thermal storage wall necessary to provide the desired solar heating fraction. After determining that area, one may decide too much wall would be necessary for the house design or that more wall space could be utilized. If such were the case, the calculations could be re-done changing the solar heating fraction or some other variable.

EXAMPLE III

SOLAR HEATING FRACTION

A 72' x 24' building in Dodge City, Kansas is to be constructed with a 309 sq ft water wall on the south side. The water wall will contain 45 lbs of water per sq ft of south glazing for a total of 13,500 lbs of water or 1,618 gallons. The wall is double glazed with normal sealed glass units which have a net transmittance of 0.74 for sunlight striking the glass perpendicularly. Other than the thermal storage wall, the building is of light frame construction with little additional mass. It is desired to estimate the annual solar heating contribution.

Skin Conduction

Surface Type	Area (ft^2)	U-Value BTU/ft^2°F hr	U x A BTU/°F hr
Water Wall	309	(not included in BLC)	
Opaque Walls	1107	0.07	77.5
Windows (E,W,N)	120	0.55	66.0
Roof	1728	0.05	86.4
Floor	1728	0.05	86.4
Building Skin Conductance =			316.3

Infiltration:

(12320 ft^3) (½ ACH) (0.018) =	110.9
Total: Building Loss Coefficient =	427.2 BTU/hr°F
	= 10250 BTU/DD

The building is tightly sealed and equipped with an air-lock entry and thus the infiltration can probably be held to the minimum recommended level of 1/2 air change per hour.

(Step 2) The building south wall is glazed with 18 standard patio door size sealed double glass units each with a net effective exposed area of 75 x 33 in. for a total of 309 sq ft of collection area. Thus the Load Collector Ratio is 10250/309 = 33.2 BTU/degree-day-sq ft.

(Step 3) In the table for Dodge City, Kansas we find the following entries for the case of a water wall without night insulation:

SHF	0.30	0.40	0.50	0.60
LCR	61	43	31	23

Our Load Collector Ratio of 33.2 lies between the two values of 0.40 and 0.50 Solar Heating Fraction. By interpolation we obtain:

SHF = 0.48

The energy saved by the installation of the solar wall is estimated as (0.48) (10250) (4986) = 24.5 MBTU/yr.

The auxiliary energy can be estimated as:

Auxiliary Energy = (1-0.48) (10250) (4986) = 26.6 MBTU/yr.

DESIGNING A THERMAL STORAGE WALL

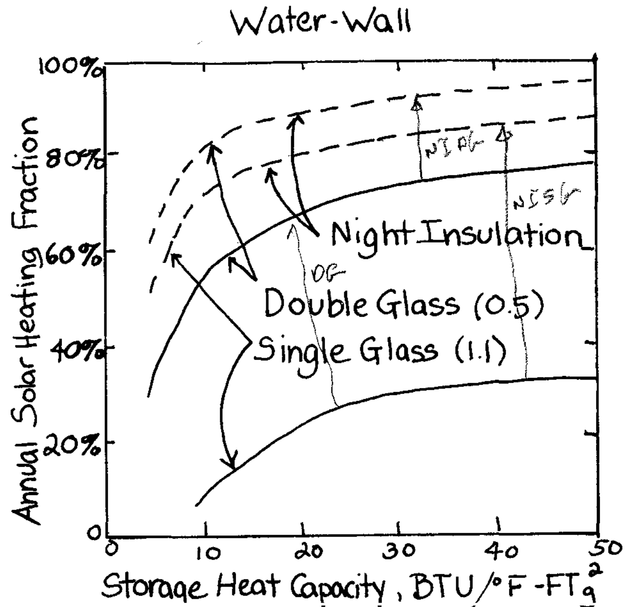
Information on glazings, wall materials, heat loss, solar heating fraction calculations, and a brief overview of thermal storage wall principles have been presented. In this section, information on components of thermal storage walls is presented In terms of actual designing. For people working with design of thermal storage walls, this is probably the most useful section. It should be used, however, **with** the other information presented in this manual.

THERMAL STORAGE WALL GLAZINGS

For thermal storage walls double glazing is recommended in most areas. Graph 1 illustrates this for a waterwall (showing also the added benefit of night insulation). The inner glazing should be able to withstand high temperatures - that is. it should have a high "maximum operating temperature."[11] An unvented Trombe wall can reach 200°F at the exterior of the mass wall and

[11] See Table I-A Comparison of Glazing Materials

EFFECT OF STORAGE MASS WALL



GRAPH 1

Source: Passive Solar Building: A Compilation of Data and Results

vented Trombes can reach 160°F although average temperatures are much lower. The inner glazing temperatures will be similar to those of the exterior of the mass wall although slightly lower.

The outer glazing should be durable. It will be directly exposed to weather and harsh ultra-violet rays. But temperatures reached by the outer glazing will not be as high as those that the inner glazing is exposed to.

Although glass is the **best** Trombe wall glazing material, various considerations such as cost, ease of handling (especially for a non-professional builder), and possibility of breakage, often make it preferable to use plastic and/or fiberglass glazings.

Polycarbonates, fluorocarbons, and polyvinyl fluorides are all good inner glazing materials in terms of heat resistance. Polyethylene and fiberglass, on the other hand, will degrade much more quickly than their projected lifetimes (see Table 1, page 6) if used as an inner glazing Because of fairly good durability properties and low cost "greenhouse quality" fiberglass makes a good outer glazing.

AIR SPACE BETWEEN GLAZING AND MASS WALL

Several factors should be taken into account when deciding on the distance between the inner glazing and the mass wall of a Trombe or thermal storage wall. If the air space is too thin (less than one-half inch), heat loss will be large, and, with vented Trombe walls, air circulation will be restricted - preventing good heat transfer into the building. With a very large air space (greater than about six inches), heat losses could be large at the top and sides and the large framing members could cause a shading problem.

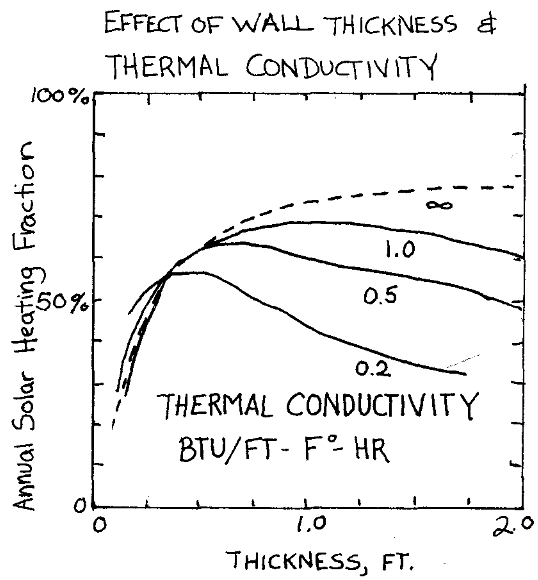
Using standard two-by-fours for framing the glazing of a thermal storage wall has proven quite successful (allowing a 3 ½ inch air space between the glazing and mass wall) and minimizes lumber expense. If heavy glass is being used for the glazing, sturdier lumber than two-by-fours may be necessary. If unsure about the structural framing requirements for the glazing area of a Trombe wall, it may be worthwhile to contact a local builder, contractor, architect, or engineer.

MASS AND WATER WALLS

The Balcomb, McFarland Solar Heating Fraction calculations presented give a very good idea of how a thermal storage wall will perform in various areas around the country. However, as mentioned previously, the procedure was developed for a very specific set of parameters (i.e.

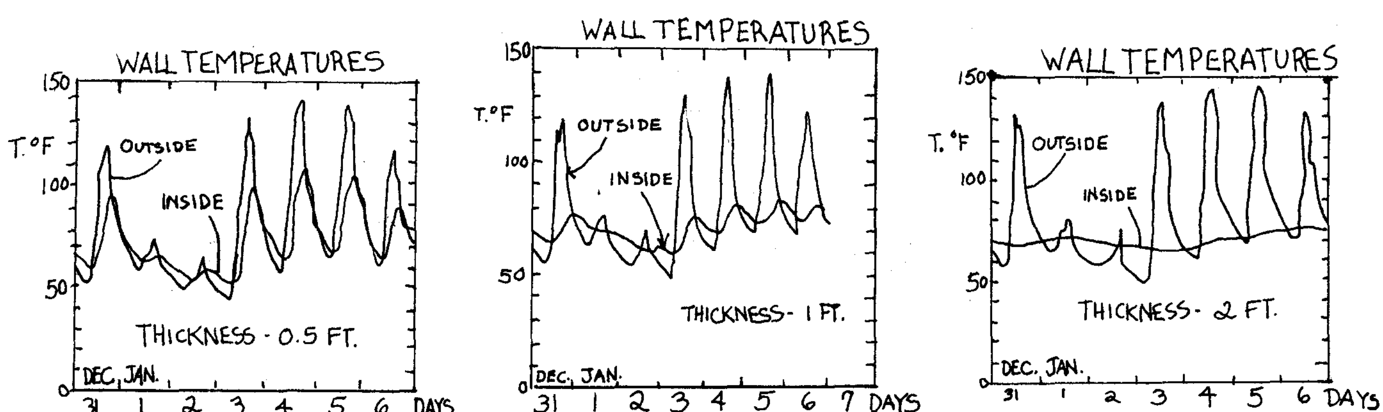
double glazing, no shading, 0.3 ground reflectance, 18 inch thick concrete wall). In this section, variations in the thermal storage wall will be discussed to give an idea to the reader of how performance and efficiency are dependent on design and materials.

The mass wall in a Trombe wall collector should have a good ability to store heat (a high heat capacity). It should also have a high thermal conductivity (see Graph 2). If the conductivity is too low (as for wood), heat cannot easily move through the material even if that material can store a lot of heat (high heat capacity). This becomes clear when one realizes that for a mass wall of low conductivity, if the wall is too thick, heat will not be able to move through it easily. If a material has high conductivity, heat will move through it readily and a thicker wall will be quite effective. Graph 2 shows the optimal thicknesses for walls of different conductivities.



Graph 2 **Source: Passive Solar Building: A Compilation of Data and Results**

Graphs 3, 4, and 5 indicate that the thicker a mass wall, the smaller the variation of temperature inside the wall. This might seem a contradiction. It can be determined from Table II and Graph 2 that the ideal thickness for a concrete mass wall is slightly less than a foot while Graphs 3,4, and 5 seem to indicate a thicker wall is better. The optimization shown in Graph 2, however, was for the maximum yearly solar heating - the **efficiency** of a Trombe wall. In terms of **performance,** a thicker wall (though less efficient) may be more desirable: it will keep a more constant inside temperature. There are no readily available charts or diagrams to illustrate this point; one must take into account both the **overall solar heating efficiency** of a wall of certain



Graph 3 Graph 4 Graph 5

Source: Passive Solar Building: A Compilation of Data and Results

thickness, and the **comfort level** it affords. Although one will get the maximum yearly amount of solar energy into a building by following Graph 2 for wall thickness, he or she may wish to sacrifice some of that heat for a smaller daily temperature variation (via a thicker wall).

One can see from the information provided here that concrete is the most effective mass wall material and that to operate at **maximum efficiency,** it should be about ten to twelve inches thick.

Thicker walls result in lower temperature swings on the inside wall and greater time delays between temperature peaks of the outside and inside wall surfaces. Data for variations in wall thickness of a concrete wall are shown in Table VII.

TABLE VII

Thickness, Inches	Inside Surface Temperature Swing	Time Delay of Peak on the Inside
8	40°F	6.8 hrs
12	20°F	9.3 hrs
16	10°F	11.9 hrs
20	5°F	14.5 hrs
24	2°F	17.1 hrs

Source: J. D. Balcomb, "Designing Passive Solar Buildings to Reduce Temperature Swings," LASL.

As discussed in the "components" section (page 9), water can be very effective for thermal storage walls. Because of the very high effective conductivity (due to convection), heat moves very quickly through a water wall resulting in usable heat inside the building early in the day. This early heat-up can be very useful in buildings such as schools and offices where heat is needed primarily in the daytime. But in other applications where evening and nighttime heat is more important, the rapid heat-transfer can be a disadvantage. While high conductivity allows heat to rapidly move **into** a thermal storagewall it also allows heat to rapidly move **out.** Cool-off in the evening will be quicker with a water wall than mass wall, and there will not be the characteristic **wave** of heat that moves through a mass wall reaching the inside wall surface 610 hours after the temperature peak on the outside wall surface (see Table VII and Graphs 3-5).

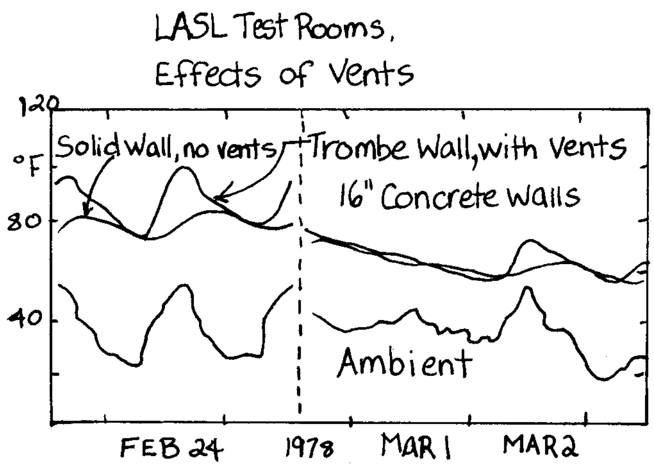
Generally a water wall utilizes containers such as 55 gallon drums or rectangular 17 gallon ammunition cans that are painted a dark color, stacked and filled with water. Steve Baer's home in Corrales, New Mexico provides a very good example of a water wall with 55 gallon drums. Other water walls are more complex. The Gunderson house outside of Santa Fe, New Mexico utilizes a thermal storage wall with both concrete and water. Sealed containers of water (eight inches thick) are sandwiched between two-inch concrete slabs.

As discussed in Chapter 2, Mass Wall section, salt hydrates or eutectic salts provide another alternative for the thermal storage wall. The use of salt hydrates for solar vent storage is increasing at a rapid rate and one can expect to soon see their widespread use around the country and world.

VENTING FOR THERMAL STORAGE WALLS

As mentioned in Trombe Wall Overview, Trombe walls may be of two types: vented or unvented. While an unvented Trombe delivers heat to the inside of a building by conduction and radiation, a vented Trombe additionally heats a building during the day by means of hot air **convection.** Diagram B (page 3) illustrates this principle showing a **convective loop** operating during the day with the vents open. This circulation will continue as long as the air in the collector is heated above the room temperature. While the daytime heat is being delivered to the building by means of air convection, the mass wall is steadily being charged with heat which will be radiated into the building at night as with all Trombe walls. In vented Trombes, convection of air provides about 30% of the heat supplied to the living area by the Trombe wall, while conduction and radiation supply the other 70%.[12]

A vented Trombe will result in more temperature variation in building than an unvented Trombe (see Graph 6). Inside temperatures will get higher during the day and temperatures may drop lower at night with a vented Trombe wall. Overly high inside temperatures can be reduced by providing enough thermal storage materials **inside** the building such as brick floors, concrete or brick partition walls, etc. These materials will absorb extra daytime heat. thus evening out the daily temperature swing. Vents are generally desirable when heat IS most needed during the day - (e.g. in a school or office building).



Graph 6

Source: J. D. Balcomb, R. D. McFarland and S. W. Moore, Passive Testing at Los Alamos

Data on overall thermal efficiency of the two types of Trombe walls is hard to come by (see Graph 6). The air between glazing and mass wall reaches higher temperatures in an unvented Trombe wall, so heat loss through the glazings of these Trombe walls tends to be somewhat greater. But with a vented Trombe wall system, not as much heat is stored in the mass wall. Therefore, if infiltration heat losses are great in the building (poor insulation. air leaks. etc.), less heat will be available in the evenings. Of course, if a Trombe wall system is built with vents through the mass wall, and daytime overheating or lack of nighttime heat proves a problem. the vents could be closed reducing the problem.

On the subject of vent sizing and placement, it is necessary to clearly differentiate between two types of vents: inner vents through the mass wall, and outer vents through the glazing. If overheating is expected to be a problem (e.g. in much of the Southwest), outer vents should be included in any Trombe wall design (unless removable insulators are used). If inner vents are **not** being built, both **upper and lower** outer vents would be necessary to adequately vent the collector area during the summer to keep the mass wall from heating up too much. If inner vents **are** being used, only high outer vents would be necessary because the lower inside vents could serve to bring cool air into the collector area (see Diagram D).

For either inner or outer vents to work best, the distance between high and low vents should be as large as possible. It is important that the high vents are at least as large in area as the low vents so as not to impede air flow. Some people suggest that the high vents should be somewhat larger to insure free movement of the warmer, relatively expanded air, though this is not necessary.

12Balcomb et al. "Passive Solar Heating of Buildings"

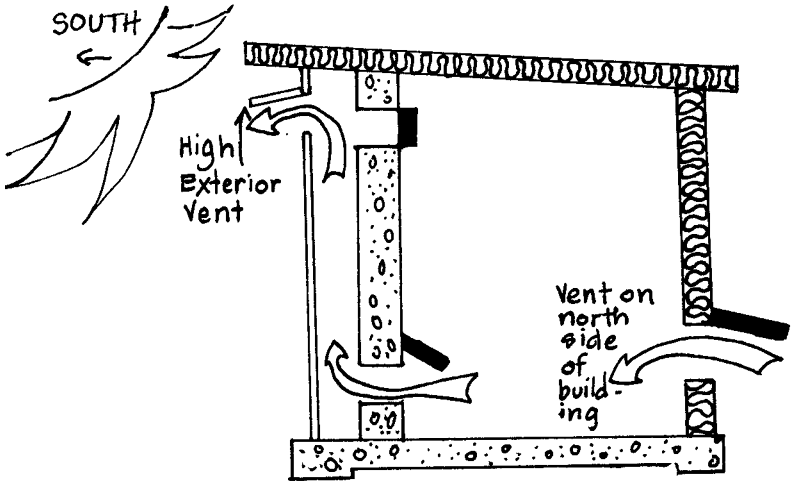


Diagram D — The Use of Vents for Summer Cooling

How large the vents should actually be and how many one should have is a question on which there is no definitive information. Dr. J. D. Balcomb of the Solar Division of Los Alamos Scientific Laboratories suggests a total combined vent area of 1 to 2% of the total Trombe wall area.[13] If too much wall area is taken up by vents, too little heat will go into the wall. If vents are too small, there will be less convection of daytime heat into the room. Several upper and lower vents spaced evenly across the wall will operate more effectively than one large localized vent because the convective airflow will be more even. This is true for both inner and outer vents. For the inner vents; vertically offsetting the vents (so that upper vents are not directly above lower vents) allows for better transfer of heat into the building than if upper vents are directly above lower vents. This is because the flow of air into the building (through upper vents) and out of the building (through lower vents) cannot be as direct, resulting in heat moving further into the room.

There are several possibilities for actual construction and operation of the vent closures. Outer vent covers should be clear or translucent like the glazing to allow light to penetrate. Alternately, vents can be cut through the wood framing. Inner vent covers can be of any material, though one that insulates against heat loss when closed is best. The simplest system for inner vents uses Styrofoam or some other material cut to fit into the vent opening - it is removed to open the vent. Other systems include hinged vent covers that are manually opened and closed, controlled by a thermostat, or controlled by heat-sensing motors (these devices push out a piston when heated - the piston can be used to open vents when the collector area heats up). Another possibility for inner vent closures, developed by Doug Kelbaugh, is a simple "automatic" damper. The damper consists of hardware cloth or screening across the vent opening, with a section of thin flexible polyethylene taped on the air out-flow side. The system allows air to flow in the direction of the daytime convective loop (see Diagram B, page 3) but prevents a reverse convective loop from forming. The use of vents is covered under Operation and Performance.

SOUTH ROOF OVERHANG

Diagram E illustrates how the south roof overhang of a Trombe wall house can effectively be used to keep a building cool in the summer but allow adequate heating in the winter. In the summer months the sun is high in the sky (78° maximum in Santa Fe, New Mexico -latitude of 36°N) and the Trombe wall collector is shaded from the sun's rays. In winter, with the sun much lower in the sky, the Trombe wall is in full sun all day. In spring and fall months, some percentage of the wall will be shaded by the sun and partial heating will result.

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[13] Personal communication.

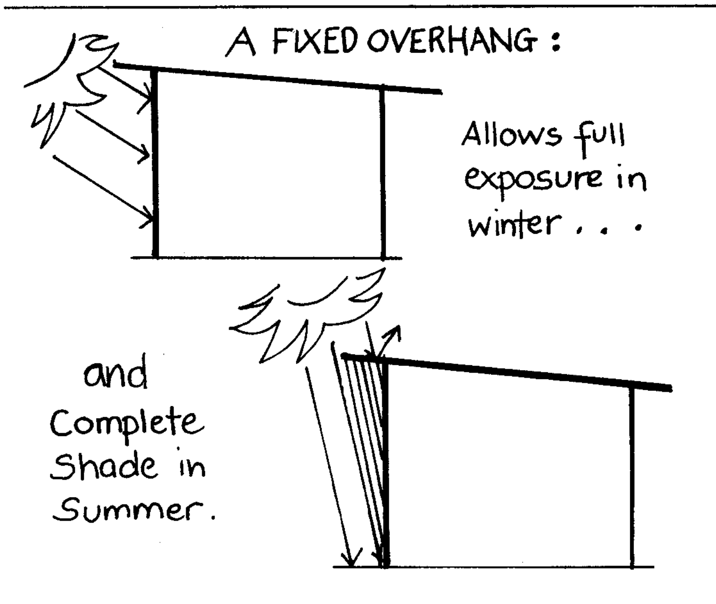


Diagram E

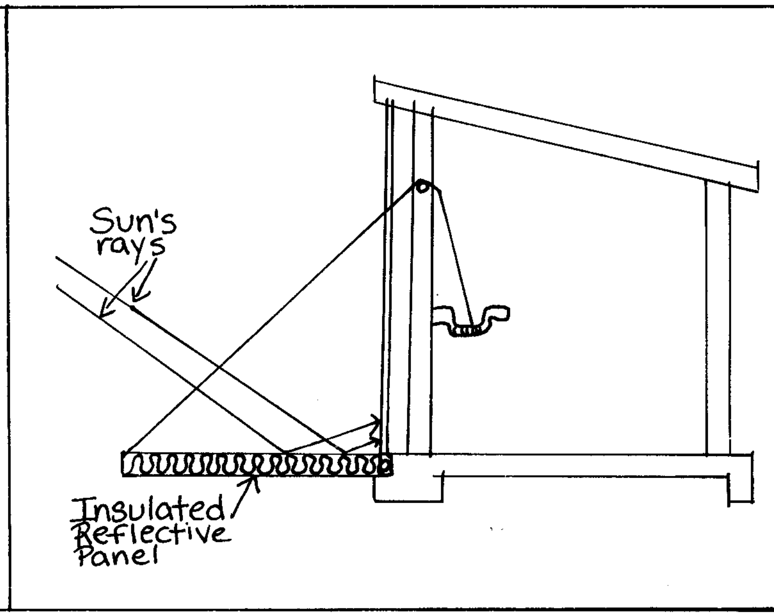


Diagram F

The optimal overhang distance can best be calculated using 1) **Sun Angle Chart** which is specific for a given latitude, 2) a scale drawing of your Trombe wall house, 3) an architect's scale and 4) a protractor. From a Sun Angle Chart one can easily find the altitude of the sun (height above the horizon in degrees) at different times of the day and year. With the maximum summer sun altitude and minimum winter sun altitude, one can draw lines through the tip of the overhang (see Diagram E) at those prescribed degrees using a protractor and ruler and see where the sun will strike the Trombe wall. If a great deal of the wall is exposed to the sun in summer, lengthen or change the angle of the overhang. If too little sun falls on the wall in winter, shorten or tilt up the overhang in the drawing.

Other systems such as movable or adjustable overhangs and "organic shades" (climbing plants, sunflowers, grapes, etc.) can allow more control. Fall is the most difficult season to design for in terms of overheating because of warm temperatures and a fairly low-altitude sun. Spring is a difficult season for heating. Some form of adjustable shading can be very important for these times.

INSULATORS AND REFLECTORS

A "standard" Trombe wall, either vented or unvented, can provide a substantial portion of one's heating demand. The exact amount, of course, depends upon the size of the Trombe wall relative to the heat requirements of the house, orientation of the Trombe wall, climatic conditions in the region, etc. Certain adaptations can be made in the standard design, however, which will substantially improve the efficiency by controlling solar gain and heat loss.

The fold-down insulated reflector shown in Diagram F is a good example of such an adaptation. In the winter, the insulated panel with a reflective surface can be hinged down during the day so that it will reflect additional light onto the Trombe wall collector surface. At night, it can be pulled up and the insulation will reduce heat loss through the Trombe wall glazing. In summer months, with such a system, one could leave the panel up during the day preventing all solar gain and thereby keeping the house cool.

Of course other applications of this idea are possible, including very simple removable Styrofoam insulating panels or a light-colored patio in front of the Trombe wall which will reflect some additional light onto the collector surface. Adapting a Trombe wall, as with any passive solar heating system, is merely a matter of common sense, creativity, ingenuity, and correct information. The information in Appendix A - for use in calculating the heating fraction a thermal storage wall will provide - has figures for both thermal storage walls without night insulation, and with it.

Chapter 4

Operation and Performance

OPERATION

The operation of a Trombe wall will vary with the seasons, and the user's needs. The tilt of reflectors can be adjusted as the sun moves higher and falls in the sky (in spring and fall especially). Most important in the operation, however, are the vents.

We have described below how vents through the mass wall and through the glazing are used in winter daytime operation, winter nighttime operation, and summer operation.

During winter daytime operation when heat is desired in the building, the high and low vents through the mass wall are opened. As the sun strikes the dark surface of the mass wall, the air between the glazing and mass wall heats up, expands, rises to the top of the air space and escapes through the upper vents into the building. As warm air leaves the Trombe collector area, cooler air is drawn into the collector through the low vents from the building. This cool air, in turn, is heated, expands, rises, and passes back into the building, thus setting up a natural air circulation pattern.

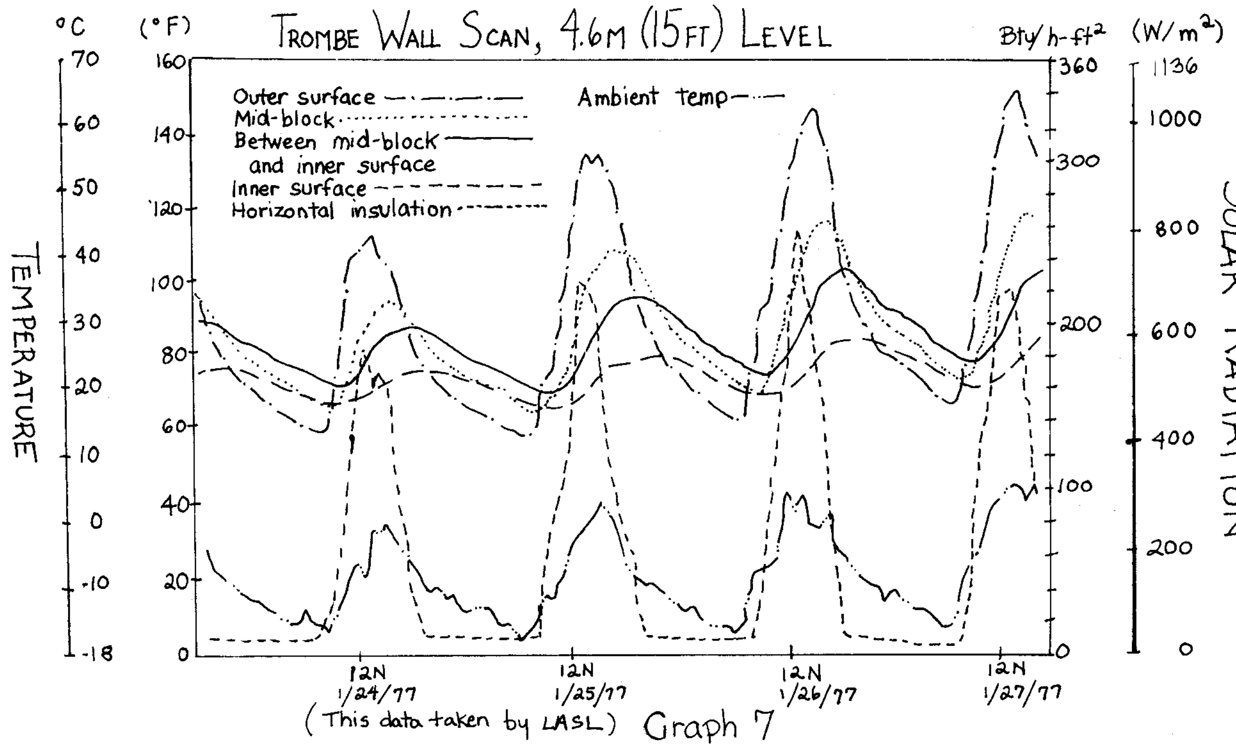
On winter nights it is important that all vents be **closed.** If they are left open, a **reverse convective loop** can be set up. Because heat can readily escape through uninsulated Trombe wall glazing, the collector air space cools off until that air is cooler than air inside the building. At this point, if the mass wall vents are open, warm air from the building would enter the Trombe wall collector area through the upper vents, cool off, and return to the building.

In the summer months when heating is **not** desired. the upper mass wall vent should be **closed** and the lower mass wall vents and upper outside (glazing) vents should be **open** (see diagram D). A window on the north side of the building should also ideally be open to allow relatively cooler air to flow freely through the building and into the Trombe wall collector. As air in the Trombe collector is heated. it expands, Rises, and flows out the vents to the outside drawing air behind it from the building (this is called the chimney effect). This constant flow of relatively cool air will prevent the collector air and mass wall from heating up much and thus keep the building cool. With these vents open, heat will escape from the building both during the day and night.

THERMAL PERFORMANCE OF THERMAL STORAGE WALLS

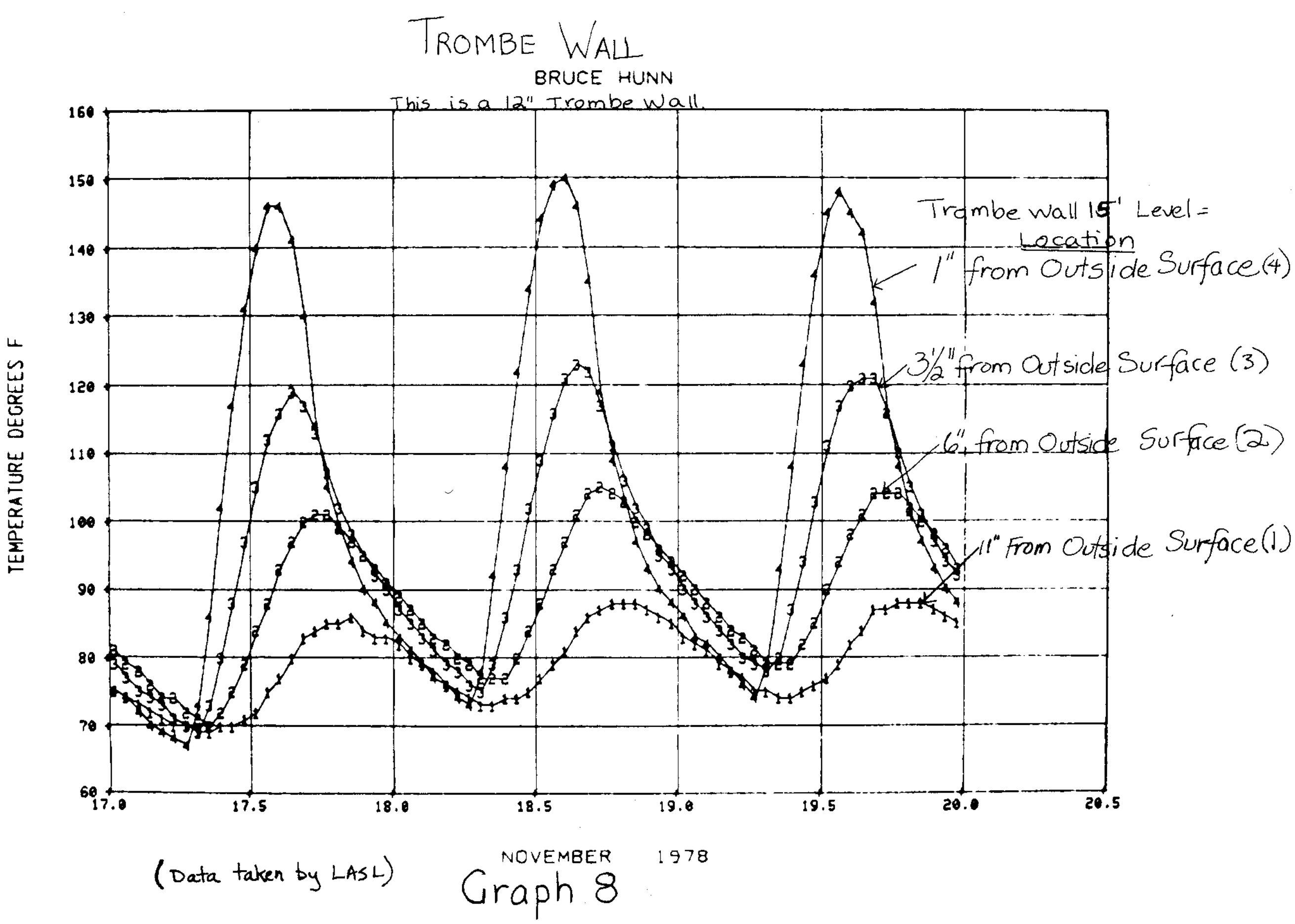
Some actual data on the performance of thermal storage walls are shown below. Graph 7 illustrates the thermal performance of Bruce Hunn's house in Los Alamos. New Mexico. The data were collected on four consecutive days in January, 1977, and show the movement of heat through the wall.

The inner wall surface, which faces the interior of the living space, shows a relatively smooth daily temperature rise and fall. The temperature of this surface may reach as high as 90°F around 6-8 pm each day. As it gives off its heat to the room all night, its temperature gradually decreases, until it reaches the lowest temperature shown, 68°F. The wall is, in effect, a room size radiant heating panel which, even with the 0-1 °F outside (ambient) temperatures of 6:00 am, continues to radiate at temperatures well within the commonly accepted 65°F home comfort minimum. It can also be seen that the outer surface of the wall daily reaches temperatures as high as 156°F, and may go as low as 60°F during the night. This daily temperature swing decreases the farther into the wall that the temperatures are measured.



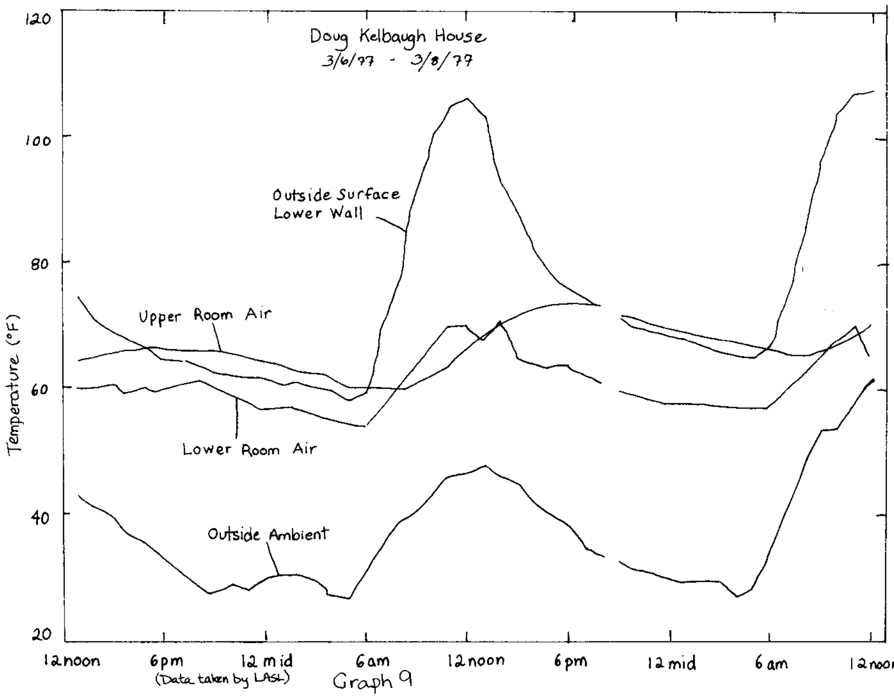
(This data taken by LASL) Graph 7

Graph 8 also shows the thermal performance of the Bruce Hunn house. The evening out of temperature swing on the inside of the wall can easily be seen here as can the movement of the peak through the wall with time.



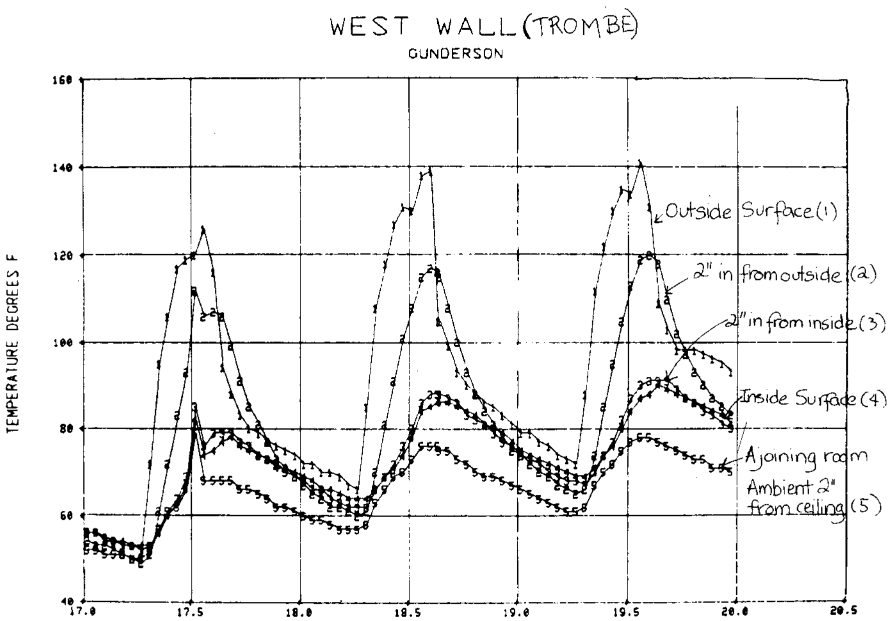
(Data taken by LASL) Graph 8

Graph 9 shows the thermal performance of the Doug Kelbaugh house in Princeton, New Jersey. The data shown were collected during a two-and-a-half day period in March, 1977 and show similar thermal performance. Although mid-wall temperatures are not shown, the large fluctuation of outside wall surface temperature and the small fluctuations of the inside room temperature illustrates the Trombe wall's effect in reducing interior temperature swing.



Graph 9

Graph 10 shows performance of the Gunderson water/concrete wall (described on page 21).



Graph 10

The Bruce Hunn Trombe wall is unvented but equipped with blowers to circulate hot air from the Trombe collector to a rock storage bed. The Doug Kelbaugh house is heated with a vented Trombe wall and is totally passive. Both owners are very satisfied with their homes, and comment on the comfort of **radiant** heat provided through the wall.

THERMAL STORAGE WALL VARIATIONS

There are many possibilities for variation from standard thermal storage wall designs. A specific design should depend on four basic criteria: 1) resources, including money, and building supplies; 2) heating requirements; 3) building uses, and 4) the geographical and climatic location of the site.

Low cost designs of thermal storage walls might include fiberglass and plastic glazing materials rather than glass, and mass walls of adobe (see Table I) or 55-gallon drums filled with water. Performance of the glazing at expected temperatures should be taken into account. As mentioned, building one's own thermal storage wall will result in a very substantial savings of money.

More expensive thermal storage walls might use two or even three layers, dependent on climate, of high-quality glass and more attractive wood for framing the glazing. Venting arrangements could also be more elaborate - utilizing perhaps rather expensive heat-driven pistons.

In hot climates, such as the southwestern and southeastern United States, cooling should be a major emphasis. Vents through the glazing are very important as are shading considerations. A removable cover for the Trombe wall collector could also be utilized to keep the sun off it in warm months. Efficiency of the Trombe wall is not as important in warm climates as it is in cool ones. In an area with a great deal of sun, the storage wall could be designed **thicker** than the optimal thickness for thermal efficiency. Not as much heat would ultimately get into the building, but a more constant and comfortable inside temperature would be maintained.

In cool climates, and those with little available sunlight (Northern U.S., Canada), the thermal storage wall design would have to be very efficient. The optimal mass wall thickness chart (page 20) should be followed closely even though it might mean greater temperature fluctuations inside the building. Reduction of heat loss should be a priority; if the heating requirements are reduced for a house, the thermal storage wall will supply a larger percentage of necessary heat. An insulated reflector such as the one shown schematically on page 25 should be used. Tilting the thermal storage wall collector is another option. If the collector surface is perpendicular to the winter sun's rays, it will be more efficient. so a tilt of 10-30° for northern climates might be worthwhile, although a bit more difficult to construct.

The expected **use** of the building should also have bearing on its design. A building used only during the day, such as most schools and office buildings, would not need to store as much heat so the mass wall could be thinner. Also, such a building should definitely have vents through the mass wall to allow for convective heating. A home largely unused during the daytime hours, on the other hand, should have a relatively **thick** mass wall able to store a large amount of heat. It should also be thick enough so that the heat radiating into the living areas will reach a maximum in the evenings (see Table VII).

Trombe walls can very effectively be combined with other passive solar heating systems. Direct gain south windows along with a Trombe wall are quite effective in supplying heat during the day when the Trombe wall is "charging up." In most cases, such a combination will negate the need for vents through the mass wall.

"Perforated" Trombe walls are being experimented with by Dr. Francis Wessling in Albuquerque, New Mexico.[14] The resulting system is a sort of "hybrid" between direct gain and Trombe wall heating systems. Available information indicates that these Trombes, with perforations or holes throughout the mass wall, are quite successful thermally and quite esthetically pleasing.

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14 Wessling. F. C .. "Solar Retrofit Test Module" 1978

Chapter 5

Retrofitting Existing Buildings with Trombe Walls

The potential of incorporating Trombe walls into new buildings has been demonstrated. There is very often also the possibility of adapting or retrofitting **existing** homes and buildings with Trombe walls.

If a building has mass walls (adobe, filled concrete block, brick, or stone) and one wall faces close to south, there is a good chance the wall could be turned into a Trombe wall. Other considerations have been discussed in the site selection section: sun path, obstructions, etc.

An insulated frame house would not work for a Trombe wall without serious alterations because no heat could be stored in the wall (although a no-storage air collector could be retrofitted). Though more expensive and probably less cost effective, it would be possible to build a Trombe wall onto a frame house by building a new south wall (removing the insulated frame wall). In doing so, of course, the proper materials for the wall would have to be used as outlined in this manual.

Assuming one has a wall of proper materials oriented correctly, turning it into a Trombe wall could be as easy as putting up a two-by-four frame on the south wall, attaching a layer of plastic glazing to it, adding 1 x 2 strips of wood and a second outer layer of glazing. As discussed, vents are not necessary for a Trombe wall although they can be very useful additions. Putting in vents would mean cutting holes through your mass wall which is not impossible, but may require quite a lot of work.

A very simple Trombe wall retrofit such as this could cost as little as $1.50 per square foot of Trombe wall area. This investment would be returned in energy savings in less than six years according to current estimates by Larry Sherwood of the New Mexico Solar Energy Association.

Diagrams G and H provide one example of how such a Trombe wall retrofit could be easily constructed. The mass wall to be covered should first be painted a dark color (with paint able to

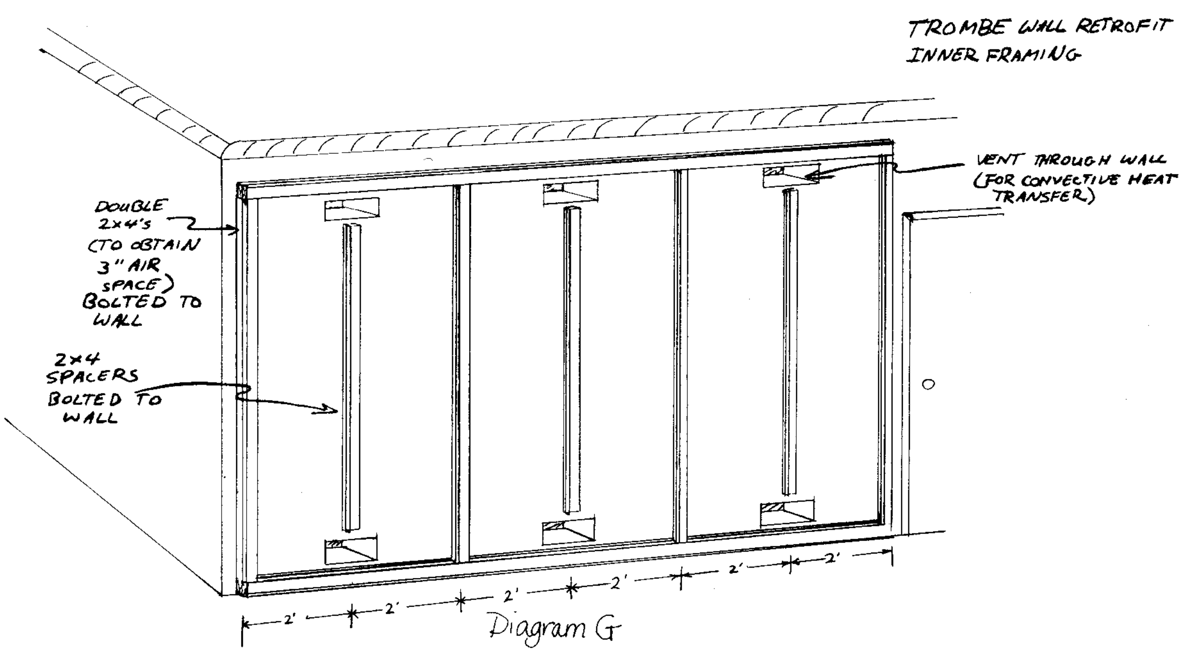

Diagram G

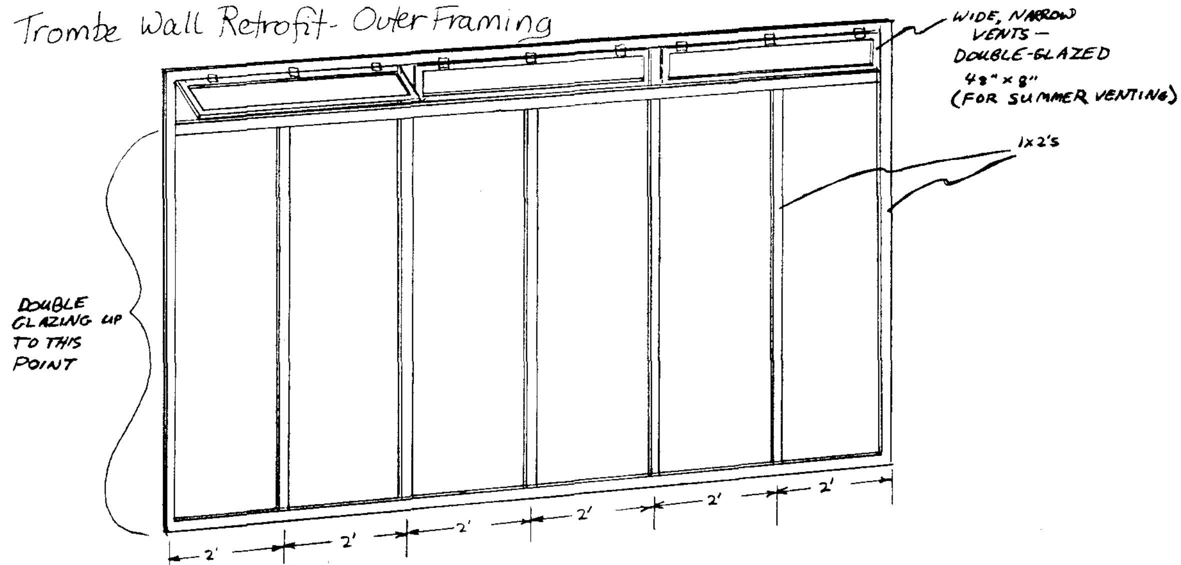

Diagram H

Drawn by A.T. Wilson

withstand high temperatures). If a **vented** Trombe wall is to be built the vents should be cut through the wall. The actual framing with two-by-fours can be done on the ground (select a **flat** area). Measurements should be made carefully (especially when framing around windows and doors). In most cases, for plastic and fiberglass glazing, vertical framing members should be two or four feet on center (horizontal distance from the center of one to the center of the next), and 2-4 ft. edge to center for the uprights at each edge. This allows one to easily attach the glazing material (usually in four foot widths) without much waste. If a vented Trombe wall is being built care should be taken to ensure that air can freely circulate through the vents. One method of doing this if framing is 2 ft. on center (as in diagram G). is to notch out the two-by-fours over the upper and lower vents. In this way, the Trombe wall will be divided into four foot wide sections with one upper and lower vent serving each four foot section. The frame should be stained or painted to preserve the wood (again. with painting. select a paint able to withstand high temperatures).

Attaching the two-by-four frame to the house wall can present some problems. At the New Mexico Solar Energy Association, for a Trombe wall retrofit onto an adobe wall, we have used three different methods to secure the frame to the wall. First, anchor bolts were used to anchor the bottom of the frame to poured concrete foundation posts located every four feet along the Trombe wall. Second, threaded rod running all the way through the two-by-fours and wall was used every four feet to secure the top of the frame to the wall. And third, screws through the uprights anchored into expanding plastic shields. hold the frame tightly against the wall. Most of the strength was provided by the anchor bolts and the threaded rod through the wall: the screws and plastic shields were used merely to hold the frame snugly against the wall and hold fiberglass insulation in place between the two-by-fours and wall. If the mass wall is not adobe (e.g. brick, stone, filled block, etc.), expanding lead shields and lag bolts can generally be used to secure the structure to the building. Both fiberglass insulation and caulk should be used to prevent heat loss through the perimeter of the framing.

With the two-by-four frame tightly in place, a layer of glazing should be attached. Some people suggest attaching a **temporary** layer of cheap polyethylene for a few weeks to allow the paints and/or stains to **out-gas** upon heating up. The concern is that fumes coming off paints and stains could coat the glazing and reduce solar transmission. The permanent inner layer of glazing should then be nailed on (with three penny galvanized nails). See pages 6 and 8 for information on the correct glazing type. If summer cooling vents through the glazing at the top are to be used (as in the diagram), this glazing should only come up to where the vents start.

With the inner layer of glazing in place, the outer framing can be attached. One-by-twos are satisfactory for the outer framing, providing a 3/4 inch space between the double layers of glazing. The one-by-twos can be nailed or screwed directly onto the two-by-fours and inner glazing (caulk is worthwhile here to make a tight seal). The upper vents through the glazing (if used) can be built of the same one-by-twos, glazed on both sides and attached to the framing with hinges (see diagram H). Outer glazing should then be added (below the vents) on the outside surface of the one-by-twos. Again caulk should be used to ensure a tight seal. Finally, stained or painted ¼ by one inch wood strips can be added over the glazing seams and edges to provide a better seal and improve the appearance of the Trombe wall.

With a vented Trombe wall, some sort of vent closures must be built to control air flow (see page 21). Having completed all this, the Trombe wall should operate quite well. Adaptations such as insulated reflectors and shading overhangs can improve the performance of the wall but are not strictly necessary.

Another example of a Trombe wall framing system is shown in Diagrams I through K. In this system 2 x 2's are used for inner framing with 2 x 4's used for the Trombe wall periphery and around windows and doors. Such a framing system is a good one for vented Trombes as it allows free circulation of hot air into the living area while conserving on wood and allowing fewer vents to be built for circulating hot air.
It should be mentioned that the two examples presented are just that - examples. There is room for a great deal of innovation and experimentation with designs. It is hoped that these examples might serve as a starting point from which many new and better designs will emerge.

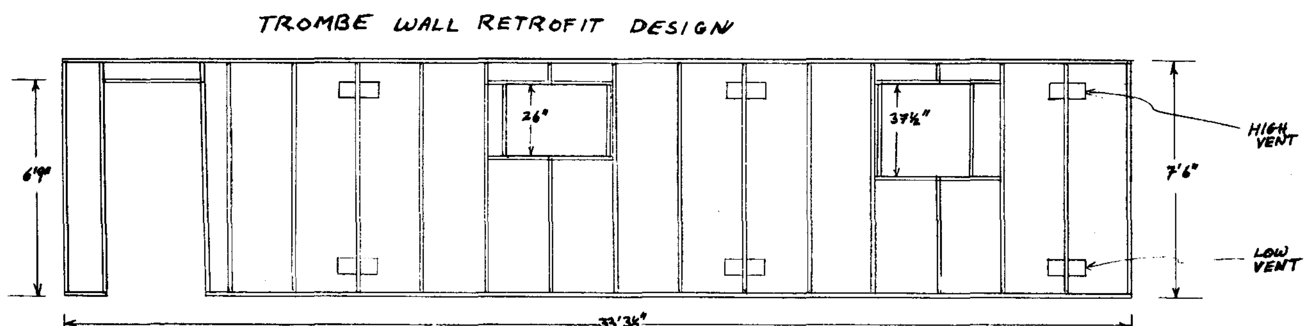

Diagram I

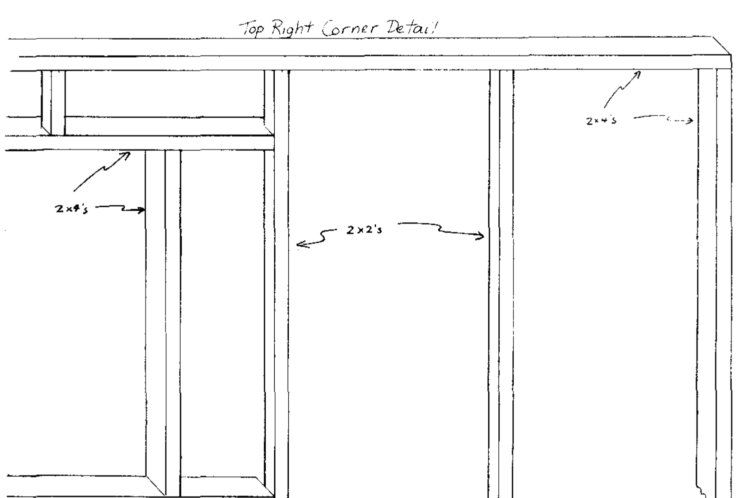

Diagram J

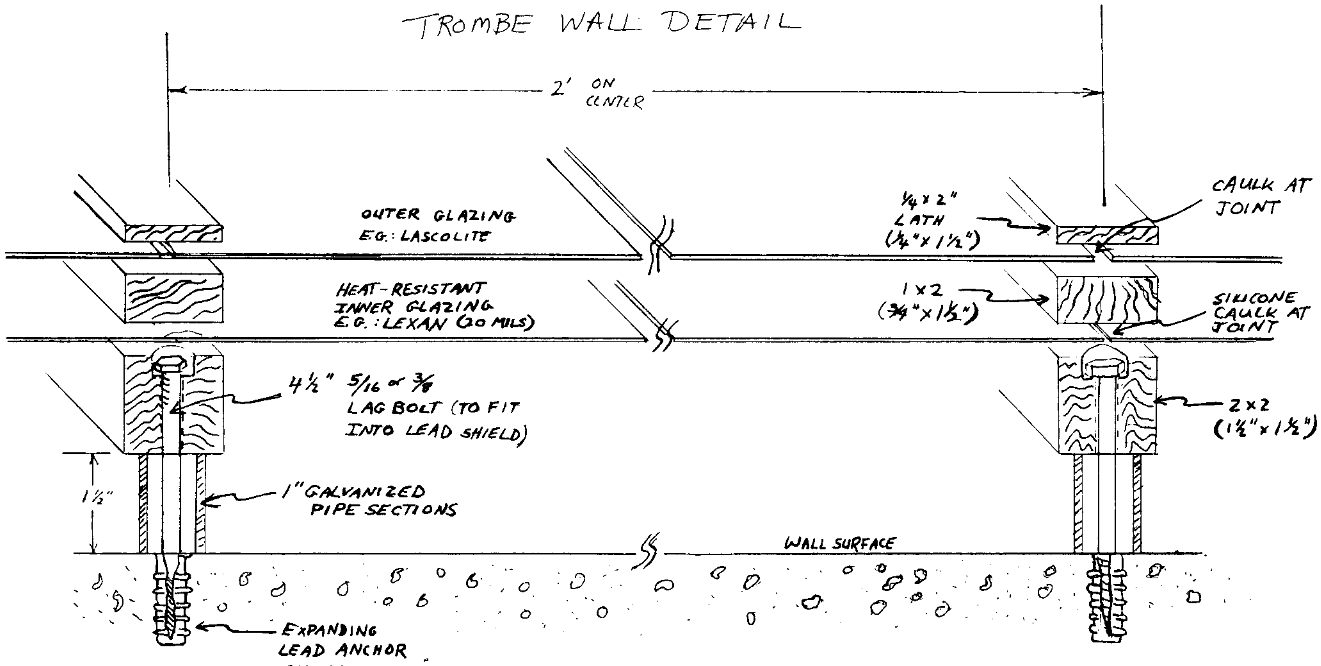

Diagram K

Photo: Bristol Stickney

APPENDIX A — LOAD COLLECTOR RATIOS

PERFORMANCE PARAMETERS FOR PASSIVE SOLAR HEATING SYSTEMS USING THERMAL STORAGE WALLS
Load Collector Ratio (BTU/DD-ft^2) for particular values of Solar Heating Fraction (SHF)

Page, Arizona	SHF	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
	WW	196	88	54	37	27	19	13	7	
6632 DD	WWNI	312	145	91	65	49	38	29	22	15
	TW	195	94	56	37	25	17	11	6	
37°N	TWNI	304	141	89	63	46	35	26	18	12

Phoenix, Arizona	SHF	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
	WW	626	294	188	135	102	78	60	44	29
1765 DD	WWNI	863	407	261	189	145	114	90	69	49
	TW	577	287	179	123	88	64	47	33	21
33°N	TWNI	819	386	247	176	132	101	76	56	38

Tucson, Arizona	SHF	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
	WW	631	291	184	132	100	77	59	43	29
1800 DD	WWNI	871	403	256	185	142	112	89	68	49
	TW	578	284	176	121	87	63	46	33	21
32°N	TWNI	825	383	243	173	130	99	75	56	38

Little Rock, Arkansas	SHF	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
	WW	239	108	66	46	33	24	17	11	
3219 DD	WWNI	365	172	107	76	57	44	35	26	18
	TW	232	112	67	44	30	21	14	9	
35°N	TWNI	356	165	103	73	54	40	30	22	14

Davis, California	SHF	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
	WW	409	187	115	79	57	42	30	21	11
2502 DD	WWNI	585	272	170	120	89	68	52	39	26
	TW	376	183	111	74	51	36	25	16	9
39°N	TWNI	556	259	161	112	82	61	45	32	21

El Centro, California	SHF	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
	WW	1028	482	301	214	161	125	97	72	50
1458 DD	WWNI	1375	649	407	290	221	175	139	107	77
	TW	916	458	284	194	140	103	75	54	36
33°N	TWNI	1294	608	382	270	202	154	117	87	60

Fresno, California	SHF	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
	WW	405	186	113	77	55	40	29	19	10
2492 DD	WWNI	577	271	168	117	87	66	50	37	25
	TW	370	181	109	72	49	34	24	15	8
37°N	TWNI	550	257	159	110	79	59	43	31	20

Inyokern, California	SHF	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
	WW	453	209	129	90	66	50	37	26	16
3528 DD	WWNI	641	300	188	132	100	77	60	46	32
	TW	419	204	124	84	59	42	30	20	12
36°N	TWNI	613	284	177	124	92	69	52	38	25

Los Angeles, California	SHF	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
	WW	763	362	225	158	118	91	70	52	35
2061 DD	WWNI	1032	498	310	219	165	131	103	80	57
	TW	687	344	213	145	103	75	55	39	26
34°N	TWNI	979	464	291	205	153	116	88	65	45

Riverside, California	SHF	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
	WW	767	356	224	160	121	94	72	53	36
1803 DD	WWNI	1039	488	308	221	169	134	106	82	58
	TW	692	344	214	146	105	77	56	40	26
34°N	TWNI	984	459	290	207	155	118	90	67	46

Santa Maria, California	SHF	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
	WW	544	272	176	126	96	74	56	41	27
2967 DD	WWNI	752	376	247	179	137	108	86	66	45
	TW	514	264	167	115	83	61	44	31	20
35°N	TWNI	720	358	231	166	126	96	73	54	36

Granby, Colorado	SHF	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
	WW	196	90	56	39	28	20	14	8	
5524 DD	WWNI	313	146	94	67	51	40	31	23	15
	TW	197	96	58	38	26	18	12	7	
40°N	TWNI	303	143	91	65	48	36	27	19	13

Grand Junction, Colorado	SHF	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
	WW	199	92	56	39	28	20	13		
5641 DD	WWNI	317	150	95	67	51	39	30	22	15
	TW	201	97	58	38	26	17	11	6	
39°N	TWNI	310	145	91	64	48	36	26	19	12

Washington, D. C.	SHF	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
	WW	179	79	47	32	22	15	9		
4224 DD	WWNI	292	135	83	58	44	33	25	18	12
	TW	180	85	50	32	21	13	8		
39°N	TWNI	285	131	81	57	41	31	22	16	10

Apalachicola, Florida	SHF	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
	WW	700	322	204	145	110	85	65	48	32
1308 DD	WWNI	956	444	281	203	155	123	97	75	53
	TW	635	313	194	133	95	70	51	36	24
30°N	TWNI	906	240	266	189	142	108	82	61	42

Gainesville, Florida	SHF	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
	WW	731	333	212	152	116	90	69	51	35
1239 DD	WWNI	1000	457	292	211	162	129	102	79	56
	TW	662	326	202	139	100	73	54	39	25
30°N	TWNI	943	435	276	197	148	113	86	64	44

Tallahassee, Florida	SHF	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
	WW	621	285	179	128	97	75	57	42	28
1485 DD	WWNI	857	397	249	180	138	109	87	67	48
	TW	563	279	172	117	84	61	45	32	21
30°N	TWNI	809	376	237	169	127	97	73	54	37

Tampa, Florida	SHF	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
	WW	1147	573	374	272	210	166	129	98	69
683 DD	WWNI	1520	760	500	365	283	227	182	141	102
	TW	1059	548	351	245	179	134	100	73	49
28°N	TWNI	1443	717	467	339	258	199	[illegible]	114	80

Atlanta, Georgia	SHF	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
	WW	301	136	83	58	43	31	23	15	8
2961 DD	WWNI	448	207	129	91	69	54	42	32	22
	TW	286	138	83	55	38	27	18	12	7
34°N	TWNI	431	198	123	87	64	48	36	26	17

Boise, Idaho	SHF	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
	WW	185	83	48	31	20	12	6		
5809 DD	WWNI	299	139	86	59	43	31	23	16	10
	TW	182	86	50	31	20	12	6		
44°N	TWNI	290	135	83	56	40	29	21	14	8

Lemont (ANL) Illinois	SHF	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
	WW	120	51	29	18	11				
6155 DD	WWNI	219	100	61	42	31	24	18	13	8
	TW	129	59	33	20	12	7			
42°N	TWNI	216	99	61	42	30	22	16	11	7

Indianapolis, Indiana	SHF	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
	WW	136	58	33	21	14	7			
5699 DD	WWNI	239	109	67	46	34	26	19	14	9
	TW	142	65	37	23	14	8			
40°N	TWNI	235	107	66	45	33	24	17	12	7

Ames, Iowa	SHF	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
	WW	117	50	29	18	11				
6588 DD	WWNI	215	99	61	42	31	23	18	12	8
	TW	127	58	33	20	12	6			
42°N	TWNI	213	98	60	41	30	22	16	11	7

Dodge City, Kansas	SHF	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
	WW	214	99	61	43	31	23	16	10	
4986 DD	WWNI	335	160	101	72	54	42	33	25	17
	TW	214	104	63	41	28	20	13	8	
38°N	TWNI	327	154	97	69	51	38	29	21	14

Manhattan, Kansas	SHF	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
	WW	165	74	44	30	21	14	8		
5182 DD	WWNI	274	128	80	56	42	32	25	18	12
	TW	169	80	47	30	20	13	8		
39°N	TWNI	269	125	78	54	40	30	22	15	10

Lexington, Kentucky	SHF	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
	WW	143	63	36	24	16	10			
4683 DD	WWNI	246	114	70	49	36	28	21	15	10
	TW	148	70	40	25	16	10	5		
38°N	TWNI	242	112	69	48	35	26	19	13	8

Lake Charles, Louisiana	SHF	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
	WW	522	239	152	109	82	63	48	35	23
1459 DD	WWNI	730	338	214	155	119	94	74	57	40
	TW	481	237	146	100	71	52	38	26	17
30°N	TWNI	695	322	204	146	109	83	63	46	32

Shreveport, Louisiana	SHF	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
	WW	361	166	104	74	65	42	31	22	14
2184 DD	WWNI	524	245	154	111	85	67	53	40	28
	TW	340	167	103	69	49	35	25	17	10
32°N	TWNI	500	234	148	105	79	60	45	33	22

PERFORMANCE PARAMETERS FOR PASSIVE SOLAR HEATING SYSTEMS USING THERMAL STORAGE WALLS (Cont.)
Load Collector Ratio (BTU/DD-ft^2) for particular values of Solar Heating Fraction (SHF)

Location	SHF	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
Caribou, Maine	WW	83	34	17	8					
9769 DD	WWNI	172	78	48	33	24	17	13	8	
	TW	97	43	23	12	5				
47°N	TWNI	172	79	48	33	23	17	12	8	4
Portland, Maine	WW	125	54	31	20	13	7			
7511 DD	WWNI	223	103	64	45	33	25	19	14	8
	TW	133	62	35	22	14	8			
44°N	TWNI	221	102	63	44	32	23	17	12	7
Boston, Massachusetts	WW	137	60	35	23	15	9			
5634 DD	WWNI	241	110	68	48	36	27	21	15	9
	TW	145	67	39	24	15	9	5		
42°N	TWNI	238	108	67	47	34	25	18	13	8
East Lansing, Michigan	WW	111	46	25	15	8				
6909 DD	WWNI	208	94	57	39	29	22	16	11	7
	TW	120	54	30	18	10	4			
43°N	TWNI	206	93	57	39	28	20	15	10	6
Sault St. Marie, Michigan	WW	100	40	21	11					
9048 DD	WWNI	193	87	53	36	26	19	13	9	5
	TW	110	49	26	15	7				
46°N	TWNI	192	87	53	36	25	18	13	8	4
St. Cloud, Minnesota	WW	96	39	21	11					
8879 DD	WWNI	189	85	52	36	26	19	14	9	5
	TW	108	48	26	15	7				
46°N	TWNI	189	86	52	36	25	18	13	8	5
Columbia, Missouri	WW	175	77	46	31	21	14	8		
5046 DD	WWNI	287	133	82	57	43	33	25	18	12
	TW	177	83	49	31	20	13	8		
39°N	TWNI	281	129	80	55	41	30	22	15	10
Glasgow, Montana	WW	168	75	44	29	19	12	6		
8996 DD	WWNI	277	130	81	56	41	31	23	17	10
	TW	171	80	47	30	19	12	7		
48°N	TWNI	272	126	78	54	39	29	21	14	9
Great Falls, Montana	WW	143	63	37	23	14	8			
7750 DD	WWNI	246	115	71	49	36	27	20	14	8
	TW	149	69	40	25	15	9			
47°N	TWNI	243	112	69	48	34	25	18	12	7
Lincoln, Nebraska	WW	175	77	45	30	21	14	8		
5864 DD	WWNI	288	133	82	57	42	33	25	18	12
	TW	176	83	48	31	20	13	8		
41°N	TWNI	280	129	79	55	40	30	22	16	10
Ely, Nevada	WW	172	80	50	35	25	18	12	6	
7733 DD	WWNI	282	134	85	61	47	36	28	21	14
	TW	178	86	52	34	23	16	10	6	
39°N	TWNI	277	131	83	59	44	33	25	18	11
Las Vegas, Nevada	WW	448	209	130	92	68	52	39	28	17
2709 DD	WWNI	632	300	188	134	102	80	63	48	33
	TW	414	205	126	85	60	43	31	21	13
36°N	TWNI	603	284	179	126	94	71	53	39	26
Reno, Nevada	WW	192	88	54	37	26	18	12	6	
6332 DD	WWNI	307	145	91	65	49	37	28	21	13
	TW	192	93	55	36	24	16	10	5	
39°N	TWNI	298	141	89	62	46	34	25	18	11
Seabrook, New Jersey	WW	163	72	43	29	20	13	8		
4812 DD	WWNI	271	126	78	55	41	31	24	17	11
	TW	167	78	46	29	19	12	7		
39°N	TWNI	267	123	76	53	39	29	21	15	9
Albuquerque, New Mexico	WW	278	133	83	59	44	33	24	16	9
4348 DD	WWNI	414	201	128	92	70	55	43	33	23
	TW	271	135	83	56	39	28	19	13	7
35°N	TWNI	402	193	123	87	65	49	37	27	18
Los Alamos, New Mexico	WW	179	84	52	36	26	18	12	7	
6604 DD	WWNI	288	139	89	64	48	37	29	21	14
	TW	183	89	54	36	24	16	11	6	
36°N	TWNI	283	136	86	61	45	34	25	18	12
Ithaca, New York	WW	93	36	18	9					
6914 DD	WWNI	189	83	50	34	24	18	13	9	5
	TW	106	46	24	13	6				
42°N	TWNI	188	83	50	34	24	17	12	8	4
New York City, New York	WW	147	64	38	25	17	11	5		
4871 DD	WWNI	250	117	72	51	38	29	22	16	10
	TW	152	71	42	26	17	11	6		
41°N	TWNI	247	114	71	49	36	27	20	14	9
Sayville, L.I. New York	WW	165	74	45	30	21	14	9		
4811 DD	WWNI	272	129	80	57	43	33	25	18	12
	TW	169	81	48	31	20	13	8	4	
41°N	TWNI	268	125	78	55	40	30	22	16	10
Schenectady, New York	WW	84	34	18	9					
6650 DD	WWNI	174	79	48	33	24	18	13	9	5
	TW	98	43	23	13	6				
43°N	TWNI	175	79	49	33	24	17	12	8	5
Greensboro, North Carolina	WW	237	107	66	46	33	24	17	11	
3805 DD	WWNI	367	170	107	75	57	44	35	26	18
	TW	231	112	67	44	30	21	14	9	
36°N	TWNI	354	165	103	72	54	40	30	22	14
Hatteras, North Carolina	WW	412	189	118	82	61	46	34	24	15
2612 DD	WWNI	588	274	173	123	93	73	57	43	30
	TW	381	187	115	77	54	39	28	19	11
35°N	TWNI	560	261	164	115	86	65	49	36	24
Raleigh, North Carolina	WW	256	117	71	50	37	27	19	12	7
3393 DD	WWNI	391	182	114	80	61	48	37	28	19
	TW	249	120	72	48	33	23	16	10	5
36°N	TWNI	378	175	109	77	57	43	32	23	15
Bismarck, North Dakota	WW	111	46	25	14	6				
8851 DD	WWNI	208	94	57	39	28	21	15	10	6
	TW	120	54	30	17	9				
47°N	TWNI	207	94	57	39	27	20	14	9	5
Cleveland, Ohio	WW	103	41	22	12					
6351 DD	WWNI	202	89	53	36	26	20	14	10	6
	TW	114	50	27	15	8				
41°N	TWNI	200	89	53	36	26	19	13	9	5
Columbus, Ohio	WW	120	51	29	18	11				
5211 DD	WWNI	218	100	61	42	31	23	17	12	7
	TW	128	59	33	20	12	6			
40°N	TWNI	216	99	61	42	30	22	16	11	6
Put-in-Bay, Ohio	WW	102	39	20	9					
5796 DD	WWNI	199	88	52	35	25	18	13	8	
	TW	112	48	26	14	6				
42°N	TWNI	199	87	52	35	25	18	12	8	4
Oklahoma City, Oklahoma	WW	250	115	70	49	36	26	19	12	6
3725 DD	WWNI	382	179	112	80	60	47	37	28	19
	TW	243	118	71	47	32	23	15	10	5
35°N	TWNI	370	172	108	76	57	43	32	23	15

WW - WATER WALL

PERFORMANCE PARAMETERS FOR PASSIVE SOLAR HEATING SYSTEMS USING THERMAL STORAGE WALLS (Cont.)
Load Collector Ratio (BTU/DD-ft^2) for particular values of Solar Heating Fraction (SHF)

Astoria, Oregon	SHF	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
	WW	207	98	59	39	26	17	9		
5186 DD	WWNI	322	158	99	69	50	37	27	19	11
	TW	205	99	59	38	25	16	9		
46°N	TWNI	315	152	95	65	47	34	24	16	9

Corvallis, Oregon	SHF	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
	WW	224	96	57	37	24	16	9		
4726 DD	WWNI	352	158	97	67	48	36	26	18	11
	TW	217	100	58	36	24	15	9		
45°N	TWNI	341	153	93	63	45	33	23	16	9

Medford, Oregon	SHF	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
	WW	188	83	49	31	20	12			
5008 DD	WWNI	306	139	86	60	43	32	23	16	9
	TW	186	87	50	31	20	12	6		
42°N	TWNI	296	136	83	57	40	29	21	14	8

State College, Pennsylvania	SHF	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
	WW	117	50	28	18	11				
5934 DD	WWNI	214	98	61	42	31	23	17	12	7
	TW	126	58	33	20	12	6			
41°N	TWNI	213	97	60	41	30	22	16	11	6

Newport, Rhode Island	SHF	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
	WW	150	66	40	27	19	12	7		
5804 DD	WWNI	256	118	74	52	39	30	23	17	11
	TW	156	74	43	27	18	11	7		
41°N	TWNI	251	116	72	51	37	28	20	14	9

Charleston, South Carolina	SHF	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
	WW	442	204	127	90	67	52	39	28	18
2033 DD	WWNI	624	295	184	132	100	79	63	48	34
	TW	407	202	124	84	59	43	31	21	13
33°N	TWNI	594	279	176	124	93	71	53	39	27

Rapid City, South Dakota	SHF	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
	WW	149	67	40	26	18	11	6		
7345 DD	WWNI	253	118	74	52	39	30	22	16	10
	TW	155	73	43	27	17	11	6		
44°N	TWNI	249	116	72	50	37	27	20	14	9

Nashville, Tennessee	SHF	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
	WW	227	99	59	40	28	20	13	8	
3578 DD	WWNI	355	161	98	68	51	39	30	23	15
	TW	219	103	61	39	26	18	11	7	
36°N	TWNI	343	155	95	66	48	36	27	19	12

Oak Ridge, Tennessee	SHF	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
	WW	204	90	54	36	26	18	12	6	
3817 DD	WWNI	325	149	92	64	48	37	29	21	14
	TW	201	95	56	36	24	16	6		
36°N	TWNI	315	145	89	62	46	34	25	18	11

Brownsville, Texas	SHF	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
	WW	1052	526	348	254	194	151	117	88	60
600 DD	WWNI	1399	700	465	342	265	209	165	127	90
	TW	976	506	324	226	165	123	91	66	44
26°N	TWNI	1330	664	435	315	238	183	140	104	71

El Paso, Texas	SHF	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
	WW	431	205	129	92	69	52	39	28	18
2700 DD	WWNI	608	295	187	134	103	80	63	48	34
	TW	402	202	125	85	60	44	31	22	13
32°N	TWNI	582	279	178	126	94	72	54	40	27

Fort Worth, Texas	SHF	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
	WW	364	171	108	76	57	43	32	23	14
2405 DD	WWNI	526	251	159	115	87	69	54	41	29
	TW	344	171	106	71	50	36	26	18	10
33°N	TWNI	503	239	152	108	81	61	46	34	23

Midland, Texas	SHF	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
	WW	385	184	115	82	61	47	35	25	16
2591 DD	WWNI	548	267	169	121	93	73	57	44	31
	TW	362	182	113	76	54	39	28	19	12
32°N	TWNI	527	253	161	115	86	65	49	36	24

San Antonio, Texas	SHF	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
	WW	547	253	159	114	86	66	50	37	24
1546 DD	WWNI	762	355	224	162	124	98	78	60	42
	TW	501	248	154	104	75	54	40	28	18
30°N	TWNI	722	337	213	152	114	87	66	49	33

Flaming Gorge, Utah	SHF	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
	WW	170	79	48	33	23	16	10	5	
6929 DD	WWNI	277	132	84	60	45	35	27	20	13
	TW	173	84	50	33	22	15	9	5	
41°N	TWNI	272	129	82	58	43	32	24	17	11

Salt Lake City, Utah	SHF	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
	WW	192	86	52	35	24	16	10		
6052 DD	WWNI	308	143	90	63	46	35	27	19	12
	TW	190	91	54	34	23	15	9	4	
41°N	TWNI	299	140	87	60	44	32	24	17	10

Burlington, Vermont	SHF	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
	WW	80	30	15						
8269 DD	WWNI	171	75	46	31	23	17	12	8	4
	TW	94	41	21	11					
44°N	TWNI	172	77	46	31	22	16	11	7	4

Pullman, Washington	SHF	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
	WW	178	78	44	27	17	9			
5542 DD	WWNI	291	134	82	56	40	29	21	14	8
	TW	175	81	46	28	18	10			
47°N	TWNI	282	130	79	53	37	27	19	13	7

Richland, Washington	SHF	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
	WW	179	77	43	25	15	7			
5941 DD	WWNI	293	133	81	54	38	27	19	13	7
	TW	176	80	45	27	16	9			
47°N	TWNI	285	130	78	52	36	26	18	12	7

Seattle, Washington	SHF	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
	WW	219	93	52	32	20	11			
4424 DD	WWNI	346	154	93	62	44	31	22	15	9
	TW	211	95	54	33	20	12	6		
48°N	TWNI	333	149	89	59	41	29	20	13	8

Spokane, Washington	SHF	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
	WW	149	63	34	20	10				
6655 DD	WWNI	255	116	70	47	33	23	17	11	6
	TW	151	68	38	22	13	6			
48°N	TWNI	251	114	68	45	32	22	16	10	5

Madison, Wisconsin	SHF	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
	WW	108	44	24	14	7				
7863 DD	WWNI	206	92	56	38	28	21	16	11	6
	TW	119	53	29	17	10				
43°N	TWNI	204	92	56	38	27	20	14	10	6

Lander, Wyoming	SHF	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
	WW	163	76	47	32	22	15	9		
7870 DD	WWNI	267	129	82	58	44	34	26	19	12
	TW	168	81	49	32	21	14	9	4	
43°N	TWNI	264	126	80	56	41	31	23	16	10

Laramie, Wyoming	SHF	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
	WW	157	72	44	31	22	15	10		
7381 DD	WWNI	263	124	79	56	43	33	26	19	13
	TW	164	79	47	31	21	14	9	4	
41°N	TWNI	259	122	77	55	41	30	23	16	10

Edmonton, Alberta	SHF	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
	WW	93	34							
10268 DD	WWNI	184	83	48	31	20	13	8	4	
	TW	102	42	20						
54°N	TWNI	184	83	48	31	20	14	9	5	

Ottawa, Ontario	SHF	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
	WW	91	35	17	7					
8735 DD	WWNI	185	81	49	33	24	17	12	8	4
	TW	103	45	23	13					
45°N	TWNI	184	82	49	33	24	17	12	8	4

Toronto, Ontorio	SHF	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
	WW	103	42	23	14	6				
6827 DD	WWNI	198	89	55	38	27	21	15	10	6
	TW	114	51	28	16	9				
44°N	TWNI	197	89	55	37	27	19	14	9	5

Winnipeg, Manatoba	SHF	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
	WW	74	27							
10679 DD	WWNI	162	73	44	29	20	14	9	5	
	TW	88	37	18	7					
50°N	TWNI	164	74	44	29	20	14	9	5	

Source: "A Simple Empirical Method for Estimating the Performance of a Passive Solar Heated Building of the Thermal Storage Wall Type"

GLOSSARY

Absorber. The blackened surface in a collector that absorbs the solar radiation and converts it to heat energy.
Absorptivity. The ratio of solar energy absorbed by a surface to the solar energy striking it.
Active System. A solar heating or cooling system that requires external mechanical power to move the collected heat.
Adobe. A sun-dried, unburned brick of clay (earth) and straw used in construction.
Air type collector. A collector which uses air as the heat transfer fluid.
Ambient temperature. The prevailing temperature outside a building.
Angle of incidence. The angle that the sun's rays make with a line perpendicular to a surface.
Azimuth. The angular distance between true south and the point on the horizon directly below the sun.
Btu (British Thermal Unit). The quantity of heat needed to raise the temperature of one pound of water 1^0 F.
Calorie. The quantity of heat needed to raise the temperature of one gram of water 1^0 C. One calorie is approximately equal to 4 Btu's.
Concentrating Collector. A device which focuses sunlight onto a small area for collection.
Conductance (C). The quantity of heat (Btu's) which will flow through one square foot of material in one hour, when there is a 1^0 F temperature difference between both surfaces. Conductance values are given for a specific thickness of materials, not per inch of thickness.
Conduction. The transfer of heat through materials by molecular excitation of adjacent molecules.
Conductivity (k). The quantity of heat (Btu's) that wi ll flow through one square foot of material, one inch thick, in one hour, when there is a temperature difference of 1^0 F between its surfaces.
Convection. Heat transfer through a fluid by currents resulting from the natural fall of heavier, cool fluid and the rise of lighter, warm fluid.
Dead air space. A confined space of air tending to reduce both conduction and convection of heat.
Degree Day. Unit representing 1^0 F deviation of one day's mean outside temperature from a fixed standard (650 F); used in estimating a house's heating or cooling requirements.
Delta T. A difference in temperature.
Design temperature. A designated temperature close to the most severe winter or summer temperature extremes of an area, used in estimating a house's heating and/or cooling needs.
Diffuse radiation. Sunlight that is scattered by air molecules, dust and water vapor.
Direct gain. Technique of solar heating in which sunlight enters a structure through windows and is absorbed inside as heat.
Direct radiation. Solar radiation that comes straight from the sun, casting a shadow on a clear day.
Efficiency. In solar applications, the amount of useful solar energy collected divided by the amount of solar energy available to the collector. Not to be confused with solar heating fraction.
Eutectic Salts. A group of salts that melt at low temperatures (80 - 120^0 F). absorbing large quantities of heat.
Equinox. Either of two times during the year when the sun crosses the celestial equator and when the length of day and night are approximately equal. The autumnal equinox is on September 22 and the vernal equinox is on March 22.
Flat-Plate Collector. A solar collection device in which sunlight is converted to heat on a plane surface.
Glazing. A covering of transparent or translucent material (glass, fiberglass, or plastic) used for admitting light.
Greenhouse Effect. Ability of glass or clear plastic to transmit short wave solar radiation Into a room or collector but to trap long-wave heat emitted by the room or collector interior.
Heat Capacity. A property of a material defined as the quantity of heat needed to raise one cubic foot of the material 1^0 F. Numerically, the mass multiplied by the specific heat.
Heat Gain. An increase in the amount of heat contained in a space, resulting from direct solar radiation and the heat given off by people, lights, equipment. and other sources.
Heat Loss. A decrease in the amount of heat contained in a space, resulting from heat flow through walls, windows, roof and other building components.

Hybrid System. Solar heating system that combines active and passive techniques.
Incident solar radiation. The amount of solar radiation available at a surface. Infiltration. Air flowing inward through cracks, leaks, etc.
Insolation, The incident solar radiation received per unit area of surface.
Insulation. Materials or systems used to prevent loss or gain of heat. usually employing very small dead air spaces to limit conduction and convection.
Liquid-Type Collector. A collector with a liquid as the heat transfer fluid.
Magnetic south. "South" as indicated by a compass; changes markedly with latitude.
Microclimate. Climate of a very small area such as a house site; formed by topography exposure, soil. vegetation, etc.
Passive System. A solar heating or cooling system that uses no external mechanical powerto move the collected solar heat.
Pyranometer. A solar radiometer which measures total insolation, including both direct and diffuse radiation.
Orientation. Alignment of a building to face a certain direction.
Radiation. One of three ways in which heat is transferred (the others being conduction and convection). Radiation is the direct transfer of energy through space, needing no air or other medium for its transmission.
Reflectance. The ratio of the amount of light reflected by a surface to the amount incident. Good light reflectors are not necessarily good heat reflectors.
Resistance (R). The tendency of a material to retard the flow of heat.
Retrofitting. Installing solar heating or cooling systems in buildings not originally designed for them.
R-factor. A unit of thermal resistance used for comparing insulating values of different materials; the reciprocal of conductivity; the higher the R-factor of a material the greater its insulating properties.
Selective Surface. Specially adapted coating with high solar radiation absorbance and low thermal emittance, used on surface of an absorber plate to increase collector efficiency.
Solar altitude. The angle of the sun above the horizon measured in a vertical plane.
Solar constant. The amount of solar radiation that reaches the outside of the earth's atmosphere.
Solar heating fraction. That portion of a building's heating needs which is provided by a solar system.
Specific Heat. The number of Btu's required to raise the temperature of one pound of a substance 1^0 F.
Thermal Conductance. (See conductivity.)
Thermal Mass. The amount of potential heat storage capacity available in a given assembly or system.
Thermosyphon. The convective circulation of fluid which occurs in a closed system when warm fluid rises. displaced by denser, cooler fluid in the same system.
Translucent. The quality of transmitting light but causing sufficient diffusion to eliminate perception of distinct images.
Transmissivity. The ability of a material to transmit light.
Transmittance. The ratio of radiant energy transmitted through a substance to the total radiant energy incident on its surface.
Trombe Wall. A south-facing wall of massive construction (typically masonry) that is of a dark color and is exteriorally glazed. The glazing acts to trap heat resulting from the sun's rays striking the wall. The heat can be vented to the interior by convection or conducted through the wall itself.
True South. South with reference to the stars, not to the compass; opposite to the Pole Star.
U-factor. A coefficient which indicates the energy (Btu's) conducted through a substance for every degree F of temperature difference from one side to another under steady state conditions. The reciprocal of the R-factor.
Vapor Barrier. A component of construction, usually a membrane, which is impervious to the flow of moisture or air.
Waterwall. An interior wall of water-filled containers constituting a one-step heating system which combines collection and storage.

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