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A SIMPLE EMPIRICAL METHOD FOR ESTIMATING THE PERFORMANCE OF A PASSIVE SOLAR HEATED BUILDING OF THE THERMAL STORAGE WALL TYPE*

by

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ABSTRACT

Two methods are presented for estimating the annual solar heating performance of a building utilizing a passive thermal storage wall of the Trombe wall or water wall type with or without night insulation and with or without a reflector. The method is accurate to ± 3% as compared with hour-by-hour computer simulations.

INTRODUCTION

A simple procedure has been devised for predicting the performance of solar heated structures. It has been determined that reasonable estimates (± 3%) can be made based on monthly values of solar radiation, heating degree days, and the thermal loss and solar gain characteristics of the building. The method was originally developed for studying active systems[1] but proves to be even more accurate for the analysis of passive systems. The correlations are based on a very comprehensive set of calculations which have been made using the hour-by-hour computer simulation analysis techniques developed at Los Alamos for passive systems. Several hundred year-long calculations were made for 29 different cities and for 6 different building loads in each city. The simplified method relies on the use of an appropriate correlating parameter (the Solar Load Ratio) and an empirical fit to this large ensemble of results.

The method is presented in two options. Method A, which is the simplest to use, is described first. Temperature and solar radiation are compacted into a single coefficient called the Load Collector Ratio given for 84 cities. These tabulated values have been derived from the more general Method B, which is the Monthly Solar Load Ratio technique.

The designer may wish to use Method B for any of the following reasons.

1. The location of interest is not in Table 1.

2. The building load is more complex than a simple conductance. For example, accounting for internal heat generation in the building would require using Method B.

3. The user wishes to obtain an estimate of month-by-month distribution of heating load and solar heating contribution.

Both methods are quite constraining. They only apply to the specific systems which were studied: a Trombe wall and a water wall with and without night insulation. An extension of the technique to apply to cases utilizing a horizontal reflector, located in front of the collector wall, is presented in the last section.

Although the data sets which were used to generate the correlations are from the United States, Southern Canada, and three other cities, it is believed that the method can be used for most climates throughout the world. In order to obtain the best estimates possible, however, it is desirable to use the best technique available for calculating the solar radiation transmitted through the glazing. For latitudes outside the

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U. S. range, it is recommended that the correlations developed for calculating the ratio of vertical radiation transmitted to horizontal not be used. The monthly solar load ratio curves, however, should be usable at any location.

The definition of load is confusing and the user should be alert to handle this correctly. The auxiliary energy required is unambiguous and is accurately estimated by both methods.

METHOD A

In order to obtain an estimate of the solar heating fraction and auxiliary energy required for any location listed in Table 1, perform the following steps.

Step 1

Estimate the Building Loss Coefficient (BLC) in BTU/degree-day. This is the sum of the building skin conductance plus infiltration. It is the extra energy required (BTU) per day for each additional one °F increase in temperature difference between the building interior and outside. It can be calculated from the sum of the UxA values for the exterior areas of the building plus infiltration. IMPORTANT--in calculating the Building Loss Coefficient, the passive thermal storage wall should not be included in the load.

Step 2

Calculate the building Load Collector Ratio (LCR) defined as follows:

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

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 solar wall.

Step 3

Go to Table 1 and locate the city of interest and the wall type of interest. If the Load Collector Ratio determined in Step 2 corresponds exactly to one of the values listed in the Table under 0.25 or 0.75 Solar Heating Fraction (SHF), then this is the desired answer. If not, one needs to interpolate in the table. The meaning of a Solar Heating Fraction is ambiguous when applied to a passive solar building. What is the building being compared with? As used herein, the SHF is the fraction of the degree-day load (in the product of the degree-days times the Build-Loss Coefficient which is supplied by the solar 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.

The auxiliary used is a less ambiguous peg point, leaving the basis of comparison up to the user.

Step 4

The annual auxiliary energy required to maintain the building at a minimum temperature of 65°F can be estimated from the following equation:

$$\text{Auxiliary Energy BTU/yr} = (1\text{-SHF})\begin{pmatrix}\text{Annual}\\ \text{Heating}\\ \text{Degree-}\\ \text{Days}\end{pmatrix}\begin{pmatrix}\text{Building Loss}\\ \text{Coefficient,}\\ \text{BTU/Degree-}\\ \text{Day}\end{pmatrix}$$

Example

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 1618 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.

(Step 1) The Building Loss Coefficient is estimated as follows:

Skin Conduction:

Surface Type	Area ft^2	U-Value BTU/ft^2°F hr	UxA 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:

($12320\ ft^3$)(1/2 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 energy actually supplied by the solar wall will be greater than this as discussed in the last section of the paper.

(Step 4) The auxiliary energy can be estimated as:

$$\text{Auxiliary Energy} = (1-0.48)(10250)\ (4986) = 26.6\ \text{MBTU/yr.}$$

METHOD B

The values listed in Table 1 for use in Method A were derived using the Monthly Solar Load Ratio Method. This method provides an empirical means of estimating the monthly solar auxiliary energy requirements based on the Monthly Solar Load Ratio (SLR). The Monthly Solar Load Ratio is a dimensionless correlation parameter defined as follows:

$$SLR = \frac{\text{monthly solar energy absorbed on the thermal storage wall surface}}{\text{monthly building load (including the wall steady-state losses in the absence of solar gains)}}$$

The numerator is equal to the product of the total solar collection wall area times the monthly solar energy transmitted through one square foot of south glazing times the wall absorptance. The denominator is equal to the building loss coefficient (including the steady state conduction through the south solar collection wall) times the monthly heating degree days.

The SLR can be expressed as follows:

$$SLR = \frac{\begin{pmatrix}\text{Collector}\\ \text{Wall Area}\end{pmatrix}(\text{Absorptance})\begin{pmatrix}\text{Monthly Solar Energy}\\ \text{Transmitted through}\\ \text{the Glazing}\end{pmatrix}}{\begin{pmatrix}\text{Modified Building}\\ \text{Loss Coefficient}\end{pmatrix}(\text{Monthly Degree Days})}$$

$$SLR = \frac{\begin{pmatrix}\text{Monthly Solar Energy}\\ \text{Transmitted}\end{pmatrix} \Big/ (\text{Monthly Degree Days})}{\begin{pmatrix}\text{Modified Building}\\ \text{Loss Coefficient}\end{pmatrix} \Big/ \begin{pmatrix}\text{Wall area}\\ \text{x Absorptance}\end{pmatrix}}$$

$$SLR = \frac{\text{Solar Capability Index}}{\text{Modified Load Collector Ratio}}$$

The SLR is given by the ratio of two different terms, the Solar Capability Index, which depends only on the weather for the locality and a Modified Load Collector Ratio (MLCR) which depends only on the building construction.

Step 1

Determine the Building Loss Coefficient in the same manner as in Step 1 of Method A. Compute a Modified Building Loss Coefficient by adding the term 24 x (Solar Wall Area(U_w) where U_w is taken from the following table:

BTU/hr°F ft^2	Plain Double Glazed	With R9 Insulation added from 5:00 p.m. to 8:00 a.m.
Water Wall	0.33	0.18
18" Trombe Wall	0.22	0.12

The value of U_w is the steady-state conduction coefficient of the combined wall, glazing, and insulation, averaged over the day.

Step 2

Determine the SLR for each month of the year. Solar radiation values generally available in tables are measured on a horizontal surface, whereas the values required in order to determine the SLR are the actual solar radiation transmitted through the vertical south facing surface. The values of solar radiation in the ASHRAE tables for clear-day conditions are not applicable. The use of a cloudiness factor, which is an approach sometimes used, is not accurate enough. Thus it is necessary to provide a simple method of making a transformation.

Hour-by-hour calculations were made for one month periods for the 29 locations for each month of the year. The hourly transformation from the horizontal to the vertical was made using the correlation technique developed by Boes,[2] for separating diffuse from direct beam radiation. A ground reflectance of 0.3 was assumed. The fraction of the incident energy which is actually transmitted through the glazing was then calculated using the Fresnel relationship for the hourly angles of incidence and the absorption coefficient of ordinary double strength glass. The hourly values were summed in order to determine monthly integrals. It was found that the results could be correlated quite well using the following parameter

L-D = Latitude - Solar Declination at Mid-Month

The solar declination at mid-month should be estimated from the following equation:

$$D = 23.3^\circ \cos(30^\circ M - 187^\circ)$$

M = month (i.e., June = 6)

This plotting parameter, L - D is equal to the noon-time angle between the vertical and the sun. A plot of the results is shown in Fig. 1. The solid line plotted on Fig. 1 is a least-squares fit through the data given by the following equation:

$$\frac{\text{Monthly Solar Energy Transmitted through South Double Glazing}}{\text{Monthly Solar Energy Incident on Horizontal Surface}} = 0.2260 - .002512(L-D) + .0003075(L-D)^2$$

The errors which would be incurred by using the least-squares fit rather than the actual values of solar radiation transmitted do not significantly increase the error in Monthly Solar Heating Fraction indicating that the two errors are uncorrelated.

If the building does not face due south, then this equation cannot be used as is. It will be necessary to make another correction for building orientation. LASL has not yet devised a separate series of correlations for different tilts and orientations. It is felt, however, that a correction factor based on the ASHRAE clear-day tables would probably be a reasonable estimate. Those tables provide values for the clear day conditions for southwest and southeast orientations as well as due south, as a function of latitude. For the time being, a straight proportional correction factor based on these tables is recommended. Note that a separate correction factor will be required for each month.

Step 3

Determine the Monthly Solar Heating Fraction for each month of the year based on the values of SLR computed in Step 2. Plots of the function for the four different cases of Trombe wall and water wall with and without night insulation are given in Fig. 2.

Step 4

Compute the auxiliary energy required each month from the following equation:

$$\text{Auxiliary Energy} = (1-\text{SHF})(\text{Degree Days})(\text{Modified Building Loss Coefficient})$$

Step 5

Compute the sum of the monthly auxiliary energy requirements. This is the annual auxiliary energy. The annual solar heating fraction can then be determined from the following equation:

$$\text{Annual SHF} = 1 - \frac{\text{Annual Auxiliary Energy}}{\begin{pmatrix}\text{Annual}\\ \text{Degree}\\ \text{Days}\end{pmatrix}\begin{pmatrix}\text{Building Loss}\\ \text{Coefficient}\\ \text{(Unmodified)}\end{pmatrix}}$$

Example

The same building in Dodge City, Kansas will now be used as an example for Method B. The Building Loss Coefficient has already been determined as 10250 BTU/degree-day. The latitude of Dodge City is 38°. Following through these steps, one by one, results in the table on the next page.

The small error observed between the auxiliary energy calculated by Method A and that by Method B in this example is attributed to the slight error in interpolating in the table and the round-off of the numbers listed in Table I.

If the user desires to calculate values of the collector load ratio similar to those listed in Table I, but for a different locality or a different set of values of solar radiation or heating degree-days, he can easily do so by carrying through the five steps of Method B for various values of the Load Collector Ratio. In this manner as many points as are desired can be filled in to the table for various values of Solar Heating Fraction. It will be necessary to iterate in order to determine an exact value of Solar Heating Fraction.

The values of heating degree-days and solar radiation incident on a horizontal surface which were used to compute Table I are the standard values

Dodge City	DD	Modified Monthly Load, MBTU/Mo.	Horizontal Solar Radiation BTU/Mo. ft^2	L-D	Solar Radiation Absorbed MBTU/Mo.	SLR	SHF	Auxiliary MBTU/Mo.
Oct.	251	3.19	41180	47.1	10.05	3.15	.972	.09
Nov.	666	8.46	28560	56.6	9.43	1.11	.631	3.12
Dec.	939	11.92	25050	61.1	9.45	.79	.474	6.77
Jan.	1051	13.35	27910	59.4	10.02	.75	.450	7.34
Feb.	840	10.67	33270	57.0	9.53	..89	.529	5.03
Mar.	719	9.13	47590	40.8	9.34	1.02	.592	3.73
Apr.	354	4.50	58230	28.9	7.38	1.64	.797	.91
May	124	1.57	65320	19.4	5.91	3.76	.992	.01
Total	4944							27.00

The column labeled Modified Load is calculated with a Modified Building Loss Coefficient of 12700 BTU/DD. The added loss is (309 ft^2)(.33)(24) = 2450 BTU/DD to account for the steady state solar wall loss coefficient. The Solar Heating Fraction is calculated from the (unmodified) Building Loss Coefficient as follows:

$$SHF = 1 - \frac{27.0 \times 10^6}{(10250)(4944)} = 0.47$$

which have been listed in the literature. Revised values of solar radiation will probably be generated to reflect better knowledge of pyranometer calibrations and other factors. As these numbers become available, more accurate values for Table I can be generated. It should be noted however, that the accuracy of the Solar Load Ratio Method itself does not depend on the accuracy of the solar radiation data used, since there was complete consistency between the values of the hourly solar radiation used and the monthly integrals of solar radiation.

EFFECT OF INTERNAL GENERATION IN THE BUILDING

Heat generated in the building, by people, lights and equipment is effective in reducing the monthly load. This reduces both the auxiliary energy requirements and the monthly solar contribution.

The original basis for defining the degree-day base at 65°F was on the assumption that these internal energy sources would raise the building temperature from 65°F up to the accepted comfort standard of 72°F. This assumption can still be made in using the results from this section, namely, that the actual building temperature would be several degrees greater than the 65°F to 75°F band assumed in the analysis.

However, experience has been that most people now set their thermostat at lower levels. This is especially true of people who live in passive solar homes because the effect of the warm surrounding surfaces of these buildings increases the mean radiant temperature within the space so that one can be comfortable at a reduced air temperature. In any case, a 65°F thermostat setting seems more consistent with actual practice in the winter than the ASHRAE standard value of 72°F.

The hour-by-hour analysis used to determine the Monthly Solar Load Ratio curves did not provide any internal energy in the building to account for that generated by people, lights and equipment. The user of the method can correct for this by subtracting the estimated internal energy generation from the monthly loads prior to computing the monthly Solar Load Ratio. The effect of this would be to increase the Solar Load Ratio, increase the Monthly Solar Heating Fraction, and decrease the auxiliary energy requirements.

VARIATIONS FROM THE ASSUMED REFERENCE SYSTEMS

The monthly solar load ratio curves which have been determined are for very specific reference systems as defined in Table II. If it is desired to estimate the performance of the system which is different than one of these reference systems, then it is necessary to make a correction. The most reliable way of doing this is to refer to results of hour-by-hour calculations which are made for a specific system varying only the parameter of interest. Quite a few such calculations have been made by LASL and have been published.[3,4] These describe the effect of water mass in a water wall, the effect of using or not using the vents in the

Trombe wall, the effect of thickness of a Trombe wall, and the effect of different thermal conductivities of the material.

The recommended procedure is to make a calculation for the reference case and then to adjust that value up or down.

EFFECT OF A REFLECTOR

A tremendous performance advantage can be achieved through the use of a reflector to increase the total amount of solar radiation on the solar collection wall. A combination of a reflector and night insulation was demonstrated by Steve Baer in his Corrales home using water walls. He used a fold-down door hinged at the base with a reflective surface on the inner side. The door was insulated so that when it was raised it would reduce nighttime heat loss. When lowered during the day, the reflector augmentation increased performance.

LASL has calculated the performance increase to be expected from the reflector, and has determined that the estimating procedure can accurately be separated into two steps. The first step is to estimate the increase in solar radiation transmitted through the south facing glazing. The second step is to use this information in Monthly Solar Load Ratio calculation to determine monthly performance.

The reflector geometry which was studied is as follows: The size of the reflector is exactly equal to that of the solar collection wall. It is positioned horizontally in front of the solar collection wall so that the edge of the reflector is against the base of the wall (as if it were folded down from the wall, hinged at the bottom). The end effects were calculated assuming that the width of both the wall and the reflector is equal to five times the height of the wall. The reflectance of the material of the reflector was assumed to be 0.8, equivalent to that of the best commercial reflective materials available. (Reflectance of normal shop-grade aluminum is approximately 0.6.)

The method used to calculate the reflector enhancement achieved was similar to that used to calculate the ratio of vertical energy transmitted to horizontal energy as described in Step 2 of Method B. Hour-by-hour calculations were made for the 12 months of each year for 10 locations. The angular effects were calculated each hour as well as the effect of the modified incidence angle on the collection wall of the reflected beam. The energy transmitted through the glazing was decreased by the amount which would have been reflected from a diffuse foreground with a reflectance of 0.3, which is the assumption which had been made for all of the preceding calculations.

The ratio of the total monthly solar energy transmitted with the reflector to that without the reflector is plotted in Fig. 3. Again it was found that the parameter L - D was an effective correlating parameter for this ratio. A least-squares fit of these data is given by the following equation:

$$\text{Enhancement} = 1.0083 - .01787(L-D) + .001916(L-D)^2 - 4.031 \times 10^{-5}\,(L-D)^3 + 2.466 \times 10^{-7}\,(L-D)^4$$

which is the solid line shown on the figure.

If a reflector is used with a reflectance other than 0.8, the enhanced values of solar radiation can be computed from the above equation by assuming that the difference between unity and the calculated enhancement is proportional to the reflectance.

DERIVATION OF THE CORRELATIONS

The method is based on a brute-force empirical curve fitting approach using appropriate correlating parameters (the solar load ratio and monthly degree-days) based on detailed hour-by-hour computer simulation analyses from a wide variety of climates and building loads. Thus far, the method has been developed only for four types of passive solar heating buildings all of which fall in the category of thermal storage walls.

The method was first applied to active systems.[1] In an active system the load is a separable quantity unconnected to the solar heat supply. However, in most passive systems the thermal load and the solar heat supply are inter-related. It was determined, by trial and error, that if the load were calculated to include the steady-state load associated with the collector wall, then the Solar Load Ratio (SLR) is an effective correlating parameter. Consistent results were only obtained by using this approach.

The basic assumption of the method is that the monthly Solar Heating Fraction can be expressed as a unique function of the SLR, independent of either location or time of year. This is a rather brash assumption considering the variability of the weather in various locations and clearly one cannot expect exact answers from such a broad-brush approach.

In order to test the hypothesis, hour-by-hour computer simulation analyses were run for 29 different cities scattered throughout the U. S., Southern Canada, and three foreign locations. Six different values of the Load/Collector Ratio were chosen for each city so that the total of 174 year-long calculations were made altogether, representing a total of 1390 months during the heating season. A plot of all these results is shown on Fig. 4 for the case of a Trombe wall.

In order to make such a calculation the system had to be completely defined. A reference system was chosen as indicated in Table II.

The data of Fig. 3 show a relatively good correlation between Monthly Solar Heating Fraction and Monthly Solar Load Ratio. The individual plotting symbols shown on Fig. 4 identify the city for which the calculation was made. A list of these cities and their associated plotting parameters are given in Table III.

The reason for the scatter in Fig. 4 is that the assumption made is not quite correct. Two months may have the same Monthly Solar Load Ratio and yet actually have a different load, a different amount of sunshine incident on the wall and furthermore, the distribution of sunny and cloudy days within the two months may be entirely different. However, given these disparities, it is encouraging to note the total range of monthly solar heating fractions is as small as observed.

A least squares fit could have been made through the data of Fig. 4. Such a fit would give a minimum rms error in the predicted Monthly Solar Heating Fraction. However, it was desired to obtain a minimum error in the annual Solar Heating Fraction, not the monthly values. In order to do this, a functional form was chosen for the relationship between Monthly Heating Fraction and Monthly Solar Load Ratio as follows:

$$SHF = a_1(SLR) \qquad SLR < R$$

$$SHF = a_2 - a_3 e^{-a_4 (SLR)} \qquad SLR > R$$

such that the values are equal at SLR = R. The values of the parameters in the function were chosen to give a minimum least square error in the annual solar heating fraction for the 174 sample years calculated. The resulting function for a Trombe wall is shown plotted on Fig. 4; the results on Fig. 5.

The values of the least-squares coefficients and the standard deviation of annual SHF are as follows:

Case	R	a_1	a_2	a_3	a_4	σ
WW	0.8	0.5995	1.0149	1.2600	1.0701	.028
WWNI	0.7	0.7642	1.0102	1.4027	1.5461	.026
TW	0.1	0.4520	1.0137	1.0392	0.7047	.024
TWNI	0.5	0.7197	1.0074	1.1195	1.0948	.023

Discussion of Loads

Two coefficients have been used to describe the heat loss characteristics of the building: a Building Loss Coefficient, used in Method A, and a Modified Building Loss Coefficient, used to determine the Solar Load Ratio in Method B. The difference is the steady-state or static loss coefficient of the solar wall in the absence of solar gains, 24 x A_W x U_W. The Modified BLC was introduced only to facilitate the calculation of the Solar Load Ratio, as discussed above.

Monthly heating degree-day values were used in the correlation procedure because they are the only indicators of heating load that are readily available in most localities. The actual annual auxiliary heating values used in calculating the abscissa of Fig. 4 were the sum of the hour-by-hour requirements from the simulation. Thus the auxiliary will be accurately estimated provided the user is consistent in calculating loads in the same way that was used to determine the correlations.

The Modified Monthly Load, which is the product of the monthly degree-days times the Modified Building Loss Coefficient, has no accurate physical meaning. It is simply a convenient intermediate parameter used in the calculation.

It is possible to distinguish between two solar heat contributions from the solar wall: 1) the energy saved, and 2) the energy supplied. The difference is explained in the following paragraphs. In this paper the energy saved is used to define the solar heating fraction even though it gives a lower value.

Since the auxiliary energy is only required during periods when the temperature inside the room is actually at 65°F, the auxiliary energy requirements determined by the simplified method will be a good estimate.

The actual solar energy supplied by the solar collection wall will be greater than that estimated by taking the difference between the annual degree-day load and the auxiliary energy. The extra solar heat is the amount used to maintain the building above 65°F during a significant portion of the year. Since it is the actual auxiliary energy required which is the most important number to be estimated, it was felt that the approach used was best.

In reality, the solar heated building will generally be warmer than the non-solar heated building, assuming that the thermostat is set at 65°F in both cases. The non-solar heated building will frequently rise above that value and occasionally to 75°F, at which time it is assumed that any additional energy is dumped (presumably by opening a window).

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1. J. D. Balcomb and J. C. Hedstrom, "A Simplified Method for Calculating Required Solar Collector Array Size for Space Heating," Proceedings, 1976 ISES Annual Meeting, Vol. 4, Winnipeg, Canada, Aug. 15-20, 1976. See also: ERDA's Pacific Regional Solar Heating Handbook, Nov. 1976.

2. E. C. Boes, et al., "Distribution of Direct and Total Solar Radiation Availabilities for the USA." Proceedings of the 1976 ISES Annual Meeting, Vol. 1, Winnipeg, Canada, Aug. 15-20, 1976.

3. J. D. Balcomb, et al., "Simulation Analysis of Passive Solar Heated Buildings--Preliminary Results," Solar Energy, Vol. 19, pp 277-282 (1977).

4. J. D. Balcomb, J. C. Hedstrom, and R. D. McFarland, "Passive Solar Heating of Buildings." Printed in SAND-77-1204 and also Solar Architecture, Ann Arbor Science (1977).

TABLE III

WEATHER DATA USED FOR CORRELATIONS

City	Symbol (Figs. 3-4)
Los Alamos, NM	1
El Paso, TX	2
Fort Worth, TX	3
Madison, WI	4
Albuquerque, NM	5
Phoenix, AZ	6
Lake Charles, LA	7
Fresno, CA	8
Medford, OR	9
Bismarck, ND	0
New York, NY	A
Tallahassee, FL	B
Dodge City, KS	C
Nashville, TN	D
Santa Maria, CA	E
Boston, MA	F
Charleston, SC	G
Los Angeles, CA	H
Seattle, WA	I
Lincoln, NE	J
Boulder, CO	K
Vancouver, BC	L
Edmonton, ALB	M
Winnipeg, MAN	N
Ottawa, ONT	P
Frederickton, NB	Q
Hamburg	R
Denmark	S
Tokyo	T

TABLE II

REFERENCE PASSIVE SOLAR SYSTEMS USED FOR CORRELATIONS

Assumptions for both Method A and Method B:

- Thermal Storage = 45 BTU/°F ft^2 of glazing
- Trombe wall has vents with backdraft dampers
- Double Glazing (normal transmittance = 0.747)
- Temperature Range in Building: 65°F to 75°F
- Building Mass is Negligible
- Night Insulation (when used) is R9; 5:00 p.m. to 8:00 a.m.
- Wall to room conductance = 1.0 BTU/hr °F ft^2
- Trombe wall properties k = 1.0 BTU/ft hr °F; ρc = 30 BTU/ft^3 °F

Additional Assumptions for Method A:

- Vertical, south-facing glass
- Wall absorptance = 1.0
- Ground reflectance = 0.3

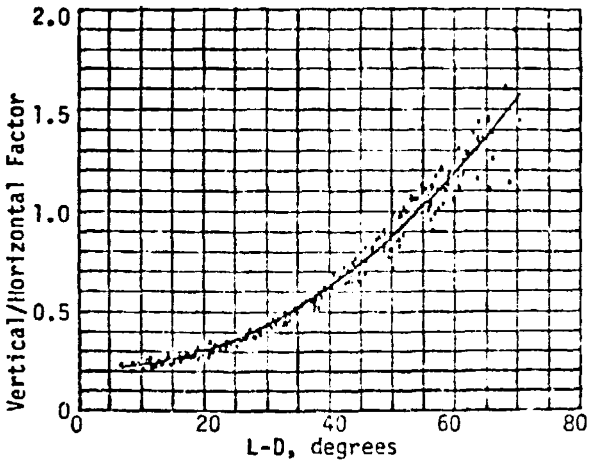


Fig. 1. The vertical/horizontal factor is the ratio of the monthly solar radiation transmitted through vertical south-facing double glazing to the monthly total horizontal solar radiation. L-D is the latitude minus the solar declination at mid-month. Ground reflectance is 0.3 and is diffuse.

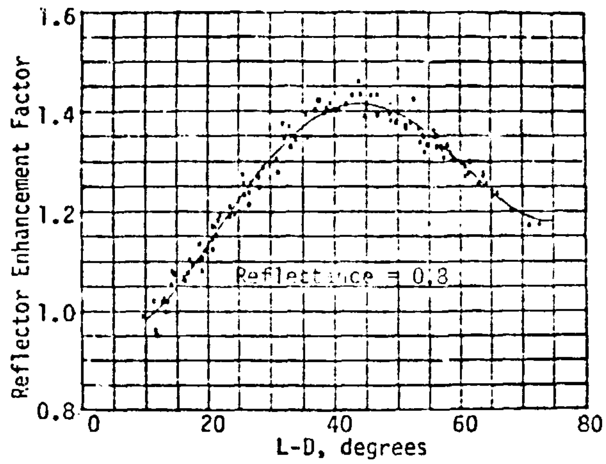


Fig. 3. The reflector enhancement factor is the ratio of the monthly solar radiation transmitted through vertical south facing double glazing with a reflector to that without a reflector. The reflector size is equal to the window size and is horizontal in front of the window. Reflectance is 0.8 and is specular.

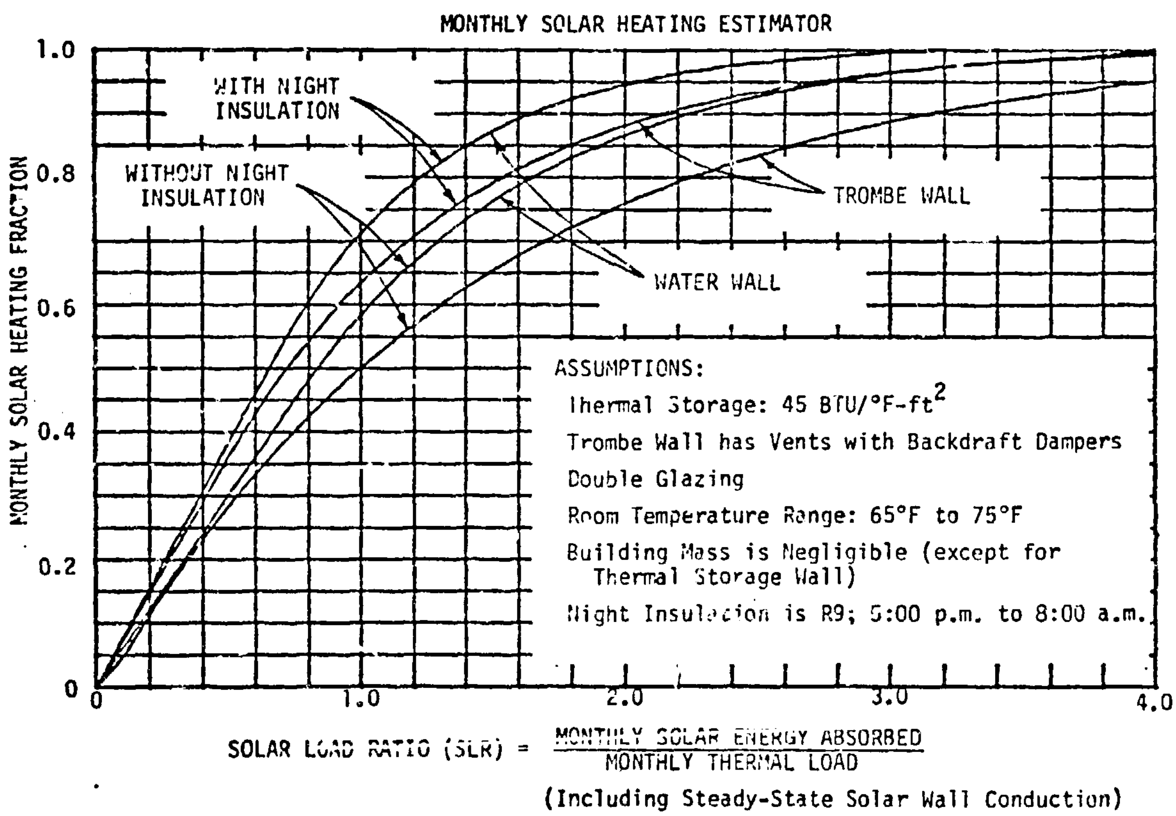


Fig. 2. Least-square monthly solar load ratio curves for thermal storage walls.

Fig. 4

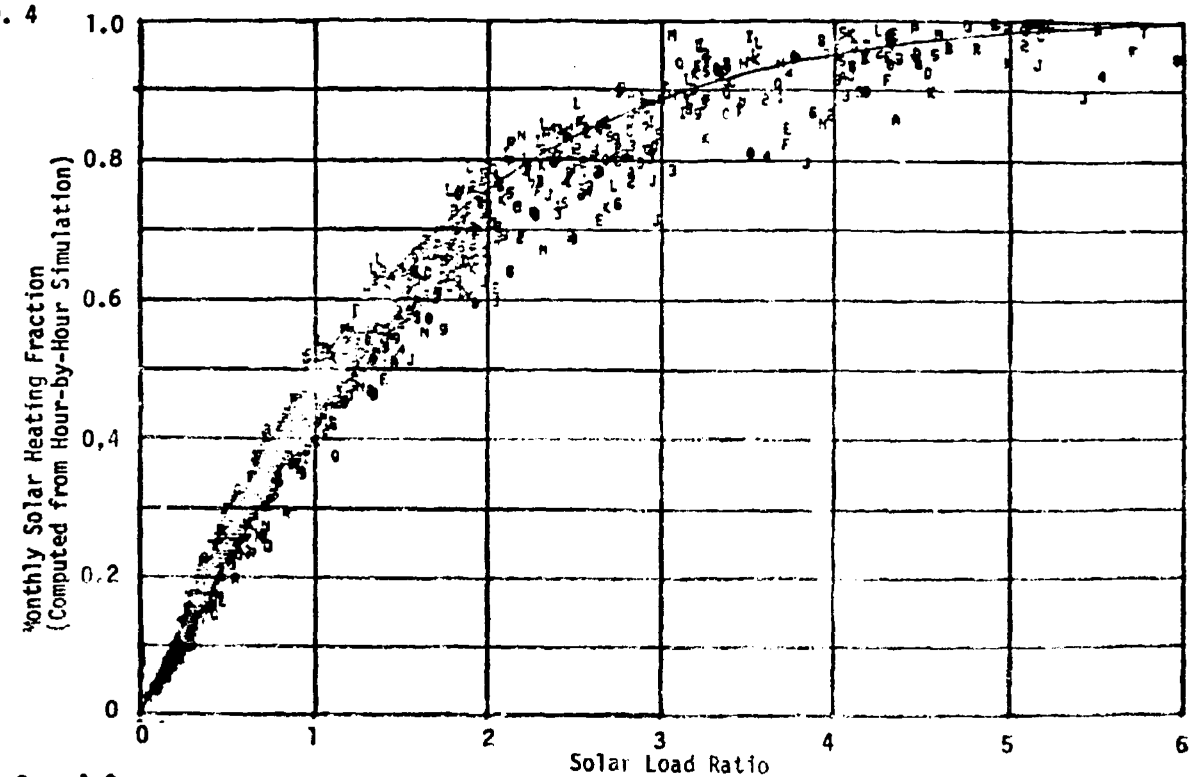
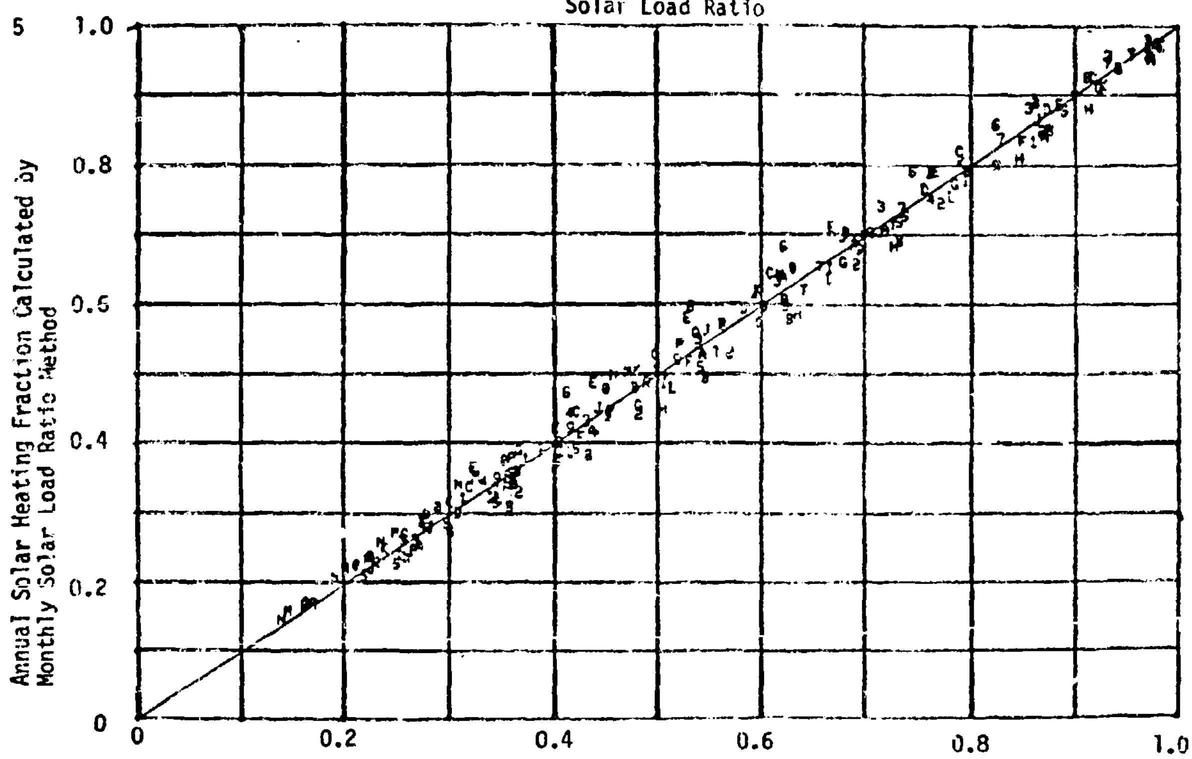


Fig. 5



Annual solar heating fraction calculated by hour-by-hour simulation.

See Table III to identify plotting symbols on Figs. 4 and 5.

TABLE I: 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)

Location										
Page, Arizona	SHF	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
	WW	198	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	139	145	114	90	69	49
	TW	577	287	179	123	68	64	47	33	21
33°N	TWNI	819	386	247	17[illegible]	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	93	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	75	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	25
	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	[illegible]	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	WWN	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	105	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	375	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	35
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	97	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

Location										
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
1208 DD	WWNI	956	444	281	203	155	123	97	75	5[illegible]
	TW	635	313	194	133	95	70	51	36	24
30°N	TWNI	906	240	266	159	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	337	212	152	115	90	69	51	35
1239 DD	WWNI	1000	457	292	211	162	129	102	79	55
	TW	662	326	202	139	100	73	54	39	25
30°N	TWNI	943	435	276	197	119	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	235	179	123	97	75	57	42	28
1485 DD	WWNI	857	397	249	180	138	[illegible]	87	67	43
	TW	563	279	172	[illegible]	84	61	45	32	21
30°N	TWNI	809	376	237	159	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	93	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	[illegible]	199	152	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	13	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	45	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	15	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	259	125	73	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	143	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	145	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	46	31	22	14
2184 DD	WWNI	524	245	154	111	85	67	53	40	28
	TW	340	167	103	63	49	35	25	17	10
32°N	TWNI	500	234	143	105	79	60	45	33	22

TABLE I: PERFORMANCE PARAMETERS FOR PASSIVE SOLAR HEATING SYSTEMS USING THERMAL STORAGE WALLS (Cont.)
Load Collector Ratio (BTU/DD-ft²) for particular values of Solar Heating Fraction (SHF)

Location										
Caribou, Maine	SHF	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
	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	
Portland, Maine	SHF	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
	WW	125	54	31	20	13	[illegible]			
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	SHF	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
	WW	137	60	35	23	15	9			
5634 DD	WWNI	241	110	63	48	36	27	21	[illegible]	9
	TW	145	67	39	24	15	9	5		
42°N	TWNI	23[illegible]	108	67	47	34	25	18	[illegible]	8
East Lansing, Michigan	SHF	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
	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	SHF	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
	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	SHF	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
	WW	96	39	21	11					
8879 DD	WWNI	189	85	52	36	26	19	14	9	5
	TW	108	48	26	15	7				
45°N	TWNI	189	86	52	36	25	18	13	8	5
Columbia, Missouri	SHF	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
	WW	175	77	46	31	21	14	8		
5046 DD	WWNI	28[illegible]	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	SHF	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
	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	SHF	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
	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	SHF	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
	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	SHF	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
	WW	172	80	50	35	25	11	12	6	
7733 DD	WWNI	182	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	19	11
Las Vegas, Nevada	SHF	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
	WW	448	209	130	92	68	52	[illegible]	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	SHF	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
	WW	192	88	54	37	26	16	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	SHF	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
	WW	163	72	43	29	20	13	8		
4812 DD	WWNI	271	126	78	55	41	31	24	17	11
	TW	157	78	46	29	19	12	7		
39°N	TWNI	267	123	76	53	39	29	21	15	9

Location										
Albuquerque, New Mexico	SHF	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
	WW	278	133	83	59	44	43	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	SHF	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
	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	SHF	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
	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	SHF	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
	WW	147	64	38	25	17	11	5		
4871 DD	WWNI	250	117	72	51	38	29	22	16	10
	TW	152	71	42	25	[illegible]	11	6		
41°N	TWNI	247	114	71	49	36	27	20	14	9
Sayville, L.I. New York	SHF	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
	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	SHF	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
	WW	[illegible]	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	SHF	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
	WW	237	107	66	46	33	24	17	11	
3805 DD	WWNI	367	173	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	SHF	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
	WW	412	189	118	82	61	46	34	24	15
2612 DD	WWNI	588	274	173	123	93	73	57	43	30
	TW	381	1[illegible]7	115	77	54	39	28	19	11
35°N	TWNI	560	261	164	115	86	65	49	36	24
Raleigh, North Carolina	SHF	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
	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	SHF	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
	WW	111	46	25	14	6				
8351 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	SHF	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
	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	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				
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	SHF	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
	WW	102	39	20	9					
6796 DD	WWNI	199	88	52	35	25	18	13	8	
	TW	112	[illegible]	26	14	6				
42°N	TWNI	199	87	52	35	25	18	12	8	4
Oklahoma City, Oklahoma	SHF	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
	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

TABLE I: PERFORMANCE PARAMETERS FOR PASSIVE SOLAR HEATING SYSTEMS USING THERMAL STORAGE WALLS (Cont.)
Load Collector Ratio (BTU/DD-ft²) for particular values of Solar Heating Fraction (SHF)

Location		0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
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	27	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
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	87	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	[illegible]	[illegible]	[illegible]	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	[illegible]
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
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	[illegible]	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	95	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
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	75	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	[illegible]	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	21	13					
45°N	TWNI	184	82	49	33	24	17	12	8	4
Toronto, Ontario	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, Manitoba	SHF	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
	WW	74	27							
10479 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	