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DOMESTIC SOLAR WATER HEATING

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Water heating consumes 14-20 percent of the energy used in a typical home. It is usually the second largest energy requirement, exceeded only by space heating and/or air conditioning. Water heating can also be a major item in the family budget. For example, an electric water heater, depending on location, supplying the needs of a typical family of four, can cost up to $30 per month to operate.

Solar energy can be used to replace all or part of the electricity, gas, or other fuel used to heat water. Unlike conventional energy sources, solar energy is free and a virtually unlimited supply is available. However, equipment is needed to collect, store, and utilize the energy. Today, many companies market solar equipment, both components that can be assembled into a suitable system or complete, pre-designed, package units.

A solar water heater is more expensive to purchase than a conventional unit of equivalent capacity. However, a properly designed, installed, and maintained solar water heater should save energy and be less expensive to operate. The money saved by using the solar equipment will usually defray the higher initial cost in 5 to 10 years.

Solar Water Heating Systems

A solar water heating system includes; 1) a collector to trap the sun's energy, 2) a fluid that travels through the collector absorbing the captured heat, 3) a water storage tank, and 4) assorted pipes, pumps, and controls (Figure 1).

Some systems use a water and antifreeze mixture as the collector fluid. A heat exchanger is required to transfer heat to the water in the storage tank. Other systems circulate household water directly through the collector to the storage tank. The antifreeze and heat exchanger are not needed, but precautions must be taken to keep the system from freezing in cold weather.

Solar collectors are not difficult to understand. Light radiation enters the collector through glass or clear plastic and is absorbed by a black surface that is consequently raised in temperature. The heat is then carried away by the collector fluid. The amount of heat the collector captures depends on its construction, location, and orientation. These factors, along with cost, useful lifetime and maintenance, will determine the practicality of a solar energy system.

[1/] Material in this publication was adapted from Home Hot Water Heating with Solar Energy by C. A. Myers and B. A. Stout.

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Legend

A. Solar collector
B. Air relief valve
C. Vacuum relief
D. Water storage
E. Auxilliary heater
F. Pump
G. Controls

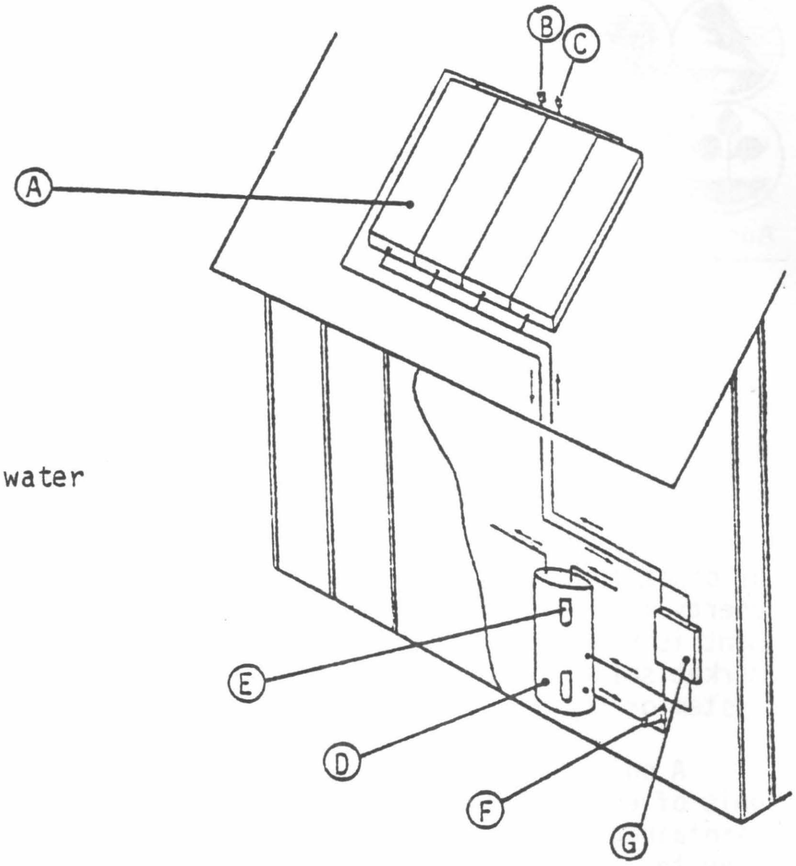

Figure 1: A typical solar water heating system.

What Are Your Needs?

In Virginia, to provide hot water whenever it is needed, a solar system will probably be combined with a conventional water heater. The cost to supply all of a typical household's hot water using only solar energy will be high. However, a solar home hot water system that will supply one-third to three-fourths of the hot water needs for a family of four can probably be purchased and installed for $1,500 - $2,500 (1982).

Is solar water heating a good investment? The advantages and disadvantages should be evaluated realistically and carefully for every situation. On the disadvantage side are initial costs, anticipated annual maintenance costs, interest and principal payments on a loan, extra insurance, and depreciation. Advantages include annual fuel savings, possible tax breaks, and tax deducations for interest payments. It all boils down to the amount of time needed to recover the investment. If the payback period is 10 years, and you have a sound, durable product, you can be fairly sure that the system will hold up for that period before any major extensive repairs or replacements are needed. If the payback period is 20 years, the risks are appreciably higher.

For example, a $2,000 system to supply part of the hot water used by a family of four in Richmond would have a payback period of 7 1/2 to 10 years if the solar heat replaces 5¢ per kilowatt-hour electricity. If the price of electricity increases, the payback period would naturally shorten. Similarly, if a cheaper form of energy is used for the comparison, the payback period would be longer. A more expensive system would also have a longer payback period.

Since initial cost is closely related to system size, particularly collector area and storage capacity, the solar system should be carefully selected. It should be large enough to supply a useful amount of energy, but not so large and expensive that the payback period is unduly long.

This publication presents one procedure for determining the solar collector area and the storage capacity needed for a home water heating system. There are five basic steps involved:

1. Estimate the monthly hot water energy requirements;
2. Calculate the energy that can be collected each month by the solar system;
3. Find the percentage of heating needs that the solar system will supply;
4. Calculate the saving due to solar water heating, and payback period of solar system; and
5. Calculate the necessary storage capacity.

The procedure, organized into a step-by-step format, is presented on the following pages. The procedure, which is adaptable to any Virginia location, can be completed by filling out Charts 1, 2, 3 and 4. Some of the required data is included in the publication. Other information, which depends on the particular situation being evaluated, should be gathered locally.

Samples of completed worksheets, for an example family of four in Richmond, have been included along with blank charts for the use of the reader.

EXAMPLE

Estimate Hot Water Energy Needs

Follow the procedure detailed on the chart and discussed in the following eight steps to complete Chart 1 and estimate energy requirements. The completed chart for the example and the blank chart are both shown on page 4.

Line 1 - Enter the months of the year that the system is intended to be used. For the example, it is assumed that the system will be active all year long.

Line 2 - Enter the number of days per month.

Line 3 - Enter the estimated hot water requirements. On the average, a person uses 15 to 20 gal. of hot water per day (i.e. a family of four using 15 gal. each would need 60 gal. per day). Hot water requirements are fairly constant throughout the year.

Line 4 - Enter desired or required hot water temperature. Homeowner preferences for water temperatures vary, ranging from 125°F to 180°F. A fairly common temperature is 140°F. Keep water temperature as low as is practical to conserve energy and reduce the cost of the necessary solar equipment.

CHART 1

Daily and Monthly Hot Water Energy Requirements

Line	Description	Source	Units	Data (by months)											
1	Month			Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
2	No. Days per month		Days	31	28	31	30	31	30	31	31	30	31	30	31
3	Gal. hot water needed per day	See discussion	Gal. per day	60	60	60	60	60	60	60	60	60	60	60	60
4	Desired hot water temperature	See discussion	°F	140	140	140	140	140	140	140	140	140	140	140	140
5	Incoming water temperature	See discussion	°F	54	54	54	54	54	54	54	54	54	54	54	54
6	Temperature difference	Line 4 - Line 5	°F	86	86	86	86	86	86	86	86	86	86	86	86
7	Energy required per day	(Line 3 x Line 6 x 8.33) ÷ 1,000	1,000 BTU per day	43	43	43	43	43	43	43	43	43	43	43	43
8	Energy required per month	(Line 2 x Line 7) ÷ 1,000	Million BTU per month	1.33	1.20	1.33	1.29	1.33	1.29	1.33	1.33	1.29	1.33	1.29	1.33

CHART 1

Daily and Monthly Hot Water Energy Requirements

Line	Description	Source	Units	Data (by months)											
1	Month			Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
2	No. days per month		Days	31	28	31	30	31	30	31	31	30	31	30	31
3	Gal. hot water needed per day	See discussion	Gal. per day												
4	Desired hot water temperature	See discussion	°F												
5	Incoming water temperature	See discussion	°F												
6	Temperature difference	Line 4 - Line 5	°F												
7	Energy required per day	(Line 3 x Line 6 x 8.33) ÷ 1,000	1,000 BTU per day												
8	Energy required per month	(Line 2 x Line 7) ÷ 1,000	Million BTU per month												

Line 5 - Enter the incoming water temperatures. Groundwater temperature is stable at 54 to 56°F throughout the year. Municipal water supply temperatures can be more variable. Consult your Municipal Water Department or measure the temperature of your water supply, if necessary.

Line 6 - Calculate and enter the temperature difference between the incoming water and the heated water. Subtract line 5 from line 4.

Line 7 - Calculate and enter the energy required per day. It takes 1 BTU[2/] of energy to heat 1 lb. of water 1°F. Therefore, multiply the number of gallons of hot water per day by the temperature difference by 8.33 lb. per gallon of water. Divide by 1,000 to express the result in 1,000's of BTU's per day for the chart.

Line 8 - Calculate and enter the energy used per month. Multiply the entry on line 7 (energy per day in thousands of BTU's) by the number of days. Divide by 1,000 to express the result in millions of BTU's per month for the chart.

<u>Calculate the Amount of Solar Energy That can be Collected by a Solar System</u>

Follow the procedure in the 16 steps outlined below to complete Chart 2 and estimate the amount of solar energy that can be collected by a solar system.

Line 1 - Enter the months of the year.

Line 2 - Enter the number of days per month.

Line 3 - Determine and enter the daily solar insolation. Insolation (not insulation), is the amount of solar energy that reaches a surface. It is expressed in BTU's per square foot per day. The insolation that strikes a solar collector is determined by: the collector latitude; collector orientation; (angle to the ground of the collector top); and the time of year. The collector should face as near due South as possible. For maximum year-round efficiency, the collector should be oriented at an angle equal to or slightly greater than the latitude of the site. Table 1 provides estimates of the total theoretical insolation which strikes one square foot of collector surface per day, for each month of the year, at different latitudes and collector orientations. (Solar insolation information is also presented graphically in figures 4, 5, and 6 at the end of the publication.) For our example, the daily insolation for each month is obtained from Table 1 using a collector angle of 38° which is approximately equal to the latitude of Richmond (Figure 2).

Line 4 - Determine and enter the hours of usable sunshine per day. Table 2 lists the number of usable hours of sunshine per day for each month of the year at various latitudes. (An hour of usable sunshine provides more than 50 BTU per square foot of insolation.) For our example we use the data for Richmond - latitude 38°.

Line 5 - Calculate and enter the hourly solar insolation. Divide line 3 by line 4.

[2/] A British Thermal Unit (BTU) is a common unit of energy used in the United States.

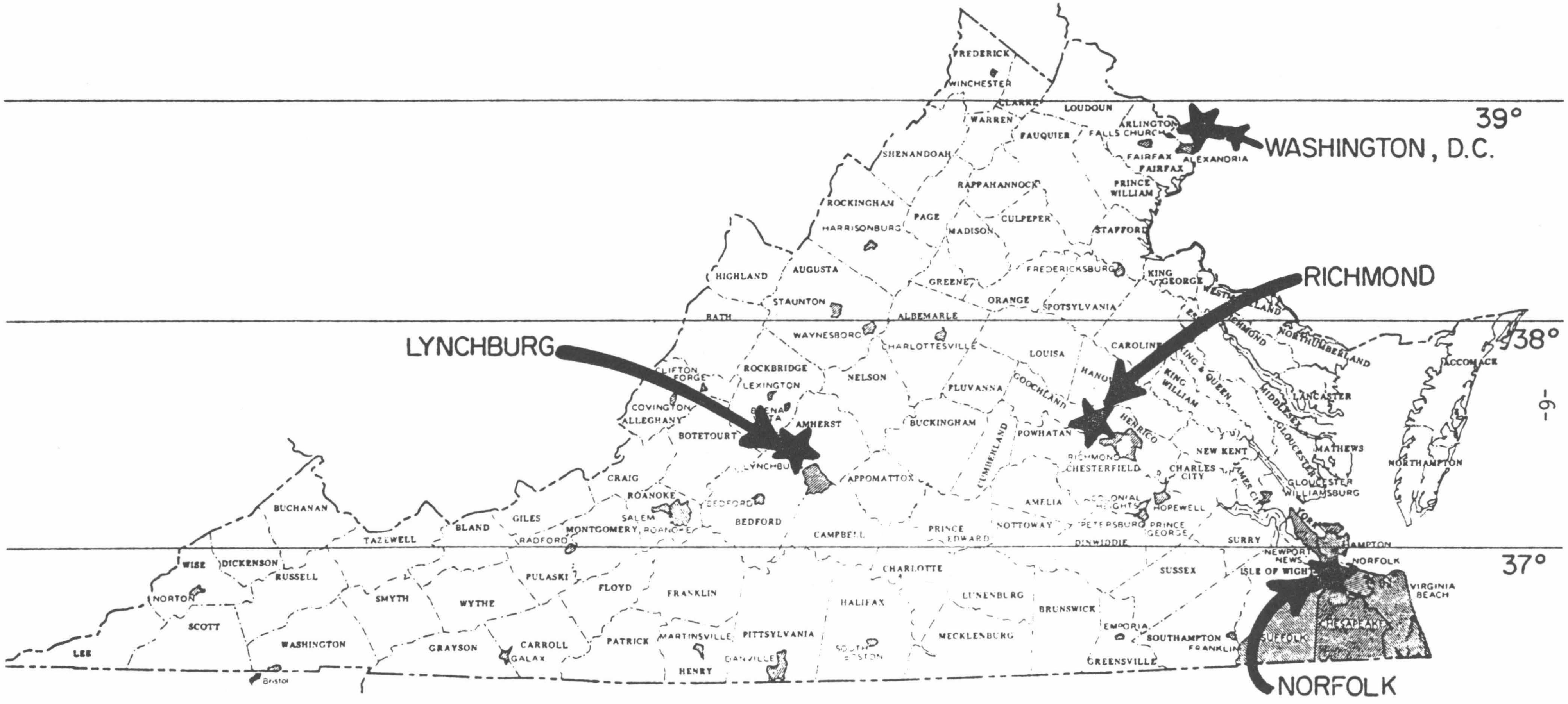

Figure 2: The latitudes and counties of Virginia.

CHART 2

Energy That Can Be Captured by Solar System per Square Foot of Collector per Month
for a Family of 4 in Richmond

Line	Description	Source	Units	Data (by months)											
1	Month			Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
2	No. days per month		Days	31	28	31	30	31	30	31	31	30	31	30	31
3	Daily insolation	See discussion Table 1	BTU per ft^2	1850	2200	2350	2320	2270	2220	2240	2280	2260	2050	1830	1690
4	Hours of usable sunshine per day	Table 2	Hour	9	9	9	11	11	11	11	11	9	9	9	8
5	Hourly insolation	Line 3 ÷ Line 4	BTU per ft^2 per hour	206	244	261	211	206	202	204	207	251	228	203	211
6	Desired water temperature	Line 4 Chart 1	°F	140	140	140	140	140	140	140	140	140	140	140	140
7	Incoming water temperature	Line 5 Chart 1	°F	54	54	54	54	54	54	54	54	54	54	54	54
8	Average collector water temperature	(Line 6 + Line 7) ÷ 2	°F	97	97	97	97	97	97	97	97	97	97	97	97
9	Average outdoor temperature	Table 3	°F	37.5	39.4	46.9	57.8	66.5	74.2	77.9	76.3	70	59.3	49	39
10	Loss factor	(Line 8 - Line 9) ÷ Line 5	°F-ft^2-hr per BTU	.29	.24	.19	.19	.15	.11	.09	.10	.11	.17	.24	.27
11	Collector efficiency	Figure 3		.49	.53	.57	.57	.60	.63	.65	.64	.63	.58	.53	.50
12	Possible sunshine	Table 3		.51	.55	.59	.62	.64	.67	.66	.64	.63	.60	.49	.51
13	Monthly collected insolation per square foot	(Line 2 x Line 3 x Line 11 x Line 12) ÷ 1,000	1,000 BTU per ft^2 per month	14.3	18	24.5	24.6	27.0	28.1	29.8	29	26.9	22.1	14.3	13.4
14	Heat exchanger losses	(Line 13 ÷ 10)	1,000 BTU per ft^2 per month	1.43	1.8	2.45	2.46	2.7	2.81	2.98	2.9	2.69	2.21	1.43	1.34
15	Available energy after heat exchanger	(Line 13 - Line 14)	1,000 BTU per ft^2 per month	12.87	16.2	22.05	22.14	24.3	25.29	26.82	26.1	24.21	19.89	12.87	12.06
16	Available energy from solar system	(Line 15 x .9	1,000 BTU per ft^2 per month	11.6	14.6	19.8	19.9	21.9	22.8	24.1	23.5	21.8	17.9	11.6	10.9

CHART 2

Energy That Can Be Captured by Solar System per Square Foot of Collector per Month

Line	Description	Source	Units	Data (by months)											
1	Month			Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
2	No. days per month		Days	31	28	31	30	31	30	31	31	30	31	30	31
3	Daily insolation	See discussion Table 1	BTU per ft^2												
4	Hours of usable sunshine per day	Table 2	Hour												
5	Hourly insolation	Line 3 ÷ Line 4	BTU per ft^2 per hour												
6	Desired water temperature	Line 4 Chart 1	°F												
7	Incoming water temperature	Line 5 Chart 1	°F												
8	Average collector water temperature	(Line 6 + Line 7) ÷ 2	°F												
9	Average outdoor temperature	Table 3	°F												
10	Loss factor	(Line 8 - Line 9) ÷ Line 5	°F-ft^2-hr per BTU												
11	Collector efficiency	Figure 5													
12	Possible sunshine	Table 3													
13	Monthly collected insolation per square foot	(Line 2 x Line 3 x Line 11 x Line 12) ÷ 1,000	1,000 BTU per ft^2 per month												
14	Heat exchanger losses	(Line 13 ÷ 10)	1,000 BTU per ft^2 per month												
15	Available energy after heat exchanger	(Line 13 - Line 14)	1,000 BTU per ft^2 per month												
16	Available energy from solar system	Line 15 ÷ 10)	1,000 BTU per ft^2 per month												

TABLE 1

Theoretical Daily Insolation (Solar Energy) for Each Month at Different Latitudes and Collectors Orientations (BTU/FT^2-Day)

Latitude	Collector Orientation	Jan	Feb	March	April	May	June	July	August	Sept	Oct	Nov	Dec
36	Vertical	1740	1680	1360	890	570	490	580	850	1330	1620	1710	1720
	56°	2050	2250	2200	1970	1770	1680	1740	1920	2110	2140	2010	1930
	45°	2010	2270	2310	2180	2050	1980	2020	2120	2220	2170	1970	1880
	36°	1900	2230	2370	2330	2280	2220	2240	2290	2280	2100	1880	1760
	26°	1740	2120	2340	2420	2440	2430	2410	2370	2250	2020	1720	1590
	Hor.	1110	1560	1950	2330	2570	2650	2540	2300	1900	1500	1120	960
38	Vertical	1730	1700	1420	950	640	550	640	920	1370	1630	1700	1680
	58°	2000	2220	2180	1950	1760	1670	1730	1910	2090	2100	1960	1860
	48°	1960	2240	2300	2170	2040	1970	2020	2120	2200	2140	1920	1800
	38°	1850	2200	2350	2320	2270	2220	2240	2280	2260	2050	1830	1690
	28°	1690	2090	2320	2420	2440	2430	2410	2360	2240	1990	1680	1540
	Hor.	1030	1480	1900	2290	2560	2650	2530	2280	1850	1430	1030	870
40	Vertical	1710	1720	1470	1010	720	620	700	980	1410	1660	1680	1650
	60°	1940	2190	2170	1950	1770	1670	1730	1890	2070	2070	1910	1790
	50°	1900	2210	2280	2150	2040	1970	2010	2100	2180	2100	1870	1740
	40°	1800	2160	2340	2310	2270	2210	2230	2260	2240	2010	1780	1630
	30°	1650	2060	2300	2410	2440	2430	2410	2350	2220	1950	1630	1490
	Hor.	950	1400	1850	2270	2560	2650	2530	2250	1780	1350	940	780
42	Vertical	1660	1720	1510	1080	790	670	760	1040	1450	1670	1610	1560
	62°	1850	2130	2140	1930	1950	1660	1720	1880	2040	2010	1820	1680
	52°	1820	2160	2250	2140	2030	1960	2000	2090	2150	2050	1780	1640
	42°	1730	2100	2300	2300	2260	2210	2220	2250	2220	1970	1700	1530
	32°	1570	2010	2280	2390	2430	2430	2400	2340	2190	1900	1550	1390
	Hor.	850	1330	1780	2220	2550	2650	2500	2210	1720	1270	850	700

TABLE 1 (Continued)

Latitude	Collector Orientation	Jan	Feb	March	April	May	June	July	August	Sept	Oct	Nov	Dec
44	Vertical	1600	1720	1550	1140	860	730	820	1100	1480	1670	1560	1470
	64°	1760	2080	2110	1920	1740	1650	1710	1870	2010	1970	1730	1570
	54°	1730	2110	2220	2130	2020	1950	1990	2070	2120	1990	1690	1540
	44°	1640	2070	2280	2280	2250	2200	2210	2240	2180	1930	1610	1430
	34°	1500	1970	2250	2380	2420	2420	2390	2330	2160	1860	1480	1300
	Hor.	770	1250	1700	2170	2520	2640	2490	2170	1650	1180	770	620
46	Vertical	1530	1720	1590	1200	920	790	890	1160	1520	1650	1490	1390
	66°	1670	2030	2080	1910	1740	1640	1700	1860	1980	1930	1630	1470
	56°	1640	2080	2200	2120	2010	1950	1980	2060	2100	1940	1600	1430
	46°	1550	2010	2250	2270	2240	2200	2210	2220	2160	1890	1530	1330
	36°	1420	1920	2230	2360	2410	2420	2380	2310	2140	1810	1400	1220
	Hor.	680	1160	1640	2130	2500	2630	2470	2130	1580	1100	680	530
48	Vertical	1470	1710	1630	1260	980	870	950	1210	1550	1620	1430	1300
	68°	1580	1980	2060	1900	1730	1640	1690	1840	1960	1870	1550	1370
	58°	1550	2020	2170	2110	2010	1940	1970	2040	2070	1890	1510	1330
	48°	1470	1970	2230	2260	2230	2190	2200	2210	2130	1860	1450	1240
	38°	1350	1870	2210	2350	2400	2420	2380	2300	2100	1760	1330	1130
	Hor.	600	1080	1570	2100	2480	2620	2460	2080	1530	1020	600	450

TABLE 2

Hours of Usable Sunshine per Day

Latitude	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
36	9	9	9	11	11	11	11	11	9	9	9	9
38	9	9	9	11	11	11	11	11	9	9	9	8
40	9	9	9	11	11	11	11	11	9	9	9	8
42	8	9	9	11	11	11	11	11	9	9	8	8
44	7	9	9	10	10	11	11	11	9	9	7	7
46	7	9	9	10	10	11	11	11	9	9	7	7
48	7	9	9	9	10	10	11	10	9	9	7	7

Line 6 - Enter desired or required hot water temperature, Line 4, Chart 1.

Line 7 - Enter the incoming water temperature, Line 5, Chart 1.

Line 8 - Calculate and enter average collector water temperature. Add the desired or required hot water temperature and the incoming water temperature then divide by 2.

Line 9 - Determine and enter the average outdoor temperature (Table 3).

Line 10 - Calculate and enter the loss factor associated with the collector. Subtract the average outdoor temperature from the average collector water temperature and then divide by the daily insolation.

Line 11 - Determine and enter the collector efficiency percentage. Use the loss factor associated with the collector as calculated in line 10. In our example the loss factor for January is .29. Using this number and the method illustrated on Figure 3, a collector efficiency of .49 is obtained. The literature which companies selling solar hot water heating systemsprovide will often contain a graph similar to Figure 3 for their specific collector. The factor is generally expressed as:

$$\frac{T_{coll} - T_{amb}}{I}$$

. . . which is the average collector temperature minus the ambient (outside) temperature divided by the hourly insolation. Not all companies use this method. Most, though, will have some type of efficiency graph and will explain how to use it.

Line 12 - Determine and enter the percentage of possible sunshine as listed in Table 3. In our example, Richmond received about 51% of the total sunshine that is possible in January, and 66% of the total sunshine that is possible in July. These numbers must then be divided by 100 to obtain the proper chart entries of .51 and .66, respectively. Individuals should choose the location they believe to be indicative of their location, (i.e., for Wise and Albemarle Counties the percentage sunshine data for Lynchburg should probably be used).

TABLE 3

Percentage of Possible Sunshine and Average Daytime Temperature (°F)

City	Jan		Feb		March		April		May		June		July		Aug		Sept		Oct		Nov		Dec	
	Temp	% Sun	Temp	% Sun	Temp	% Sun	Temp	% Sun	Temp	% Sun	Temp	% Sun	Temp	% Sun	Temp	% Sun	Temp	% Sun	Temp	% Sun	Temp	% Sun	Temp	% Sun
TIDEWATER																								
Fredericksburg	35.4		36.7		44.6		55.7		65.1		73		76.9		75.1		68.8		58		47		36.8	
Holland	39.7		41.2		48.3		58.4		66.9		74.2		77.6		76		70.7		60.5		50.7		41.2	
Hopewell	40.5		42.3		49.6		60.3		68.6		75.8		79.1		77.8		71.9		62.5		51.5		41.6	
Norfolk	40.5	57	41.4	58	48.1	63	57.8	66	66.7	67	74.5	68	78.3	65	76.9	65	71.8	64	61.7	60	51.6	60	42.3	57
Williamsburg	39.3		40.8		47.9		58.3		66.7		73.9		77.5		76.1		70.5		60.3		50.5		40.6	
EASTERN PIEDMONT																								
Columbia	35.8		37.4		45.3		56.2		65.3		72.9		76.8		75.2		68.5		57.9		47		37.2	
Farmville	38		39.7		47		57.6		65.8		73.2		76.8		75.3		68.7		58.4		47.9		38.6	
Richmond	37.5	51	39.4	55	46.9	59	57.8	62	66.5	64	74.2	67	77.9	66	76.3	64	70	63	59.3	60	49	56	39	51
Louisa	36.1		38		45.7		56.6		65.3		72.7		76.2		74.7		68.1		57.6		47.1		37.1	
WESTERN PIEDMONT																								
Bedford	37.9		39.4		46.8		57.3		65.7		72.7		75.8		74.4		68.2		58.4		47.9		38.9	
Charlottesville	36		37.6		45.6		57		66		73.3		77.1		75.6		69.4		59.5		48.5		37.8	
Danville	39.3		41.1		47.5		59.2		67.7		74.9		77.9		76.9		70.6		59.9		49		40	
Lynchburg	36.6	50	38.1	55	45.5	58	56.6	60	65.2	62	72.6	65	75.8	61	72.4	61	68.1	61	58	62	47	56	37.8	51
NORTHERN																								
Culpeper	35.3		37.3		45.4		56.3		65.2		72.8		76.4		74.6		68.4		57.6		46.8		36.4	
Luray	33.9		35.8		43		54.1		62.8		70		73.4		72.1		66.1		56		45.2		35.1	
Washington	32.1	48	33.8	51	41.8	55	53.1	56	62.6	58	71.2	64	75.3	62	73.6	62	66.9	62	55.9	60	44.7	50	34	47
Woodstock	34.4		36.2		43.7		54.7		63.7		71.1		74.7		73.4		86.7		56.6		45.9		35.9	

TABLE 3 (Continued)

City	Jan		Feb		March		April		May		June		July		Aug		Sept		Oct		Nov		Dec	
	Temp	% Sun	Temp	% Sun	Temp	% Sun	Temp	% Sun	Temp	% Sun	Temp	% Sun	Temp	% Sun	Temp	% Sun	Temp	% Sun	Temp	% Sun	Temp	% Sun	Temp	% Sun
CENTRAL MOUNTAIN																								
Hot Springs	31.6		33		40.3		51.4		60.2		67.1		70.2		69		62.7		53		42.2		32.8	
Lexington	36.1		38		45.5		56.3		64.6		71.5		74.9		73.7		67.3		57		46.2		37.1	
Roanoke	36.4		38.1		45.3		55.9		64.4		71.7		75.2		74.1		68		57.8		46.7		37.4	
Timberville	33.3		34.9		42.6		53.4		62.6		70.1		73.8		72.4		65.7		55.4		44.5		34.6	
SOUTH WESTERN MOUNTAIN																								
Burkes Garden	31.5		33		39.6		50		57.7		64.3		67.4		66.4		60.7		51.1		40.6		32.7	
Floyd	34.2		35.4		42.2		53.1		61.2		67.9		71.1		70		63.9		54.3		43.7		35.3	
Wytheville	34.4		36.1		43		53.4		61.5		68.2		71.3		70.3		64.3		54.7		43.8		35.4	
Pennington Gap	34.4		36.5		43.9		54.5		63		70		73		72.1		66.4		56		44.2		36.2	

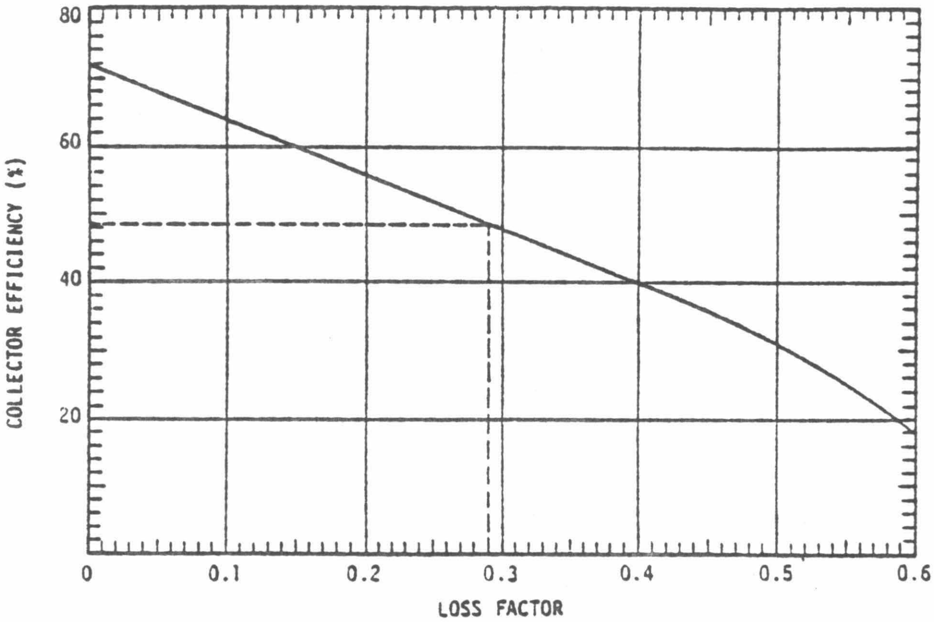

Figure 3: A Typical Flat Plate Solar Collector Efficiency Curve.

Line 13 - Calculate and enter the total amount of solar energy that can be captured per month per square foot of collector. This is done by multiplying the number of days per month by the daily solar insolation, which is then multiplied by the collector efficiency and the percentage of possible sunshine. This number should then be divided by 1,000 to obtain the proper chart entry.

Line 14 - Calculate and enter the losses due to a heat exchanger. Divide the total amount of solar energy that can be collected per month per square foot of collector by 10. If a heat exchanger is not to be used in the system, enter zeros across this row.

Line 15 - Calculate and enter the energy available from the system after the losses due to the heat exchanger are taken into account. This is done by subtracting the losses due to the heat exchanger from the total amount of solar energy that can be collected per month per square foot of collector.

Line 16 - Calculate and enter the energy available from the solar system after the heat losses due to storage are taken into consideration. There is always a loss of heat from the storage tank even if it is well insulated. An approximation of this heat loss is about 10%. Therefore, 90% of the heat remains in the storage tank. To obtain the energy available from the solar system after the heat losses due to storage are accounted for, multiply the energy available from the system after the losses due to the heat exchanger are taken into account by .9.

Calculate the Percentage of Your Hot Water Needs That can be Supplied by a Solar Water Heater

Follow the procedure in the 9 steps outlined below to complete Chart 3 and estimate the percentages of your hot water needs that can be supplied by a solar water heater.

Line 1 - Enter the months of the year.

Line 2 - Enter the number of days per month.

Line 3 - Enter the energy required per month, Line 8, Chart 1.

Line 4 - Enter the energy available from the solar system after the heat losses due to storage are taken into consideration, Line 16, Chart 2.

Line 5 - Calculate and enter the area the solar collector should have.

The collector area required each month to supply 100% of hot water needs is equal to the energy required per month divided by the energy available from the solar system after heat losses due to storage are taken into consideration. In our example the collector area needed for July is 55 ft^2.

For July:

$$\text{Collector area} = \frac{1.33 \times (1{,}000{,}000)^{*}}{24.1 \times (1{,}000)^{**}} = 55 \text{ ft}^2$$

The collector area needs for December, however, are 122 ft^2.

$$\text{Collector area} = \frac{1.33 \times (1{,}000{,}000)}{10.9 \times (1{,}000)} = 122 \text{ ft}^2$$

From the collector area needed for December it is obvious that if the solar system were designed to meet the hot water needs of the winter months, it would have a much greater capacity than is necessary during the rest of the year. Such a system would be far too expensive and wasteful. For our example we will use a 50 ft^2 collector because it is a fairly common size.

Commercial solar hot water systems often come with 50 to 60 ft^2 of collector area. The best way to approach the problem is to determine the percentage of the hot water energy requirement that can be supplied by various sized collectors and do a cost comparison (i.e. repeat lines 5 through 9 of chart 3 with 40, 60, and 80 square feet).

Line 6 - Calculate and enter the total insolation collected per month with a 50 ft^2 collector surface. Multiply the available energy from the solar system after heat losses by the area of the collector. Divide by 1,000 to obtain the proper chart entry.

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* Note unit (Chart 1) is million BTU per month.

** Note unit (Chart 2) is thousand BTU per month.

CHART 3

Percentage of Hot Water Energy Requirement That Can Be Supplied by Solar

Line	Description	Source	Units	Data (by months)											
1	Month			Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
2	No. days in month		Days	31	28	31	30	31	30	31	31	30	31	30	31
3	Energy required per month	Line 8 Chart 1	Million BTU per month	1.33	1.20	1.33	1.29	1.33	1.29	1.33	1.33	1.29	1.33	1.29	1.33
4	Available energy from solar system	Line 16 Chart 2	1,000 BTU per ft^2 per month	11.6	14.6	19.8	19.9	21.9	22.8	24.1	23.5	21.8	17.9	11.6	10.9
5	Collector area	See discussion	ft^2	50	50	50	50	50	50	50	50	50	50	50	50
6	Energy collected per month	(Line 4 x Line 5) ÷ 1,000	Million BTU per month	.58	.73	.99	.995	1.10	1.14	1.2	1.18	1.09	.895	.58	.545
7	Insolation used per month	Smaller of Line 3 or Line 6	Million BTU per month	.58	.73	.99	.995	1.10	1.14	1.2	1.18	1.09	.895	.58	.545
8	% energy requirement supplied by solar per month	(Line 7 x 100) ÷ Line 3	Percent	43.6	60.8	74.4	77.1	82.7	88.4	90.2	88.7	84.5	67.3	45	41
9	% energy requirement supplied by solar per year	Add all the %'s in Line 8 together and divide by 12	70.3 Percent of annual needs	x	x	x	x	x	x	x	x	x	x	x	x

CHART 3

Percentage of Hot Water Energy Requirement That Can Be Supplied by Solar

Line	Description	Source	Units	Data (by months)											
1	Month			Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
2	No. days in month		Days	31	28	31	30	31	30	31	31	30	31	30	31
3	Energy required per month	Line 8 Chart 1	Million BTU per month												
4	Available energy from solar system	Line 16 Chart 2	1,000 BTU per ft^2 per month												
5	Collector area	See discussion	ft^2												
6	Energy collected per month	(Line 4 x Line 5) ÷ 1,000	Million BTU per month												
7	Insolation used per month	Smaller of Line 3 or Line 6	Million BTU per month												
8	% energy requirement supplied by solar per month	(Line 7 x 100) ÷ Line 3	Percent												
9	% energy requirement supplied by solar per year	Add all the %'s in Line 8 together and divide by 12	Percent												

5	Collector area	See discussion	ft^2
6	Energy collected per month	(Line 4 x Line 5) ÷ 1,000	Million BTU per month
7	Insolation used per month	Smaller of Line 3 or Line 6	Million BTU per month
8	% energy requirement supplied by solar per month	(Line 7 x 100) ÷ Line 3	Percent
9	% energy requirement supplied by solar per year	Add all the %'s in Line 8 together and divide by 12	Percent

Line 7 - Determine the insolation that is actually used each month. This is the smaller of Line 3 or Line 6.

Line 8 - Calculate and enter the monthly percentages of the hot water energy requirement which can be supplied by solar water heating. Multiply the insolation used per month by 100 and divide by the energy required per month.

Line 9 - Calculate and enter the percentage of the hot water energy needs that can be supplied by the solar water heater for the year. Add all the monthly percentages together and divide by 12. In our example, the 50 ft^2 collector can provide about 70.3% of the year's hot water needs. The remaining 29.7% must be supplied by a conventional (oil, natural gas, or electric) hot water heater. For our example a similar computation with a collector area of 60 ft^2 yields that 82.5% of the hot water needs for the year can be supplied by solar while the remaining 17.5% would have to be supplied by a conventional water heater.

Calculate and Estimate the Savings and Pay Back Period of Different Sizes of Solar Systems

Follow the procedure in the steps outlined below to complete Chart 4 and estimate the savings per year and pay back period of different sizes of solar systems. We will compare the different size solar systems to electric hot water heating.

Line 1 - Enter the collector sizes you used in line 5 of Chart 3. We will use 50 ft^2 and 60 ft^2.

Line 2 - Calculate and enter the initial cost of a solar hot water heater and conventional hot water heater. The cost of a solar system is generally between 30-50 dollars per square foot. Multiply the rate per square foot times collector area. For our example we will use a price of \$40 ft^2. We will assume a cost of \$200 for a conventional electric hot water heater.

Line 3 - Calculate and enter the Federal Tax Credit available. Current federal tax laws allow a tax credit of 40% up to a maximum of \$4,000. Multiply the initial cost of the solar system by .4. Note there is no tax credit for conventional systems.

Line 4 - Calculate and enter the cost of the solar system after the tax credit. Subtract the tax credit from the initial cost of the solar system.

Line 5 - Calculate and enter the cost difference between conventional and solar water heaters. Subtract the cost of conventional hot water heaters from the cost of the solar water heater. Both appear on line 4.

Line 6 - Calculate and enter the energy needed per year to heat water. Add the values of energy required per month found in Line 8 Chart 1.

CHART 4: SAVINGS AND PAYBACK PERIOD OF VARIOUS SIZE SOLAR SYSTEMS

Line	Description	Source	Units	Conventional	Solar	Solar
1	Solar System Collector Area	Line 5 Chart 3	Sq. Feet	0	50	60
2	Initial Cost of System	See Discussion	Dollars	200	2,000	2,400
3	Federal Tax Credit	See Discussion	Dollars	0	800	960
4	Cost After Tax Credit	Line 2 - Line 3	Dollars	200	1,200	1,440
5	Cost Difference Between Conventional and Solar Systems	See Discussion	Dollars	0	1,000	1,240
6	Energy Needed Per Year	Line 8 - Chart 1	Million BTU/Year	15.671	15.671	15.671
7	Energy Needed Per Year	See Discussion	KWH/Year	4591.31	4591.31	4591.31
8	Energy Supplied by Solar System	(Line 7 x Line 9 Chart 3)/100	KWH/Year	0	3227.69	3787.83
9	Energy Supplied by Conventional System	Line 7 - Line 8	KWH/Year	4591.31	1363.62	803.48
10	Operating Cost (Conventional)	See Discussion	Dollars/Year	229.57	68.18	40.17
11	Operating Cost (Solar)	See Discussion	Dollars/Year	0	14.29	14.29
12	Total Operating Cost of System	Line 10 + Line 11	Dollars/Year	229.57	82.47	54.46
13	Savings Using Solar System	See Discussion	Dollars/Year	0	147.10	175.11
14	Payback Period	Line 5/Line 13	Years	-	6.8	8.2

CHART 4: SAVINGS AND PAYBACK PERIOD OF VARIOUS SIZE SOLAR SYSTEMS

Line	Description	Source	Units	Conventional	Solar	Solar	Solar	Solar
1	Solar System Collector Area	Line 5 Chart 3	Sq. Feet					
2	Initial Cost of System	See Discussion	Dollars					
3	Federal Tax Credit	See Discussion	Dollars					
4	Cost After Tax Credit	Line 2 - Line 3	Dollars					
5	Cost Difference Between Conventional and Solar Systems	See Discussion	Dollars					
6	Energy Needed Per Year	Line 8 - Chart 1	Million BTU/Year					
7	Energy Needed Per Year	See Discussion	KWH/Year					
8	Energy Supplied by Solar System	(Line 7 x Line 9 Chart 3)/100	KWH/Year					
9	Energy Supplied by Conventional System	Line 7 - Line 8	KWH/Year					
10	Operating Cost (Conventional)	See Discussion	Dollars/Year					
11	Operating Cost (Solar)	See Discussion	Dollars/Year					
12	Total Operating Cost of System	Line 10 + Line 11	Dollars/Year					
13	Savings Using Solar System	See Discussion	Dollars/Year					
14	Payback Period	Line 5/Line 13	Years					

Line 7 - Convert the energy required per year expressed in BTU's to kwh. 1 BTU = .002930 kwh. Multiply the energy needed per year by .0002930. Then multiply by 1,000,000. (Multiplying the energy required per year by 293 will be equivalent.)

Line 8 - Calculate and enter the amount of energy supplied by the solar systems. Multiply the kwh used per year by the percent of annual energy needs supplied by solar system, Line 9 Chart 3 and divide by 100.

Line 9 - Calculate and enter the amount of energy supplied by conventional water heater per year. Subtract the energy supplied by the solar system per year from the energy required per year.

Line 10 - Calculate and enter the operating cost of the conventional electric hot water heater per year. Multiply the amount of energy supplied by the electric water heater by the cost of electricity per kwh. We will use a cost of 5 cents per kwh.

Line 11 - Calculate and enter the operating cost of solar water heating per year. The cost of solar heating will be the cost of using the pump to pump the collector fluid. For our use we will use a pump with a 1/10 hp motor, and efficiency of 70% because this is a common type. Assume this pump will operate 75% of the available daylight hours. The pump would use 285.7 kwh per year which would cost $14.29 per year.

Line 12 - Calculate and enter the total operating cost of each type of water heating system. Add the operating cost of the conventional water heater and the cost of the solar water heater.

Line 13 - Calculate and enter the savings of each size solar system per year. Subtract the total operating cost of the solar systems from the total operating cost of the conventional hot water heater. Both appear in line 10.

Line 14 - Calculate and enter the pay back period of the solar system. Divide the cost difference between the conventional water heater and the solar hot water heater by the savings per year. For our example the savings per year is about $147 for a 50 ft^2 system which has a pay back period of about 7 years. The 60 ft^2 system provides a savings of about $175 with a pay back period of slightly more than 8 years. Note these savings and pay back periods are based on the assumption that electric rates will remain constant. Since the cost of energy is continually rising,the savings realized would probably be greater each year and therefore the pay back period would be shortened.

<u>Determine the Size Storage Tank That Should be Used</u>

Water is the most practical storage medium for a hot water solar system. In a small storage tank, the temperature will be high, which means heat losses will be large, and the stored energy can supply heat for only a short time.

Large storage tanks, on the other hand, are prohibitively expensive, and the water temperature will frequently be too low to be useful. The best storage volume is considered to range from 10 to 15 lb. of water for each square foot of collector surface. The volume in gallons can be obtained as follows:

Storage volume = collector area x 10 to 15 lb. per ft^2 x 1 gal. per 8.33 lb.

In our example, the minimum storage volume would be:

$$\text{Storage volume} - 50\ ft^2 \times \frac{10\ lb.}{ft^2} \times \frac{1\ gal.}{8.33\ lb.} = 60\ gal.$$

While the maximum storage volume would be:

$$\text{Storage volume} - 50\ ft^2 \times \frac{15\ lb.}{ft^2} \times \frac{1\ gal.}{8.33\ lb.} = 90\ gal.$$

The storage tank should hold somewhere between 60 and 90 gal. for a 50 ft^2 collector. Repeat this procedure for different size collectors (i.e. 40, 60, and 80 square feet).

Additional Sources of Information

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   (Excellent, general explanation of solar energy and its applications. The book is easy to read and has many accompanying graphs and tables.)

4. Kreider, Jan F., and Kreith, Frank (1975). Solar Heating and Cooling - Engineering, Practical Design and Economics. Scripta Book Co., Division of Hemisphere Publishing Corporation, Washington, D.C. 342 pp.

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   (A do-it-yourself approach to alternative energy sources. A series of articles which stress practical aspects of solar energy. It also has an appendix of books, magazines, pamphlets, movies, manufacturers, etc. - most anything dealing with solar energy.)

6. The Mother Earth News Handbook of Homemade Power. (1974). Bantam Books, Inc., New York, N.Y. 374 pp.

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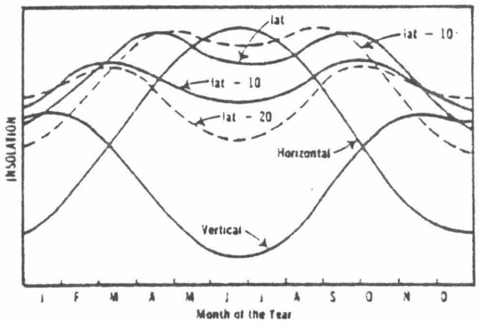

Figure 4. Differences between flat plact collector orientations and amount of solar radiation that can be captured.

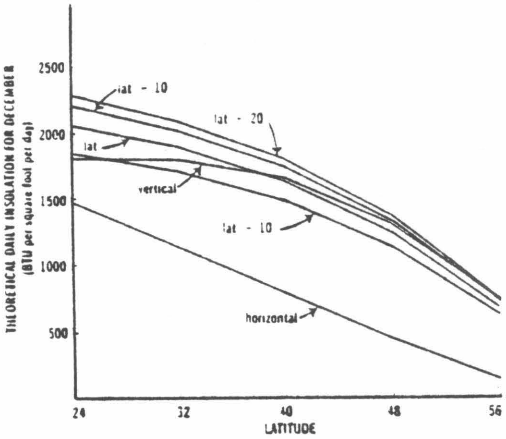

Figure 5. December insolation for several collector orientations and latitudes.

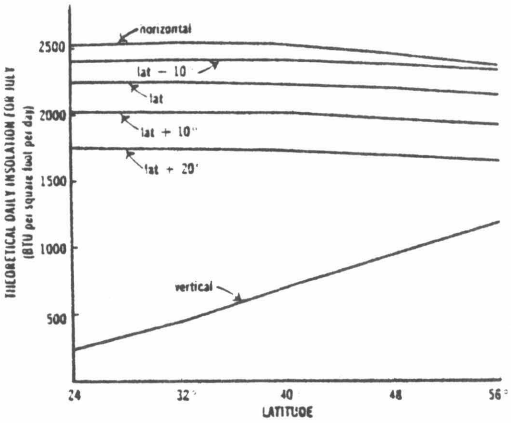

Figure 6. July insolation for several collector orientations and latitudes.