Energy Facts: Home Hot Water Heating with Solar Energy
Michigan State University
Cooperative Extension Service

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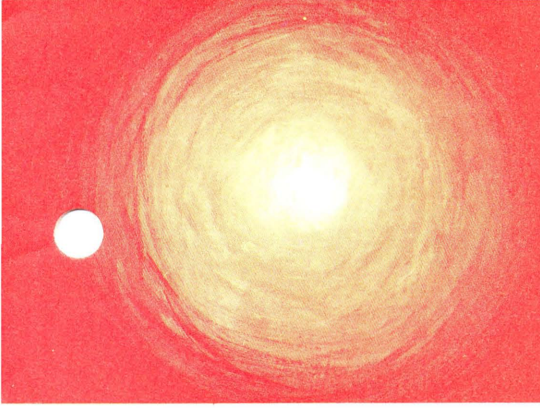
February 1981
8 pages



ENERGY FACTS

FILE 18.825
or 18.861

Cooperative Extension Service
Michigan State University

Energy Fact Sheet | Extension Bulletin E-1151 | February 1981

Home Hot Water Heating with Solar Energy

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Heating hot water for the home using solar energy is possible today. Many companies sell the necessary components and/or the complete systems. But before you purchase a solar water heating system, learn the differences between systems and what can realistically be expected in your area.

Types of Solar Hot Water Systems

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

Some systems use a water antifreeze mixture and, therefore, require a heat exchanger to transfer heat from the collector fluid to the water in the storage tank. Other systems run the household water directly through the collector. Neither an antifreeze nor a heat exchanger is needed, but care must be taken to keep water from freezing in cold weather.

All solar collectors work on the same basic principles. Light radiation enters the collector through glass or clear plastic; it is absorbed by a black surface that is consequently raised in temperature, and the heat is carried away by a 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.

What Are Your Needs?

In Michigan, to provide hot water whenever you need it, the solar system must be supplementary to a conventional hot water system. The cost to supply all or most of your hot water with 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 be purchased and installed for roughly $1,500 (fall, 1977).

But there are considerations besides initial cost and efficiency. Determine whether the collector is covered under warranty and for how long. Product durability is extremely important. How long will it last? Is it weatherproof, and does it shed water? If something goes wrong, who will fix it, how long will it take, and are parts easily obtained? Also ask whether the collector meets interim standards of the National Bureau of Standards. If the manufacturer claims such standards are met, get it in writing, because the manufacturer is legally accountable for that claim (4)[1].

[1] Numbers in parentheses refer to references on page 7.

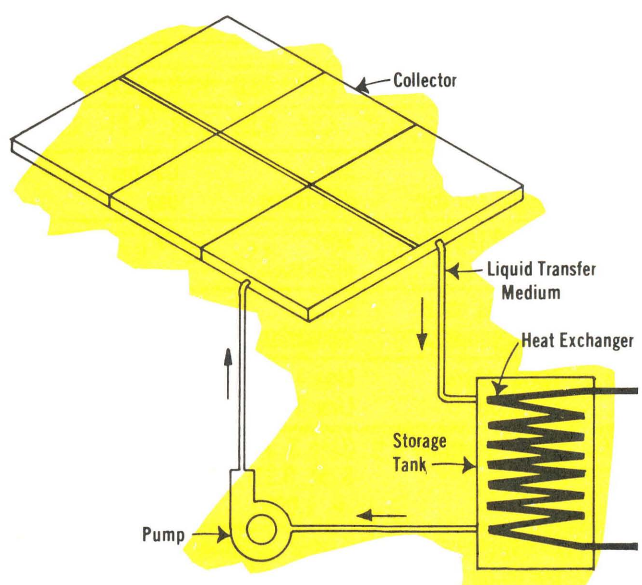

Figure 1. Solar water heating system.

Is solar water heating a good investment for you? On the debit 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 deductions for interest payments (4). What it all boils down to is 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 (4).

For example, the $1,500 system mentioned previously would have a payback period of about 10 years compared to the energy cost of an electric hot water heater. Compared to a natural gas based heater, the payback period is close to 20 years (4). These payback periods are based on 1977 prices of gas and electricity.

Calculations

Determining the solar collector area and storage capacity needed for home hot water heating involves four basic steps:

1. Determine 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 the heating needs that the solar system will supply; and
4. Calculate the necessary storage capacity.

On the following pages is a step-by-step method for approximating collector area and storage capacity. The format provided can be used by anyone in Michigan to determine their requirements; simply complete the worksheets for your specific situation. The example we use is for a family of four in East Lansing. But remember that the method won't give exact answers—only good estimates.

EXAMPLE

Hot Water Energy Needs (Chart 1)

Line 3—On the average, a family uses 15 to 20 gal of hot water per person per day. 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—Homeowner preferences for water temperatures vary, ranging from 125°F to 180°F. A fairly common temperature is 140°F.

Line 5—A deep well supplies water to the city of East Lansing. As a result, the city water temperature varies from a low of 52°F to a high of 56°F year-round. Since the range is so small, an average of 54°F will suffice in this example. Check with your city water engineers or measure the temperature of the water from your well.

Line 6—The temperature difference between the desired and incoming water temperature is

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 × Line 6 × 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 × 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

found by subtracting line 5 from line 4. In this example it is the same for each month of the year.

Line 7—It takes 1 BTU[2] of energy to heat 1 lb of water 1°F, and a gallon of water weighs a little over 8 lb. Therefore, the energy required to heat the water to 140°F each day would be the number of gallons per day times the temperature difference times 8.33 lb per gal.

Line 8—The hot water energy requirement each month is the amount of energy required per day times the number of days in the month.

Amount of Solar Energy That Can Be Collected by Solar System (Chart 2)

Line 3—Insolation is the amount of solar energy that reaches a surface and is measured in

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

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	1730	2100	2300	2300	2260	2210	2220	2250	2220	1970	1700	1530
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	192	233	256	209	205	201	202	205	247	219	189	191
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	25	25	34	48	59	72	75	74	64	53	39	29
10	Loss factor	(Line 8 − Line 9) ÷ Line 5	°F-ft^2-hr per BTU	0.38	0.31	0.25	0.23	0.19	0.12	0.11	0.11	0.13	0.20	0.31	0.36
11	Collector efficiency	Figure 6		0.42	0.48	0.52	0.54	0.58	0.62	0.63	0.63	0.62	0.56	0.48	0.44
12	Possible sunshine	Table 3		0.36	0.44	0.49	0.52	0.64	0.68	0.71	0.69	0.60	0.55	0.31	0.30
13	Monthly collected insolation per square foot	(Line 2 × Line 3 × Line 11 × Line 12) ÷ 1,000	1,000 BTU per ft^2 per month	8.1	12.4	18.2	19.4	26.0	28.0	30.8	30.3	24.8	18.8	7.6	6.3
14	Heat exchanger losses	(Line 13 ÷ 10)	1,000 BTU per ft^2 per month	.8	1.2	1.8	1.9	2.6	2.8	3.1	3.0	2.5	1.9	.8	.6
15	Available energy after heat exchanger	(Line 13 − Line 14)	1,000 BTU per ft^2 per month	7.3	11.2	16.4	17.5	23.4	25.2	27.7	27.3	22.3	16.9	6.8	5.7
16	Storage losses	(Line 15 ÷ 10)	1,000 BTU per ft^2 per month	.7	1.1	1.6	1.8	2.3	2.5	2.8	2.7	2.2	1.7	.7	.6
17	Available energy from solar system	(Line 15 − Line 16)	1,000 BTU per ft^2 per month	6.6	10.1	14.8	15.7	21.1	22.7	24.9	24.6	20.1	15.2	6.1	5.1

BTUs per square foot. The insolation that strikes a solar collector depends on latitude, time of the year, and the collector orientation. Michigan ranges from about 40° to 48° north latitude (Figure 2). For all practical purposes the collector must be facing south.

The orientation is the angle to the ground at which the collector is set. Figure 3 indicates the difference in solar energy that can be captured over the course of a year for various collector orientations. For maximum year-round collection, an angle slightly greater than, or equal to, that of the latitude is best.

Table 1 gives the total theoretical insolation striking one square foot of collector per day for each month at different latitudes and collector orientations. Figures 4 and 5 depict the same information for December and July, respectively. East Lansing is at a latitude of about 42°. So from Table 1, using a collector orientation equal to the latitude, the daily insolation for each month can be obtained.

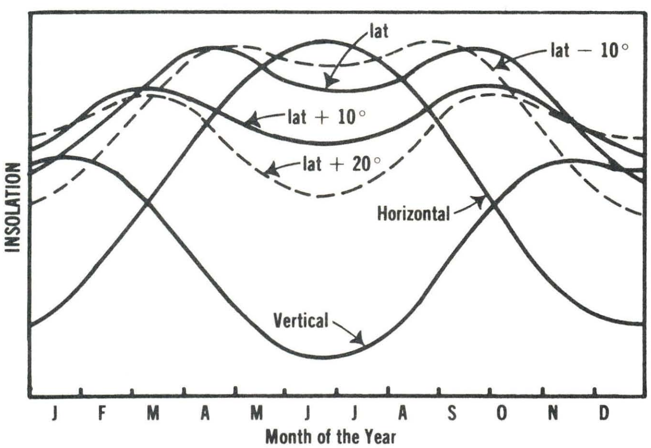

Figure 3. Differences between flat plate collector orientations and amount of solar radiation that can be captured (6).

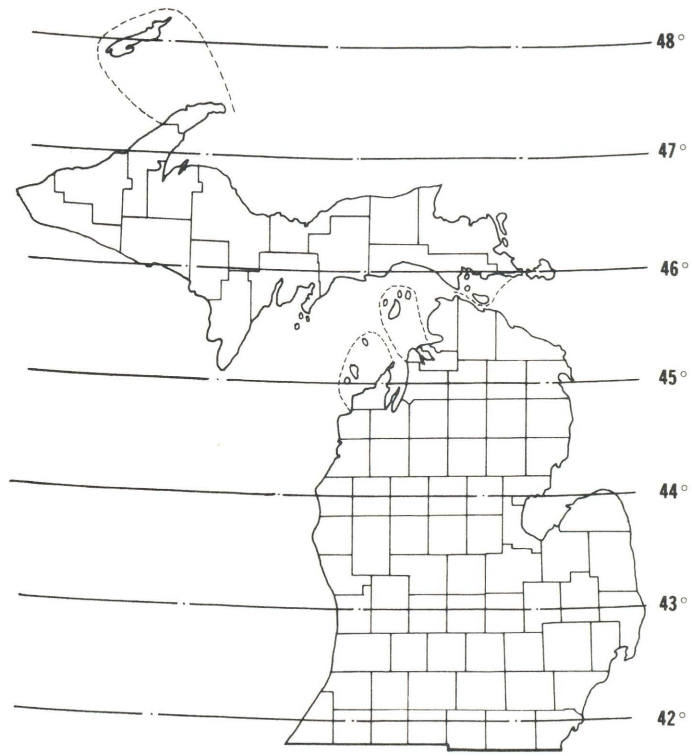

Figure 2. Michigan latitudes and counties.

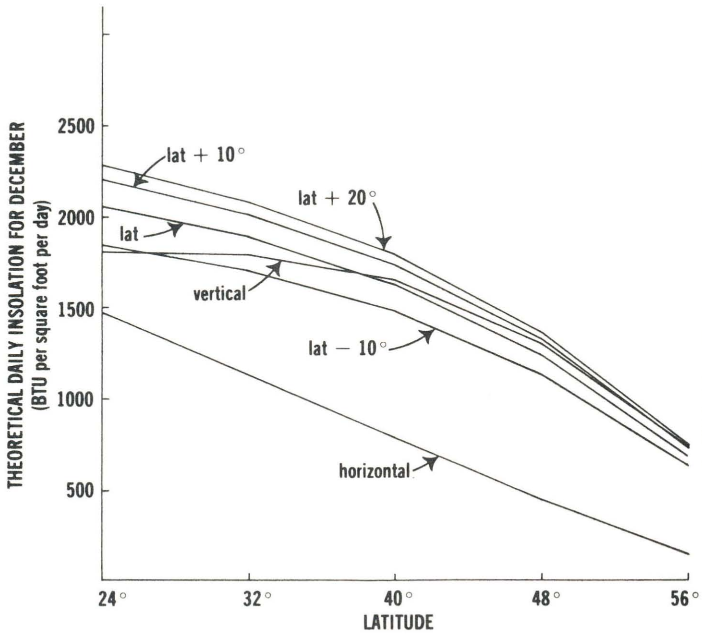

Figure 4. December insolation for several collector orientations and latitudes (1).

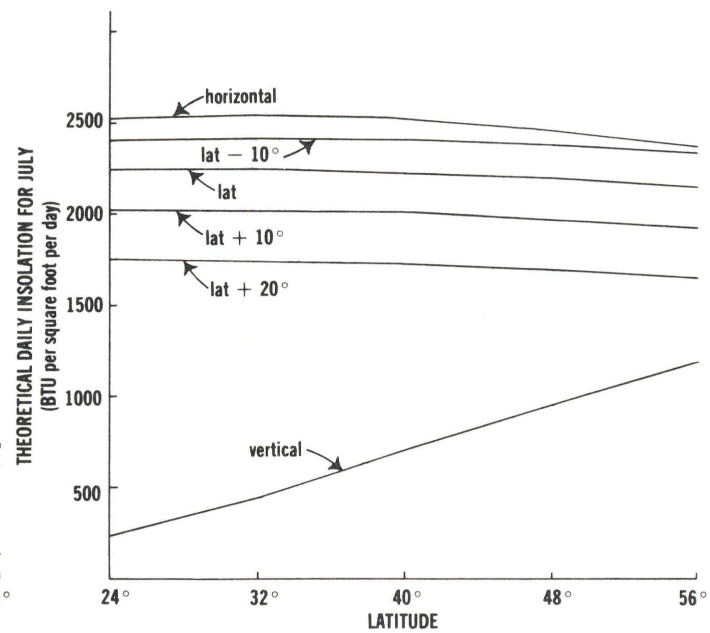

Figure 5. July insolation for several collector orientations and latitudes (1).

Line 4—Table 2 lists the number of usable hours of sunshine per day for each month of the year at various latitudes. Since a latitude of 42° is not listed we'll use the data for 40°.

Line 9—The average daytime outdoor temperature is obtained from Table 3.

Line 10—The loss factor is a term used to determine the efficiency of the collector.

Line 11—Figure 6 depicts the efficiency of a typical solar collector. For each month, find the loss factor on the bottom axis, follow the line straight up until it intersects the diagonal curve and read across horizontally to find the collector efficiency. Company literature will often have a graph similar to Figure 6 for their specific collector. The loss factor is generally expressed as: $\frac{T_{coll} - T_{amb}}{I}$

TABLE 1.
Theoretical Daily Insolation (Solar Energy) for Each Month at Different Latitudes and Collector Orientations (BTU/Ft²-Day).

Latitude	Collector Orientation[1]	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec
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	Ver.	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
44	Ver.	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	Ver.	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	Ver.	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

[1]Angle of the collector to the ground
Source:(1)

TABLE 2.
Hours of Usable Sunshine per Day.

Latitude	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
40	9	9	9	11	11	11	11	11	9	9	9	8
45	7	9	9	10	10	11	11	11	9	9	7	7
50	7	9	9	9	10	10	11	10	9	9	7	7

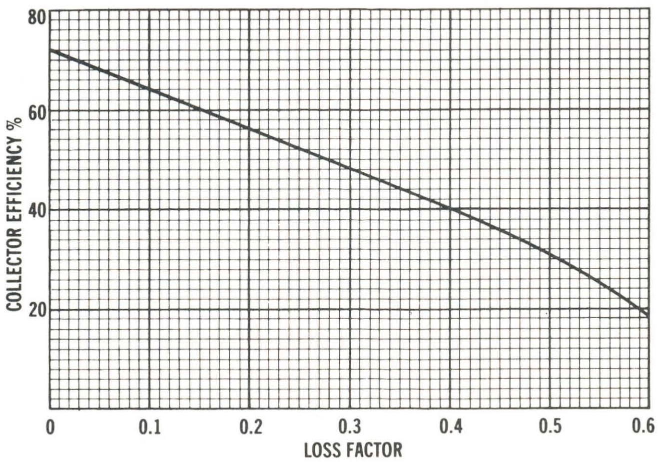

Figure 6. Typical flat plate solar collector efficiency curve.

. . . 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—Table 3 lists the percentage of possible sunshine that can be expected in several Michigan cities throughout the year. For instance, during January, Lansing receives about 36% of the total sunshine that is possible. In July it receives about 71%. These percentages must be expressed as decimals in the chart, that is, 36% is equivalent to 0.36.

Line 13—The total amount of solar energy that can be captured per month per square foot of collector can be found by multiplying lines 2, 3, 11 and 12 together, and dividing by 1,000.

Line 14—If a heat exchanger is used, the efficiency of the system will decrease about 10%. Divide line 13 by 10 to determine the heat losses associated with the heat exchanger. If a heat exchanger is not used in the system, then fill in zeros across the row.

Line 15—The energy available from the solar system after the heat exchanger is taken into account is line 13 minus line 14.

Line 16—There will always be heat losses from the storage tank even if it is well insulated. A rule of thumb is to figure a heat loss of roughly 10% from the storage tank. Divide line 15 by 10.

Line 17—The energy available from the solar system after heat losses are taken into consideration is line 15 minus line 16.

Collector area = energy required for December (Chart 1, line 8) ÷ collectable insolation for December (Chart 2, line 17)

$$\text{Collector area} = \frac{1.33 \times (1{,}000{,}000)^{*}}{5.1 \times (1{,}000)^{**}} = 261 \text{ ft}^2$$

* Note unit (Chart 1) is million BTU per month.
** Note unit (Chart 2) is thousand BTU per month.

TABLE 3.
Percentage of Possible Sunshine and Average Daytime Temperature (°F).

City	Jan % Sun	Jan Temp.	Feb % Sun	Feb Temp.	Mar % Sun	Mar Temp.	April % Sun	April Temp.	May % Sun	May Temp.	June % Sun	June Temp.	July % Sun	July Temp.	Aug % Sun	Aug Temp.	Sept % Sun	Sept Temp.	Oct % Sun	Oct Temp.	Nov % Sun	Nov Temp.	Dec % Sun	Dec Temp.
Alpena	38	21	49	20	56	28	54	41	61	52	66	65	68	69	64	69	55	58	48	48	29	36	31	25
Detroit City	32	28	43	28	49	37	52	50	59	61	65	74	70	77	65	77	61	67	56	56	35	41	32	31
Detroit Metro	38	27	45	28	53	36	54	49	60	59	63	72	64	75	73	75	59	65	54	54	31	40	27	30
Flint	35	26	45	26	40	35	55	47	55	58	60	71	65	74	65	74	65	64	55	54	30	39	30	29
Grand Rapids	35	25	42	25	48	35	52	48	61	58	64	72	65	75	67	74	53	64	47	53	27	38	26	28
Houghton Lake	35	20	50	20	50	29	50	43	55	54	65	67	65	70	70	70	55	59	50	49	25	35	30	25
Lansing	36	25	44	25	49	34	52	48	64	59	68	72	71	75	69	74	60	64	55	53	31	39	30	29
Marquette	34	21	43	21	52	29	55	41	57	51	60	64	67	70	62	70	52	60	46	50	27	35	28	25
Muskegon	20	27	30	27	50	35	50	47	55	57	60	71	70	74	70	74	60	65	55	55	30	41	25	31
Sault Ste. Marie	34	17	45	17	54	26	53	40	55	51	58	63	63	68	59	68	45	58	42	48	23	34	27	22

Source:(2)

For July:

$$\text{Collector area} = \frac{1.33 \times 1{,}000{,}000}{24.9 \times 1{,}000} = 53 \text{ ft}^2$$

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.

Commercial solar hot water systems often come with 50 to 60 ft² of collector area. The best way to approach the problem is to determine the percentage of your hot water energy requirement that can be supplied by various sized collectors and do a cost comparison.

Percentage of Your Hot Water Needs That Can Be Supplied By Solar (Chart 3)

Line 5—We are trying a 50 ft² collector because it's a fairly common size.

Line 6—This is the total insolation collected per month with the 50 ft² collector.

Line 7—The insolation that is actually used each month is the smaller of either line 3 or 6. In June, July, and August more energy can be captured by the collector than is actually needed.

Line 9—Add all 12 of the percentages obtained in line 8 together and divide by 12. The result is the percentage of the hot water energy needs that can be supplied by the solar system for the year. In this case, the 50 ft² collector can provide about 60% of the year's hot water energy needs. The remaining 40% must be supplied by a conventional (oil, natural gas, or electricity) hot water heater.

Size Of Storage Tank

For hot water solar systems, the most practical storage medium is water. In a small storage tank, the temperature will be high, 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 temperature will frequently be too low to be of use. The best storage volume is considered to range from 10 to 15 lb of water for each square foot of collector (5). The volume in gallons can be obtained as follows:

$$\text{Storage volume} = \text{collector area} \times 10\text{-}15 \text{ lb per ft}^2 \times 1 \text{ gal per } 8.33 \text{ lb}$$

In this example, the minimum storage volume would be:

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

CHART 3

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

Line	Description	Source	Units	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
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 17 Chart 2	1,000 BTU per ft² per month	6.6	10.1	14.8	15.7	21.1	22.7	24.9	24.6	20.1	15.2	6.1	5.1
5	Collector area	See discussion	ft²	50	50	50	50	50	50	50	50	50	50	50	50
6	Energy collected per month	(Line 4 × Line 5) ÷ 1,000	Million BTU per month	0.33	0.51	0.74	0.79	1.06	1.14	1.25	1.23	1.01	0.76	0.31	0.26
7	Insolation used per month	Smaller of Line 3 or Line 6	Million BTU per month	0.33	0.51	0.74	0.79	1.06	1.14	1.25	1.23	1.01	0.76	0.31	0.26
8	% energy requirement supplied by solar per month	(Line 7 × 100) ÷ Line 3	Percent	25	43	56	61	80	88	94	92	78	57	24	20
9	% energy requirement supplied by solar per year	Add all the %'s in Line 8 together and divide by 12	Percent	60											

The maximum volume would be:

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

So the storage tank should hold somewhere between 60 and 90 gal.

References and Suggested Readings

(1) Adapted from **ASHRAE Handbook of Fundamentals** (1972). American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., 345 East 47th Street, New York, N.Y. 10017.

(2) Adapted from **Climate of Michigan by Stations** (1971). Michigan Department of Agriculture, Michigan Weather Service.

(3) Daniels, Farrington (1964). **Direct Use of the Sun's Energy**. Ballantine Books, New York, N.Y. 271 pp.

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

(4) Dawson, Joe (1976). **Buying Solar**. Federal Energy Administration, Stock No. 041-018-00120-4. U.S. Government Printing Office, Washington, D.C. 20402. 71 pp. Price $1.85.

(5) 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.

(An engineering guide to the design of solar heating and cooling equipment for buildings. Many examples are given and it is highly technical.)

(6) Meinel, Aden B., and Marjorie P. (1976). **Applied Solar Energy—An Introduction**. Addison-Wesley Publishing Co., Reading, Mass. 651 pp.

(This is a highly technical reference book. It is extremely detailed and thorough with many graphs, tables, and equations.)

(7) **Energy Primer**. (1974). Portola Institute, 558 Santa Cruz Avenue, Menlo Park, Calif. 200 pp.

(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.)

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

(Another do-it-yourself guide to alternative energy sources. People who have their own solar system share their experiences and designs.)

(9) **Solar Heating Systems Design Manual** (1976). ITT, Training and Education Department, Fluid Handling Division, Morton Grove, Illinois.

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MICHIGAN STATE UNIVERSITY
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COOPERATIVE EXTENSION SERVICE

Issued in furtherance of cooperative extension work in agriculture and home economics, acts of May 8, and June 30, 1914, in cooperation with the U.S. Department of Agriculture. Gordon E. Guyer, Director, Cooperative Extension Service, Michigan State University, E. Lansing, MI 48824.

2P-1R-7.5M-2:81-UP, Price 20 cents. Single copy free to Michigan residents.

Michigan State University Printing

0-12747