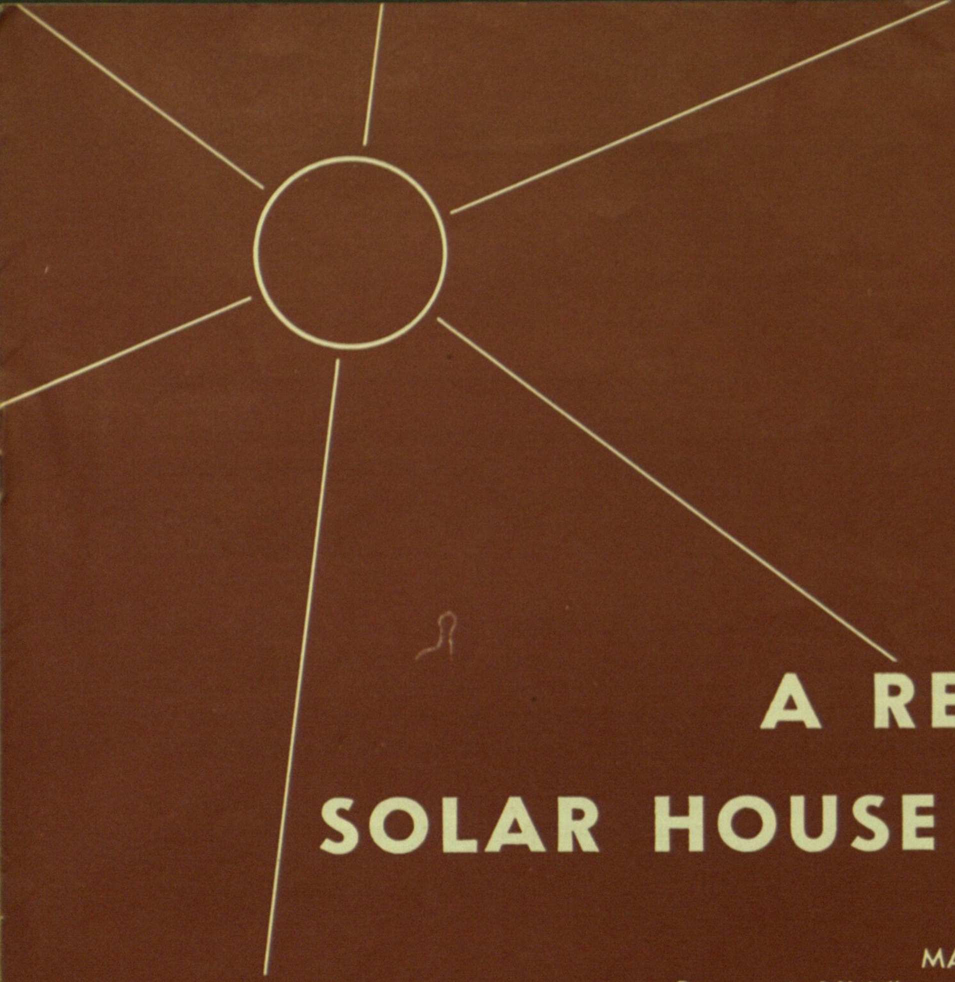

# A REVIEW OF SOLAR HOUSE HEATING

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**Various methods of solar house heating are summarized in their relation to the efficiency of collecting and storing the available solar energy.**

THE age-old dream of keeping warm enough during the winter and comfortably cool during the summer, has been the subject of most Utopias. To use the sun for this purpose has tantalized many minds and various schemes have been advocated in the past. Any plan based upon solar energy for house heating, must face and solve the following problems:

*(1) Collection of solar energy.* Winter sunshine must be collected, efficiently, simply and economically.

*(2) Storage of solar energy.* It has been shown definitely that storage of summer sunshine for winter use is not economical (1).* It is necessary to store solar energy, received during clear winter days, for the inevitable dark days when no solar energy can be collected. It is not economical to attempt capturing the last Btu of collectible sunshine; it is preferable to store efficiently the amounts available on clear, or partly cloudy days.

*(3) Distribution of stored solar energy.* The stored heat must be available when called for by a thermostatically controlled distributing system that is simple to operate, with minimum attention from and disturbance to the occupants. It is important that the house should not become overheated, especially during the rapidly changing weather of spring and autumn. Finally, it is important that the solar heating system should operate only during the winter and most definitely not during the summer.

## What Has Been Done?

It was relatively recent, during the last century, that large enough glass window areas could be acquired at an economical cost to admit winter sunshine. The size and importance of windows have been increasing and with them the attention paid to the sun shining through the windows (2-5).

Solar houses were first popularized in this country about 1930. Experiments at Purdue University, Lafayette, Ind., under the direction of F. W. Hutchinson, were planned to settle the question: How much fuel actually can be saved? In a series of articles (7-11) the results of two identical test houses were compared. One of these, the "orthodox" house had the usual window area, while the "solar" house had a greater area of glass on the south side. In both houses two glass panes were used, with sealed air space between them. Both houses were electrically heated, to avoid human errors in coal stoking. They were thermostatically maintained at identical temperatures. The Purdue houses were not occupied during the tests and no attempts were made to control the excessive heat losses through the glass during the night.

Results indicated, surprisingly, that the Purdue solar house required about 16% more fuel heat than did the orthodox house during a December-January test period. It is obvious that a great deal of sunshine is admitted through large, south-facing windows on clear days and even on partly cloudy winter days, with the result that fuel is saved only while the sun shines. The house may often become overheated. However, at night and on cloudy days, the large windows dissipate a great deal of heat.

According to F. W. Hutchinson, the large-windowed solar house requires a larger than usual fuel-burning furnace, than does its conventional-windowed counterpart. The Purdue results apply only to the local conditions and different results may be obtained elsewhere.

Architectural designs illustrated in "Your Solar House" (12) may, or may not save considerable amounts of fuel, depending upon geographical latitude and also upon the latitude used in interpreting the word considerable.

Large heavy walls can store heat. The cyclic variation of wall temperatures, especially on the south side of buildings, has been studied (13) (14). The heat storage capacity of many a thick-walled old building has been obviously noticed, as well as the relatively cooler summer comfort of such houses.

Deliberate storage of solar heat has been used in solar water heaters, increasingly popular in Florida and California (15). All that was required was a heat trap on the roof, consisting of a flat tank or zig-zag arrangement of pipes, in a well insulated box, covered by one or two air-spaced glass panes. Water circulated in the pipes, became heated by the sun and accumulated in an insulated storage tank, to be used as required (16).

An enlarged version of the solar water heater was used to heat a two-room test structure built at Massachusetts Institute of Technology, during 1939-1940 (1). The 17,000 gal insulated tank occupied the entire basement. A similar house, occupied by tenants, has been completed recently at M.I.T. with a 1,200 gal water tank located in the attic.

G. O. G. Lof (17) (18) conducted solar heat collection and storage experiments at the University of Colorado. He covered about one-third of the roof of his own house with a solar heat collector, circulating air through it and blowing the warm air directly into the rooms, or into a heat storage duct, filled with crushed rock. During the first season a fuel saving of 20% was attained. Heat transfer problems of storage in crushed rock were summarized by Lof (19). The amount of heat storage was limited to the heating requirements of one day.

Simple methods of solar heat storage, using water, or rocks, are based on the specific heat effect. A new method for storing solar heat has been suggested by M. Telkes (6). This uses the heat of fusion, or heat of transformation. It is well known that all materials, when melted, require a rather large amount of heat to change their solid forms into their liquid forms. While the melting or fusion process progresses, the temperature of the material does not change but remains at the melting point.

The magnitude of this effect can be illustrated by the well known fact that 144 Btu are required to melt one pound of ice to ice cold water. The same amount of heat imparted to one pound of ice cold water, at 32F, will increase the temperature of the water to 32 + 144 = 176F (neglecting factors as lateral heat losses).

Most materials have a well defined melting point and their heat of fusion is a known physical constant. The important problem was to find an inexpensive and easily available material, with a melting point convenient for solar heat storage and with a relatively large heat of fusion. The principles of adapting this method for house heating have been analyzed in a previous article (6) and several methods have been proposed.

## How Much Sunshine Can We Expect?

The United States Weather Bureau has exact records of sunshine, dating back many years. These records cover the following data:

*(1) Sunshine hours.* The monthly total of sunshine hours for more than 200 stations is published regularly by the Weather Bureau. Maps have been printed giving the number of sunshine hours for each month, as an average for the past 50 years. The instrument used records sunshine only when the amount of solar energy is more than 82 Btu per (sq ft) (hr). To account for the early morning and the late afternoon sunshine, a correction factor is added. Weather bureaus of Europe and other parts of the world use the Campbell-Stokes recorder, a slightly different instrument, recording sunshine in excess of 73 Btu per (sq ft) (hr). Brooks (20) established the correction factors, which make it possible to compare foreign records with United States records.

**TABLE 1—SUNSHINE RECORD**

| City | Daily Amounts of Sunshine | | | |
|---|---|---|---|---|
| | Winter | | Summer | |
| | Sunshine Hours | Percentage of Possible Sunshine Hours | Sunshine Hours | Percentage of Possible Sunshine Hours |
| Boston, Mass. | 4.9 | 51 | 9.0 | 61 |
| New York, N. Y. | 5.5 | 56 | 9.7 | 67 |
| Miami, Fla. | 7.6 | 70 | 8.8 | 65 |
| Chicago, Ill. | 4.3 | 44 | 10.7 | 70 |
| Los Angeles, Calif. | 7.4 | 72 | 10.5 | 75 |
| Seattle, Wash. | 2.6 | 29 | 9.4 | 62 |

**TABLE 2—SOLAR ENERGY RECORDED AT BLUE HILL** 42°10'

Data are based upon 4 years' graphical averages

| Month | Btu per (sq ft) (day) | | | | | Ratio, Vertical/Horizontal | |
|---|---|---|---|---|---|---|---|
| | gcal cm⁻² | Horizontal | $\sqrt{H^2+V^2}$ | Vertical | gcal/cm²d | | DPol, 42° H |
| January | 158 | 584 | 1220 | 1070 | 331 | 1.84 | 180 |
| February | 239 | 880 | 1530 | 1250 | 415 | 1.42 | 270 |
| March | 328 | 1210 | 1740 | 1250 | 472 | 1.04 | 390 |
| April | 372 | 1370 | 1640 | 900 | 445 | 0.66 | 510 |
| May | 425 | 1750 | 1880 | 700 | 510 | 0.40 | 590 |
| June | 513 | 1890 | 2050 | 710 | 553 | 0.38 | 620 |
| July | 507 | 1870 | 2060 | 780 | 554 | 0.42 | 610 |
| August | 485 | 1790 | 1980 | 860 | 537 | 0.48 | 550 |
| September | 364 | 1340 | 1730 | 1100 | 469 | 0.83 | 440 |
| October | 298 | 1100 | 1630 | 1210 | 442 | 1.10 | 300 |
| November | 171 | 630 | 1160 | 980 | 315 | 1.55 | 210 |
| December | 136 | 502 | 1170 | 960 | 317 | 1.90 | 160 |

*(2) Percentage of possible sunshine.* The total number of hours from sunrise to sunset give the number of hours when sunshine were possible if clouds would not interfere.

The actually observed hours of sunshine can be expressed as the percentage of the maximum possible. Maps of this type as well as maps showing the number of sunshine hours for each month, as a 50-year average, may be obtained from the U. S. Weather Bureau.

To illustrate the various sunshine records with definite examples, the records of several cities are compared in Table 1.

*(3) Solar energy received on a horizontal surface.* Under the direction of I. F. Hand (21) the Weather Bureau records the exact amount of solar energy falling, or incident, on a horizontal surface at some 20 stations. The instrument used is the pyrheliometer and the records are automatically traced on a recording instrument. The *Monthly Weather Review* tabulates the exact amount of sunshine for each day of each month for the different stations. The records are expressed in calories per square centimeter per day and can be converted into Btu per square foot per day, by multiplying them by 3.69. Recently several new stations have been opened.

*(4) Solar energy received on a south-facing vertical surface.* These records have been observed since 1945 by I. F. Hand at the Blue Hill Observatory (10 miles south of Boston, Mass.). From the point of view of house heating, the amount of solar energy reaching a south-facing vertical wall is most important, because the vertical surface receives more solar energy during the winter than does a horizontal surface of the same area. The comparison has been reported by I. F. Hand (22) ((23). During December-January, on clear days, nearly twice as much solar energy is received on a vertical surface than on a horizontal surface. During the spring and fall there is not much difference, while during the summer, the sun being high in the sky, more sunshine reaches the horizontal surface. The amount of solar energy for each month has been cal-

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*Numbers in parentheses refer to the bibliography at the end of this article.

### TABLE 3—NUMBER OF SUNNY AND CLOUDY DAYS IN DECEMBER

| Days | 4 Years' Vertical Data | 15 Years' Horizontal Data | Per Cent of Monthly Total (Approximate) |
|---|---|---|---|
| | Number of Days | | |
| (A) Dark | 10 | 10 | 5 |
| (B) Partly cloudy | 5 | 6 | 15 |
| (C) Above average | 16 | 15 | 80 |

culated from Hand's results and is expressed in engineering units, Btu per (sq ft) (day).

Observations made at Blue Hill reveal that the amount of winter sunshine reaching a vertical wall is increased by reflection from snow on the ground, which is, of course, included in the records.

Calculations have been made to convert the horizontal incidence data, to predict the amount of solar energy receivable on south-facing tilted and vertical surfaces. The cosine law is used in such calculations, but it is applicable only to the direct solar radiation and not to the diffuse part. For exact data, actual measurements have to be made, which are more reliable than voluminous calculations.

The vertical incidence data have been available only since 1945 and only for the single Blue Hill station. Four years are too short a time to establish averages, but the knowledge of the vertical/horizontal ratios increases the usefulness of the longer records available on a horizontal surface.

*(5) Distribution of clear and cloudy days.* It is unnecessary to recall that the weather is capricious and nothing can be done about it. All that can be done is to observe the records and derive statistics from them. From the point of view of solar house heating, the most important problem is the sequence of clear, partly cloudy and cloudy days, during the winter.

## Use of Solar Statistics

To illustrate the use of available solar statistics, an analysis is given of the Blue Hill station's records. Amounts of solar energy incident on a south-facing vertical surface are shown in Table 3 for each day of December, during the past four years. Examining these records we can see some really dark days, when less than 10 Btu per (sq ft) (day) has been received, but in contrast to the dark days there were several clear days, when the amount of solar energy reached levels higher than 2,000 Btu per (sq ft) (day). From day to day, the amount of sunshine may change 200-fold. The average value for the four December months was 1,003 Btu per (sq ft) (day); the more probable graphical average is 960 Btu per (sq ft) (day).

To visualize the solar energy groupings, the dark days, are marked *A*. These days received less than 480 Btu per (sq ft) (day), or half of the probable average. The partly cloudy days, *B*, received 480 to 959 Btu per (sq ft) (day), and the balance of the days marked *C*, are the above-average, or clear days, with more than 960 Btu per (sq ft) (day). There were several two- and three-day periods of dark days, when probably none of the incident solar energy could be collected for house heating and the heat had to be drawn from the storage reservoir.

The horizontal incidence records have been available for the past 15 years for Blue Hill. For an analysis of these data, see Table 3.

An examination of the 15 Decembers on record shows that dark day sequences of two, three or even four days' duration are not unusual. The longest dark period observed in December lasted five days and was recorded only once in 15 years. The January distribution showed one six days' and one seven days' sequence, which appeared to be the longest dark day sequence on record.

On the sunny side of the statistics, the above-average, or clear day (C) sequences, are more numerous. During the past 15 Decembers, a sequence of five such days occurred eight times, one six-day, two seven-day and one eight-day sequence of clear days have been recorded.

## How Much Heat Storage?

Variations during the December months were generally within 10% from the 15-year average and they were very seldom more than 20%. This would correspond to a surplus or deficit of three or six days' sunshine per month. The conclusion can be reached that in the vicinity of Boston, a solar heat storage system capable of storing 9 or 10 days' heat supply, should be sufficient. It is possible to calculate that a system capable of storing fewer days' heat requirement may be sufficient, by providing an auxiliarly booster (possibly with electrical heating). The booster may be needed only during adverse weather and only for a limited number of days during the heating season.

### TABLE 4—SOLAR AND SKY RADIATION IN DECEMBER

Total solar and sky radiation received on a vertical south-facing surface at Blue Hill, Mass., Btu per (sq ft) (day)

| | 1945 | 1946 | 1947 | 1948 | 4-Year Average |
|---|---|---|---|---|---|
| Total for month | 31125 | 25440 | 39245 | 28580 | 31100 |
| Average for day | 1005 | 820 | 1265 | 920 | 1003 |
| Sum of A days | 1480 | 1405 | 555 | 2080 | 1380 |
| Sum of B days | 3300 | 5360 | 4015 | 2915 | 3900 |
| Sum of C days | 26345 | 18675 | 34675 | 23595 | 25820 |
| Number of Days in Group for Month | | | | | |
| Group A* | 11 | 11 | 6 | 12 | 10 |
| Group B* | 5 | 7 | 5 | 4 | 5 |
| Group C* | 15 | 13 | 20 | 15 | 16 |
| Per Cent of Month's Total Radiation | | | | | |
| Group A | 5 | 5.5 | 1.5 | 7 | 4.5 |
| Group B | 10.5 | 21 | 10 | 10 | 12.5 |
| Group C | 84.5 | 73.5 | 88.5 | 83 | 83 |

*Days in *A* group received 0-479 Btu per (sq ft) (day); *B*, 480-959; *C*, 960 plus.

Such calculations involve economic factors, but they cannot be reliable without further tests under actual living conditions. The cost of the initial installation of the auxiliary heater, the cost of its maintenance during intermittent service conditions and the cost of the electricity that is consumed by the system must be considered.

Weather Bureau records are available giving the hourly distribution of solar energy. More sunshine will be received around noon than during the early morning, or late afternoon. An analysis was made of the Blue Hill south-facing vertical records. It appears that during December-January the amount of solar energy received before 8 a.m. and after 4 p.m. (solar time) is less than 3.2% of the total amount received during the entire day.

There will be a certain minimum amount of solar energy that cannot be collected at all. This amount may be tentatively set down at 30 Btu per (sq ft) (hr). During December-January only 4.3% of the total solar energy was less than this minimum value.

During the December-January period, about 15 days per month will be above-average, or clear days, in the vicinity of Boston. An analysis showed that about 80% of the monthly total solar energy is received during the clear days and most of this could be collected.

An estimate of the solar radiation during cloudless days has been published recently by Fritz (24) for the entire United States. The complex problem of the available solar energy for any geographical location should give the following facts: Amount of solar energy; sequences of dark and clear days; deviations from the expected average.

## Sunshine – Heat Load Relation

The amount of heat required to maintain a building at comfortable temperature can be calculated according to standard practice. The heat load is proportional to the degree days, that is, the daily average temperature difference below 65F. Weather Bureau records and maps are available giving the degree days for every month at many stations.

The most important factor in solar house heating is an exact knowledge of the collectible solar energy and its relation to the heat load, both on a monthly distribution basis. The heat load is known for a large number of places, but the exact amount of solar energy received on a south-facing vertical surface is known only for a single station (Blue Hill). The amount of solar energy received on a horizontal surface is known at 20 stations, but they represent only scattered dots on the map.

Lacking adequate quantitative data of solar energy, comparision can be made only on the basis of the available sunshine hour records. Some 200 stations have such data collected during the past 50 years. It has been mentioned that the U. S. sunshine hour recorder responds to solar energy in excess of 82 Btu per (sq ft) (hr); hence, a correction factor is added to the instrument readings. Records of the sunshine hours, therefore, indicate solar energy above a certain level which may approach the minimum value that can be collected.

Even if these data are at best only approximate, it is interesting to compare the Weather Bureau records (25) of sunshine hours with the degree days.

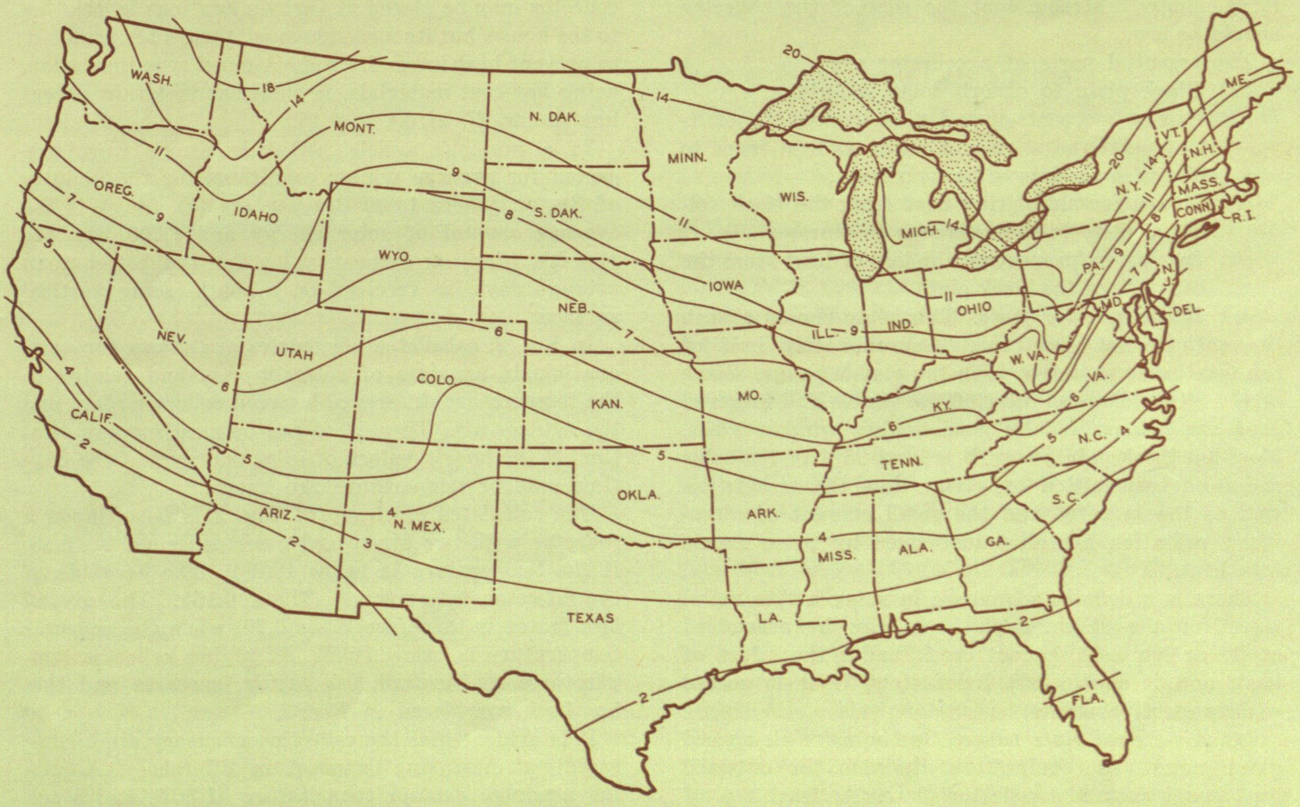

Fig. 1. Degree days per sunshine hours based on December and January data. The larger the number, as shown on this map, the more elaborate is the heating system required.

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The ratio of degree day *D* and sunshine-hour *S* or D/S for December and January are plotted in Fig. 1. The ratio contours, drawn to connect places of about equal ratios, represent the number of degree days which would have to be compensated by one hour of sunshine. Some latitude was taken in drawing these lines in the Rocky Mountain and western areas. A high ratio indicates the need for a larger or more elaborate solar heating system. In the south, the line runs somewhat parallel to the latitude, while further north the lines dip down at the Great Lakes and curve upward near the sea coast. The line 8.0 represents ratios similar to those that exist just north of Boston.

The map represents only an attempt to visualize the geographic limits of the possibility of solar house heating and the lines should not be regarded as exact demarcation limits.

### Efficiency of Solar Heat Collection

The solar heat collector is a device which absorbs the radiant energy of the sun and transforms it into heat which is delivered into the house or into a storage reservoir. The collector should be designed in such a way, that it should gather the greatest amount of winter sunshine. It should not become overheated by the unavoidable summer sunshine.

The amount of heat collected can be expressed as a percentage of the total incident solar energy, this figure being the efficiency of collection. It is desirable that the collection efficiency should be high during the winter, but low during the summer. At the same time it is equally desirable that the cost of the collector should be low.

The essential parts of a collector are:

1. Black plate to absorb solar radiation.
2. One or more air-spaced glass panes, transmitting solar radiation and acting as heat traps to diminish the loss of heat outward.
3. Means for circulating heat from the black collector plate to the rooms or to storage.
4. Insulation, preventing the loss of heat from the backside of the black plate.

*(1) Black collector plate.* This plate should absorb the entire solar spectrum. Approximately half of the total solar radiation is in the visible range. Some of the ultraviolet and most of the visible and infrared rays are transmitted by good quality window glass. Most flat black paints absorb at least 95% of the solar radiation transmitted by glass; thus the visable, as well as the infrared and the small amount of ultraviolet radiation are all transformed by these means into heat.

There is a definite advantage in using a thin metal plate for the collector plate. It can be assembled easily at low cost, cannot crack under the effect of heat, and it should last indefinitely, if it is coated with protective paints.

*(2) Air-spaced glass panes.* One or more air-spaced glass panes are required, to diminish the outward heat losses from the collector plate. At least 8% of the incident solar energy is reflected and about 2% is absorbed by each glass pane. If the angle of incidence for solar energy is greater than 60°, the reflection losses increase rapidly. The transmission of glass, used in a south-facing vertical collector, will be the greatest around the noon hour, but it will be lower during the early morning and the late afternoon. Less solar energy will be transmitted through the vertical glass, when the altitude of the sun increases. It is expected that relatively little solar energy will be collected by a south-facing vertical collector during May, June, July and August, to the great advantage of this type of collector.

It is obvious that a tilted collector could be arranged at an optimum winter tilt (around 60°-70° for the vicinity of Boston) to collect somewhat more solar energy during the winter. This effect may be counteracted by heavy snow, accumulating on the tilted collector, while the vertical surface would remain clear and could even receive additional sunshine reflected from the snow on the ground. The tilted collector would definitely collect more solar energy during the spring and autumn, when the heat requirement is not very great; it will collect heat most generously during the summer to the detriment of overheating the collector.

*(3) Means for circulating the heat.* Various methods are available for circulating the heat from the black collector plate to the rooms or to storage. Pipes can be attached to the black metal plate, circulating a liquid to the heat reservoir. Or the black metal plate can form one side of an air duct, with fans circulating warm air to the heat storage. Which method is selected is governed by costs.

*(4) Insulating the backside of the collector.* The collector may be placed at various locations in relation to the house, but its backside must always be insulated, to prevent heat losses from it. A panel type insulation, using low cost materials, is sufficient to attain a heat loss factor, *U*, of 0.1 to 0.15.

In a previous article, (6) calculations were presented for average winter conditions for the vicinity of Boston, where 1,000 Btu per (sq ft) (day) is the average amount of solar energy and 1,500 Btu per (sq ft) (day) is a mean value for the better than average days, as received on a south-facing vertical surface.

In Fig. 2, calculated efficiencies are shown for various hourly amounts of solar energy, and related to the temperature difference between collector plate and the outdoor air. These data can be used for any location, if the hourly values of solar energy and the daytime outdoor temperature are known.

The calculated efficiency of Fig. 2 is based upon a collector with two air-spaced glass panes (U = 0.55, if the temperature is below 100F). The backside of the collector is insulated (U = 0.15). The overall loss factor is therefore U = 0.70, when the collector temperature is below 100F. At higher collector temperatures, the overall loss factor increases and this has been considered in Fig. 2.

It is evident that the collection efficiency diminishes rapidly at increasing temperature differences. Assuming a winter outdoor temperature of 30F, and a collector temperature of 120F, the temperature difference will be 90F. At this level the collection efficiency will be 38 to 49% for the higher solar intensities, while only 8% will be collected when the amount of solar energy is 100 Btu per (sq ft) (hr).

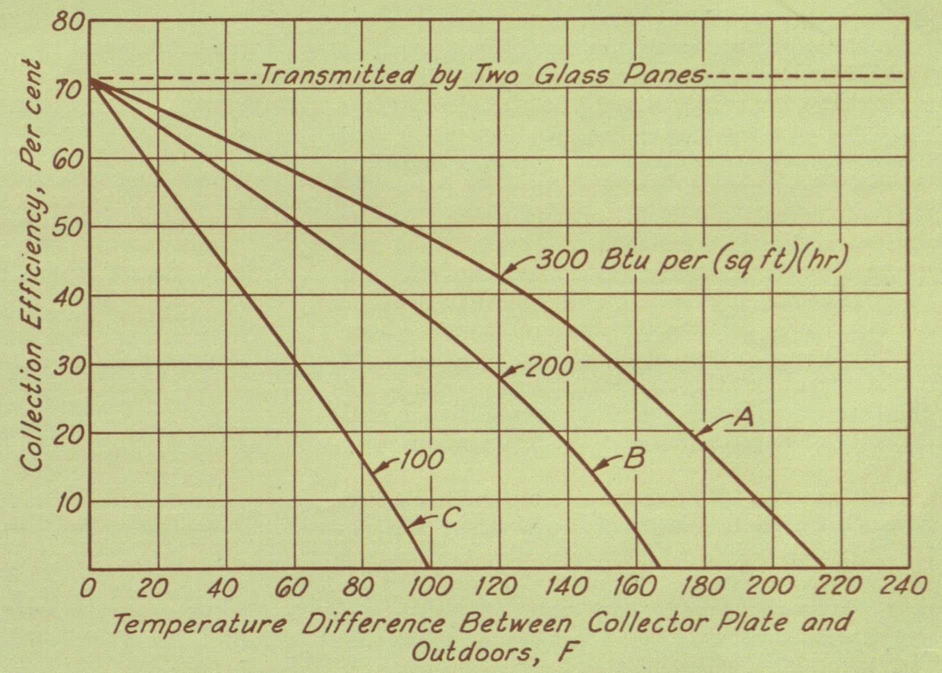

Fig. 2. Calculated efficiency of solar energy collector. Calculations are based upon a collector with two glass panes and an overall U of 0.7 and larger. Weather conditions for A, clear between 10 a.m and 2 p.m.; B, slight haze or few clouds between 10 a.m. and 2 p.m.; C, partly cloudy cr overcast—clear early morning or late afternoon.

It is obvious, therefore, that high collection efficiencies can be attained only on clear days or slightly cloudy days, unless the energy is collected at a relatively low temperature difference. On partly cloudy days collection would still be possible at a temperature of 110F, while nothing could be collected, during the winter, on such days at 130F.

### Collector Temperature

The collected solar heat cannot be transferred to the heat storage reservoir unless a temperature difference is maintained. For this reason the storage temperature should be at a relatively lower level, probably around 100F, otherwise the early morning and late afternoon winter sunshine and the partly cloudy days sunshine could not be collected.

With the specific heat type heat storage material (water for instance) a daily cycle may be contemplated, starting in the morning with the temperature of the water at 85F. During a clear winter day, collection will be quite efficient during the morning and around the noon hour, but as the temperature of the water increases above 115F, and as the amount of solar energy decreases during the afternoon, it is probable that no additional energy can be collected during the later part of the afternoon.

TABLE 5—CHEMICALS FOR HEAT STORAGE

| Chemical compound | Melting Point, F | Heat of Fusion, Btu per lb | Cost, Dollars per Ton |
|---|---|---|---|
| $CaCl_2 \cdot 6H_2O$ | 84-102 | 75 | 13 |
| $Na_2CO_3 \cdot 10H_2O$ | 90-97 | 115 | 24 |
| $Na_2HPO_4 \cdot 12H_2O$ | 97-118 | 114 | 70* |
| $Ca(NO_3)_2 \cdot 4H_2O$ | 104-108 | 90 | * |
| $Na_2SO_4 \cdot 10H_2O$ | 88-90 | 104 | 9 |
| $Na_2S_2O_3 \cdot 5H_2O$ | 120-126 | 90 | 58* |

*Cost not certain.

Therefore high collection efficiency can be attained only if the temperature of the heat storage is at a relatively low level, probably 90-100F.

Temperature of the collector can be controlled by the flow of air, or water, adjacent to the collector plate.

### Heat of Fusion Type Heat Storage

Requirements for heat of fusion compounds are low cost and availability. The low cost limits the choice to sodium, calcium, magnesium and possibly iron compounds which are generally available.

For house heating purposes the melting point of the chemical compound, or mixture, should preferably be in the 90 to 100F range.

Some of the materials which meet these requirements are given in Table 5.

There are many other materials or mixtures of different materials, which may show further advantages.

It should not be imagined that these chemical compounds could be packed haphazardly into containers, cans, tubes or tanks of any size and shape. If the proper conditions are disregarded, the chemical compound may not perform any better than a specific heat type heat storage material. The following important five factors must be considered.

*(1) Undercooling.* Most materials, melted in a closed container, without any stirring, will undercool below their melting points without any solidification. The presence of "seed" crystals, providing crystallization nuclei, promotes the process of crystallization. In closed, sealed containers it would be impossible to seed the chemical compounds from the outside and therefore crystallization nuclei must be provided, being in suspension in the material. Each material re-

quires a special additional agent to prevent undercooling and promote crystallization.

*(2) Temperature stratification or segregation.* During melting, the solid material being heavier, sinks in the liquid. Ice is an exception. The molten top layer may become warmer than the unmelted solid and therefore heat must be delivered in such a way that it should reach the unmelted material first. Temperature stratification is encountered frequently and various means have been suggested to lessen its effect. In the heat of fusion method, the heat must be delivered in such a way that the temperature currents should produce a certain amount of mixing.

Stirring or rotating the container by some simple and inexpensive method would of course eliminate the difficulty of undercooling and the temperature segregation.

*(3) Corrosion.* Most chemical compounds are more or less corrosive to metal containers. In a closed system, a small amount of corrosion inhibitor can stop the corrosive action.

*(4) Volume changes.* Most materials listed show very little change in volume on melting and solidifying. Metal containers withstand the slight volume changes, but glass or ceramic containers may crack, unless properly designed.

*(5) Possible improvements.* The heat of fusion type solar heat storage requires further development. The design of low cost containers, simple filling methods similar to mass-production canning operations, should produce standard heat storage units which can be manufactured and assembled at low cost.

The heat of fusion of the listed materials is around 75 to 115 Btu per lb and it is not expected that any suitable, low cost material could be found which has a considerably greater heat of fusion. The density of the listed materials is 90 to 110 lb per cu ft. The heat storage ability on a volume basis is around 10,000 Btu per cu ft.

## Merits of Heat of Fusion

Below and above their melting points, the chemical compounds are capable of storing heat as the specific heat, which is very nearly the same as the specific heat of water, when compared on an equal volume basis.

The advantage of heat of fusion type materials is therefore:

(1) Heat storage as the heat of fusion, which is around 10,000 Btu per ~~lb~~ cu. ft. at the melting point, generally within a rather narrow temperature range.
(2) Higher solar heat collection efficiency due to the relatively low, nearly constant, storage temperature.
(3) Additional heat storage as specific heat, which is about the same as that of water on an equal volume basis.

It is estimated that about five to nine times more solar heat can be stored as the heat of fusion, than can be in water or any other specific heat storage material, compared on an equal volume basis.

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