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DESIGN OF A THERMOSYPHONIC SOLAR WATER HEATER FOR DOMESTIC USE

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1973

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ABSTRACT

This paper deals with a method for trapping a portion of the enormous amount of energy that the sun continually pours upon the earth. Presented in this paper is a solar water heater designed for a family of four living in Florida, Texas, the Southwestern United States or Southern California. This unit is lower in cost than any solar water heater now on the market that performs the same task. It also eliminates the problems of corrosion, leakage, freezing, and weight that are prevalent in other solar water heaters of comparable price. It has a storage capacity of 80 gallons and by utilizing the sun's energy is capable of providing a continuous water supply for the average household at a temperature of 140°F. The unit can be built for less than $75 and has a life expectancy of over 20 years. This makes it competitive with one of the cheapest models of an 80 gallon electric water heater whose wholesale price is in excess of $110.

The design method presented in this paper is rather simplistic in nature. Much of the complex theory which substantiates many of the assertions made is completely eliminated. It is the practicality of the approach that is stressed. The feasibility of all aspects of the design has previously been mathematically and experimentally proven. This paper is devoted to obtaining a practical solution from a conglomeration of very feasible ideas.

INTRODUCTION

The greatest sociological concern of today's world and in particular of the United States is the energy crisis. Energy has always been the key to man's goals and aspirations and to his dreams of a better tomorrow. As the consumption of the world's energy increases exponentially, man is rapidly depleting his organic fuel sources upon which he now depends so heavily. Although there is much exploration for new fuel reserves and much experimentation performed to obtain more energy from the fuels available, a great challenge lies before the technologist. He must find entirely different sources of energy and harness these sources to meet the ever increasing demands of a burgeoning population and a more complex technology. This paper devotes itself to one new source of energy - the entrapment of the vast but elusive power of the sun. The device presented, a solar water heater, is rather simple when compared to today's complex technology, but the synergistic effect of solar water heaters used world-wide would have an exhilirating effect on the earth's standard of living.

Solar water heating is perhaps the most widespread engineering use of solar energy. At present no other direct use of solar energy competes with solar water heating in the amount of energy produced. The flat plate collectors that are used to heat large quantities of water through a limited range of temperatures are cheap and require no attention once installed. For this reason their feasibility for use in a project concerning a domestic solar water heating unit was thoroughly investigated.

SOLAR WATER HEATERS AVAILABLE

Various types of solar water heaters are now commercially available. They range in price from a few dollars to $500. Perhaps the simplest solar water heater is the garden hose. It is common knowledge that the water in a hose sitting in the sun will gradually become warmer than when it first entered the hose. Thus, there are solar water heaters that are nothing more than black garden hoses placed in the sun. Water is slowly passed through the hose, exiting at a higher temperature than its entrance temperature.

The open type solar water heater is based on the observation that if water is poured into a container and allowed to sit in the sunshine, the water is warmed. As soon as the water in the container heats up, heat is lost through evaporation, radiation, convection, and conduction. Thus, the solar water heater is provided with a transparent cover that permits radiation in at the same time trapping the long infrared radiation emitted by the hot water. This trapping of heat is the same effect observed in a greenhouse. Insulating the box reduces heat loss by convection and conduction. The simple closed membrane type of solar water heater is generally made of a plastic film in the form of a water pillow. These two water heaters, however, must be placed horizontally, resulting in a very poor heating effect in the winter because the sun's rays decline in this season.

Closed type heaters are constructed in incline toward the sun, thus receiving the strong rays of the sun. Here collectors are made in the form of pipes or of corrugated sheets soldered to each other. These collectors, which convey the absorbed heat of the sun into the water system, are generally the most expensive item in the construction of a flat plate solar water heater. The corrugated sheet flat plate collector is cheaper and, if the water layer is thin, more efficient than the tube construction. The latter is comprised of water carrying pipes that are welded to a plate which captures the sun's energy. The major difficulties of the former lie in the leakage around the edges and in resisting internal water pressure. It is common to experience leaks soon after the collector is put into use. This design, though cheap and efficient, is not a success as far as durability is concerned. The materials most commonly used in collectors are aluminum, galvanized iron, or copper, the last being the most efficient but also the most expensive. These collectors are placed in an insulated box and covered by a transparent film. (See Figures 1 & 2)

The problem encountered with the closed type water heater is the lack of storage. That is, hot water can only be had when the sun is shining and the amount used is limited to the flow rate of the water through the absorber. Thus, another basic design for solar water heaters is a closed type water heater that utilizes an insulated storage tank for hot water use during periods of no solar radiation. Circulation is usually accomplished thermally without a pump and electric motor. A serious problem that is often encountered is the freezing of the water in the collector and the subsequent bursting of metallic pipes. Such freezing may occur when the temperature of the surrounding air is several degrees above the freezing point of water because of the cooling effect of the black metal sheets by radiation to the night sky. Because draining the system is inconvenient and unreliable, in many locations a dual system is used in which the absorbing unit is filled with an antifreeze solution and the water in the storage tank is heated via a heat exchanger. This, however, is done at a great increase in the cost of the solar water heater.

BASIC REQUIREMENTS

In this paper a hot water supply for domestic requirements has been investigated. Units such as this one are currently in commercial production in many countries and are competing on various levels of success with systems utilizing other energy sources. The main drawback in these systems has been either the initial cost or their inadequacy for many situations. As the unit depends on the sun for its operation it is intuitively obvious that location has a great deal to do with a solar water heater's feasibility and ultimately its design. Also, the standard of living in a locality dictates the practicality of the design from an economic viewpoint. The solar water heater presented in this paper is designed for the daily domestic hot water requirements of a family of four residing in the Southwestern part of the United States. Due to similarity in the amount of solar energy received and to a similar standard of living, this design can also encompass the areas of Florida, Texas, and Southern California. From this, one can conclude that the design presented is practical world-wide at latitudes encompassed by the mentioned areas. The only criteria that need be met is an economic one.

There are several basic requirements that need to be met for a water heater to be a marketable item in the United States.

1. It must provide water at a temperature between 120° and 140°F.
2. It must provide water at anytime during the day or night.

3. It must be relatively maintenance free.

4. It must not be liable to damage due to freezing.

5. It must be easily installed.

6. It should be designed so that if a failure should occur it can be cheaply and easily repaired.

7. It must be economically competitive with water heaters utilizing another energy source.

The solar water heater presented in this paper meets these requirements. It consists of two basic units - the absorber and the storage tank. The two units are coupled and water flow between the two is provided by means of a thermosyphonic circulation system.

ABSORBER

Three of the problems associated with present solar water heaters are:

1. The high cost of the absorber
2. The heaviness of the absorber
3. The damage occurring in the absorber because of freezing.

A collector developed by Andrassy has helped overcome these problems.[2] It is comprised of sheet metal and durable plastic tubing. The sheet metal captures the sun's energy and transmits it to the water which flows through the plastic tubing. After much experimentation with various dimensions such as thickness of the metal sheet, the inside and outside diameter of the tubing, and the spacing of the tubing, the following collector was optimized. Sheet aluminum .019 inches thick is corrugated to form tubular openings forming a continuous coil. In order to increase the heat conductivity of the tubing and to improve heat conductivity through the tube wall, copper powder (2% by Weight) is mixed in with the plastic. The plastic used is flexible polyethylene. The outside diameter of the tubing is 7/16 inches and the wall thickness is 1/16 inches. Comparative tests were made with what is regarded as one of the most efficient collectors on the market. The other panel is made of 0.019 inch thick copper "Tube-in-Strip" with metal headers soldered to the bottom and top ends of parallel vertical tubes. Both panels were coated with dull black and resulting experimentation showed no difference in the performance of the panels, within the limit of experimental errors.

The collector used in this design is similar to the Andrassy panel with a few improvements. The polyethylene contains not only copper powder but also 3 - 5% carbon black which improves the weather resistance of the plastic material. Such polyethylene has withstood over 15 years exposure without undergoing a measurable degree of loss of physical properties.[35] The other improvement is the preparation of the aluminum surface by precipitating copper oxide from solution onto a sheet of anodized aluminum.[23] A dilute solution of copper nitrate is sprayed on a heated aluminum sheet that possesses a shiny substrate. Heating the aluminum to above 170°C converts the coating to black cupric oxide. This increases the efficiency of the solar collector. The collector painted with dull black paint has an emissitivity of 95% equal to its absortivity of 95%. The selective surface has an absortivity of 95% but has a low temperature emissitivity of only 10%. That is the selective surface has a high absorbance for solar radiation and a low emittance for long wave radiation. Thus, the same amount of energy is absorbed by the selective surface as by the painted surface but a lot less energy is given off. (Figure 3)

Selective black[12,23] has the added advantages of stability of color, the possibility of cleaning such surfaces, and its resistance to high temperatures. Paint has a tendency to crack, peel, and flake off after a few years. The color of paint becomes grey with time and gradually loses its absorpitive properties. Also, ordinary black metal sheets show signs of rusting due to condensed humidity in the collector.[12, 23, 43]

The collector plate must be placed in a well insulated box and covered by a transparent sheet.[31, 34, 37] For ease of installation the box is made of styrofoam which has the added advantage of being a good insulator. The walls of the box are made one inch thick and the bottom of the box is ½ inch thick. The box is padded with three inches of glass wool to provide further insulation. Interesting problems arise from the optimum choice of rear edge insulation. Many solar design engineers have suggested that the thickness of the edge insulation be equal to that of the rear insulation. This has been arrived at by optimizing the design utilizing only heat loss from the absorber. One may approach the problem from the point of view that the collector area must be reduced if the edge insulation is increased, or if the collector area remains the same, the absorber box must be enlarged to accomodate the extra insulation. In the former less BTU are absorbed while in the latter the cost per BTU absorbed is increased. Since the cost of the collector plate used in this design is relatively cheap, eliminating the edge insulation not only contributes to the simplicity of the design, but decreases the cost per BTU absorbed.[34]

The transparent plastic Tedlar was chosen to cover the insulated box containing the collector.[46] It has the same transmittance to light as the glass which is currently used to enclose absorbers but is considerable cheaper: 3.5¢ vs. 98¢ per square foot. The one drawback Tedlar possesses is it has a life expectancy of only five years when exposed to the weather. But due to the large amount of transparent covering needed, up to 60 square feet, and the enormous difference in price, it is proposed that the Tedlar be used and replaced every five years. This operation is rather easily performed. The Tedlar is enclosed on four sides by styrofoam, forming a window-like arrangement, and is placed on top of the styrofoam box. It is held there because of the overlapping edges of the styrofoam frame. Thus, the operation involves nothing more than lifting out the old window frame and replacing it with a new one. (Figure 4)

Styrofoam was chosen for the above uses because it is light in weight, less expensive than other materials used for enclosing collector plates, a good insulator, free from attack by nature as opposed to wood (i.e. rotting, insect attack, etc.), fireproof, durable, and easy to fabricate and handle. It should be noted that the styrofoam must be painted in order to prevent degradation due to the sun.

This absorber has the following advantages over present absorbers:

1. It is light.
2. It is more economical.
3. It is free from the dangers of freezing.
4. It is corrosion proof.
5. It is free from problems of leakage.
6. The collector is free of cracked, peeling, or graying paint.

STORAGE

The size of the storage tank has been chosen to provide 1½ to 2 days supply of hot water for the domestic use of a typical family of four.[14,34] It is estimated that 20 gallons of hot water per person per day is more than adequate.[14,34] Most hot water is needed during the day when the system is continually making more hot water. Furthermore, it must be realized that even on fairly cloudy days a considerable amount of solar energy is collected. Thus, a well insulated tank that is capable of storing 80 gallons of water should suffice. The tank is made of 16 gauge galvanized steel and is insulated with three inches of fiberglass. If the water is supplied to the tank at a temperature of 140°F, it is capable of delivering water between 120 and 130°F the next morning.[31,34,37] This is adequate for domestic use. Any additional insulation is not usually justified as it is more economical to increase the absorber area.[34] (Figure 5)

POSITION OF TANK AND ABSORBER

For natural circulation it is of utmost importance that the tank be located higher than the absorber. This natural circulation is accomplished thermally and is based on the fact that as the temperature of water increases its density decreases. Thus, the warm water will rise through the absorber into the tank above and the cold water will flow into the bottom of the absorber. (Figure 6) In order to prevent reverse flow at night the lower tank connection must be about six inches above the upper absorber header and the connections to the tank well insulated. If for architectural reasons this condition can not be met, an anti-return valve can be used to prevent reversal of flow. The valve is comprised of an inlet, an outlet, and a plastic conical device of the same density and coefficient of cubical expansion as water in the middle.[15] (Figure 7) The upper tank connection should be placed 2/3 the distance of the height of the tank to prevent colder water to be mixed with the warmer water.[8, 15, 17, 31, 33]

Figure 8 is a schematic of the installed tank and absorber - their relative positions and the direction of water flow.

AVAILABILITY OF SOLAR ENERGY

In designing any apparatus that converts solar energy into a useful form and harnesses it for effective utilization, it is essential that one acquire a fundamental understanding of the nature and extent of the availability of solar energy. It is an area in which meteorologists play a predominant role, but one in which the design engineer must evaluate his own needs and adapt given solar data accordingly. The electromagnetic radiation that is emitted by the sun and reaches the earth amounts to 1.5×10^{18} kw hr/year. Although quite an astounding figure, only a fraction of this energy actually reaches the ground. Nearly a third of this colossal bombardment is lost by reflection to space. The earth's meteorological thermodynamic engine and its associated cloud belts and cloudy regions is responsible for intercepting another sizable fraction. Approximately 70% of the remaining energy falls upon the earth's waters and is inaccessible for feasible utilization. That energy that does reach the ground varies with latitude, altitude, season, time of day, topography, meteorological elements, atmospheric dust, and contamination.

The radiation available on the ground is composed of direct and diffuse radiation. The latter greatly varies with locality. In the humid tropics it can account for over half the available energy supply, while in clear, dry climates it is of less importance. This remaining solar energy that is incident on land is described in terms of average daily insolation per unit of horizontal land area.

There is also data available concerning the amount of diffuse radiation in a particular locality. The primary objective behind such data collection and its subsequent analysis is to gather information concerning different types of radiation on the total and mean daily, monthly and annual value and on frequency of periods of successive days of low radiation. The duration of periods of low availability play a large role in the determination of the size of energy storage space required. Statistical knowledge of cloud interference at a location is therefore essential to proper designs for the use of solar energy. Though rough approximations of solar energy availability can be obtained by use of various formulae incorporating latitude, longitude, and number of sunshine hours, the use of actual data is of much more benefit in the design of a solar collection unit.[3,4,5,19,20,26,27,50]

The charts of Figure 9 were used in the design presented in this paper.

INCLINATION OF ABSORBER

Knowing how much solar energy can be intercepted in a given locality is perhaps the crux of the design of a solar water heater. It is evident that a surface that faces the sun receives considerably more sunshine per unit area than either a verticle or horizontal surface. There is an optimum angle of inclination that will vary throughout the year as the sun's declination changes. The mechanism needed to make the absorber follow the sun, if operated manually, is a nuisance as the absorber, which is located on the roof, is rather difficult to reach, or if the mechanism is to be operated electrically, it is too expensive. There can, however, be found an angle of elevation for which the energy collected annually will reach a maximum.

In the northern hemisphere, at moderate latitudes, the sun is in a southerly direction the majority of the day. Thus, it is advantageous for the absorber to face south. During the winter the sun shines fewer hours than in the summer, and the lower air temperature makes it more difficult for the absorber to deliver the required amount of hot water during this season. On the other hand, an absorber designed for the winter will deliver a large excess of heat in the summer.

It is the consensus of solar engineers that for a stationary absorber facing due south the best year round performance is obtained when the absorber is inclined to the horizontal ten to fifteen degrees more than the local latitude.[14,38] It should be pointed out that correcting an apparently unsuitable roof alignment with costly and unsightly mountings is usually unjustified. It is generally less expensive and definitely tidier to use a simple mounting on a not ideally oriented roof and correct by providing extra absorber area.

Such an inclination offers the added advantage of preventing excessive dust and dirt from clinging to the transparent plastic and reducing its transmission. The dirt that does accumulate on collector covers has little effect on the transmission qualities of the transparent plastic. Collector covers that to the eye appear to be extremely dirty after a few weeks of rainless weather in highly industrialized areas have been found to transmit only 4% less solar energy than when clean.[47] As for the presence of snow, the tilt of the absorber makes it highly improbable that snow will remain on the collector surface. Snow, however, increases the amount of energy absorbed by the collector because of its property of total reflection of radiant energy. The snow on the ground reflects radiation much of which is received by the collector.

COMPUTATION OF ABSORBER AREA

The main factors that contribute to the calculation of the absorber area are:

1. Heater Configuration
2. Water Flow Rate
3. Spectral Reflection-Transmission Properties of Absorber Covering
4. Spectral Reflection Properties of Absorber Plate
5. Heat Transfer Coefficient Between Absorber Plate and Water Stream
6. Insulation at Absorber Base
7. Insolation

A rigorous mathematical treatment of the problem involving these and other variables results in something too complex to have much engineering utility. The work done here is a design that utilizes known experimental data and incorporating a safety factor obtains an estimate of the optimum area for a required task.

The first step involves the determination of how much solar energy radiates on the locality in question. This information can be found in various literature sources concerning solar energy. The values given, however, pertain to the total solar radiation falling on a horizontal surface. Since the absorber is an inclined surface, one must calculate the radiation falling on an inclined surface. This is calculated for both December 21 (the shortest day of the year and usually one of the coldest in the northern hemisphere) and June 21 (the longest day and probably one of the warmest). If the absorber area required to heat the water to a desired temperature is much larger in December than in June, assuming electrical power is available, it is usually economically advantageous to use a smaller absorber area and during winter months help heat the water by means of an electric heater.

The following relationships were used to calculate the amount of energy striking the inclined absorber surface.[22, 38]

$$H_T = H_D R_D - H_S R_S$$

$$R_D = \cos\theta_T / \cos\theta_H$$

$$R_S = (1 + \cos\beta)/2$$

$$\cos\theta_T = \sin(\phi-\beta)\sin + \cos(\phi-\beta)\cos\delta\cos\omega$$

$$\cos\theta_H = \sin\phi\sin\delta + \cos\phi\cos\delta\cos\omega$$

$$ABS = H_T(\tau\alpha)$$

where:

H_T = Instantaneous rate of incidence of total radiation falling on the outer surface of the collector

H_D = Direct Component of radiation

H_S = Diffuse component of radiation

R_D = Orientation factor

R_S = Orientation factor

ABS = Gross daily rate of absorption.

τ = Transmitivity

α = Absortivity

ω = Hour angle from noon

δ = Declination of sun

To find the amount of energy needed to heat the water to a specific temperature the following relationship was used:

$$Q = mC_p dT$$

where:

Q = The amount of heat
m = The mass of the water to be heated
C_p = The heat capacity of the water
dT = The rise in temperature of the water

CALCULATIONS

DATA

Average radiation for the Southwestern United States, Southern California, Texas, and Florida

December: 300 Langleys (gm-cal/cm^2)

June: 750 Langleys

Albuquerque, New Mexico

Latitude: 35°03'

Longitude: 106°37'

December 21 Diffuse Radiation is 15% of Direct Radiation.

$\omega = 0^\circ$

$\delta = -23.5^\circ$

June 21 Diffuse Radiation is 15% of Direct Radiation.

$\omega = 0^\circ$

$\delta = +23.5^\circ$

$\phi = 35^\circ 03'$

$\beta = 35^\circ 03' + 15^\circ$

$\tau = 95\%$

$\alpha = 95\%$

Plugging given data into equations of preceding section one obtains for

December:

Gross daily rate of absorption: 2010 BTU/ft^2

June:

Gross daily rate of absorption: 2306 BTU/ft^2

Cold water is never supplied below 40°F.

Therefore ΔT of 100°F is used to obtain maximum temperature of 140°F.

80 gallons of cold water = 667 lbs.

$Q = mC_pdT = (667)(1)(100) = 66700$ BTU required to heat 80 gallons of water to 140°F.

Efficiency of the plastic tube and sheet metal collector is that of the "Tube-in-Strip" copper collector.[2] The efficiency of the latter has been reported to be as high as 90%. The efficiency of these copper collectors in actual use in Florida is more than 70%.[13,27] Designing in a 15% safety factor for reasons such as a poor inclination upon installation we obtain the following surface area for the collector:

$$66700/2010 \times .55 = 60 \text{ square feet of collector area}$$

Because of the ambiguity that is often associated with the term efficiency, it is of utmost importance that its connotation in this design be explained. 70% efficiency implies that 70% of the BTU that strike the collector surface are absorbed by the water. This is the year round efficiency of an installed system. This efficiency varies plus or minus 10% throughout the year. The lower efficiency, however, occurs during the summer months when the ΔT needed to raise the water to the desired temperature is lower.

The safety factor in this design is actually greater than 15%. The efficiency ratings used were obtained from both laboratory data and estimates of year round performance of solar water heaters installed in domestic and industrial situations. Because of the multitude of ever-changing variables, such as time of day, time of year, water temperature, air temperature, availability of sunshine, wind velocity and more, mathematics can not replace the hard-core data obtained over a period of years from actual installations. The efficiency 70% was chosen because it was the lowest year round efficiency rating reported for an installed system comparable to the one in this design. The selective surface incorporated in the design presented will increase the efficiency between 10% and 15%. Also, one must realize that the amount of energy that is required to raise the water temperature to 140°F is generally less than that calculated. The initial water temperature will usually be greater than 40°F. Thus, the ΔT needed to raise the water to 140°F is lower. As is the case with any design that deals with the quirks of nature, it is of engineering utility to overdesign. The slight increase in initial investment is greatly offset by the guarantee of a continuous hot water supply.

DETAILS OF CONSTRUCTION

ABSORBER

Built in three sections

Styrofoam box: 5'1" x 4'1" x 5½"

Wall thickness 1"

Bottom thickness ½"

Corrugated aluminum: 5' x 4'

Corrugations spaced 3" on center

Polyethylene tubing: 100' per sheet of corrugated aluminum

Outside diameter 7/16" wall thickness 1/16"

Contains 2% by weight copper

6 tube connections 5/16" inside diameter (galvanized steel)

The three sections of the absorber are placed in parallel to improve efficiency.

Transparent covering: .50 mil Tedlar 5'2" x 4'2"

STORAGE

Built of 16 gauge galvanized steel

Dimensions: 33" height - 13.6" radius

Insulation: 3" thick fiberglass

Four connection points (See Figure 5 for locations)

Contains float valve to regulate cold water flow into tank

STORAGE AND ABSORBER CONNECTIONS

Rigid polyethylene tubing

Outside diameter 3/4" wall thickness 1/16"

Two - 4 way connections

Three sides - 5/16" inside diameter

One side - 5/8 inside diameter (galvanized steel)

Insulation: 3" thick fiberglass

MATERIALS AND COSTS

The prices presented here are estimated for a production of 2000 units. The cost per unit will increase as the number of units produced decreases. The following costs are calculated per unit (60 square feet of absorber and an 80 gallon storage tank).

Aluminum 1100 (Alcoa)

42¢/lb.

.019" thick density = .274 lb/sq. ft.

30 square feet of flat sheet is required to produce 20 square feet of corrugated sheet.

Cost of 90 square feet of flat sheet is $10.35.

Polyethylene 5/16" inside diameter tubing

Extruded with 2% by weight copper powder and 4% by weight carbon black.

Cost of extruded tubing is $2.00 per hundred feet.

100 feet of tubing is required to thread 20 square feet of corrugated sheet.

Cost of 300 feet of tubing is $6.00.

Labor costs of collector

Corrugation of aluminum: 5¢/square foot

Applying selective surface: 3¢/square foot

Threading polyethylene tubing

Requires 6 minutes labor to thread 20 square feet of corrugated sheet. At $3.00 per hour the cost of threading 60 square feet is 90¢.

The labor cost of 60 square feet of collector plate is $5.70

Total Cost of Collector Plate: $22.05

Styrofoam (Amspec)

Type: S.M. 1" thick @ 15¢/square foot

Three boxes of 5'1"x 4'1"x 5'½"

Total material needed: 57 square feet

Cost of styrofoam box is $8.55.

Box can be assembled on site using Styrofoam Mastic No. 11 adhesive @ $4.50 per gallon.

Fiberglass (Owens-Corning)

3" thick @ $.057/square foot

92 feet needed for absorber base, storage tank, and connections.

Total cost of insulation is $5.25.

Tedlar (Dupont)

.50 mils thick

3.5¢ per square foot

Cost of 60 square feet is $2.10

Labor cost for styrofoam encased Tedlar

Estimated time of labor is 5 minutes.

At $3.00 per hour the cost of producing three styrofoam encased Tedlar frames is 75¢.

Total cost of styrofoam encased Tedlar is $2.85.

Galvanized Steel (Bethlehem Steel)

Approximately 80 lbs. of material is needed to make an 80 gallon 16 gauge galvanized steel storage tank.

10.8¢ per pound

Cost of material for tank is $8.64.

Tank connections

Cost of two 5/8" inside diameter connections is 50¢.

Cost of two 3/4" inside diameter connections is 50¢.

Cost of float valve is $1.50.

Labor cost

At $5.00 per hour the labor cost of the tank with fittings and float valve is $15.00.

Total cost of the storage tank is $26.14.

Connection Costs

Cost of 20 feet of connecting tubing @ $10.00/hundred feet is $2.00.

Cost of two four way connections is $3.00.

Cost of six 5/16" inside diameter tube connections is $1.50.

TOTAL COST OF UNIT: $71.34

SUGGESTIONS

1. A more efficient and less cumbersome method of storing heat.

   Although water is now considered one of the best media for storing heat, there ought to be investigations for other media that store heat. One promising but heretofore technologically poor method is the utilization of heats of crystallization. By melting and recrystallizing certain materials, heat can be readily stored. One problem lies in controlling the heat once the material is recrystallized.

2. Better materials

   There should be much research devoted to improvements in:

   a. Selective surfaces for better heat absorption

   b. Insulation to reduce heat losses

   c. Inexpensive plastics that have either good heat transfer for the absorber or good transmittivity for the covering.

3. Introduce a selective paint that is as of more efficient than the present method of either electroplating or oxidizing.

4. Implementation of solar water heating in the original design of the building

   The cost of building a solar water heater can be greatly reduced if the builder incorporates it into his design. Part of the roof of the house can be substituted for by a solar collector and adequate room for the storage tank can be provided for in the attic of the structure. Designs at the outset of construction can make the cost of a solar water heater negligible when compared to other methods of water heating.

5. Better bonding between tube and sheet

   In the collector presented in this paper, the amount of heat transmitted to the water would greatly improve if the bonding between the plastic tubing and aluminum sheet were tighter.

6. Plastic tube and strip

   There is now available on the market copper "Tube-in-Strip" which is originally flat and blows up into a plate and tube construction under air pressure. This type of collector has one of the best efficiencies for transmitting solar energy to the water. New plastics with good heat transfer, the most promising ones to date contain fluorine, should be used to make tube and strip.

7. The configuration of receiving surfaces should be investigated to find the optimum shape of a solar collector.

8. Investigate ways to control heat transfer

   One promising development along this line involves the use of paraffin as the heating medium. Copper tubes are submerged in paraffin. When exposed to solar radiation the paraffin melts and remains at a constant temperature of 131°F. This heat is then transferred to the water circulating through the tubes. Such a scheme can be an economical method for utilizing solar energy at a controlled temperature. The inherent problem is one of limited physical size.

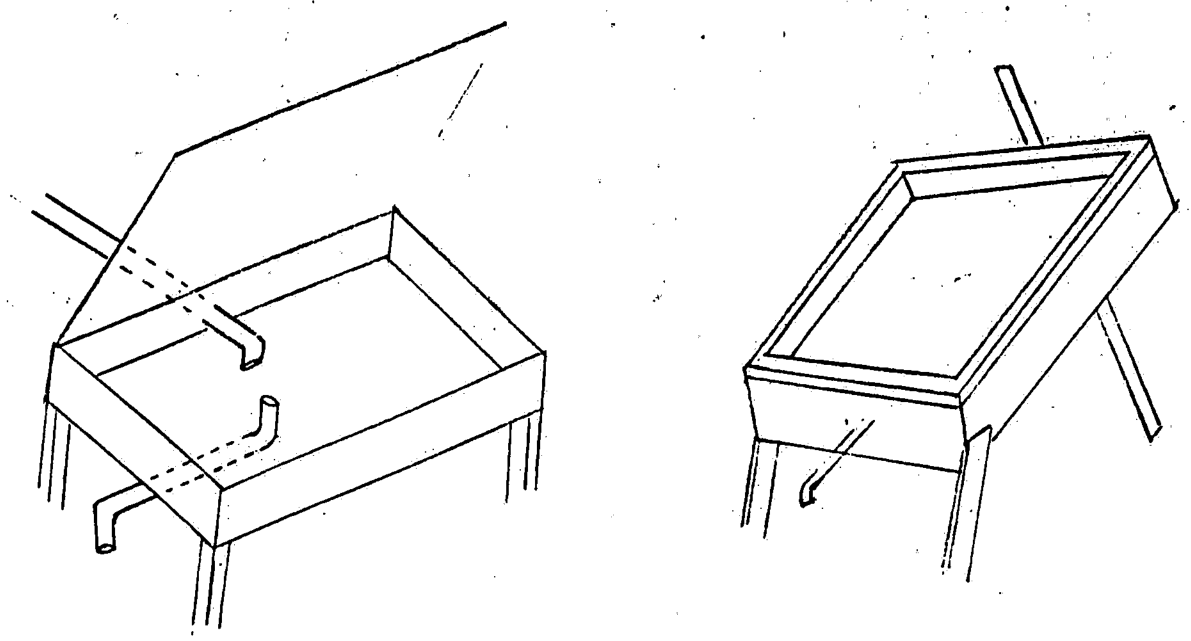
CONCLUSION

The tremendous impact of the energy crises upon society has greatly, and justifiably so, intensified the search for new energy sources. Presented in this paper is both a practical and economically feasible method for utilizing the ever present solar radiation that saturates us daily. Solar water heaters have been around for some time. The one presented here, however, alleviates many of the formidable problems encountered by its prototypes. It can provide the daily hot water requirements for the average family living in Florida, Texas, Southwestern United States, and Southern California. It has a longevity of over 20 years and can be manufactured for under $75.

The sun bombards us with 2.4×10^{15} kcal per minute. The conversion of a small percentage of this energy for use in man's continuous struggle for an improved standard of living would greatly alleviate the drain on man's fossil fuels. Utilization of the sun's vast but elusive power also eliminates the problems of pollution, which if allowed to continue at their present alarming rate could poison the earth and turn it into a barren and hostile place, unfit for the survival of man. The small contribution of solar water heating in man's quest for energy can greatly improve his standard of living without forcing the enviroment to pay a toll.

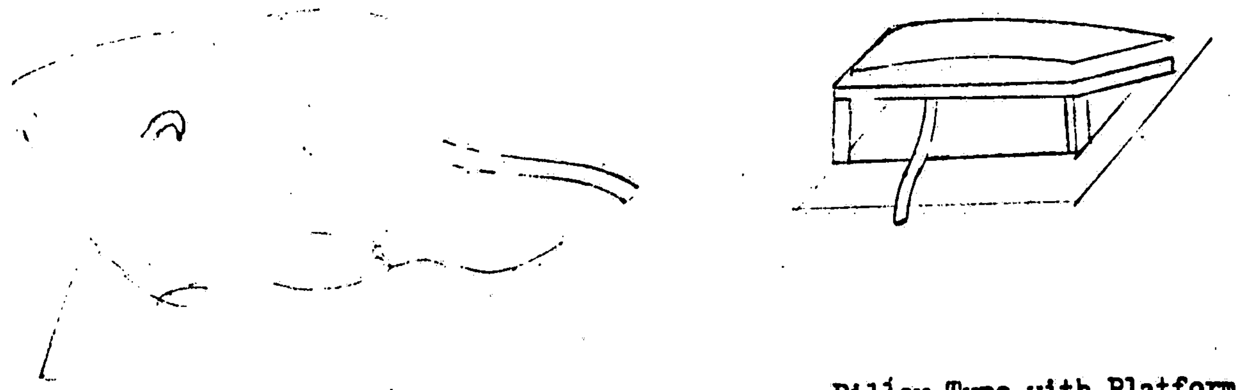
Of primary concern now should be the education of the public. The public must be made aware that the everyday use of solar energy is not a product of the runaway imagination of a science fiction writer. It is a reality. It does work. The prudent blending of all forms of energy can turn many of man's dreams of a better tomorrow into today's reality. The very existence of future man lies in the proper marriage of solar energy with other available forms of energy.

ILLUSTRATIONS



Closed tray type with cover

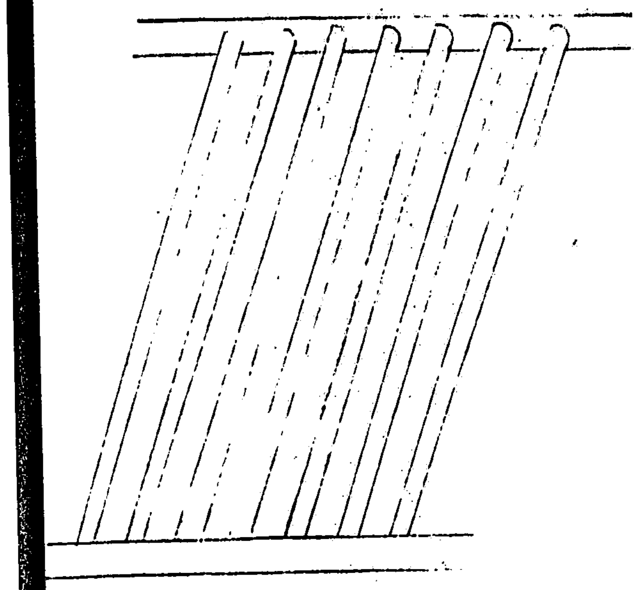
Closed Type (Inclined)



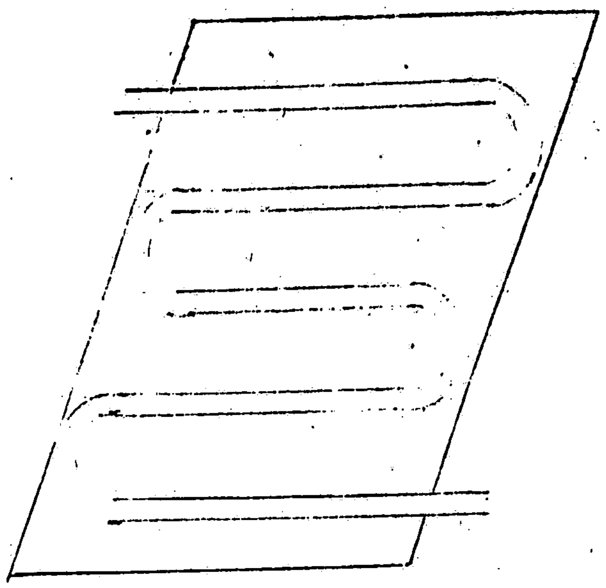
Pillow Type

Pillow Type with Platform

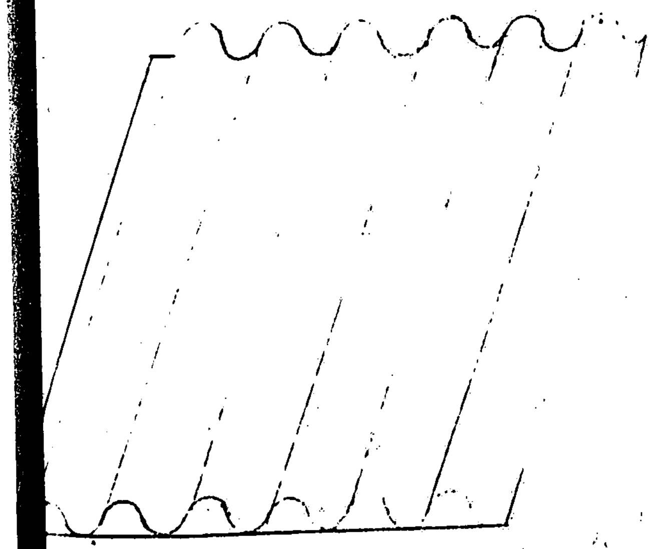
Figure 1 WATER HEATERS



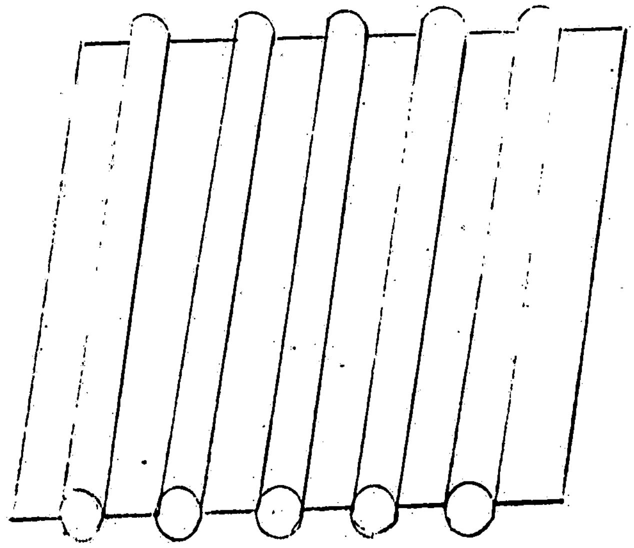
Parallel Pipes



Pipe soldered to metal receiver

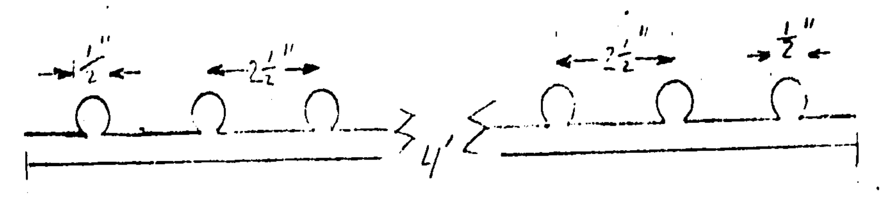


rrugated Sheet soldered to plate



Tube-in-Strip

gure 2 COLLECTORS



End View

Top View

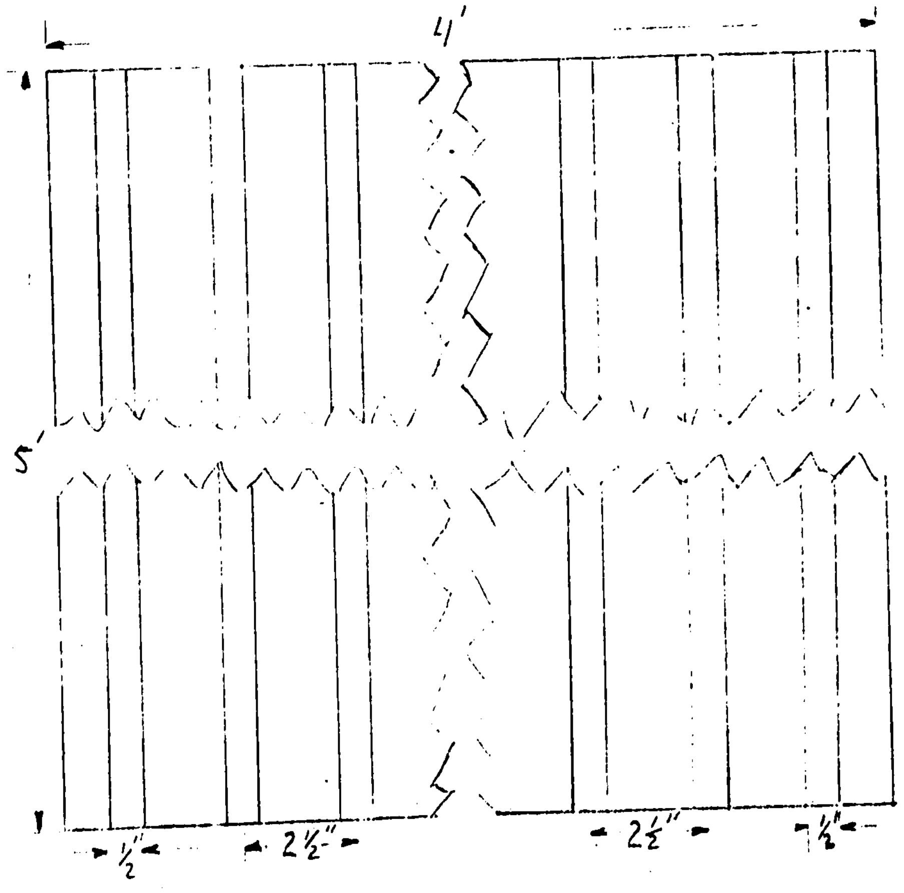


Figure 3 COLLECTOR PLATE

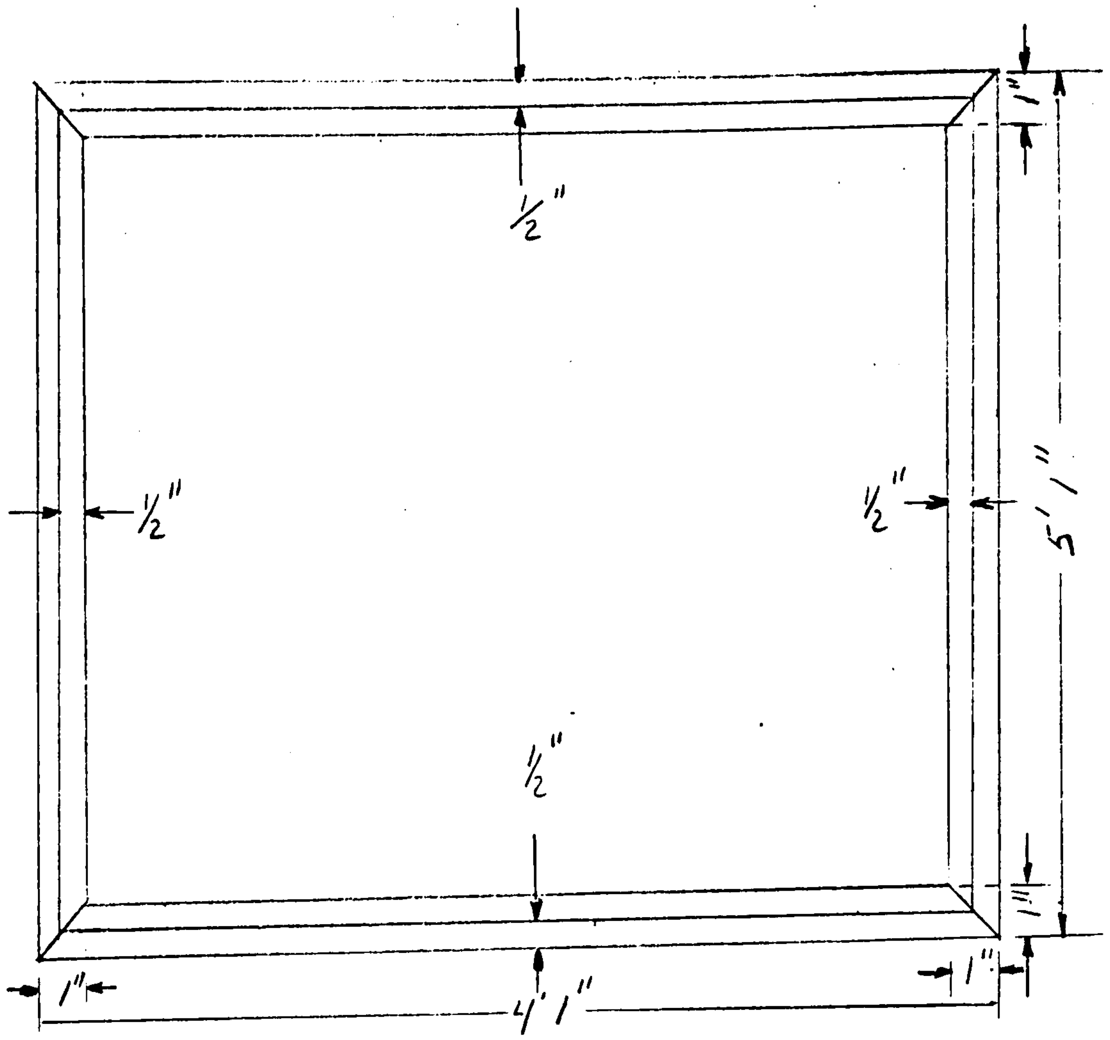


Figure 4a TOP VIEW ABSORBER BOX

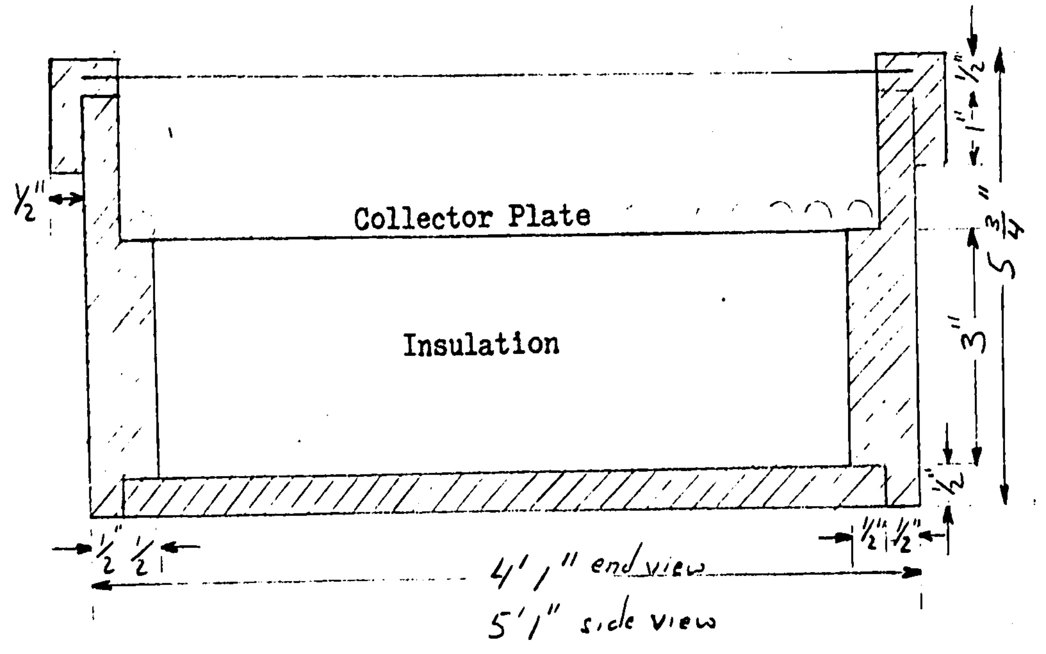
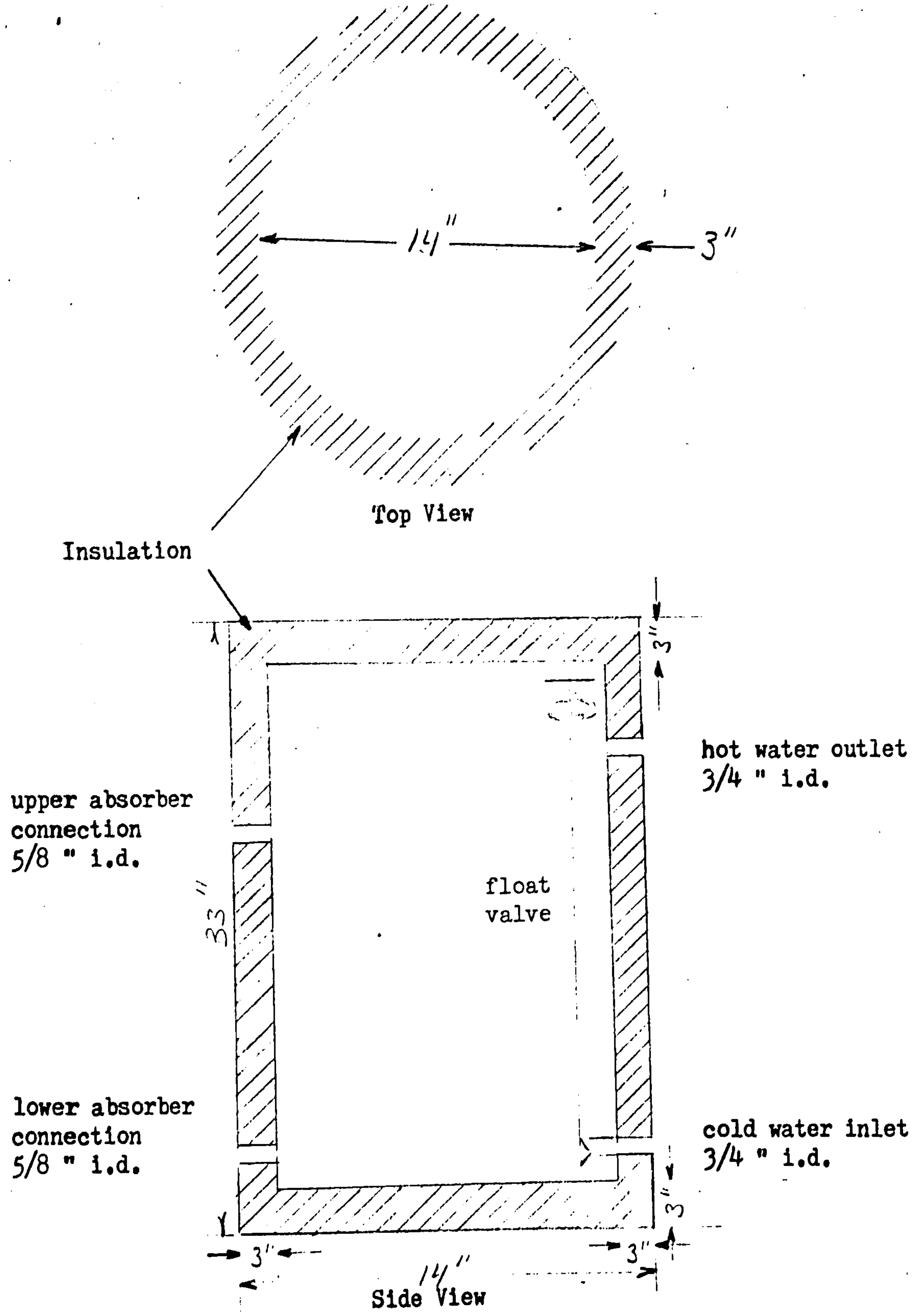


Figure 4b CUT-AWAY VIEW OBSORBER WITH ABSORBER COVERING


Top View

Side View

Figure 5 STORAGE

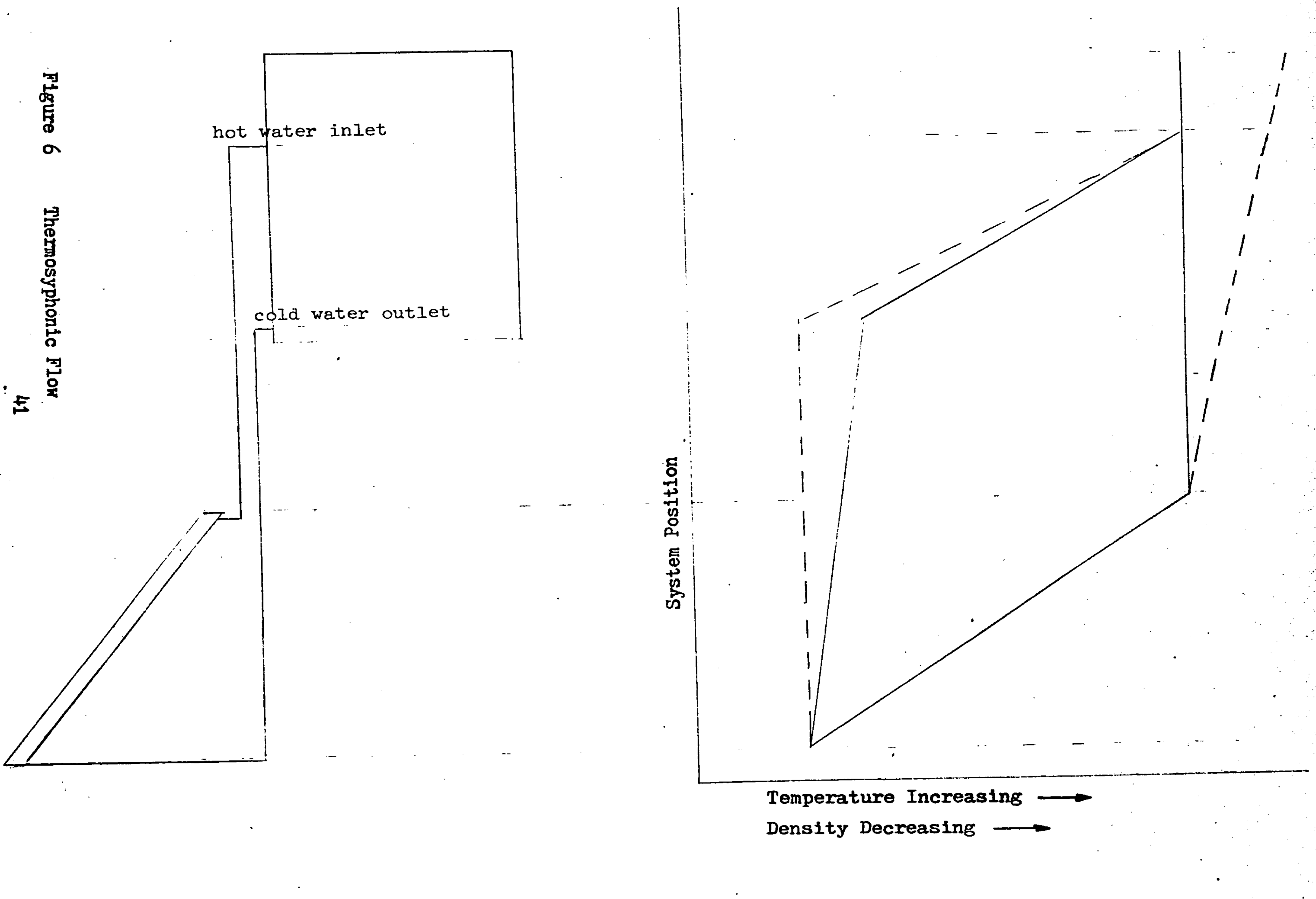


Figure 6 Thermosyphonic Flow

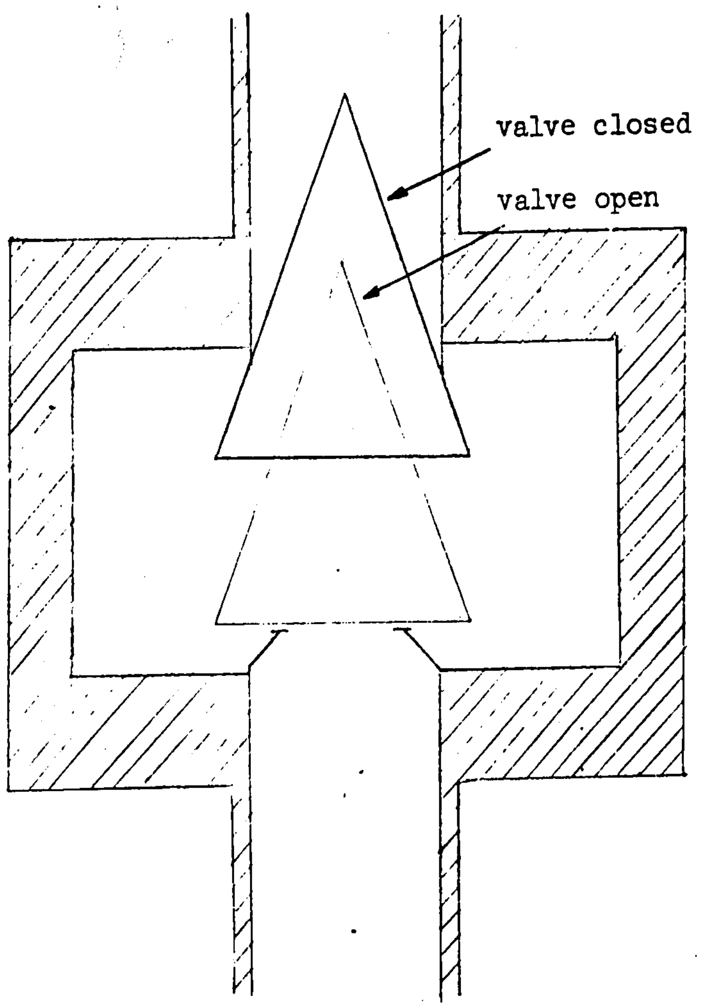


Figure 7 ANTI-FLOW RETURN VALVE

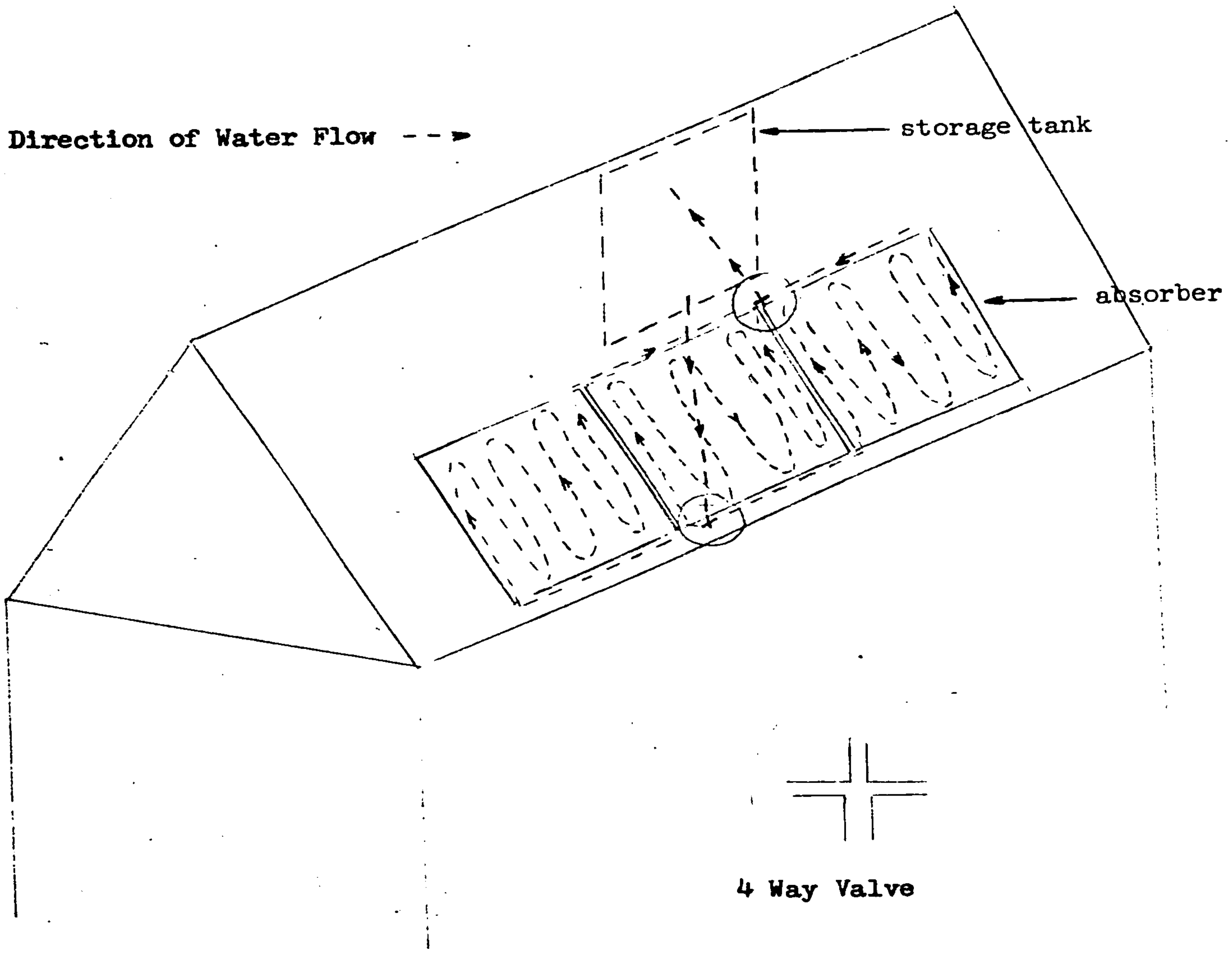


Figure 8 Schematic of Installed System

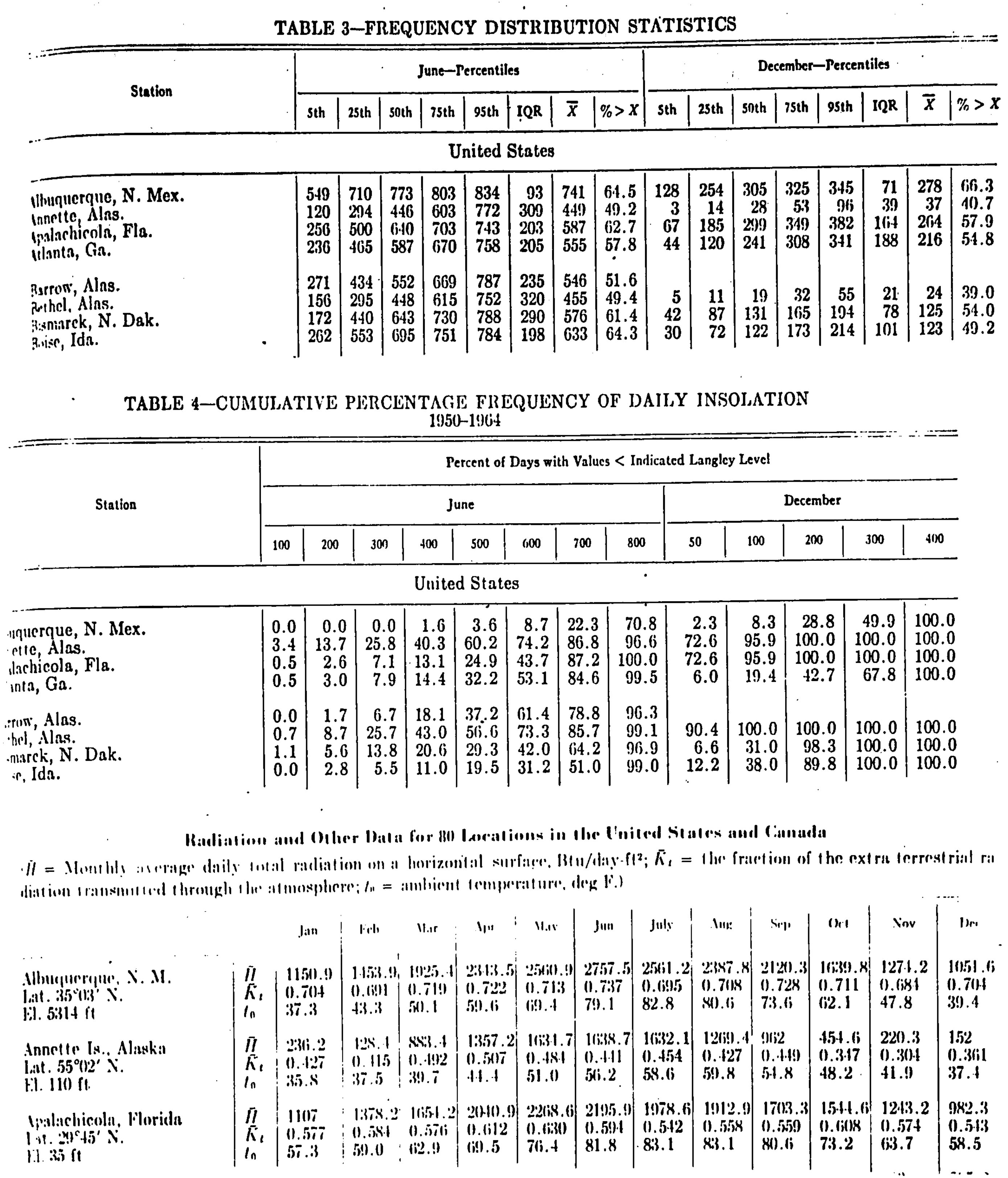


TABLE 3—FREQUENCY DISTRIBUTION STATISTICS

Station	June—Percentiles								December—Percentiles							
	5th	25th	50th	75th	95th	IQR	$\bar{X}$	% > X	5th	25th	50th	75th	95th	IQR	$\bar{X}$	% > X
United States																
Albuquerque, N. Mex.	549	710	773	803	834	93	741	64.5	128	254	305	325	345	71	278	66.3
Annette, Alas.	120	294	446	603	772	309	449	49.2	3	14	28	53	96	39	37	40.7
Apalachicola, Fla.	256	500	640	703	743	203	587	62.7	67	185	299	349	382	164	264	57.9
Atlanta, Ga.	236	465	587	670	758	205	555	57.8	44	120	241	308	341	188	216	54.8
Barrow, Alas.	271	434	552	669	787	235	546	51.6								
Bethel, Alas.	156	295	448	615	752	320	455	49.4	5	11	19	32	55	21	24	39.0
Bismarck, N. Dak.	172	440	643	730	788	290	576	61.4	42	87	131	165	194	78	125	54.0
Boise, Ida.	262	553	695	751	784	198	633	64.3	30	72	122	173	214	101	123	49.2

TABLE 4—CUMULATIVE PERCENTAGE FREQUENCY OF DAILY INSOLATION
1950–1964

Station	Percent of Days with Values < Indicated Langley Level												
	June								December				
	100	200	300	400	500	600	700	800	50	100	200	300	400
United States													
uquerque, N. Mex.	0.0	0.0	0.0	1.6	3.6	8.7	22.3	70.8	2.3	8.3	28.8	49.9	100.0
ette, Alas.	3.4	13.7	25.8	40.3	60.2	74.2	86.8	96.6	72.6	95.9	100.0	100.0	100.0
lachicola, Fla.	0.5	2.6	7.1	13.1	24.9	43.7	87.2	100.0	72.6	95.9	100.0	100.0	100.0
nta, Ga.	0.5	3.0	7.9	14.4	32.2	53.1	84.6	99.5	6.0	19.4	42.7	67.8	100.0
row, Alas.	0.0	1.7	6.7	18.1	37.2	61.4	78.8	96.3					
hel, Alas.	0.7	8.7	25.7	43.0	56.6	73.3	85.7	99.1	90.4	100.0	100.0	100.0	100.0
marck, N. Dak.	1.1	5.6	13.8	20.6	29.3	42.0	64.2	96.9	6.6	31.0	98.3	100.0	100.0
e, Ida.	0.0	2.8	5.5	11.0	19.5	31.2	51.0	99.0	12.2	38.0	89.8	100.0	100.0

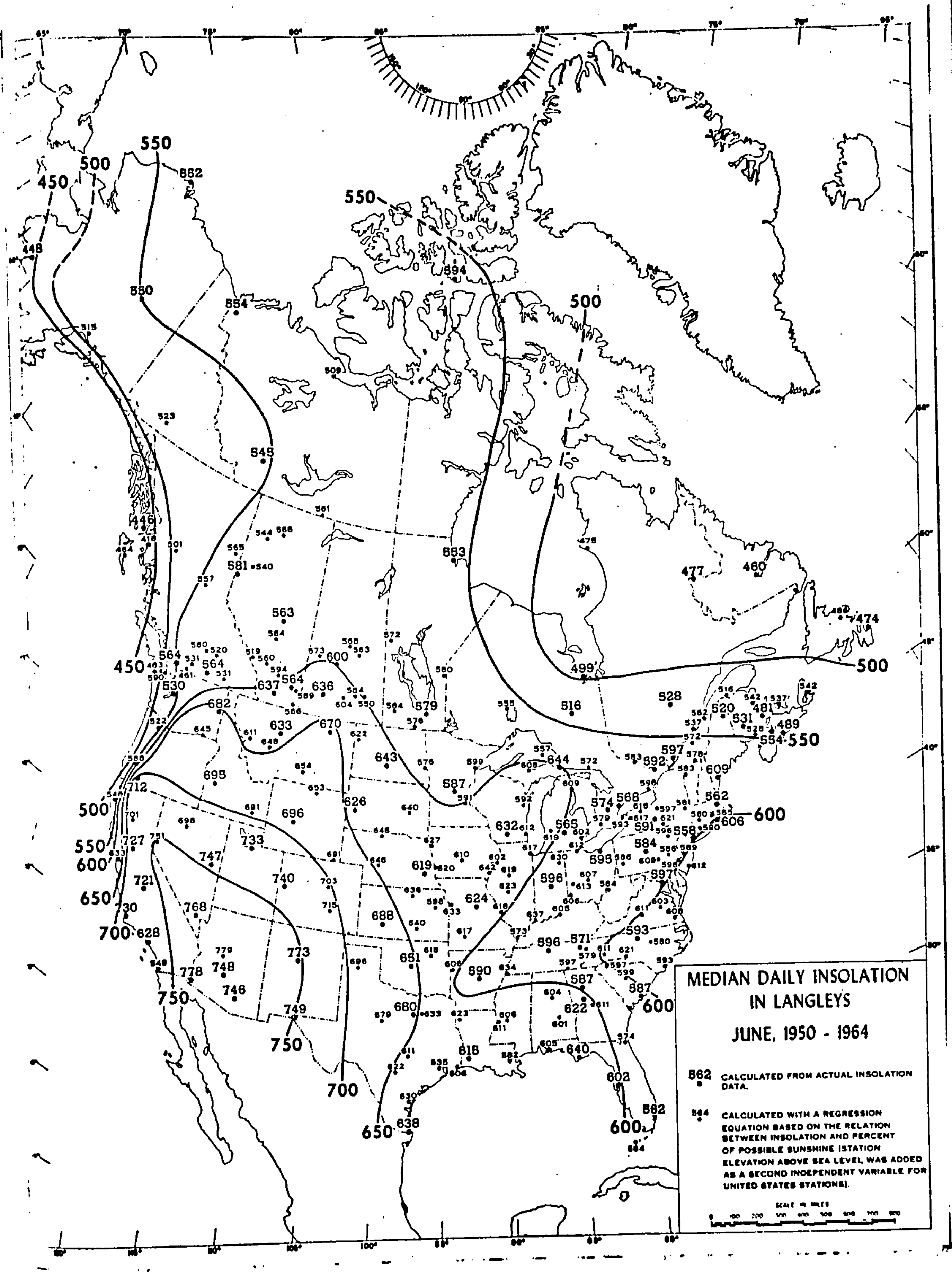
Radiation and Other Data for 80 Locations in the United States and Canada

($\bar{H}$ = Monthly average daily total radiation on a horizontal surface, Btu/day-ft²; $\bar{K}_t$ = the fraction of the extra terrestrial radiation transmitted through the atmosphere; t_a = ambient temperature, deg F.)

		Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
Albuquerque, N. M.	$\bar{H}$	1150.9	1453.9	1925.4	2343.5	2560.9	2757.5	2561.2	2387.8	2120.3	1639.8	1274.2	1051.6
Lat. 35°03′ N.	$\bar{K}_t$	0.704	0.691	0.719	0.722	0.713	0.737	0.695	0.708	0.728	0.711	0.684	0.704
El. 5314 ft	t_a	37.3	43.3	50.1	59.6	69.4	79.1	82.8	80.6	73.6	62.1	47.8	39.4
Annette Is., Alaska	$\bar{H}$	236.2	428.4	883.4	1357.2	1634.7	1638.7	1632.1	1269.4	962	454.6	220.3	152
Lat. 55°02′ N.	$\bar{K}_t$	0.427	0.415	0.492	0.507	0.484	0.441	0.454	0.427	0.449	0.347	0.304	0.361
El. 110 ft	t_a	35.8	37.5	39.7	44.4	51.0	56.2	58.6	59.8	54.8	48.2	41.9	37.4
Apalachicola, Florida	$\bar{H}$	1107	1378.2	1654.2	2040.9	2268.6	2195.9	1978.6	1912.9	1703.3	1544.6	1243.2	982.3
Lat. 29°45′ N.	$\bar{K}_t$	0.577	0.584	0.576	0.612	0.630	0.594	0.542	0.558	0.559	0.608	0.574	0.543
El. 35 ft	t_a	57.3	59.0	62.9	69.5	76.4	81.8	83.1	83.1	80.6	73.2	63.7	58.5

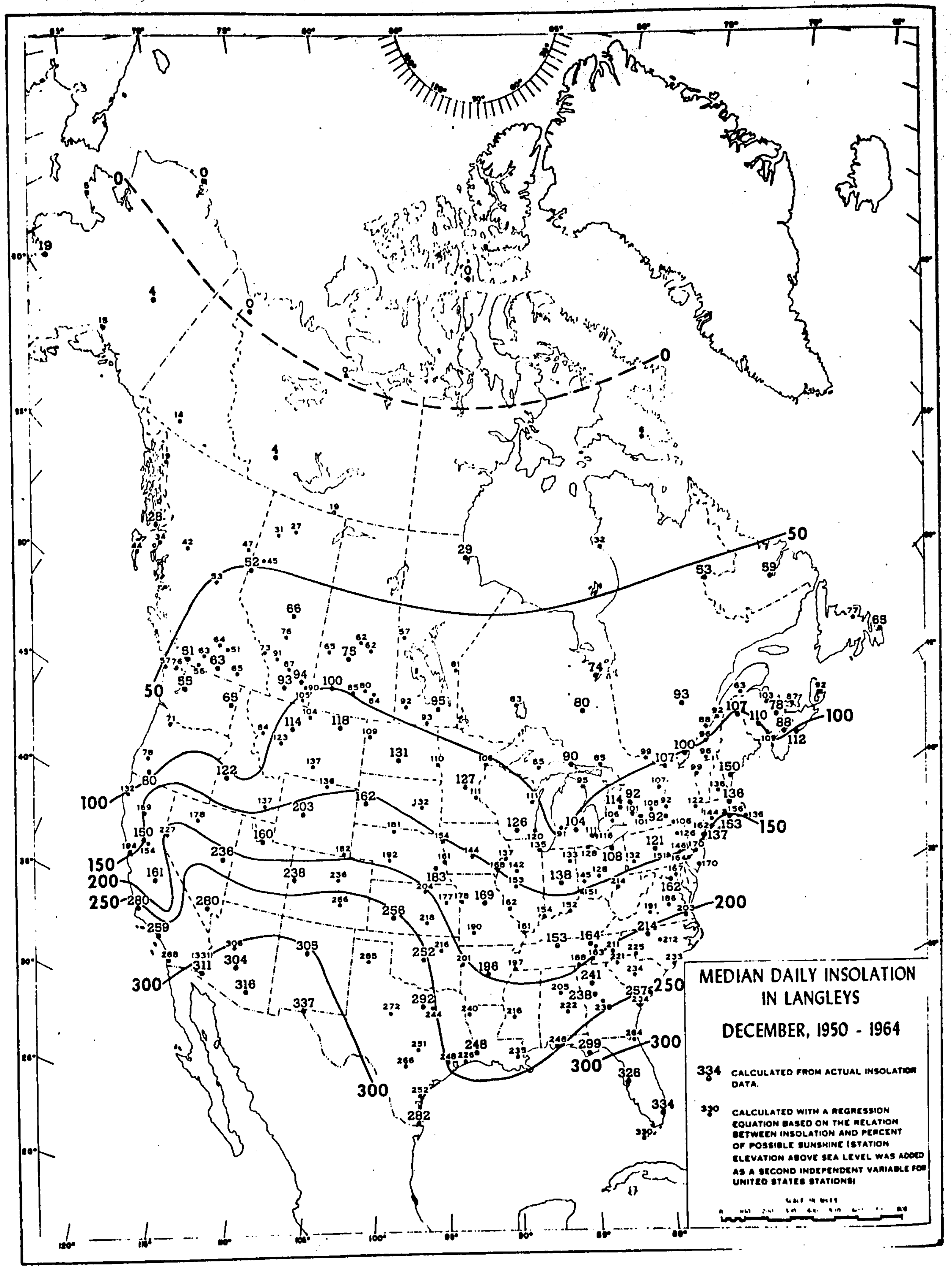
9a

Fig. 9 Solar Energy Data[4-27]


MEDIAN DAILY INSOLATION IN LANGLEYS

JUNE, 1950 - 1964

9b



MEDIAN DAILY INSOLATION
IN LANGLEYS

DECEMBER, 1950 - 1964

334 CALCULATED FROM ACTUAL INSOLATION DATA.

330 CALCULATED WITH A REGRESSION EQUATION BASED ON THE RELATION BETWEEN INSOLATION AND PERCENT OF POSSIBLE SUNSHINE (STATION ELEVATION ABOVE SEA LEVEL WAS ADDED AS A SECOND INDEPENDENT VARIABLE FOR UNITED STATES STATIONS)

9c

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North Penn Manufacturing Co. Philadelphia, Pennsylvania	Metal Fabrication
Owens-Corning Fiberglass Corp.	Fiberglass

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