technical report

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how to design and build a solar swimming pool heater

COPPER DEVELOPMENT ASSOCIATION INC.

PREFACE

In these days of rising interest in solar energy, it should be noted that the preparation of this manual involved no new development as such. A large amount of solid, practical research and development has been done in solar energy already, and this work is to be found in technical and scientific papers published 10 years, 30 years, even 100 years ago. Preparing this manual was simply a matter of tracking down the material, tying it all together and then making calculations based on present-day costs and requirements. Only a few of the most important of the references to the technical literature on solar energy are included in the manual. The authors of those references – and indeed of many others consulted during the preparation – made this manual possible.

HOW TO DESIGN AND BUILD A SOLAR SWIMMING POOL HEATER

Francis de Winter
Altas Corporation
Santa Clara, California

1975

Copper Development Association Inc.
405 Lexington Avenue, New York, N.Y. 10017

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INTRODUCTION

In most of the U.S., unheated swimming pools are only comfortable for a few months of the year. Only rarely is the water warm enough for extended swimming in the evening or early morning.

The temperature requirements for swimming depend on a number of things. For short periods, or after a sauna bath, almost any temperature is acceptable. Pools used for competitive swimming are usually kept around 72 F. Most recreational swimmers feel more comfortable at around 80 F. For early morning or for evening swimming, when the air is cool, 85 F or higher is desirable. Small children require temperatures of 85 F or more to be able to swim any length of time without shivering. They tend to cool off rapidly because of their large surface-area-to-weight ratio.

A permanent swimming pool costs a *minimum* of about $3,000, requires year-round maintenance, and takes up a significant amount of yard space which could be put to other uses. If the pool is only useful for a few months of the year without heating it makes sense to invest in pool heating so as to increase the usefulness of the investment in the pool, maintenance and land area.

Pool heating, like pool ownership, costs money. A pool has high natural heat losses caused by thermal radiation, convection and evaporation. If you want the pool temperature to be higher than nature wants it to be, you have to pour in heat on a virtually continuous basis to make up for the natural heat losses. This takes heavy-duty (and expensive) heating equipment plus large amounts of heat energy. With natural gas heaters, despite the fact that natural gas is inexpensive, heating bills of $70 per month for pool heating are not at all uncommon. Many people spend more.

There is only a limited amount of natural gas, and there already is beginning to be a squeeze due to the ever-increasing demand at today's prices. In some areas new gas hook-ups for pool heating are no longer permitted. Gas which is imported, or produced from coal or other fossil fuels, is much more expensive, and in the near future we can expect natural gas prices to rise significantly. Over the next 10 years they will probably double.

Heating a swimming pool is an ideal use for solar energy. The heat is needed at low temperatures, so that simple collector designs can be used. A pool is equipped with a filter and circulation pump, so that a solar heat collector can be supplied with a large flow rate of filtered water. Pool water is normally treated so that it is of dependable chemistry. Temporarily bad weather is not too bothersome; the effectiveness of solar heating is reduced, but swimming desires normally fluctuate in phase with the weather. Most other applications of solar energy are not only more difficult, but also more demanding.

Solar energy is not new. Agriculture, mining of fossil fuels, the use of windmills, among others, all involve the collection of what was once solar energy. Nuclear energy and geothermal energy are probably the only energy sources commonly used which can not be traced back to the sun.

Solar energy has been used to heat water for many years, and the design requirements of solar water heating equipment have been studied for more than 30 years. The lack of widespread application has not been due to lack of understanding. It is simply that up to this time other sources of energy have been so economical. This has limited interest in solar water heating to those with the understanding and enthusiasm necessary to build their own equipment.

Copper is the ideal material for solar water heaters. It has no corrosion problems, except in some very few cases in which the water has aggressive impurities. It has a very high thermal conductivity. It is easy to cut, bend, and solder. It lends itself to simple heater designs, which can be easily designed and easily assembled. It is virtually unaffected by the atmosphere or by sunlight. It does not rust or get brittle with age.

Virtually all solar energy researchers have agreed on the superior qualities of copper. If occasionally other materials have been considered, it has generally been in an attempt to reduce the first cost to the manufacturer of an industrially-produced heater.

Building a solar heater yourself leads to great cost advantages. The only expenses are for the raw materials. In most parts of the United States it is possible to build a solar heater which can heat a swimming pool more cheaply than can be done with gas. And copper fabrication processes are simple enough so that it is possible to turn out a professional looking job with a minimum of experience or of special tooling.

This manual is designed to allow you to heat a swimming pool as cheaply as possible using a home-built solar energy collector. It is as complete as possible. The performance of solar heat collectors of the type covered can be described quite accurately with interesting mathematical expressions, which are included. The economics of solar energy collection are also described in detail. You can choose from several heater designs. In all of these areas the manual is fairly thorough, since the construction and use of the solar heater can be more enjoyable when things are understood in depth. The manual has five main sections.

Section 1 "How To Use This Manual" is for those who may not want to become too involved in the physics or the economics of solar energy collection, but who simply want some guidance on what to build and how to do it. Others, having studied the physics and the economics in depth, may find it useful to read Section 1 as a means of reviewing the material, and as a help in organizing the steps in the design and construction of the heater.

Section 2 describes the physics of solar heat collection in detail. This will allow you to predict the performance of a collector anywhere in the continental U.S. at any time of the year, and to determine what effect the collector will have on the pool temperature. (There is a separate Appendix of sample calculations, using the equations and calculation procedures discussed in Section 2. This should be of help in setting up calculations of your own, and can be obtained from Copper Development Association.)

Section 3 is a detailed discussion of the economics of solar heat collection compared to gas heating, including interest rates, equipment lifetimes, and annual costs of equipment. Detailed calculations are shown for operation of a solar heater in Pasadena, California for (1) year-round use in conjunction with a gas heater, only for the purpose of saving gas, and (2) use of the solar heater by itself, during an extended swimming season to save not only on gas but also on the gas heater investment. In Pasadena a solar heater is competitive with gas either way. In other areas gas costs may be different, and you may wish to use different interest rates and equipment lifetimes in your own calculations. After studying calculations in Section 3 you should be able to set up calculations to apply to your own situation. And note especially that gas costs are rising continuously compared to the figures used in this report.

Section 4 is concerned with the construction of the solar heater, once you have decided on the size and other design details based on the calculations of Sections 2 and 3. Two different types of heaters are possible. One involves building a copper roof which is then also used as a solar heat collector. The other type is only a collector and must be mounted on top of an existing roof or other structure. Section 4 includes a description of the construction of batten seam copper roofing, and of heaters with or without the roofing function. Piping diagrams and instructions are also included.

Section 5 is a short discussion of maintenance and operation requirements. It is followed by a short list of references.

A prototype solar pool heater was built in Pasadena, California, using the dual roofing/heater concept, and following the approach outlined in this manual. A photograph of the heater, which uses flat seam (rather than the more convenient batten seam) roofing, is shown in Figure 1. The test heater has an area of 382 sq ft and is used to heat a 720 sq ft. pool. It has operated according to expectations. During the Summers of 1973 and 1974 it raised the pool temperature about 7 degrees, compared to a nearby unheated pool. In previous years, before the pool was heated, the highest temperature ever recorded in the pool was 83 F during the peak hot spell of a hot summer. In 1973 and 1974 with the solar heater in place, the temperature reached 80 F in April, 83 F in May, and averaged 86 F in June, July and August with occasional peaks up to 90 F. Swimming was comfortable in most of September, and occasionally in October in both years.

1. HOW TO USE THIS MANUAL

Solar collectors have some interesting idiosyncracies of which you should be aware. There are also tricks here and there in the construction of the heater, some of which are quite important to heater operation. You should read through the manual at least once, so as to have at least an overview of the things which may be of interest to you. If you are not really interested in the equations or calculations, you can just ignore them and read the rest of the material.

If you decide to build a heater you will have to read Chapter 4 quite thoroughly in order to get familiar with the construction technique material in an effective way.

1.1 Should You Build a Heater

To determine whether you should build a heater you

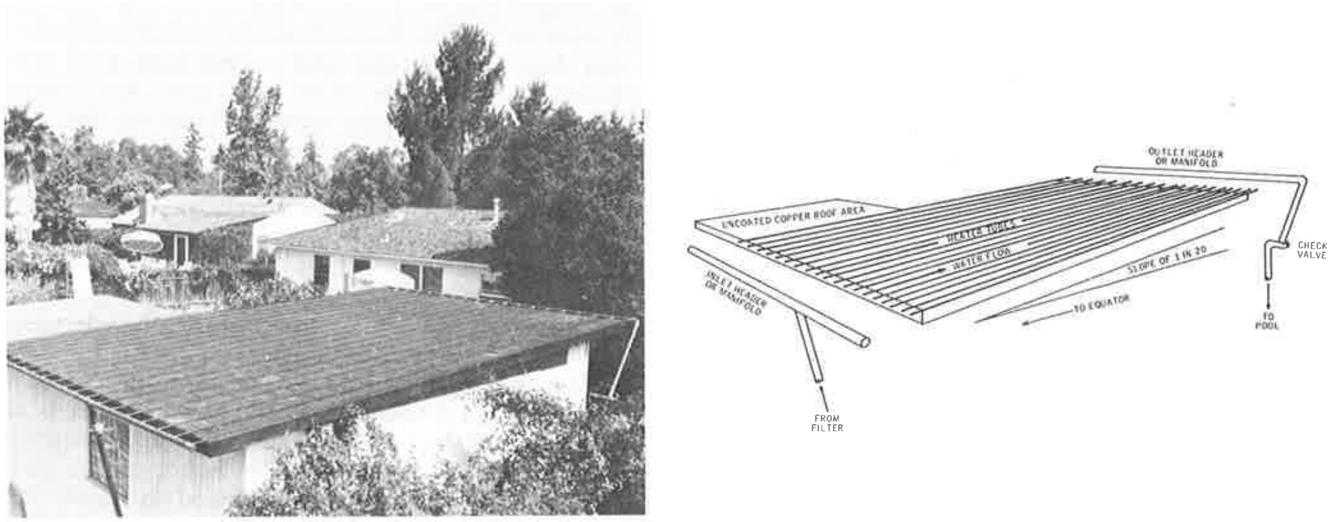

FIGURE 1. PROTOTYPE SOLAR SWIMMING POOL HEATER DESIGNED AND BUILT BY THE AUTHOR

must first decide if you want to heat the pool, by how much and for how many months in the year. This you can get either from past experience or from discussions with other pool owners in the vicinity. If you foresee large gas heating bills, and if during the months in which you want heating the weather is generally sunny, a solar heater can probably be a good investment. To find out if it is, use Figure 31 in Section 3.1.4. At the end of Section 3.1.4 there is a stepwise method for using the figure. You can find out, for any time of year, how many degrees of pool temperature rise you will get for your investment.

In order to get a good temperature rise you will have to invest perhaps \$1.00 or \$2.00 per square foot of pool surface. This corresponds to a solar heater with a surface area equal to roughly half the surface area of the pool (for the \$1.00 number) or equal to the surface area of the pool (for the \$2.00 number). The prototype (Figure 1) with an area equal to 53% of the area of the pool, raises the pool temperature roughly 7 degrees during most of the swimming season. (This measured performance is about 20% better than that predicted from Figure 29 in this manual. This is because wind velocities are low in Pasadena, so that heating is extra effective.)

A solar heater costing \$1.00 or \$2.00 per square foot of pool surface area represents a significant investment. On the other hand, if you heat with gas you will need an expensive gas heater (probably \$500 to \$1,000 installed). For every degree F that you want to raise the pool temperature, the cost will be a minimum of about 1/2¢ per square foot of pool surface area per month. The heater in Figure 1, raising a pool of 720 sq ft about 7 degrees, collects the equivalent of about 720 x 7 x 1/2¢ = \$25.20 worth of gas per month. In some areas the gas costs may be as much as twice as high, leading to a figure of 1¢ per square foot of pool area per degree F temperature rise. And gas costs are rising.

Playing around a bit with figures like these for your own pool heating case, you can decide whether the investment makes sense. If you wish to go into the calculations in more detail, you can follow the calculations shown in Section 3, substituting your own numbers for the ones that are shown.

In addition to the decision regarding the advisability of the investment there is another one to be made. Building a solar heater of the type described in this manual constitutes a significant home project. To some people, building something themselves is an enjoyable experience that leads to a sense of accomplishment and pride of ownership which are highly rewarding in themselves. For those people, this alone might make the project worthwhile.

1.2 Design to Use

Once you have decided to build a heater, you must then decide:

(1) How large it should be
(2) What type of heater you should build

To get significant heating, the heater should have a minimum area of roughly half the area of the pool. You can determine the actual size yourself by using Figure 31 (as discussed above) and Figure 29. Figure 29 is a companion to Figure 31, but is plotted on an area basis rather than a dollar basis, using a heater cost of \$2.30 per square foot of solar heater surface. You can use Figures 31 and 29 to balance off your heating desires and your budget possibilities.

Your heater size may be fixed by the area of the roof on which you will mount it. This makes the size decision easy. You can determine what performance to expect by using Figure 29.

If you build a very large heater properly it will work with no problems, but you may end up with more heating than you really want. If you build the heater much larger than the pool area, you should be sure that you want all the heat you will be collecting with it. Figure 29 can help you find out.

The heater you build can either be just a heater or it can also double as a copper roof. A copper roof will last essentially forever. If you have a requirement for a new roof, this approach might make sense. Then you will want to read Section 4 carefully.

To design the heater you want to build, you can follow two approaches. Either you can go through Section 2, 3, and 4, follow the calculations in detail, and run through some numbers of your own to determine the design parameters such as tube sizes, lengths, number of tubes, tube spacing, and so forth, or you can follow the simple guidelines shown at the beginning of Section 4. If you follow the simple guidelines, you still should read all the Sections at least once.

2. THE PHYSICS OF THE SOLAR HEATER

The function of the solar heater is to collect the solar energy incident on a large area, and to transfer this to the pool water at a minimum cost. One could simply cover the area with blackened tubes so that all the sunlight would fall on the tubes. But this would be too expensive. One could use lenses or mirrors to concentrate the energy on tubes spaced some distance apart. This approach was actually used by John Ericsson, the famous ship-builder of the U.S. Civil War, in the 1860's. More recently it was studied extensively by Abbot in the 1930's and 1940's.* This method is also too expensive, except when one wants to collect the energy at high temperatures. The concentrators have to follow the sun, and this is costly. Mirrors or lenses are expensive to buy and to maintain. On cloudy days concentrators simply will not work. Only the energy coming directly from the sun can be used since most of the diffuse light can not be concentrated properly. On clear days the diffuse light can amount to 10 to 20% of the total solar energy.

The most economic way to collect the solar energy seems to be with the so-called flat-plate collector. This was developed more than 30 years ago, and has been built, tested, refined and analysed by many people. It generally consists of tubes fastened at regular intervals (preferably with solder) to a flat sheet of highly conductive metal as shown in Figures 1 and 2. The whole assembly is given a coating which will absorb sunlight. It can also be covered with one or more layers of glass or transparent plastic and it can be insulated in the back to prevent heat losses. Both

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*U.S. Patents 2,133,649; 2,141,330; 2,205,378; 2,247,830; and 2,460,482.

are necessary when one wants to get high temperature water.

The operation of such a panel is quite simple in concept. Solar energy heats up the sheet (or fins) and the tubes. Some of this solar energy is lost back to the atmosphere, but hopefully most of it ends up in the water. The part falling on the tubes is conducted directly through the tube wall and transferred to the water. The part falling on the fins heats the fins locally so that they become warmer than the tube, with the result that heat flows towards the tube. If the fins are too long and thin, they will heat up excessively and too much of the solar energy will be lost back to the air rather than going into the water. If the fin is long and *thick*, two problems can arise:

(1) Costs are excessive because too much metal is being used.

(2) Too much heat is collected per tube, so that the tube becomes much warmer than the water flowing inside of it, and again, one has too much heat loss to the atmosphere.

If not enough water is passed through the panel, then the water (and the panel) will become too warm, also increasing losses. The same result is obtained when the water flowing into the panel is very warm.

In addition to these heat losses the performance of the panel is also affected by panel inclination, latitude, weather, time of year and by the effectiveness of the radiation coating. All of these can be calculated. The weather is however pretty random, and at best only statistically predictable. In many locations solar input information is lacking, and may be either higher or lower than the values which are thought to be applicable.

The above discussion covers most of the variables of flat-plate solar water heaters performance in a qualitative way. Things could be left at that, and it would be possible simply to give specifications for reasonable heater designs. The heater can however be analyzed and designed quite accurately with equations developed over the past 30 years by a series of competent researchers (Reference 1, 2, 3, 4).

The heat collected by a flat plate collector is usually described by an equation of the form:

$$Q_{coll} = F_3 Q_{ideal} A_c \qquad (1)$$

In this equation, F_3 is a collector efficiency which depends on the collector construction and design, on the water flowrate through the collector, and on the windspeed. F_3 includes most of the heat transfer loss effects discussed in a qualitative way earlier. Q_{ideal} is an ideal collection heat flux which depends mostly on location, time of the year, time of the day, weather, panel inclination, ambient temperature, temperature of collection and windspeed. Other than panel inclination, the only collector design features which enter into the calculation of Q_{ideal} are the radiation properties of the solar energy absorbing coating, and whether the collector is covered with glazing or not. A_c is simply the area of the collector. The units for this equation are:

Q_{coll} - Btu per hr
F_3 - has no units, (a "dimensionless" efficiency)
Q_{ideal} - Btu per sq ft per hr
A_c - sq ft

In Equation (1) the square feet of Q_{ideal} and of A_c cancel out, yielding the correct units for Q_{coll} In all equations used to describe physical processes, units must check out in this way.

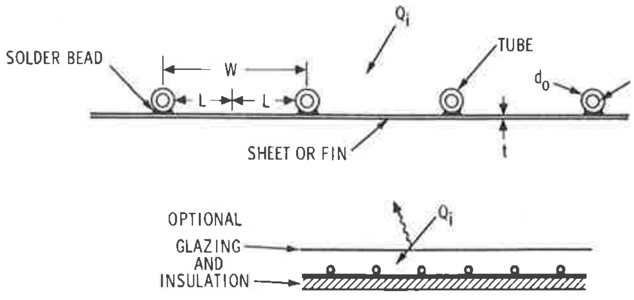

FIGURE 2. CROSS SECTION OF HEATER

Equation (1) does not really say much. It merely describes one unknown quantity in terms of two other unknown ones. Unless one knows the value of Q_{ideal} and F_3, one is no closer to understanding collector operation.

The following subsections discuss the important equations which have been derived over the past 30 years or so to describe the collector efficiency F_3 and Q_{ideal} Understanding the physics (i.e. the origin) of these equations would require a background of calculus and differential equations, some familiarity with heat transfer, fluid flow and thermodynamics, and a careful study of References 1 through 4. This background is not included in this manual. The references themselves are written in a somewhat terse form, aimed primarily at people who are familiar with the field.

The ideal collection rate for a panel is presented first in the section that follows. Then in three successive subsections, equations are presented for three factors, F_1, F_2, and F_3 which describe definite heat transfer effects which were discussed earlier in a qualitative way. The last of these factors, F_3, is the one required by Equation (1).

After the description of Q_{ideal} and of F_3 other factors affecting collector operation are discussed. Included are such effects as panel inclination, geographical location, time-of-day, time of year, shade, etc.

Those who are bored by numbers can move on to the recommended designs (Section 4) forthwith. These designs have been picked, insofar as possible, to yield optimum designs from a cost point of view. This means using a minimum amount of copper per unit of heat collected. In designs that combine the heater with a roof, copper thicknesses are dictated by roofing practices, and are significantly greater than required for heating purposes only. The cost of the extra thickness (which does produce some heating benefits) can be written off to the roofing function.

The recommended designs are used as examples in calculations in the Appendix (available separately). To get an intuitive feel for the physics of solar collection, you can run through the calculations with varying values of the parameters.

2.1 The Ideal Collection Rate Q_{ideal}

If the collector were operating at a steady state*, and

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*"Steady state" means that nothing is changing. This would require the sun to be stationary, the weather to be unchanging, and the water flowrate and temperature to be constant. Steady-state results are used since they are quite good and comparatively simple.

the complete surface of the collector were at the temperature at which the water comes from the pool, the heat collected would be described by the equation:

$$Q_{ideal} = \alpha Q_i - \epsilon R - U_L(t_{wi} - t_a) \tag{2}$$

where for a bare collector

$$U_L = h_{ca} + h_r$$
$$= h_{ca} + 1.00 \text{ Btu/sq ft/hr/deg F} \tag{3}$$

and for a collector with one glass or plastic cover

$$U_L = 1.00 \text{ btu/sq ft/hr/deg F} \tag{4}$$

In these equations

Q_{ideal} - is the ideal rate of heat collection, with units of Btu/sq ft/hr

α - is the solar absorptivity of the radiation coating used on the panel. This has a maximum possible value of 1.00. For a good coating it might equal 0.9. It has no units.

Q_i - is the incident (direct plus diffuse) solar energy falling on the panel. This varies with location, time of the day and year, weather, and panel inclination. It is lower for a glazed panel than for a bare one. The units are Btu/sq ft/hr.

ϵ - is the emissivity for infrared radiation of the radiation coating of the panel. This also has a maximum value of 1.00. It would be nice to have this as low as possible, but for most black paints it is equal to about 0.9. It has no units.

R - is an infrared radiation heat loss to the sky, produced by virtue of the fact that the sky is at a lower temperature than the ambient temperature. According to Bliss (Reference 9) R is approximately equal to 25 Btu/sq ft/hr for a bare panel. For a glazed panel R can be assumed to be zero.

U_L - is the collector heat transfer coefficient for losses by convection and radiation, different for bare collectors and for glazed collectors, as given by Equations (3) and (4). The units are Btu/sq ft/hr/deg F.

t_{wi} - is the temperature at which the water enters the panel (equal to the pool water temperature) in degrees Fahrenheit.

t_a - is the ambient air temperature in deg F.

h_{ca} - is the heat transfer coefficient for losses by convection to the air. Its magnitude is shown as a function of windspeed in Figure 3. A value often used is 1.5 Btu/sq ft/hr/deg F, corresponding to a 6 mph wind.

h_r - is the heat transfer coefficient for losses by radiation to the surroundings. For a surface with a high value of ϵ operating close to room temperature, its value is approximately equal to 1.00 Btu/sq ft/hr/deg F.

The term αQ_i represents the solar input. The term ϵR and the term U_L $(t_{wi} - t_a)$ represent heat losses from the collector. The value of Q_{ideal} is mostly a function of geographical location, time of the day and year, weather, inclination of the panel, panel radiation properties, and the water temperature of the swimming pool. Some of these effects are discussed in later sections.

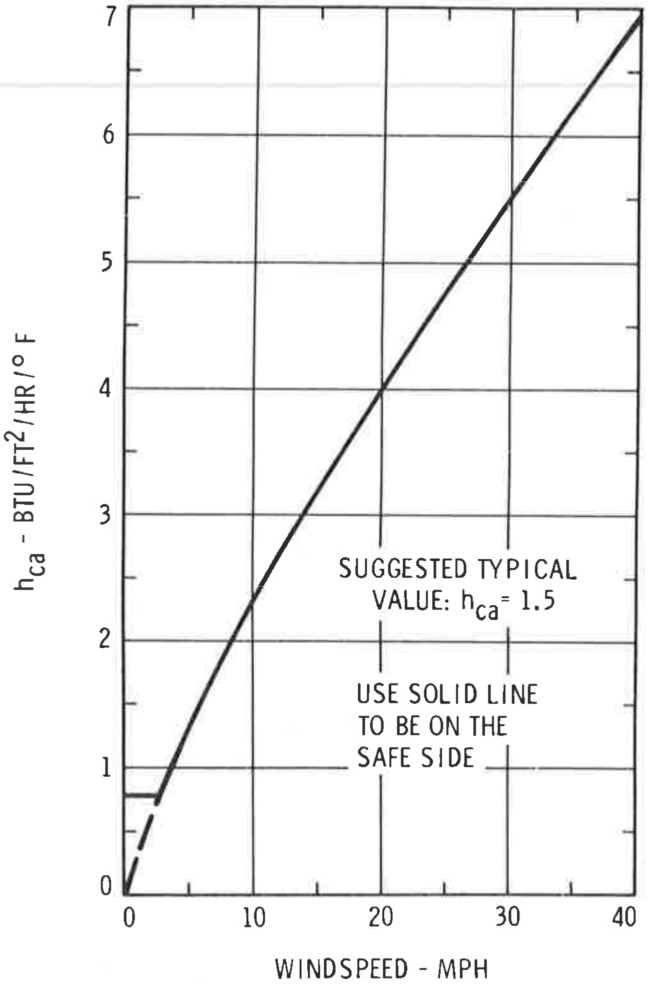

FIGURE 3. HOW CONVECTION HEAT TRANSFER COEFFICIENT h_{ca} VARIES AS A FUNCTION OF WINDSPEED

Collection of the full value of Q_{ideal} would of course be too much to expect. There are a number of effects which make the value of F_3 (see Equation (1)) less than 1.00. These effects, most of which are tied in with panel design and construction details, are described in the sections and equations which follow. There are three successive factors, F_1, F_2, and F_3 describing identifiable heat transfer effects which limit performance. As mentioned earlier, the equations for these factors were first derived by the authors of References 1 through 4.

2.2 The Fin Efficiency or Tube Spacing Factor F_1

The simplest effect which reduces the collection efficiency of the panel involves the so-called fin efficiency. The fin, i.e., the copper sheet to which the tube is soldered, is supposed to absorb the sunlight and conduct it to the tubes. In doing so the fin away from the tube gets hot, and because of the increase in temperature loses heat to the surroundings. A very long and very thin fin would have a very low efficiency since most of the heat would be lost to the surroundings rather than to the tube. An analysis of this type of fin behavior leads to a simple equation for the fin efficiency F_1:

$$F_1 = \frac{\tanh(mL)}{mL} \qquad (5)$$

where

$$m = \sqrt{\frac{U_L}{kt}} \qquad (6)$$

In these equations

F_1 - is the fin efficiency, a dimensionless number the significance of which is explained below.

U_L - is the heat transfer coefficient for losses from the panel, as before, in Btu/sq ft/hr/deg F.

k - is the thermal conductivity of the fin, equal to 220 Btu/ft/hr/deg F for copper.

t - is the fin thickness in ft (see Figure 2)

L - is the fin length – i.e. half of the total spacing between the tubes in ft (see Figure 2)

tanh - is the hyperbolic tangent, a function found in many mathematical tables. Since tables may not be accessible to some readers, a plot of F_1 versus mL is shown in Figure 4.

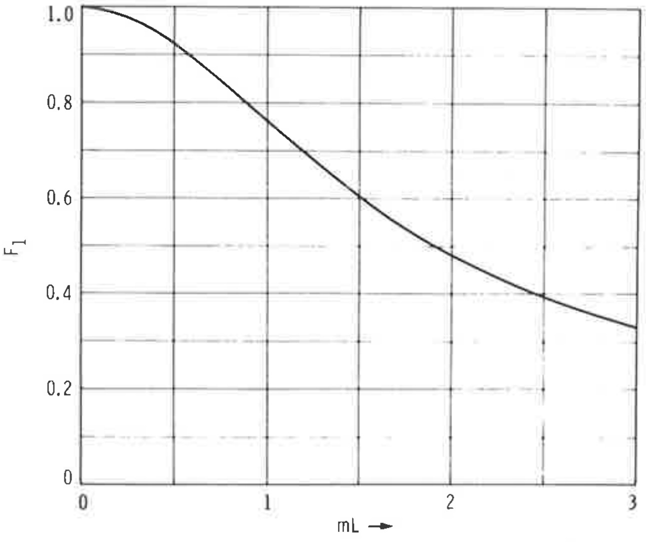

FIGURE 4. HOW FIN EFFICIENCY F_1 VARIES AS A FUNCTION OF THE FIN LENGTH PARAMETER mL

The significance of F_1 is as follows. A fin of area A_f which is cooled at one end (for example by a tube carrying water which is soldered to it) in such a way that the fin end is at t_{wi} (see Equation 2) will not collect heat at the rate $Q_{ideal} \times A_f$, but at the rate $F_1 \times Q_{ideal} \times A_f$. If the complete fin were to be kept at the temperature t_{wi}, the collection would of course be given by $Q_{ideal} \times A_f$.

2.3 The Section Efficiency F_2

The water flowing through the tube cools the tube (and the fin tied to it). The tube must however be slightly warmer than the water for this to happen. Similarly, for the heat to flow, there must be a temperature increase through the solder bond. This makes both the tube and the fin operate at a higher temperature than the water temperature, so that some more heat will be lost to the surroundings than is included in Q_{ideal}. The temperature increase found in the fin (as discussed earlier) is already included in part in the equation for the fin efficiency F_1. The second efficiency factor includes F_1 and a number of the other parameters. For a panel using copper tubes on top of a copper fin, with a soldered joint, the efficiency F_2 is given by:

$$F_2 = \cfrac{1}{\cfrac{WU_L}{\pi d_i h_{cw}} + \cfrac{1}{\cfrac{d_o}{W} + \cfrac{1}{\cfrac{WU_L}{C_s} + \cfrac{1}{(1 - \frac{d_o}{W})F_1}}}} \qquad (7)$$

In Equation (7), the new parameters introduced are:

F_2 - the section efficiency, a dimensionless number the significance of which is explained below.

W - the width of the collector area corresponding to one tube (equal to the spacing between tube centers) in ft. (see Figure 2).

π - equal to 3.1415....

d_i - the internal diameter of the tubes in ft.

h_{cw} - the heat transfer coefficient of the water flowing inside of the tubes (see Figure 5 for the magnitude) in Btu/ft²/ hr/deg F.

d_o - the external diameter of the tubes in ft.

C_s - the conductance of the solder bond per lineal foot --- roughly equal to 100 Btu/ft/hr/deg F for the recommended solder bond.

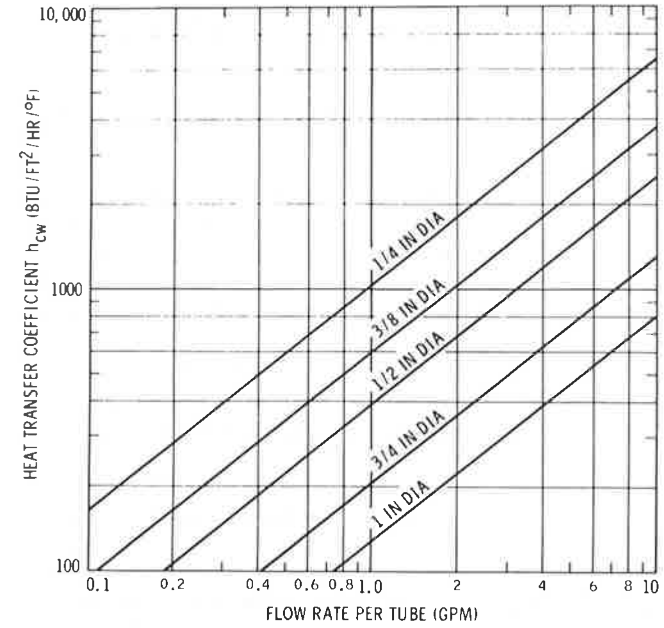

FIGURE 5. COEFFICIENT h_{cw} AS A FUNCTION OF WATER FLOWRATE AND TUBE DIAMETER

The significance of F_2 is as follows. A section of the collector (such as shown in Figure 2) of area A_s which is cooled with water at temperature t_{wi} (see Equation 2) will not collect heat at the rate $Q_{ideal} \times A_s$, but at the rate $F_2 \times Q_{ideal} \times A_s$. If the complete cross section of the collector were at t_{wi}, the collection would of course be given by $Q_{ideal} \times A_s$.

Equation (7) has so many terms in it that it does not lend itself to neat representation in tables or figures. You can best run through the calculations personally, whether for obtaining an understanding of the interaction of the parameters of the panel design, or for performing design calculations. A sample calculation is shown in the Appendix, available separately.

2.4 The Flow Efficiency, or Overall Efficiency F_3

We finally come to the last efficiency term, associated with the effect of flowrate. If a very low water flowrate is passed through the panel, then the water temperature will rise very rapidly, and in a very short distance from the water entrance the panel will be so hot that no further heat can be collected. The more water that is pumped through the panel, the more uniform the panel temperature will become. At very high flowrates the water will be at essentially the same temperature throughout the panel, in which case the efficiency of the panel should be equal to F_2. At very low flowrates the panel should have an efficiency of zero.

An equation for a final efficiency F_3 can then be derived to describe these effects as shown in Equation (8):

$$F_3 = F_2 \frac{GC_p}{F_2 U_L} \left(1 - e^{-\frac{F_2 U_L}{GC_p}}\right) \qquad (8)$$

In Equation (8) the new parameters introduced are:

F_3 - the collector efficiency, a dimensionless number.

C_p - the specific heat of water, equal to 1.0 Btu/lb/deg F.

G - the water flowrate per-unit-panel-area, in lbs/sq ft/hr.

e - the base of the natural logarithm, a number which (like $\pi = 3.14159$) often comes up in mathematics. The value of e is 2.71828....

As might be expected from the previous discussion, Equation (8) contains F_2.

Values of F_3 can be calculated from Equation (8) for any value of F_2 and of the parameter $(G\ C_p)/U_L$. This was done for a wide range of values, and the results are shown in Figure 6.

The heat collection rate of the collector is then given by the product of Q_{ideal}, F_3, and the collector area A_c:

$$Q_{coll} = F_3\ Q_{ideal}\ A_c \qquad (1)$$

where F_3 is given by Equation (8) and Q_{ideal} by Equation (2).

Readers who do not struggle with equations on a daily basis may still be at a loss to proceed. It is probably best to read through this material a few times to get a feeling for the way the effects and equations tie in with each other. A detailed set of sample calculations is shown in the separate Appendix as a guide to set up calculations of your own,

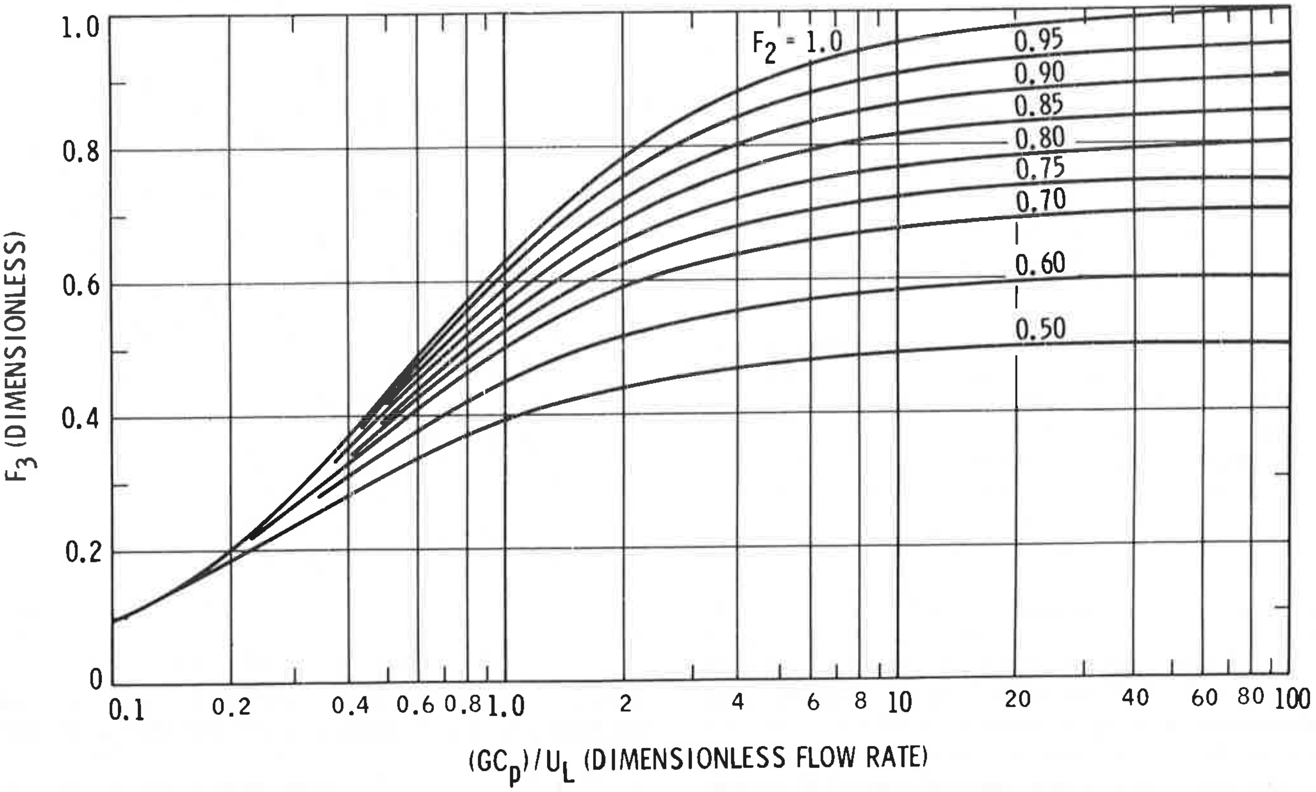

FIGURE 6. HOW COLLECTOR EFFICIENCY F_3 VARIES AS A FUNCTION OF SECTION EFFICIENCY F_2 AND OF A DIMENSIONLESS WATER FLOWRATE

and to get a starting check on the accuracy of your calculations.

It should be noted that the preceding equations for F_1, F_2 and F_3 cover virtually all of the design features of the panel which are easily subject to change. The size of the tubes (see Section 2.5) is chosen on the basis of pressure drop and not according to heat transfer considerations. If the size of the tubes is correct, then the tubes will have virtually no heat transfer influence, since both the solder bond and the water flow will make it possible to transfer heat without significant temperature drops. The panel slope may be fixed by an existing roof or by esthetics, and the panel size may also be fixed, either by the roof size available or by balancing off desires and budgets. The local weather and sunshine conditions affect Q_{ideal}, and this becomes the basis for deciding whether to build a heater or not; since F_1, F_2, and F_3 are not affected much, the same heater design will do in different parts of the world. The use of a glass or plastic cover over the panel will reduce the value of both Q_i and U_L, and virtually eliminate the term ϵR, but will not really change anything conceptually.

With these equations for the F factors and for $\dot{Q}_{ideal}$ we have thus really summed up the panel physics. Everything else which follows is somewhat secondary, serving only to feed numbers into these equations. If at this point the significance of the three F factors makes sense, then you can appreciate the interplay of the numbers by performing some calculations. After building a heater you can confirm some of these effects in an approximate manner without any special instruments.

2.5 The Effect of Tube Size

It turns out that in a solar heater for a swimming pool the tubing size is mainly determined by its pressure drop effect. This is because:

(a) Pool water should be recirculated and filtered regularly. The recommended recirculation rate involves pumping a volume equal to the pool volume through the filter once every 8 to 12 hours.

(b) If this same flowrate is passed through a solar heater, it will automatically lead to large values of h_{cw}, so that the section efficiency F_2 will be automatically high (see Equation (7)).

(c) The overall efficiency F_3 will also be high, unless the panel has been made very large (this would affect the value of G in Equation 8).

Between (b) and (c) all the heat transfer requirements which might be imposed on tubing size are satisfied. The only design question remaining then simply involves the use of large enough tubes so as to pass the required flowrate without imposing excessive pressure drops.

Gas heaters are normally designed for a pressure drop of about 2 to 4 psi. The same can be done with your solar heater. Since filters normally operate with a back pressure of 10 to 15 psi (they are "red-lined" at about 20 psi) this will not choke the flowrate down much. The same pump can be used whether a heater is involved or not. The filtration flowrate will still be sufficient.

The intention in heater design should be to supply a number of tubes with nearly equal flowrates, and to end up with a reasonable pressure drop in the process. This can be done using Figure 7 which gives the pressure drop per foot of tubing, for different flowrates and tube sizes. There are many ways of running through the necessary calculation. One convenient way is outlined below:

(a) Calculate the volume of your pool in gallons. Volume equals pool area (in sq ft) times average depth (in ft) times 7.481 gallons/cu ft.

(b) Assume that the circulation pump will circulate one pool volume every 10 hours. The flowrate in gallons per minute (GPM) is then the pool volume divided by 600 minutes. This is probably as high a flowrate as is to be expected, so that the tubes will be sized on the generous side.

(c) Sketch out the heater you are planning to build, including measurements of the length in the water-flow direction as well as the width of the heater. This will depend on the available roof size, on the heating desired and on the budget possibilities. If you have not yet made up your mind on panel size, you might perform some calculations based on a panel with one half the area of your pool, equal to the area of your pool, and twice the area of your pool. You can lay out these possibilities on an available roof or other area, and run through the rest of the calculations. As the desired heater size becomes clearer, you can always come back and refine the calculations. To decide on the actual heater size you will have to balance off your budget possibilities and heating desires as shown elsewhere* in this manual.

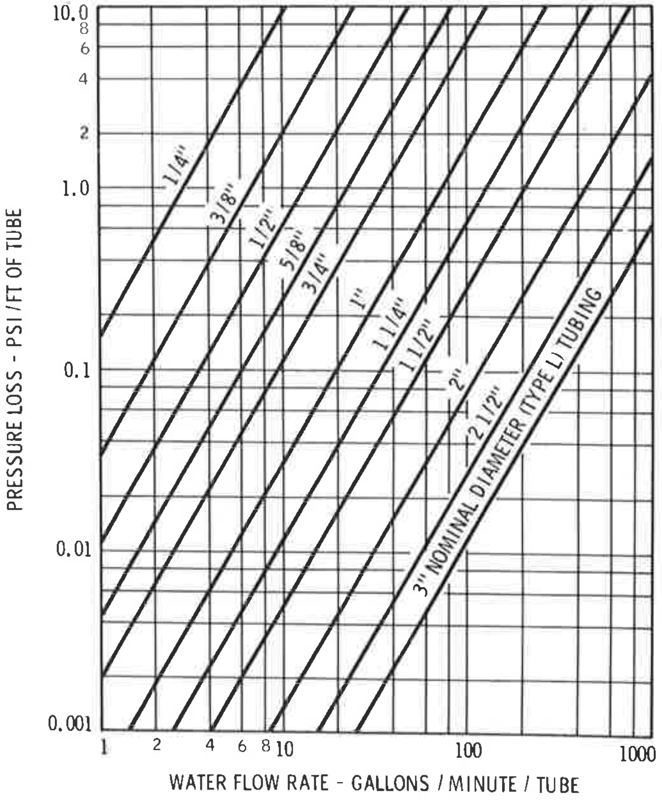

FIGURE 7. HOW PRESSURE DROP PER FOOT OF TUBE VARIES AS A FUNCTION OF WATER FLOWRATE AND TUBE DIAMETER

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*See Section 2.13 for the effect of panel size on pool heating, and Section 3.1.4 for the effect of panel size on cost.

(d) Calculate the number of tubes. From (c) above you have the width of the heater, and you can assume that the tubes will be roughly 10 inches apart. By dividing the width by 10 inches you can hence get the number of tubes.

(e) Choose a tube size — say 3/8-inch nominal diameter.

(f) Calculate the GPM per tube from parts (b) and (d), and then find the pressure drop per foot length for the tube, from Figure 7.

(g) To determine the pressure drop, you must then multiply the pressure drop per foot length, by the flowlength you determined in (c) above.

(h) If the pressure drop is between 2 and 4 psi you have an acceptable tube diameter. If the pressure drop is too large, go back to step (e) and choose a larger tube diameter. If the pressure drop is too small, take a smaller diameter. Repeat steps (e) through (h) until the pressure drop is what you want it to be.

(i) Now the headers (i.e., the distribution manifolds) must be sized so as to distribute the flow equally among the tubes. This can be done by ensuring that most of the pressure drop occurs in the heater tubes rather than in the headers. Assume that all of the circulation flowrate goes the full length of the header (i.e. the full width of the collector), and go through routine (e), (f), (g), and (h) as above. Start with a tube of 1–1/2 inch nominal diameter. Shoot for a final pressure drop of no more than about 1/4 or 1/3 of the pressure drop which you obtained in the collector tubes.

An illustration of the above calculation process is shown in The Appendix. It will be helpful to play around with some numbers to get a feel for the pressure drop effect. In the recommended designs, guidelines are included so that the designs will be fairly reasonable, without requiring extensive calculations.

The pressure drops in the rest of the plumbing network can be calculated using the same technique. The aim should be to keep the total pressure drop small compared to the 15 psi or so that the pump has to supply to the filter. Fittings, such as elbows, tees, valves, etc. produce extra pressure drops in the lines. As an approximate way of adding in this extra effect, you can add an extra tubing length equal to 25 times the tube diameter for each fitting in your circuit. CDA's Copper Tube Handbook contains additional information on sizing plumbing systems. (See Reference 14.)

2.6 The Effect of Panel Inclination

The effect of the inclination of the panel to the sun is quite intricate. Its main effect is on Q_i (see Equation (2)). It is quite clear that Q_i is maximum when the panel is perpendicular to the incoming sunlight, since it intercepts more sunlight in this position than in any other position. But the sun sweeps across the sky every day, and shifts north and south with the seasons. The position of the sun in the sky at noon at various times of the year is shown in Figure 8. It is obvious that a stationary panel can not possibly collect the maximum (perpendicular) heat input all the time.

If you want to collect more heat than can be collected with a stationary panel of a given size, you can do one of two things. You can build an automatic tracking system and a pivoting support for the panel, so as to keep it normal to sunlight throughout the day. You can also leave it stationary, but simply make it somewhat larger. It is much cheaper to make the panel somewhat larger and to keep it stationary, than it is to build an automatic (and safe) tracking system for a large, heavy panel.

You must decide what orientation or inclination to give the panel. Roughly speaking, a stationary panel will collect the most heat if it is perpendicular to the incoming sunlight at noon. This means that if the panel is a roof, then the roof must drain towards the equator. The position of the sun of course varies with the seasons. You must then decide during what season you want to collect the most energy, and build the panel accordingly. This can be most easily understood by examining Figure 8, showing the sun at different times of the year in relation to the earth, and a house on which a panel is to be mounted.

The seasons result from the annual north and south shift of the sun. This shift is caused by the earth being tilted about 23°27′ with respect to the plane of the ecliptic, the plane in which the earth moves around the sun. Twice a year, on about June 22 and December 22, the sun is at a solstice. The name solstice derives from the fact that the sun appears to reach the same elevation in the sky at noon for several days in succession, and then begins to recede back towards the equator.

At the time of solstice the declination (i.e. the angle between the incoming sunlight and the plane of the equator) is the 23° 27′ mentioned earlier. March 21 and September 23, the times at which the sun is overhead at the equator, are called the equinoxes. This name derives from the fact that at these times day and night are of equal length everywhere.

For roughly equal heat collection summer and winter, the panel should have an inclination equal to the latitude. If it is desired to collect heat in winter, then the panel should have a steeper inclination. If it is desired to collect in summer, the panel should be more horizontal. You should not go the full 23° 27′ away from the "latitude inclination" since you would only be collecting at a maximum rate at the time of the solstice (December 22 or June 22), and at less than the maximum possible during

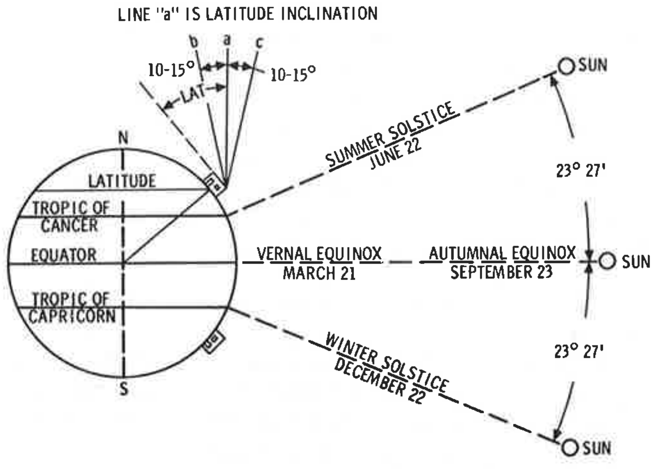

FIGURE 8. POSITION OF THE SUN IN THE SKY AT NOON, AND ITS RELATION TO THE INCLINATION AND LOCATION (LATITUDE) OF THE COLLECTOR

the rest of the year. It is better to build the panel only about 10° – 15° steeper than the "latitude inclination" for winter collection, about 10° – 15° less steep than the latitude inclination for summer collection. This way the collection rate is close to optimum for a longer time.

Summarizing:

(a) For equal collection year-round:
Build panel with an inclination equal to the latitude where you live – see line a on Figure 8.

(b) When you are most interested in heating during the summer:
Build panel with an inclination equal to the latitude minus about 10° to 15° – see line b on Figure 8.

(c) When you are most interested in heating during the winter:
Build panel with an inclination equal to the latitude plus about 10° to 15° – see line c on Figure 8. But remember, solar pool heating is likely to be of most interest in summer, not in winter, in most of the U.S.A.

This is all very interesting, but you may be stuck with a roof that does not have an optimum inclination. It is also possible that you decide that an optimum panel inclination is too steep or too horizontal to suit your taste. In either case an optimum panel may be impractical. It turns out that so long as the panel is not more than 15° away from the optimum it will not affect the heat collection very much. This is true even in the case of a nearly horizontal roof which drains due east or west, rather than towards the equator.

The above discussion concerned the best inclination to use for particular applications, but did not cover in a precise way the actual amount of heat which can be collected at any particular inclination. The reason this was avoided is as follows: Virtually all measured results of solar energy have been for horizontal surfaces. Occasionally inputs have been measured or calculated for vertical surfaces, for use in calculating the heat inputs in buildings. These are normally for walls facing south, east, north, or west. Horizontal collectors are however optimum only close to the equator, vertical ones only at high latitudes.

Calculation of the heat inputs to an inclined surface from horizontal values is fairly complicated. If only the direct solar input were involved the problem would be simple. One would simply apply trigonometry, and average things over the day in question. A significant amount of incoming sunlight gets scattered, however, by the air, by dust particles in the sky and by clouds. Buildings, snow on the ground, mountains or vegetation can also reflect significant amounts of sunlight. One of the advantages of the type of flat panel described in this manual is precisely that it can use this "diffuse" sunlight. Even on cloudy days, when little sunlight comes directly from the sun, a flat panel can still collect sizable amounts of solar energy.

Methods have been developed for including this diffuse component, as well as the ground-reflected component, in the calculation of the heat input to inclined surfaces. Unfortunately the calculations are quite time consuming and complex. To start with, they require the values of heat input to a horizontal surface as shown in the maps in Section 2.7 below. These horizontal values themselves are not too accurate because of the limited number of measurements on which they are based.

You can appreciate why values for inclined surfaces were not calculated for this manual if you consider the variability of the input maps, the inaccuracy of these maps due to the limited number of sites at which solar values are measured, and the complexities of calculation of inclined surface values. It would have been necessary to do this for a number of inclinations, so that a number of maps would have resulted for each month, where now only a single horizontal one is given. The results would have been of doubtful accuracy, yet would have made the manual longer and more complex.

It is much better simply to include the horizontal values. If anything, actual collector performance will be better than predicted values, so that you may get a pleasant surprise. The use of horizontal values also automatically discourages marginal installations in cold climates. In warm climates, where pools are most common, roofs tend to be close to horizontal anyway.

By using a reflector as a backdrop to the collector, you can reflect more energy onto the panel. This is a way of increasing the effective size, or of improving the apparent inclination, at a small cost.

2.7 The Effect of Geographical Location

If the atmosphere did not exist, or if it did not influence solar radiation, the effect of geographical location would be simple. The solar input each day would only vary with the latitude and the time of the year. The only complication might be that in some places mountains (or something else) might help by reflecting extra sunlight our way, or might reduce inputs by casting shadows. Otherwise everything would be simple, and it would in fact be possible to calculate the effect of geographical location, rather than having to depend fully on measurements.

Unfortunately things are not that simple. Cloud cover, atmospheric dust, smog or smoke can have very significant effects on solar inputs. These factors can vary due to altitude, proximity of mountains, deserts, bodies of water, or urban or industrial concentrations. If the sunlight comes into the atmosphere at an angle it has to go through more air (and dust, etc.) than if it enters directly overhead. Measurements in a city may be as much as 15 to 20% lower than values in the surrounding countryside. Hence, measurements in a city may not be applicable to the suburbs or countryside, and vice versa.

If a large amount of data existed for a myriad of different locations, all would be well. The results could be digested by a computer, and we could get "insolation" maps of sufficient accuracy and resolution so that any locality could be described with trustworthy solar inputs. Unfortunately this is not the case. There have been only about 100 stations established in the United States where solar input measurements have been made for any length of time, and the results are often not too accurate. For most stations many days are missing. In other countries, the distance between solar input measuring stations is even greater.

There are several good compilations of solar energy

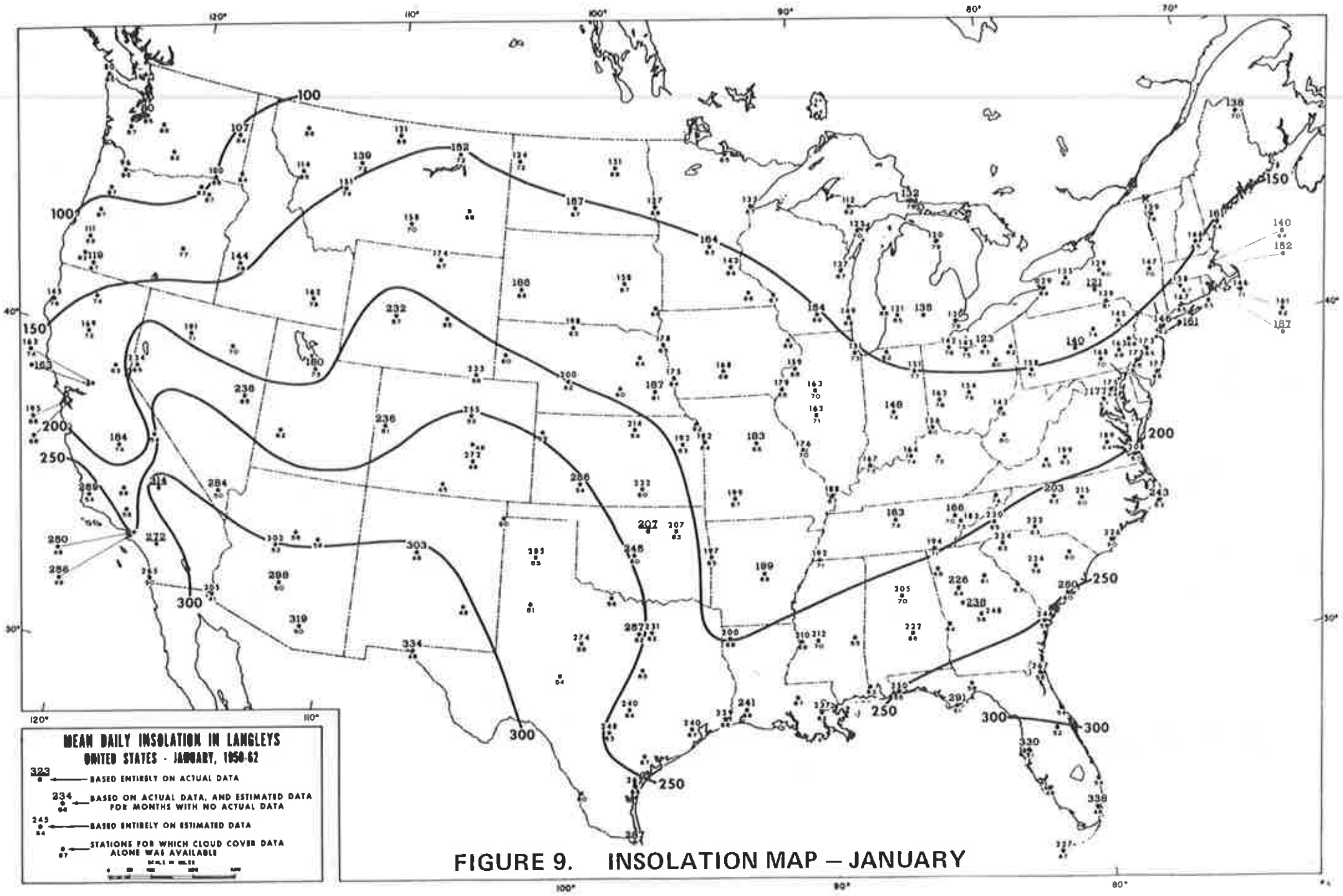

FIGURE 9. INSOLATION MAP – JANUARY

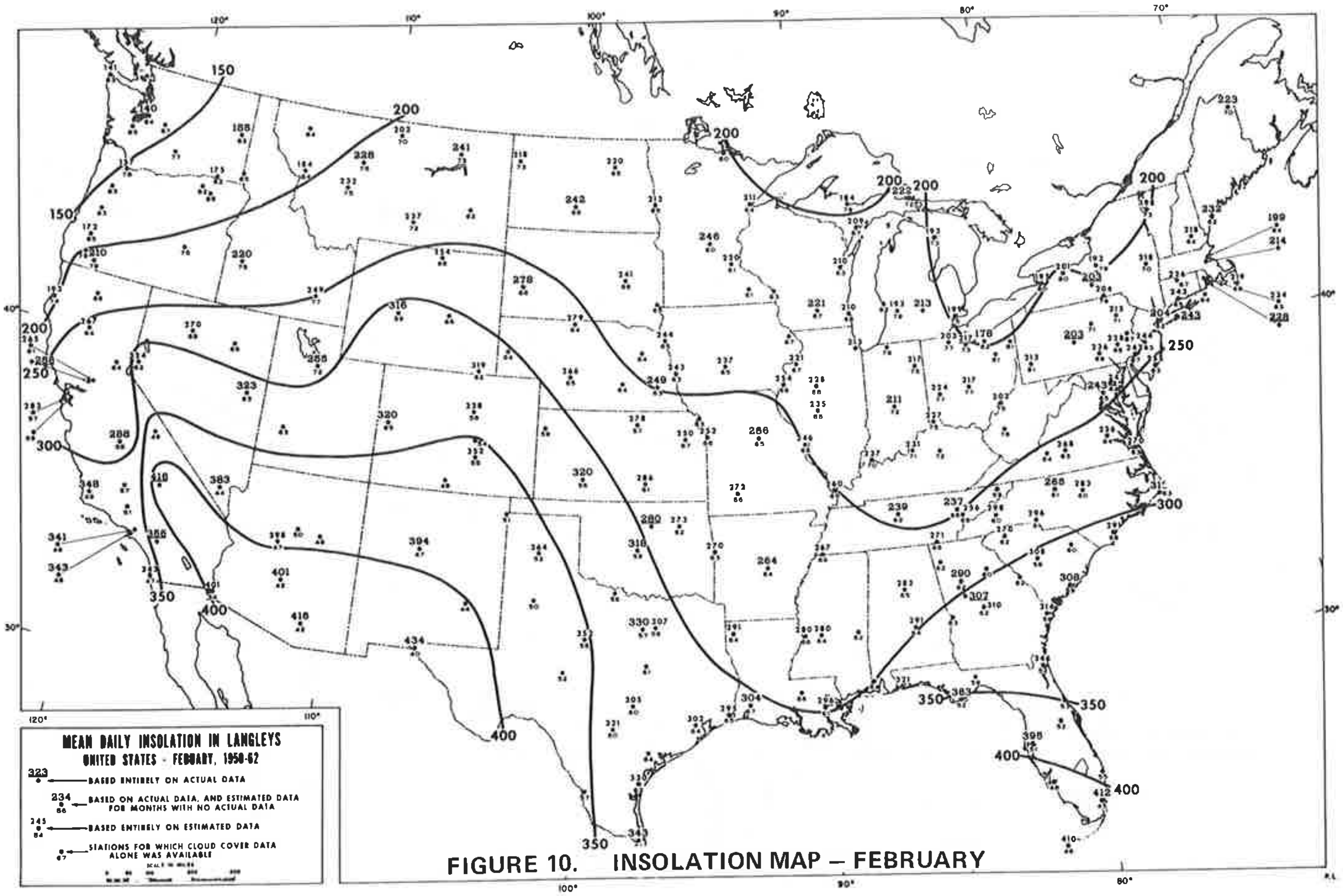

FIGURE 10. INSOLATION MAP – FEBRUARY

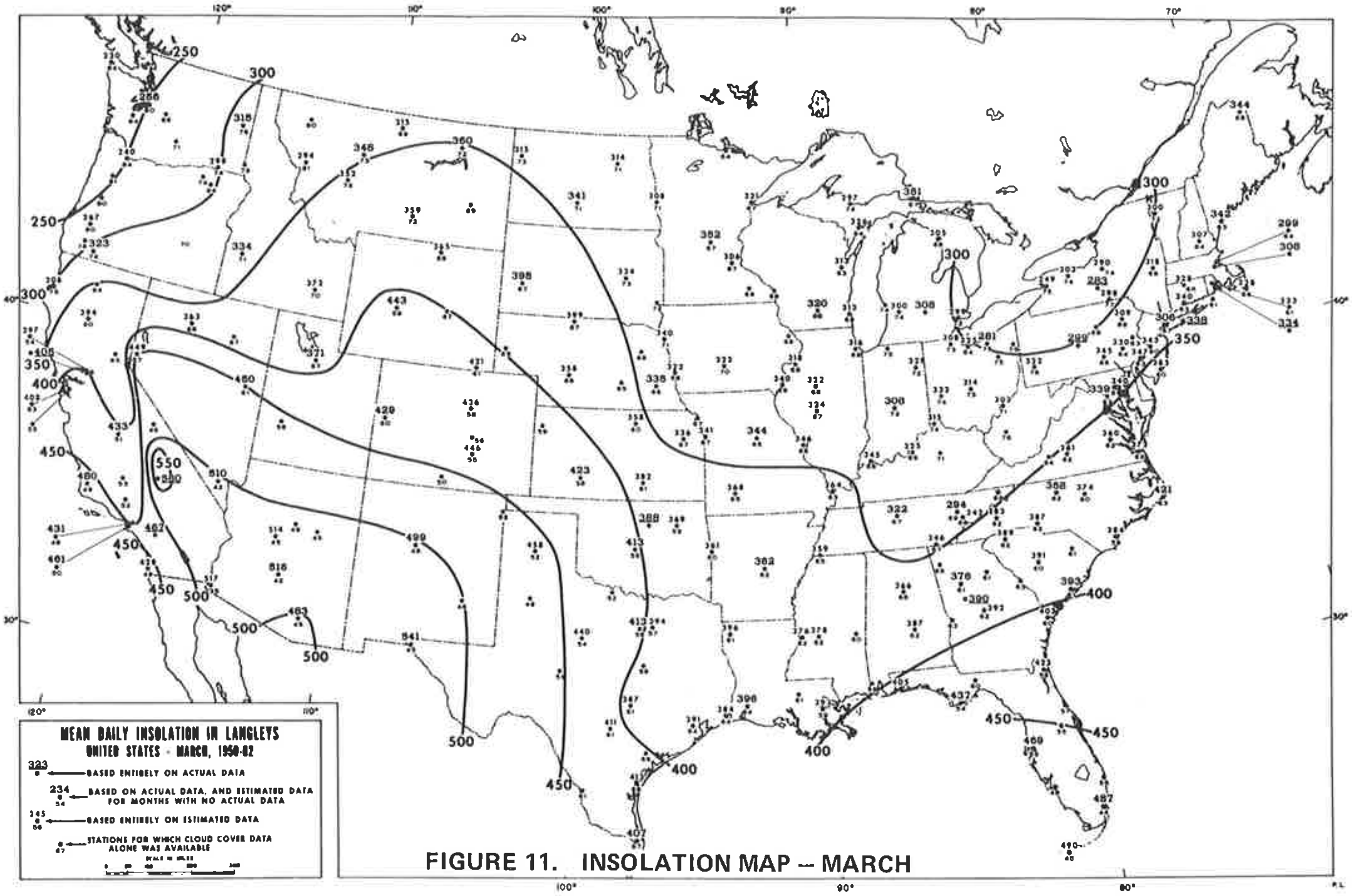

FIGURE 11. INSOLATION MAP – MARCH

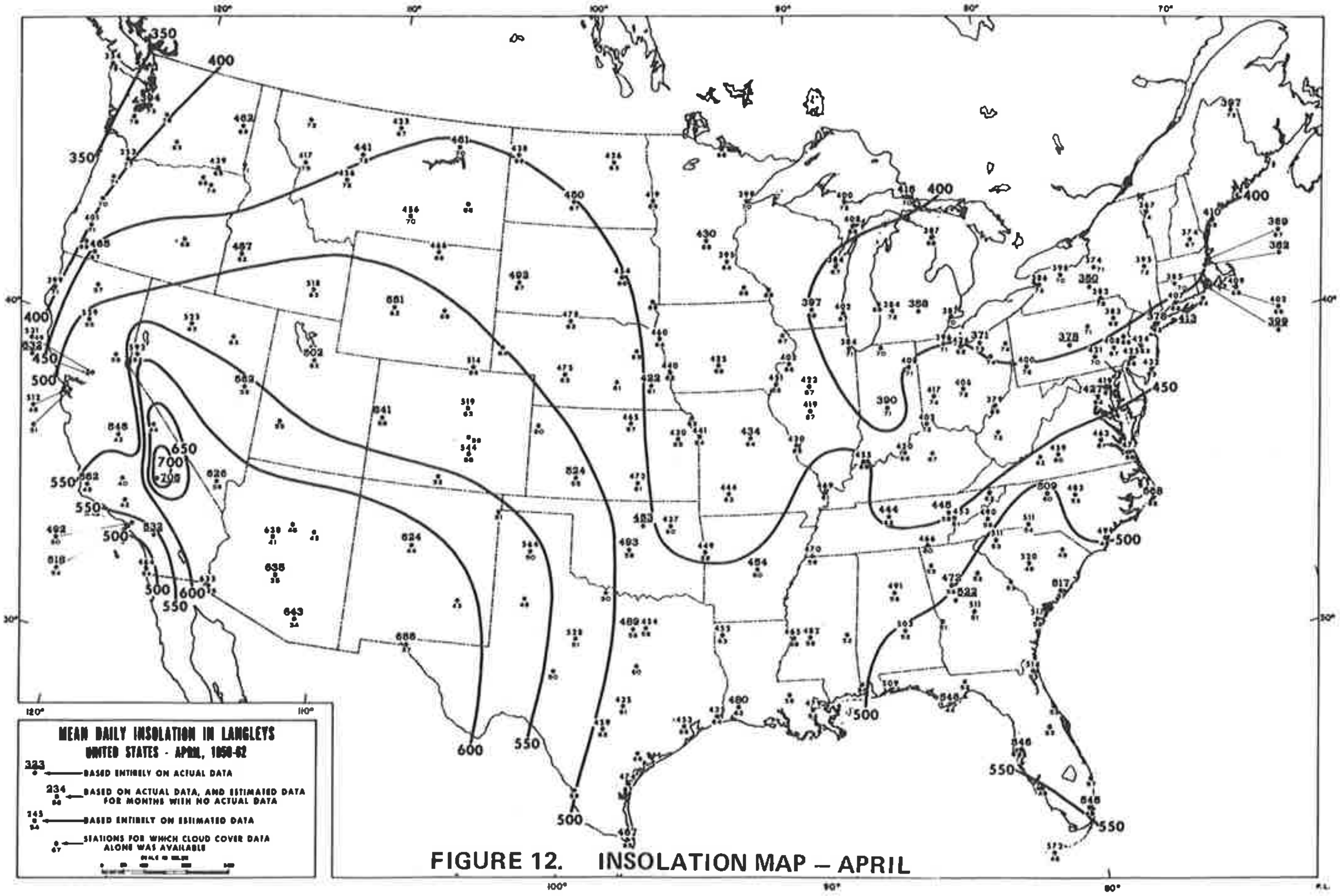

FIGURE 12. INSOLATION MAP – APRIL

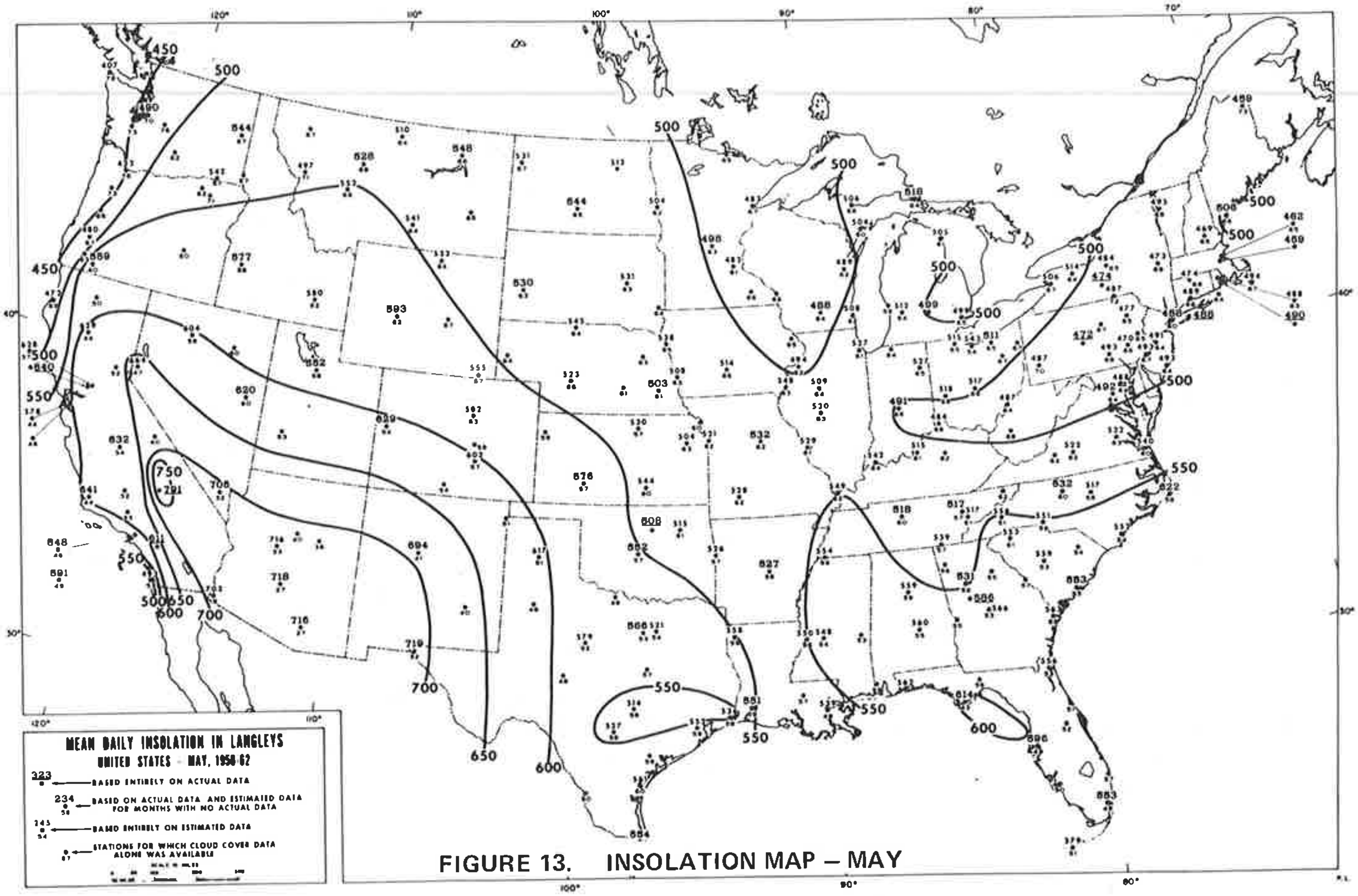

FIGURE 13. INSOLATION MAP – MAY

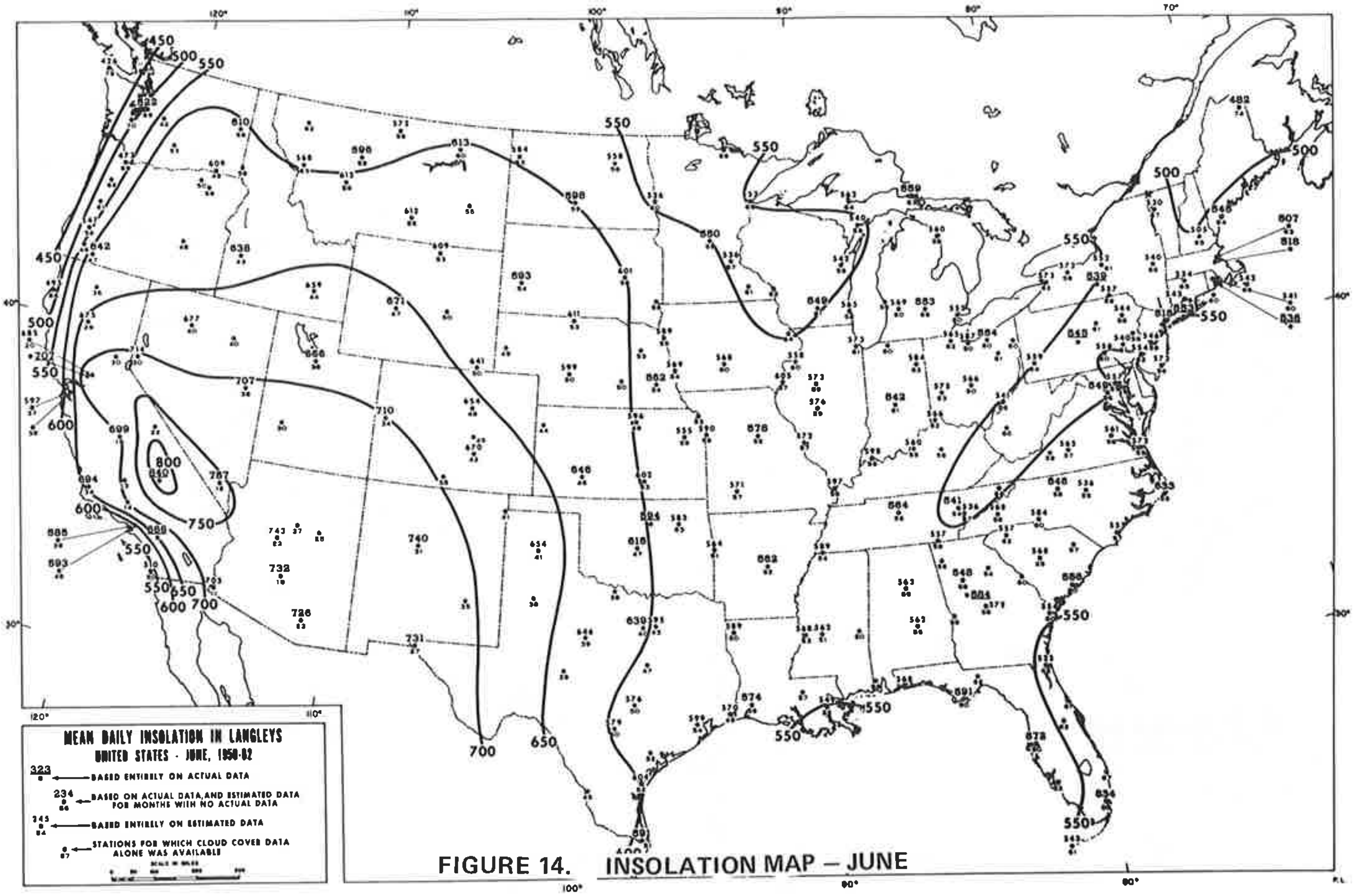

FIGURE 14. INSOLATION MAP – JUNE

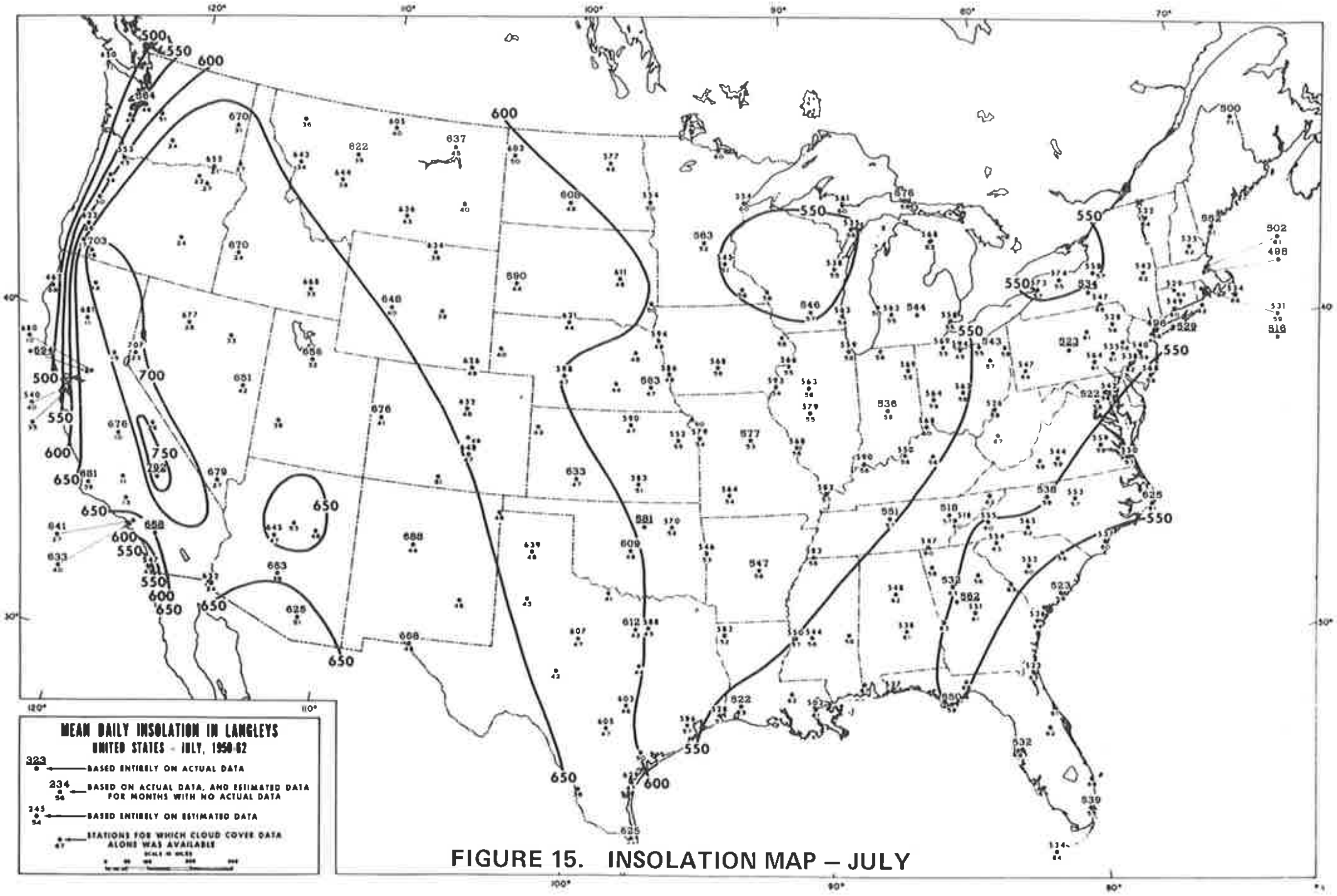

FIGURE 15. INSOLATION MAP – JULY

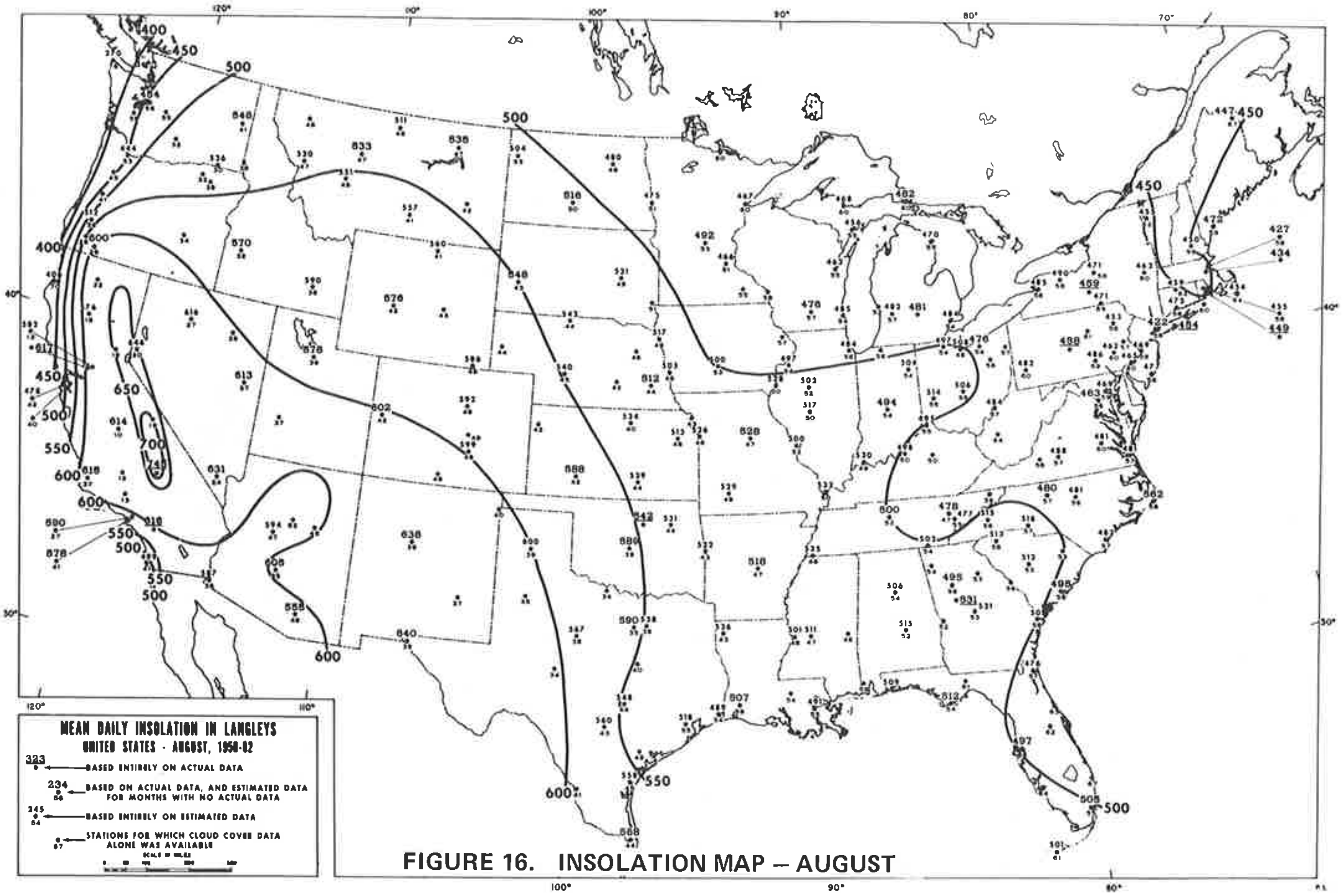

FIGURE 16. INSOLATION MAP – AUGUST

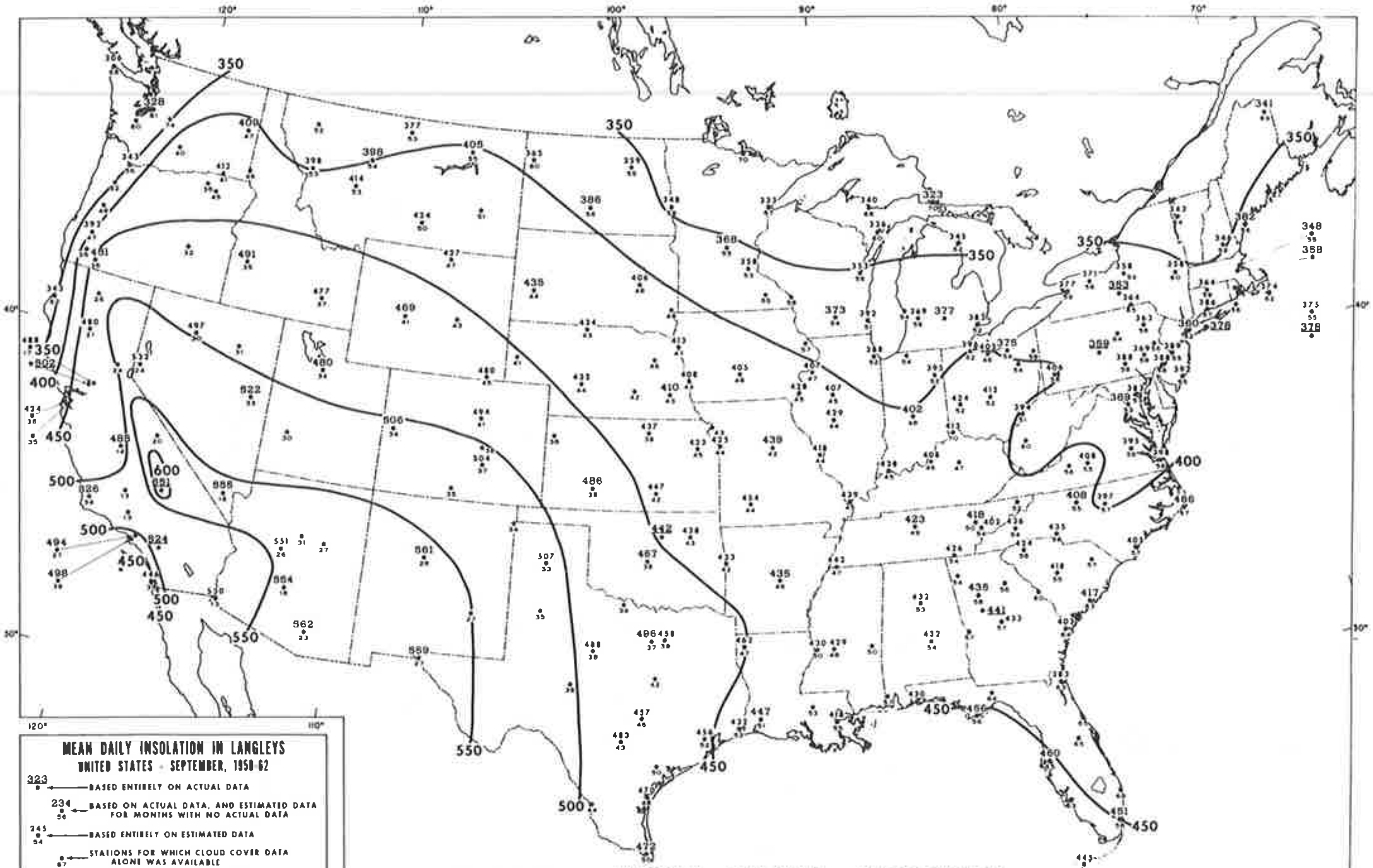

FIGURE 17. INSOLATION MAP – SEPTEMBER

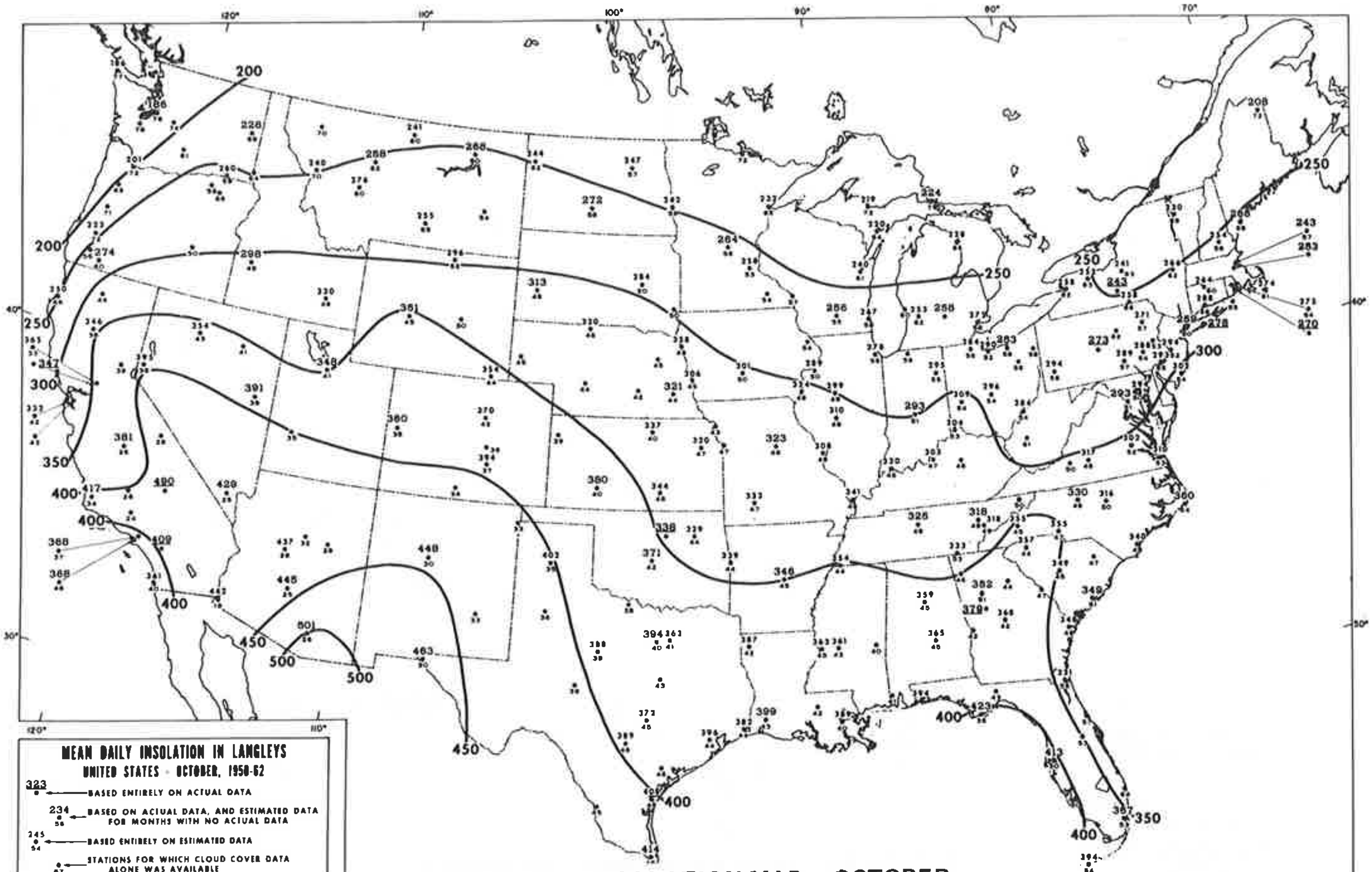

FIGURE 18. INSOLATION MAP – OCTOBER

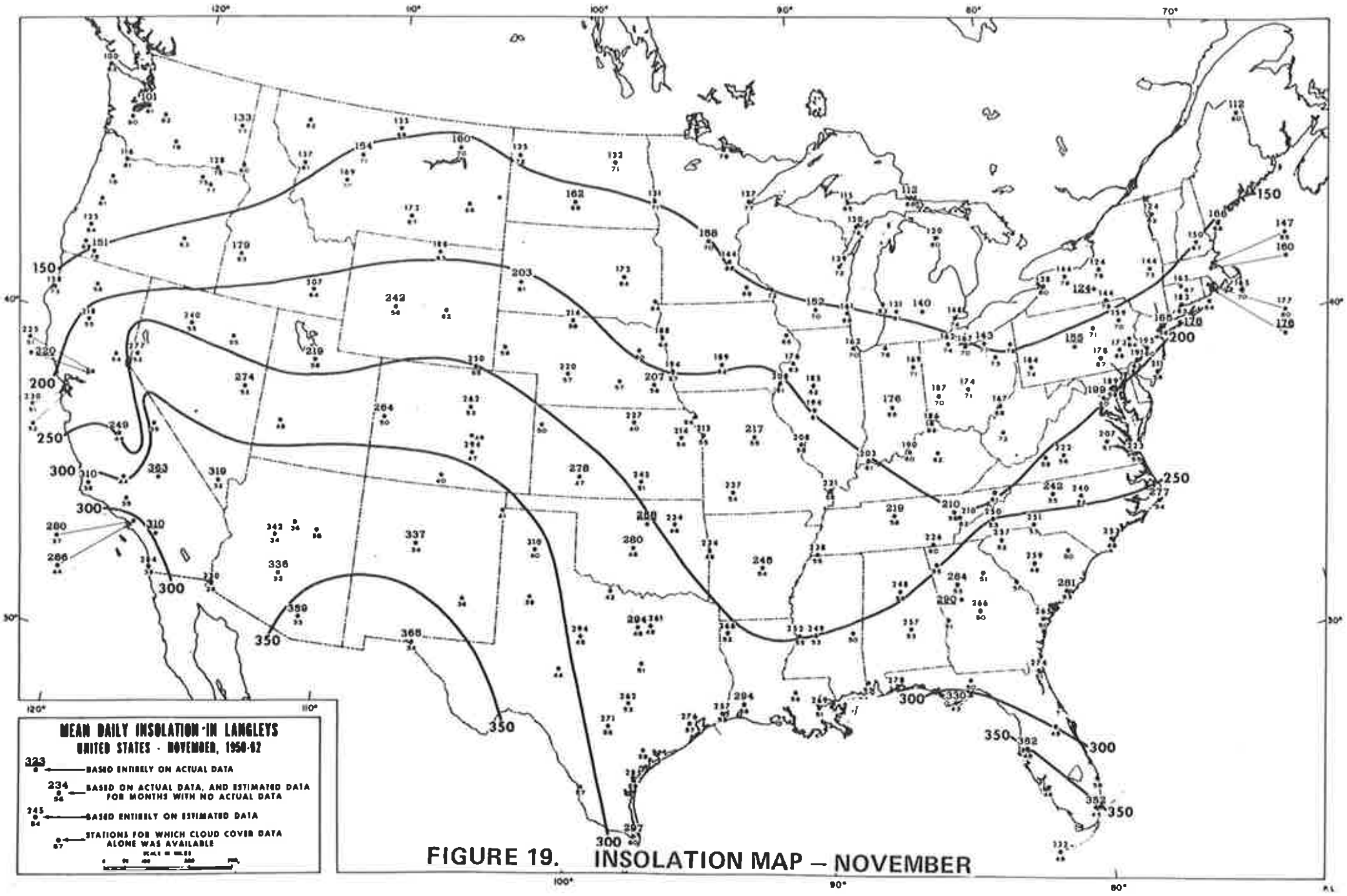

FIGURE 19. INSOLATION MAP – NOVEMBER

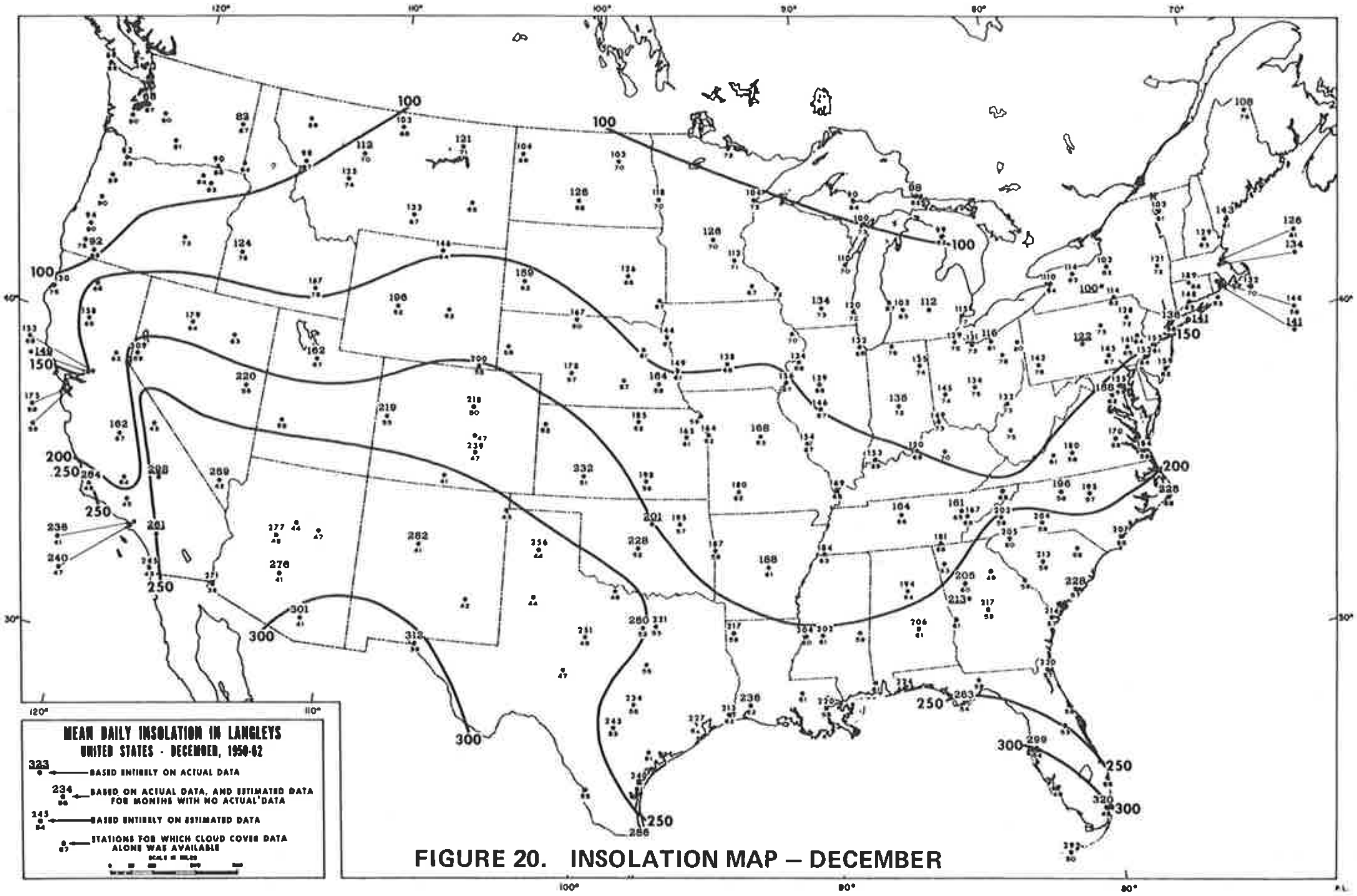

FIGURE 20. INSOLATION MAP – DECEMBER

input. Lof, Duffie and Smith (Reference 5) have prepared maps showing worldwide distribution of solar energy for each month of the year. Bennett (Reference 6) has prepared maps for the U.S., which are reproduced here as Figures 9 through 20. These are, as mentioned in Section 2.6, for horizontal surfaces. The maps show the locations of the stations. It is clear that there are really few stations, and of these, only a few have complete and trustworthy results.

The units in the maps are given in Langleys per day. A Langley equals 1 gram-calorie/sq cm or 3.69 Btu/sq ft. A conversion table covering the range of interest of the maps is shown below.

Langleys/day	Btu/(sq ft day)
100	369
150	554
200	738
250	922
300	1,110
350	1,290
400	1,475
450	1,660
500	1,845
550	2,130
600	2,220
650	2,400
700	2,580
750	2,760

2.8 The Effect of Time-of-Day

The solar collector equations shown in Section 2.1 to 2.4 are based on the assumption that the collector is operating at steady state. Of course this is not true. The assumption is made simply because the results that can be based on it are quite good and also simple. There are many things that contribute to transient effects in the collector. The position of the sun in the sky is changing constantly, and as a result the solar input changes during the day. The water temperature and flow rate may change. There may be transients when the water flowrate is started in the morning. The panel might be quite hot so that one might start with a bonus of stored solar energy. In addition there are transient changes in the collector due to all the externally-imposed changes. The temperature drop along the fins is changing, and the temperatures of all other parts of the collector are adjusting continuously.

The solution of the collector transient in full glory is by no means impossible, but to do a proper job a computer is needed. An enormous amount of work would be involved otherwise, and the accuracy gained would simply not be worth the effort.

The steady state results are adequate so long as one uses the right solar input and ambient temperature, which vary throughout the day. They could be calculated and used on an hourly basis, but this is not really necessary. Calculation of reliable average values for Q_i and t_a during collection hours is shown below.

To obtain the average temperature during collection hours, one would have to read a thermometer periodically, and then average all the values. Even if this were done with automatic equipment it would be bothersome. It is much better to have something simple, if only approximate, to use for average temperature. A simple estimate of the average temperature can be obtained if we assume the temperature undergoes a simple cycle between a minimum at midnight and a maximum at noon.* This makes it possible to obtain the relationship shown in Figure 21. A sample calculation using this figure follows. Take a day with a maximum temperature of 100 F and a minimum of 60 F. Then $T_{max} - T_{min} = 40$ F. For collection between 6 A.M. and 6 P.M., as shown in Figure 21, $T_{max} - T_{avg} = 7.2$ F, so that $T_{avg} = T_{max} - 7.2$ F $= 100$ F $- 7.2$ F $= 92.8$ F.

The calculation of the solar input variation or average during collection hours is not so simple. The most widely accepted method for taking this effect into account seems to be the method of Whillier (Reference 7). The first two figures used in Whillier's method, Figures 22 and 23, are based on calculations. Figure 22 shows the declination, i.e. the angle the plane of the equator makes with a line drawn between the earth and the sun, as a function of the time of the year. Figure 23 shows the time of sunset for specific values of declination and latitude. This figure and the three that follow it are based on the assumption that noon is halfway between sunrise and sunset. If you live on the edge of a time zone, or if you are on some daylight savings time arrangement this will not be quite true.

The remaining figures, Figures 24 to 26, give different versions of the daily solar input variation as a function of

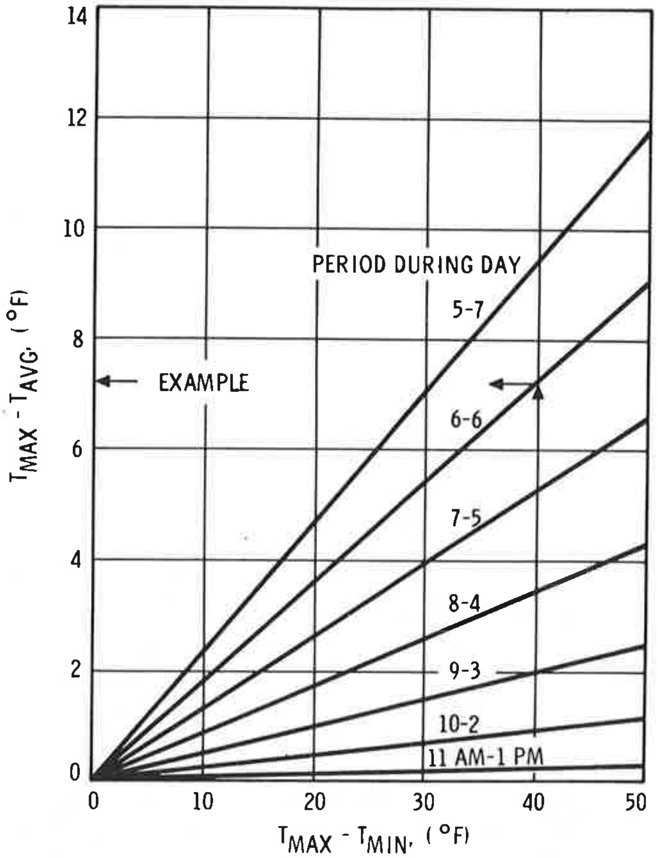

FIGURE 21. CHART FOR DETERMINING MEAN AIR TEMPERATURE DURING HOURS OF COLLECTION.

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*Actually the minimum is usually at dawn, the maximum between 2 and 4 P.M. The model used is simple and reasonably good.

the time of the day and the length of the day. These charts are based on measurements made at many latitudes ranging between 50° south to 50° north of the equator. Unless you experience unusual weather patterns (e.g. showers at the same time each day) the results should be quite accurate. It should be noted that the results apply to horizontal surfaces. One can use Figure 22 and Figure 23 to get the "hour of sunset" on an inclined collector by adjusting the latitude to include the collector inclination. There is however no easy way of getting completely accurate data out of the other figures for an inclined collector.

Examining the graphs, several conclusions can be reached which are pointed out by Whillier. During the middle two-thirds of the day 90% of the day's radiation is received. The radiation intensity during this time (in which 90% of the energy is coming in) is greater than 40% of the intensity which comes in at noontime. Coupled with the fact that the heat losses from the panel increase close to sunset and sunrise (due to the drop in average t_a discussed earlier), it is clear that 90% or more of the "collectable" energy is to be harvested in the central two-thirds of the day. Running water through the panel at other times will not produce much useful heat.

For actual collector performance calculations, the most useful numbers to be gotten from the Whillier figures are:

(a) The average hourly radiation, calculated by multiplying the day's total input (found from Section 2.7) by the fraction of the day's input received during the collection period (found from Figure 26) and dividing by the length of the collection period.

(b) The radiation intensity at particular hours, found by multiplying the day's total input (found from Section 2.7) by the ratio of hourly to daily total solar radiation found from Figure 24.

In most cases the average values are sufficient. An example of the use of these numbers is shown in the Appendix, available separately.

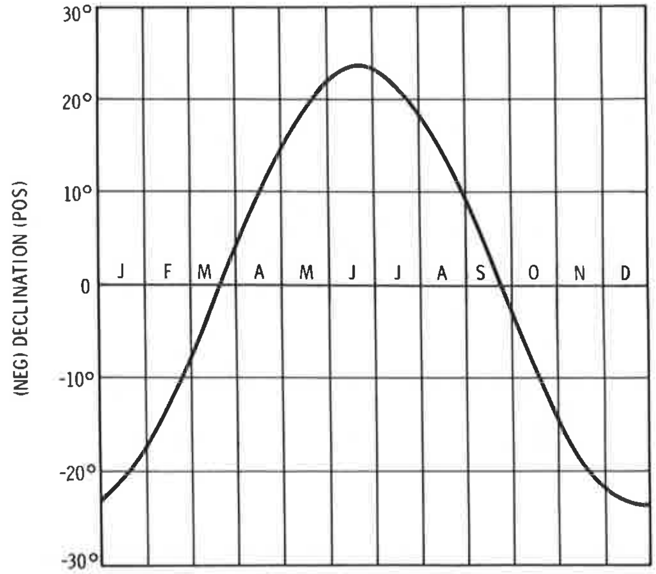

FIGURE 22. EARTH DECLINATION DURING THE YEAR

2.9 The Effect of Shade on the Pool or Collector

If either the pool or the collector is shaded (in part or

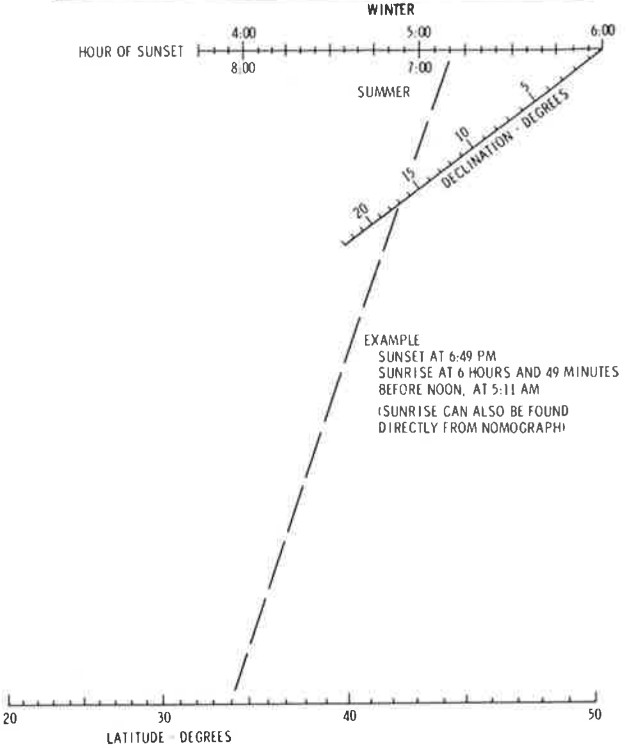

FIGURE 23. NOMOGRAPH TO DETERMINE THE HOUR OF SUNSET OR SUNRISE

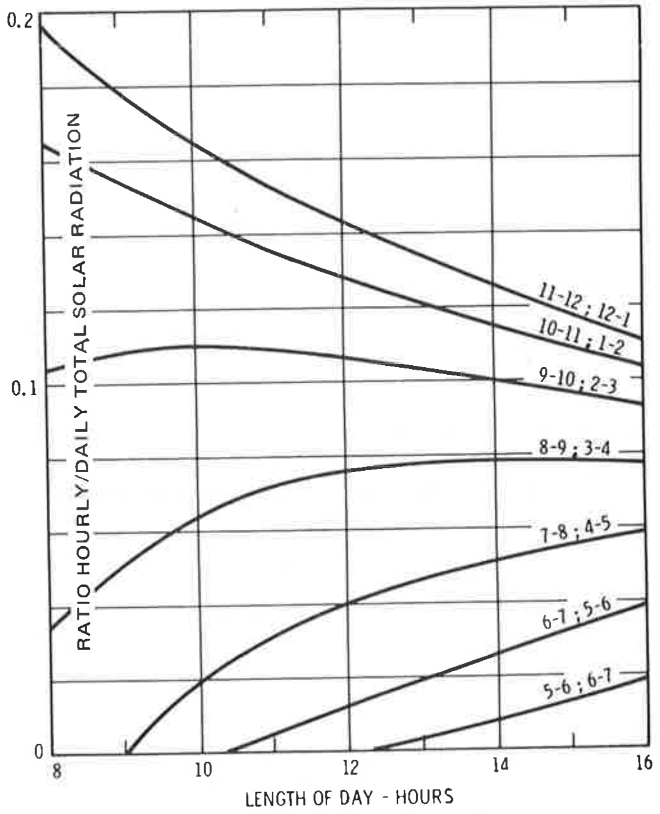

FIGURE 24. RELATIONSHIP OF HOURLY RADIATION TO LENGTH OF DAY

in full) during a part of the day, you will be deprived of a corresponding amount of the direct solar energy. The diffuse solar energy may still come in and be collected in part, but in most sunny locations this does not amount to much.

There is a significant incentive to build the pool as well as the collector in a sunny spot. A fully shaded pool will typically be about 10 degrees colder than a sunny pool in the same neighborhood – but of course may still be considered better than no pool at all. *Building a collector in a shady place is, however, quite futile.*

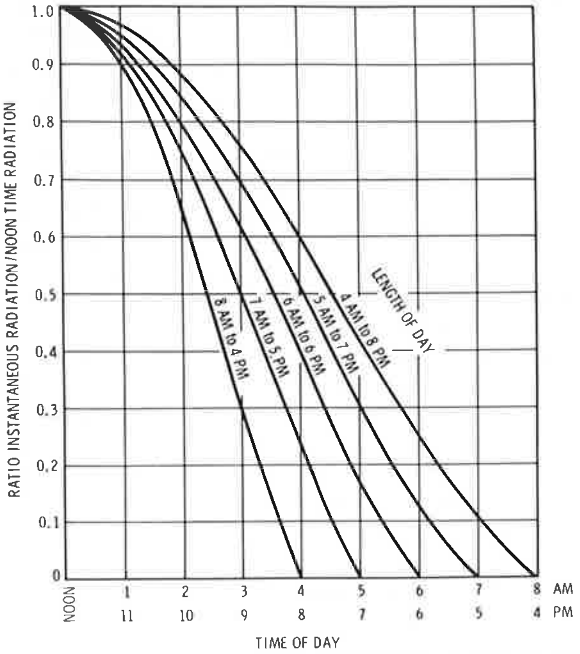

FIGURE 25. RELATIONSHIP BETWEEN INSTANTANEOUS TO NOON-TIME RADIATION AND TIME OF DAY

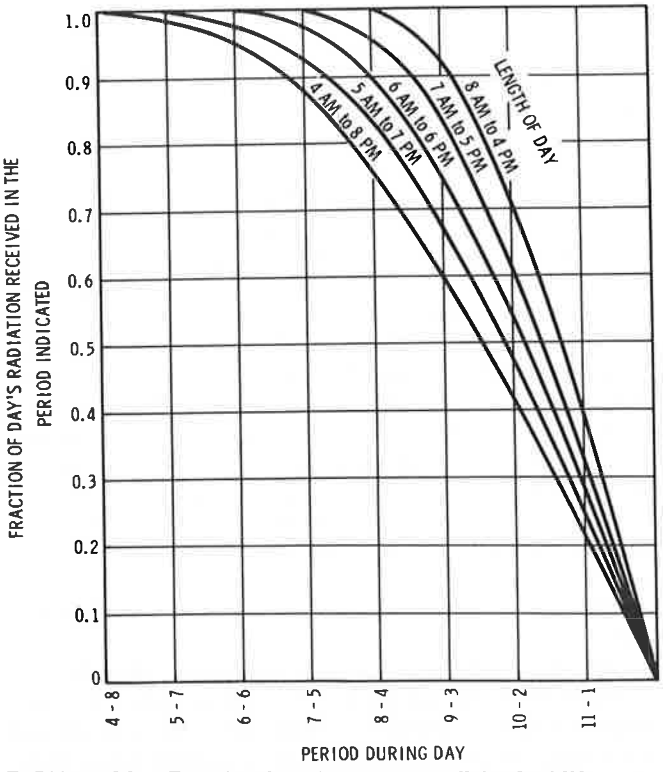

FIGURE 26. FRACTIONAL PART OF THE DAY'S SOLAR RADIATION THAT IS RECEIVED BETWEEN SPECIFIC HOURS

The effect of partial or total shading during part of the day can be calculated using the results of Section 2.8. The amount of radiation coming in at any time of the day can be calculated, and if during that part of the day some or all of the collector surface is shaded, the heat collection will be reduced accordingly. The same can be done for shading of the pool, and the effect on pool temperature can be calculated using the techniques shown in the Appendix, where a sample calculation is included.

From the discussion in Section 2.8, it is clear that early morning or late afternoon shade is not likely to have much effect on solar inputs. The benefit of such obstructions as windbreaks may be far greater than the harm they produce by shading.

2.10 The Effect of a Glass or Plastic Cover Over The Panel

Most solar heaters for domestic water heating have been built with one or more glass or plastic covers above them, enclosing one or more air-gaps each about 3/4 inch thick. The glazing insulates the heater. Without it, a heater can only go to a limited temperature before all the absorbed solar energy is lost back to the atmosphere. The glazing raises this temperature, making it possible to collect heat at a higher temperature – and produce hotter water – than would otherwise be possible.

The glazing is, however, a mixed blessing. It reflects some of the solar energy, and absorbs some more, before the energy has a chance to get to the panel itself. And the glazing is expensive to buy and to install. Unless it is of heavy gauge or is protected, it may be damaged.

One layer of good glass (see Section 4.3) or of a good Tedlar-coated plastic will reduce the solar heat flux Q_i incident on the collector — see Equation (2) — by nearly 20%. In addition to this loss, purely due to light reflection and absorption of the glazing, there is some shadowing of the collector by the support structure for the glazing. You can estimate this yourself since it will depend on the construction details. The heat loss coefficient U_L — see Equations (2), (6), (7), and (8) — will become roughly equal to 1 Btu/sq ft/hr/deg F, rather than the value of roughly 2.5 which might be expected for a bare panel. In addition, since glazing is virtually opaque (nontransparent) to infrared radiation, the panel will lose no direct radiation to the sky, and hence the term ϵR can also be dropped out of Equation (2) with little loss in accuracy.

A simple comparison between bare and covered collectors can be made by calculating the value of Q_{ideal} as given by Equation (2).*

$$Q_{ideal} = \alpha Q_i - \epsilon R - U_L (t_{wi} - t_a) \qquad (2)$$

Using for a bare collector:

α = 0.9
ϵ = 0.9
R = 25 Btu/sq ft/hr
h_{ca} = 1.5 Btu/sq ft/hr/deg F
$U_L = h_{ca} + 1.0 = 2.5$ Btu/sq ft/hr/deg F

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*This is the heat flux collected by a panel which has an efficiency F_3 of 1.0.

Equation (2) becomes:

$$Q_{ideal} = 0.9Q_i - 22.5 - 2.5\,(t_{wi} - t_a)$$

We can easily calculate the three lines shown for a bare collector in Figure 27 using this equation. For a covered collector with an absorptivity $\alpha = 0.9$, roughly 75% of the incident solar energy is transmitted through the glazing and absorbed by the collector (Reference 4). Taking $\epsilon R = 0$, and $U_L = 1.0$ Btu/sq ft/ hr/deg F, Equation (2) becomes:

$$Q_{ideal} = 0.75\,Q_i - 1.0\,(t_{wi} - t_a)$$

Three lines are calculated for this equation to match the ones calculated for the bare collector.

It is clear that at high temperatures (high values of $t_{wi} - t_a$) a covered collector will outperform a bare one, since with the same value of the solar input Q_i it will be able to collect more solar energy. At lower temperatures, a bare collector may do better than a covered one. The temperature at which the cross-over point occurs increases with increasing solar heat flux.

Figure 27 does not tell the whole story.* The reduction of U_L obtained by using a cover gives a covered collector higher values of F_1, F_2, and F_3. The covered collector is hence somewhat better than might be assumed from Figure 27. On the other hand, the glazing is expensive to buy, install, and maintain. One needs a significant performance incentive before it is worthwhile to go to a covered collector for pool heating.

For most pool heating applications, the heating requirements will be so modest that it will not be desirable to build a covered collector. Because of the evaporative cooling in the pool most unheated pools are at a temperature well below the average daytime ambient temperature. A solar heater operating by itself might raise the pool temperature by 10 deg or even 20 deg depending on collector size (see Section 2.13), but this would generally still be well within the design range of a bare collector. It is perhaps only when one goes to a heater operated in conjunction with a gas heater that it may become desirable to use at most one layer of glass or plastic over the heater (see Section 2.11).

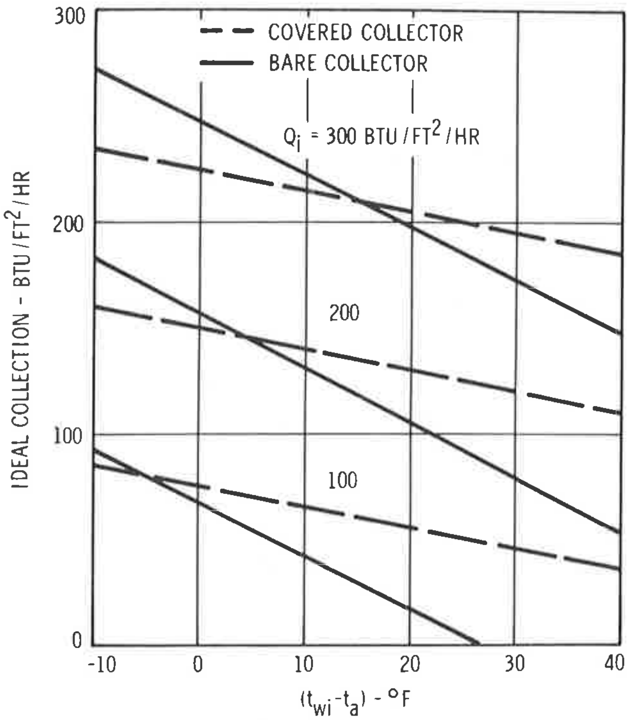

FIGURE 27. IDEAL COLLECTION RATES FOR BARE AND COVERED COLLECTORS

Two special effects of glazing deserve attention. With full sunlight on the panel, the panel will become very hot – perhaps 200 F – if the water is not flowing through the panel. If the panel has been built on top of a roof the heat load into the building will be excessive unless extra insulation is placed under the glazed panel. The other effect concerns the transmission of glass or plastic, which becomes very poor at low glancing angles. A bare panel will receive significant amounts of solar energy even if it has an inclination far from optimum (see Section 2.6). For a glazed panel it is more important to have the sunlight coming in at near-perpendicular angles, since the sunlight coming in at glancing angles will be largely reflected by the glass or plastic, or absorbed by it. If you put glazing on the panel try to build it reasonably close to the optimum inclination given in Section 2.6.

If the effects of glazing are only of interest during short times of the year — as might be the case if you want to operate a solar heater in conjunction with a gas heater in the cold months — then you might consider the use of a cheap plastic film which you can throw away after use.

2.11 Operation in Conjunction with a Gas Heater

In most of the United States it is not a good idea to design a solar heater large enough to heat a pool over the entire year. The heater would simply become too large, one would only be operating it at full capacity for a short time of the year, and the rest of the year one would have a very large and under-employed investment operating at part load.

If you insist on swimming in midwinter, the use of gas heating is almost essential. It is however possible to reduce gas consumption by using a solar heater, whether it is midwinter or not. Some suggestions on this follow.

It may be necessary to build a glass or plastic cover over the panel. If there are times of the year in which you want the pool temperature to be significantly above the day-time ambient temperature, the solar heater may not be able to collect much heat unless it is covered (see Section 2.10). You might consider the use of a temporary plastic film, which can be taped on and removed after use.

The gas and solar heaters can probably best be hooked up in parallel, since there is normally more than enough water flow for both. A possible piping diagram is shown in Section 4.4.1. For minimum pressure drop the inlet valves to both heaters should be full open. If one of the heaters is not getting enough water, the other can be throttled down a bit.

One possibility is to circulate water only when the sun is available. If gas heating is to be used at night, the solar heater should be bypassed. Make sure that you do not have stagnant water in the panel on a night when there may be frost, since the tubing may be damaged if repeatedly frozen with water inside.

If the panel is to be used during the cold months it is

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*See also Sections 2.13 and 3.1.4.

desirable to optimize the panel inclination accordingly (see Section 2.6). This is particularly worthwhile if the panel is to be covered with glazing (see Section 2.10).

Some sample calculations on operation in conjunction with a gas heater are shown in Section 3.4.1 and in the Appendix.

2.12 Heating Requirements of the Pool

A swimming pool operating in steady weather will settle down to a temperature at which the heat inputs and losses are equal. The heat inputs may be produced in part by a gas heater or a solar heater. The operation of these heaters is described elsewhere in this manual. The direct heating of the pool by the incident solar energy is described below. This is followed by a description of the heat losses, and a discussion of the heating requirements for operation at any particular temperature. The equations are illustrated with sample calculations in the Appendix.

In a well-filtered pool with an average depth of about 5 feet, at least 75%, but probably no more than 85%, of the incident solar energy will be absorbed, heating the water. Approximately 5% of the solar energy is reflected from the water surface without heating the water. A significant amount of solar energy (particularly the energy at short wavelengths) is able to penetrate to the bottom or sides of the pool, reflect back up through the water and out of the pool. The white plaster ordinarily used for pool construction is a poor absorber of short wavelength radiation. This is precisely one of the reasons it is used. The sky is blue because of scattered solar radiation of a wavelength of about 0.4 microns wavelength. Enough of this is able to pass through the water, bounce off the pool walls and bottom, and reach your eyes so as to give you the illusion of having blue water in your pool. If the pool water is not filtered properly so that it is murky, or if the pool bottom and sides are given an absorbent coating, probably between 85% and 95% of the solar energy incident on the pool will be converted to useful heat. Both of these choices are probably aesthetically unacceptable.

The pool "collection efficiency" of 75% to 85% mentioned above is based on an average pool depth of about 5 feet, and an average angle of incidence of the solar energy on the water surface of about 45°. The actual angle of incidence, of course, changes throughout the day. For a totally unshaded pool, the energy incident on the water can be found using Section 2.7. For shading during some part of the day, see Section 2.8 and 2.9.

The heat losses from the pool increase as the pool temperature is increased. If we want the pool to be at a higher temperature, we simply have to pour in enough heat to compensate for the increased losses. If less heat than necessary is supplied the temperature will drop; if more than necessary, the temperature will rise.

An average pool of reasonable depth, has a great deal of thermal inertia. Normally it will take several days to adjust to changed conditions, whether the change is a change in heating or in weather. These transients need not concern us too much. If the weather turns really bad chances are that interest in swimming will be slight. If the weather suddenly becomes very warm, a time lag of a day or so may be temporarily bothersome, but this is unlikely to happen too often.

The heating requirements can be obtained by simply calculating the heat losses of the pool at the desired operating temperature. Part of this heating requirement is received free of charge from direct sunlight impinging on the pool. The rest must be supplied on purpose and will cost money.

There are a number of factors involved in the loss of heat from a pool. Normally the losses into the ground are negligible, and are readily returned whenever the pool temperature drops a bit. There are significant radiation (infrared radiation) losses to the sky. The effective sky temperature for radiation purposes is always lower than the ambient temperature. There are convection heat transfer losses to the air. If there is no wind, this occurs by natural convection, through the rising of hot or moist air; if it is windy, then one has "forced convection". Finally, and most significantly, there are evaporative losses whenever the air is dry enough and the water is warm enough. Even if you live in a muggy climate, once you start heating the pool much of the heat loss will be by evaporation.

Water will evaporate from the pool whenever the water vapor pressure in the air is lower than the vapor pressure of the pool water. The heat necessary for the evaporation process is drawn from the pool water. The vapor must be carried away by the air by diffusion and convection (flow) processes. If the air is stagnant the water vapor pressure next to the pool surface increases, and the process slows down. The evaporation heat losses will be as large as the vapor removal process (by air) will allow it to be. Fortuitously, the vapor removal process by the air is very similar to the convection heat transfer process in air, so that both the evaporative and the convective losses can be tied to the same heat transfer coefficient.

Equation (9) shown below gives the total heat loss per hour due to all of these mechanisms. The equation is based on the ones shown by Czarnecki (Reference 8). The parameter U_L used previously has been broken up into the convection heat transfer coefficient h_{ca}, and the radiation heat transfer coefficient which at pool temperatures happens to be roughly equal to 1.0 Btu/sq ft/hr/deg F. The evaporative heat loss has been included, as suggested earlier, by using the convection heat transfer coefficient, water vapor pressures as a "driving force," and a proportionality factor which also gets the units straight. The final equation is:

$$Q_L = A_p\,[\epsilon R + 1.0(t_w - t_a) + h_{ca}(t_w - t_a) + 200 h_{ca}(P_w - P_a)] \tag{9}$$

In this equation

Q_L - is the heat loss from the pool in Btu/hr.

A_p - is the area of the pool in sq ft.

ϵ - is the effective emissivity of water, equal to about 0.9.

R - is the radiation heat loss to the sky of a black body ($\epsilon = 1.0$) at t_a (ambient temperature), about 25 Btu/sq ft/hr according to Bliss (Reference 9).

t_w - is the temperature of the pool water in deg F.

t_a - is the ambient temperature in deg F.

h_{ca} - is the convection heat transfer coefficient between the pool water and the air, equal to about 1.5 Btu/sq ft/hr/deg F at a wind speed of 6 MPH. (See Figure 3 for other windspeeds).
P_w - is the water vapor pressure in equilibrium with the swimming pool water, as found from Figure 28 (see below), in lb/sq in.
P_a - is the water vapor pressure in the air, as found from Figure 28 (see below), in lb/sq in.

The humidity in the air is usually given as relative humidity. The trouble with relative humidity is that it fluctuates very much during the day, since it is related not only to the water-vapor content of the air, but also to the air temperature. Absolute humidity, described as water vapor pressure (P) or as water vapor content of the air, is much more stable. The relative humidity is generally maximum just before dawn, and drops to a minimum which approximately coincides with the maximum temperature. Absolute humidity generally rises slightly during the day because of sun-produced evaporation, and drops slightly during the night because of dew condensation.

The water vapor pressure P_w in equilibrium with pool water at temperature t_w can be found from Figure 28 by using the 100% relative humidity line, and using t_w for the temperature. The water vapor pressure in the air, P_a, can probably be determined in a fairly reliable way by using Figure 28 with the maximum temperature measured during the day, together with the lowest relative humidity. You might, as a check, determine a vapor pressure value using the highest relative humidity together with the lowest temperature. If there is a spread between these two values, you might use the average. The input numbers are generally available in daily weather reports. If the use of Equation (9) seems too troublesome, Equation (10) below, is much simpler and may be quite adequate.

Equation (9) can either be used hour-by-hour, with the ambient temperature t_a and the heat transfer coefficient h_{ca} (but not the vapor pressure P_a changed hourly as necessary, or it can be used to describe operation during the full day, by multiplying by 24 hours and using average values. The temperature of the swimming pool normally does not change much in one day.

To use this equation one must balance the heat losses with the heat gains. Part of the heat gains are obtained free by direct sunlight falling on the pool, of which about 80% is absorbed. Part can come from either a gas or solar heater. If one wishes to evaluate an existing installation, one must find the temperature at which the heat losses and gains are equal. To design a heater system, decide on the water operating temperature, determine the heat losses, determine how much of this has to be supplied by the heater, and then size the heater accordingly. Sample calculations are shown in the separate Appendix.

One interesting thing to obtain from Equation (9) is the increase in heat losses from the pool when the pool temperature is increased. If we draw a straight line to approximate the 100% relative humidity line on Figure 28, we find that for every degree F of increase of the pool temperature, the water vapor pressure P_a goes up roughly 0.016 lb/sq in. With this number, we can get from Equation (9):

change in Q_L =

$$A_p(1.0 + h_{ca} + 3.2h_{ca})(\text{change in } t_w) \qquad (10)$$

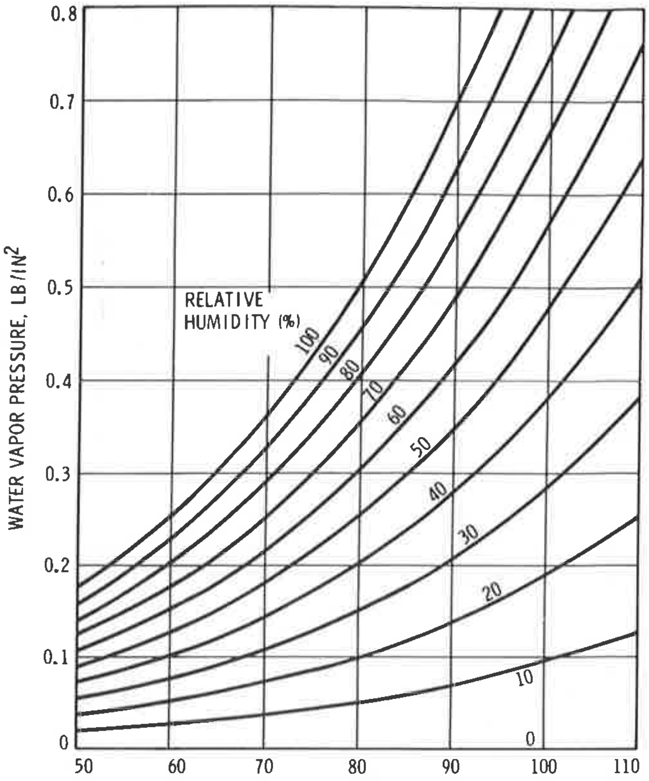

FIGURE 28. RELATIONSHIP BETWEEN WATER VAPOR PRESSURE, AIR TEMPERATURE AND RELATIVE HUMIDITY

Only the terms involving t_w in Equation (9) were used in Equation (10). The product of the factor of 200 in Equation (9), and the factor of 0.016 mentioned in the last paragraph, leads to the factor of 3.2 in the last (evaporative) heat loss term in Equation (10). It is clear that as the pool temperature is increased, 3.2 times more heat is lost by evaporative cooling than by convective cooling. This is why a pool cover is so effective, although all it does is prevent evaporation.*

Equation (10) has some advantages and some disadvantages. It is much simpler than Equation (9), and does not need complicated and hard-to-obtain weather inputs. Since the pool temperature does not generally change much in one day, Equation (10) can be used throughout the day. In Equation (9), on the other hand, since the ambient temperature changes continuously, one must determine average conditions or calculate results for different times of the day. From Equation (9) one can calculate the temperature of the unheated pool, from Equation (10) one can not. If however there is another unheated pool in your neighborhood, or if your pool was previously unheated, you may not need to calculate this at

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*The cheapest way to "heat" a swimming pool is not with gas or even with a solar heater, but with a pool cover. Simply floating a transparent plastic film, or hollow balls, on the water, for example, can reduce evaporative cooling (as well as associated water loss). (Reference 10).

all. You may already know the temperature of the unheated pool, or you can make a good guess at it. If your guess is anywhere near correct, then you will be able to make accurate calculations of the temperature rise which will be produced by a given amount of heating. Examples are shown in the Appendix.

Completely satisfactory calculations using Equation (9) or (10) are made difficult by the lack of reliable weather data. Most people have no way of knowing the wind velocity near their pool. The temperature values given in weather reports are normally maximum and minimum values for a location which may have a somewhat different climate. Weather report humidity values have the same limitations, and besides, the relative humidity values can not be translated into accurate values of water content of the air. Insolation values are not even given in weather reports, so that one must use average values measured for a particular time of the year. The only way around these difficulties would be to set up a fairly complete weather station of your own with continuous data recording. This is obviously impractical, yet even this would only allow you to make historical calculations after the fact. Reliable predictions are out of the question. One must be content with results approximately applicable to different times of the year.

2.13 The Effect of Collector Size

The effect of collector size follows in a logical and simple way from the effects and equations which have been described previously. The effect merits some extra discussion simply because the collector size is one of the most important parameters involved in a pool heater installation. The cost will be almost totally determined by the size of the collector. The amount of heat collected will also be related to collector size.

Consider a collector of a given orientation. Taken by itself, the larger the collector the more heat it will collect. When it is coupled to a pool, however, as soon as heat is put into the pool the pool temperature will begin to rise. As this happens the operating temperature of the collector is increased, and it will begin to collect less heat per unit area. As a result of this selflimiting mechanism one gets a diminishing return on investment as one makes the collector larger and larger.

This is not the only mechanism which produces a diminishing return on investment. The circulation flowrate depends on pool size. As the collector is increased in size (pool size and flowrate remaining constant) the panel efficiency F_3 will decrease since the value of G in Equation (8) (see also Figure 6) is decreased. Heat losses from a large panel are hence inherently larger than from a small one, and it is less efficient as a result.

These effects are apparent when the performance of some pool and heater combinations are calculated for some typical days, and for some different values of the ratio of heater area to pool area. Such results for a bare panel are shown on the next page in Figure 29, for a panel with one glass or plastic cover in Figure 30. One sample calculation for each of these figures is shown in the Appendix. If there were no diminishing return on investment all the lines would be straight. The fact that the lines bend down represents a reduction of collection efficiency.

The lines on the figures are based on 8-hour-collection day. It is assumed that the temperature of the unheated pool will be 10 deg F below the average ambient temperature during collection hours, as shown in the Appendix. For the bare panel it is assumed that $F_2 = 0.80$. This is the approximate average for the optimum bare panel designs discussed in the Appendix. For the glazed panel $F_2 = 0.85$, again taken from the Appendix. Values are given for different average solar input fluxes during the eight collection hours.

The figures can be used, in conjunction with the solar input maps of Section 2.7 and the hourly calculation techniques of Section 2.8, to get a fairly accurate estimate of the heating value you can expect from a solar heater. You can then decide how big to make it. It should be noted that the figures are not only useful for the 8 hour collection time at the fluxes given. The performance is quite similar for other combinations of collection times and fluxes, so long as the product of the collection times and fluxes is the same. The performance of a panel collecting a flux of 150 Btu/hr/sq ft for 8 hours is very close to that corresponding to 4 hours at 300, 6 hours at 200, or 12 hours at 100.

It is interesting to compare the performance of the bare and the glazed panels. Earlier in Section 2.10 a simple illustration was given of the advantages of a glazed panel, using the calculation of Q_{ideal}. It was mentioned that the reduction of the heat loss coefficient U_L produced by the glazing improved the performance further. This is now evident from the two figures. When used for obtaining a small temperature increase of the pool, the bare and glazed panels have virtually identical performance. As soon as the temperature increase (or the panel size) becomes appreciable the glazed panel begins to outperform the bare panel. This is still, of course, on an area basis. The glazed panel is inherently more expensive. In Section 3.1.4 the lines are replotted on a cost basis, using the estimated costs of the panels.

3. THE ECONOMICS OF SOLAR POOL HEATING*

The main reason for the relative lack of success of solar water heating has been in economics rather than technology. Commercially built solar water heaters have not often been competitive, compared to heating with fossil fuels. Up to now, it has generally not been possible for a manufacturer to make a profit on a competitive solar heat collector. This has discouraged potential manufacturers.

The economics of solar energy is tied to competing fuels or heat sources. Where these are expensive or unavailable, solar energy has often proved to be a viable alternative. In Australia, Japan and the Middle East solar energy for domestic water heating, for example, has long been used. In the United States the low cost of natural gas has made solar energy economically uninteresting, except in Florida where solar water heating has been (and to some extent continues to be) quite successful. Had it not

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*The costs, interest rates, etc. used here are those that prevailed at the time of writing for the author. The reader will want to adjust the calculations to reflect current costs in his locality.

been for the widespread advent of cheap natural gas, solar water heating might have long ago become common in many parts of the nation. As it is, many people who have built well-designed solar heat collectors themselves (and thereby saved themselves all costs except the cost of materials) have been very happy with the savings realized. This has not been restricted to Florida by any means, but has included most states with reasonably sunny weather.

Quite possibly you also can have an economically worthwhile solar energy collector, if you build one using the instructions in this manual. You can determine this by following the calculations in this section and then running through some numbers of your own. It will be assumed throughout this section that you will be donating your time to the project. Some rough estimates of time consumption are given in Section 4.

Use of Figures 29 or 30

To use figures 29 or 30, go to the month and place of interest in insolation Figures 9 — 20, and find the daily insolation in Langleys per day. Multiply this by 3.69 to convert to Btu/(sq ft day), then multiply by 0.9 to get the easily collectable heat input, and divide by 8 to get hourly values for use in Figures 29 or 30. You can then find the temperature rise you will get in your pool as a function of the ratio: (collector area)/(pool area).

The appearance of your solar panel will depend on your sense of esthetics and on the quality of your design and construction. Conservation of natural (fossil fuel) resources, pride of craftsmanship or similar arguments are difficult to place a value on. Usefulness however can be pinned down in a very specific way. A solar heater requires a certain amount of investment. This can be compared to the savings in gas heating (and in gas heating equipment) which can be realized. In some cases a solar heater can double as a roof cover which will probably outlive most houses.* This again can be taken into account.

In the following sections the economics of solar pool heating are explored in some detail. In Section 3.1 the costs of solar heating are discussed for the different types of heaters one can build following this manual. In Section 3.2 the competing gas costs are discussed. The annual cost of the equipment is related to the expected lifetime and to the cost of borrowing money in Section 3.3. Section 3.4 is concerned with cost comparisons. The costs of copper and

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*In addition, a heater mounted on your roof will keep the sunlight from heating the roof, and will reduce air conditioning costs and increase comfort.

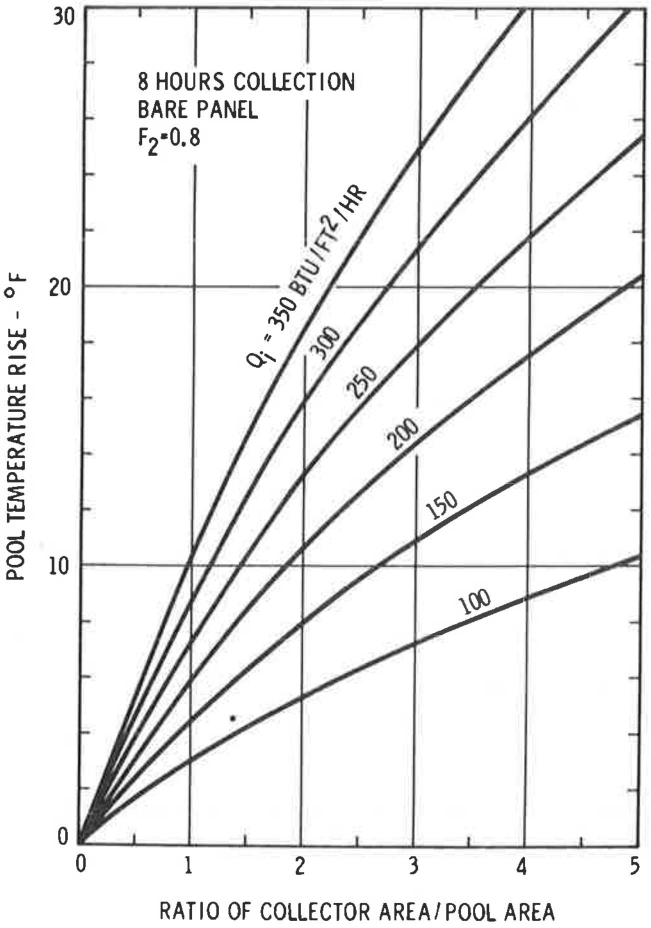

FIGURE 29. HOW THE RISE IN POOL TEMPERATURE PRODUCED BY A BARE SOLAR COLLECTOR VARIES DEPENDING ON SOLAR INPUT AND ON THE RATIO OF COLLECTOR AREA TO POOL AREA

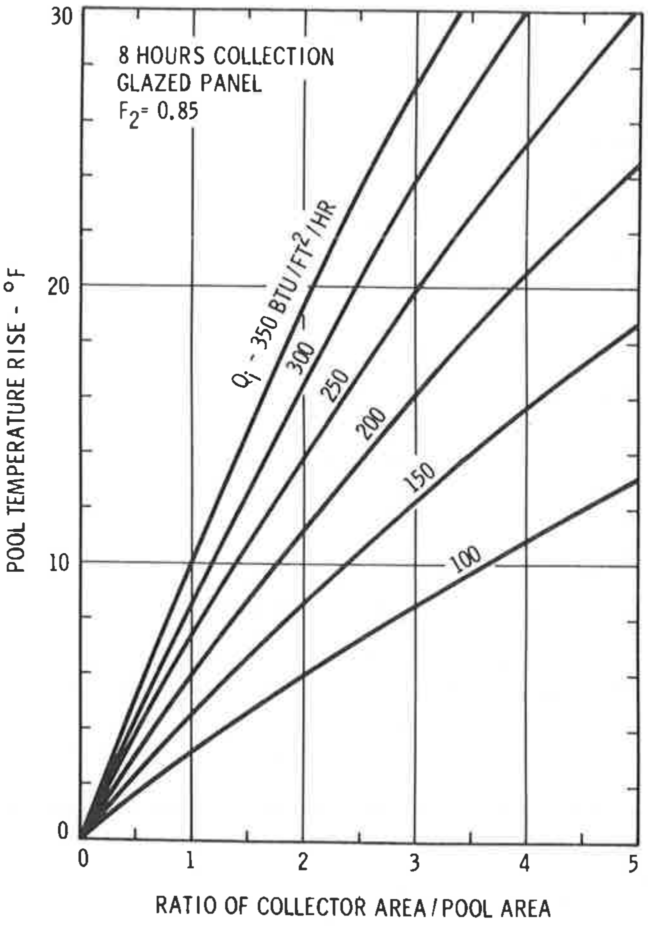

FIGURE 30. HOW THE RISE IN POOL TEMPERATURE PRODUCED BY A GLAZED COLLECTOR VARIES DEPENDING ON SOLAR INPUT AND ON THE RATIO OF COLLECTOR AREA TO POOL AREA

gas (or other fuel) in your area may be somewhat different, and will change as time passes; solar heat inputs also vary from place to place. It is easy to substitute your own numbers for the ones used in the examples calculated.

3.1 The Cost of Solar Collectors

Two types of solar water heaters are described in this manual. One is a simple heater, the other is a heater also used as a roof. Either can be left bare or covered with a glass or plastic cover.

The cost of these types of heaters is discussed below for a typical design size and configuration. The discussion does not include every nut and bolt in detail, since this would add more in confusion than in accuracy. Instead, reasonable allowances are included for the odds and ends which will vary from installation to installation. If you make careful design drawings or sketches for your own installation, you can pin down the required materials and costs as accurately as you wish.

In a gas heater installation one normally gets a complete setup ready to function. To compare solar heater costs with gas heater costs, the solar heater should also be charged with all the plumbing and other parts needed to make a complete setup. Normally a solar heater requires more piping than a gas heater. One might want to try to get a gas heater off in a corner somewhere where its appearance is unnoticeable. It probably can be placed close to the filter and pump. If esthetics is a concern, the filter installation will probably have been placed in an inconspicuous location, and no extra effort will be required for the gas heater. For a solar heater however one has to install piping to go to the nearest roof or other collection area, and there is no guarantee that this is close to the filter system. A total of 60 feet of extra plumbing is included in the solar heater systems for this reason. It is assumed that the large tubing used is of 2-inch nominal diameter, Type L. It could be Type M, which is about 25% lighter, or Type DWV, lighter still.

3.1.1 Cost of a Simple Collector

Let us look at a panel of 600 sq ft, 30 ft long in the direction of flow and 20 ft wide. This is the same as the example used in the sample calculations for Section 2.5 (see the separate Appendix). Let us use 3/8-inch nominal diameter (i.e. 1/2 inch actual O.D.) Type L tubing for the heater tubes, and look first at a panel with 10 oz thick sheet material, then at one with 20 oz to get a cost spread. Typical copper prices are used. Optimum tube spacing values are from Section 4.

For the 10 oz material, we get a cost of about $2.05 per sq ft, quite competitive with natural gas as shown in Section 3.4. It is assumed that no special mounting structure is necessary, and that a roof is available on which the heater can be mounted. If a special mounting fixture is needed, this can be added in. Per square foot, such a structure is however not likely to cost too much.

The 20 oz material leads to a collector roughly 80¢ more expensive per sq ft than the 10 oz material. At $2.83 per sq ft, this is still cheaper in some cases than heating with gas. As before, the cost of any necessary structure can be added, on a per square foot basis.

The Cost of Glazing. The best grades of Tedlar-coated greenhouse glazing material costs roughly 40¢ per sq ft. A mounting structure to mount the glazing about 1 inch above the panel is not likely to cost more than 15¢ per sq ft in materials. The total cost of glazing is hence unlikely to be more than about 55¢ per sq ft. For temporary use, thin plastic films can be used at a negligible cost.

COST BREAKDOWN *

Collector Using 10 Ounce Material

Copper Sheet:	600 sq ft of 10 oz material (375 lbs)	
Heating Tubing:	30 tubes spaced 8 inches apart X 30 ft long (900 ft) of 3/8 inch nominal diameter type L tubing	
Solder:**	Bought at $2.50/lb, this takes roughly 15¢/ft of tubing joined to the panel, X 900 ft	
Fittings:	For joining heater tubes to headers, 60	
Large Tubing:	5 lengths of 20 ft each	
Valves:	2	
Other Fittings, Paint and other odds and ends:		
	TOTAL	$1,228.00

Collector Using 20 Ounce Material

Copper Sheet	600 sq ft of 20 oz material (750 lbs)	
Heater Tubing:	27 tubes spaced 9 inches apart X 30 ft long (810 ft) of 3/8 inch nominal diameter type L tubing	
Solder:**	Bought at $2.50/lb, this takes roughly 15¢/ft of tubing joined to the panel, X 810 ft	
Fittings:	For joining heater tubes to headers, 54	
Large Tubing:	5 lengths of 20 ft each	
Valves:	2	
Other Fittings, Paint and other odds and ends:		
	TOTAL	$1,699.00

* CDA does not include price information in its publications. The totals were calculated by the author based on the prices paid early in 1973 and will increase 30% to 40% for late 1975 prices.

** The plumbing takes virtually no solder

Summary of Simple Panel Costs

Costs were calculated for 14 oz and for 16 oz material in the panels, and the results for all the panels are summarized below.

Sheet Weight	Sheet Thickness	Tube Spacing	Panel Cost (600 sq ft)	Panel Cost Per sq ft
10 oz	0.0135″	8 ″	$1,228.00	$2.05
14 oz	0.0189″	8½″	$1,390.00	$2.31
16 oz	0.0217″	8½″	$1,491.00	$2.49
20 oz	0.0270″	9 ″	$1,669.00	$2.83

3.1.2 Cost to be Assigned to the Heating Function of a Dual Heating/Roofing Collector

Let us look again at a 600 sq ft heater, built using batten seam roofing. When building such a heater/roof, you can estimate the copper sheet requirements quite accurately if you make careful drawings and calculations. As a rough estimate it can be assumed that about 50% more sheet will be needed than the area to be roofed. This includes a modest allowance for scrap as well as the cleats, batten caps, pans, etc.

As before in the simple panels, 3/8-inch nominal diameter (i.e. 1/2 inch actual O.D.) tubing of Type L is used for the heater tubes. These are to be used two to a pan. In most designs this yields a tube spacing somewhat larger than the cost-optimum, but this has only a negligible effect on cost-effectiveness. The tubes are assumed to be an average of 8 inches apart for a roof using 16 oz material, and 9 inches apart for a roof using 20 oz material. The actual width of the pans is not specified. It does not affect the numbers very much, and enough of a safety factor has been built into the results to allow for different pan widths.

For a heater/roof using 16 oz copper sheet, the cost per square foot is $3.27, for one with 20 oz sheet material, the cost is $3.71 per sq ft.

The question now is how much of these costs should be charged off to the heating function, and how much to the roofing function. This is a difficult question to answer, since a number of things are involved. A copper roof will outlast most other types of roofs, and probably most houses. Any reasonably good roof is likely to cost between 50¢ and $1.00 per square foot in materials alone. How much to apply as a subsidy in determining the actual cost to be charged to the heater is an answer only you can supply. It depends not only on the cost of competing roofing materials, but also on whether you need a new roof.

The Cost of Glazing. As in Section 3.1.1, the cost of glazing can be assumed to be no more than 55¢ per sq ft.

COST BREAKDOWN

Heating/Roofing Collector Using 16 Ounce Material

Copper Sheet:	600 sq ft X 1.5 = 900 sq ft of 16 oz material (900 lbs)
Heater Tubing:	30 tubes spaced 8 inches apart X 30 ft long (900 ft) of 3/8 inch nominal diameter type L tubing
Solder: *	Bought at $2.50/lb, this takes roughly 15¢/ft of tubing joined to the panel, X 900 ft
Fittings:	For joining heater tubes to headers, 48
Large Tubing:	5 lengths of 20 ft each
Valves:	2
Other Fittings:	
Paint, nails, rivets, battens, building paper, and other odds and ends	
TOTAL	$1,964.00

Heating/Roofing Collector Using 20 Ounce Material

Copper Sheet.	600 sq ft X 1.5 = 900 sq ft of 20 oz material (1,125 lbs)
Heater Tubing:	27 tubes spaced 9 inches apart X 30 ft long (810 ft) of 3/8 inch nominal diameter type L tubing
Solder: *	Bought at $2.50/lb, this takes roughly 15¢/ft of tubing joined to the panel, X 810 ft
Fittings:	For joining heater tubes to headers, 40
Large Tubing:	5 lengths of 20 ft each
Valves:	2
Other Fittings:	
Paint, nails, rivets, battens, building paper, and other odds and ends	
TOTAL	$2,260.00

* The plumbing takes virtually no solder.

3.1.3 Collector Lifetime

Although there is not much actual experience on the specific heaters described in this manual, there is a virtually unlimited amount of experience on the long term performance of copper in essentially identical applications.

Since WW II alone, more than 7 million miles of copper plumbing have been installed. Most of this is expected to outlast the buildings in which it is used. The cases in which failures have occurred have been miniscule in number and the types of failures that can occur have been studied carefully. Some have been due to faulty workmanship. Where tubes have corroded, corrosion has generally been associated with water which was aggressive either as a result of high concentrations of dissolved carbon dioxide, or hydrogen sulfide, or sulfates, or ammonia. If swimming pool water is kept at the recommended acidity, alkalinity, and available chlorine levels, copper tubing should last indefinitely, since there will never be high concentrations of these corrosive substances. Copper tubing buried in naturally occurring soils is rarely corroded. Filling the trench with ashes or similarly corrosive material should be avoided, of course. Heavy application of fertilizer or of de-icing salts could also cause trouble. Excessively high water velocities can lead to failures. Freezing should be avoided, although some water-filled copper tubes have been frozen repeatedly as many as 15 times before failure, since copper can deform significantly.

In the solar heater application, the main danger seems to be freezing. If there is any possibility of freezing in your area, make sure that the heater will drain completely whenever the pump is not running.* If this is done, if the pool water is kept at the recommended chemistry levels, if the tubing is assembled and soldered properly, and if it is not buried in ashes or drowned in fertilizer, then the tubing should last essentially forever.

Copper roofs have lasted for centuries. Solder joints do not produce galvanic corrosion effects because lead and tin are close to copper in electrochemical potential. In areas in which severely corrosive atmospheres exist it is

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*Gas heaters must also be drained when there is danger of freezing.

sometimes recommended that copper roofing or flashing components be coated.*

The solar heaters described in this manual really only involve a straightforward combination of plumbing and of roofing components. If the heater is assembled properly, if it drains properly in freezing weather, and if there are no earthquakes, hurricanes or similar events, there is every reason to expect the heater to outlast the pool and associated structures.

For calculation purposes, a lifetime of 20 years has been chosen for use in this manual. The building supporting the heater might not last more than 20 years. Many other things can happen, including change of ownership, removal of pool, etc. It is hard to plan ahead more than 20 years. As shown in Section 3.3, there is not much to be gained in using lifetimes longer than 20 years, except at very low interest rates. At current interest rates one might as well use a 20 year life.

3.1.4 The Effect of Collector Size

In Section 2.14 the effect of collector size on performance was explored in some detail. It was shown that there was a diminishing return on investment as the area of the collector was made larger, and that this was different for a glazed collector and a bare one. The comparison was made on the basis of area. In most cases it is probably more significant to compare on the basis of cost. This can be done quite simply using the graphs shown in Section 2.14, and the costs developed in Section 3.1.1 and 3.1.2.

As a typical cost for a bare heater, let us take a cost of \$2.30 per sq ft of heater surface; for a glazed heater let us use \$2.85 per sq ft. This could apply to a collector which only serves as a heater, or as the cost of the heater portion of a dual heater/roof, after the roof function subsidy has been subtracted. The figures can then simply be replotted, multiplying the lower axis by \$2.30 per sq ft of collector area in the case of bare collector, and by \$2.85 per sq ft of collector area in the case of a glazed one. The results are shown in Figures 31 and 32.

It is quite clear from the figures that a bare panel will almost invariably be more cost-effective than a glazed one. Virtually the only type of application where one might want to use a glazed panel, is where a solar heater is to be used in conjunction with a gas heater. In a sample calculation for such a situation, it was shown (see the calculations for Section 2.12 in the separate Appendix) that in one particular application the glazed panel would

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Use of Figures 31 or 32

To use Figures 31 or 32, go to the month and place of interest in insolation Figures 9 – 20, and find the daily insolation in Langleys per day. Multiply this by 3.69 to convert to Btu/(sq ft day), then multiply by 0.9 to get the easily collectable heat input, and divide by 8 to get hourly values for use in Figures 31 or 32. You can then find the temperature rise you will get in your pool as a function of heater investment per unit of pool surface area.

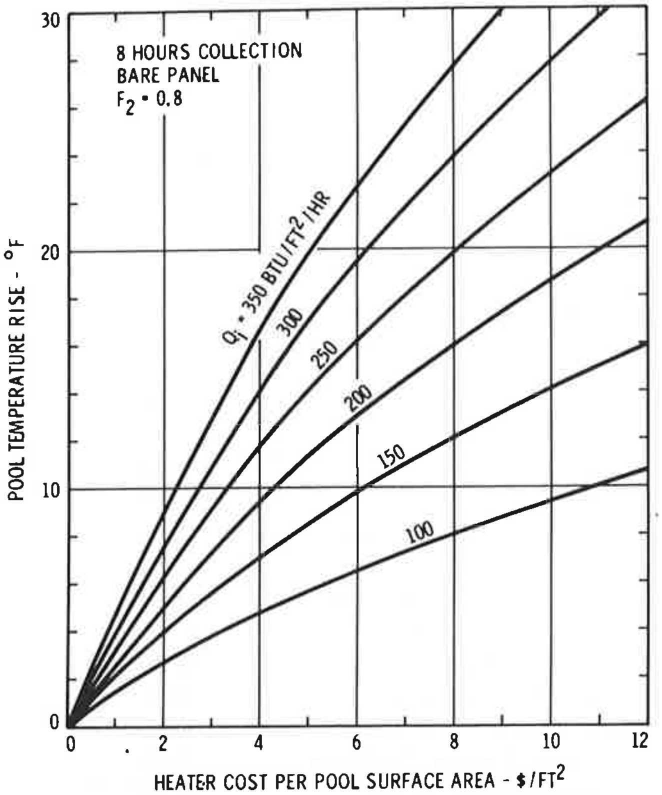

FIGURE 31. HOW THE RISE IN POOL TEMPERATURE PRODUCED BY A BARE SOLAR COLLECTOR VARIES DEPENDING ON SOLAR INPUT AND THE INVESTMENT IN THE COLLECTOR PER SQUARE FOOT OF POOL AREA

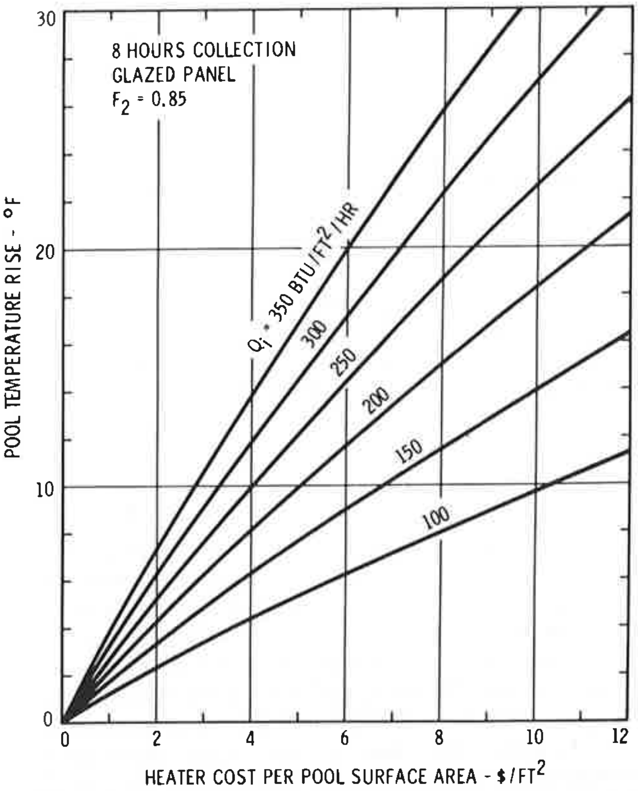

FIGURE 32. HOW THE RISE IN POOL TEMPERATURE PRODUCED BY A GLAZED SOLAR COLLECTOR VARIES DEPENDING ON SOLAR INPUT AND THE INVESTMENT IN THE COLLECTOR PER SQUARE FOOT OF POOL AREA

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*The solar heaters are thoroughly coated with paint or with asphaltum, so that they have this protection whether there are corrosive atmospheres or not.

be 34% better (i.e. 1.34 times better). This must now be adjusted by the ratio of panel costs, $2.30 vs. $2.85. When this is done, the glazed panel is only 1.34 x 2.30/2.85 = 1.08 times better than the bare one, so that the margin is cut from 34% to 8%. We do not recommend the use of a glazed panel for a swimming pool heater. It simply is not cost effective.

The moral of the story is clear. Unless you are absolutely certain after a lot of calculations that you need a glazed collector, build a bare one. If you want to enhance collection at times when the heat losses from a bare panel are high, you can always use a temporary, inexpensive plastic film, removing it after use.

The downward curve of the lines in Figures 31 and 32 represents a diminishing return on investment as the collector is made larger. The reason is quite simple. As the collector is made larger, it heats the pool to a higher temperature, and hence collects less per unit area. This diminishing return on investment mechanism is not very serious; the lines do not bend down very much. One can make an enormous – and enormously costly -collector and still collect at fairly good efficiencies.

You can evaluate the economics of a collector of any size following the calculations shown in Section 3.4. This can help you decide on the size collector to build. In all probability the diminishing return on investment effect will not be the factor which limits the maximum size of your collector, since this effect is very slight. The maximum size of your collector will probably be determined by the amount of heating you want, or the cost of the collector, as follows:

(1) The amount of heating you want. If you make the collector so large that it heats the pool to a temperature higher than you really want, you will be paying for energy you do not need and do not use.

(2) The cost of the collector. The collector can represent a sizable investment. You should estimate the costs carefully before you decide on the size of the collector.

3.2 Competing Costs of Gas Heating

Gas heating of a swimming pool involves a sizable investment in a gas heater, and sizable gas bills whenever you have the heater turned on.

3.2.1 The Cost of Gas

Natural gas is an inexpensive commodity. As it becomes more expensive, solar energy will become much more popular. And it its probable that gas prices will go up significantly and steadily in the future, since the demand appears to be beginning to exceed the supply.

Gas is normally sold based on a volume measurement, in units of 100 cubic feet. Each cubic foot, on combustion, yields roughly 1000 Btu of heat. Since pipelines are interconnected the mix you are burning can vary, so that the actual heating value can be more or less than 1000 Btu per sq ft. The bill is generally adjusted accordingly, and you are charged so much per "therm." One therm is equal to 100,000 Btu, so that it is equivalent to the heating capability of 100 cubic feet of gas of 1000 Btu per cu ft.

The Btu numbers refer to the "high heat value" of the gas, obtained when the water vapor formed in combustion is condensed out. The "low heat value", obtained when the water vapor is exhausted as steam, is about 10% lower.* In a pool heater one cannot afford to condense the steam since the coils would become wet and the combustion gases would form corrosive acids. Thus, in any well designed pool heater, at least 10% of the rated heating value of the gas is lost in the flue gases.

The cost of gas varies widely in different parts of the United States. The following table was taken from the 1968 edition of the Statistical Abstract of the U.S. (Ref. 11). Later editions no longer carry this table, and prices have already gone up significantly. Local rate schedules can be obtained from your gas company. In Pasadena, California, for example, the rate per 100 therms is $7.705 (as per Schedule No. G-2, dated May 14, 1971), plus a "users tax" of 7%, for a total of $8.244 per 100 therms Where natural gas is not available, L.P. gas or other gaseous fuels are at least 2 to 3 times more expensive than natural gas.

3.2.2 Cost, Life Expectancy and Efficiency of Gas Swimming Pool Heaters

The better gas heaters have a "list price" between $300 and $700 for an average pool. Almost invariably they can be bought well below the list price. Installation normally

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*For natural gas ("Pittsburgh") the high heat value is 1129 Btu per cu ft, the low heat value is 1021 Btu per cu ft.

Natural Gas Prices in Selected "Standard Metropolitan Statistical Areas" — Heating Rates in 1967 (Reference 11)

Standard Metropolitan Statistical Area	Average Price per 100 Therms at Heating Rates*
Atlanta, Georgia	$8.24
Baltimore, Maryland	12.77
Boston, Massachusetts	14.26
Buffalo, New York	8.86
Chicago, Ill. – N.W. Indiana	9.44
Cincinnati, Ohio – Kentucky	7.57
Cleveland, Ohio	7.29
Dallas, Texas	7.34
Detroit, Michigan	8.50
Houston, Texas	7.72
Kansas City, Missouri – Kansas	5.81
Milwaukee, Wisconsin	10.67
Minneapolis, St. Paul, Minnesota	8.11
New York, N.Y. – N.E. New Jersey	12.92
Philadelphia, Pennsylvania	13.67
Pittsburgh, Pennsylvania	8.00
St. Louis, Missouri – Illinois	8.39
San Francisco, Oakland, California	6.08
Seattle, Washington	11.50
Washington, D.C. – Maryland – Virginia	12.87

* Including taxes. 100 therms equals 10 million Btu's.

requires a permit for the gas piping. The installation of the gas piping can be expected to cost between \$1.50 and \$2.00 per lineal foot. A new installation for the average size pool can be expected to cost somewhere between \$400.00 and \$800.00.*

Most of the better gas heaters have a 1-year guarantee on the working parts and a 5-year guarantee on all others. The lifetime to be expected is probably close to 10 years.** The annual cost to be assigned to the heater depends on the lifetime, the original cost, and the cost (i.e. interest cost) of money, as discussed in Section 3.3.

Gas heaters are not able to convert all of the heat content of the gas into useful water heating. The efficiency of gas swimming pool heaters is usually advertised at 75% or 80%. There are several reasons for this. To begin with one cannot use the "high heat value" of the gas since this would lead to condensation on the coils, acid formation, and corrosion, as mentioned. In trying to collect only the "low heat value" about 10% is lost immediately. The more one wants to collect of the available heat, the more heat transfer surface is necessary. There one runs into the same type of diminishing-return-on-investment picture that one has with the solar heaters and it is simply not worthwhile to design for an excessively high efficiency, i.e., there is an efficiency optimum. Finally there are heat losses through the heater walls, which cannot be completely designed away.

Almost all gas appliances are built to satisfy an appropriate American National Standard prepared by the American Gas Association***. These involve reasonable criteria of safety, quality of construction, durability and suitability of materials, etc. Until recently there was no swimming pool heater standard, so that swimming pool heaters were built to satisfy Gas Water Heater standards 221.10.3–1971, or Gas-Fired Low-Pressure Steam and Hot Water Boiler standard 221.13–1972. In 1972 a special standard for Gas-Fired Swimming Pool Heaters 221.56–1972 was issued. This standard requires a minimum efficiency of 70%, and provides for standard methods to determine efficiency. In the next year or so, most manufacturers should switch over to the new standard, making the design and performance of heaters somewhat more uniform than it is now.

In this manual the efficiency of a typical gas heater is assumed to be 75%. It is unlikely that gas heater designs will ever be made much higher than 80% in efficiency, and they are unlikely to be below the 70% now incorporated into the American Gas Association standard. The efficiency of a gas heater is not likely to change significantly with changes in water temperature of the pool.

3.3 The True Annual Cost of Equipment

Equipment generally has a limited life, and its use involves tying up a significant amount of money. It is not correct simply to split the equipment cost among the years-of-life of the equipment. This is only an adequate accounting scheme if you keep your money in a mattress, and if the money you spend on the equipment has no influence on what you do with the rest of your funds.

It is much more realistic to imagine that you have to borrow the money (for buying the equipment) from a bank (or from yourself) at prevailing interest rates, and then pay it back in equal installments during the life of the equipment. Payments would be at the end of each year. The setup is the same as a home mortgage, and the only difference is that at the end of the payments the equipment is presumably worn out and has no remaining scrap value.*

The equation describing annual mortgage payments in terms of percentage rates and number of years is:

$$I = 100 \frac{(1 + r/100)^n (r/100)}{(1 + r/100)^n - 1} \qquad (11)$$

In this equation:

I - is the annual installment, as percentage of equipment cost

r - is the annual percentage rate (cost of money)

n - is the number of years

Numbers calculated with this equation are shown in Figure 33. As an example, using the figure, equipment

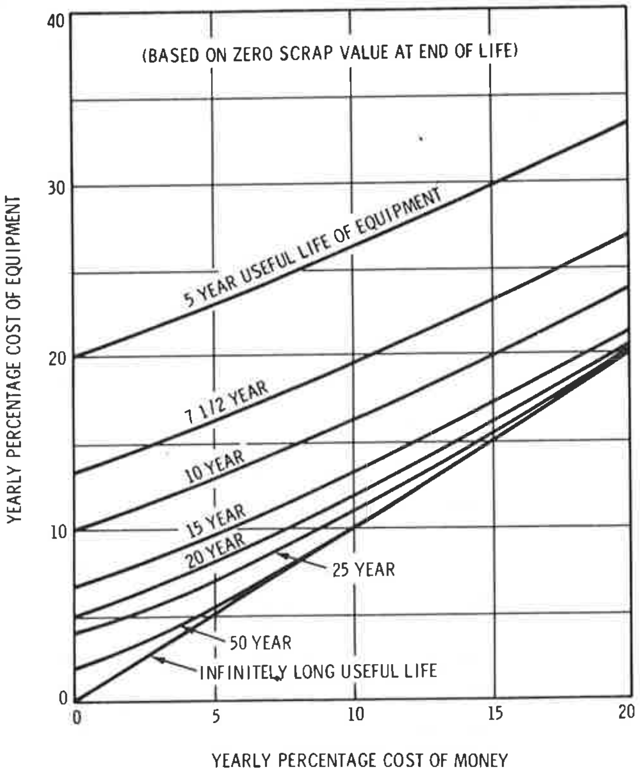

FIGURE 33. HOW THE YEARLY PERCENTAGE COST OF EQUIPMENT VARIES DEPENDING ON THE ANNUAL PERCENTAGE COST OF MONEY (INTEREST) AND ON THE LIFETIME OF THE EQUIPMENT

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*Because of the large consumption of gas, the piping often has to be installed back to the gas meter. In case of doubt, you might get a quotation.

**The life expectancy of the heater probably does not depend too much on how much the heater is used, particularly if the heater is installed outdoors.

***American Gas Association, Arlington, Va. 22204.

* Scrap value can of course be included in the equation. It is not predictable and it is conservative to leave it out, and treat whatever is obtained in scrap value as a windfall. It is worth noting however, that the value of copper scrap today is more than what it cost to buy as new mill products twenty years ago.

with a 10 year useful lifetime bought with money borrowed at 10% interest will cost 10 equal installments of 16.2%. If the equipment purchase cost is $600.00, the annual cost would be 16.2/100 x $600.00 = $97.20. The difference between the $600.00 and the 10 x $97.20 = $972.00 in actual payments is simply the cost of borrowing the money.

The interest rate to charge yourself in the calculations depends on where the money comes from. If it is withdrawn from a savings account or was invested in bonds, it would be earning about 6%. Since taxes have to be paid on these earnings, money you borrow from yourself is unlikely to cost more than about 5% per year, unless you have an investment with high earnings. If you have to borrow money from a lending institution, the best you can do is probably around 10%, after adjustment for the income tax deductions. These values, 5% and 10%, are based on a zero inflation rate. If there is a significant inflation rate, your cost of borrowing money is correspondingly less since you will be repaying your loan with money of decreased value.

3.4 Cost Comparisons

To compare the costs of gas and solar heating some decisions must be made. If you want to swim year-round, a gas heater seems essential. Even so, a solar heater can cut your gas bills at all times, year-round – and, during many months, there may be no gas consumption at all. If you are not interested in year-round swimming, you may not need to install a gas heater, which is an extra saving. The use of a pool cover adds another complicating factor to the calculations, generally increasing the effectiveness of both gas and solar heating. It is quite clear that the possible combinations of comparisons are endless.

Two cases are considered below as examples. In one case, calculations are made for a solar heater operating year-round in conjunction with a gas heater. In the other case a heater operates by itself only during the warmer part of the year. Only bare heaters are considered. Calculations for a glazed heater can be set up easily using the bare calculations as a model, but in most cases bare pool heaters will be more cost-effective than glazed.

After the calculations for the technical performance of the heaters, costs are calculated using two typical interest rates you might charge yourself, 5% and 10% per year (as discussed above). The calculations show that at 10% interest a solar heater can earn its keep, and at 5% it will almost invariably be a profitable investment.

The calculations are for the City of Pasadena; for other locations different weather input numbers will have to be used. The Pasadena values are shown in the following table. The daily heat input values are determined as shown in Section 2.7 (see sample in separate Appendix). The length of the day is determined as shown in Section 2.8. As before, collection during only 2/3 of the day is used, covering 90% of the incoming energy during this period. Average maximum and minimum temperature values were obtained from the Pasadena City Hall and the Chamber of Commerce (Reference 13). The mean air temperature during collection hours (t_a) was determined as shown in Section 2.8.

3.4.1 Solar Heater Used to Reduce Gas Consumption Only

The amount of heat collected at any time of the year (and hence throughout the year) can be calculated in a straightforward way using the methods described in Section 2, and the weather table above. It is necessary to decide the temperature at which the gas swimming pool heater thermostat will be set. In the calculations below this is assumed to be at 85 F. At the end of the calculations numbers are given for other operating temperatures.

Basic Weather Information for Solar Heater Performance Calculations in Pasadena, California

Month	Heat Input (horizontal collection)	Length of Day	Length of Collection	Temperature		
				Max Avg	Min Avg	Average
January	925 Btu/ft²/day	10.2 hr	6.8 hr	66 F	41 F	64.5 F
February	1,230	10.7	7.2	72	47	70.2
March	1,620	11.6	7.7	73	48	71.0
April	1,880	12.8	8.5	74	48	71.5
May	2,100	13.8	9.2	76	52	73.3
June	2,140	14.2	9.5	82	57	79.0
July	2,340	14.0	9.3	89	61	85.6
August	2,210	13.8	8.8	90	62	87.0
September	1,780	12.2	8.2	89	60	86.4
October	1,350	11.2	7.5	81	53	78.7
November	1,000	10.3	6.9	73	47	71.3
December	870	9.8	6.5	65	42	63.6

The total number of hours of collection is of interest when one wants to calculate the effect of the temperature of collection on the total heat collected. The total number of hours of collection in one year, using the above collection schedule, is 2,934 hours.

The calculations can be performed using the heat collection equations shown in Section 2. The heat collected during a month, per square foot, is given by:

$$Q_{month} = \text{(days per month) x (hours of collection per day) x } F_3 \text{ x } Q_{ideal} \text{ avg.}$$

$$= \text{days x hours x } F_3 \text{ x } [\alpha Q_i - \alpha R - U_L(t_{wi} - t_a)]$$

In the sample calculation for Section 2.12 (see Appendix) it was found that a typical bare panel equal in size to the pool and operated in parallel with a gas heater, might have an F_3 value of 0.75. It is not necessary to calculate Q_i and then multiply it by hours of collection, since we already have the heat input in a daily form. The rest of the equation is quite straightforward.

The calculations are arranged in the following table. In the first column is the month, in the second the number of days. The third column has the amount of heat absorbed per day during the month. This is obtained by multiplying the daily heat input first by 0.9 (since 90% of the input comes in during the 2/3 of the day using for collection), and then by the surface absorptivity $\alpha = 0.9$. For the first entry, 925 x 0.9 x 0.9 = 749. The next column (number 4) lists the temperature difference $(t_{wi} - t_a) = 85 \text{ F} - t_a$. For the first entry, using t_a as given in the previous table, we get 85 – 64.5 = 20.5. Column 5 gives the product of the temperature difference and U_L, for a bare panel equal to 2.5 Btu/sq ft/hr. Column 6 adds this to the radiation loss term $\alpha R = 0.9 \text{ x } 25 = 22.5$. Column 7 multiplies the result by the number of hours of collection. In column 8 these heat losses are subtracted from the absorbed heat input, and in column 9 the result is multiplied by $F_3 = 0.75$, and by the number of days, to give the total heat collection during the month. Finally the results are added to yield an annual value for the heat collected per square foot.

We now have all the figures necessary to make financial comparisons. We have numbers for the first cost of the solar heater, the heat collection of the solar heater, the efficiency of the gas heater, and the cost of gas.

Let us make the comparison on the basis of 1 square foot of collector area. During the full year this is able to collect 261,090 Btu's. Getting this from a gas heater with an efficiency of 75%, using gas costing $0.85 per million Btu's would cost*:

$$\text{Gas cost} = \frac{261{,}090}{0.75} \text{ x } \frac{\$0.85}{1{,}000{,}000} = \$0.296$$

Thus, one square foot collects the equivalent of about 30¢ worth of gas per year. The annual cost of a square foot of collector can be found from the equation in Section 3.3. If the collector costs $2.30 per square foot, if it is assumed to last 20 years, and if the money is borrowed at an interest of 10%, then the annual cost will be (see Figure 33) 11.8% of $2.30, or $0.272. The net annual profit per square foot of collector will be

Profit = $0.296 – $0.272 = $0.024

This is not very much, but it is a profit. At 5% interest (see Section 3.3) the profit would be $0.112 per square foot, quite a bit better.

These calculations were for operation at 85 F. If the gas heater had been set at a lower temperature, the collector would have collected more heat. You might check that the change in heat collection is given by:

change in collection = annual coll. hours x F_3 x U_L x change in temperature

In the weather table it was mentioned that the total number of hours of collection was 2934 hours. If the temperature of collection is dropped 5 degrees to a collection temperature of 80 F, the extra heat collection is:

change in collection = 2934 x 0.75 x 2.5 x 5 = 27,500 Btu/sq ft

the extra value of this is given by

Calculation of the Performance of a Bare Collector Throughout the Year in Conjunction with a Gas Heater Operating at 85°F in Pasadena, California

① Month	② Days	③ Q_{abs}	④ 85 – t_a	⑤ 2.5 X④	⑥ 22.5 +⑤	⑦ hrs X⑥	⑧ ③–⑦	⑨ 0.75 X②X⑧
January	31	749	20.5	51.2	73.7	501	248	5,760
February	28¼	1000	14.8	37.0	59.5	428	572	12,100
March	31	1310	14.0	35.0	57.5	443	867	20,200
April	30	1520	13.5	33.7	56.2	478	1042	23,700
May	31	1700	11.7	29.3	51.8	476	1224	28,500
June	30	1730	6.0	15.0	37.5	356	1374	30,900
July	31	1900	– 0.6	– 1.5	21.0	195	1705	39,800
August	31	1790	– 2.0	– 5.0	17.5	154	1636	38,200
September	30	1440	– 1.4	– 3.5	19.0	156	1284	28,900
October	31	1090	6.3	15.7	38.2	287	803	18,700
November	30	810	13.7	34.2	56.7	391	419	9,420
December	31	705	21.4	53.5	76.0	494	211	4,910

Total collected during year = 261,090 Btu/sq ft

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*See gas cost table in Section 3.2.1. Note that gas costs are already *much* higher than those 1967 values.

$$\frac{27,500}{0.75} \times \frac{\$0.85}{1,000,000} = \$0.0312 / \text{sq ft.}$$

The lower you set the temperature of the gas heater, the more your solar heater will be able to contribute. An additional 3.12¢ profit can be added, per square foot, by operating 5 degrees colder during a whole year.

It would be noted that there is one catch to the above 3.12¢ figure. Perhaps the pool and the solar heater already operated at 85 F during some of the summer months, without the need for gas heating at that time. This depends on the size of the panel, wind speed, shade conditions, etc. If this is the case, then setting the gas heater thermostat lower is not going to help you collect more during those months. The 3.12¢ figure should be reduced accordingly.

3.4.2 Solar Heater Replaces Gas Heater and Avoids Gas Consumption

In Section 3.4.1 the temperature at which the collector operated was controlled by the gas heater thermostat, and thus collector performance could be calculated in a straightforward manner. The pool and collector sizes never entered the picture, except insofar as they determined the flowrate of water through the collector, which affected F_3– a relatively minor effect.

When the solar collector is operated by itself without a gas heater, calculations are not so simple. In this case the relative sizes of pool and collector become important since the operating temperature of the collector must be calculated before one can determine how much heat it is collecting. It is shown in the Appendix that the temperature of an unheated pool was about 10 deg below the average daytime temperature, in a dry climate during times of high solar input (2200 Btu/sq ft/day).*

Starting from this 10 deg value, calculations were made of the heating performance to be expected from collectors of varying sizes operating with varying solar inputs. The results of these calculations are shown in Figures 29 and 30, in the form of temperature increase of the swimming pool due to the solar collector.

Calculations are shown in the following table for the heat collection for one full year in Pasadena, California. Calculations for other locations can be set up in the same way. The calculations are for a heater equal in area to the pool (assume both have an area of 600 sq ft). The calculations can be made the same way with any other set of areas.

The calculations are similar to those shown in Section 3.4.1. The first column shown is the month, the second the number of days in the month, and the third the number of hours of collection needed to intercept at least 90% of the daily insolation incident on a horizontal surface. Column 4 gives the average daily insolation on a horizontal surface; column 5 the daily absorbed radiation 90% of column 4 multiplied by the absorptivity ($\alpha = 0.9$) for a total factor of $0.9 \times 0.9 = 0.81$; column 6 calculates a somewhat fictitious number — the average heat flux in an 8-hour collection day which would give the same total as 90% of the insolation ($0.9/8 = 0.1125$). This is the value needed in Figure 29 to get the temperature rise the solar heater will produce. With a heater (collector) equal in area to the pool ($A_c/A_p = 1.0$) the temperature rise values obtained from Figure 29 are as shown in column 7.

Now Figure 29 was based on a pool which was 10 deg colder than the ambient temperature during collection hours. The temperature difference between the water temperature of the heated pool and the ambient during collection hours is calculated in column 8. This is multiplied by U_L, equal to 2.5 for a bare heater operating under typical conditions, in column 9. The negative sign shows that the heater is collecting heat from the air, since the air is hotter than the heater. Column 10 adds in the radiation heat loss αR. Column 11 multiplies the result by

Calculation of the Performance of a Bare Collector Throughout the Year Without Supplementary Gas Heating in Pasadena, California

① Month	② Days	③ Hours	④ Insol. Day	⑤ 0.81 X④	⑥ 0.1125 X④	⑦ T rise	⑧ ⑦—10°	⑨ 2.5 X⑧	⑩ 22.5 +⑨	⑪ ③X ⑩	⑫ ⑤–⑪	⑬ 0.77 X②X ⑫
Jan	31	6.8	925	749	104.0	3.2	– 6.8	– 17.0	5.5	37.4	711.6	16,950
Feb	28¼	7.2	1230	1000	138.5	4.0	– 6.0	– 15.0	7.5	54.0	946.0	20,800
Mar	31	7.7	1620	1310	182.0	5.4	– 4.6	– 12.5	10.0	77.0	1233.0	29,500
Apr	30	8.5	1880	1520	211.0	6.2	– 3.8	– 9.5	13.0	110.0	1410.0	31,800
May	31	9.2	2100	1700	236.0	6.8	– 3.2	– 8.0	14.5	133.0	1567.0	37,500
Jun	30	9.5	2140	1730	241.0	7.0	– 3.0	– 7.5	15.0	142.0	1588.0	36,600
Jul	31	9.3	2340	1900	263.0	7.7	– 2.3	– 5.75	16.75	156.0	1744.0	41,600
Aug	31	8.8	2210	1790	248.0	7.3	– 2.7	– 6.75	15.75	139.0	1651.0	39,400
Sep	30	8.2	1780	1440	200.0	5.9	– 4.1	– 10.2	12.3	101.0	1339.0	31,000
Oct	31	7.5	1350	1090	152.0	4.5	– 5.5	– 13.8	8.7	65.0	1034.8	24,700
Nov	30	6.9	1000	810	112.5	3.4	– 6.6	– 16.5	6.0	41.5	768.5	17,700
Dec	31	6.5	870	705	98.0	2.6	– 7.4	– 18.5	4.0	26.0	679.0	16,200

Total collected during year = 344,000 Btu/sq ft

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*Notice that the winter months (of low solar input) are not very important since a solar heater operating without the assistance of a gas heater is unlikely to make a swimming pool warm enough anyway.

the hours of collection, column 12 adds in the absorbed solar energy, and column 13 multiplies by the days in one month, and by F_3(equal to 0.77 in this case).

Notice that the total amount of heat collected during the year is more than that collected in the case shown in Section 3.4.1; the reason is simply that the heater is cooler, hence collects more. Of course the heat collected during the winter season is useless, if it does not heat the pool enough to make swimming enjoyable. To evaluate the economic performance of the heater we should look only at those months which will be part of the swimming season.

Consider the five months starting in May and going through September. The total heat collection per square foot during these months, added from the table, is 186,100 Btu. From a gas heater with an efficiency of 75%, using gas costing \$0.85/million Btu, this would cost:

$$\frac{186{,}100 \times}{0.75} \frac{\$0{,}85}{1{,}000{,}000} = \$0.211$$

The total heat collection from 600 sq ft collector is hence worth:

$$600 \times \$0.211 = \$126.60$$

A solar collector of 600 sq ft costing \$2.30 per square foot costs \$1380.00. At 10% interest, amortized over 20 years, the annual cost is 11.8% of the investment,* or \$163.00. A gas heater, costing \$600.00 amortized at 10% interest over 10 years has an annual cost of 16.2%, or \$97.20. The cost of gas heating in this case would then be \$126.60 + \$97.20 = \$223.80. The same function performed by the solar heater costs \$163.00, for a saving of \$60.80 per year.

If you charge yourself 5% interest per year, things are even better. The annual cost of gas heating becomes \$126.00 + \$78.00 = \$204.00. The annual cost of solar heating is \$110.40, for a saving of \$94.20.

This approach, using the solar heater alone, without a gas heater, seems to be the most profitable way of using solar heating for a pool. A solar heater can extend the season appreciably, and make swimming much more comfortable (especially early in the morning and late at night) during the summer. By eliminating both the need for gas and for a gas heater when used in this way, the economics are much enhanced — and you are not adding to the energy crisis by using up gas resources. It is very likely that solar heating when used in this way is cheaper than gas heating in many locations. Some calculations can show you whether the economics are favorable in your locality.

There are several things to keep in mind as you are deciding on the size of your own collector. It was shown above that a collector of a size equal to that of the pool was able to produce a nice profit. As the collector is made larger, it will operate at a higher temperature, collect less heat per unit area, and be a less profitable investment. This shows up in Figures 29, 30, 31 and 32 in the fact that the lines are not straight, but bend downwards. It is however quite possible to build a collector 3 or 4 times as large as the pool, still collecting the heat more cheaply than if you heated the same amount with gas. But there are two questions you must ask yourself:

(1) How much heating do I really want? A heater 3 or 4 times as large as the pool would heat the pool up by about 20 or 30 deg in summer, and this probably is more than you really want.

(2) How much do I want to invest? At \$2.30 or so per square foot a heater represents a sizable investment, and you should run through some careful figures.

3.4.3 Comments on the Cost Comparisons

The previous cost comparisons are only for one area in the United States at a particular time. You may want to run through some numbers of your own. The numbers as shown however are probably quite conservative. Eight points which can actually make the costs of solar heating more favorable than the conservative analysis made in the preceding paragraphs are listed below:

(1) If you use the 10 ounce copper sheet material your panel will cost about \$2.05 per square foot, rather than \$2.30.

(2) You may not need 2 inch plumbing. The use of 1 1/2 tubing will save money.

(3) You could use Type M or Type DWV tubing for some or even all of the plumbing. These lighter weight tubes will save some money.

(4) You may not need 100 feet of large diameter tubing.

(5) Horizontal insolation values were used. If your collector is inclined towards the sun at all it will collect more solar energy.

(6) The prices of gas heaters, of gas, and of copper will change in the future. Gas heaters will probably not go up very much in price, simply keeping up with inflation. The price of copper will probably increase faster than the inflation rate. The deposits being mined are no longer as rich as they used to be, and the pollution controls being added to copper smelters will cost money. The price of gas will surely rise drastically in the next decade, however. The supply and demand situation — the well-known energy crisis — can simply not continue at today's prices. This effect will be more than sufficient to counterbalance the increase in copper prices, and solar energy will become much more competitive as time passes because of it.

(7) The eventual scrap value of copper is quite significant. Including the scrap value in cost comparisons would make solar heating more competitive.

(8) If solar heaters are protected against freezing (gas heaters also have to be drained) there should be no problem in getting a 20 year life out of them.

4. CONSTRUCTION OF THE HEATER, AND RECOMMENDED DESIGNS

Two types of solar heaters can be made using this manual: one of them is also a roof cover with full weatherproofing properties, the other one is only a solar heater. Both feature an inlet and an outlet manifold which are plumbed into the pool recirculation system. The inlet and outlet manifolds are connected by many small tubes which are in turn soldered to copper sheet. The sheet intercepts and collects the solar energy, and conducts it to

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*See Section 3.3.

the tubes, where it is carried off by the water.

For a heater which is also a roof it is desirable to use the 16 ounce or the 20 ounce copper sheet, as described in Section 4.2. For a solar heat collector only, any thickness of copper sheet shown is acceptable, but the 10-ounce material will be less expensive (per unit heat collected) than the thicker ones.

There is an optimum spacing for the tubes soldered to the sheet, as explained in Chapter 2. If the spacing is too large, the sheet between the tubes gets too hot, too much heat gets lost to the surroundings and the heat collected per dollar of investment suffers. If the spacing is too small, the sheet metal is not being made to work hard enough, and again one loses in dollar efficiency. The optimum spacing is shown in the table below.

Copper Sheet Description		Optimum Spacing of Collection Tubes	
Weight	Thickness	Unglazed	Glazed
10 oz	0.0135 in	7¾ in	8½ in
14 oz	0.0189 in	8¼ in	9¼ in
16 oz	0.0216 in	8½ in	9½ in
20 oz	0.0270 in	8¾ in	10 in

It does not matter very much if you build your collector with a spacing an inch or two off-optimum. The cost effectiveness will not change very much.

Most collectors for heating swimming pools should be of the "unglazed" type. You should not build a glazed collector for swimming pool heating unless you have thoroughly read all parts of this manual dealing with glazing.

Enough material has been included in this manual to allow you to design your own collector, and to determine not only what the technical performance will be, but whether it makes sense economically to build one in the first place. For those who are not interested in the detailed work of designing a collector, some simple guidelines on good design follow. This will allow you to avoid doing some calculations. You should still read through the manual to understand what precautions apply to your case.

Simple Design Guidelines, Pool Plumbing – If you have a small or medium-size pool, use 1-1/2-inch tubing for the plumbing, if the pool is large, use 2-inch tubing, if it is very large, you should determine the diameter (Section 2.5).

Collector Tube Spacing – With thin sheet material, you might use a spacing of 8 inches, for thick material either 8 inches or 10 inches, depending on the width of sheet material you are able to buy. Use tubes of 3/8-in. nominal diameter, i.e. of 1/2-inch actual outside diameter.

Number of Tubes on Collector – Do not use less than about 10 heater tubes in parallel. If you use relatively few, use 1/2-inch tubing (i.e. 5/8-inch actual outside diameter). If you use about 15 tubes or more you might use 3/8-inch tube (i.e. 1/2-inch actual outside diameter).

Length of Tubes on Collector – On a combination heater/roof the length of the tubes should not be more than about 30 feet. On a heater which does not have a roofing function you can build it longer if you wish, but you should allow for thermal expansion, and run through some pressure drop calculations (Section 2.5).

If you follow these simple design guidelines you should end up with a heater which will operate properly. This should not keep you from doing your own calculations and your own design work. You can predict the performance of the collector by following the instructions given in Section 1.

4.1 Solar Collector with no Roofing Function

A solar collector with no roofing function can be mounted on any smooth surface which has an acceptable orientation and is not shaded (Sections 2.6 and 2.9). This may be on a roof, on a covered patio area, on any platform, on a hillside or in an unused portion of a garden where the collector can be tied down and nothing will grow to shade it.

A solar heater of this type will look very similar to the test heater shown in Figure 1, with inlet and outlet headers, joined by a number of tubes which are soldered to copper sheet. There is one major difference. Since the copper sheet does not have to also be a waterproof roofing membrane, you can put it together in any of a number of ways.

You can cut strips of copper, equal in width to the optimum spacing of the tubes and solder the tubes in the middle of each strip. In view of the widths available in the sheet material, the most convenient width of the strip would probably be 8 inches or 10 inches. If you buy sheets 8 feet or 10 feet long, you will end up with a number of successive strips soldered to each heater tube. For extra strength you might solder the ends of the strips together, with perhaps a 1/2 inch overlap. If you can get the material in the form of a roll of the desired width, you can save in cutting and soldering time.

Or you can use a wide strip for several heater tubes, soldering each in the middle of the strip from which it should be collecting solar energy. This will save some cutting work, and will make the final product easier to fasten to the support structure. If you have to move the parts after the soldering operation, you should not make them too large.

The collector should be held down well enough so that a windstorm will not cause damage. If it is necessary to make penetrations through roofing or roofing shingles, it is best to use barbed copper or bronze nails (or screws), which will not rust and cause leaks. Sealant should be applied generously around the fasteners.

You should not nail or screw directly through the copper sheet, since thermal expansion might enlarge the holes or loosen the fasteners. It is probably best to use some cleating arrangement such as that used in the roofing, or a copper strap or a strong wire (say No. 8 copper wire) stretched over the tube(s). If you live in an area where there is frequent and serious damage caused by windstorms, the heater strips should be held down about every 18 inches. If you live in a calm area, you might use a hold-down spacing of 3 feet. There should be a support close to the manifolds so that you can strap the manifolds down to the support structure.

Fabrication of the manifolds is discussed in Section 4.4.3. The soldering operations are discussed in Section 4.5, the final coating operation in Section 4.7. Both can best be done before the collector is mounted and assembled on the final support structure. When you decide on the spacing of the holes drilled in the manifold, remember to leave a space between the heater strips for the hold-down fasteners. For protection against freezing the manifolds and tubes have to be tilted slightly so that they will drain empty when the solar heater is turned off.

By the time you finish the manifolds, with all the drilling, tapping and soldering operations, the manifolds may be slightly bent. It is best to line everything up and fit everything together before soldering the heater tubes into the manifold. You can then use a level to find out whether everything slopes in the right direction, and by bending tubes (including the manifold) here and there, make sure that when the heater is soldered together there will be no more need for additional adjustments.

4.2 Solar Collector Using Copper Roofing

Well-built copper roofs have been known to last for centuries. If you are building a new house, a new house addition, a cabana or if you are replacing worn-out roofing, it is unlikely that you will ever have to worry about the roof again if you put on copper. Brief instructions for making copper roofing suitable for a solar heater are given below. The economics of this approach are discussed in Section 3.

There are three types of copper roofing in common usage:

(1) *Flat seam copper roofing* employs 20 ounce copper sheets (0.027 inches thick) about 18 x 24 inches in size. The corners are snipped off, the edges are tinned and bent over, and the panels are interlocked on the roof. There are three "cleats" per panel (see below) holding the panel to the roof. After the panels are in place the joints are hammered flat and all the seams are filled with solder

Flat seam roofing will yield a perfectly good roof and a perfectly good solar heater. But the amount of work involved is great compared to that involved in batten seam roofing. The author's roof-heater was done in the flat seam style. It involved soldering about 600 lineal feet of flat seams, a task which took 48 hours, and approximately 60 pounds of solder. Soldering the tubes on also takes more solder and work than it does on a batten seam roofing.

(2) *Standing seam copper roofing* is quite similar to the batten seam roofing described below, except that the batten (and the associated cap) is left out and the adjacent pans are joined to each other with a lock-seam. It is probably more difficult for the homeowner to do a good job with the standing seam roofing than with the batten seam roofing.

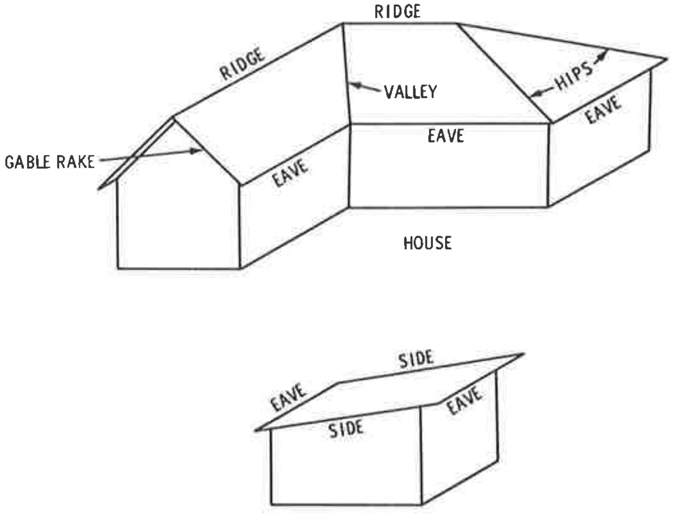
(3) *Batten seam copper roofing* involves installing flat copper "pans", which may be as long as 30 feet, between "battens" fastened on a flat roof.

The pans are fastened between the battens, and a number of special techniques are used to ensure that complete waterproofing is obtained in all locations where the copper is made into joints. The construction of batten seam roofing is explained in detail in the following section.

4.2.1 Batten Seam Roofing

The construction of batten seam roofing is illustrated by Figures 34 through 44 which should be consulted as you read the steps involved in making a batten seam roof, as given below.

Roofing Deck – Batten seam roofing can be applied over any smooth standard roofing deck. A concrete deck may need a coating of asphalt paint to make it smooth enough. If you wish to insulate an existing roof at the same time you are installing a copper roof, you may wish to do this by building a raised deck over a layer of building insulation. The currently recommended thermal insulation for roofing involves using material with a resistance value of "R-19." This means that a temperature difference of 19 F is necessary to get a heat loss or gain of 1 Btu per sq ft per hr.



LEAN-TO OR SHED ROOF

FIGURE 34. ROOF NOMENCLATURE

Surface Preparation – Before installation of the battens all the surfaces should be covered with 15-pound weight roofing felt laid with a lap of at least 2 inches at all edges. The felt should be nailed with copper nails driven through sheet copper washers at least 1 inch square. Standard monel staples may also be used. Care should be taken that the fasteners do not project above the roofing felt significantly. On a concrete deck, the roofing felt can be glued with asphalt or tar. Rosin-sized paper should be applied over the roofing felt, between the battens, immediately preceding the application of the copper pans. The rosin-sized paper serves to keep the pans from sticking to the tar-impregnated roofing felt.

Battens – Battens are approximately 1-5/8 inches wide and 1-5/8 inches high, of a good grade building lumber. Clear spacing between the battens should be 26 inches maximum. To allow for expansion, the width of the copper pan should be 1/4 inch less than the clear dimension between the battens. To avoid pans of fractional width at the end of the roof, a sufficient number of spacings should be adjusted by 1 inch or less. Place battens at all gable rakes and roof sides, at all vertical walls, and on all ridges and hips. Battens are attached to concrete, gypsum or steel roof decks by through bolts (or expansion bolts for concrete) of the cinch type spaced not more than 3 feet apart. Battens are fastened to wood decking by sturdy woodscrews or nails spaced not more than 1-1/2 feet apart. To protect steel fasteners from galvanic corrosion it is desirable to recess them a bit into the wood and to give the heads a good coating of paint.

Cleats – Cleats are made of 16 ounce minimum cold rolled copper cut 2 inches wide. They are fastened with two barbed copper or bronze nails to the bottom of the battens, with the ends bent up to form a "U". The ends should project 1 inch above the top of the battens. Cleats are spaced 12 inches on centers.

Copper Pans – Copper pans are made from cold rolled copper sheet. For use between battens spaced 20 inches (or less) apart, 16-ounce copper sheet can be used; between battens spaced 20 to 26 inches apart, 20-ounce copper is recommended. The pans should be made 1/4 inch narrower than the space between the battens to allow for thermal expansion. Pans should be centered. The side of the sheet is turned up to the height of the batten plus 1/2 inch. This extra 1/2 inch is bent to form a horizontal flange at the top of the battens.

Pans are made continuous the full length of the roof (not to exceed 30 feet in length). The ends of the sheets forming the pans are joined by a riveted and soldered lap-seam. Seams in adjacent pans are usually staggered. Cold-rolled 16 ounce copper can be obtained in rolls so as to minimize the number of seams. Cold-rolled 20-ounce copper is available in 10-foot-long sheets. When calculating the required lengths, be sure to include the amount needed for finishing the eaves and the ridges at the ends of the pans.

Batten Caps – The batten caps or cover strips are made of cold-rolled copper of a minimum weight of 16 ounces per square foot. They are placed over the battens with their side edges locked to the 1/2-inch horizontal flanges of the roof pans. Before placing the batten caps a continuous strip of butyl rubber sealing tape 1/8 inch thick by 1/4 inch wide or, alternatively, a continuous bead of rubber or synthetic base sealant, is applied to the top of the horizontal flanges on both sides of the battens. The ends of batten caps are joined in a 3/4-inch lock seam or lapped 3 inches in the direction of flow. This joint is also sealed. After the side edges of the batten caps are locked to the horizontal flanges of the roof pans they are malleted down against the vertical sides of the battens with a rubber mallet thoroughly enough so that the outline of the individual cleats is visible. The ends of the battens are finished as discussed below for eaves.

Ridges and Hips – Copper-covered battens similar to the roof battens are used at both hips and ridges. They should be high enough to receive the ends of the roof battens. At such intersections, the roof pans are folded, or cut and soldered (Figure 38). The ends of the roof pans, where they abut the hip or ridge battens, terminate in a 1/2-inch flange turned down as shown in the details. This joint should be sealed in the same way as the batten-cap seals.

Eaves – The end of the batten at the eaves is finished with a copper cap (Figure 39). An edge strip, extending at least 4 inches onto the roof deck, is nailed with copper or bronze barbed nails spaced 4 inches apart. The edge strips

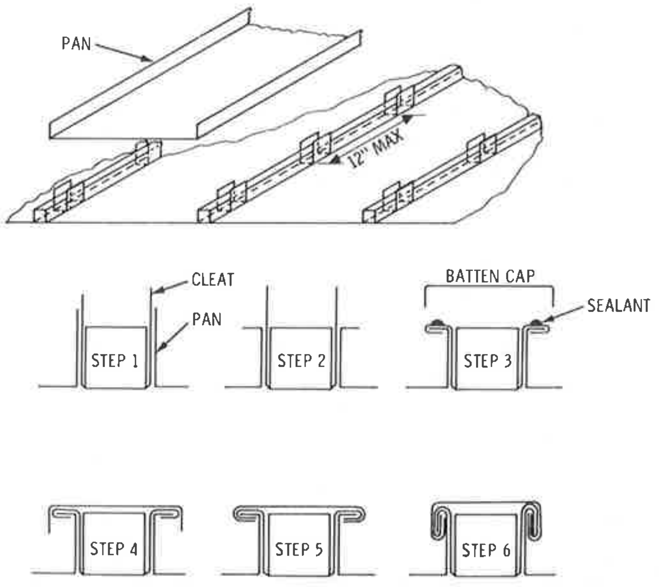
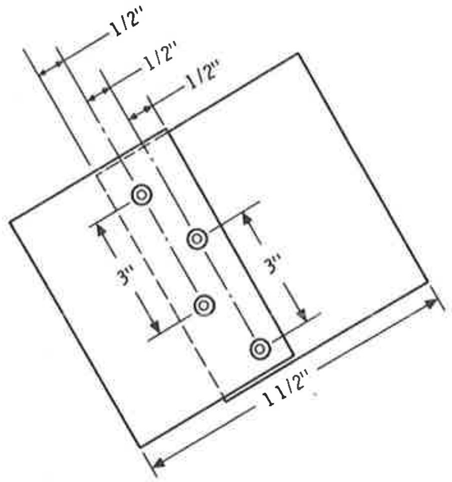


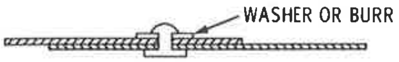
FIGURE 35. BATTEN SEAM ROOFING ASSEMBLY



COPPER RIVETS: 5/32" DIAMETER MINIMUM (NO. 52 RIVETS)

CAN USE
1. "BLIND" RIVETS
2. EXPLOSIVE RIVETS
3. SOLID RIVETS

SOLID RIVETS MUST BE USED WITH COPPER WASHERS OR "BURRS" TO PREVENT DAMAGE TO THE PARENT METAL. CROSS SECTION OF SEAM WOULD LOOK LIKE



SOLDER AROUND EACH RIVET

SEAM SOLDERED THOROUGHLY

FIGURE 36. RIVETED AND SOLDERED LAP SEAM

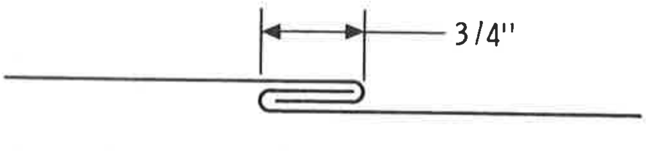


FIGURE 37. DETAIL OF LOCK SEAM

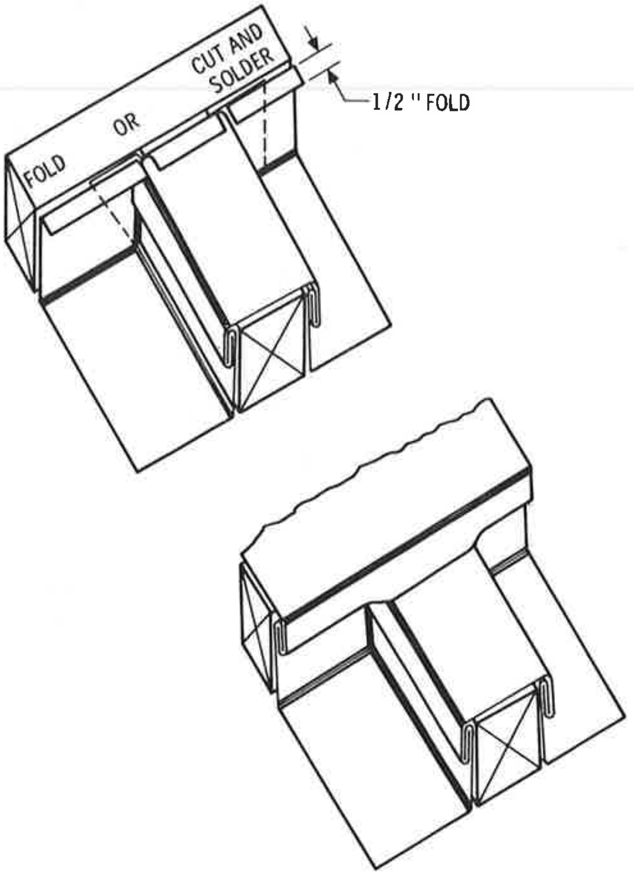


FIGURE 38. SHEETWORK DETAILS AT RIDGES AND HIPS

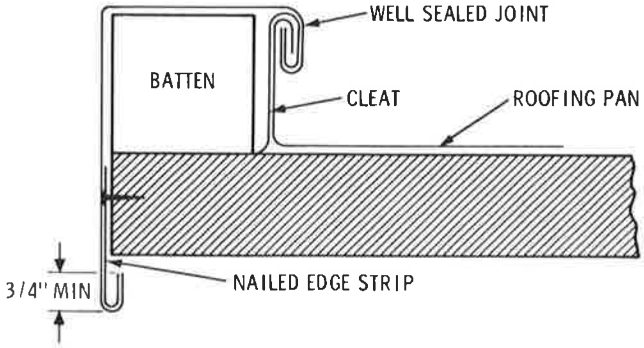


FIGURE 39. SHEETWORK DETAILS AT GABLE RAKES OR ROOF SIDES.

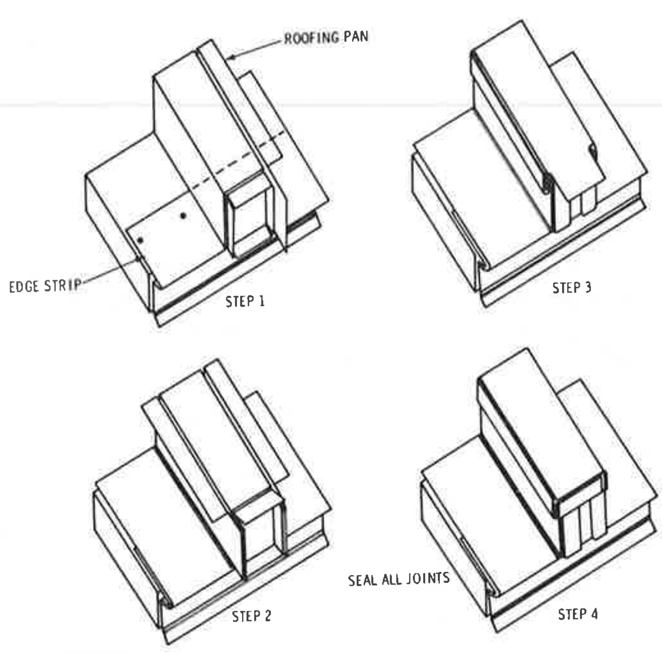


FIGURE 40. SHEETWORK DETAILS AT EAVES

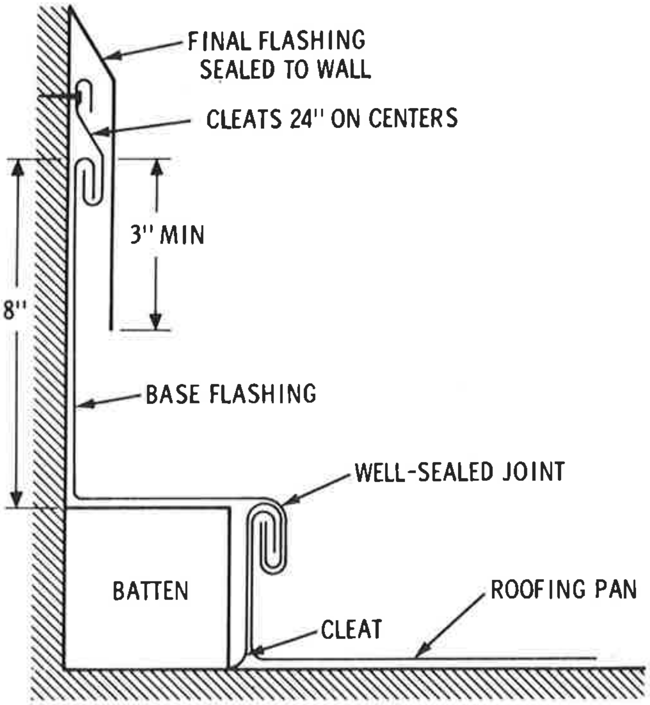


FIGURE 41. SHEETWORK DETAILS AT VERTICAL WALL

are 20 ounce cold rolled copper in lengths of 8 to 10 feet. The ends should be lapped 1 inch. The bottom of each pan, and the lower part of the end cap of each batten, is hooked 3/4 inch over the edge strip. Prior to making this joint, sealant tape or a sealant bead is applied to the edge strip for waterproofing. If a gutter is incorporated, it, too, can hook into the edge strip. The top edge of a "lean-to" or "shed" roof can be finished in the same way as the eaves.

Gable Rakes and Roof Sides – A batten must be used at all gable rakes and roof sides. The roof pan should be finished as usual. The batten cap should fold down over the batten and be folded over an edge strip as shown in the details. The edge strip is 20-ounce cold rolled copper in 8 to 10 foot lengths, nailed with copper or bronze barbed nails spaced 4 inches apart, with the ends lapped 1 inch. Joints in this batten cap are the same as those on the batten caps between roofing pans.

Vertical Wall – The simplest way to tie in the roofing with a vertical wall is to put a batten right next to the wall. The roofing pans are then finished like gable rakes, or ridges or hips. A batten cap is then made, the only difference being that (Figure 41) it extends up the wall 8 inches and is fastened to the wall with copper cleats. The cleats, made as before, are cut about 3 inches long, and the top is bent over to cover the heads of the barbed copper or bronze nails. All joints should be thoroughly sealed.

This upturned copper sheet constitutes the "base flashing." Wooden sheathing, or metal (or other) flashing built into the wall must be used to ensure that the water which may run down the wall will flow over the base flashing onto the copper roof.

Valleys – Valley sheets are of 20-ounce cold rolled copper not exceeding 10 feet in length. Each sheet should lap the lower sheet at least 8 inches in the direction of flow and the lap joint should be sealed. The valley sheets are nailed at the top edge only, using barbed copper or bronze nails spaced no more than 4 inches apart. The side of the valley sheet is folded 1/2 inch for cleating and into these folds, 2 inch wide copper cleats are applied at spacings not greater than 18 inches. The cleats are fastened with two barbed copper or bronze nails, and the ends of the cleats are malleted back over the nail heads to protect the underside of the final roofing. At 6 inches from the side edge, a double fold (3/4 inch wide) is formed in the valley sheet. The roof pan is hooked into this edge. The width of the valley, between the edges of the roofpans, should be at least 8 inches. If the valley is installed between two roofs of unequal slopes, the water of higher velocity might force its way past the opposite edge of the valley flashing. To prevent this a fold in the form of an inverted V, 1 inch high, can be made in the middle of the valley.

The ends of the battens terminating at the valley are notched at the bottom to allow the folded edge of the valley sheets to pass underneath. The ends of the battens are cut at an angle, parallel to the valley sheets, and are covered with copper as described for eaves. The upper part of the valley sheets can be finished as described for ridges and hips, the lower part as described for eaves. All the joints involved in the fabrication of the valley should be thoroughly sealed.

Hung Molded Gutter – Hung molded gutters are made following the design shown in Figures 43 and 44. Figure 43 shows the maximum size of gutter that can be made following the description. A larger size gutter would involve additional straps. Before you build a gutter according to the drawing specifications, sketch out the gutter cross-section in full scale. It may be larger than you really need, and you may want to make the cross section smaller.

The gutters should be constructed of 20-ounce cold rolled copper sheets 8 to 10 feet long. The ends of each length should be joined by a riveted and soldered lap seam.

The outer edge of the gutter should be folded over a continuous 3/4-by-3/16-inch copper or brass stiffening bar. Transverse gutter braces, formed from 20-ounce cold rolled copper 3 inches wide, are formed into a channel 1-1/2inches wide with 3/4-inch flanges, as shown on the drawings. The braces are attached with rivets and soldered across the gutter, and are spaced no more than 3 feet apart. On the outer edge, the rivets holding the braces should go through the gutter stiffening bar. The rear edge should be at least 1 inch higher than the front edge of the gutter and should terminate, at roof edge, in a 3/4-inch fold which should be folded into the roofing (eave) edge strip and the ends of the roofing pans.

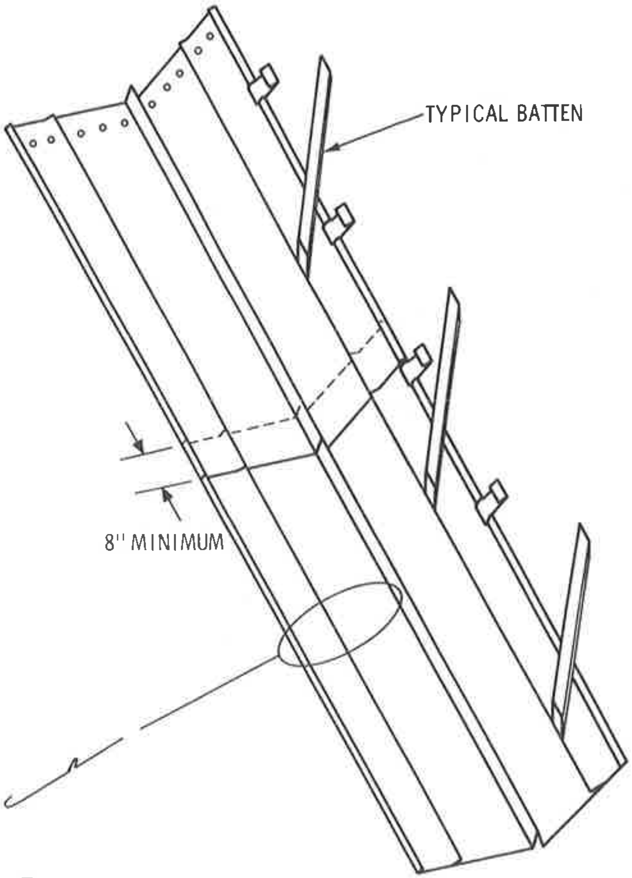


FIGURE 42. SHEETWORK DETAILS OF VALLEY

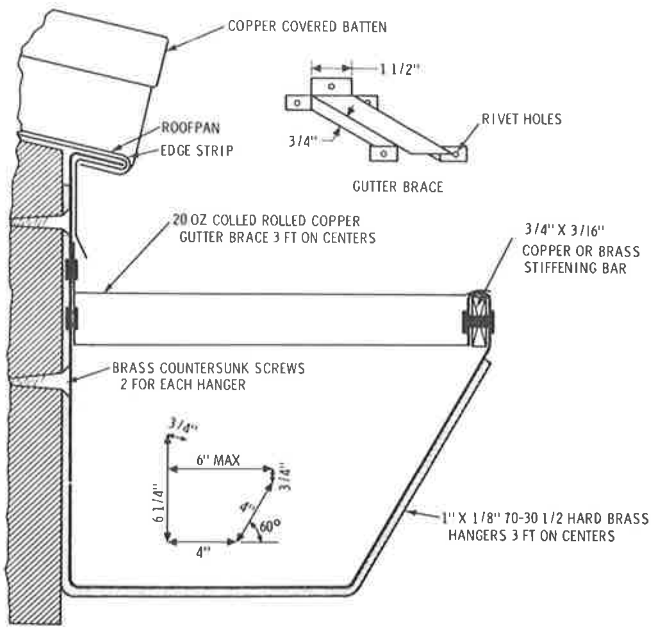


FIGURE 43. HUNG MOLDED GUTTER

Hangers are formed from half-hard copper or half-hard brass, 1 by 1/8 inch, and are spaced not more than 3 feet apart, preferably halfway between the position of the braces. The hangers are secured to either fascia or structure by two countersunk brass screws and extend outward under the gutter for support, and up the front face, as shown in the drawings.

The ends of the gutters are closed with a 20-ounce end cap, made with 1/2-inch soldering flanges so that it fits into the gutter, and soldered around the full periphery.

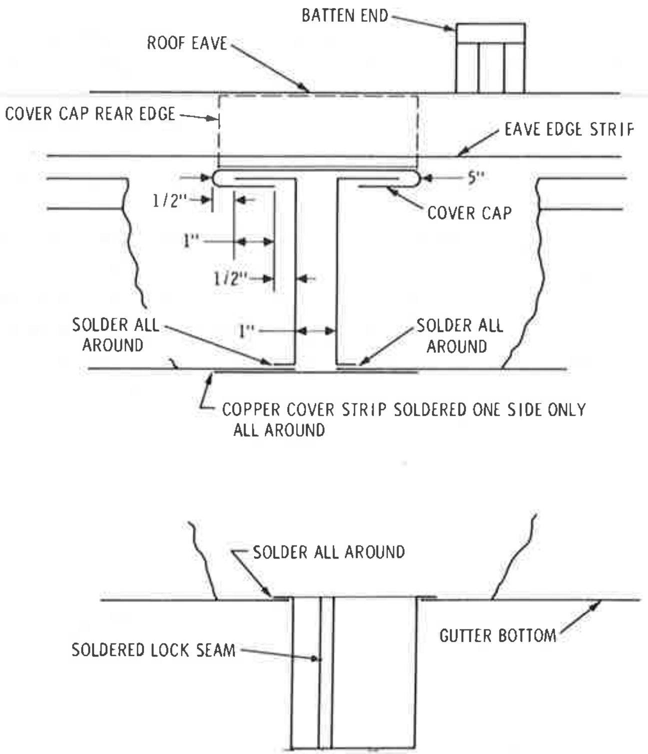


FIGURE 44. GUTTER EXPANSION JOINT AND OUTLET TUBE

The top has a 1/2-inch flange for stiffness. Expansion joints are located at regular intervals of no more than 48 feet. The expansion joint should be no more than 24 feet from the nearest fixed point, such as a corner or downspout. Expansion joints are made by closing both sides of the gutter, and by putting a cover cap over the top flanges of the gutter end caps, which are made extra long for this purpose, as shown in the drawings. The rear edge of this cover cap is made to extend under the eave edged strip up to the top rear edges for waterproofing.

Gutter corners are made by putting two appropriately cut sections together and putting a soldered and riveted reinforcement strip on the inside of the gutter extending at least 1 inch on each side of the corner.

The "leaders" (the downspouts that carry the water away) can be bought, as Type DWV tubing, or made in a variety of sizes either in a round or rectangular cross section. The outlet tubes that connect to the outside leaders are formed of 16 ounce minimum cold rolled copper, with a soldered lock seam running longitudinally. The upper end of the tube should be flanged 1/2 inch, and soldered to the inside of the gutter. The tube should extend into the leader at least 3 inches. If a strainer is desired at the outlet tubes, make it in the form of a basket (upside down) fitting snugly into the outlet tube. It is formed of screen made of copper wire of at least No. 14 B&S gauge (0.064 inches diameter), or of cast bronze.

The easiest way to incorporate a gutter is to build the gutter first, and suspend it in the hangers. The eave edge strip is located and nailed in place, and finally the roofing is put in place.

Sealant Tape and Sealant Specifications – Recommended butyl rubber sealing tape is available from several manufacturers: Tremco's No. 440, PPG Industries' No. 1082, Presstite Products' 155.8, or their equivalent. The tape should be used in conformance with manufacturer's recommendations.

Sealants conforming to Federal Specification TT-S-0030 include: Tremco's Mono-Lasto-Meric, General Electric's Silicone Construction Sealant, PPG Industries' 4040–70 Butyl Rubber, or their equivalent. Sealant usage can be expected to be roughly 2 lb per 100 feet of sealed joint.

Incorporation of the Solar Heater – The preceding sections have given a description of the fabrication of batten seam copper roofing. The fabrication of the solar heat collector, to be done after the roofing is in place, is described in the section that follows.

4.2.2 Collector Construction Details

A solar collector which will also fulfill a roofing function can be built on any roof which has an acceptable orientation (see Section 2.6), is not shaded (Section 2.9) and which has sufficient surface area so that you can get the pool heating effect you want (Sections 2.13 and 3.1.4).

A solar heater of this type will look quite similar to the test heater shown in Figure 1, with inlet and outlet headers, joined by a number of tubes which are soldered to copper sheet material. The main difference is that instead of the roofing being of the shingled flat seam type, it will be of the batten seam type, just discussed, with roofing battens running parallel to the heater tubes.

Depending on the width of the spacing between the battens and the tube spacing you use (for optimum tube spacing see Section 5), you can divide the space between the battens in two or three heat collection strips, with a heater tube soldered to the sheet in the middle of each.

The techniques for soldering the tubes to the sheet material are discussed in Section 4.5.4. Remember not to overheat the sealant used on the batten caps and in other sealing areas during the soldering operation. A wet towel draped over the sealing joints during the soldering operation can avoid this.

If there is a ridge or a hip at the top of the heater, then the outlet manifold has to be placed above the batten which is used at the ridge or hip. The heater tubes should only be soldered to the roofing pan to within perhaps 12 inches of the top batten. The tubes should then be bent upwards, away from the roofing pan, so as to join the outlet manifold.

The coating operation is discussed in Section 4.7. The surface should be very well cleaned before coating.

Section 4.4.1 stresses that for protection against freezing the manifolds and tubes have to be sloped somewhat so that they will drain almost empty when the water flow is turned off. By the time you get through making the manifolds (Section 4.4.3), with all the drilling, tapping and soldering operations, the manifolds may be somewhat bent. Make sure that, if bent at all, they are bent in the right direction to drain. Try to get everything sloping in the right direction *before* it is soldered together. Straightening things out after the soldering is completed is unpleasant and difficult.

4.3 Optional Glass or Plastic Cover for High Temperature Water

If, after having read Sections 2 and 3 thoroughly, you have decided you want glazing on the heater, here are some suggestions.

For temporary winter use, you might just use a layer of inexpensive plastic film (e.g. a drop cloth for painting) fastened securely with adhesive tape. In summer the plastic can be taken off.

For longer life, use glass, or fiberglass-reinforced plastic (FRP) corrugated panels of the type used for greenhouse glazing. Of these two the FRP is by far the easier to use. The greenhouse type of FRP should not be confused with the very opaque patio-cover plastic awning material. This lets through so little sunlight it is quite useless for solar energy purposes.

A suitable FRP material is a Tedlar coated panel made by the Filon Division of Vistron Corporation (Hawthorne, California) called "Supreme Grade." This is available in weights of 4, 5, or 6 ounces per square foot. The heavier weights are thicker and stronger. The material has a 20-year guarantee on the amount of light transmission so long as it is cleaned of accumulated dust and dirt at least twice a year. Some of the less expensive grades of Filon materials are also quite good, but are not covered by Tedlar and must be recoated occasionally with a material called "NuGlas" to keep a high transmissivity. The FRP material can be supported and fastened following the instructions shown in Filon Design Manual No. 160, available from the distributor or from the manufacturer. The glazing support system can be fastened to the solar heater support structure in several ways. In a heater and roof combination, you can use brass screws right through the batten caps into the battens. (In a heater which does not have a roofing function you can use fasteners between the heater strips.) Although the FRP will give you a waterproof membrane, it is advisable to seal all fastener penetrations with a good caulking material.

If you use some other FRP, it should be Tedlar covered so that, when new, it has a solar energy transmissivity* of at least about 80% as measured by ASTM method E 424 (1–71). The guarantee should include a guarantee of a reasonably high transmissivity at the end of a reasonably long period. These points are normally included in the manufacturers literature.

Glass is more difficult to use. Most glass support designs are made for vertical glazing and will not work too well when the glass is near-horizontal. Glass should never rest on metal directly. If there are frequent hail storms with large hailstones you may have to go to very thick glass, or you may have to use a screen to protect it. It does not seem advisable to cover a large swimming pool heater with glass unless you really know what you are doing.

Three final points with glazing: (1) All edges should be closed so wind does not destroy the thermal blanketing effect of the glazing or lift the glazing off. (2) There should be a good layer of insulation under the heater, if it is built on a roof. Otherwise the room below will heat up when the water is turned off. *(3) Do not use the tar absorption coating; use a paint such as 3M "Nextel" Black Velvet.*

4.4 Plumbing Details

The following subsections give some plumbing hints and precautions not given elsewhere in this manual. Soldering techniques are covered in Section 4.5.4, some additional comments on assembly techniques to be used on the actual solar heaters are in Section 4.1 and 4.2.

4.4.1 Typical Piping Diagrams

A typical piping diagram for the overall pool plumbing system is shown in Figure 45. Some comments follow.

The symbol (reversed Z) shown above the solar heater is a one-way valve (or "check valve"). Its purpose is to empty the solar heater when the pump is not on by letting air into the heater, so freezing weather won't damage the heater. For this to work properly, the heater should be above the water level of the pool. The one-way valve can be hooked into the heater plumbing anywhere above the water level of the pool. When the pool circulation pump turns off, air will be sucked into the solar heater, and the water will flow into the pool. When the pump turns on in the morning, the air in the heater will be "burped" into the pool. The one-way valve can be quite small. A valve with a Teflon seat is recommended. (A gas heater also has to be drained in freezing weather.)

The optional gas heater is shown connected in parallel with the solar heater. With modern recirculation rates (1 pool volume every 10 hours or so) there is more than enough flow rate for both.

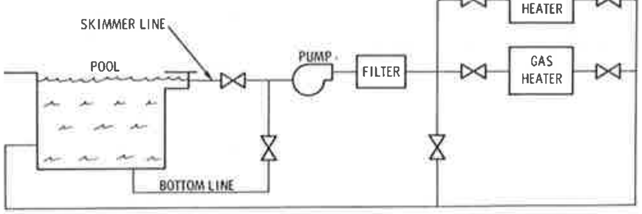
It is recommended that a bypass line be included so as to bypass the heater(s). The heaters are shown valved at both entrance and exit, so that they will not be forced full of stagnant water when the bypass line is being used.

Figures 46 and 47 constitute an exercise in heater plumbing logic. The objective is twofold:

(1) The heater should empty completely when the pump stops and the one-way valve lets air into the plumbing. Otherwise freezing damage may result.

(2) The heater should fill completely with water when the pump turns on. All air bubbles should be driven towards the exit, and all tubes should end up carrying water. Otherwise part of the heater would have no water flowing through it, and do no useful work.

Some examples follow. Consider the *undesirable* arrangements (Figure 46). Note that all the heaters are drawn so that the top of the heater is at the top in the figure. Undesirable arrangement B will function, but it will never empty completely. Undesirable arrangements A, C, D, and E will empty; but might end up with some dry tubes during operation.



POOL EMPTYING AND FILLING PROVISIONS, AND FILTER BACK-FLUSH PROVISIONS NOT SHOWN

FIGURE 45. PLUMBING DIAGRAM INVOLVING BOTH SOLAR AND GAS HEATERS

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*Not to be confused with transmissivity of light for plant photosynthesis, generally about 10% higher.

By contrast, the 3 *desirable* arrangements (Figure 47) all fill completely when the water *is* turned on, and all are able to empty completely *if built properly*. This requires that the horizontal tubes in the design, if tilted at all, be tilted in the right direction. For example, in desirable arrangements A and B the manifolds or headers are nominally horizontal. Both inlet and outlet headers should be able to drain completely by being tilted slightly so that the water will flow in the proper direction. In desirable arrangement C the heater tubes are nominally horizontal. They should be tilted slightly so that the water can flow towards the inlet header. The lower part of the outlet header is shown as a dead end which will stay filled with water when the pump is turned off. This dead end section should be as short as possible.

The reader should confirm that between the desirable and undesirable arrangements all possible arrangements have been covered. The recommended arrangements are desirable arrangements A or B (see also Figure 1).

In the figures the one-way (air-fill) valve is shown on the heater manifold. As mentioned earlier, it can be located anywhere in the heater circuit, just so long as it is above the water level of the pool. It should not be very much above the water level of the pool. Otherwise it may let in air continuously when the pump is operating.

If your pump is above the pool water level this automatic air filling approach is not recommended, since your pump might lose its prime. In this case it is best to drain your heater manually and by-pass it in cold weather, when you probably are not using the pool anyway.

4.4.2 Tube Sizes and Types to Use

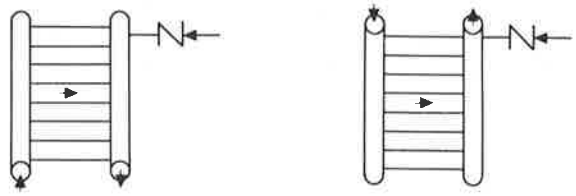
On all the above-ground plumbing with the exception of those used in making the heater, Types DWV, M and L copper tube are all adequate. Type DWV is available only in sizes 1–1/4 inch and larger.

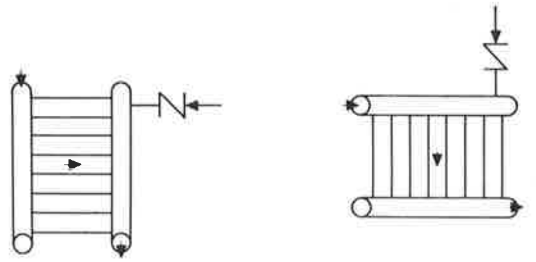
The best tube sizes to use can be determined readily using the techniques shown in Section 2.5 and illustrated in the separate Appendix. Some approximate guidelines follow. The best tube size for the main lines of the pool is probably 2 inches if the pool is relatively large (say 800 sq ft, 30,000 gallons), and 1 1/2 inches if the pool is relatively small (say 400 sq ft, 15,000 gallons). Tubing of 3/8-inch nominal diameter* or perhaps of 1/2-inch or even of 5/8-inch nominal diameter for an extra large pool should be adequate for the heater tubing. You should not use tubing smaller than 3/8-inch nominal diameter for this. The pressure drops would probably be excessive, and the small tubing might never empty properly due to capillary effects, giving potential freezing problems. Again, the best tube sizes can be easily determined using the methods of Section 2.5, and this is an easy and interesting exercise.

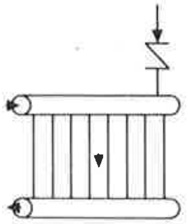
4.4.3 Assembly Techniques

In the assembly of the plumbing the importance of planning the plumbing diagram, determining the required tube lengths, and careful measurement and cutting cannot be stressed too much. If the platitude "haste makes waste" is ever appropriate, this is the time.

In planning the plumbing layout, make sure that you allow for thermal expansion. It is not a good idea to have a straight tube rigidly tied to something at both ends, particularly if the tube is long. When the temperature of


A. HEADERS IN COUNTERFLOW B. HEADERS IN COUNTERFLOW


C. HEADERS IN PARALLEL FLOW D. HEADERS IN PARALLEL FLOW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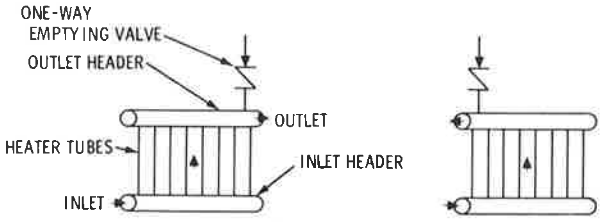
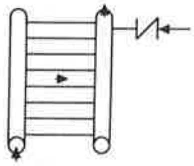
ROOFS DRAIN TOWARDS THE EQUATOR

E. HEADERS IN COUNTERFLOW

FIGURE 46. UNDESIRABLE HEATER PLUMBING ARRANGEMENTS (See Text)



A. HEADERS IN PARALLEL FLOW B. HEADERS IN COUNTERFLOW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ROOFS DRAIN TOWARDS THE EQUATOR

C. HEADERS IN PARALLEL FLOW

FIGURE 47. DESIRABLE HEATER PLUMBING ARRANGEMENTS

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*The actual outside diameter if the tube is 1/8 inch larger than the nominal diameter. This holds true in the 2 inch and 1–1/2 inch tubing as well.

the tube changes the ends will want to push out or pull in, and if they are restrained stresses will be imposed on the tube and the joints. The temperature expansion is proportional to the temperature change and the length of tubing. A 10-foot length of tubing increased in temperature 100 deg will expand (lengthen) roughly 1/8 inch. Thermal stress problems can be avoided by building some flexibility into the tubing system. This can be done by building an offset or U-Bend into the tubing, which can then give and take up slack as necessary. One can also simply build in a right angle here and there. If two fixed points are connected by a tube in the shape of an "L" (rather than with the shortest straight line), there is some built-in flexibility. Note that horizontal tubing should be supported at least every 8 feet.

In measuring the tube you will need to take into account the length taken up by the fittings. A tube cutter is best for cutting the tube. You can also use a hacksaw, particularly for the large tube (large tube cutters are expensive). It is not easy to make square cuts with a hacksaw. A miter box is useful. All burrs and slivers must be removed before making any tubing joints, whether you used soldered joints or flared joints.

It is a good idea in a soldered tubing assembly to consider whether it might ever be necessary to disassemble part of it. At those points you can build in a soldered union or a flared joint, either of which can be taken apart easily.

Copper tubing can be readily bent with a tube bender. One can also bend annealed copper tubing by hand, using a circular wooden disc as a support and guide. The radius of the disc should be approximately 8 times as large as the tube diameter. For tubing larger than 1 inch in diameter it is better to use fittings than to make a bend.

The fabrication details for the connection between the headers (or manifolds) and the heater tubes are shown in Figure 48. A hole is drilled and tapped into the side of the Type L manifold tubing. A CxM fitting (or adapter) is then screwed and soldered into the hole. The heater tube is soldered into the CxM adapter. To get a good solder bond between the CxM adapter and the threaded hole, the parts should be properly cleaned and fluxed, and twisted around a bit while the solder is melted.

The required drill diameter is shown in the table below, for the different diameters of pipe thread (National Pipe Thread, NPT) you might use. Drilling into the side of the tube is not easy*, and you are well advised to drill some test holes in a piece of scrap before cutting into the actual manifold. It is best to drill a small pilot hole first. The final one can best be made either with a variable speed drill or with a carpenter's hand brace. For the sake of esthetics it is important for all the holes to aim in the same direction. You can improvise a drilling fixture to achieve this.

Required Drill Sizes for Various National Pipe Threads

National Pipe Thread	Drill Diameter
1/8 inch	21/64 inch
1/4 inch	27/64 inch
3/8 inch	9/16 inch
1/2 inch	11/16 inch
5/8 inch	25/32 inch
3/4 inch	29/32 inch
7/8 inch	1 1/16 inch
1 inch	1 1/8 inch

After all the CxM adapters are installed, cap off one end of the manifold. Then the header is ready to be installed on the collector and connected to the rest of the plumbing.

4.5 Solders and Soldering

4.5.1 Soldering Alloys

Solders are highly specialized alloys, the most common ones consisting of tin and lead. Some contain carefully controlled amounts of other metals. For virtually all work on copper sheet (roofing or otherwise) and copper tubing, the best solder is 50A solder, composed of 50% (by weight) tin and 50% lead. This composition will melt completely at a relatively low soldering temperature, has very good wetting and capillary action and produces good reliable joints in both sheet and tube with a minimum of trouble.

Since tin is much more expensive than lead, there might appear to be an incentive to use a solder with less tin such as the 40% tin-60% lead (40A) alloy. This will not wet (i.e., "tin") copper as well, and it will stay "pasty" to a much higher temperature, making it difficult to fill narrow joints properly through capillary action. It simply is not worth the trouble, and the 50A composition is by far the best for all of the sheet and plumbing work.

The 50A solder can also be used to join the tubing to the collector sheets. But there is some advantage to using the 40% tin-60% lead (40A) composition to join the tubing to the collecting sheets. There are no really close

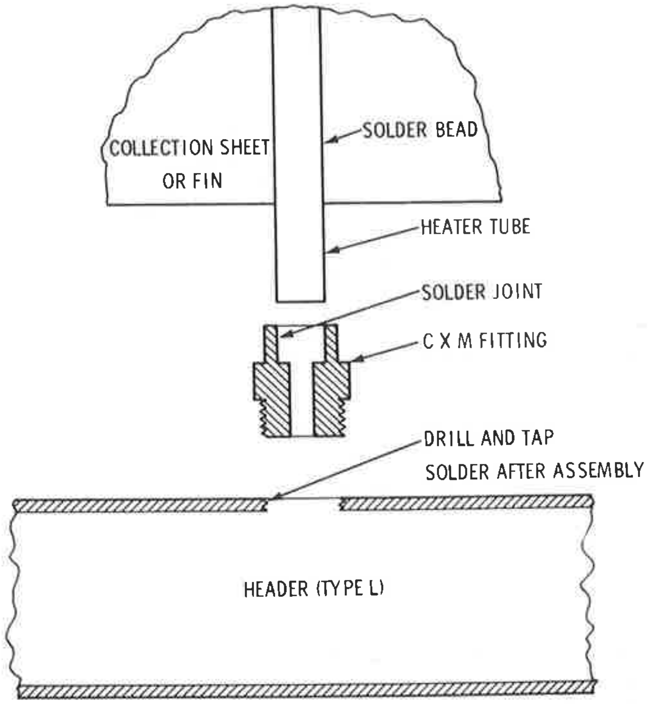

FIGURE 48. DETAILS OF MANIFOLD FABRICATION

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*The most important precaution is to make a very light cut, applying very light pressure, to keep the drill from binding in the tube wall. There are special drills for sheet metal. These are helpful but may be hard to find, and they are not really essential.

clearances involved, so high capillarity is not required. If the copper tubing and the sheet are cleaned properly, wetting (i.e., "tinning") will be no problem. Since the 40A solder is pasty to a higher temperature, it is somewhat easier to keep it in place next to the tube, and to get a substantial filler between the tube and the sheet. It should be noted that the solders between 30A* and 40A, are called "wiping solders" because of their pasty behavior, which allows them to be spread almost like butter. A small pad of folded cloth, soaked in tallow, is usually used to wipe the solder in place.

Solder in retail hardware stores costs as much as $2.75 per lb (1973 prices). Industrial plumbing and metal supply houses — where you will be buying most of your copper parts anyway — should have it at a cheaper price. In some cases it may be necessary to buy in large (say 50 lb) lots to get low prices.

The most convenient solder for the tubing is the round wire type, 1/8 inch in diameter with no flux core. The flux should be bought separately. For soldering the tubes to the sheet the 1/8-inch solder is a bit thin. It is best to twist 3 or 4 wires together in a "rope" of solder for convenient handling.

4.5.2 Soldering Flux

A flux is used for most soldering operations to facilitate the soldering process by performing a number of tasks. The surfaces should be clean before the flux is applied. Then the flux can dissolve any oxide layer or other dirt which still might be on the surface. If a perfectly clean surface were heated without flux, the oxide layer formed by the time the surface got to soldering temperature would make the soldering process difficult. The flux protects the surface from oxygen as well as dissolving any oxide layers. The flux helps the solder wet the metal, and is displaced by the solder.

For soldering copper a number of fluxes are acceptable. There are a number of different paste fluxes, made of petroleum jelly and zinc chloride (or ammonium chloride and zinc chloride). They are quite inexpensive and effective. Muriatic (hydrochloric) acid by itself is not desirable. Muriatic acid with an excess of zinc dissolved in it produces a good zinc-chloride flux. It is however simpler to buy a water-based zinc chloride flux, or, even better, one that has both zinc and ammonium chloride.

For the plumbing, a paste flux is best. For the sheet work either a paste or a water-solution can be used. A toothbrush or some other brush will do for applying flux. If a steel brush (there are some steel brushes shaped like a toothbrush) is used, material can be cleaned and fluxed in one operation.

Some of the fluxes sold in retail hardware stores are not very good, and as a rule all are quite expensive. It is best to buy the flux in an industrial plumbing supply house, and to accept their advise on a reliable brand. As a starting guide, you will probably need roughly 1 lb of flux (1 pint of water-based flux) for every 8 lbs of solder.

4.5.3 Soldering Techniques in Plumbing

The most common method of joining copper tube is by soldering with capillary fittings. This is the process to be used for the solar heater. A complete description of the process, explained with photographic illustrations appears in the CDA Copper Tube Handbook* (Reference 14) and will not be repeated here.

4.5.4 Soldering Techniques for Sheet Metal Work, and for Soldering Tubing to Sheet

For other soldering work the cleaning and fluxing requirements are the same as for plumbing. Soldering sheet metal, and soldering the tubes to copper sheet, is not difficult. There are however a number of things involved which will require a bit of practice, and which will depend somewhat on your choice of tooling, type of collector, flux, solder, roof slope, etc. Some general precautions are listed below. These should be read carefully before starting.

(1) Soldering in the copper roofing trade is traditionally done, not with a torch, but with soldering irons called "soldering coppers." A torch can be used, but care must be taken not to overheat the work if a large torch is used. Overheating may burn the flux, and it can become necessary to clean the material again, flux again, and solder again.

(2) A small torch may not have the capacity to do the job. A large propane, butane or gasoline torch, or an air-acetylene or oxy-acetylene torch should be used. Be careful not to overheat the work if you use a large torch.

(3) Heat both parts being soldered, and avoid keeping the torch in one spot for a long time. A sweeping motion is best.

(4) You can feed the solder into the flame area intermittently, and then "draw" it along with the flame until more is needed.

(5) Before starting on either the tube-to-sheet soldering, or the sheet metal work, it is advisable to practice on some pieces of scrap.

(6) It is essential to keep the tube from shifting while the solder is solidifying. If the tubing moves the solder may have cracks in it, and much of the heat transfer effectiveness of the solder bond may be lost. I used a board resting with one edge on the tube, stood on top of the board, and soldered the tube from the side about 1 foot at a time in building the heater shown in Figure 1.

(7) You might try soldering uphill or downhill on your roof.

(8) On a roof/heater put in 2 or 3 tubes first, then put in the finished manifolds using these 2 or 3 tubes as support. Then put in the other tubes, first soldering them to the manifolds and tacking them down every 2 feet or so before you start soldering. The tubing tends to expand in the soldering operation. Tack it down first at the two ends, then in the middle, then in the middle of the two halves, etc. This will minimize waviness in the final product.

(9) When soldering tubes on a roofing heater, it is

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*Do not use the 30A solder, it is difficult to get good bonds with it.

*Available free of charge from Copper Development Association, 405 Lexington Ave., New York, N.Y. 10017 important to avoid overheating the sealant used on the nearer battens. You might use a wet towel draped over the batten next to the tubing you are soldering to the roof. Or, you might solder the tubes on first, and then put on the sealant and the batten caps.

(10) A heater which does not have a roofing function can be made in parts and then assembled, without requiring the routine described in (8) above.

(11) When soldering on a steep slope, paste flux may be best. Otherwise, a water-based flux is recommended. It is much easier to clean off after the soldering operation.

(12) Flux should be applied no more than an hour before soldering. It should not be left on overnight, since soldering will be more difficult.

4.5.5 Amount of Solder Required

The amount of solder required will depend on the size of your installation, and the length and type of seams or joints involved. For riveted seams, the solder requirement is roughly 0.1 lb. of solder per foot of seam. This requires type 50A solder.

For joining tubes to flat sheet (i.e. batten seam roofing or flat sheet) the solder requirement is roughly 0.06 lb of solder per lineal foot of joint. This can be either 40A or 50A type solder.

For each plumbing joint, one will require an amount of solder which depends on the diameter of the joint. The table below gives the approximate amount of solder involved. It will become obvious that the amount of solder involved in the plumbing is rather small. Type 50A solder is required for these joints.

Copper Tube Size (Nominal Diameter)	Amount of Solder Required per Joint
3/8 inch	0.0025 lbs
1/2 inch	0.004 lbs
3/4 inch	0.005 lbs
1 inch	0.0075 lbs
1½ inch	0.01 lbs
2 inch	0.0125 lbs

4.6 Forming and Cutting Copper Sheets

Copper sheet is easy to cut and form. Cutting can be done with tinsnips or with heavy scissors. A standard paper cutter is very fast, makes neat cuts, and can handle any of the thicknesses mentioned in this manual. Bending can be done by hand, but the result is generally not very neat. Long straight bends (for example the turned-up edges of a roofing pan) can be made by putting a sheet on a flat surface, putting a board (say a 2 x 4) on one side of the bend, clamping the board down or standing on it so that it does not slip, and then bending up the edge. Some taps here and there with a rubber mallet or with a hammer and a piece of wood will straighten things out so that it will look neat.

One precaution: copper hardens somewhat when bent, so that it is difficult to straighten it out and bend it repeatedly and still end up with a good looking job. For neat results it is important to get the bends in the right place the first time. The basic pan shape of the roofing pan can be made with the help of a 2 x 4 as mentioned earlier. Bending over the top flange of the pan can also be done with the 2 x 4 (the actual measurements of a 2 x 4 are 1–5/8 in. x 3–5/8 in.) Simply hold the 2 x 4 flat in the pan next to the edge, and bend and pound the upright side of the pan over the top of the 2 x 4 to make the horizontal flange.

4.7 Coating the Solar Collector

Much research and development has been done on coatings for solar collectors. The search has been for an ideal "selective absorber," which will absorb close to 100% of the incoming sunlight, but will radiate as little as possible of the energy back to the surroundings. The coating should be inexpensive (on a square foot basis), and should have a long useful life. Much of this work is not suited to home applications, since the coatings require intricate chemical treatments or vacuum deposition techniques not available to the homeowner. Many of the coatings are meant to be protected from the environment with a glazing system, and simply would not stand up outdoors. As an alternative to "selective coatings," one can consider black paint.

The recommended coating for a bare collector is sold by Sears Roebuck and Company as: "Tar Emulsion Driveway Coating and Sealer."* This is easy to apply without requiring a primer coat, has good solar absorption qualities which do not change rapidly, and can easily be renewed if necessary after a few years. It is made by the Chevron Asphalt Company. Accelerated tests of one year effective duration by Chevron showed little change in solar absorption effectiveness.

For a glazed collector, do not use a tar coating. It will evaporate partially in service, coating the glass. Use a black paint and primer combination which is recommended by the manufacturer for coating copper collectors, and follow instructions, taking care to clean the surfaces well. The "Nextel Black Velvet" paint and primer of 3M is recommended.

For application, the surfaces should be cleaned thoroughly. Paste flux should be cleaned off with an organic solvent. Water-based zinc chloride fluxes can be removed with hot water containing about 2% of hydrochloric acid, followed by a clear water rinse. After the flux has been removed, the surfaces should be rubbed clean with an abrasive household cleaner (Ajax, Comet, or equivalent), and then hosed and brushed off thoroughly. The "Coating and Sealer" should then be applied in two coats, following the instructions. It can best be done with a common (say 4-inch) paint brush, and should be done in the morning so as to leave a full day of drying time before there is a chance to condense dew on the coating.

If the coating gets very dusty in service it can be hosed down occasionally. If it should become desirable to renew the coating, the surface should be rubbed down thoroughly with an abrasive household cleaner, and then hosed and brushed off well, before it is re-coated.

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*Not the "Coating and *Filler*."

4.8 Probable Time Requirements

The time required to prepare a support structure will depend entirely on the work needed. It might be no work at all or it might involve the construction of a new building.

The actual time spent doing the plumbing work is not extensive. A significant amount of time is needed however to lay out the tubing network and make the measurements, measuring and cutting the tubes and other preparatory work. You should be prepared to spend at least a day or two on the plumbing work.

The soldering of the tubes on the sheet material is more time consuming and tedious. Using an oxy-acetylene torch, Robert Reines in New Mexico managed to get up to 2 feet of tubing bonded to the sheet per minute. His average speed was closer to 1 foot per minute. Using a somewhat anemic gasoline torch, I averaged about 1/4 foot per minute on the roofing collector in Figure 1, but this involved flat seam roofing in which many steps had to be filled in, and included frequent resting periods.

The sheet metal work needed for batten seam roofing is not particularly time consuming or tedious, but you should plan to devote perhaps 3 to 4 days to it if your roof is of reasonable size. Cleaning and coating your roof might take at most one day.

It should be quite clear that building a solar heater is a project which will take a significant amount of time. Time spent in building something by hand is a joy for some and boring to others.

4.9. Available Copper Sheet and Plumbing Components

Copper sheet is available in several hardnesses. The soft, malleable type called: "110 soft copper" is of no interest for the solar heaters which also fulfill a roofing function. For the simple heaters the soft material is however quite adequate.

The roofing/heater will require the type of copper called: "110 cold-rolled copper." Copper No. 110 is also known as "electrolytic tough-pitch copper."

The thickness of copper sheet is described by the weight of one square foot. The standard thicknesses are shown in the following table. The thicknesses shown are nominal, with about a 10% allowable tolerance due to manufacturing variations.

Weight per square foot – in ounces	Thickness – in inches
8 oz	0.0108
10 oz	0.0135
14 oz	0.0189
16 oz	0.0216
20 oz	0.0270
24 oz	0.0323
32 oz	0.0431

The most convenient sizes generally available for the 16 oz and 20 oz sheets (to be used for roofing) are probably those which are either 24 inches or 30 inches wide, and 8 feet or 10 feet long. Before you do any detailed planning, you might check whether these sizes are actually available in your locality, and whether there might be another convenient form. Sometimes copper sheet is available in large rolls

Copper tubing for plumbing is available in four different types with different wall thicknesses. Starting with the thickest wall tubing, there are Type K, Type L, Type M, and Type DWV. Type DWV is the lightest and is used primarily for drainage, waste and vent lines, either above ground, underground, or in buildings. The low pressure requirements in the solar heater make a thin wall possible; corrosion resistance of copper is such that even in waste lines a thin-walled tube will last essentially indefinitely. Type L and Type M are the types normally used in water plumbing. Type K is only required for systems with extra high pressure. It should be noted that the outside diameters of all these tube types are matched; it is only the wall thickness – hence also the inside diameter – which is different. One can use the same fittings with all the different types of tube.*

Copper Tube Sizes

Nominal Tube Diameter, or "Size" – in inches	Actual Outside Tube Diameter in inches	Type L		Type M	
		Wall Thickness inches	Weight, per foot – lb/ft	Wall Thickness inches	Weight per foot – lb/ft
3/8	0.500	0.035	0.198	0.025	0.145
1/2	0.625	0.040	0.285	0.028	0.204
5/8	0.750	0.042	0.362	no such tube	
3/4	0.875	0.045	0.455	0.032	0.328
1	1.125	0.050	0.655	0.035	0.465
1½	1.625	0.060	1.14	0.049	0.940
2	2.125	0.070	1.75	0.058	1.46
2½	2.625	0.080	2.48	0.065	2.03
3	3.125	0.090	3.33	0.072	2.68

Smaller size tubing than shown in this table should not be used in the heater

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*There is still a fifth type of copper tubing, not of interest for the swimming pool solar heater. This is Air Conditioning and Refrigeration (ACR) tubing. This is generally the same as Type L, except that it is available in smaller diameters. It is used to carry the refrigerant in most refrigerators and air conditioner systems.

The diameter designation of copper tubing for plumbing was originally specified so as to be equivalent to the steel piping it was designed to replace. This led to a nominal tubing diameter, with the actual outside diameter being 1/8 inch larger, as shown in the following table.

The tubing is normally used with solder joint fittings, which are soldered to the tubes as mentioned in Section 4.5.3. All the standard fittings: 45° and 90° elbows, T's, couplings, couplings with ground contacting surfaces, valves, return bends, crosses and adapters of various kinds are readily available. In addition many of the fittings are available with the different sides of different diameters, having a male or female screw thread on one side and a solder cup on the other, or other such variations. These are described using the following observations.

M - side of fitting with male thread
F - side of fitting with female thread
C - side of fitting for soldering directly to a tube
Ftg. - Side of fitting for soldering into another fitting.

You can hence get a Coupling CxC, an Adapter CxM, a T CxCxC or CxCxM or CxCxF, and dozens of other exotic variations which have been found to be useful for one purpose or another.

A table for listing your eventual requirements is shown in Section 4.10.

4.10 Materials Requirement List

After you have decided on the size and type of solar heater you want to build you can determine the materials you will require. Many of these will depend very much on the type of heater, and on how much work is required to build a supporting structure, roof, or even building. There is an almost infinite variety of things you might consider, and the material might be purchased from many different sources.

The plumbing parts, the copper sheet material, and the solder and flux is somewhat more predictable. Likely as not you would buy all these at one outlet, and you might get a better price if you order all the material at one time. You can use the accompanying tabular form to mark up your requirements. On most of these you should have no trouble figuring out your needs. On a batten roof you can go through the exercise of determining your exact needs. As a guideline, you will need approximately 50% more in sheet area than the actual area of the roof. For every 100 square feet of roofing, you will need roughly 1 pound of 1-inch barbed copper or bronze nails. For every 100 feet of sealing joint you make on the roof, you will need roughly 2 pounds of sealant.

5. OPERATION AND MAINTENANCE

The collector should be hosed down every now and then to remove accumulated dirt. Bird droppings should not be left on indefinitely, since they tend to make the coating peel. Every few months or so the collector might be left turned off for a full (hot) day so that any moisture which may have accumulated on the roofing, has a chance to evaporate. If the roof is always cooled by the solar heater during the daytime, condensed moisture might accumulate. Every few years, when it becomes apparent that the coating is either beginning to get thin or to lighten appreciably, the surface can be recoated as described in Section 4.7.

In the hours just after sunrise and just before sundown, very little solar energy is collected (Section 2.8). About 90% of the available solar energy can be collected during the middle two thirds of the day. You can get the time of sunrise and of sunset from the newspapers, or determine these times as shown in Section 2.8. Solar time and local clock time do not coincide, and calculated sunrise and sunset values from Section 2.8 have to be shifted accordingly. The circulation timer of the pool can be adjusted occasionally to circulate only during the middle two thirds of the day.

The filter should be cleaned regularly so that the solar heater gets a high enough water flowrate.

For operation in conjunction with a gas heater, see Section 2.11.

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MATERIALS REQUIREMENT LIST

Tubing	3/8"	1/2"	3/4"	1½"	2"	Other
Length required						
Number of 20 ft lengths						

Fittings	3/8"	1/2"	3/4"	1½"	2"	Other	Other
90° Elbows C x C							
45° Elbows C x C							
Couplings C x C							
T's C x C x C							
End Caps							
Adapters C x M							
Ground Joint							
Unions C x C							
Valves C x C							
Other							
Other							

Sheet	Area required – sq ft	Size of sheet Width of strip	Number of sheets Length of strip
10 ounces (0.0135 in.)			
14 ounces (0.0189 in.)			
16 ounces (0.0126 in.)			
20 ounces (0.0270 in.)			

Solder and Flux			
50 A solder		Paste flux	
40 A solder		Liquid flux	

Nails	
Barbed Copper or Bronze Nails (1 inch)	

COPPER DEVELOPMENT ASSOCIATION INC.
405 Lexington Avenue, New York, N. Y. 10017

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