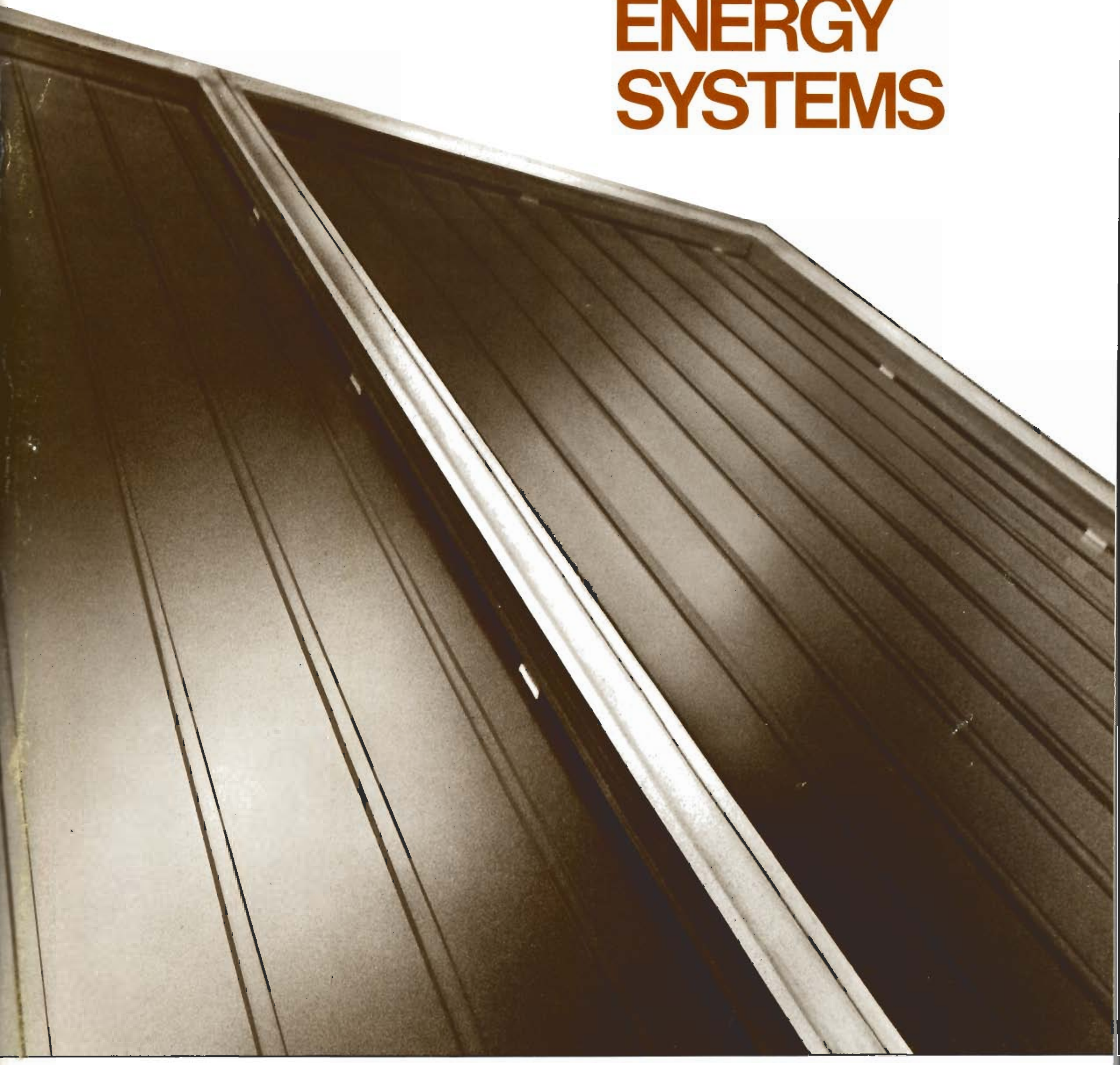
Copper Brass Bronze Design Handbook

SOLAR ENERGY SYSTEMS



COPPER DEVELOPMENT ASSOCIATION INC.

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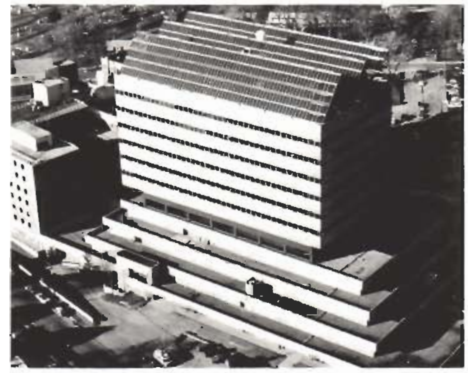
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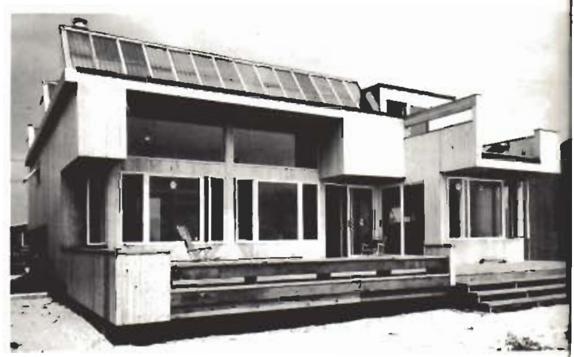
Residence, Riviera Beach, FL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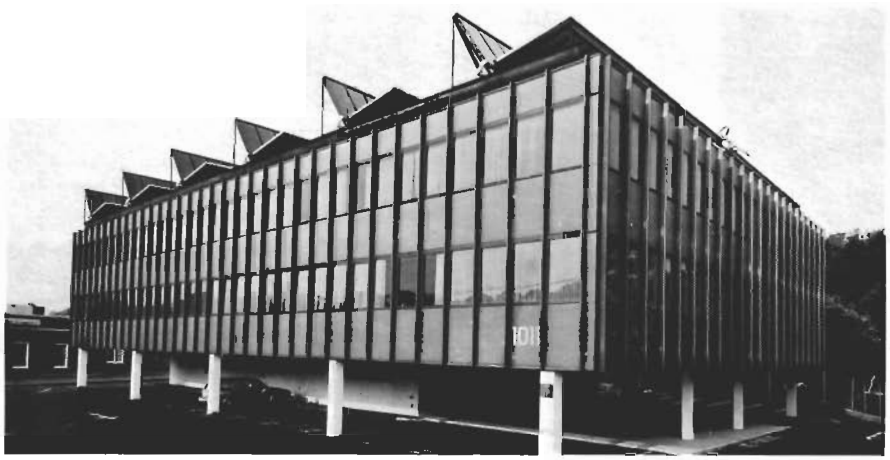
Residence, Breckenridge, CO

This handbook outlines procedures for calculating energy collected from a solar energy system and suggests different alternatives for collection, storage and distribution. Each solar system must be engineered to meet the particular circumstances of its use, and Copper Development Association Inc. assumes no responsibility or liability of any kind in connection with the calculations or system designs set forth herein or their use by any person or organization, and makes no representations or warranties of any kind.

Burt Hill Kosar Rittelmann Associates assisted in the preparation of this CDA Design Handbook.

COPPER BRASS BRONZE DESIGN HANDBOOK

SOLAR ENERGY SYSTEMS



Office Building, Stamford, CT

Residence, Sugarmill Woods, FL

Motel, Temple, TX

INTRODUCTION

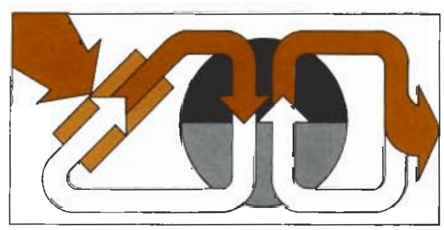
Most of the energy used presently to keep buildings warm and to heat water for domestic purposes comes indirectly from the sun. The fossil fuels, coal, gas and oil, burned in our furnaces and water heaters, were formed over thousands of years from decayed plants and animals that once depended on the sun for life and growth. These fossil fuels may accurately be thought of as "stored" solar energy.

Since the onset of the energy crisis just a few years back, we have become sharply aware that the supply of fossil fuels available to us is rapidly being depleted. If we continue to deplete our fossil fuel resources at current rates, they may, in time, run out completely. Before this happens, we must know how to make *direct* use of the vast amounts of solar energy the earth receives each day. For instance, on a global scale, two weeks of solar energy is equivalent to the fossil energy stored in all the earth's known reserves of coal, oil, and natural gas. The purpose of this publication is to explain means by which solar radiation can be put to work satisfying the thermal energy requirements for space and domestic water heating.

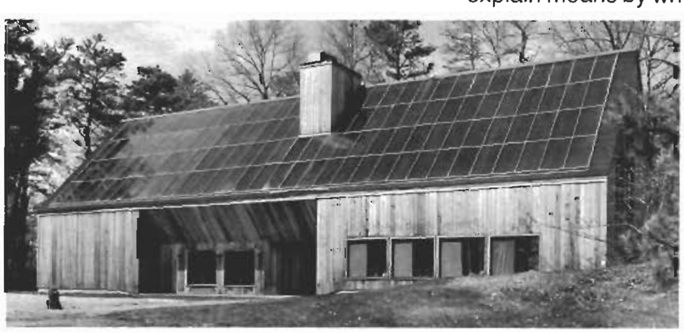
The direct utilization of solar energy is by no means an entirely new concept. Man's tentative approaches to harnessing the sun's power can be traced over many centuries. In the past 50 years or so, applications of solar energy systems for space heating and hot water have appeared in states, such as Florida, where sunshine is abundant and fuel expensive, and in countries such as Japan and Australia. The recent energy crunch has accelerated the development of solar technology, a field in which the copper and brass industry is playing a leading role.

Solar energy systems are very practical now for many applications in the building industry, such as space heating, water heating and swimming pool water heating. Space cooling is also showing great promise of being an economically feasible option.

Applying solar energy to buildings involves three things. It must be collected; it must be stored; and it must be "distributed"—put to work within the structure for some purpose. Collection and storage are areas featuring some new methods, components and systems. Distribution, on the other hand, can be accomplished by the familiar means used for the traditional fossil-fuel systems.



COLLECTION/STORAGE/DISTRIBUTION

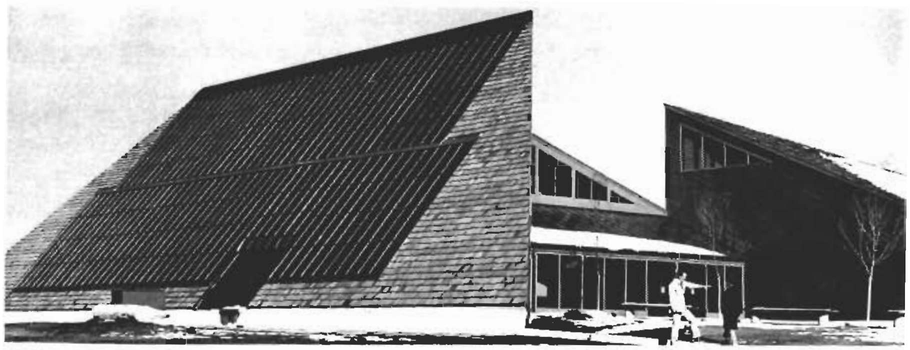


Community Center. Albany, NY

Community Center, Santa Clara, CA

SECTION 1

FUNDAMENTALS OF SOLAR ENERGY



Church, Denver, CO

Characteristics Of Solar Radiation

The sun is a star and source of most of our life and energy. Radiating in all directions, only a small percentage of its tremendous energy reaches the earth's atmosphere. The portion that actually reaches the surface of the earth is smaller still because of the reflective and filtering characteristics of the earth's protective atmosphere. Yet, despite all of these limiting factors, the amount of solar energy delivered to the earth each day is thousands of times greater than man's total daily use of energy for all purposes.

Solar energy covers a wide range of wavelengths in the light spectrum, ranging from the ultraviolet through visible light to the infrared regions. When it reaches the outer ring of the earth's atmosphere, about 30 percent of the solar radiation is immediately reflected back into space. As the remainder continues on its path through the atmosphere toward the earth, several other effects reduce its intensity. First, most of the ultraviolet and some of the infrared components are filtered out so that what is left is largely in the form of visible light.

As shown in Fig. 1, a significant portion of the incoming radiation is reflected by the clouds back into space. A smaller portion is absorbed by water particles in the atmosphere and another portion diffused by atmospheric particles, clouds and pollutants. This last portion of the sun's radiation is called *diffuse* or scattered radiation.

The remainder of the radiation which is not affected in one of these manners passes more or less directly to the earth's surface from the direction of the sun. This is called *direct* radiation. The energy available for collection is the direct radiation plus a portion of the diffuse radiation.

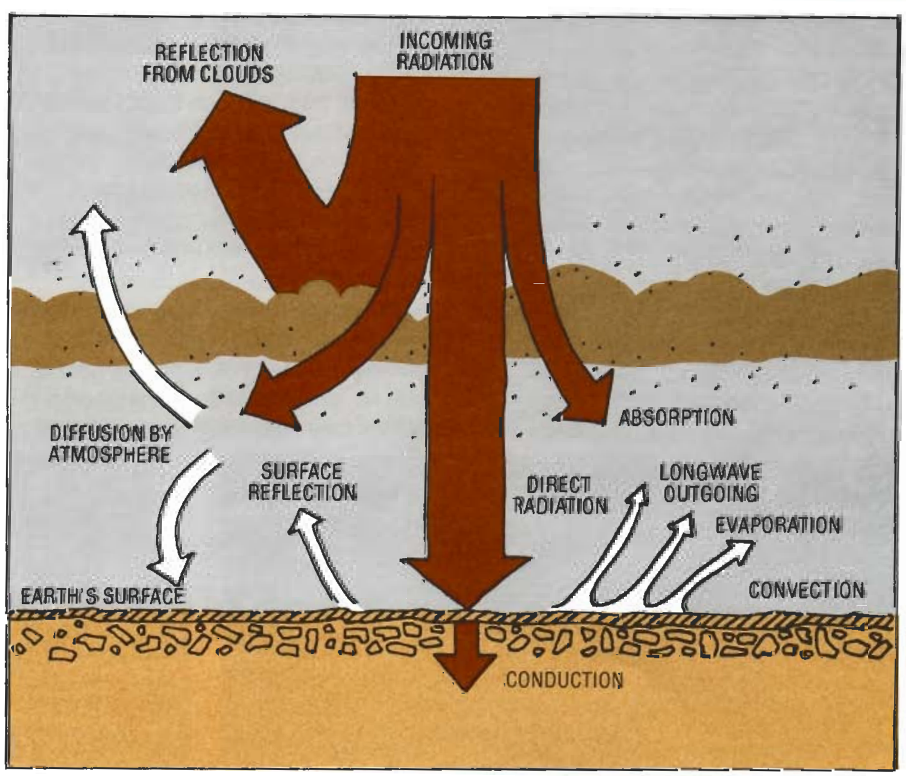


FIGURE 1/ DISTRIBUTION OF INCOMING RADIATION

Solar Geometry

The rate at which solar energy reaches the outer limits of the earth's atmosphere is the same at all times. This rate, known as the *solar constant,* is equal to 429 Btu (British thermal units) per square foot per hour falling upon a surface perpendicular to the direction of the sun's rays. Despite the fact that the sun's intensity remains the same, we experience a change of seasons as a result of the varying geometric relationships between earth and sun. These relationships are depicted in Fig. 2.

The earth revolves once each day around an axis, which passes through the North and South Poles. Because its axis is tilted with respect to the sun, the intensity of the sunshine reaching the earth's northern and southern hemispheres rises and falls as the earth makes its yearly orbit and the seasons change. The angle of this tilt, called the *declination angle*, is the primary reason for the variation in the distribution of solar energy over the earth's surface, for the varying number of hours of daylight and darkness over the year, and for the great differences in the intensity of solar energy received at any one location.

The amount of radiation which reaches the earth depends in part on the distance it travels through the atmosphere. As indicated in Fig. 3, solar energy impacts at various angles, depending upon the sun's position relative to the earth. This angle determines the length of travel. The longer its path through the atmosphere, the less direct energy will reach the earth's surface. The three classifications for lengths of travel shown are referred to as Air Mass 1, 2 and 3.

Air Mass 1 identifies the shortest path through the atmosphere and occurs when there is a 90 degree angle between the sun's radiation and the earth's surface. This position of the sun is referred to as the zenith position and it occurs at the Tropic of Cancer (23½ deg North latitude) on the summer solstice. An Air Mass of 2 exists when there is a 60 degree angle between a perpendicular to the earth's surface and the incoming angle of the solar radiation. In Air Mass 2, the sun's rays pass through twice as much atmosphere as in Air Mass 1. Similarly, in Air Mass 3, the sun's rays pass through three times as much atmosphere as in Air Mass 1.

Altitude and Azimuth

The characteristics of solar geometry have a significant effect on the physical parameters and performace of solar col-

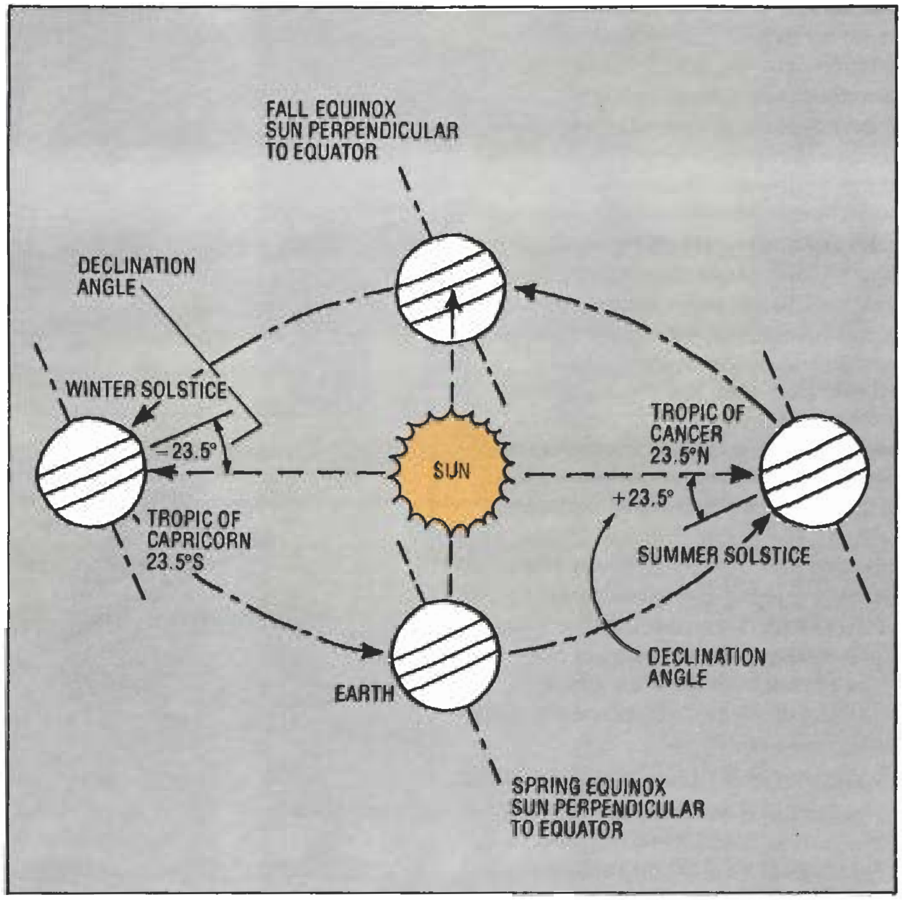


FIGURE 2/ SOLAR GEOMETRY

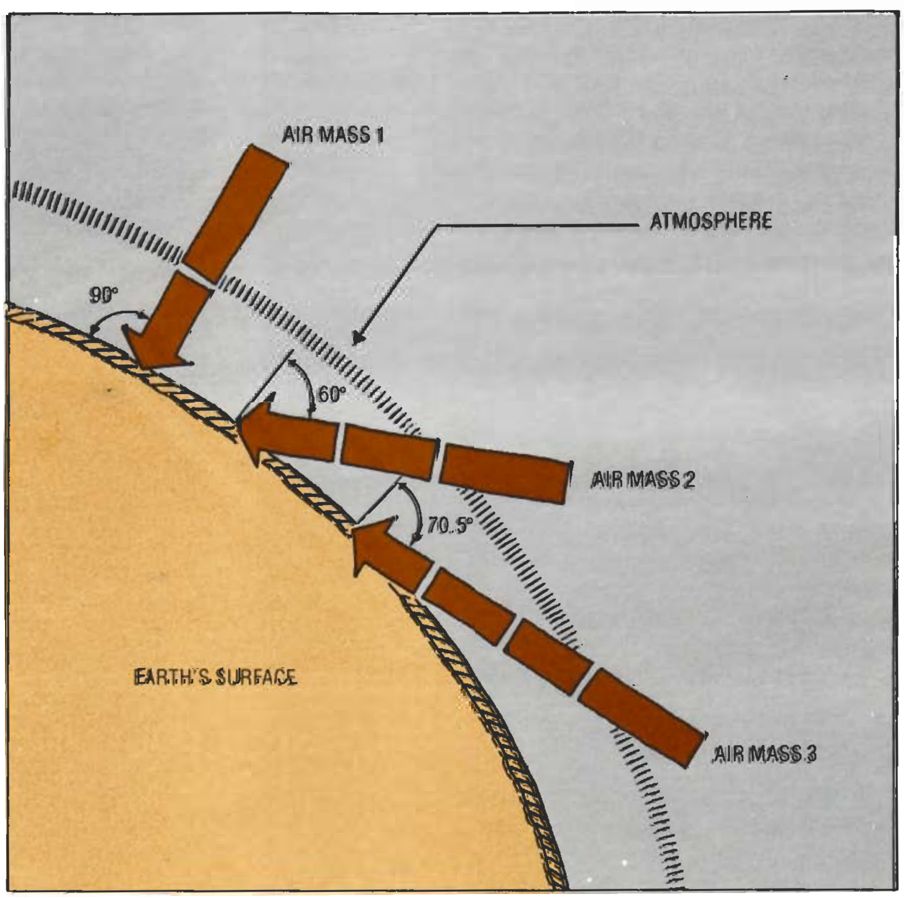


FIGURE 3/RELATIONSHIP OF INCIDENT ANGLE AND AIR MASS

lection systems. Fig. 4 illustrates typical altitude and azimuth positions of the sun at the equinox and solstice days. It can be seen from this diagram that at the summer solstice, the sun rises from a position north of due east, climbs to a high position in the sky at solar noon and sets at a position north of due west. On the equinox days, the sun rises at a position of due east, climbs to an intermediate position in the sky and sets at a position of due west. At the winter solstice, the sun rises south of due east, climbs to a low position in the southern sky, and sets south of due west. The angle of the sun's position in the sky with respect to the earth is known as the *solar altitude*. The position of the sun with respect to compass directions is referred to as the *solar azimuth*. The actual positions of solar altitude and azimuth vary each day of the year and, furthermore, are different for each position of latitude. These are two of the most significant factors in determining how a collector of solar energy should be positioned with respect to the sun.

Collector Tilt

Since the sun is low in the southern sky during winter, more solar energy will strike a flat collector if it is tilted up from the horizontal at a steep angle toward the sun. The effect of collector tilt is illustrated in Fig. 5. In summer, the flat collector will intercept more solar radiation in a horizontal position than it will tilted up steeply from the earth. It can be seen that a collector tilted up toward sun during winter will intercept more solar radiation than the same sized collector in a horizontal position.

The actual angle at which a collector should be tilted is a function of the particular characteristics of the intended application. If the intention is to collect the most solar energy in the winter period, the collector tilt should be steep. Conversely, if the intention is to collect the most heat during the summer period, collector tilt should be relatively flat.

There are convenient rules-of-thumb for determining the most appropriate collector tilt. These are as follows:

A. To collect the most radiation in the winter period, tilt the collector at an angle equal to the latitude plus 15 degrees.

B. To collect the most solar radiation during the summer period, tilt the collector at an angle equal to the latitude minus 15 degrees.

C. To collect the most radiation averaged over the year, tilt the collector at an angle approximately equal to the latitude.

These rules should be taken as guidelines only and adjusted for the specific characteristics of an application.

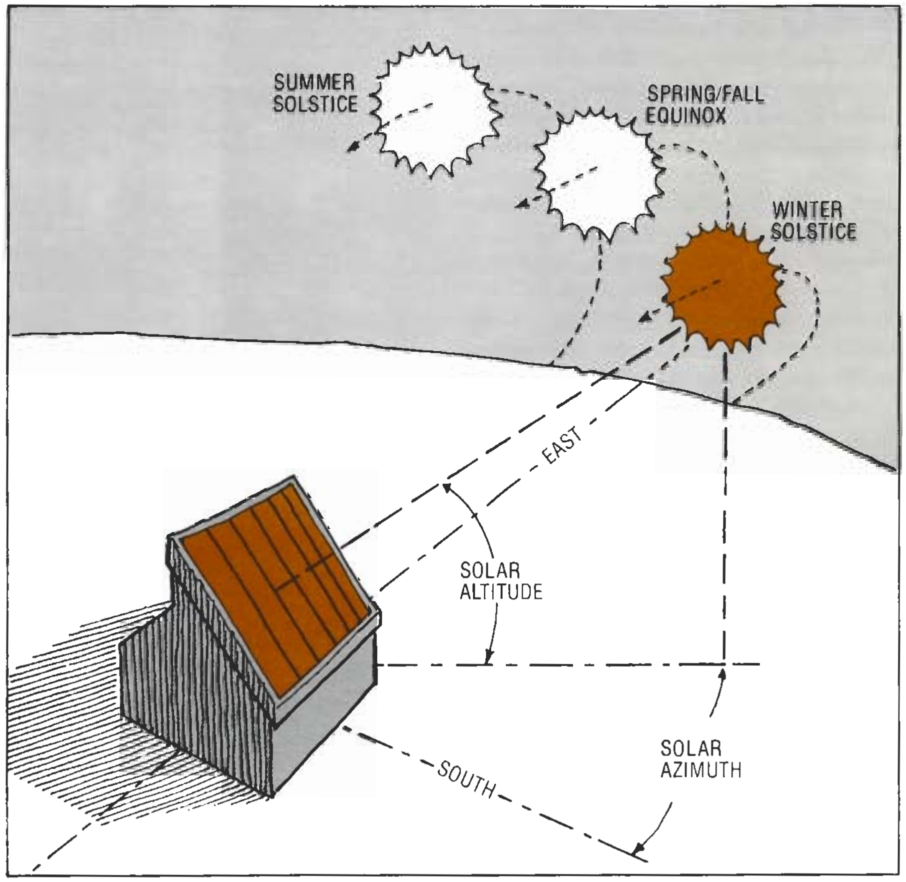


FIGURE 4/ ALTITUDE AND AZIMUTH

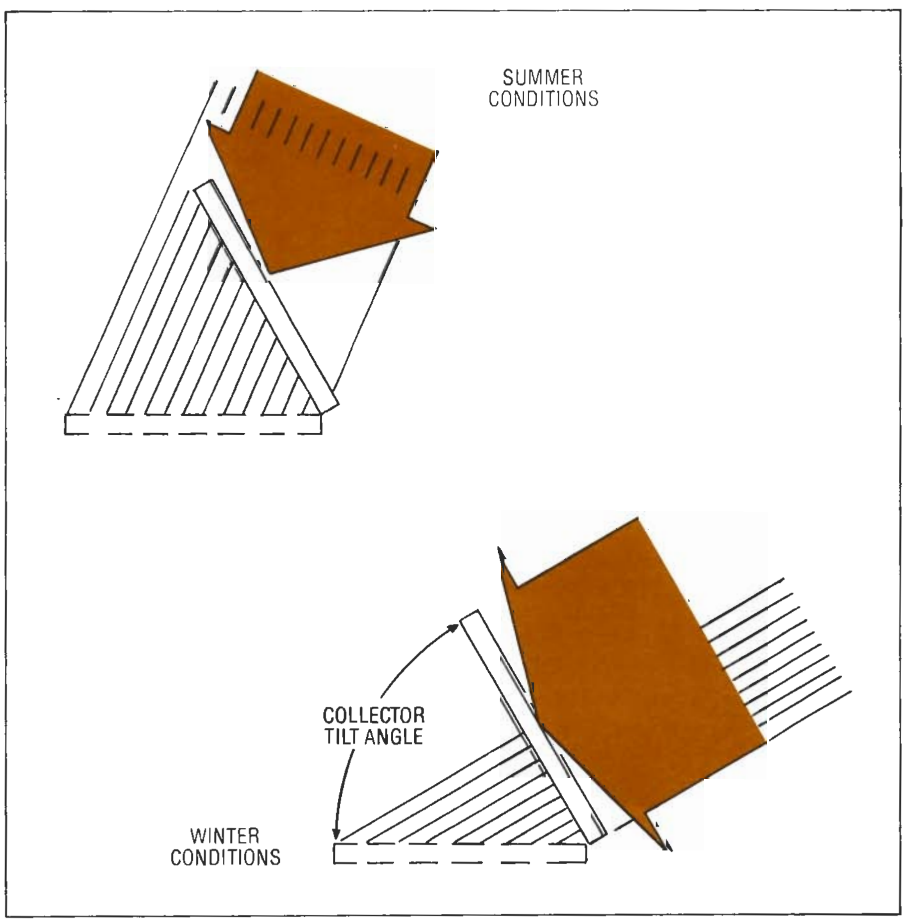
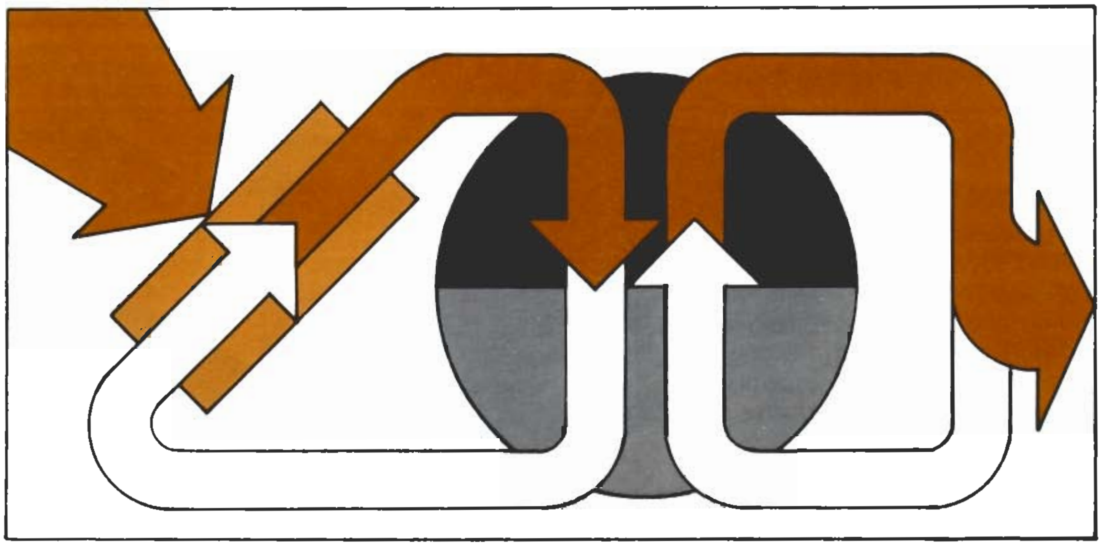


FIGURE 5/ EFFECT OF COLLECTOR TILT ON INCIDENT RADIATION

FIGURE 6/ COLLECTION, STORAGE AND DISTRIBUTION ARE THE THREE BASIC COMPONENTS OF ALL SOLAR ENERGY SYSTEMS.



SECTION 2

COLLECTION

Solar radiation out in space has a characteristic pattern of wavelengths and intensity. By the time this radiation reaches the earth, most of the ultraviolet component has been filtered out. What remains is mostly in the visible region of the spectrum, with a smaller portion covering the short infrared region, as shown in the left portion of Figure 7. This incoming radiation is converted to heat when absorbed by a surface, such as that of the blackened copper *absorber plate* in a solar collector.

Some of the absorbed energy will be lost from this surface, by either conduction, convection, or re-radiation. Conducted losses come from direct contact with a colder material, while convection losses arise from heat being carried away by air currents. Surfaces also reradiate absorbed energy, but its wavelength will have changed to "long infrared", also shown in Figure 7. This outgoing energy is a significant factor in the design and performance of the collectors in the solar heating system.

There are many possibilities for the collection of heat from solar energy. Direct gain through window areas is one, but this often provides too much heat when and where it is not needed and the resulting energy is difficult to control. Aiming to store this energy for future use, most solar energy collection systems utilize a heat-transfer fluid—either a liquid or air—to move the collected thermal energy from the collectors to a heat storage material. The collectors are typically one of two basic types: concentrating collectors or flat-plate collectors. Concentrating collectors utilize lenses or reflective surfaces to focus the sun's rays onto a relatively small absorbing area, and are able to build up higher temperatures than flat-plate collectors. Concentrating collectors

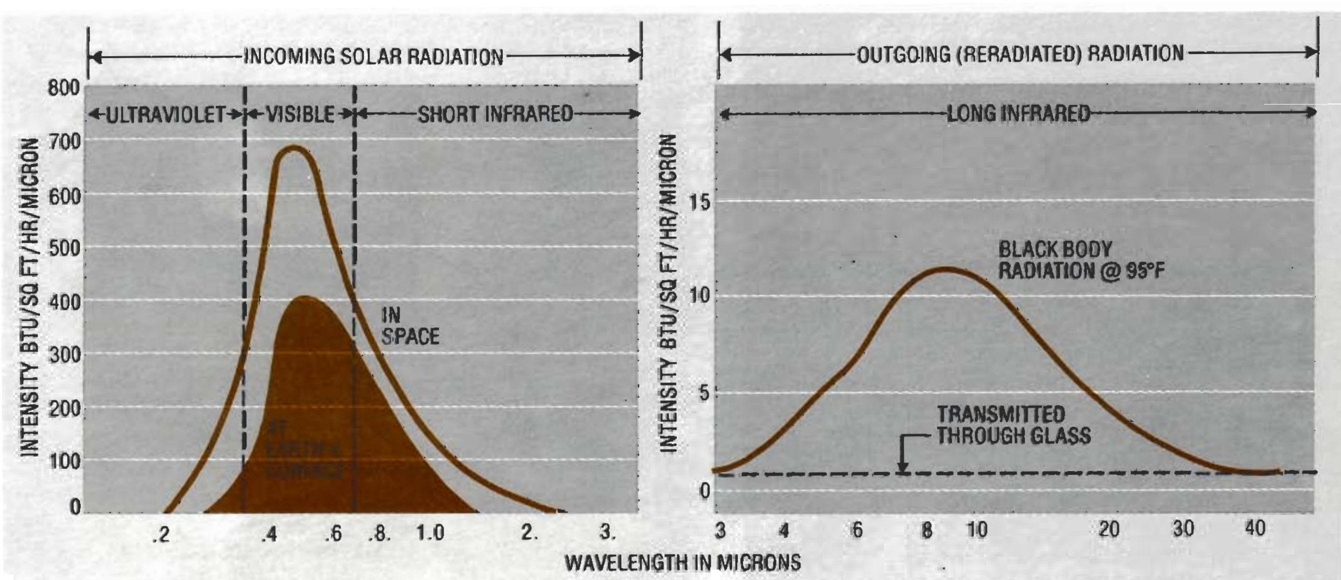


FIGURE 7/ SPECTRAL DISTRIBUTION

are generally unable to effectively focus the diffuse component of solar radiation, and thus their performance is based largely upon available levels of direct insolation.

Flat Plate Collectors

Flat plate collectors take advantage of both the diffuse and direct radiation falling on the absorber plate. In order to collect as much energy as possible, the collectors are often covered with a glazing material, such as glass or certain plastics, which are highly transparent to the incoming solar radiation. These covers serve as insulation over the absorber plate, as they keep convective heat losses down. In addition, glass is virtually opaque to the outgoing long-wave infrared radiation, and thus traps this radiation inside the collector, a phenomenon known as the "greenhouse effect".

Figure 8 illustrates how this phenomenon affects the performance of three different collector types. In the first type, Flat Black Plate Without Glazing, much of the radiation absorbed by the absorber plate is lost from the top surface of the plate, with some lost through the back insulation. Some useful heat is retained without a glazing cover, but only if the temperature of the absorber plate is close to the temperature of the surrounding air.

In the second type, Flat Black Plate With Glazing Cover, the radiation absorbed by the black plate is re-emitted as it was in the previous type. But the glass cover blocks the loss of the re-emitted radiation to the outside. There is some heat loss through conduction and convection, but more heat is retained with a glazing cover. This is especially true as the temperature difference between plate and outside air becomes greater. It may be desirable to utilize more than one layer of glazing, depending upon the magnitude of the temperature difference.

The third portion of Fig. 8 illustrates a collector with a Selective Surface and Glazing Cover. A selective surface is a very thin layer of special material applied to the top of the absorber plate. The layer's thickness is approximately equal to the wavelength of the incoming solar radiation. The selective surface reradiates a much smaller portion of the absorbed energy, which makes the collector operate more efficiently. There is still some heat loss through conduction and convection to the outside air, but more heat is retained with a selective surface than with an ordinary flat black surface. A selective surface may be used with single or multiple glazing. Selective surfaces are especially useful in collectors that operate at high temperatures. They in-

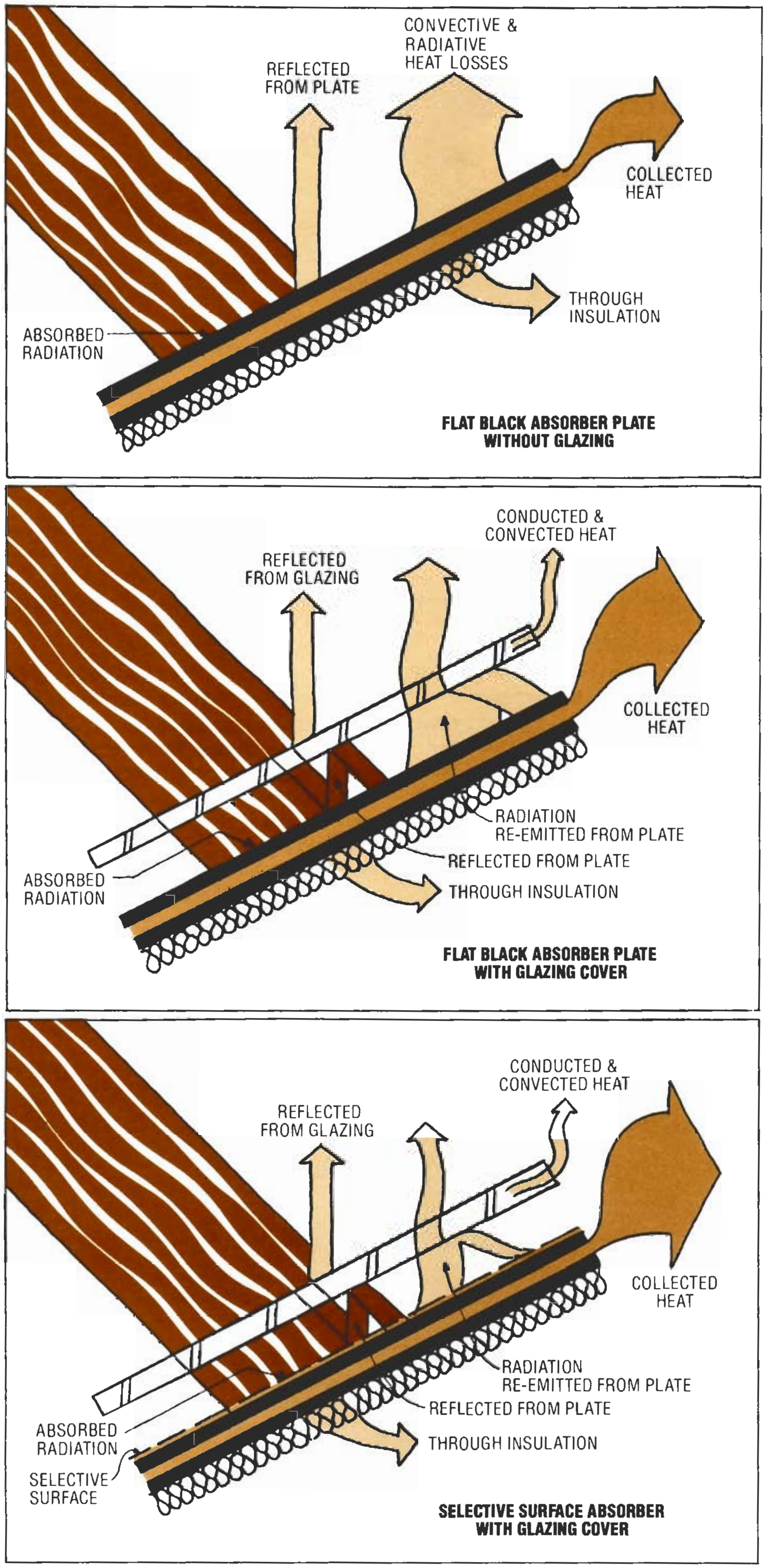


FIGURE 8/THREE TYPICAL FLAT PLATE COLLECTOR DESIGNS

crease collection efficiency, but at the premium of higher cost than non-selective flat black surfaces.

Collector Construction

Flat plate collectors utilize liquid as the heat transfer medium. Typically they have blackened copper absorber plates with an integral or attached array of copper tubes. This absorber plate may be packaged into a modular collector panel, which is complete with glazing covers, insulation, and enclosure box, or the absorber plate may be incorporated as an integral part of a roof or other structure.

Figure 9 illustrates the major components of a typical modular liquid flat plate solar collector panel. There are one or two layers of glazing material held by a frame over a blackened copper absorbing plate. The plate has an integral or attached array of tubes for circulation of a liquid. The liquid inlet connection shown at the bottom of the collector is diagonally opposite the liquid outlet connection at the top. Usually this configuration is used so the flow length is the same through every passage. The aim is to achieve a balanced flow of liquid through the collector and, thus, maintain a relatively uniform temperature pattern over the plate.

Site-fabricated collectors may have the absorber plate laid over or between structural members. Insulation is placed behind, and glazing covers, if appropriate, are installed over the absorber plate. Care must be taken to insure that the cover and insulating materials are compatible with the high temperatures reached by the absorber plate. Properties of appropriate materials are covered in Section 6-Design Recommendations.

The solar collector must be protected from freezing in the winter and from very high temperatures which can occur when liquid is not flowing through the collector. Also, when cold water is put into a hot collector, a thermal shock can occur, damaging the collector. Methods of providing protection against thermal shock and freezing are contained in Section 6–Design Recommendations. Methods of freeze protection are also covered in Section 4–Distribution: Domestic Water Heating.

Beneath the absorber plate is an insulating material that retards loss of the absorbed heat through the back of the collector panel. Heat losses from the sides of the collector panel are minimized by maintaining a space or "thermal break" between the metal absorber plate and the collector framing.

It is helpful to maintain a moisture-free condition in the collector to retard the loss of heat which tends to be greater in moist air than in dry air. A second reason is to prevent condensation of water on the glazing covers which would reflect incoming solar radiation away from the collector.

One method for keeping air within the collector dry is the incorporation of spacers made of a desiccant (moisture-absorbing) material. These spacers are inserted between cover and absorber plate and, also, between layers of multiple-glazing covers.

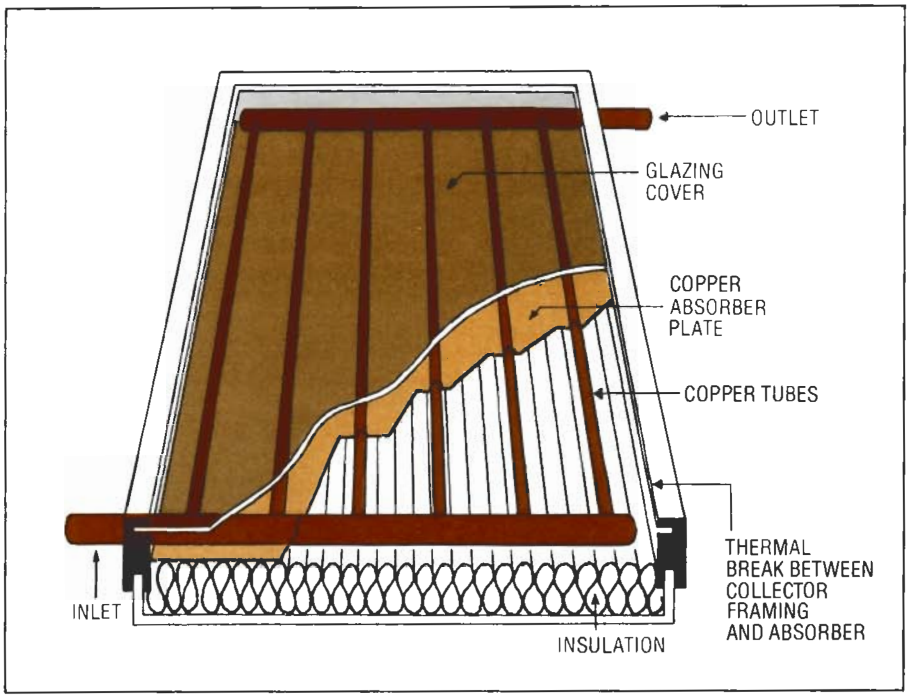


FIGURE 9/ TYPICAL FLAT PLATE COLLECTOR

Collector Efficiency

A collector's usefulness depends mainly on how much of the solar energy it can make available for heating. This is its efficiency. The operating efficiencies of several different types of collectors are compared schematically in Fig. 10. The significant improvement achieved by adding glazing covers is immediately apparent. Fig. 10 reveals several other general conclusions about the

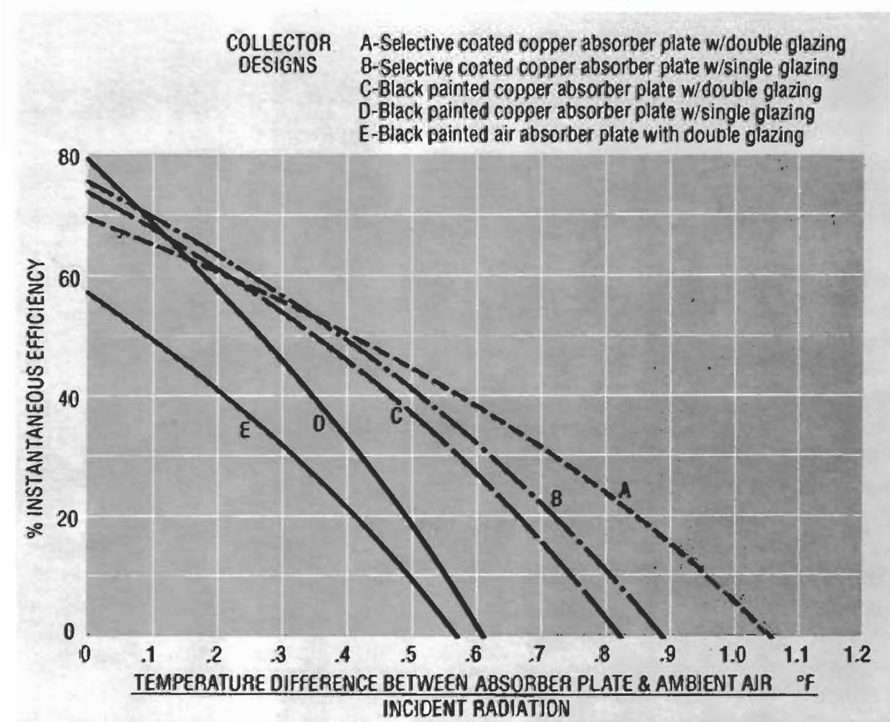


FIGURE 10/ PERFORMANCE EFFICIENCY OF TYPICAL COLLECTORS efficiency of collectors:

1. All collectors operate with highest efficiency when the difference in temperature between the absorber plate and ambient air is lowest.

2. For the same temperature difference, efficiency will be higher if the incident solar radiation is higher. Thus, at the same temperature difference, higher efficiencies can be expected in summer when more solar energy is available than in winter when less solar energy is available at the collector surface.

3. The highest possible efficiencies are achieved when there is no temperature difference between the absorber plate and the surrounding air. But even under this condition, 100 percent efficiency is not achievable. This is because there are always losses caused by incomplete transmission through the glazing covers, reflectance from the blackened absorber plate, and incomplete transfer of heat absorbed by the absorber plate into the heat transfer liquid or air.

4. The choice of collectors should be related to the operating temperature difference, the amount of solar radiation available, and the cost of adding options such as selective black surfaces or additional glazing covers. It can be seen from Fig. 10, for example, that in the range of 0 to 20°F temperature difference, such as might exist in a swimming pool heater application, a collector with no cover plates is an appropriate choice. When high temperature differences are anticipated, such as in solar cooling operations, a selective surface may be needed to obtain these temperatures.

5. Collector efficiency is increased by minimizing the temperature rise from collector inlet to outlet. A common range is 7 to 10°F; this can be accomplished by circulating water at the rate of 1 to 3 gallons per square foot of collector per hour.

It is important to realize that Fig. 10 represents the *instantaneous* efficiency of solar collector operation. This is the efficiency at a particular time, usually stated as an hourly efficiency. The lines plotted on this graph are based upon a specific intensity of solar energy available at the collector plate. During the day, the amount of solar radiation available to the absorber plate varies continually.

Fig. 11 illustrates the relationship between time of day and intensity of solar radiation. The horizontal line, marked "critical or threshold intensity", represents the point at which the heat losses from the absorber plate (determined by the temperature difference between the plate and the surrounding air, and collector design) are equal to the heat gain experienced by the plate.

This line moves up if the temperature difference becomes greater, down if the temperature difference becomes less. When the intensity of radiation reaches this threshold point, the collector begins operation. No heat would be produced if the system were operated before this threshold intensity was reached. In fact, if the collector system were operated below threshold intensity, heat would be lost from the previous day's collection.

It can be seen that there are portions of the daily solar radiation that are too low in intensity to justify operation of the collector. These are signified by the shaded triangular areas below the line of critical intensity. After the critical intensity has been reached and the collector has begun operation, the instantaneous efficiency of the collector varies through the period of collector operation. At the beginning and end of the period of

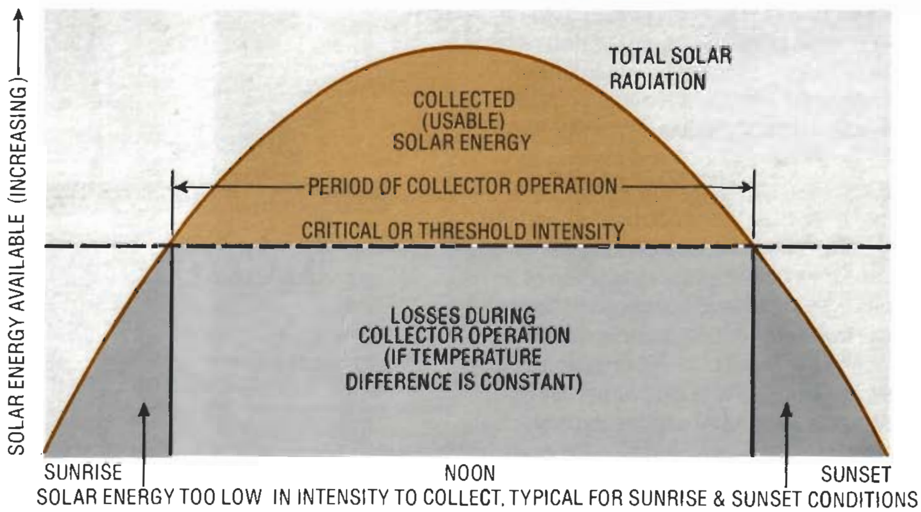
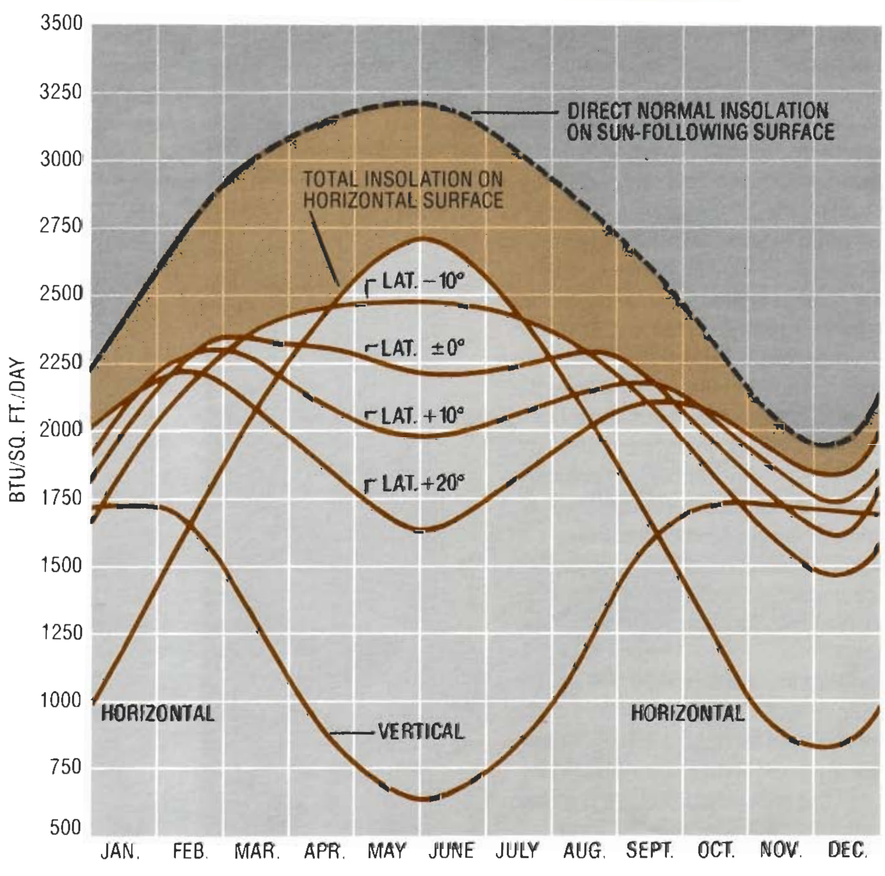


FIGURE 11/ COLLECTION OF SOLAR RADIATION THROUGHOUT THE DAY



Solar radiation on horizontal and south facing surfaces at various collector tilts, 40° north latitude, 21st day of each month, clear sky conditions.
SOURCE: 1974 ASHRAE Applications Handbook and Product Directory.

FIGURE 12/ COMPARISON OF COLLECTOR TILTS collector operation, for example, very little solar energy is collected in comparison with the collector's operational losses. The instantaneous efficiency of operation will be quite high at the midpoint of the period of collector operation.

There is an important difference between instantaneous collector efficiency and day-long collector efficiency. The day-long collector efficiency is the amount of solar energy collected as a percentage of the total available for the entire day, including portions too low in intensity to operate the collector. Some collector manufacturers judge their collector performance by instantaneous efficiency. While this indicates the collector's capabilities, the figures cannot be applied to the entire day's solar radiation.

Collector Tilt And Orientation

The amount of energy falling on the collector surface during the year at any position of latitude, depends upon the tilt and orientation of the collector. Fig. 12 shows how collector tilt affects incident radiation at 40 deg north latitude on a cloudless day. The radiation incident on a horizontal surface experiences a sharp peak during the month of June when the sun is high in the sky. It falls off very sharply toward the winter months when the sun is much lower.

Tilting the collector to 30 deg (equivalent to the position of latitude minus 10 deg) flattens the curve somewhat. Maximum production still occurs during summer, but there is a significant improvement in production during winter. Further increases in tilt to 40 deg (equal to the latitude of the installation), to 50 deg (latitude plus 10 deg), and to 60 deg (latitude plus 20 deg) cause progressive shifts of the curve so that the maximum production occurs more toward the winter heating season. For this latitude, a collector tilted vertically (90 deg) experiences its greatest amount of incident energy during winter, but the collected energy drops off sharply during summer.

The dashed line on the top of the graph shows the amount of solar energy incident on a surface which "tracked" or followed the sun, always adjusting its tilt and orientation so that solar energy was received at right angles. Although there is somewhat more energy incident on such a surface, the economics of building a mechanism to allow the collector to follow the sun may not be justifiable.

Orientation refers to the compass direction in which the collector faces. It also plays a significant role in determining the amount of incident energy, as shown in Fig. 13. Orientation of collectors used for space heating systems is especially important. It can be seen that in winter, when the sun rises south of due east and sets south of due west, an orientation of southeast or southwest (45 deg from due south) receives only 70 to 80 percent of the radiation received by a south-facing surface at the same tilt.

The actual percentage figure depends upon the latitude, with the more northerly latitudes (which experience shorter days) suffering the greatest reduction in incident radiation for variations from a south orientation. In spring and fall, orientation becomes less critical. In summer, orientation is least critical, with south facing surfaces actually receiving slightly less radiation during June than surfaces facing south-southeast or south-southwest.

Since collector heat production capacity is affected by the temperature of the surrounding air, local conditions at the point of collection are also important. In most areas, maximum air temperature is reached in the early afternoon, usually around 2 to 3 p.m. Also, many locations experience morning haze which clears by early afternoon. Where such conditions prevail, peak collection may be experienced by a collector which faces 10-15 deg west of south, instead of the theoretical value of due south.

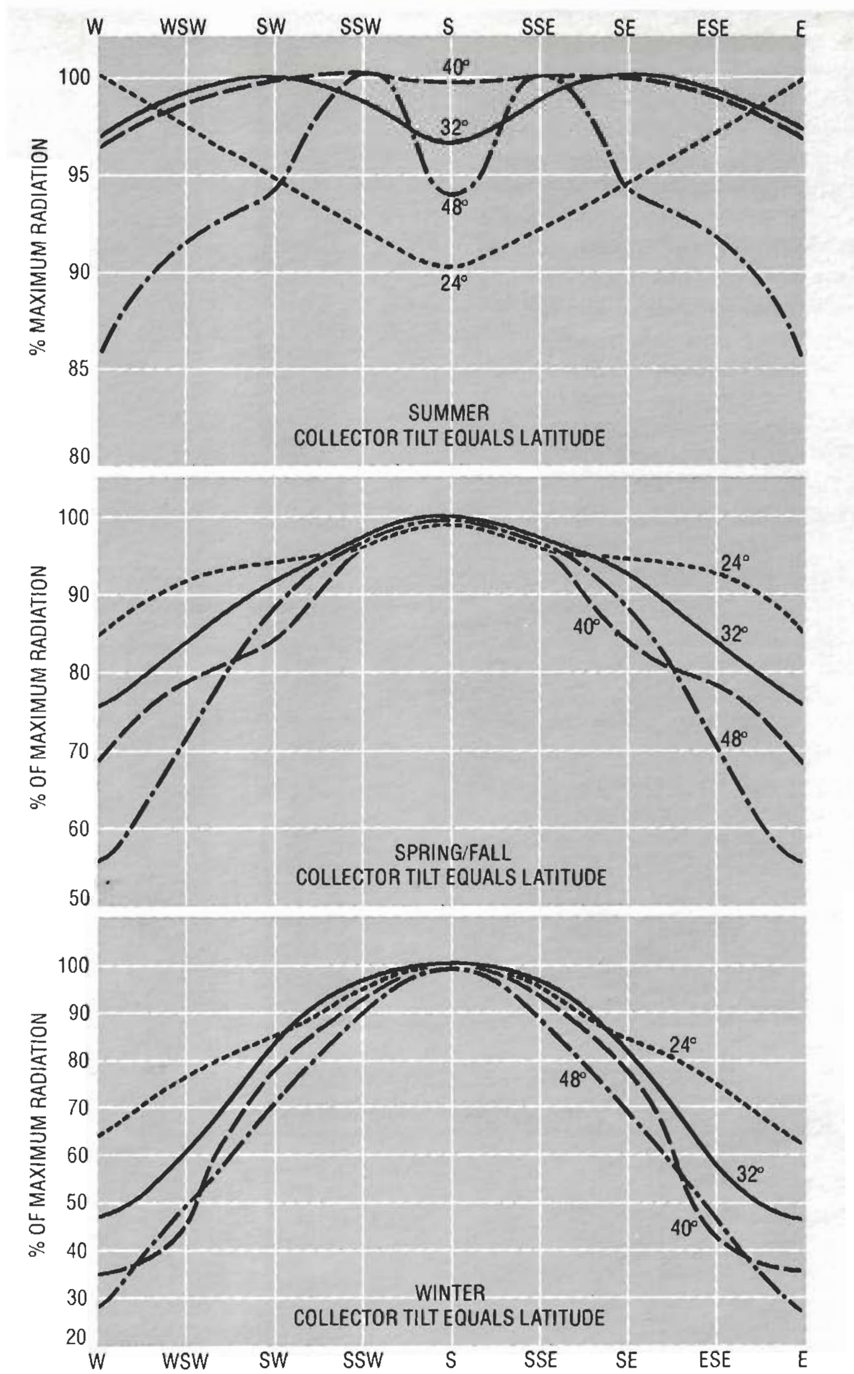


FIGURE 13/ EFFECTS OF COLLECTOR ORIENTATIONS

SECTION 3

STORAGE

Approaches to Heat Storage

Allowing for the intermittent quality of sunshine, any practical system must include a capability for storing the collected solar energy until it is needed. However, in most applications it is not economically feasible to install storage capacity large enough to guarantee a supply of solar-heated water at all times. A more practical approach is to rely on solar energy for a portion of a building's heating needs and to supplement it with a second heat source, using electricity or one of the fossil fuels. The solar system can be sized to meet a portion of the normal space and water heating requirements, while the supplementary heat source stands by in readiness for times when there are long periods without sunshine or when demand for heat is unusually heavy.

There are two basic types of storage: sensible heat storage and latent heat storage. Sensible heat storage is based on the principle that a definite amount of energy is required to raise the temperature of a unit volume of a given substance 1°F. "*Unit heat capacity*" is equal to the specific heat of the material times its density. Water, for example, has a specific heat of 1.0 and a density of 62.5 lb./cu ft. Therefore, 1 cu ft of water will rise in temperature 1°F when 62.5 Btu is applied.

Table 1 indicates the sensible heat storage capacity of various types of solid and liquid materials. Liquid sensible heat storage materials are most commonly used with liquid flat-plate collectors. Similarly, solid sensible heat storage materials are most commonly used with air flat-plate collectors. A significantly greater volume of solid materials is required to attain the same amount of heat storage as water because the specific heat is much lower for solid materials than it is

	Specific Heat BTU/Lb. °F.	Density Lb./Ft.³	Unit Heat Capacity BTU/Ft.³/°F. No Voids	Unit Heat Capacity BTU/Ft.³/°F. 30% Voids
Water	1.0	62.5	62.5	(62.5)
Water (30%)—Ethylene Glycol (70%) Mixture (230°F.)	.8	64.1	51	36
Scrap Iron	.112	489	55	38
Magnetite	.165	320	53	37
Scrap Aluminum	.215	168	36	25
Concrete	.27	140	38	26
Rock (Basalt)	.20	180	36	25
Brick	.2	140	28	20
Rock Salt (NaCl) (30-70% by weight at 230°F.)	.219	136	30	21

TABLE 1/SENSIBLE HEAT STORAGE MATERIALS

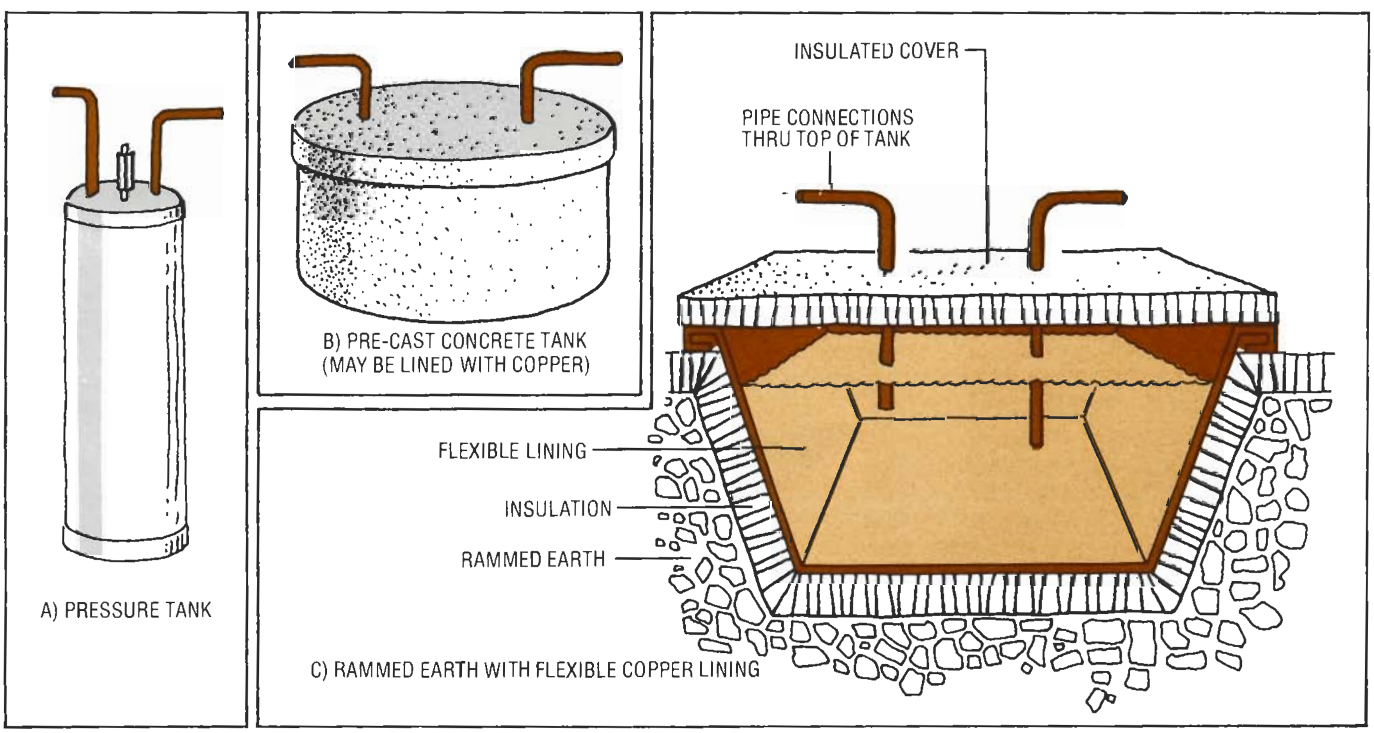


FIGURE 14/ LIQUID HEAT STORAGE OPTIONS

for water. Solid materials must also make an additional allowance for the circulation of air around the materials to cause the heat transfer to take place. A common solid-to-void ratio is 70 percent solid to 30 percent void for solid sensible heat storage materials. Thus, solid heat storage volumes will be two to three times liquid heat storage volumes for the same storage capacity. Also, greater fan motor horsepower is often required to circulate air through the storage medium, the supply ducts and the collector.

Latent heat storage makes use of the principle that it takes considerable energy to change the physical state of a substance (such as from a solid to a liquid). The material gains sensible heat until it reaches the melting point. It then gains an amount of latent heat equivalent to its heat of fusion which causes a change of state. The temperature (dry bulb) of the substance remains constant throughout the change of state.

When water changes from a solid (ice) to a liquid, about 143.5 Btu are required per pound to make the change of state. After the solid has turned to a liquid, only 1 Btu per pound is required to raise the temperature of water 1°F. A total of 8970 Btu of heat are required to change a cubic foot of ice into water. Once the change of state has been accomplished, however, only 62.5 Btu are required to raise one cubic foot of water 1°F.

The volume of the storage required for solar energy systems would be much smaller if the principles of latent heat storage could be used effectively. The choice of a storage material which has a melting point near the temperature at which the heat is to be used is important. Materials called "eutectic salts" change state at temperatures in the range of 90 to 120°F. Latent heat storage utilizing eutectic salts is not recommended unless a dependable means of assuring the stability of eutectic materials through many changes of state can be provided.

Water Storage Systems

Water is the most commonly used liquid heat storage material because of its availability and low volume requirement. There are many options for the containment of the water in a liquid sensible heat storage system. Some containers are illustrated in Fig. 14.

Domestic water heating systems require the use of tanks which are pressure tested. These tanks are frequently lined with a copper alloy material to provide protection from corrosion and to increase durability. Many manufacturers produce special domestic hot water tanks which are designed for solar systems. Some have an internal heat exchanger to permit a nontoxic antifreeze solution to be used in the collector loop. Most have four pipe connections–two for collector supply and return tubing, one for fresh water supply and one for domestic hot water supply. With potable water in the collector loop, a standard water heater can be adapted for use in a solar system by connecting the cold water and the collector supply lines into the drain outlet of the existing hot water tank.

Space heating systems are normally not pressurized. When operating at atmospheric pressure, a variety of options exist for storing the water. Commercially available liquid storage containers are frequently used. The container also may be made of pre-cast concrete, concrete block, pressure-preserved wood, or rammed earth. It is advisable to use a flexible liner in the site-built storage tank to prevent leaks. Sheet copper is an appropriate material for this application.

It is important to minimize the "thermal inertia" of the storage system. If there is a large storage volume to heat up, it may take considerable time before the storage temperature is useful for the system application. In large systems, such as those in commercial projects, it is appropriate to use more than one storage tank to provide sufficient storage capacity without imposing a large thermal inertia on the system. Multiple tank storage systems require sophisticated controls to allow the automatic determination of the fluid pumping sequence from among the various tanks to the collector and the building load.

The most appropriate storage volume for economics and system performance in space heating systems is approximately one to two day's building heat requirements under average winter conditions. Fig. 15 shows the water storage volume requirements in gal/sq ft of collector area to achieve the best system performance. The line relating storage volume and collector area has a sharp curve at about 1.75 gal of water per sq ft of collector. If much less volume is provided, the load fraction supplied by solar will drop. If much more volume is provided, little benefit will be obtained. Therefore, the most appropriate storage size is 1½ to 2 gal of water per sq ft of collector.

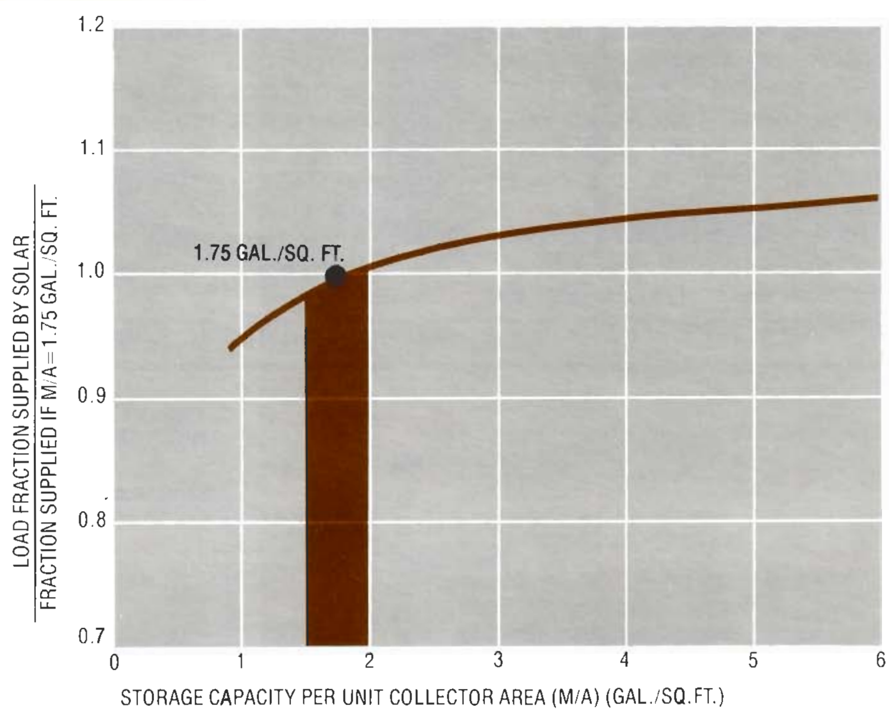


FIGURE 15/ OPTIMUM WATER STORAGE VOLUME

DISTRIBUTION: DOMESTIC WATER HEATING

Residence, Mamaroneck, NY

General Requirements

Domestic water heating is an area of high potential for the application of solar energy in buildings. There are many approaches to the design of successful solar water heating systems. The principal differences among them relate to the ways by which the heat transfer fluid is circulated between collector and storage tank, the type of freeze protection provided and the means for introducing supplementary heat.

The approach chosen for a particular application will depend on variables such as climate, heat requirements, and available storage capacity. Despite the existence of such variables, all applications have several things in common:

1. Tapwater temperature requirements are fairly consistent and are compatible with the fluid temperatures obtainable from solar collectors.
2. The collectors, pipe connections, and storage tanks in solar energy systems that operate under pressure from city water mains or on-site pumps, must be capable of withstanding these pressures. These are similar to those pressures encountered in conventional water heating systems.
3. For most efficient operation, the water brought to the collector for heating should be the coldest available. Thus, the collector supply line should draw from the bottom of the storage tank where the coldest water is located. Return from the collector should enter near the top of the tank.
4. A three-way modulating valve should be used at the point where the storage tank feeds into the building's hot water supply pipes. The purpose of this valve is to automatically maintain downstream water temperature in the 135-140°F range by blending hot and cold water. During the summer months, water stored in the tank could reach very high temperatures. The modulating valve effectively prevents scalding water from reaching the taps.

Collection: System Types and Configurations

Thermo-syphon System. In this most basic solar water heating system, the circulation of the water between tank and collector is maintained by the natural convection currents that are set up when water is heated. As shown in Fig. 16, there is no heat exchanger in the tank and the same water that circulates through the collector will later appear at the hot water tap. When the water in the solar collector becomes hotter than the

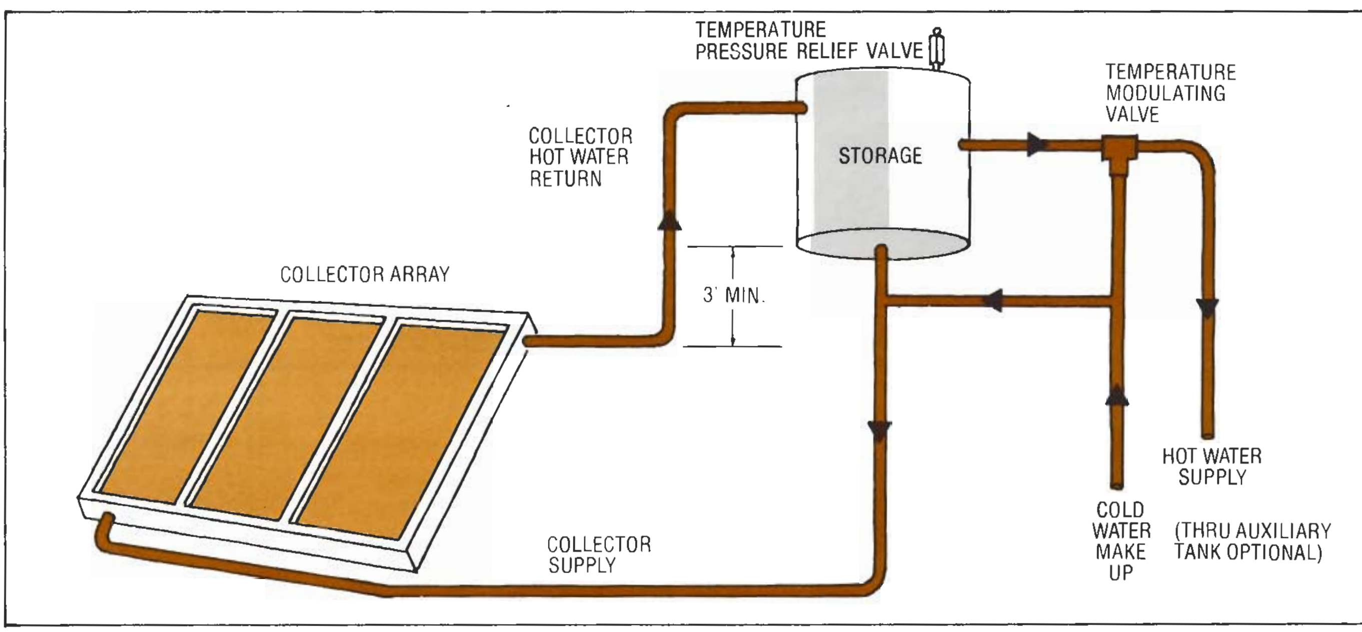


FIGURE 16/ PRESSURIZED THERMO-SYPHON DOMESTIC WATER HEATING SYSTEM

water in the storage tank, it rises to the tank. At the same time the colder tank water drops into the collector supply line. Assuming that no water is being run off at the tap, circulation will continue until tank and collector temperatures are equalized.

Lacking both circulating pump and heat exchanger, this approach offers appealing simplicity. But it has some limitations, one of which is that the rate of flow cannot be controlled. Also, because it is difficult to provide freeze protection without draining the collectors, this system is most appropriate for regions that do not reach freezing temperatures.

Pumped Circulation with Heat Exchanger. In the system depicted in Fig. 17, collector water is pumped through a closed pipe loop incorporating a heat exchanger coil which is immersed in the storage tank. Because collector water and domestic water do not intermingle, an antifreeze solution can be added to the collector water for low-temperature protection. Single-wall heat exchangers may be permitted when the antifreeze is of a non-toxic type such as propylene glycol. Safety regulations may call for use of a "double-wall" heat exchanger which provides a double barrier between antifreeze solution and potable water, when toxic antifreeze solutions are used. The closed collector pipe loop must have an expansion tank and a separate pressure relief valve in addition to the valve on the storage tank.

Because collected heat must be transferred through the heat exchanger, the collection fluid must be hotter, and thus this system is somewhat less efficient than one in which domestic water circulates through the collector directly. A check valve in the collector return prevents the migration of heat from tank to collector by thermo-syphon action on cold nights.

Pumped Circulation with Freeze Control. The system shown in Fig. 18 employs a circulating pump, but dispenses with the heat exchanger. Because the collector circuit is not sealed off from the stored water, an antifreeze solution cannot be used. Instead, protection against freezing temperatures is

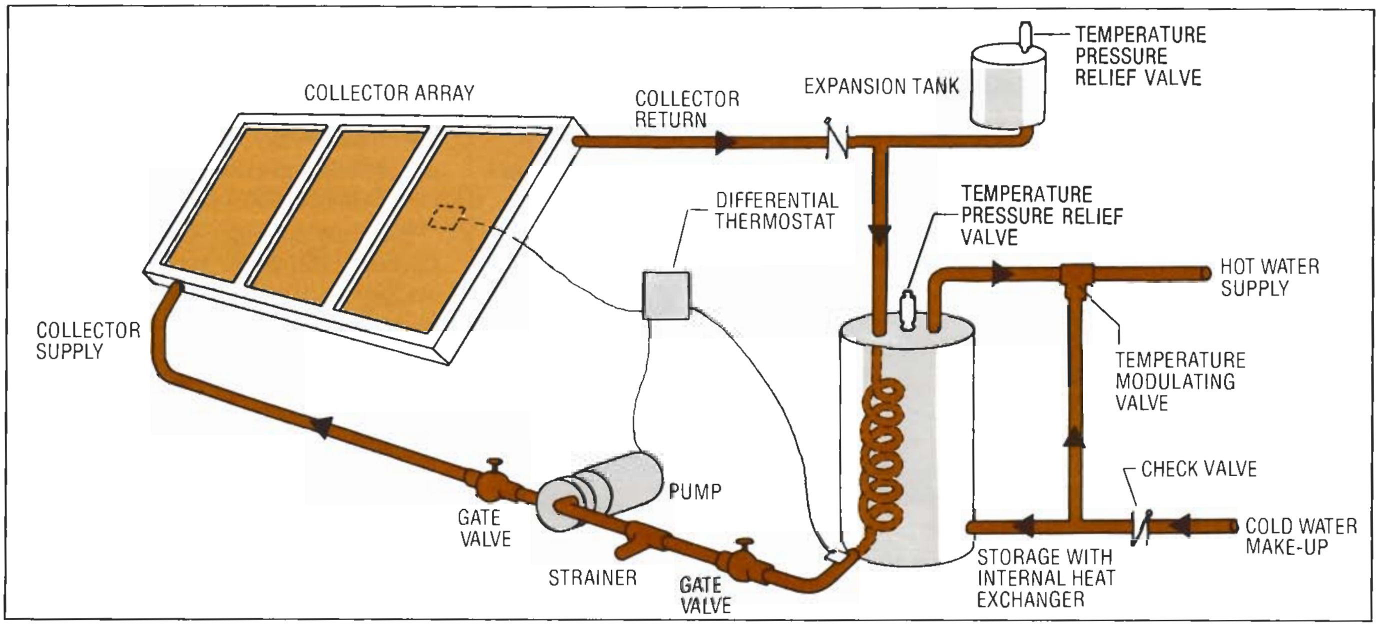


FIGURE 17/ PUMPED DOMESTIC WATER HEATING SYSTEM WITH HEAT EXCHANGER

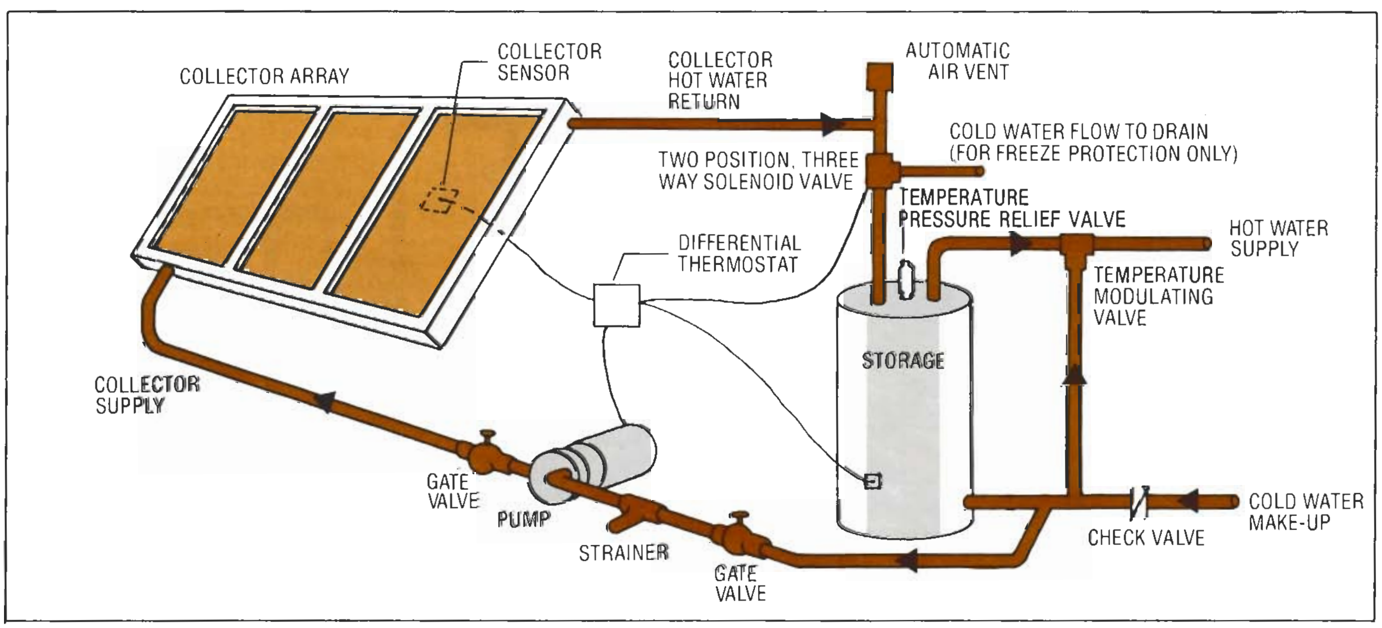


FIGURE 18/ PRESSURIZED/PUMPED DOMESTIC WATER HEATING SYSTEM WITH HEAT BLEED FREEZE CONTROL

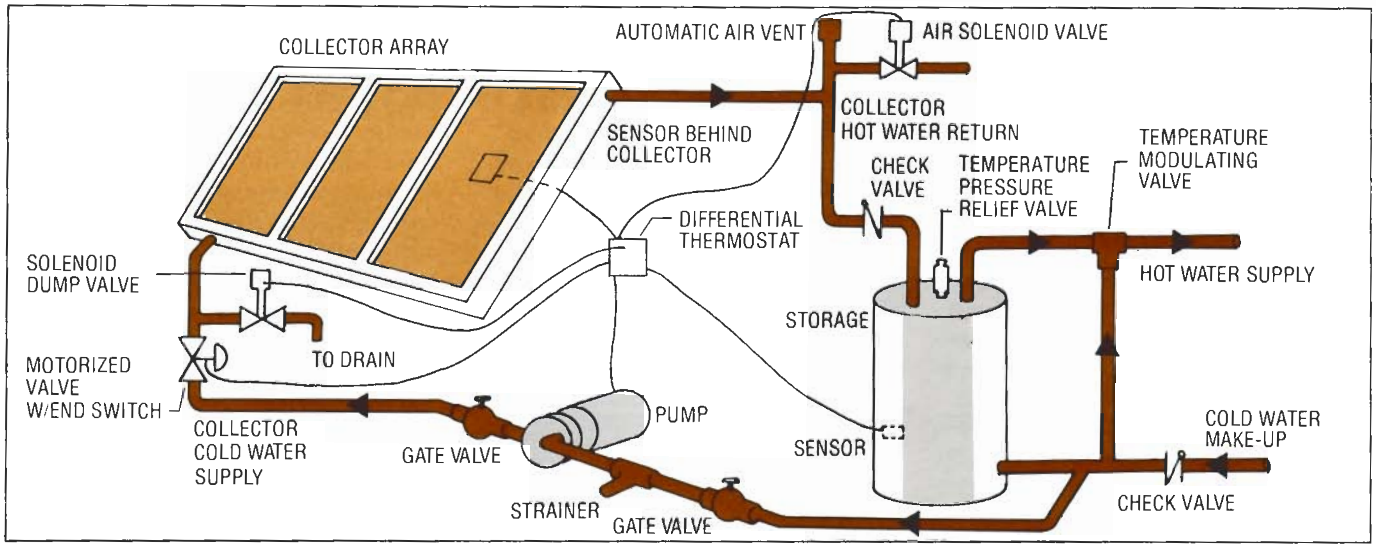


FIGURE 19/ PUMPED CIRCULATION DOMESTIC WATER HEATING SYSTEM WITH DRAINDOWN

afforded by passing cold water from well or city mains through the collector system. The rate of flow of this water is maintained high enough to prevent freezing before it leaves the collector.

A three-way solenoid valve is the key control element in this system. During normal operation, the valve is positioned so that water circulates freely between tank and collector. No cold water is admitted to the system unless a hot water tap is opened somewhere within the building, in which case makeup water enters from the supply source. When freezing temperatures are encountered, the three-way valve automatically cuts off the storage tank and diverts return water from the collector into a dry well or sump. This sets up a constant flow of water from the source through the collector circuit and out to the sump.

Pumped Circulation with Draindown. Fig. 19 shows a third method for providing freeze protection in solar water heating systems. This system, again, incorporates a circulating pump for collector water, but does not employ a heat exchanger. With this method, the collector circuit is drained of water when freezing temperatures appear imminent.

When a temperature sensor affixed to the bottom of the absorber plate detects a drop to about 40°F, it initiates closing of the motorized valve in the collector supply. Reaching its fully closed position, the valve trips an end switch that trips the solenoids of both the dump valve and the air inlet valve. Water then drains freely from the collector circuit and out of the system. Typically, the amount of water drained is not more than two or three gallons including that in all piping exposed to freezing temperatures. The pressurized source water is prevented from flowing to the collector by means of the motorized valve in the supply line and the one-way check valve in the return.

Whenever the absorber plate temperature rises to a pre-set difference above storage, the motorized valve begins to open, the circulating pump restarts, and the dump valve and air inlet valve close. As the collector circuit refills, trapped air is relieved through the automatic vent and normal circulation of collector water is resumed.

Storage: Domestic Hot Water Tank Arrangements

Most applications of solar water heating require a back-up or auxiliary source of heat for periods of low solar availability, or high heat requirements. The manner in which the solar heat and auxiliary heat are employed in a system has a significant effect on the amount of useful solar energy which can be collected and applied to the heating load.

Separate Solar and Conventional Domestic Hot Water Tanks. One of the many proven arrangements for introducing supplementary heat is illustrated in Fig. 20. The larger tank is connected into the collector loop and stores water heated by the sun by one of the methods described earlier. In tandem with the storage tank is a conventional water heater having a fossil-fuel burner or an electric heating element. The outlet line of the solar storage tank is a pipe connected to the "cold" or inlet line of the conventional heater. When there is a demand for hot water somewhere in the

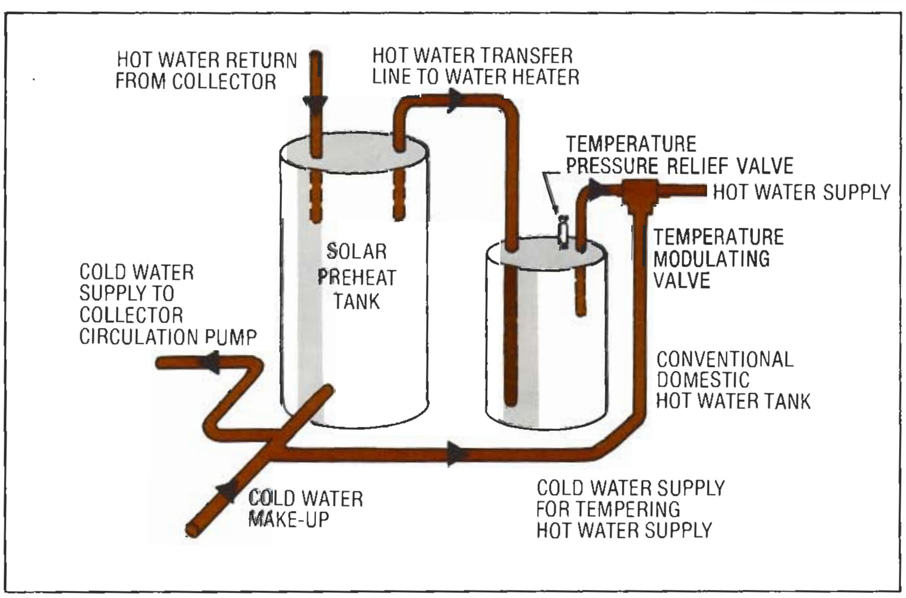


FIGURE 20/ DUAL DOMESTIC HOT WATER STORAGE TANKS

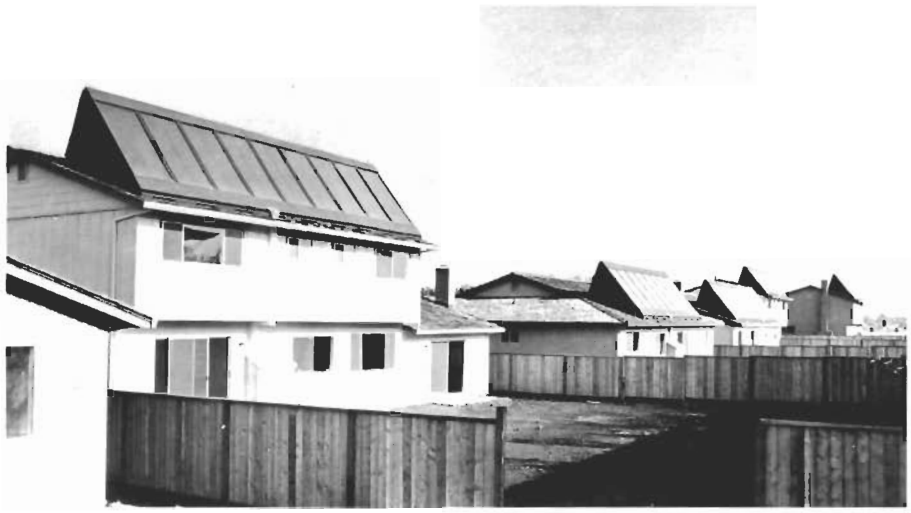
building, city water pressure forces water through the solar storage tank, through the conventional tank, and out to a water tap or fixture.

When the solar-heated water is warm enough it will move through the conventional tank without affecting its thermostat or without requiring additional heat. However, should the conventional tank water drop below a preset temperature, it will cause the thermostat to trip, energizing the burner or electrode of the conventional heater. The heater then continues to operate in its normal fashion, cycling on and off as needed to maintain tap-water temperature at design levels. An advantage of this configuration is that only the relatively colder water in the large storage tank circulates through the collector which, thus, is permitted to function at a higher efficiency.

Single Storage Tank. It is also possible to provide both solar and auxiliary storage in the same tank as shown in Fig. 21. When this system is used, a large storage tank should be selected. The temperature of the auxiliary fuel input should be set to maintain a tank temperature of about 110-120°F. This will mean that the coldest water that can be circulated to the solar collectors will be 110°F unless some natural or artificial means of stratification is achieved in the tank. The primary disadvantage of the system is that because the water temperature which is circulated through the collector is higher than in the previous arrangement, the efficiency of the collector is much lower.

Combined Solar Space and Domestic Water Heating System. Fig. 22 shows the combination of solar space heating with a domestic water heating system. Water in the solar storage tank is warmed in one of the ways described earlier. If the solar storage tank temperature is high enough, cold domestic make-up water passing through a heat exchanger in the storage tank will pick up sufficient heat to avoid drawing energy from the domestic water tank heater. Whenever the temperature of the domestic water tank drops below the storage tank temperature, the domestic water is pumped through the heat exchanger, transferring whatever heat is available. Final temperature boosting, if necessary, of the domestic supply, is provided by an auxiliary heater in that tank.

It is possible to put the heat exchanger in the domestic storage tank and circulate water from the solar tank through it. It is also possible to combine a solar space heating system with a two-tank domestic water heating system, as shown in Fig. 20.



Residential homes, Santa Clara, CA

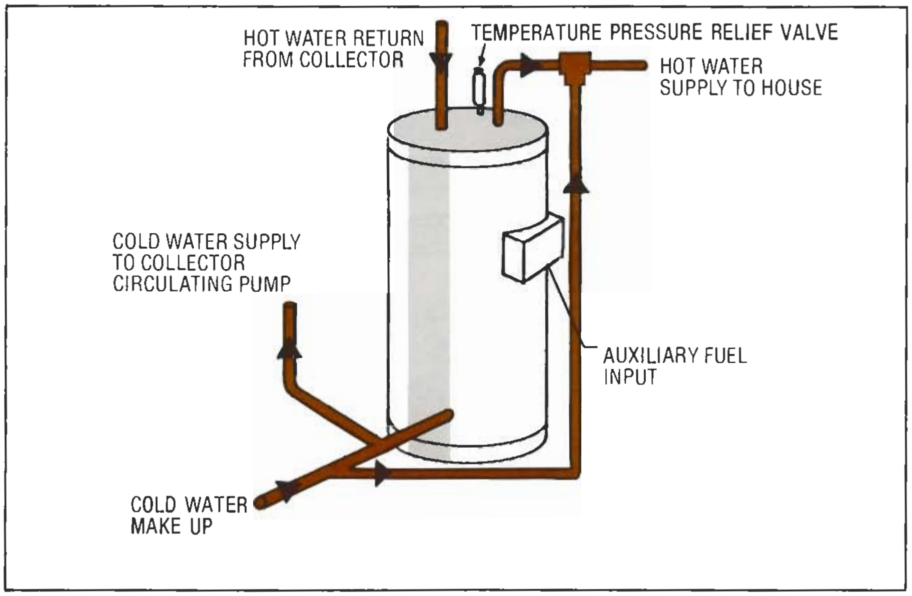


FIGURE 21/ SINGLE DOMESTIC HOT WATER TANK

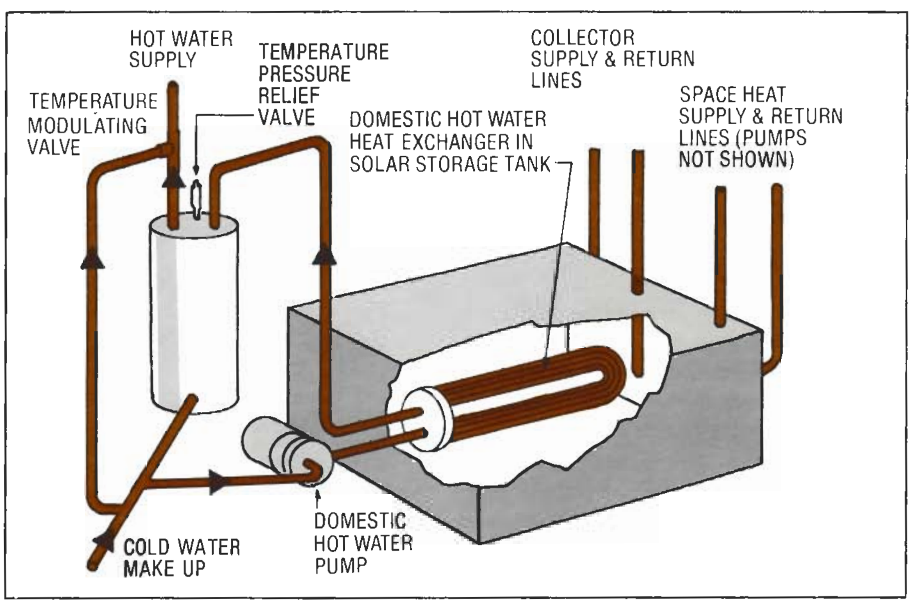


FIGURE 22/ COMBINED SOLAR SPACE AND DOMESTIC WATER HEATING SYSTEM

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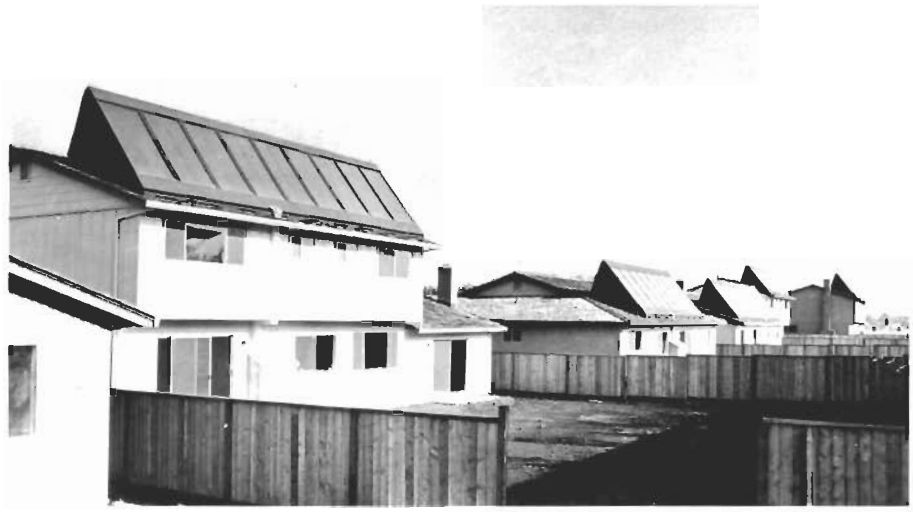


Residential homes, Santa Clara, CA

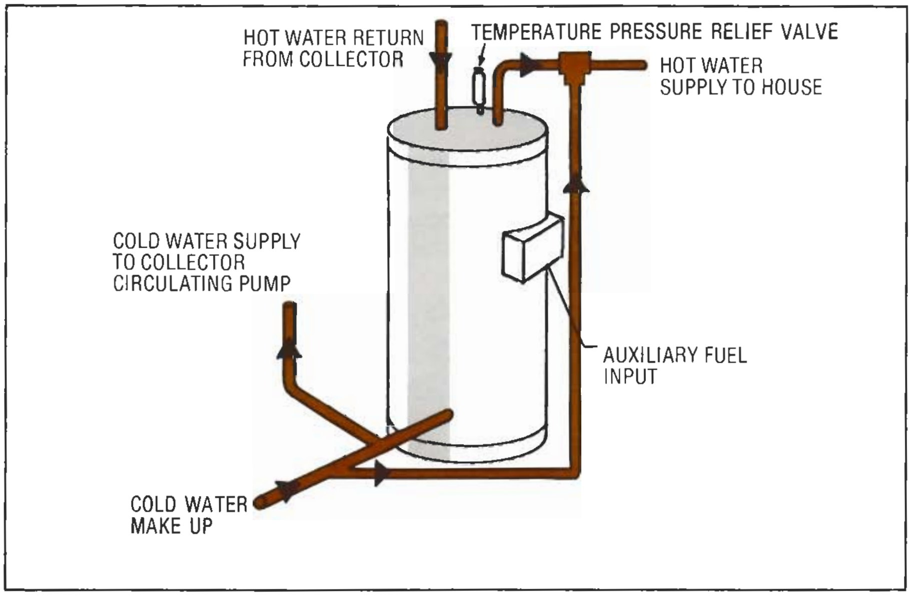


FIGURE 21/ SINGLE DOMESTIC HOT WATER TANK

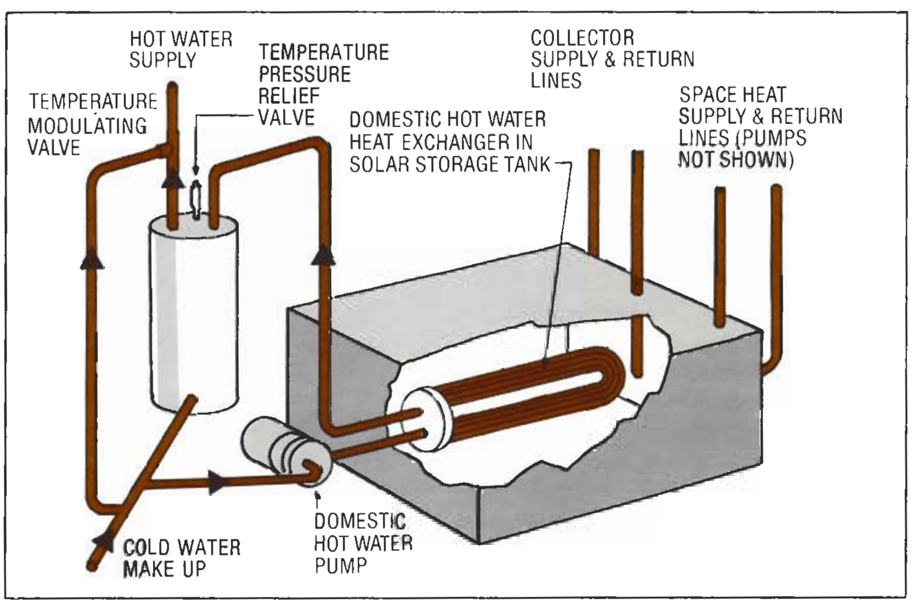


FIGURE 22/ COMBINED SOLAR SPACE AND DOMESTIC WATER HEATING SYSTEM

DISTRIBUTION: SPACE HEATING

System Requirements

Solar energy collected at relatively low temperatures can be used effectively for space heating. However, the design requirements for space heating systems differ from those for domestic water heating, because space heating needs are seasonal and larger. These differences affect the choice of collector type, size and tilt and influence the design of storage and distribution systems as well.

Fig. 23 compares space heating energy demand with collector production over a year's time. Available solar energy is least when heating needs are highest. For this reason it has been found advisable to design solar systems to handle only about 60 to 70 percent of the total annual space heating loads. Systems can be sized to supply the complete winter requirements, but these will not fully utilize collector potential in the summer months and, consequently, may show a poor economic return on first cost investment. A second economic consideration stems from the fact that it is necessary to provide an auxiliary system capable of meeting 100 percent of space heating requirements at times when no solar contribution is forthcoming. Care should be taken, however, that the auxiliary system not be oversized.

Solar collectors for space heating purposes are quite similar to those for domestic water heating. In general, collection temperatures will be higher. Collectors that operate at higher temperatures lose more heat. Thus the use of double glazing may be appropriate in some climates. In climates where freezing is a danger, liquid collection systems must be protected by draining the collectors and related tubing, incorporating an antifreeze solution or other appropriate means.

There is an additional need for high temperature protection in summertime when collectors continue to absorb solar energy even when there is little or no demand for heat in the building. Temperature buildup can be checked by maintaining circulation in the collector loop and incorporating a means for rejecting heat. If circulation is to be stopped in warm weather and temperatures allowed to build, collectors and supporting structures must be engineered to withstand the severe thermal stresses that can result.

Whatever the high temperature protection, however, all collectors should be designed to withstand high thermal stress to protect against unforeseen circumstances.

Space heating systems can take many different forms, each with its own particular combination of the various approaches to collecting, storing and distributing solar energy. Four workable systems, each based on a different means of distribution, will serve to illustrate some of the possible combinations. Three of these involve direct distribution of stored heat by pump or blower. The fourth uses a heat pump to boost the level of stored heat to some higher temperature that is more compatible with the design requirements of the chosen space heating system. Three use water as the medium for collecting and storing solar energy, while one uses air as the medium for collecting and solid material for storage.

System 1: Water Collection/ Water Storage/Air Distribution.

The system depicted in Fig. 24 and slight variations of it have found wide acceptance because they are simple to operate and control. The circulating pump in the collector loop operates whenever collector temperature is higher than the temperature of storage tank water by a preset amount. When the pump stops, water in the collectors and pipe lines drains into the storage tank. To permit this automatic draining process, the return pipe must be coupled to the tank in such a fashion that the end of the pipe is kept above the level of the stored water or the pipe must be vented by some other means.

When the building thermostat calls for heat, a pump circulates stored water through a heat exchanger coil in the return air duct upstream of the furnace. At the same time, the furnace fan begins to draw air through this heat exchanger coil and into the building. As long as the coil transfers sufficient heat to maintain supply air temperature high enough, the furnace burner or heating element remains inoperative. When the supply of solar heat falls short of the building's requirements, the furnace comes on to furnish supplementary heat.

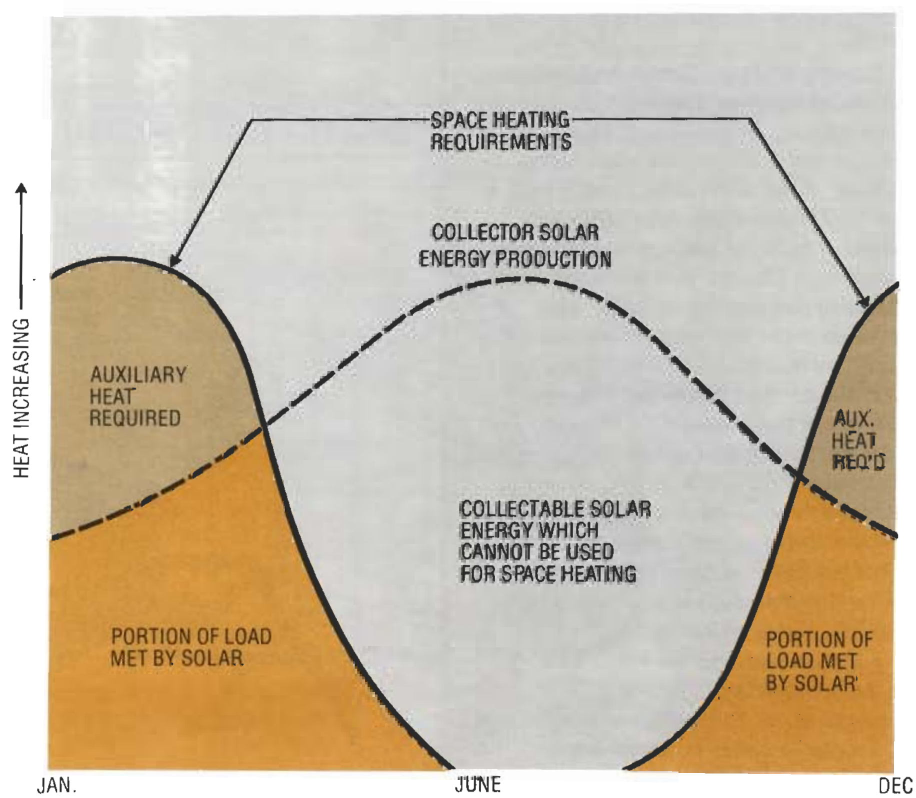


FIGURE 23/ SPACE HEATING DEMAND VS. COLLECTOR PRODUCTION

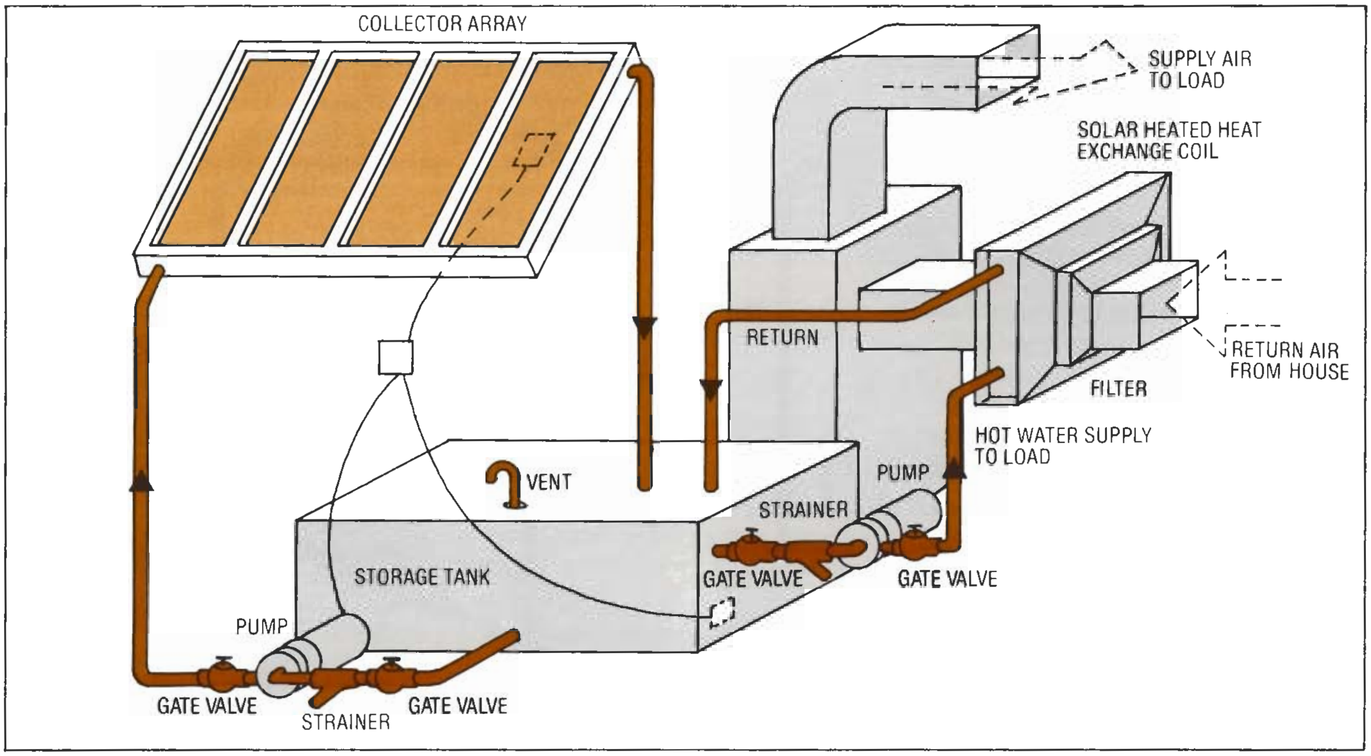


FIGURE 24/ WATER COLLECTION/WATER STORAGE/AIR DISTRIBUTION SPACE HEATING SYSTEM

There are several common methods for control of the input of auxiliary energy. One of these involves the conventional furnace thermostat which normally ignites the burners when bonnet temperature drops below 130°F approximately. Resetting the furnace bonnet temperature to about 100 to 110°F should be considered for improved economy. The furnace fan operates for a slightly greater period of time, but more benefit is derived from the solar system because it is useful at lower temperatures. Reducing the bonnet temperature still further during the spring and fall seasons can save additional energy.

A second method uses a two-stage thermostat with the first stage controlling solar heat alone and the second, solar and auxiliary heat. When the thermostat calls for heat, the first stage is activated. If it is incapable of meeting the heating requirement, the second stage activates the auxiliary heat.

This system could be modified somewhat by the addition of three-way valves to circulate water directly from the collector array to the house heat exchange coil when heat is available in the solar collectors and there is a simultaneous space heating requirement. This would bypass the storage tank and eliminate the necessity of raising the temperature of the entire volume of the storage tank to a usable temperature before the solar energy can be utilized. This modification to the system would require additional sensing and control capabilities. In most instances the primary heating demand occurs during non-collection hours and with a properly sized storage volume the benefits added by this modification will probably be minimal.

System 2: Water Collection/ Water Storage/ Water Distribution.

Solar energy systems using water collection and storage are highly suited for fin tube and radiant panel installations. Finned-tube convectors, however, normally require a higher water temperature than fan-coil units to achieve an effective heat exchange. To compensate for the lower temperatures of solar heated water, therefore, it is usually necessary to specify a greater amount of tube than would normally be installed.

When finned-tube convection devices are used for heat distribution, there are two possible configurations:

Fig. 25 shows a *series* configuration, in which heat is supplied by either the solar system or the auxiliary boiler. When the solar storage tank is hot enough to supply the heating load, water is pumped from the storage tank through the finned tubes and bypasses the boiler. If the storage tank is not hot enough to supply the heating load completely, water is pumped through the boiler and then the finned tubes, bypassing the storage tank.

It is not advisable to pump water from the storage tank, through the boiler and then through the finned tubes. This type of arrangement would actually use less solar energy and more auxiliary energy than the one described below.

The inset on p. 18 shows a parallel distribution configuration, in which heat can be supplied by both the solar system and the auxiliary boiler simultaneously if necessary. If the heating requirement can be supplied by the water from the solar tank, the auxiliary boiler does not operate. When more heat is required than the solar system can supply alone, the auxiliary boiler begins operating, supplementing the solar heat. This arrangement permits lower temperature water in the solar system to be used to supply a portion of the heating load. The result is higher collector efficiencies, and more usable solar energy.

Larger systems sometimes employ outdoor-air temperature sensors to control boiler water temperatures. This feature provides flexibility in meeting fluctuations in the building's heating load imposed by changing weather conditions. When outdoor temperature drops, for example, boiler water temperature is raised automatically to compensate for increased heat load from the building. Like System I, the hydronic system can be modified to allow collector water to be

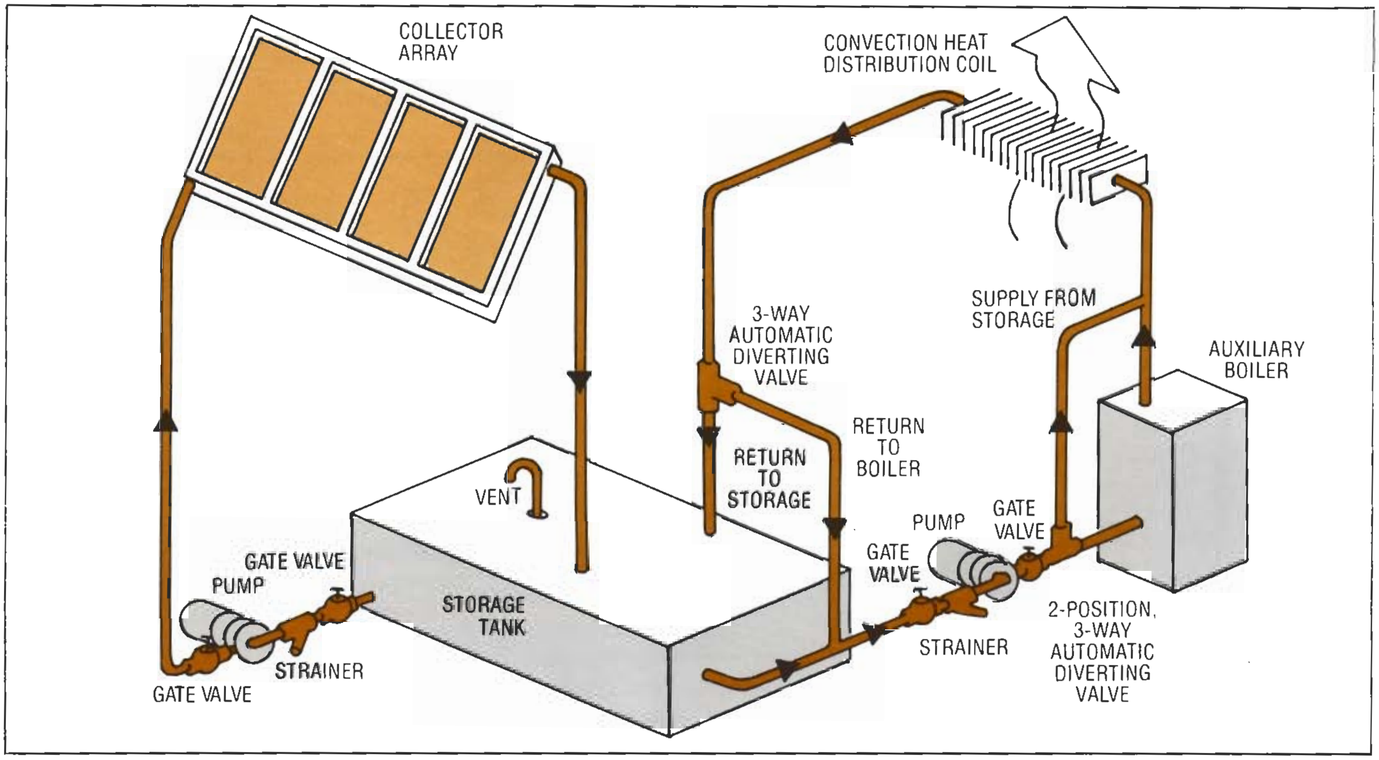
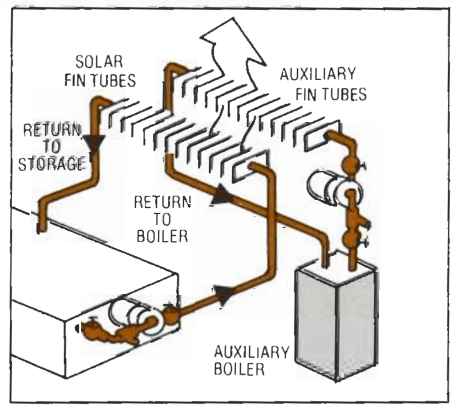


FIGURE 25/ WATER COLLECTION/WATER STORAGE/SERIES WATER DISTRIBUTION SPACE HEATING SYSTEM

pumped directly to convectors and radiant tubes, thus bypassing the storage tank.

Even more compatible with the characteristics of water collection and storage are radiant panel heating systems employing copper tube embedded in concrete floor slabs and in wall and ceiling construction. Such radiant systems operate with lower fluid temperatures and, consequently, the utility of the solar heated water will be higher. Such a system is represented in Figure 26.

Experience dictates that the maximum surface temperature for a ceiling or wall radiant heating system is 120 °F; for a floor panel, 85 °F. Because of the higher distribution temperatures available, wall and ceiling radiant heating systems require less panel area than a floor panel, in order to meet the same load. However, any calculation of heat transfer from a radiant panel heating system to the room air must consider both the convective and conductive heat transfer rates. Technically, transfer of heat by convection is 0.4 Btu (per hr. per sq. ft. per 1 °F) for a ceiling panel, 0.8 Btu for a wall panel, and 1.1 Btu for a floor panel. In addition, there is the transfer of heat by radiation, which is



PARALLEL DISTRIBUTION

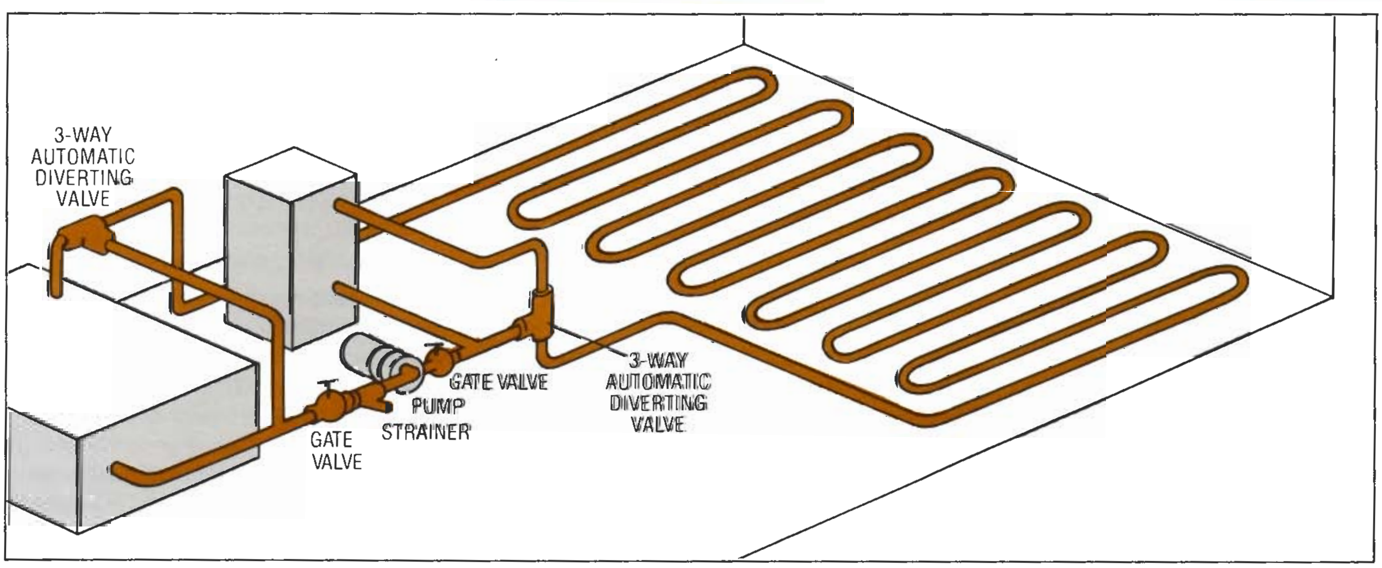


FIGURE 26 / WATER COLLECTION / WATER STORAGE / SOLAR RADIANT HEATING

typically about 1.0 Btu for all three distribution types. Therefore, the sums of heat transfer are 1.4 Btu for a ceiling panel, 1.8 Btu for a wall panel, and 2.1 Btu for a floor panel. These rates must, in turn, be multiplied by the surface-to-air temperature difference for the hourly heat transfer in Btu per square foot of panel area.

Floor installations have been the most common, with copper coils embedded in concrete, having one inch or more of concrete above and never less than one-half inch below. For slab on grade construction, insulation is imperative beneath the slab. It is also important to insure that ground water will not also carry away heat. Floor panels are particularly appropriate for structures with high-ceilings.

Ceiling and wall panels are usually embedded in plaster. Centering the coils between rooms or floors is not recommended, as it usually results in poor heat transfer and lack of room temperature control. For wall panel installations, very heavy insulation is necessary to reduce heat loss to the exterior from the warm walls.

Conventional hot water heating controls are appropriate, and air vents should be installed at the system high points. Drain cocks should also be provided at system low points. One-half inch Type L copper tube is often an appropriate size.

System 3: Air Collection/ Solid Material Storage/ Air Distribution.

Air may be appropriate as the heat-transfer fluid in systems where the primary use of the energy is for the heating of living spaces. Air collection systems have several distinct characteristics when compared to circulating liquid collection systems:

- Air collectors are somewhat less efficient, requiring a greater area of solar panels.
- Rock storage requires greater volume than water because of its lower heat capacity, and the requirement for space around the rocks to permit the circulation of air. About 0.5 cubic feet of storage should be allotted per sq. ft. of collector (or about 2-3 times the requirement for water storage).
- The collector supply and return ducts must be large enough to accommodate a flow of about 2 SCFM (Standard Cubic Feet per Minute) of air/sq. ft. of collector. For most residential applications, this will necessitate an area of 3-5 square feet.
- Since large quantities of air must be circulated, and since there is a pressure drop through both the collectors and the storage container, greater fan motor horsepower may be required than pump motor horsepower in comparable water systems, reflecting higher costs.
- It is quite important to have a relatively clean, dust-free collector to maintain efficiency and reduce pressure drop. A high quality filter which is regularly cleaned is important.
- It is important to waterproof the outside of the rock storage container to prevent the penetration of ground water. A warm, moist storage container is very conducive to the formation of fungi which can reduce air flow and distribute allergy-irritating spores through the house distribution system.
- Since the transfer of heat from air to water is not as efficient as from water to water, larger heat exchangers will be required to heat domestic water supplies.
- It is important to provide an air plenum above and below the storage container to permit a uniform flow of air. It is also necessary to flow warm air down through the storage container for collection, while distribution requires reversing and flowing up through storage.

Fig. 27 illustrates a typical air collection/rock storage/air distribution system.

When heat is available for collection, and there is not a simultaneous demand in the house, the collector circulation fan begins operation drawing air down through the storage container. Motor operated damper number 3 is open whenever the collector fan is operating and closed at all other times. The

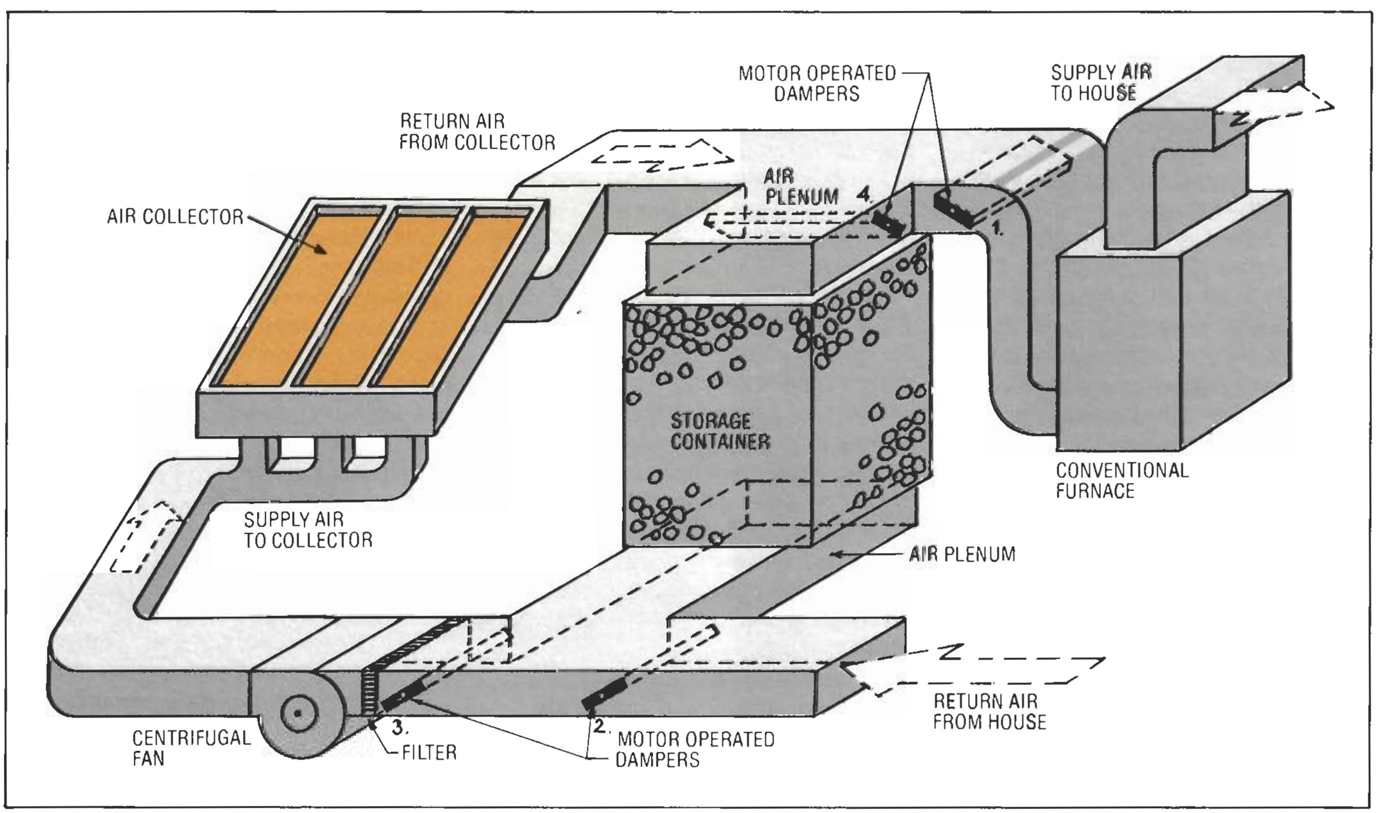


FIGURE 27/ AIR COLLECTION/SOLID MATERIAL STORAGE/AIR DISTRIBUTION SPACE HEATING SYSTEM

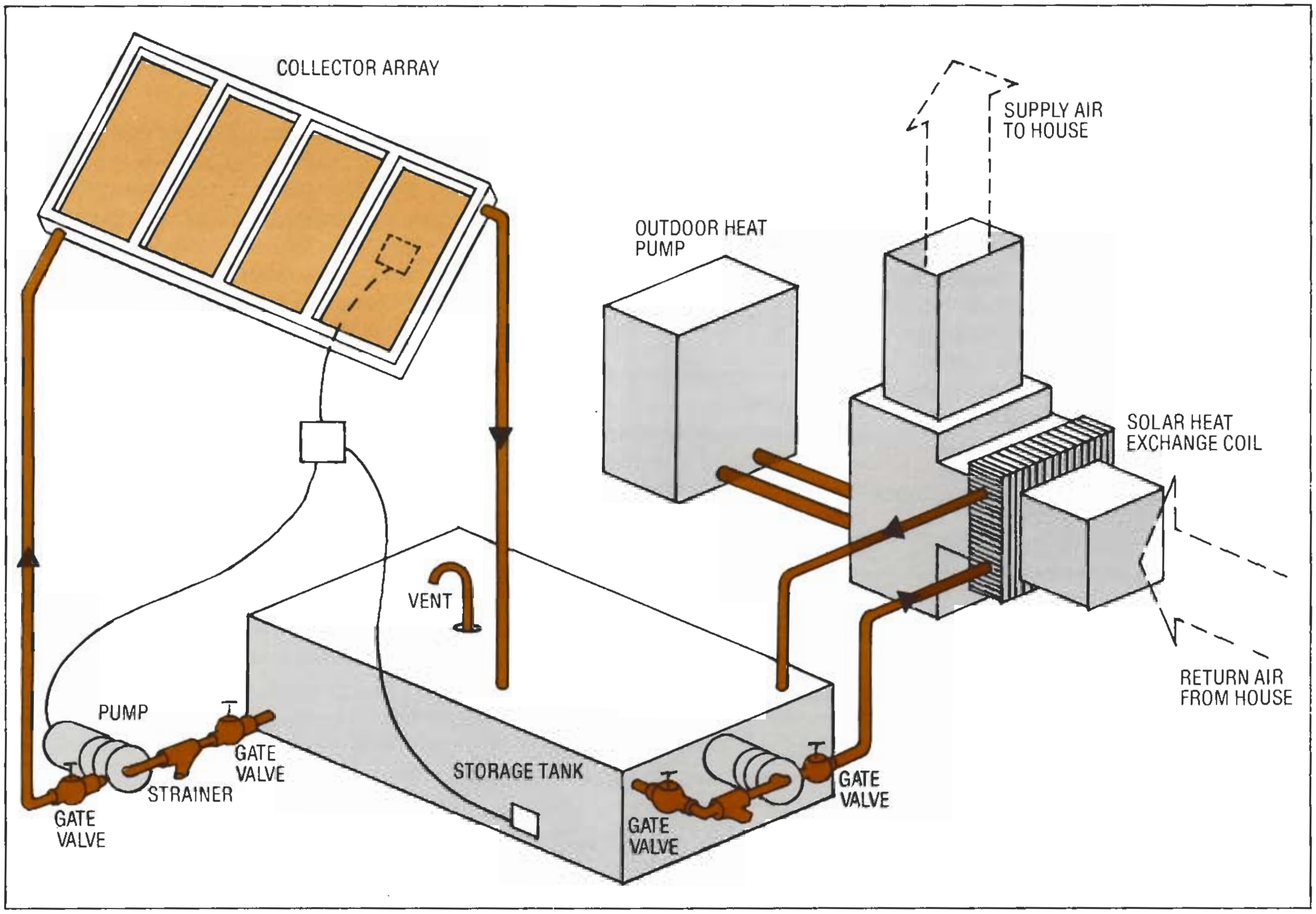


FIGURE 28/ WATER COLLECTION/WATER STORAGE/AIR-TO-AIR HEAT PUMP DISTRIBUTION SPACE HEATING SYSTEM

top portion of the storage container contents will heat first, and the heat will extend downward as more energy is collected. Motor operated damper number 4 is normally open.

When heat is required by the space, but no heat is being collected, the centrifugal fan in the furnace begins operation, signaling dampers 1 and 2 to open. (These dampers are closed unless this fan is operating). Return air is drawn upward through the storage, exiting at maximum temperature, and circulated to the house. Auxiliary energy is not added by the furnace unless the heating load cannot be provided by the solar system.

If there is a simultaneous collection of energy and demand for heat by the house, motor-operated damper 4 is closed. This damper is open unless both collection and distribution fans are operating simultaneously. Air is thus circulated directly from the collector to the house. This is more important in air-rock systems since the heat transfer into and out of storage is not as fast or efficient as water collection, water storage systems.

System 4: Water Collection/ Water Storage/Heat Pump Distribution.

Energy in the form of heat flows "downhill" from a warmer substance to a colder substance. The rate of flow is proportional to the thermal gradient, which is the temperature difference that exists between the warmer and colder materials. Therefore, the ability of a solar-heated fluid to feed energy into a space heating system depends on the thermal gradient between the solar-heated storage source and the air or water circulating in the heating system. As heat is taken from it, the stored water experiences a continual drop in temperature until a point is reached when the diminishing thermal gradient is insufficient to provide the flow of energy needed by the structure's space heating system.

In the three systems just described which make direct use of solar-heated storage, the thermal gradient may become inadequate to provide sufficient heat when storage temperature drops to, say, 90°F. The exact temperature for any system depends on whether that system is hydronic or ducted air, the type of heat delivery equipment (finned-tube baseboard, fan-coil units, etc.), and the indoor design temperature. In any case, there is a low point at which the thermal gradient becomes insufficient, and supplementary heat must be introduced.

The electrically driven heat pump offers a means of enhancing the flexibility and efficiency of solar systems. It has the capability of extracting heat from a cooler source and pumping it up to a higher temperature, thereby increasing the thermal gradient. This makes it possible to extract useful heat from the solar storage system even when its temperature has fallen below the room temperature.

Heat pumps most commonly used in small commercial and residential projects are of two types:

1. *Air-To-Air Heat Pump*–When heating is required, the heat pump extracts heat from one air source (usually the outside air), pumps it up in temperature, and warms the room air.
2. *Water-To-Air Heat Pump*–When heating is required, the heat pump extracts heat from the storage

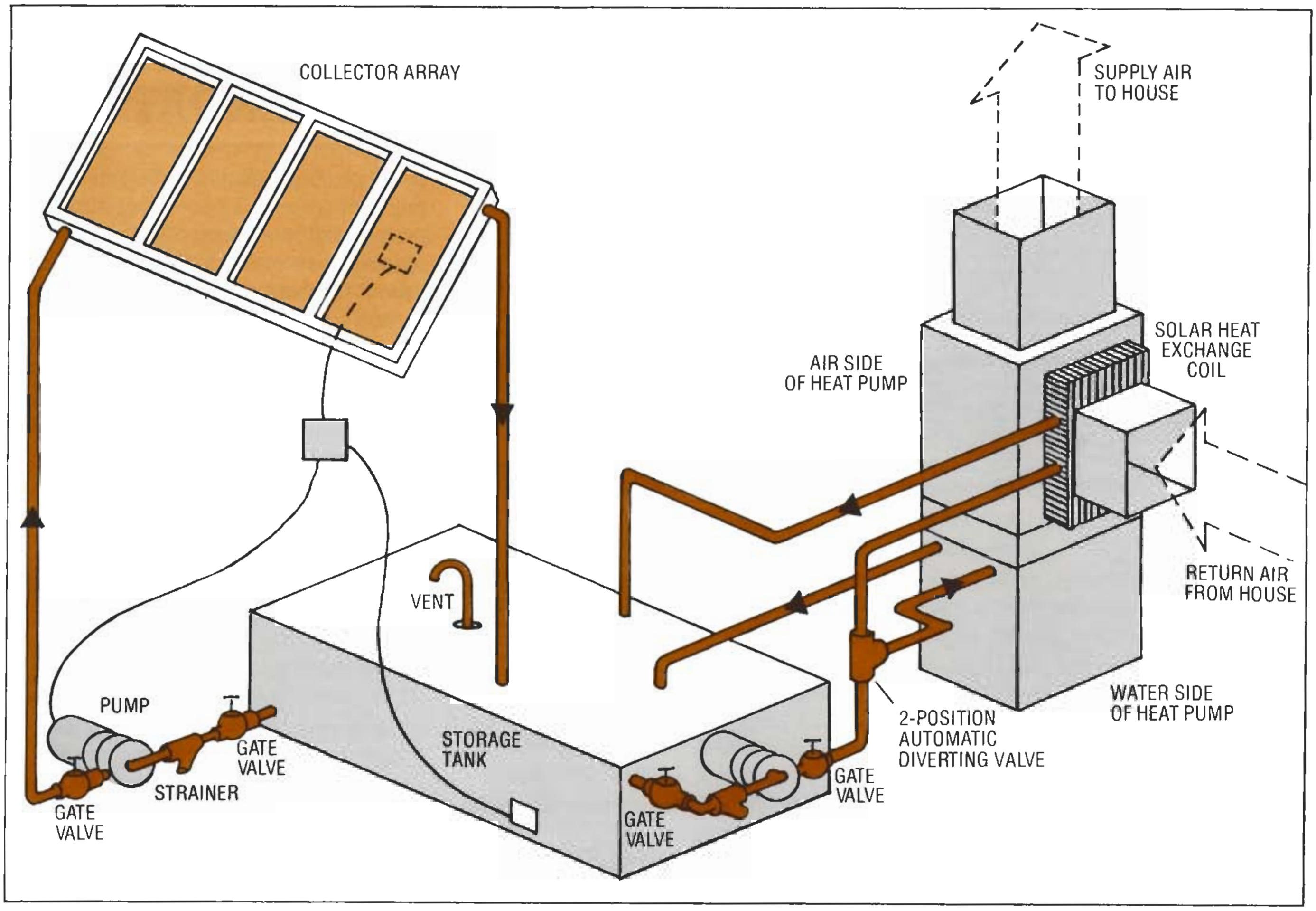


FIGURE 29/WATER COLLECTION/WATER STORAGE/WATER-TO-AIR HEAT PUMP SPACE HEATING SYSTEM

water, pumps it up in temperature and warms the room air.

The heat pump is essentially a heat-transfer refrigeration device that puts the heat rejected by the refrigeration to good use. It is similar in design to a conventional refrigeration machine and has the same three basic components: compressor, condenser and evaporator. The uniqueness of the heat pump lies in its reversing valve which permits changing the direction of refrigerant flow. Because of the reversing valve, all heat pumps currently manufactured can provide cooling as well as heating. For space cooling, the process is the reverse of that described above.

Air-to-air heat pumps can be used in solar systems in several different ways. The simplest arrangement is similar to that shown in Fig. 28 All solar heating is done directly from storage, without the aid of temperature "boosting" by the heat pump, using the fan unit of the heat pump to circulate the room air over the solar heat exchange coil. If the heat available from the solar storage is insufficient, the heat pump begins to operate, supplying additional heat to the air. Although this configuration does not permit the stored solar energy to be used below the space temperature, it greatly reduces the operational time of the heat pump, saving the electricity needed to operate its compressor. Other heat pump configurations are possible which permit the air-to-air heat pump to extract heat from water or solid storage at temperatures below the room temperature. These systems are more complex, however, and they require additional automatic controls. Unless they are carefully designed, they may not save as much energy as other solar heating systems.

Water-to-air heat pumps can also be used in solar heating systems as illustrated in Fig. 29. When the solar storage tank temperature is over a certain point (usually about 90°F), storage is used directly for space heating with the heat pump fan circulating the room air over the solar water coil. When the storage tank temperature falls below the temperature needed for direct heating, the control valve changes position and circulates the storage water into the heat pump.

When the water flow to the heat pump has been proven by a flow switch, the heat pump compressor begins to operate, extracting heat from the water and pumping it up in temperature. It is then used for warming the room air. This continues until the heating load has been satisfied or the storage tank temperature drops to the lower operating limit of the heat pump (usually about 60°F). The actual operating temperature limits of the heat pump must be determined by the manufacturer and the solar system controls set accordingly. If another water supply of appropriate temperature is available, it can be used when the usable heat in the solar tank has been exhausted. It is usually necessary to supply a back-up heat source, such as electric resistance coils built into the heat ducting, to provide heat when the solar tank and other heat sources have been depleted.

Used in this way, the solar system improves the actual performance of the heat pump by decreasing the thermal gradient through which it must pump. This reduces both the operating time of the heat pump, and its electrical consumption during operation. Water-to-air heat pumps are often used in applications which have multiple zones in the building, and may require simultaneous heating and cooling in different zones.

SECTION 6

DESIGN RECOMMENDATIONS

Bank, Concord, NH

Introduction

All parts of the solar energy system must be carefully selected in order to obtain the best possible performance. Although most materials used in solar heating and cooling systems are well known to the construction trades, they must be chosen and assembled with special consideration for the unusual operating conditions under which the solar collectors and the associated plumbing system operate.

Absorber Plates

Copper, steel, aluminum and plastic are used for solar collector absorber plates. Copper has, by far, the longest and most successful history of use in this application.

The most important characteristics for absorber plate material are thermal conductivity, corrosion resistance, ease of fabrication, mechanical strength and availability. The absorber plate must also readily accept the desired absorptive coating.

The thermal conductivity of an absorber plate should be high enough to conduct heat to the transfer fluid with a relatively small temperature drop. It is common practice to limit this temperature drop to 10 to 15°F or even less. Generally, this heat transfer is controlled by four factors: 1) thermal conductivity of the plate material; 2) plate thickness—thicker plates conduct more heat, but tend to be more expensive, heavier, and of slower response, especially at low sun conditions; 3) tube spacing—tubes spaced closer together permit the absorber plate to be thinner when highly conductive materials are used; and 4) the thermal conductance of joints which occur between components. The thermal conductivity of copper (Copper No. 110) is 226 BTU/Hr./Ft.^{2}/Ft./°F. If we set this value equal to 100, the corresponding conductivity for aluminum is about 54, and for carbon steel, about 12. This thermal advantage of copper is summarized in Figure 29, which shows how, under typical conditions, thinner gauges of copper transfer the same amount of heat as thicker gauges of the other two metals. Since plastic acts as an insulator rather than a conductor, its use in absorber plates is limited to low temperature, noncritical operations.

The excellent corrosion resistance of copper in both all copper and mixed-metal systems, in addition to its superior thermal conductivity, have made it the most desirable metal presently used for absorber plates and fluid passages in flat plate solar collectors. Copper is readily available in various types of tube, fittings, and sheet materials which are easily fabricated or joined by brazing, soldering, and mechanical fastening. The handling and fabrication of copper are familiar to the heating, ventilating and air conditioning trades, as well as to the other building trades. Copper has been widely used for roofing, plumbing, and HVAC systems since metals were first employed in these applications.

Copper has the needed mechanical strength, particularly at the elevated temperatures developed in absorber plates. In addition, copper readily accepts a wide variety of selective and non-selective surface coatings.

Absorber Plate Coatings

In addition to durability, the most important properties of absorber plate coatings are absorptance and emittance. The collector plate should absorb as much of the incident solar radiation as possible for maximum efficiency and performance. Surfaces which absorb radiation also "re-radiate" or "emit" a portion of the energy. Limiting this emission or re-radiation of long wavelength energy improves the collector efficiency. A low emittance is especially desirable at high collection temperatures, but absorptance should not be sacrificed to obtain low emittance.

Coating stability, particularly at high temperatures, is important. A coating that has not been proven for solar absorber application might outgas volatile substances which can haze the glazing

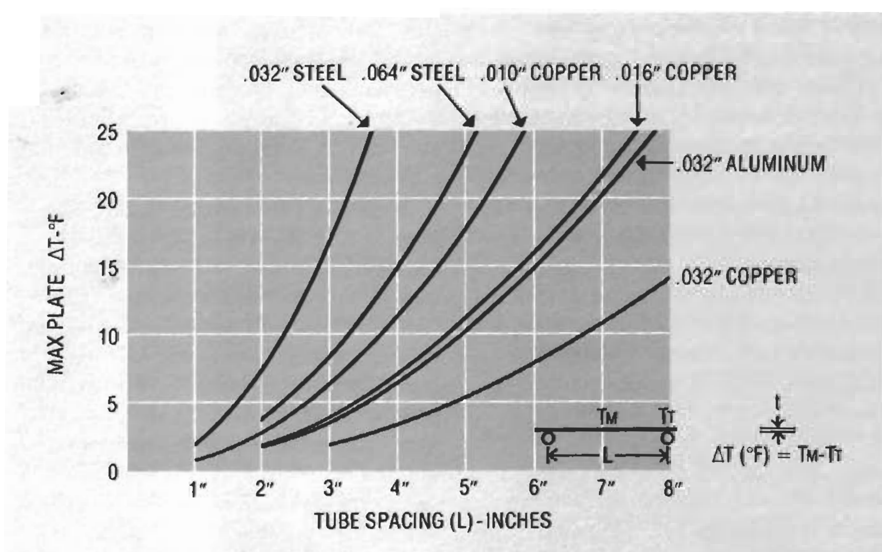


FIGURE 30/ FLAT PLATE SOLAR COLLECTOR ABSORBER PLATE DESIGN PLATE THICKNESS, TUBE SPACING AND ΔT@ 150 BTU/HR-SQ. FT.

covers and lower solar energy transmission, thus reducing collector efficiency. The absorber coating must also prove stable in the presence of moisture, and provide durability for the life of the collector.

A high performance flat black paint has an absorptance of about 0.95, and about the same emittance. Several commercial flat black paints are suitable finishes for most collector absorber plate applications. Copper absorber plates, properly cleaned, are easily painted, either on site or in the factory where the collector is assembled.

Selective surface coatings have been developed which combine the desired surface properties of high absorptance and low emittance. Copper surfaces can be made selective both by chemical treatment and by electroplating. Commercially available selective surfaces of both these types have emittance values substantially lower than their absorptance as shown in Table 2. Selective coatings are particularly beneficial in applications where collectors operate at higher temperatures. The selective surface minimizes re-radiation from the collector plate to the cover glazing. In this way, heat losses upward from the collector plate are controlled, effectively increasing collection efficiency. Selective surfaces are generally more expensive than flat black paint coatings. Their potential benefits should, therefore, be evaluated before specifying their use.

	ABSORPTANCE	EMITTANCE
1. Flat Black Paint, as applied	.95	.85-.95
2. Commercial Selective Coating (chemical treatment)		
Samples from collector manufacturer A	.86	.09
Samples from collector manufacturer B	.83	.11
3. Typical Black Chrome on Copper	.93-.96	.08-.11

TABLE 2/TYPICAL PROPERTIES OF COPPER ABSORBER PLATE COATINGS

Piping Systems

It is imperative that the fluid passages in the absorber plate be compatible, from a corrosion standpoint, with the materials used for the piping, storage tank, pump and valve bodies. Conventional hydraulic calculation methods are used to size piping in collector arrays. To avoid erosion corrosion, flow should not exceed 4 to 6 feet per second. Pipe runs should be as short and straight as possible, free from built-in "air-locks" that entrap air bubbles which restrict or cut off flow. Connections from the supply and return water lines to the collectors should provide for thermal expansion in each piping loop.

All piping should be pitched from the high point of the system to insure complete drainage when necessary. In systems protected against freezing by draining, the piping is pitched at a minimum of ⅛-inch per 1-foot of run so that the fluid drains completely.

Start-up of all liquid-carrying systems should include a flushing operation to remove all dirt and debris accumulated during installation. Follow manufacturers' recommendations when flushing systems which use a heat transfer fluid other than water.

Corrosion Protection

Solar systems can be expected to have a long, useful life, if proper steps are taken to control corrosion. There are three primary areas of concern in metal collector systems: 1) corrosion between dissimilar metals; 2) use of corrosive liquids; 3) presence of air in the system.

When dissimilar metals are used in the presence of moisture, corrosion can occur. When copper is combined with most other metals, such as aluminum or steel, in the presence of moisture, the copper will not corrode. The other metal will, however, experience accelerated corrosion in a water system. For example, if copper tube is used to connect aluminum collectors, the collectors would soon develop pits in the aluminum fluid tubes, which may cause leaks.

In a solar collector system, as in any system involving a circulating fluid, it is not sufficient simply to use dielectric fittings to separate the dissimilar metals from direct contact. Copper ions can be carried by the fluid and deposited on the other metal, causing pitting. It is difficult, as a practical matter, to exclude bronze valves and pump impellers from collector systems, especially considering the possibility of system modification or repair once in service. Although complex systems of corrosion protection are available for mixed-metal systems, the best solution simply is not to mix metals.

Copper is highly resistant to corrosion when recommended plumbing practices are followed.[1] It is especially resistant to corrosion in re-circulating hot water. There are, however, some unique circumstances which can cause corrosion in copper systems. Some liquids commonly used as heat transfer fluids can lead to corrosion in solar energy systems. Also, some localities are supplied with aggressive waters which can promote pitting corrosion in metal collector systems. Such aggressive waters typically are highly mineralized, having a high level of dissolved solids content including sulfates and chlorides, pH values ranging from 7.3 to 7.8, high (over eight parts per million) carbon dioxide content and the presence of dissolved oxygen gas. A trouble free history of copper plumbing in a locality can usually be taken as evidence that its water is not aggressive to copper. It may, however, be aggressive to other metals. In the absence of such evidence and in undeveloped areas, the water should be chemically analyzed. A qualified water treatment engineer should prescribe a treatment to make problem water non-aggressive to plumbing materials. In general, this involves raising the pH and neutralizing the free carbon dioxide.

If anti-freeze is added to the water, or if special heat transfer fluids are used, new possibilities for corrosion arise. Anti-freezes are formulated products which usually contain corrosion inhibitors. With use, inhibitors may degrade, particularly at high temperatures. The fluid then becomes corrosive and must be monitored and replenished when necessary. Recommendations of the anti-freeze manufacturer should be carefully observed to avoid system damage. Two major types of anti-freeze presently used with water in solar collector systems are propylene glycol or ethylene glycol based.

Ethylene glycol has found major applications in industrial and automotive use. It is available in both inhibited and uninhibited grades. Ethylene glycol formulations with extensive inhibition are used for automotive freeze protection. Less inhibited solutions are generally used for industrial applications. There is a long history of successful use with copper and copper alloys, especially in the automotive radiator. Inhibitors can be regenerated via controlled additions of constituents based on standard tests for pH, alkalinity, phosphates, nitrates and organic matter.

[1] Recommended plumbing practices are described in the Copper Development Association Inc. publication "Copper Tube Product Handbook" (No. 404 0)

Propylene glycol is claimed to be non-toxic. For commercial use, the Food and Drug Administration requires propylene glycol solutions where contact with food products occurs. The 10% inhibited propylene glycol solution, known as Food Freeze #35, meets FDA requirements. The use of additives (including water) may remove FDA Certification. There are presently no standard kits for monitoring propylene glycol chemistry. Since the solution involves only one or two inorganic inhibitors, laboratory tests for solution control focus on pH, alkalinity, and inhibitor concentration. Generally, inhibited propylene glycol, not ethylene glycol, should be used in solar heating systems for domestic water, unless a double walled heat exchanger is employed. For space heating purposes only, inhibited ethylene glycol may be used, if there is not a possibility of cross connections or back flow into the household plumbing system or building supply.[2]

Propylene glycol is quite corrosive to aluminum, especially in the presence of either copper or brass. It will superficially attack copper but the attack is uniform as opposed to concentrated pitting.

In summary, many anti-freeze solutions require the addition of inhibitors and buffers for pH and corrosion control. In selecting inhibitors for glycol solutions, avoid oxidizing agents, such as chromates, which tend to promote rapid degradation.

Periodic monitoring, especially of pH, is required, with eventual solution replacement when the buffers are expended. Mixed metal systems should be avoided whenever glycol solutions are used. It is advisable to install filters to remove solids that may develop in the system.

Draindown systems provide protection from freezing by draining the liquid from areas which experience freezing temperatures. When draindown systems are used, special care should be taken in selecting the metals used in the system. Copper collectors and piping will withstand repeated exposure to air and water without difficulty. Aluminum and steel are much less resistant to the corrosive effects of alternating exposure to water and air.

Collector Cover Glazing

The number of cover plates chosen depends on the desired collector operating temperature and performance. Although additional cover layers reduce heat loss, they also reduce transmission of solar energy. There is a point where additional glazing actually di-

[2] Local regulations must be observed.

MATERIAL	THICKNESS (INCHES)	SOLAR ENERGY TRANSMISSION (%)	MAXIMUM OPERATING TEMP (°F)
Clear Lime	1/8	85.0	
Float Glass	3/16	81.0	400
	1/4	78.0	
Water White	1/8	91.0	
Crystal (Low Iron)	3/16	90.5	400
Glass	1/4	90.0	
100% Acrylic	1/8	89.0	
Colorless Cast	3/16	87.0	190
Sheet	1/4	85.0	
Polycarbonate	1/8	81.0	
	3/16	78.0	270
	1/4	74.0	
Tedlar Film	0.004	93.5	227
Filon 388	0.060	82.0	
(Flat) 548	0.030	86.0	220
608	0.080	77.0	
Teflon Film	0.002	97.0	400
Mylar Film	0.001	85.0	220
Kalwall Sunlight Regular	0.025	93.0	140
Kalwall Sunlight Premium	0.040	86.0	140
Lexan Film	0.005	94.0	270
	0.007	93.0	

TABLE 3/SOLAR COLLECTOR COVER MATERIALS

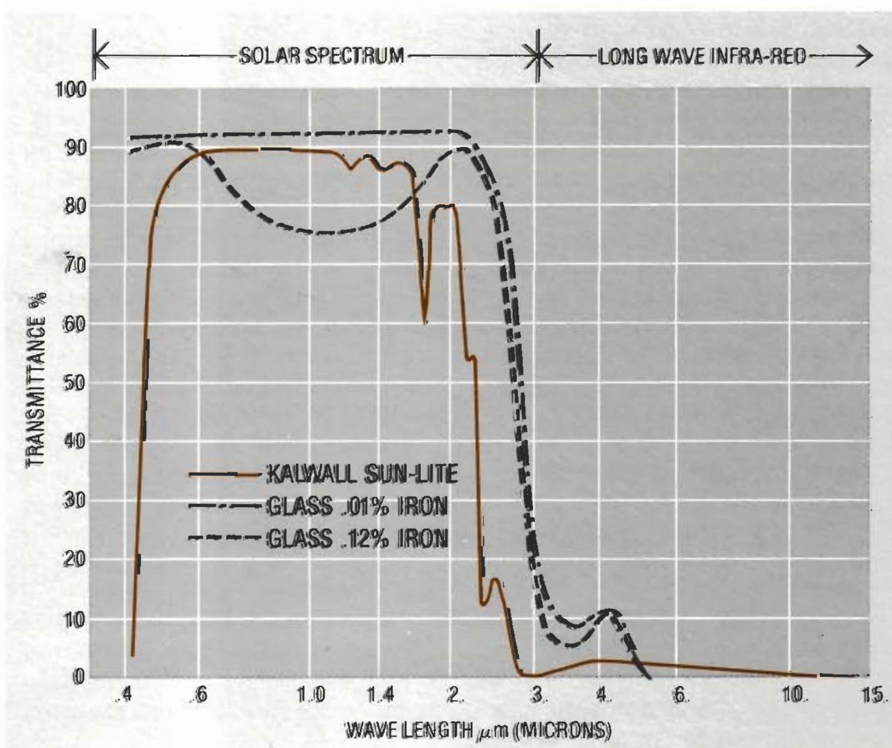


FIGURE 31/ SPECTRAL TRANSMITTANCE OF COVER PLATE MATERIALS

minishes collector efficiency. As stated in Section 2, there are some low-temperature applications where the choice of an unglazed collector is appropriate. In most cases, however, one or two covers are required. A listing of cover materials and their properties is shown in Table 3.

When using glass cover plates, tempered glass with ground edges should be specified and the manufacturers' recommendations regarding maximum permissible spans should be followed. Low-iron-content glass offers high solar energy transmittance, as well as resistance to reverse transmission of long-wavelength radiation from the absorber plate. Tempered glass has good impact resistance, and is stable under ultraviolet and high temperature conditions.

Cover-to-cover and cover-to-absorber plate seals must be tight, otherwise, dust, dirt and moisture will migrate to the collector interior through breaks caused by thermal movement. If two glass plates are hermetically sealed, they must have the same physical characteristics. A 3/32-inch-thick glass inner plate, for example, should not be used with a 3/16-inch-thick tempered cover plate. At the high temperatures existing during normal collector operation, and the even higher stagnation temperatures that result when the heat transfer fluid stops flowing, substantial internal pressures are exerted on the glazing. Thin plastic sheets or films, used as cover plates in certain applications, afford the advantages of light weight, relatively low cost, and increased fracture resistance. The plastic chosen should have proven long-term resistance to ultraviolet radiation breakdown. The durability of the plastic glazing material should also be evaluated in terms of resistance to elevated temperatures and thermal expansion properties.

Unlike glass, most plastics do not block the reverse transmission of long-wavelength radiation from the collector plate. Figure 31 shows the transmittance afforded by cover plate materials to radiation of various wavelengths. The radiation in the solar spectrum (0.4 microns to 3.0 microns) should be readily transmitted. The reradiation of long-wavelength infrared (3.0 to 15 microns) should be blocked in order to retain this heat within the collector. The ability of cover glazing to perform in this manner is important in applications where high temperature collection is required.

Absorber Plate Insulation

An absorber plate may reach temperatures in excess of 200°F regularly. To maximize energy collection from this heated plate, it must be well insulated.

	INSULATION		
	FIBERGLASS	URETHANE	EXTRUDED POLYSTYRENE FOAM
Heat Loss	Good	Excellent	Excellent
Moisture Resistance	Fair	Excellent	Excellent
Volatile Outgassing	Excellent	Poor	Fair
Temperature Resistance	Excellent	Fair	Poor
Desirability	Recommended	Not Recommended*	Not Recommended*

*Not recommended for high temperature application

TABLE 4/COMPARISON OF INSULATING MATERIAL PROPERTIES

The back of the collector is typically insulated with a 3 to 4-inch thick fiberglass blanket. The use of cellular plastics for this purpose requires special consideration. Under stagnant conditions, which occur when there is no flow of heat transfer fluid through the collector, the plate can reach temperatures approaching 400°F. Most foamed urethane insulations currently available undergo a permanent volumetric increase at approximately 250°F. Consequently, they can seriously distort if placed in direct contact with the absorber plate. Furthermore, foamed insulations are typically "blown" with chlorinated or fluorinated hydrocarbons which degrade at this temperature, producing hydrochloric and hydrofluoric acids. Both end products are corrosive to all metals.

A related problem is the outgassing of volatile elements from the insulation or from adhesives or wood products used in conjunction with the insulation. These volatile elements can condense on the inner surface of the glass and other portions of the collector. Polyurethane foam, which is "blown" with carbon dioxide, is not subject to the outgassing of such volatiles. It may offer an alternative to fiberglass insulation, when not subjected to stagnation temperatures.

Insulation materials may be combined to obtain the most beneficial aspects of each. For example, a layer of fiberglass between the collector and a foamed plastic insulation protects the latter from thermal damage. Since some foamed insulations have higher insulating values than fiberglass, this approach has merit. Care must be taken to be sure that temperature-sensitive insulation is adequately protected from the high temperatures which will occur at stagnation conditions.

Table 4 compares the important properties of three insulating materials: fiberglass, foamed urethane, and extruded polystyrene.

Freeze Protection and Heat Transfer Liquids

In climates where freezing is possible, protection must be provided to prevent damage to the collector. Two common ways of handling this problem are:

1) *The use of an anti-freeze solution*
2) *The draining of the fluid from the collector array when temperatures approach freezing.*

The basic heat transfer fluid used in liquid collectors is water. When other agents such as anti-freeze compounds are added, a solution pH of 7.0 or higher should be maintained. The addition of any substance to water, or the use of heat transfer oils, (some of which have been developed for solar systems), reduces the specific heat and requires the circulation of more fluid in order to remove a given amount of heat from the collector plate which may require the use of a larger pump. Due to the cost of anti-freeze agents, it is seldom economical to treat all of the system water—including that in the storage tank. Therefore, a heat exchanger between the fluid circulated through the collector and the storage tank fluid would be required. Any heat exchange operation reduces overall system efficiency.

When a draindown method of freeze protection is used, air is permitted to enter the system and displace the water in the collector loop. The water drains into the storage tank (or a separate holding tank) in a location not exposed to freezing temperatures. In some systems, an automatic air vent and an air solenoid valve are employed to permit the passage of air into and out of the system.

This type of freeze protection is shown in Figure 19 on page 14.

In atmospheric systems, which do not operate at an imposed pressure, it is often possible to allow the draining of the water in the collectors and the piping by the method shown in Figure 32. Because the return piping from the collector to the storage tank terminates above the water level in the tank, air can enter the piping through the vent in the tank lid. This breaks the suction at the high point of the system as air moves up the return piping. It is advisable to over-size the return piping slightly to facilitate air movement.

This method of freeze protection has been successfully employed in a number of collector installations. To insure proper system operation, the air path up the return piping must be unrestricted. Each installation should be carefully evaluated when this method is used. All the piping must be pitched to drain from the high point of the system, so that the water flows unimpeded into the storage tank. There should be no low points or pockets to trap water in portions of the piping exposed to freezing temperatures. This method of freeze protection is illustrated in the solar space heating section, Figures 24, 25, 28, 29 (pages 17, 18, 20, 21).

Some means for accommodating the expansion of fluid in all closed piping loops must be provided. All liquids expand when heated. Water, for example, expands about 4% per 100°F temperature rise.

In pressurized systems, such as domestic water heating systems, excess pressures due to expansion are normally provided for by using a pressure relief valve to drain excess water volume. A pressurized expansion tank or accumulator is appropriate for larger systems. In non-pressurized systems, expansion is accommodated by oversizing the storage tank and venting it to the atmosphere.

High Temperature Protection

Should fluid circulation through the absorber plate stop while the sun is shining, the solar collector can reach extremely high "stagnation temperatures." For a double-glass collector with a flat black surface, these temperatures reach 350°F to 400°F. Collectors with selective surfaces stagnate at even higher temperatures. The collector frame, piping connections and insulation must be able to withstand such temperatures.

Even when appropriate materials have been used, a system must be protected against the thermal shock produced when cold fluid is pumped into a collector that has reached stagnation temperature. This could be the case on initial system filling and start-up. This also might happen should a power failure prevent operation of the circulating pump. If power is not restored until after an hour or two of subsequent sunshine, the automatic restarting of the pump forces cool fluid through the collector which has reached stagnation temperatures. The resulting thermal shock can cause buckling of the absorber plate and breakage of the glass covers.

Protection against thermal shock can be provided in several ways. One method uses a temperature sensor on the back of the collector plate to actuate a cutout relay in the power supply to the circulating pump. When the collector plate reaches a preselected temperature, power to the pump is cut off preventing circulation of the collector fluid. An alternative means employs a timing device that prevents automatic restarting of the pump in the event of a power failure lasting more than a minute or two. A third method employs a temperature sensor to prevent pump operation when a preset temperature differential exists between the collector plate and the circulating fluid. The third method is generally more expensive than the two previous, especially for residential applications.

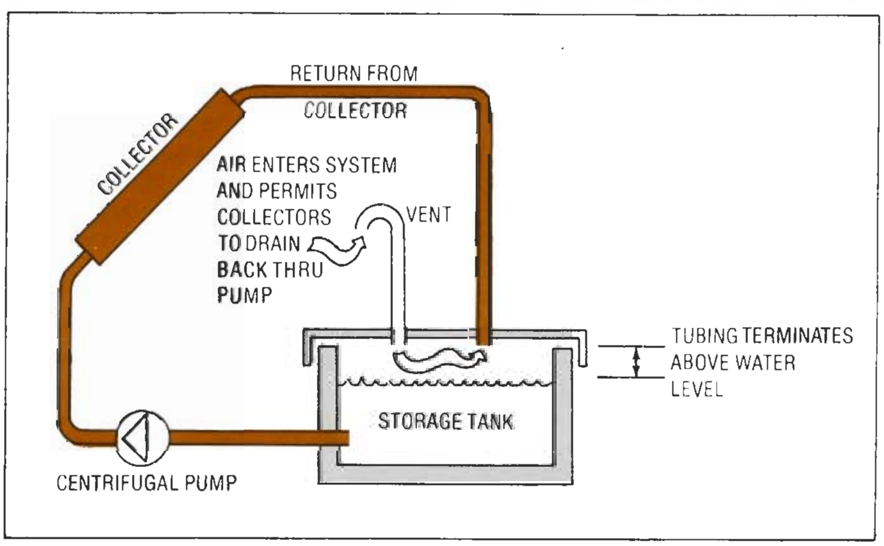


FIGURE 32/DRAINDOWN SYSTEM WITH AIR VENT

Circulating Pumps and Controls

Pumps ordinarily selected for residential and small commercial solar systems are close-coupled, in-line or base-mounted, centrifugal types with mechanical shaft seals and flexible drive couplings. Pumps used in potable water systems should be bronze bodied.

The designer should select a pump which has the proper combination of flow rate and lift characteristics for each application. In general, the pumps for solar collectors should be chosen to provide approximately one to three gallons of water per hour per square foot of collector surface in order to maintain a reasonable temperature differential across the collector plate. In open systems, pumps must have sufficient lifting capacity to raise water from the storage tank to the top of the collector circuit. For such systems which usually have a relatively high lifting requirement and low flow quantities, two small pumps connected in series are often the best alternative. In closed systems, the pumps are needed only to overcome friction losses through the piping.

The pump should not be oversized to the point where its typical operating characteristics are at a low efficiency. In most small solar systems, the pumps will not exceed 1/4 to 1/3 horsepower and may be as small as 1/6 to 1/20 horsepower in closed systems.

When centrifugal pumps are used, it is essential that they operate with a net positive suction head. This is most frequently accomplished by connecting the pump through the storage tank wall below the water level in the tank. Then, there is always a positive head of water in the tank above the pump. If the pump is not installed to operate with a net positive suction head, it will cavitate, causing damage to the pump.

The circulating pump in the collector loop is normally started and stopped by means of a differential temperature controller. This controller measures the collector temperature and the storage tank water temperature. When the collector temperature is higher than the tank water temperature, by a set amount, the controller actuates the circulation pump. When the collector water temperature approaches the tank temperature, the pump is turned off. This differential thermostatic control assures that maximum heat energy is retained in the tank under all weather conditions.

Several manufacturers offer a variety of low-priced differential temperature controllers. Options are available to set a maximum storage tank temperature and to incorporate various freeze protection methods.

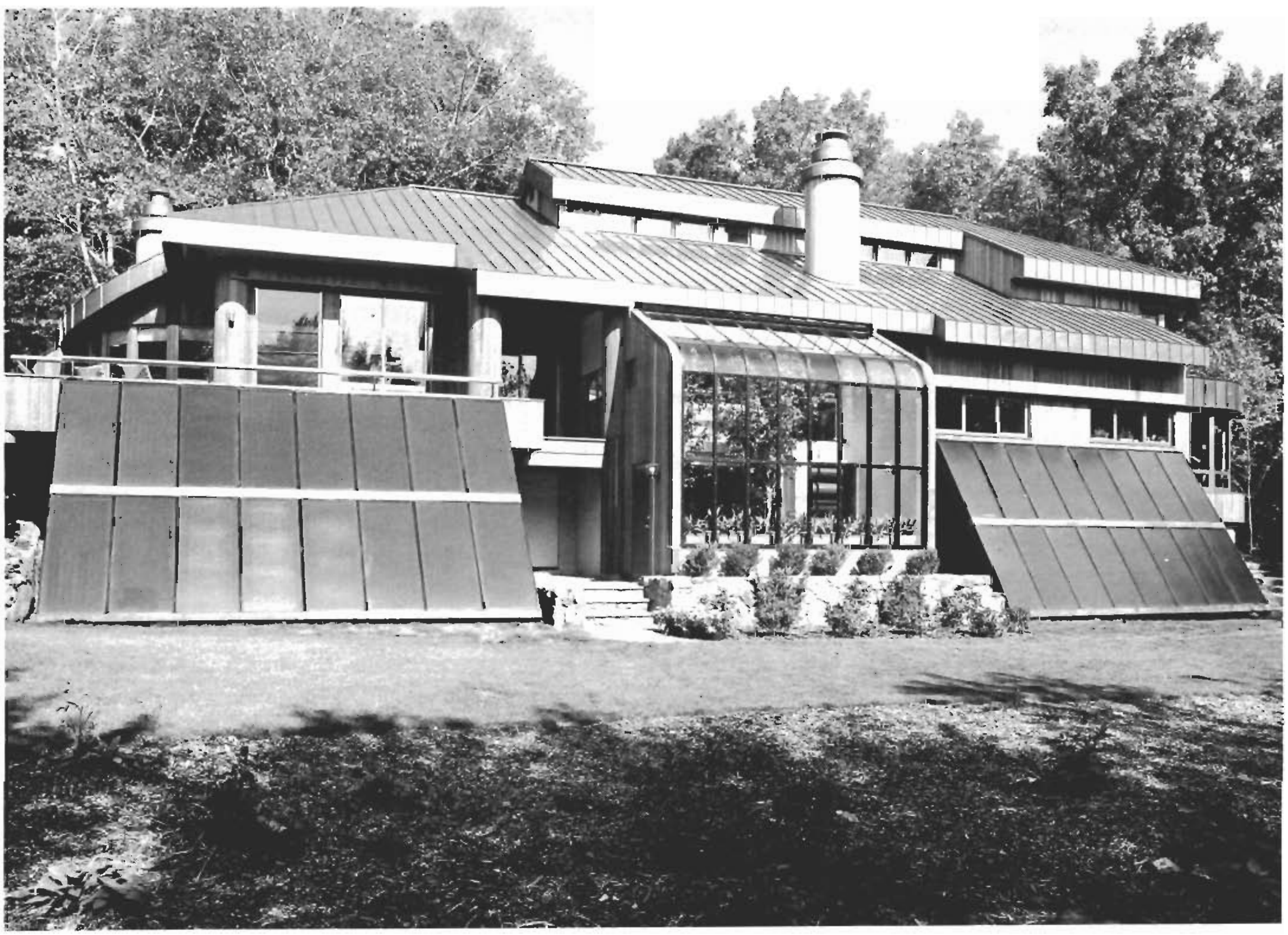
Collector Installation

Integration of collectors with the roof structure should be carefully considered. The construction should be watertight so that no leakage occurs into the collector or through the roof.

Collectors should be permitted to expand and contract freely. Temperatures will vary considerably in different sections of the collectors and the component parts will expand and contract at different rates. High temperature sealing (glazing) tapes must be used to maintain watertight seals. Silicone tapes and caulking compounds usually have excellent high temperature properties.

External sealants should be used which do not exhibit "thermal set" or a tendency to vulcanize when exposed to cycling temperatures. Thermal set can be a cause of leakage problems when contraction of the adjacent materials results from cooling. Maintenance of the collector should be considered when planning framing details. The collector should be easily removable for repairs when necessary.

When a particular collector is used, the manufacturer's recommended installation details should be followed without deviation. Neoprene glazing gaskets or commercial skylight framing systems are sometimes used. The manufacturer's recommendations for these products must be closely followed to assure a trouble-free installation. The return piping above the collector outlet should be pitched so that water is not trapped in the piping.



The "Sun/Tronic House" is a prototype solar home in Greenwich, Conn., conceived and built by Copper Development Association Inc. The active and passive solar energy systems provide more than 65% of the home's space heating and domestic hot water needs.

SECTION 7

DESIGN: SUN-CHART HAND CALCULATIONS

Sun-Chart is one method of simplified solar design. Other hand and computer methods are available for the design and sizing of solar systems. The decision to use a solar system is that of the designer or installer based on the portion of solar contribution desired. This contribution will in general range from 50-80% dependent on a number of factors which vary based on climate, building type, equipment and application. The ultimate decision of size and contribution of a solar system will normally be based on installed cost and payback period. The example used in Section 7 to carry through the Sun-Chart calculations is not intended to be representative of all climates, buildings, equipment, and applications. We are confident that the CDA Sun-Chart method along with the CDA Solar Energy Handbook will provide the solar community with a valuable tool for the development of solar energy.

Design Calculations

Solar design engineering normally entails extensive hand calculations or computer analysis to optimize system performance and cost. However, a simplified approach that permits rapid evaluation of heat loads and collector area has been developed. The CDA Sun-Chart Hand Calculations, for determining space and water heating loads, collector performance and recommended collector area, are described on the following pages.

This approach involves certain assumptions. In the majority of cases, these assumptions approximate normal conditions and generate results similar to those achieved by more extensive analysis. For most cases, results from these calculations have proved to be equal to, or slightly more conservative than, those achieved by computer analysis. The calculations are based on an average day for each month. In actual operation there will be overcast days when the solar collector may not operate, or very cold days when the requirements for heat will be higher. Generally, there is no reason to adjust the calculations unless an unusual situation exists. If the conditions on a particular application differ signficantly from the assumptions, it is advisable to have the calculations checked by a professional experienced in solar system design.

Each solar energy system must be engineered to meet the particular circumstance of its use. The Copper Development Association Inc. assumes no responsibility or liability of any kind in connection with the calculations or system designs set forth herein or their use by any person or organization and makes no representations or warranties of any kind.

Determining End-Use Heat Requirements

Water Heating. The amount of heat required to produce hot water depends on the number of gallons consumed, the inlet temperature of the cold water supply and the desired discharge temperature at the fixtures. Table 5 lists average monthly cold water supply temperatures, at the sources, for 14 cities in the United States. Deep wells, such as those in Miami, Albuquerque and Las Vegas, produce water at a relatively constant temperature that is related to locally prevailing deep earth temperatures. Water from shallow wells, lakes, and reservoirs varies in temperature throughout the year as the result of changing air temperatures.

		J	F	M	A	M	J	J	A	S	O	N	D
Albuquerque	W	62	62	62	62	62	62	62	62	62	62	62	62
Boston	Re	32	36	39	52	58	71	74	67	60	56	48	45
Chicago	L	32	32	34	42	51	57	65	67	62	57	45	35
Denver	Ri	39	40	43	49	55	60	63	64	63	56	45	37
Fort Worth	L	46	49	57	70	75	81	79	83	81	72	56	46
Los Angeles	Ri	50	50	54	55	63	70	73	73	72	68	57	52
Las Vegas	L,W	57	64	68	71	77	85	87	86	78	70	65	57
Miami	W	70	70	70	70	70	70	70	70	70	70	70	70
Nashville	Ri	46	46	53	63	66	69	71	75	75	71	58	53
New York	Re	36	35	36	39	47	54	58	60	61	57	48	45
Phoenix	Ri,Re,W	48	48	50	52	57	59	63	75	79	69	59	54
Salt Lake C.	W,C	35	37	38	41	43	47	53	52	48	43	38	37
Seattle	Ri	43	42	46	51	56	61	65	66	65	58	52	44
Washington	Ri	42	42	52	56	63	67	67	78	79	68	55	46

Source Data From Handbook of Air Conditioning System Design, p. 5-41 through 5-46; McGraw Hill Book Company, New York (1965). Abbreviations: C—Creek, L—Lake, Re—Reservoir, Ri—River, W—Well

TABLE 5/SOURCE AND MONTHLY TEMPERATURE IN °F AT THAT SOURCE FOR COLD WATER SUPPLY IN 14 CITIES

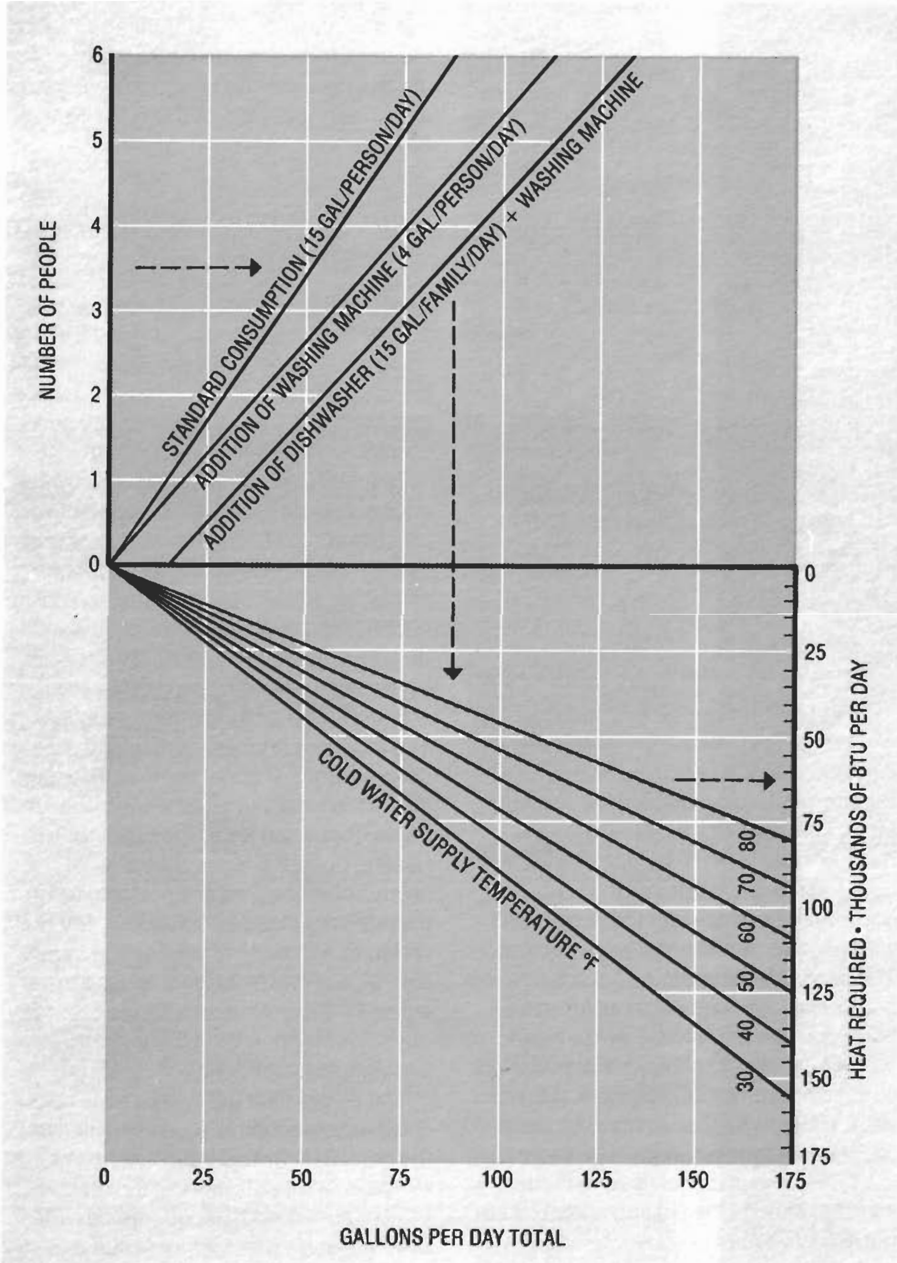


FIGURE 33/ENERGY REQUIREMENTS FOR WATER HEATING/BASED ON 135°F D.H.W. SUPPLY TEMPERATURE

Example: Family of Four—
Nashville, Tennessee
High Consumption—
91 Gallons/Day

MONTH	COLD WATER TEMP.	HEAT REQUIREMENTS (BTU/DAY)
January	46	67,500
February	46	67,500
March	53	62,200
April	63	54,600
May	66	52,300
June	69	50,000
July	71	48,500
August	75	45,500
September	75	45,500
October	71	48,500
November	58	58,400
December	53	62,200

TABLE 6/DOMESTIC HOT WATER HEAT REQUIREMENTS

Contact local water suppliers for accurate information on average water temperatures.

Hot water consumption is the major factor influencing annual heat requirements. It requires 8.33 Btu to raise one gallon of water 1°F. If one gallon of water is heated from 35°F to 135°F., 833 Btu are required. This is equal to the energy consumed by a 60 watt light bulb burning for over four hours.

Authorities[1] differ in their estimates for hot water consumption, with a range of 50-120 gallons per day for a family of four, including appliance usage. Typically, a family of four has been found to consume 60-90 gallons of hot water daily. However, the total consumption of hot water depends primarily on the individual's habits and upon the characteristics of the plumbing fixtures or appliances used. Figure 33 has been developed to determine the heating requirement for different levels of hot water consumption based on either the number of people served, or the anticipated consumption in gallons per day.

Table 6 lists the heat required month-by-month to provide 135°F. hot water for a family of four living in Nashville, Tennessee, using a dishwasher and clothes washer. It may prove advantageous to plot a graph of the data obtained from Figure 33, as a means of spotting mathematical errors. Figure 34 is a graph constructed from the data in Table 6. The graph should curve smoothly. A sharp deviation in any month is a clue that an error exists.

Space Heating. When heating load calculations are made for a conventional heating system, the custom is to first determine the highest rate of heat loss anticipated for the building. The computed amount is then increased by some percentage ("safety factor") to cover unforeseen circumstances. The adjusted figure is used as the basis for equipment selection.

This practice often leads to the installation of oversized space heating systems that operate less efficiently and thus consume more energy. Heating equipment, particularly fossil-fuel equipment, usually delivers its design efficiency only at full capacity. Below this, efficiency falls off. Oil and gas furnaces are often designed to an efficiency of about 75 percent at full load. Yet, when installed in a building, these furnaces may attain a seasonal efficiency of only 50 percent or less.

In contrast, solar systems are designed to handle only a portion of the highest anticipated heat loss. The designer, therefore, is more concerned with the average heating load per day. A solar system sized to handle average rather than peak loads requires supplementary heat input on the coldest days. The system will operate near its full rated output much of the time. Therefore, its overall seasonal efficiency should be higher.

[1]a) Study of Energy Savings Options for Refrigerators & Water Heaters. Little (Arthur D.) Inc., Cambridge, Massachusetts. 1977.
b) Patterns of Energy Consumption in the United States. Office of Science & Technology, Executive Office of the President. 1972.

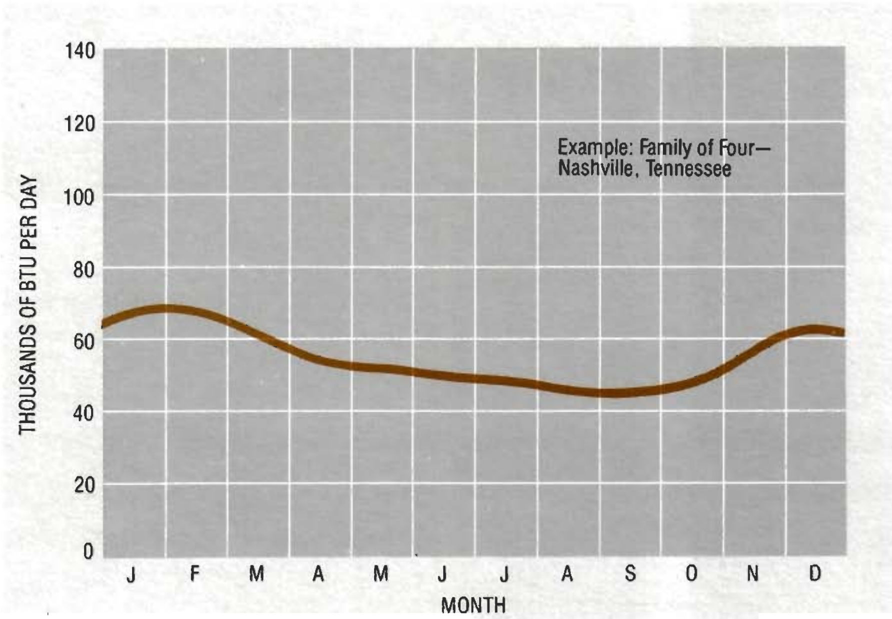


FIGURE 34/ WATER HEATING REQUIREMENTS GRAPH

Eligibility Criteria. The use of solar energy to provide space heating for a building should not be considered unless the building is energy conserving. To attempt to solar heat a building that is poorly designed from an energy standpoint is a waste of money. The investment for a solar energy system might be better spent on energy conservation features to reduce the building's heating requirements.

Many things contribute to the energy requirements of a building, including proportion, orientation (especially of large glass areas), exterior color, and the type of shell construction. Construction features which exert the greatest impact on energy conservation and are accounted for in design calculations are insulating glass or storm windows, control of the infiltration of outside air through joints between materials, and the type and amount of wall and roof insulation.

Extreme care should be exercised in selecting the wall and roof insulation materials. Cellulosic fiber insulating materials containing ammonium sulfate as a fire retardant should not be used in contact with copper or other metals. The ammonium sulfate may leach from the insulation and cause serious corrosion damage to piping, electrical and similar metal components.

Heat loss, measured in Btu per square foot per degree day, is a major criterion in judging whether or not a building is suited for solar space heating. In general, a solar system should be considered for a residence only when the space heating demand has been limited to approximately 8 Btu per square foot per degree day or less.

To apply this criterion to a building which is being considered for solar heating, calculate the building's energy requirements under peak design conditions. This calculation determines the heat required when the outdoor temperature is at the design point, and is normally done by the designer for the purpose of sizing conventional heating equipment. The design point temperature is based on hourly average temperatures for each hour of a total year. The average hourly temperatures will be above the design point temperature 97½ percent of the year. In Nashville, Tennessee, for example, the heating design point temperature is 17°F. Heat loss calculation methods are well documented in existing texts and are not repeated here.

To determine the average heating requirements, instead of the peak heating requirements, the concept of degree days is used. A degree day is a standard used to measure the heating season's severity. The number of degree days in a calendar day is determined by subtracting the day's mean temperature from 65°F. If the mean temperature on a given day is 50°F, subtracting 50°F. from 65°F. yields 15 degree days for that calendar day. By adding the number of degree days in each day, the average monthly conditions are identified. The average monthly and yearly degree days for cities in the United States and Canada are listed in Appendix A.

Sample Calculations. An example may help to illustrate how the heat loss is calculated to determine solar system feasibility.[2] Consider a home in Nashville, Tennessee, which loses 30,000 Btu per hour, when the outdoor temperature is 17°F. If this temperature exists for a 24-hour period, the building heating demand is 30,000 x 24 = 720,000 Btu. Since the design point temperature is 17°F., (48 degree days per day), the house requires a net heat input of 15,000 Btu per degree day as shown below:

$$\frac{30{,}000 \text{ Btu/hr.} \times 24 \text{ hours}}{(65°\text{F Degree Day Base} - 17°\text{F. Design Point Temperature})} = 15{,}000 \text{ Btu/DD}$$

If the home's floor area is 2,000 square feet, the required heat input is 7.5 Btu per square foot per degree day. Since this is less than the criterion of 8 Btu per square foot per degree day, the house is a good candidate for solar space heating.

In actual practice, most homes experience an annual heating requirement which is somewhat less than that obtained by the above calculation method. The reason for this difference is that the design heating load does not account for heat gain from other sources such as people, lights, and cooking. Also, the house itself acts as a solar collector to some extent. The exterior surfaces, particularly windows, absorb or admit some of the incident solar energy. In the heating season, these heat gains lower the building heating demand. Since they are not always present, they are not included in the peak heat load calculation. They are, however, accounted for when the modified degree day procedure is used to calculate heating requirements on average days. This is done by using a "Degree Day Adjustment Factor".

The adjustment factor is used to calculate average monthly requirements from the peak design load information. For example, after determining the number of Btu per square foot per degree day, the building heating requirement can be calculated by obtaining the figure for monthly degree days from the Appendix. Dividing this figure by the number of days in the month gives the average degree days per day for that month. The building's average heating requirement per day for each month is then determined by multiplying the average number of degree days by the Btu per square foot per degree day, the total floor area in square feet and the adjustment factor. The adjustment factor is obtained from Figure 35, which compares the outside design temperature with the degree day adjustment factor. In this example, since the outside design temperature in Nashville is 17°F., the adjustment factor is 0.86.

[2] The method outlined is based on the "Modified Degree Day Procedure." "ASHRAE Handbook and Product Directory, 1976 Systems", American Society of Heating, Refrigeration and Air Conditioning Engineers, Inc., New York, N.Y., 1976.

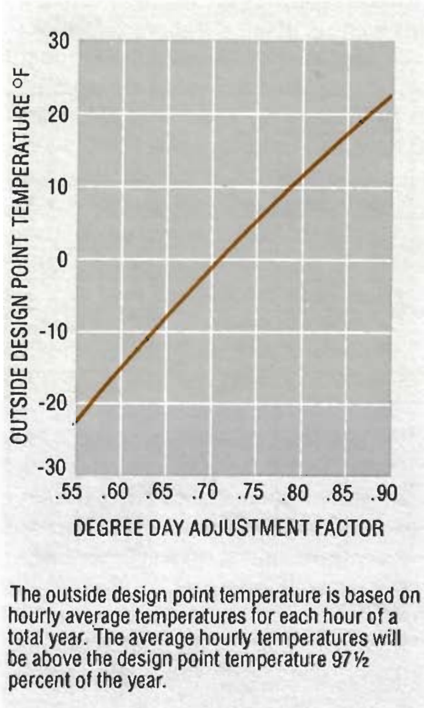


FIGURE 35/HEAT LOSS VS. DEGREE DAYS INTERIM ADJUSTMENT FACTOR[1]

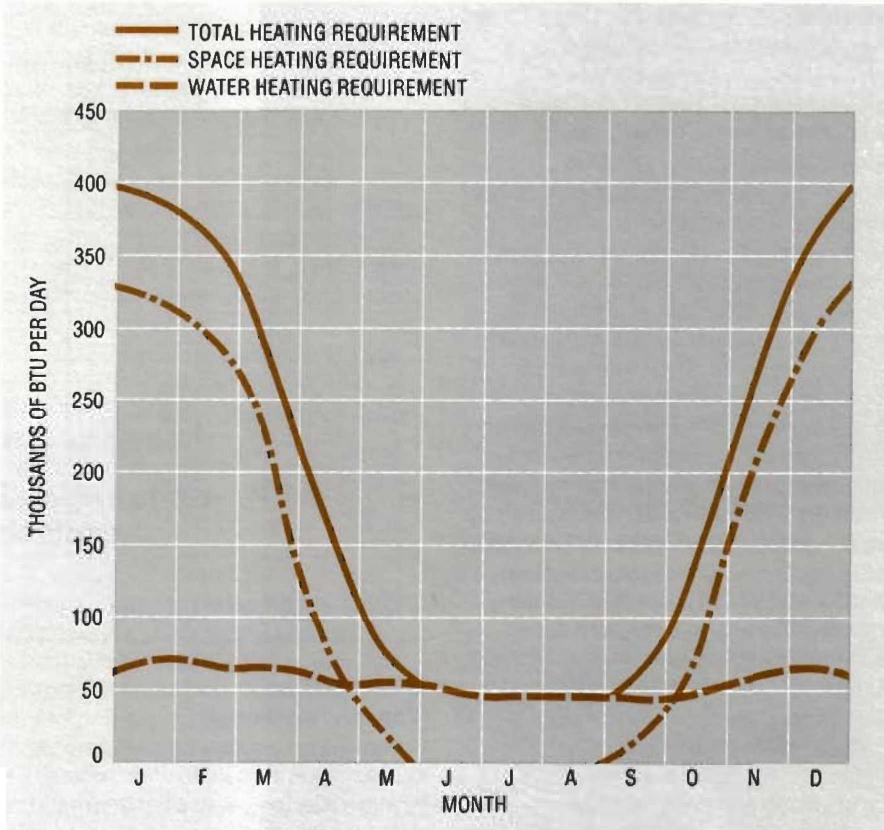


FIGURE 36/TOTAL HEATING REQUIREMENTS GRAPH

For January, the calculation is as follows:

January—NASHVILLE, TENN.

$\frac{\text{778 Degree Days/Month}}{\text{31 Days/Month}} = \text{25 Degree Days/Day}$

Average Heat Requirement (Btu/Day) = 25 DD/Day x 7.5 Btu/Sq. Ft./DD x 2000 Sq. Ft. x 0.86 Adjustment Factor = 322,500 Btu/Day

This calculation is repeated for each month of the heating season, and the results should be tabulated as in Table 7.

These space heating monthly figures can be added to the monthly figures for domestic water heating in Table 6 to obtain total heating requirement. The three curves plotted on the graph in Figure 36 then represent hot water, space heating, and total heating requirements.

Heat Required Vs. Energy Consumed. If the monthly heating requirements are supplied by a fossil fueled furnace or boiler, the energy consumed is greater than the total heating requirement because of the inefficiency of combustion.

For example, if the home in Nashville, which requires 30,000 Btu/hr. for space heating at peak design conditions, has a furnace rated at 36,000 Btu/hr., the furnace is oversized by 20 percent. As shown in Figure 37 this means that the seasonal efficiency of the furnace is about 48 percent.

In January, then, when 322,500 Btu/day are required, it will take 671,875 Btu/day of some type of fossil fuel to supply this load. (322,500 Btu/day ÷ 0.48) If fuel oil is used, which has a rated value of 140,000 Btu/gallon, 4.8 gallons are consumed per day to supply the average load. If a solar system could deliver 50 percent (161,250 Btu) of the average daily space heating requirement in January, it would supply the equivalent of 335,938 Btu of fuel oil energy.

Example: Nashville, Tennesse

Month	(BTU/Day)
January	322,500
February	296,700
March	213,000
April	81,270
May	16,650
June	0
July	0
August	0
September	12,900
October	65,750
November	212,850
December	304,600

TABLE 7/SPACE HEATING REQUIREMENTS

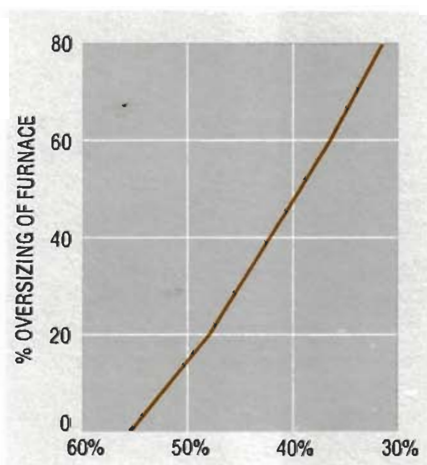


FIGURE 37/ SEASONAL EFFICIENCY OF A FURNACE WITH A RATED FULL LOAD EFFICIENCY OF 75%*

* "ASHRAE Handbook & Product Directory, 1976 Systems," ASHRAE, Inc., New York, N.Y., 1976.

Computing Collector Output

The CDA Sun-Chart Hand Calculations is an easy method to use to calculate the solar energy obtainable from collectors in residential space heating and domestic water heating applications. Normally, solar heat calculations use sophisticated computer analysis. Such analysis is required for large-scale solar energy applications, particularly those involving cooling, where it is important to determine the heat that can be collected on an hour-by-hour basis. For small-scale systems, however, this simplified method provides results which closely approximate those achieved by computer analysis. Heat pump systems in which the solar system and the heat pump are not directly linked, such as that shown in Figure 28, can also be analyzed reasonably well by this procedure.[3] More sophisticated analysis methods are required for applications which use a heat pump to extract energy from a solar storage container.

The simplification is accomplished by making the following assumptions about the solar system characteristics:

(1) The collector orientation is within 15 degrees of due South. For applications which differ significantly from this assumption, adjustments can be made by using the orientation graph in Figure 13 on p. 9 of this manual.

(2) Collectors with circulating liquids are used to carry collected energy to storage or load.

(3) Water storage capacity ranges from 1½ to 2 gallons per square foot of collector array.

The CDA Sun-Chart Hand Calculations for determining collector heat production are best explained by referring to a tabulation chart, Figure 38, devised to guide and facilitate the computation procedures. The designer begins by entering in the first five columns (A through E) available data concerning the application. He then performs six mathematical operations using these basic data and enters the results in columns F through L. A final multiplication yields data for the "Result" column; i.e., the average daily heat produced during each of the 12 months by one square foot of collector at a given tilt angle, operating at a specific temperature and installed in a particular locality. All of the computations are basic mathematical functions easily performed on a pocket calculator, or by hand.

In order to fully appreciate the logic process shown in the design chart, the user should understand the significance of each column. The following explanatory notes may be helpful.

JOB:
LOCATION:
LATITUDE:
COLLECTOR TYPE:
COLLECTOR TILT:
APPLICATION:

	A	B	C	D	E	F	G	H	J	K	L	RESULT
	COLLECTOR HEAT GAIN FACTOR (TABLE 8) OR MFG'S LIT	COLLECTOR HEAT LOSS FACTOR (TABLE 8) OR MFG'S LIT	AVERAGE DAYTIME AIR TEMPERATURE °F	HORIZONTAL SOLAR ENERGY (FROM TABLES) APPENDIX B	COLLECTOR TILT FACTOR (FROM TABLE) APPENDIX C	INCIDENT ENERGY F = D x E	COLLECTOR INLET TEMPERATURE (TABLE 9) °F	H = COLUMN G - COLUMN C °F	J = $\frac{B}{A}$x2H	K = $\frac{J}{F}$	'L' IS FOUND FROM FIGURE 40 USING 'K'	TOTAL ENERGY COLLECTED = F x L BTU/SQ. FT./DAY
JANUARY												
FEBRUARY												
MARCH												
APRIL												
MAY												
JUNE												
JULY												
AUGUST												
SEPTEMBER												
OCTOBER												
NOVEMBER												
DECEMBER												

FIGURE 38/ THE CDA SUN-CHART WORKSHEET

Data Input

(Columns A Through E)

Column A is the collector heat gain factor. Each type of collector has a characteristic ability to absorb solar energy. This ability is determined, in part, by the quality of the glass and the absorptivity of the blackened absorber plate surface. Table 8 p. 33 lists the collector heat gain factors for four representative types of copper flat plate solar collectors.

For specific flat plate solar collectors, this factor is determined from a performance graph as shown in Figure 39.[4] A graph for any collector can be obtained from the manufacturer. The collector heat gain factor is the point at which the sloped line intersects the vertical axis of the graph.

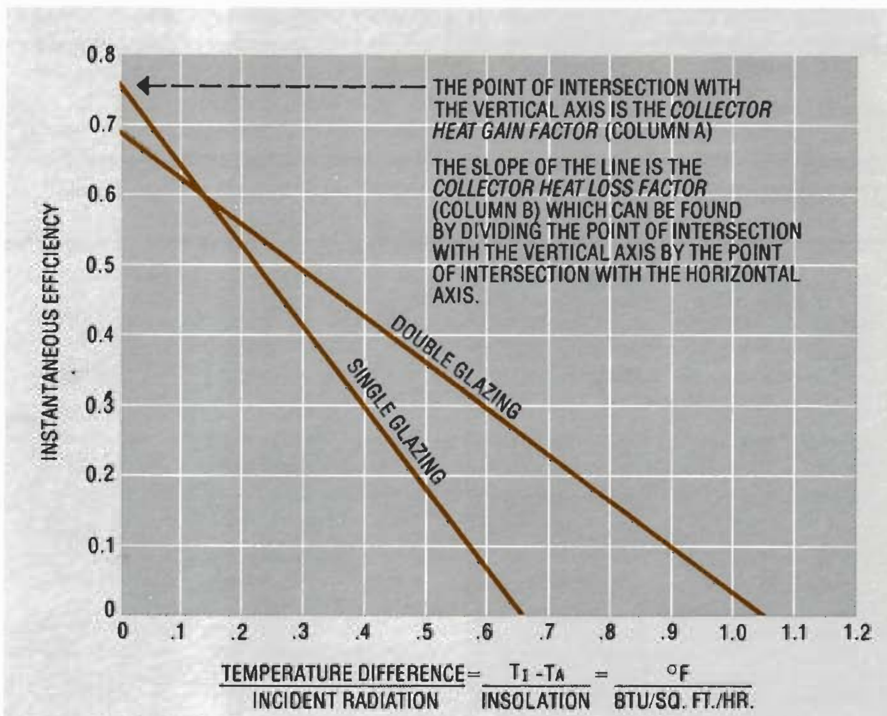


FIGURE 39/COLLECTOR PERFORMANCE CHARACTERISTICS/TYPICAL VALUES—COPPER FLAT PLATE COLLECTORS

[3]For greater accuracy, use the bin data procedure, as shown in the "ASHRAE Handbook and Product Directory, 1976 Systems", Chapter 43, ASHRAE, Inc., New York, N.Y., 1976.

[4]The graph should be the results of a test of collector production conducted in accordance with ASHRAE Standard 93-77 (ANSI B198.1-1977) "Methods of Testing to Determine the Thermal Performance of Solar Collectors", ASHRAE, Inc., New York, N.Y., 1977 or a similar recognized standard.

Column B is the collector heat loss factor. When collectors absorb solar energy, they tend to yield back the heat gained to the surrounding air. To achieve good operating efficiency, this heat loss should be minimized by insulation and other techniques. Table 8 lists the collector heat loss factors for four types of flat plate solar collectors. For other types, this value can be obtained from manufacturers' data as shown in Figure 39. The collector heat loss factor is equal to the slope of the line. The slope value is determined by dividing the point at which the sloping line intersects the vertical axis by the point at which it intersects the horizontal axis. Both collector heat gain factors and heat loss factors are a function of each particular collector and remain the same in each of the 12 months.

Column C is the average air temperature. Ideally, this temperature should be the daytime average air temperature, but this data is often not available. Average full day air temperature for each month is usually available from a local weather station. The daytime average air temperature can be found by adjusting the average full day temperature. This is done by adding a value equal to 1/3 of the daily temperature range (usually 15°-20°F.) to the average full day temperature.

Column D is the horizontal solar energy. This is the amount of solar energy received by a horizontal surface on an average day in each month. The information is given in the insolation tables, Appendix B, expressed in Btu per square foot per day. Find the city nearest the location for which the calculation is being done.

Column E is the collector tilt factor. A surface inclined toward the sun receives an amount of energy in each month of the year that differs from the radiation incident on a horizontal surface. The collector tilt factor is a multiplier used to adjust the incident horizontal solar energy to obtain the amount received by a tilted collector. Appendix C gives the collector tilt factors based on collector tilt angles at various latitudes for each month of the year.[5]

To determine the proper tilt factor, determine the "% Diffuse Radiation" from the same table and location from which the "Horizontal Solar Energy" was determined. Use this "% Diffuse" figure to select the proper tilt factor table.

For example, in January, Nashville, Tennessee has a % diffuse factor of 65%. The latitude of Nashville is 36° North. If a collector tilt (angle to horizontal) of 51° (latitude + 15°) is desired, we must interpolate between both the positions of latitude and the tables for % diffuse. First interpolate for latitude on each of the two applicable % diffuse charts (60% and 80%). On the 60% chart, we interpolate between the January factor for a collector tilt of latitude + 15°, for 32° latitude (1.37) and for 40° latitude (1.60). Since the latitude of the site (36°) is midway between, the result is 1.485 (say 1.49). Similarly, for the 80% chart, the result is 1.28. Since the % diffuse for Nashville in January is 65%, an interpolation between 1.49 and 1.28 yields a tilt factor of 1.4375 (say 1.44). Therefore, 1.44 should be inserted in Column E for January.

[5]These collector tilt factors were generated by the basic procedure described in the publication, "Applications of Solar Energy for Heating and Cooling of Buildings", ASHRAE, INC., New York, N.Y., 1977. Minor modifications to this procedure were made for the purpose of this calculation.

Computation Section

(Columns F Through L)

Column F is obtained by multiplying the quantities from Columns D and E. The result is the amount of solar energy incident on a tilted surface. This is not the amount actually collected, but the total amount that reached the outer glazing of the collector.

Column G is the assumed collector inlet temperature. In reality, the inlet temperature which the collector experiences varies throughout the day, depending upon the heating load and the available solar energy. These values, which are obtained from Table 9, were developed for these calculations only, and are different for each month.

Column H is the temperature difference between the collector inlet and the ambient air. It is obtained by subtracting Column C from Column G.

Column J is obtained by dividing Column B by Column A and multiplying the result by 2 times the quantity from Column H. This yields the "critical intensity" for a specific collector in a given location operating at a specific temperature. Critical intensity is indicative of the length of the time period in each day during which the collector produces energy. It is not necessary to know the actual period of collector operation.

Column K is obtained by dividing the result from Column J by the quantity from Column F. This is a continuation of the previous step, involving the critical intensity and the period of collector operation.

Column L is obtained by using Figure 40, Collectable Energy Graph, and the quantity obtained in Column K. The result is achieved by finding the point on the K axis which corresponds to the answer from the previous step, and moving to intersect the curved line which is a turning point from which the line is continued to intersect the L axis.

COLLECTOR DESCRIPTION	A Heat Gain Factor	B Heat Loss Factor
1 Cover Plate Copper Absorber with Flat Black Surface	.78	1.35
2 Cover Plates Copper Absorber with Flat Black Surface	.72	.90
1 Cover Plate Copper Absorber Selective Surface	.76	.85
2 Cover Plates Copper Absorber Selective Surface	.70	.65

TABLE 8/COLLECTOR DESIGN SAMPLE VALUES

	Combined Space Heating and Domestic Water Heating	Domestic Water Heating Only (Add to Cold Water Supply Temperature)
January	100°	CWS + 20°
February	115°	CWS + 35°
March	140°	CWS + 60°
April	155°	CWS + 75°
May	165°	CWS + 85°
June	175°	CWS + 95°
July	180°	CWS +100°
August	180°	CWS +100°
September	175°	CWS + 95°
October	150°	CWS + 70°
November	130°	CWS + 50°
December	105°	CWS + 30°

TABLE 9/COLLECTOR INLET TEMPERATURES (COLUMN G)

Output Data

Result Column. The final result is the amount of heat collected in Btu per square foot per day. It is obtained by multiplying the values from Columns F and L. This is the energy collected on an average day in a particular month. No further adjustments are required.

Collector Sizing. Once the rate of energy output from the collector has been determined, the designer can proceed to find the collector area needed for a specific application. As previously indicated, it is normally not economically practicable to size solar systems to handle 100 percent of the heating requirements. Generally, a domestic water heating system is sized to supply 70-80 percent of annual heating requirements. In a space heating system or combined space and water heating system, sizing is aimed at using solar energy for 60-70 percent of the annual heating requirements. As a rule, the designer achieves these percentages of overall annual load when the system is sized to supply 100% of the heat required during May for water heating or during March for space heating.

To make a preliminary estimate of collector area for a domestic water heating system, the designer refers back to the month-by-month water heating requirements tabulated and plotted in Table 6 and Figure 34. The heating requirement for May (52,300 Btu) is divided by the collector output rate calculated for that month. The collector area determined will, in theory, provide 100 percent of the May heat requirement.

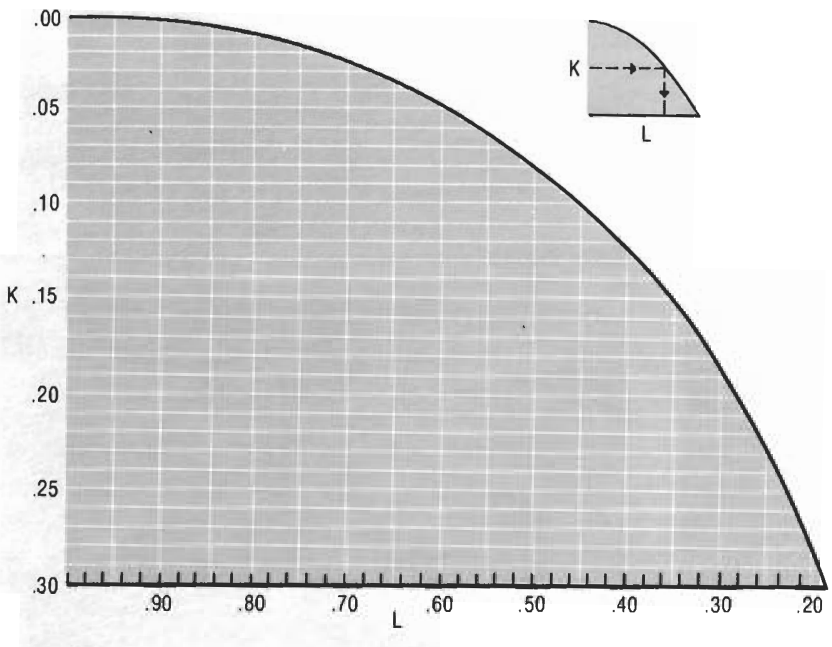


FIGURE 40/**COLLECTABLE ENERGY GRAPH** *(SEE "Column L," p. 33)*

	[1]TOTAL SPACE & DWH HEAT REQUIRED (BTU/DAY)	[2]USABLE COLLECTOR PRODUCTION FOR VARIOUS COLLECTOR AREAS (BTU/DAY)		
		500 SQ.FT.	400 SQ.FT.	350 SQ.FT.
January	390,000	181,500	145,200	127,050
February	364,200	252,500	202,000	176,750
March	275,200	272,000	217,600	190,400
April	135,870	(135,870)[3]	(135,870)	(135,870)
May	68,950	(68,950)	(68,950)	(68,950)
June	50,000	(50,000)	(50,000)	(50,000)
July	48,500	(48,500)	(48,500)	(48,500)
August	45,500	(45,500)	(45,500)	(45,500)
September	58,400	(58,400)	(58,400)	(58,400)
October	114,250	(114,250)	(114,250)	(114,250)
November	271,250	(271,250)	223,200	195,300
December	366,800	217,000	173,600	151,900
	2,188,920	1,715,720	1,483,070	1,362,870
Percent of Annual Load Supplied by Solar		78%	68%	62%

[1] Sum of Tables 6 and 7.
[2] Products of energy collected (BTU/sq. ft./day) x collector area.
[3] Numbers in parentheses are the *useful* solar energy, when the calculated production is greater than the requirement.

TABLE 10/**ANNUAL HEAT REQUIREMENTS AND CALCULATED SOLAR COLLECTOR PRODUCTION**

The collector area obtained should be considered preliminary. Next, the designer determines the percentage of the annual hot water heating requirement actually met by solar energy. For this test, the estimated collector area is multiplied, in turn, by the collector heat production figure for each of the 11 remaining months. Add the heat produced each month by the collector area selected and compare the total with the 12 months' sum of heating requirements. (For each month in which the solar collector produces more than 100 percent of the heating requirement, only that portion actually used is included in the collector production total.) The result is that fraction of the total annual hot water heating requirement met by solar energy. If the percent of the load handled by the solar array is too low or too high, adjustments are made to the collector area to bring it into the appropriate percentage range.

A graphic check is often helpful, and can be done by superimposing the values of collector production on the domestic water heating requirements curve. The juxtaposed curves provide a clear comparison of water heating requirement versus solar energy available for each month of the year. A similar curve, representing space and water heating, is shown in Figure 41.

Sample Calculation

The following example illustrates how the computation procedures are applied to a combined space and domestic hot water heating application.

Step I. List parameters of application.
Location: Nashville, Tennessee
Latitude: 36° North
Collector Type: Double Glazed with Selective Surface
Collector Tilt: 51°
Combined Space and Water Heating Heat Requirements: Shown in Table 10

Step 2. Work through the design chart to determine month-by-month solar heat output per square foot of collector surface. (Results are shown in Figure 42)

Step 3. In the completed chart (Figure 42) find the amount of heat available from the collector during March. This is 544 Btu/Sq. Ft./Day.

Step 4. Find the combined space and water heating requirement for the month of March. This is 275,200 Btu/day. (Table 10)

Step 5. Make a preliminary estimate of required collector area by dividing 544 into 275,200. The answer is about 500 square feet.

Step 6. Make a numerical check of estimated collector area by dividing the total solar heat collected (1,715,720 Btu, from Table 10) by the annual heat requirement (2,188,920 Btu, from Table 10). (In any month, only that portion of the collectable energy which can be applied to the load is considered. Therefore, for example, in May when only 68,950 Btu/day are required, only this portion of the available solar heat is applied to the load.) The estimated collector area of 500 square feet would supply 78% of the annual load, as shown in Table 10. Since this is higher than desired, an adjusted collector area of 400 square feet is tried. This yields a result of 68% of the total load supplied by solar energy. This is consistent with the recommended 60-70 percent. A third trial is made, using 350 square feet as a collector area. This area provides about 62% of the annual heating requirement. The collector area which should be selected for this job would be between 350-400 square feet.

Step 7. A graphic check of the calculated results is made (Figure 41). The shaded area is the useful solar heat produced by 350 square feet of collector area.

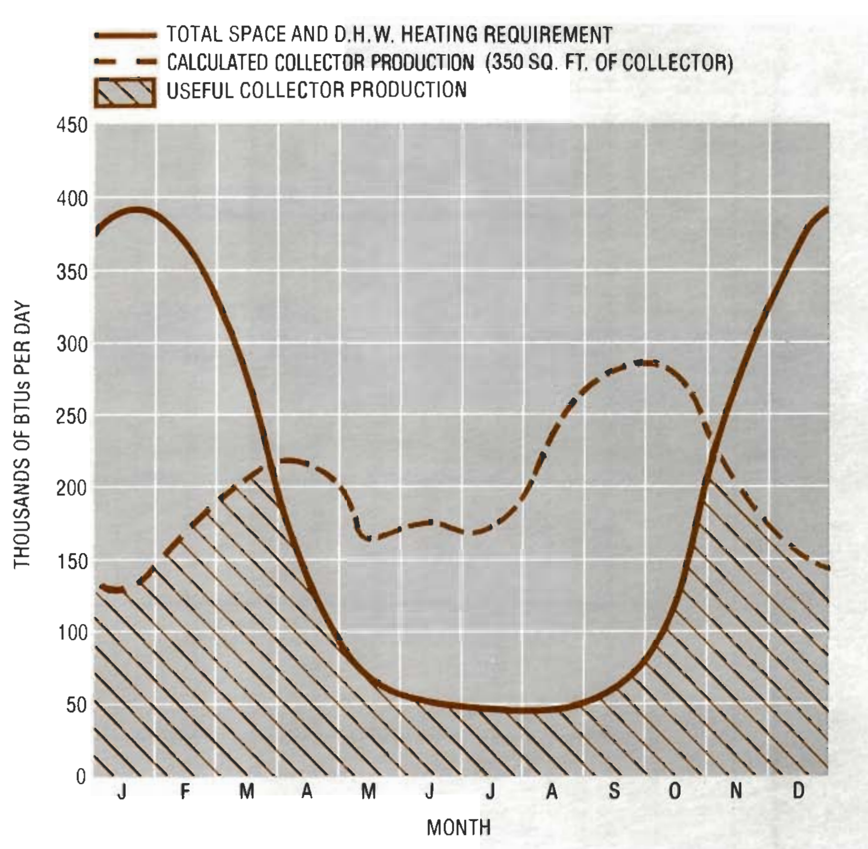


FIGURE 41/HEAT LOAD VS. SOLAR PRODUCTION GRAPH/ EXAMPLE: NASHVILLE, TENN. SPACE AND WATER HEATING

JOB: CDA Solar Home
LOCATION: Nashville, Tennessee
LATITUDE: 36° North

COLLECTOR TYPE: Double Glazed Selective Surface
COLLECTOR TILT: 51° (Latitude + 15°)
APPLICATION: Space and Water Heating

	A	B	C	D	E	F	G	H	J	K	L	RESULT
	COLLECTOR HEAT GAIN FACTOR (TABLE 8) OR MFG'S LIT.	COLLECTOR HEAT LOSS FACTOR (TABLE 8) OR MFG'S LIT.	AVERAGE DAYTIME AIR TEMPERATURE °F	HORIZONTAL SOLAR ENERGY (FROM TABLES) APPENDIX B	COLLECTOR TILT FACTOR (FROM TABLE) APPENDIX C	INCIDENT ENERGY F = D x E	COLLECTOR INLET TEMPERATURE (TABLE 9) °F	H = COLUMN G − COLUMN C °F	J = $\frac{B}{A}$x2H	K = $\frac{J}{F}$	'L' IS FOUND FROM FIGURE 40 USING 'K'	TOTAL ENERGY COLLECTED = F x L BTU SQ. FT. DAY
JANUARY	.70	.65	46	601	1.44	865	100	54	100	.12	.42	363
FEBRUARY	.70	.65	48	882	1.30	1147	115	67	124	.11	.44	505
MARCH	.70	.65	57	1188	1.09	1295	140	83	154	.12	.42	544
APRIL	.70	.65	67	1638	.88	1441	155	88	163	.11	.44	634
MAY	.70	.65	76	1911	.63	1204	165	89	165	.14	.37	445
JUNE	.70	.65	84	2081	.61	1269	175	91	169	.13	.39	495
JULY	.70	.65	87	2033	.62	1260	180	93	173	.14	.37	466
AUGUST	.70	.65	86	1845	.89	1642	180	94	175	.11	.44	722
SEPTEMBER	.70	.65	81	1561	1.10	1717	175	94	175	.10	.46	790
OCTOBER	.70	.65	69	1199	1.42	1703	150	81	150	.09	.48	817
NOVEMBER	.70	.65	55	808	1.57	1269	130	75	139	.11	.44	558
DECEMBER	.70	.65	47	605	1.63	986	105	58	108	.11	.44	434

FIGURE 42/COMPUTED COLLECTOR PRODUCTION/EXAMPLE: NASHVILLE, TENN. SPACE AND WATER HEATING

CDA SUN-CHART CALCULATION WORKSHEET

JOB:
LOCATION:
LATITUDE:

COLLECTOR TYPE:
COLLECTOR TILT:
APPLICATION:

	A	B	C	D	E	F	G	H	J	K	L	RESULT
	COLLECTOR HEAT GAIN FACTOR (TABLE 8) OR MFG'S LIT.	COLLECTOR HEAT LOSS FACTOR (TABLE 8) OR MFG'S LIT.	AVERAGE DAYTIME AIR TEMPERATURE °F	HORIZONTAL SOLAR ENERGY (FROM TABLES) APPENDIX B	COLLECTOR TILT FACTOR (FROM TABLE) APPENDIX C	INCIDENT ENERGY F = D x E	COLLECTOR INLET TEMPERATURE (TABLE 9) °F	H = $\frac{\text{COLUMN G} - \text{COLUMN C}}{\text{F}}$	J = $\frac{B}{A}$ x 2H	$K = \frac{J}{F}$	'L' IS FOUND FROM FIGURE 40 USING 'K'	TOTAL ENERGY COLLECTED = F x L BTU/SQ. FT. DAY
JANUARY												
FEBRUARY												
MARCH												
APRIL												
MAY												
JUNE												
JULY												
AUGUST												
SEPTEMBER												
OCTOBER												
NOVEMBER												
DECEMBER												

Worksheets are available upon request from Copper Development Assn. Inc.

Appendix A

TABLE 11/AVERAGE MONTHLY AND YEARLY DEGREE DAYS FOR CITIES IN THE UNITED STATES AND CANADA[a,b,c] (BASE 65°F)

HOW DEGREE DAYS ARE MEASURED:

A degree day is a standard measure used by heating engineers to measure the heating season's coldness. The number of degree days in a calendar day is determined by subtracting the day's mean temperature from 65. If the high on a given day was 60 and the low was 40 the mean temperature that day would be 50. Subtracted from 65, this would give 15 degree days for that calendar day.

UNITED STATES

State	Station	Avg. Winter Temp.°F	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	Yearly Total
Ala.	Birmingham . . . . . A	54.2	0	0	6	93	363	555	592	462	363	108	9	0	2551
	Huntsville . . . . A	51.3	0	0	12	127	426	663	694	557	434	138	19	0	3070
	Mobile . . . . A	59.9	0	0	0	22	213	357	415	300	211	42	0	0	1560
	Montgomery. . . . . A	55.4	0	0	0	68	330	527	543	417	316	90	0	0	2291
Alaska	Anchorage . . . . . . A	23.0	245	291	516	930	1284	1572	1631	1316	1293	879	592	315	10864
	Fairbanks . . . . A	6.7	171	332	642	1203	1833	2254	2359	1901	1739	1068	555	222	14279
	Juneau . . . . A	32.1	301	338	483	725	921	1135	1237	1070	1073	810	601	381	9075
	Nome . . . . A	13.1	481	496	693	1094	1455	1820	1879	1666	1770	1314	930	573	14171
Ariz.	Flagstaff . . . . A	35.6	46	68	201	558	867	1073	1169	991	911	651	437	180	7152
	Phoenix. . . . . A	58.5	0	0	0	22	234	415	474	328	217	75	0	0	1765
	Tucson. . . . . A	58.1	0	0	0	25	231	406	471	344	242	75	6	0	1800
	Winslow. . . . . A	43.0	0	0	6	245	711	1008	1054	770	601	291	96	0	4782
	Yuma . . . . A	64.2	0	0	0	0	108	264	307	190	90	15	0	0	974
Ark.	Fort Smith. . . . . . . A	50.3	0	0	12	127	450	704	781	596	456	144	22	0	3292
	Little Rock. . . . . . . A	50.5	0	0	9	127	465	716	756	577	434	126	9	0	3219
	Texarkana. . . . . . . A	54.2	0	0	0	78	345	561	626	468	350	105	0	0	2533
Calif.	Bakersfield . . . . . . A	55.4	0	0	0	37	282	502	546	364	267	105	19	0	2122
	Bishop . . . . A	46.0	0	0	48	260	576	797	874	680	555	306	143	36	4275
	Blue Canyon . . . . A	42.2	28	37	108	347	594	781	896	795	806	597	412	195	5596
	Burbank . . . . A	58.6	0	0	6	43	177	301	366	277	239	138	81	18	1646
	Eureka. C	49.9	270	257	258	329	414	499	546	470	505	438	372	285	4643
	Fresno . . . . A	53.3	0	0	0	84	354	577	605	426	335	162	62	6	2611
	Long Beach . . . . . A	57.8	0	0	9	47	171	316	397	311	264	171	93	24	1803
	Los Angeles . . . . . A	57.4	28	28	42	78	180	291	372	302	288	219	158	81	2061
	Los Angeles C	60.3	0	0	6	31	132	229	310	230	202	123	68	18	1349
	Mt. Shasta C	41.2	25	34	123	406	696	902	983	784	738	525	347	159	5722
	Oakland . . . . A	53.5	53	50	45	127	309	481	527	400	353	255	180	90	2870
	Red Bluff . . . . A	53.8	0	0	0	53	318	555	605	428	341	168	47	0	2515
	Sacramento . . . . . A	53.9	0	0	0	56	321	546	583	414	332	178	72	0	2502
	Sacramento C	54.4	0	0	0	62	312	533	561	392	310	173	76	0	2419
	Sandberg C	46.8	0	0	30	202	480	691	778	661	620	426	264	57	4209
	San Diego. . . . . . . A	59.5	9	0	21	43	135	236	298	235	214	135	90	42	1458
	San Francisco . . . A	53.4	81	78	60	143	306	462	508	395	363	279	214	126	3015
	San Francisco . . . C	55.1	192	174	102	118	231	388	443	336	319	279	239	180	3001
	Santa Maria . . . . . A	54.3	99	93	96	146	270	391	459	370	363	282	233	165	2967
Colo.	Alamosa . . . . A	29.7	65	99	279	639	1065	1420	1476	1162	1020	696	440	168	8529
	Colorado Springs A	37.3	9	25	132	456	825	1032	1128	938	893	582	319	84	6423
	Denver. . . . . A	37.6	6	9	117	428	819	1035	1132	938	887	558	288	66	6283
	Denver. C	40.8	0	0	90	366	714	905	1004	851	800	492	254	48	5524
	Grand Junction . . A	39.3	0	0	30	313	786	1113	1209	907	729	387	146	21	5641
	Pueblo . . . . A	40.4	0	0	54	326	750	986	1085	871	772	429	174	15	5462
Conn.	Bridgeport. . . . . . . A	39.9	0	0	66	307	615	986	1079	966	853	510	208	27	5617
	Hartford . . . . A	37.3	0	12	117	394	714	1101	1190	1042	908	519	205	33	6235
	New Haven. . . . . . A	39.0	0	12	87	347	648	1011	1097	991	871	543	245	45	5897
Del.	Wilmington . . . . . . A	42.5	0	0	51	270	588	927	980	874	735	387	112	6	4930
D.C.	Washington . . . . . A	45.7	0	0	33	217	519	834	871	762	626	288	74	0	4224
Fla.	Apalachicola C	61.2	0	0	0	16	153	319	347	260	180	33	0	0	1308
	Daytona Beach . . A	64.5	0	0	0	0	75	211	248	100	140	15	0	0	879
	Fort Myers. . . . . . . A	68.6	0	0	0	0	24	109	146	101	62	0	0	0	442
	Jacksonville . . . . . A	61.9	0	0	0	12	144	310	332	246	174	21	0	0	1239
	Key West. . . . . A	73.1	0	0	0	0	0	28	40	31	9	0	0	0	108
	Lakeland C	66.7	0	0	0	0	57	164	195	146	99	0	0	0	661
	Miami. . . . . A	71.1	0	0	0	0	0	65	74	56	19	0	0	0	214
	Miami Beach C	72.5	0	0	0	0	0	40	56	36	9	0	0	0	141
	Orlando . . . . A	65.7	0	0	0	0	72	198	220	165	105	6	0	0	766
	Pensacola. . . . . . . A	60.4	0	0	0	19	195	353	400	277	183	36	0	0	1463
	Tallahassee . . . . . A	60.1	0	0	0	28	198	360	375	286	202	36	0	0	1485
	Tampa . . . . A	66.4	0	0	0	0	60	171	202	148	102	0	0	0	683
	West Palm Beach A	68.4	0	0	0	0	6	65	87	64	31	0	0	0	253

Reprinted from *ASHRAE 1973* Systems Handbook, Chapter 43, "Energy Estimating Method."

a Data for United States cities from a publication of the United States Weather Bureau, *Monthly Normals of Temperature, Precipitation and Heating Degree Days* 1962, are for the period 1931 to 1960 inclusive. These data also include information from the 1963 Revisions to this publication, where available.

b Data for airport stations, A, and city stations, C, are both given where available.

c Data for Canadian cities where computed by the Climatology Division, Department of Transport from normal monthly mean temperatures, and the monthly values of heating degree days data were obtained using the National Research Council computer and a method devised by H.C.S. Thorn of the United States Weather Bureau. The heating degree days are based on the period from 1931 to 1960.

Appendix A, AVERAGE MONTHLY AND YEARLY DEGREE DAYS, CONTINUED

State	Station	Avg. Winter Temp. °F	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	Yearly Total
Ga.	Athens..........A	51.8	0	0	12	115	405	632	642	529	431	141	22	0	2929
	Atlanta..........A	51.7	0	0	18	124	417	648	636	518	428	147	25	0	2961
	Augusta..........A	54.5	0	0	0	78	333	552	549	445	350	90	0	0	2397
	Columbus.......A	54.8	0	0	0	87	333	543	552	434	338	96	0	0	2383
	Macon..........A	56.2	0	0	0	71	297	502	505	403	295	63	0	0	2136
	Rome...........A	49.9	0	0	24	161	474	701	710	577	468	177	34	0	3326
	Savannah.......A	57.8	0	0	0	47	246	437	437	353	254	45	0	0	1819
	Thomasville.....C	60.0	0	0	0	25	198	366	394	305	208	33	0	0	1529
Hawaii	Libue...........A	72.7	0	0	0	0	0	0	0	0	0	0	0	0	0
	Honolulu........A	74.2	0	0	0	0	0	0	0	0	0	0	0	0	0
	Hilo.............A	71.9	0	0	0	0	0	0	0	0	0	0	0	0	0
Idaho	Boise...........A	39.7	0	0	132	415	792	1017	1113	854	722	438	245	81	5809
	Lewiston........A	41.0	0	0	123	403	756	933	1063	815	694	426	239	90	5542
	Pocatello........A	34.8	0	0	172	493	900	1166	1324	1058	905	555	319	141	7033
Ill.	Cairo...........C	47.9	0	0	36	164	513	791	856	680	539	195	47	0	3821
	Chicago(O'Hare) A	35.8	0	12	117	381	807	1166	1265	1086	939	534	260	72	6639
	Chicago(Midway) A	37.5	0	0	81	326	753	1113	1209	1044	890	480	211	48	6155
	Chicago.........C	38.9	0	0	66	279	705	1051	1150	1000	868	489	226	48	5882
	Moline..........A	36.4	0	9	99	335	774	1181	1314	1100	918	450	189	39	6408
	Peoria..........A	38.1	0	6	87	326	759	1113	1218	1025	849	426	183	33	6025
	Rockford........A	34.8	6	9	114	400	837	1221	1333	1137	961	516	236	60	6830
	Springfield......A	40.6	0	0	72	291	696	1023	1135	935	769	354	136	18	5429
Ind.	Evansville.......A	45.0	0	0	66	220	606	896	955	767	620	237	68	0	4435
	Fort Wayne......A	37.3	0	9	105	378	783	1135	1178	1028	890	471	189	39	6205
	Indianapolis.....A	39.6	0	0	90	316	723	1051	1113	949	809	432	177	39	5699
	South Bend.....A	36.6	0	6	111	372	777	1125	1221	1070	933	525	239	60	6439
Iowa	Burlington.......A	37.6	0	0	93	322	768	1135	1259	1042	859	426	177	33	6114
	Des Moines.....A	35.5	0	6	96	363	828	1225	1370	1137	915	438	180	30	6588
	Dubuque........A	32.7	12	31	156	450	906	1287	1420	1204	1026	546	260	78	7376
	Sioux City.......A	34.0	0	9	108	369	867	1240	1435	1198	989	483	214	39	6951
	Waterloo........A	32.6	12	19	138	428	909	1296	1460	1221	1023	531	229	54	7320
Kans.	Concordia.......A	40.4	0	0	57	276	705	1023	1163	935	781	372	149	18	5479
	Dodge City......A	42.5	0	0	33	251	666	939	1051	840	719	354	124	9	4986
	Goodland.......A	37.8	0	6	81	381	810	1073	1166	955	884	507	236	42	6141
	Topeka..........A	41.7	0	0	57	270	672	980	1122	893	722	330	124	12	5182
	Wichita.........A	44.2	0	0	33	229	618	905	1023	804	645	270	87	6	4620
Ky.	Covington.......A	41.4	0	0	75	291	669	983	1035	893	756	390	149	24	5265
	Lexington.......A	43.8	0	0	54	239	609	902	946	818	685	325	105	0	4683
	Louisville........A	44.0	0	0	54	248	609	890	930	818	682	315	105	9	4660
La.	Alexandria......A	57.5	0	0	0	56	273	431	471	361	260	69	0	0	1921
	Baton Rouge....A	59.8	0	0	0	31	216	369	409	294	208	33	0	0	1560
	Lake Charles....A	60.5	0	0	0	19	210	341	381	274	195	39	0	0	1459
	New Orleans....A	61.0	0	0	0	19	192	322	363	258	192	39	0	0	1385
	New Orleans....C	61.8	0	0	0	12	165	291	344	241	177	24	0	0	1254
	Shreveport......A	56.2	0	0	0	47	297	477	552	426	304	81	0	0	2184
Me.	Caribou.........A	24.4	78	115	336	682	1044	1535	1690	1470	1308	858	468	183	9767
	Portland.........A	33.0	12	53	195	508	807	1215	1339	1182	1042	675	372	111	7511
Md.	Baltimore.......A	43.7	0	0	48	264	585	905	936	820	679	327	90	0	4654
	Baltimore.......C	46.2	0	0	27	189	486	806	859	762	629	288	65	0	4111
	Frederich.......A	42.0	0	0	66	307	624	955	995	876	741	384	127	12	5087
Mass.	Boston..........A	40.0	0	9	60	316	603	983	1088	972	846	513	208	36	5634
	Nantucket.......A	40.2	12	22	93	332	573	896	992	941	896	621	384	129	5891
	Pittsfield........A	32.6	25	59	219	524	831	1231	1339	1196	1063	660	326	105	7578
	Worcester.......A	34.7	6	34	147	450	774	1172	1271	1123	998	612	304	78	6969
Mich.	Alpena..........A	29.7	68	105	273	580	912	1268	1404	1299	1218	777	446	156	8506
	Detroit (City).....A	37.2	0	0	87	360	738	1088	1181	1058	936	522	220	42	6232
	Detroit (Wayne)..A	37.1	0	0	96	353	738	1088	1194	1061	933	534	239	57	6293
	Detroit (Willow Run)............A	37.2	0	0	90	357	750	1104	1190	1053	921	519	229	45	6258
	Escanaba.......C	29.6	59	87	243	539	924	1293	1445	1296	1203	777	456	159	8481
	Flint............A	33.1	16	40	159	465	843	1212	1330	1198	1066	639	319	90	7377
	Grand Rapids...A	34.9	9	28	135	434	804	1147	1259	1134	1011	579	279	75	6894
	Lansing.........A	34.8	6	22	138	431	813	1163	1262	1142	1011	579	273	69	6909
	Marquette.......C	30.2	59	81	240	527	936	1268	1411	1268	1187	771	468	177	8393
	Muskegon.......A	36.0	12	28	120	400	762	1088	1209	1100	995	594	310	78	6696
	Sault Ste. Marie..A	27.7	96	105	279	580	951	1367	1525	1380	1277	810	477	201	9048
Minn.	Duluth..........A	23.4	71	109	330	632	1131	1581	1745	1518	1355	840	490	198	10000
	Minneapolis.....A	28.3	22	31	189	505	1014	1454	1631	1380	1166	621	288	81	8382
	Rochester.......A	28.8	25	34	186	474	1005	1438	1593	1366	1150	630	301	93	8295
Miss.	Jackson.........A	55.7	0	0	0	65	315	502	546	414	310	87	0	0	2239
	Meridian........A	55.4	0	0	0	81	339	518	543	417	310	81	0	0	2289
	Vicksburg.......C	56.9	0	0	0	53	279	462	512	384	282	69	0	0	2041
Mo.	Columbia.......A	42.3	0	0	54	251	651	967	1076	874	716	324	121	12	5046
	Kansas City.....A	43.9	0	0	39	220	612	905	1032	818	682	294	109	0	4711
	St. Joseph.......A	40.3	0	6	60	285	708	1039	1172	949	769	348	133	15	5484
	St. Louis........A	43.1	0	0	60	251	627	936	1026	848	704	312	121	15	4900

State	Station		July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	Yearly Total
	St. Louis C	44.8	0	0	36	202	576	884	977	801	651	270	87	0	4484
	Springfield ......A	44.5	0	0	45	223	600	877	973	781	660	291	105	6	4900
Mont.	Billings..........A	34.5	6	15	186	487	897	1135	1296	1100	970	570	285	102	7049
	Glasgow ....A	26.4	31	47	270	608	1104	1466	1711	1439	1187	648	335	150	8996
	Great Falls ......A	32.8	28	53	258	543	921	1169	1349	1154	1063	642	384	186	7750
	Havre...........A	28.1	28	53	306	595	1065	1367	1584	1364	1181	657	338	162	8700
	Havre...........C	29.8	19	37	252	539	1014	1321	1528	1305	1116	612	304	135	8182
	Helena..........A	31.1	31	59	294	601	1002	1265	1438	1170	1042	651	381	195	8129
	Kalispell ....A	31.4	50	99	321	654	1020	1240	1401	1134	1029	639	397	207	8191
	Miles City ....A	31.2	6	6	174	502	972	1296	1504	1252	1057	579	276	99	7723
	Missoula ....A	31.5	34	74	303	651	1035	1287	1420	1120	970	621	391	219	8125
Neb.	Grand Island ....A	36.0	0	6	108	381	834	1172	1314	1089	908	462	211	45	6530
	Lincoln..........C	38.8	0	6	75	301	726	1066	1237	1016	834	402	171	30	5864
	Norfolk..........A	34.0	9	0	111	397	873	1234	1414	1179	983	498	233	48	6979
	North Platte .....A	35.5	0	6	123	440	885	1166	1271	1039	930	519	248	57	6684
	Omaha ....A	35.6	0	12	105	357	828	1175	1355	1126	939	465	208	42	6612
	Scottsbluff.......A	35.9	0	0	138	459	876	1128	1231	1008	921	552	285	75	6673
	Valentine........A	32.6	9	12	165	493	942	1237	1395	1176	1045	579	288	84	7425
Nev.	Elko ....A	34.0	9	34	225	561	924	1197	1314	1036	911	621	409	192	7433
	Ely..............A	33.1	28	43	234	592	939	1184	1308	1075	977	672	456	225	7733
	Las Vegas.......A	53.5	0	0	0	78	387	617	688	487	335	111	6	0	2709
	Reno ....A	39.3	43	87	204	490	801	1026	1073	823	729	510	357	189	6332
	Winnemucca ....A	36.7	0	34	210	536	876	1091	1172	916	837	573	363	153	6761
N.H.	Concord ....A	33.0	6	50	177	505	822	1240	1358	1184	1032	636	298	75	7383
	Mt. Washington Obsv............ -	15.2	493	536	720	1057	1341	1742	1820	1663	1652	1260	930	603	13817
N.J.	Atlantic City .....A	43.2	0	0	39	251	549	880	936	848	741	420	133	15	4812
	Newark ....A	42.8	0	0	30	248	573	921	983	876	729	381	118	0	4589
	Trenton C	42.4	0	0	57	264	576	924	989	885	753	399	121	12	4980
N.M.	Albuquerque ....A	45.0	0	0	12	229	642	868	930	703	595	288	81	0	4348
	Clayton ....A	42.0	0	6	66	310	699	899	986	812	747	429	183	21	5158
	Raton...........A	38.1	9	28	126	431	825	1048	1116	904	834	543	301	63	6228
	Roswell ....A	47.5	0	0	18	202	573	806	840	641	481	201	31	0	3793
	Silver City ....A	48.0	0	0	6	183	525	729	791	605	518	261	87	0	3705
N.Y.	Albany ....A	34.6	0	19	138	440	777	1194	1311	1156	992	564	239	45	6875
	Albany C	37.2	0	9	102	375	699	1104	1218	1072	908	498	186	30	6201
	Binghamton .....A	33.9	22	65	201	471	810	1184	1277	1154	1045	645	313	99	7286
	Binghamton C	36.6	0	28	141	406	732	1107	1190	1081	949	543	229	45	6451
	Buffalo..........A	34.5	19	37	141	440	777	1156	1256	1145	1039	645	329	78	7062
	New York (Cent. Park)	42.8	0	0	30	233	540	902	986	885	760	408	118	9	4871
	New York (La Guardia) ....A	43.1	0	0	27	223	528	887	973	879	750	414	124	6	4811
	New York (Kennnedy) .....A	41.4	0	0	36	248	564	933	1029	935	815	480	167	12	5219
	Rochester.......A	35.4	9	31	126	415	747	1125	1234	1123	1014	597	279	48	6748
	Schenectady C	35.4	0	22	123	422	756	1159	1283	1131	970	543	211	30	6650
	Syracuse........A	35.2	6	28	132	415	744	1153	1271	1140	1004	570	248	45	6756
N.C.	Asheville........C	46.7	0	0	48	245	555	775	784	683	592	273	87	0	4042
	Cape Hatteras....	53.3	0	0	0	78	273	521	580	518	440	177	25	0	2612
	Charlotte........A	50.4	0	0	6	124	438	691	691	582	481	156	22	0	3191
	Greensboro .....A	47.5	0	0	33	192	513	778	784	672	552	234	47	0	3805
	Raleigh ....A	49.4	0	0	21	164	450	716	725	616	487	180	34	0	3393
	Wilmington ......A	54.6	0	0	0	74	291	521	546	462	357	96	0	0	2347
	Winston-Salem ..A	48.4	0	0	21	171	483	747	753	652	524	207	37	0	3595
N.D.	Bismarck........A	26.6	34	28	222	577	1083	1463	1708	1442	1203	645	329	117	8851
	Devils Lake......C	22.4	40	53	273	642	1191	1634	1872	1579	1345	753	381	138	9901
	Fargo ....A	24.8	28	37	219	574	1107	1569	1789	1520	1262	690	332	99	9226
	Williston.........A	25.2	31	43	261	601	1122	1513	1758	1473	1262	681	357	141	9243
Ohio	Akron-Canton ...A	38.1	0	9	96	381	726	1070	1138	1016	871	489	202	39	6037
	Cincinnati C	45.1	0	0	39	208	558	862	915	790	642	294	96	6	4410
	Cleveland ....A	37.2	9	25	105	384	738	1088	1159	1047	918	552	260	66	6351
	Columbus ....A	39.7	0	6	84	347	714	1039	1088	949	809	426	171	27	5660
	Columbus C	41.5	0	0	57	285	651	977	1032	902	760	396	136	15	5211
	Dayton..........A	39.8	0	6	78	310	696	1045	1097	955	809	429	167	30	5622
	Mansfield ....A	36.9	9	22	114	397	768	1110	1169	1042	924	543	245	60	6403
	Sandusky C	39.1	0	6	66	313	684	1032	1107	991	868	495	198	36	5796
	Toledo ....A	36.4	0	16	117	406	792	1138	1200	1056	924	543	242	60	6494
	Youngstown .....A	36.8	6	19	120	412	771	1104	1169	1047	921	540	248	60	6417
Okla.	Oklahoma City...A	48.3	0	0	15	164	498	766	868	664	527	189	34	0	3725
	Tulsa ....A	47.7	0	0	18	158	522	787	893	683	539	213	47	0	3860
Ore.	Astoria..........A	45.6	146	130	210	375	561	679	753	622	636	480	363	231	5186
	Burns...........C	35.9	12	37	210	515	867	1113	1246	988	856	570	366	177	6957
	Eugene ....A	45.6	34	34	129	366	585	719	803	627	589	426	279	135	4726
	Mescham ....A	34.2	84	124	288	580	918	1091	1209	1005	983	726	527	339	7874
	Medford.........A	43.2	0	0	78	372	678	871	918	697	642	432	242	78	5008
	Pendleton ....A	42.6	0	0	111	350	711	884	1017	773	617	396	205	63	5127
	Portland.........A	45.6	25	28	114	335	597	735	825	644	586	396	245	105	4635
	Portland.........C	47.4	12	16	75	267	534	679	769	594	536	351	198	78	4109

Appendix A, AVERAGE MONTHLY AND YEARLY DEGREE DAYS, CONTINUED

State	Station	Avg. Winter Temp.°F	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	Yearly Total
	Roseburg .... A	46.3	22	16	105	329	567	713	766	608	570	405	267	123	4491
	Salem .... A	45.4	37	31	111	338	594	729	822	647	611	417	273	144	4754
Pa.	Allentown .... A	38.9	0	0	90	353	693	1045	1116	1002	849	471	167	24	5810
	Erie .... A	36.8	0	25	102	391	714	1063	1169	1081	973	585	288	60	6451
	Harrisburg ...... A	41.2	0	0	63	298	648	992	1045	907	766	396	124	12	5251
	Philadelphia..... A	41.8	0	0	60	297	620	965	1016	889	747	392	118	40	5144
	Philadelphia..... C	44.5	0	0	30	205	513	856	924	823	691	351	93	0	4486
	Pittsburgh .... A	38.4	0	9	105	375	726	1063	1119	1002	874	480	195	39	5987
	Pittsburgh C	42.2	0	0	60	291	615	930	983	885	763	390	124	12	5053
	Reading C	42.4	0	0	54	257	597	939	1001	885	735	372	105	0	4945
	Scranton .... A	37.2	0	19	132	434	762	1104	1156	1028	893	498	195	33	6254
	Williamsport ..... A	38.5	0	9	111	375	717	1073	1122	1002	856	468	177	24	5934
R.I.	Block Island ..... A	40.1	0	16	78	307	594	902	1020	955	877	612	344	99	5804
	Providence...... A	38.8	0	16	96	372	660	1023	1110	988	868	534	236	51	5954
S.C.	Charleston ...... A	56.4	0	0	0	59	282	471	487	389	291	54	0	0	2033
	Charleston C	57.9	0	0	0	34	210	425	443	367	273	42	0	0	1794
	Columbia .... A	54.0	0	0	0	84	345	577	570	470	357	81	0	0	2484
	Florence .... A	54.5	0	0	0	78	315	552	552	459	347	84	0	0	2387
	Greenville-Spartenburg..... A	51.6	0	0	6	121	399	651	660	546	446	132	19	0	2980
S.D.	Huron........... A	28.8	9	12	165	508	1014	1432	1628	1355	1125	600	288	87	8223
	Rapid City .... A	33.4	22	12	165	481	897	1172	1333	1145	1051	615	326	126	7345
	Sioux Falls ...... A	30.6	19	25	168	462	972	1361	1544	1285	1082	573	270	78	7839
Tenn.	Bristol........... A	46.2	0	0	51	236	573	828	828	700	598	261	68	0	4143
	Chattanooga .... A	50.3	0	0	18	143	468	698	722	577	453	150	25	0	3254
	Knoxville .... A	49.2	0	0	30	171	489	725	732	613	493	198	43	0	3494
	Memphis .... A	50.5	0	0	18	130	447	698	729	585	456	147	22	0	3232
	Memphis C	51.6	0	0	12	102	396	648	710	568	434	129	16	0	3015
	Nashville .... A	48.9	0	0	30	158	495	732	778	644	512	189	40	0	3578
	Oak Ridge....... C	47.7	0	0	39	192	531	772	778	669	552	228	56	0	3817
Tex.	Abilene .... A	53.9	0	0	0	99	366	586	642	470	347	114	0	0	2624
	Amarillo......... A	47.0	0	0	18	205	570	797	877	664	546	252	56	0	3985
	Austin........... A	59.1	0	0	0	31	225	388	468	325	223	51	0	0	1711
	Brownsville...... A	67.7	0	0	0	0	66	149	205	106	74	0	0	0	600
	Corpus Christi ... A	64.6	0	0	0	0	120	220	291	174	109	0	0	0	914
	Dallas........... A	55.3	0	0	0	62	321	524	601	440	319	90	6	0	2363
	El Paso .... A	52.9	0	0	0	84	414	648	685	445	319	105	0	0	2700
	Fort Worth .... A	55.1	0	0	0	65	324	536	614	448	319	99	0	0	2405
	Galveston .... A	62.2	0	0	0	6	147	276	360	263	189	33	0	0	1274
	Galveston C	62.0	0	0	0	0	138	270	350	258	189	30	0	0	1235
	Houston......... A	61.0	0	0	0	6	183	307	384	288	192	36	0	0	1396
	Houston......... C	62.0	0	0	0	0	165	288	363	258	174	30	0	0	1278
	Laredo.......... A	66.0	0	0	0	0	105	217	267	134	74	0	0	0	797
	Lubbock .... A	48.8	0	0	18	174	513	744	800	613	484	201	31	0	3578
	Midland .... A	53.8	0	0	0	87	381	592	651	468	322	90	0	0	2591
	Port Arthur ...... A	60.5	0	0	0	22	207	329	384	274	192	39	0	0	1447
	San Angelo...... A	56.0	0	0	0	68	318	536	567	412	288	66	0	0	2255
	San Antonio ..... A	60.1	0	0	0	31	204	363	428	286	195	39	0	0	1546
	Victoria .... A	62.7	0	0	0	6	150	270	344	230	152	21	0	0	1173
	Waco .... A	57.2	0	0	0	43	270	456	536	389	270	66	0	0	2030
	Wichita Falls..... A	53.0	0	0	0	99	381	632	698	518	378	120	6	0	2832
Utah	Milford .... A	36.5	0	0	99	443	867	1141	1252	988	822	519	279	87	6497
	Salt Lake City.... A	38.4	0	0	81	419	849	1082	1172	910	763	459	233	84	6052
	Wendover....... A	39.1	0	0	48	372	822	1091	1178	902	729	408	177	51	5778
Vt.	Burlington....... A	29.4	28	65	207	539	891	1349	1513	1333	1187	714	353	90	8269
Va.	Cape Henry C	50.0	0	0	0	112	360	645	694	633	536	246	53	0	3279
	Lynchburg....... A	46.0	0	0	51	223	540	822	849	731	605	267	78	0	4166
	Norfolk.......... A	49.2	0	0	0	136	408	698	738	655	533	216	37	0	3421
	Richmond .... A	47.3	0	0	36	214	495	784	815	703	546	219	53	0	3865
	Roanoke .... A	46.1	0	0	51	229	549	825	834	722	614	261	65	0	4150
Wash.	Olympia......... A	44.2	68	71	198	422	636	753	834	675	645	450	307	177	5236
	Seattle-Tacoma.. A	44.2	56	62	162	391	633	750	828	678	657	474	295	159	5145
	Seattle.......... C	46.9	50	47	129	329	543	657	738	599	577	396	242	117	4424
	Spokane .... A	36.5	9	25	168	493	879	1082	1231	980	834	531	288	135	6655
	Walla Walla...... C	43.8	0	0	87	310	681	843	986	745	589	342	177	45	4805
	Yakima.......... A	39.1	0	12	144	450	828	1039	1163	868	713	435	220	69	5941
W. Va.	Charleston ...... A	44.8	0	0	63	254	591	865	880	770	648	300	96	9	4476
	Elkins........... A	40.1	9	25	135	400	729	992	1008	896	791	444	198	48	5675
	Huntington ...... A	45.0	0	0	63	257	585	856	880	764	636	294	99	12	4446
	Parkersburg..... C	43.5	0	0	60	264	606	905	942	826	691	339	115	6	4754
Wisc.	Green Bay ...... A	30.3	28	50	174	484	924	1333	1494	1313	1141	654	335	99	8029
	La Crosse....... A	31.5	12	19	153	437	924	1339	1504	1277	1070	540	245	69	7589
	Madison .... A	30.9	25	40	174	474	930	1330	1473	1274	1113	618	310	102	7863
	Milwaukee ...... A	32.6	43	47	174	471	876	1252	1376	1193	1054	642	372	135	7635
Wyo.	Casper.......... A	33.4	6	16	192	524	942	1169	1290	1084	1020	657	381	129	7410
	Cheyenne....... A	34.2	28	37	219	543	909	1085	1212	1042	1026	702	428	150	7381
	Lander.......... A	31.4	6	19	204	555	1020	1299	1417	1145	1017	654	381	153	7870
	Sheridan........ A	32.5	25	31	219	539	948	1200	1355	1154	1051	642	366	150	7680

CANADA

Prov.	Station	Avg. Winter Temp.	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	Yearly Total
Alta.	Banff C	NOT AVAILABLE	220	295	498	797	1185	1485	1624	1364	1237	855	589	402	10551
	Calgary .... A		109	186	402	719	1110	1389	1575	1379	1268	798	477	291	9703
	Edmonton....... A		74	180	411	738	1215	1603	1810	1520	1330	765	400	222	10268
	Lethbridge ...... A		56	112	318	611	1011	1277	1497	1291	1159	696	403	213	8644
B.C.	Kamloops....... A		22	40	189	546	894	1138	1314	1057	818	462	217	102	6799
	Prince George*.. A		236	251	444	747	1110	1420	1612	1319	1122	747	468	279	9755
	Prince Rupert.... C		273	248	339	539	708	868	936	808	812	648	493	357	7029
	Vancouver*...... A		81	87	219	456	657	787	862	723	676	501	310	156	5515
	Victoria*......... A		136	140	225	462	663	775	840	718	691	504	341	204	5699
	Victoria C		172	184	243	426	607	723	805	668	660	487	354	250	5579
Man.	Brandon*........ A		47	90	357	747	1290	1792	2034	1737	1476	837	431	198	11036
	Churchill .... A		360	375	681	1082	1620	2248	2558	2277	2130	1569	1153	675	16728
	The Pas......... C		59	127	429	831	1440	1981	2232	1853	1624	969	508	228	12281
	Winnipeg........ A		38	71	322	683	1251	1757	2008	1719	1465	813	405	147	10679
N.B.	Fredericton*..... A		78	68	234	592	915	1392	1541	1379	1172	753	406	141	8671
	Moncton C		62	105	276	611	891	1342	1482	1336	1194	789	468	171	8727
	St. John......... C		109	102	246	527	807	1194	1370	1229	1097	756	490	249	8219
Nod.	Argentia .... A		260	167	294	564	750	1001	1159	1085	1091	879	707	483	8440
	Corner Brook.... C		102	133	324	642	873	1194	1358	1283	1212	885	639	333	8978
	Gander .... A		121	152	330	670	909	1231	1370	1266	1243	939	657	366	9254
	Goose*.......... A		130	205	444	843	1227	1745	1947	1689	1494	1074	741	348	11887
	St. John's*....... A		186	180	342	651	831	1113	1262	1170	1187	927	710	432	8991
N.W.T.	Aklavik.......... C		273	459	807	1414	2064	2530	2632	2336	2282	1674	1063	483	18017
	Fort Norman..... C		164	341	666	1234	1959	2474	2592	2209	2058	1386	732	294	16109
	Resolution Island C		843	831	900	1113	1311	1724	2021	1850	1817	1488	1181	942	16021
N.S.	Halifax.......... C		58	51	180	457	710	1074	1213	1122	1030	742	487	237	7361
	Sydney .... A		62	71	219	518	765	1113	1262	1206	1150	840	567	276	8049
	Yarmouth .... A		102	115	225	471	696	1029	1156	1065	1004	726	493	258	7340
Ont.	Cochrane C		96	180	405	760	1233	1776	1978	1701	1528	963	570	222	11412
	Fort William ..... A		90	133	366	694	1140	1597	1792	1557	1380	876	543	237	10405
	Kapuskasing C		74	171	405	756	1245	1807	2037	1735	1562	978	580	222	11572
	Kitchener C		16	59	177	505	855	1234	1342	1226	1101	663	322	66	7566
	London .... A		12	43	159	477	837	1206	1305	1198	1066	648	332	66	7349
	North Bay C		37	90	267	608	990	1507	1680	1463	1277	780	400	120	9219
	Ottawa.......... C		25	81	222	567	936	1469	1624	1441	1231	708	341	90	8735
	Toronto C		7	18	151	439	760	1111	1233	1119	1013	616	298	62	6827
P.E.I.	Charlottetown ... C		40	53	198	518	804	1215	1380	1274	1169	813	496	204	8164
	Summerside C		47	84	216	546	840	1246	1438	1291	1206	841	518	216	8488
Que.	Arvida C		102	136	327	682	1074	1659	1879	1619	1407	891	521	231	10528
	Montreal*....... A		9	43	165	521	882	1392	1566	1381	1175	684	316	69	8203
	Montreal C		16	28	165	496	864	1355	1510	1328	1138	657	288	54	7899
	Quebec*......... A		56	84	273	636	996	1516	1665	1477	1296	819	428	126	9372
	Quebec C		40	68	243	592	972	1473	1612	1418	1228	780	400	111	8937
Sasks.	Prince Albert .... A		81	136	414	797	1368	1872	2108	1763	1559	867	446	219	11630
	Regina.......... A		78	93	360	741	1284	1711	1965	1687	1473	804	409	201	10806
	Saskatoon C		56	87	372	750	1302	1758	2006	1689	1463	798	403	186	10870
Y.T.	Dawson......... C		164	326	645	1197	1875	2415	2561	2150	1838	1068	570	258	15067
	Mayo Landing ... C		208	366	648	1135	1794	2325	2427	1992	1665	1020	580	294	14454

*The data for these normals were from the full ten-year period 1951-1960 adjusted to the standard normal period 1931-1960.

Appendix B | INSOLATION MAP


48°
40°
32°
Caribou
MAINE
NEW HAMPSHIRE
VERMONT
Burlington
Massena
Portland
NEW YORK
Concord
Lynn
Natick
Boston
MASSACHUSETTS
Schenectady
Syracuse
Albany
Amherst
Blue Hill
Providence
Newport
RHODE ISLAND
CONNECTICUT
Hartford
Rochester
Buffalo
Ithaca
Binghamton
New York
Avoca
Newark
PENNSYLVANIA
Erie
State College
Allentown
Trenton
Lakehurst
NEW JERSEY
Harrisburg
Philadelphia
Atlantic City
Wilmington
Youngstown
Pittsburgh
Baltimore
Annapolis
DELAWARE
DC
Silver Hill
Washington
MARYLAND
Mt. Weather
Internat'l Falls
Duluth
Sault Ste. Marie
MINNESOTA
St. Cloud
WISCONSIN
St. Paul
Eau Claire
Traverse City
Green Bay
MICHIGAN
Rochester
La Crosse
Grand Rapids
East Lansing
Flint
Milwaukee
Lansing
Detroit
Madison
Sioux City
Mason City
IOWA
Put-in-Bay
Chicago
South Bend
Toledo
Cleveland
Akron
Ames
Lemont
Indanapolis
Des Moines
Moline
Peoria
OHIO
INDIANA
ILLINOIS
Columbus
Dayton
Parkersburg
Fort Wayne
WEST VIRGINIA
Springfield
Covington
Charleston
Richmond
Kansas City
VIRGINIA
Topeka
Columbia
St. Louis
Evansville
Lexington
Louisville
Norfolk
Roanoke
MISSOURI
KENTUCKY
Raleigh-Durham
Springfield
Raleigh
Cape Hatteras
Greensboro
Oak Ridge
NORTH CAROLINA
Asheville
Charlotte
Cherry Point
Tulsa
Nashville
TENNESSEE
Chattanooga
Grnvle.-Sptnbrg
Fort Smith
Memphis
Columbia
Little Rock
SOUTH CAROLINA
ARKANSAS
Atlanta
Birmingham
Augusta
Griffin
Charleston
MISSISSIPPI
ALABAMA
Macon
Meridian
Montgomery
Savannah
Shreveport
Jackson
GEORGIA
LOUISIANA
Jacksonville
Lufkin
Mobile
Tallahassee
Baton Rouge
Gainesville
Pensacola
Port Arthur
Lake Charles
Apalachicola
Daytona Beach
Houston
New Orleans
Orlando
FLORIDA
Tampa
Miami

Appendix B | INSOLATION AND PERCENT DIFFUSE TABLES[1] | BTU per sq. ft. per day / % DIFFUSE

City	Lat.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
ALABAMA													
Birmingham	33.6°	706/53	967/48	1295/45	1672/40	1855/40	1917/40	1809/42	1722/40	1454/41	1210/39	858/45	661/51
Mobile	30.7°	828/48	1099/45	1406/41	1721/39	1871/39	1867/41	1714/45	1640/44	1449/44	1298/38	955/44	759/49
Montgomery	32.3°	751/51	1013/47	1339/44	1728/39	1896/39	1971/38	1839/41	1744/40	1467/42	1261/38	915/44	719/49
ALASKA													
Annette	55.0°	232/50	424/53	870/42	1342/41	1611/45	1615/49	1615/47	1257/50	951/47	450/58	217/62	151/59
Bethel	60.8°	136/41	413/33	1040/18	1640/22	1692/40	1655/48	1364/55	936/60	734/53	431/46	166/48	85/44
Fairbanks	64.8°	70/23	280/36	859/20	1419/28	1758/36	1943/39	1637/45	1338/41	678/51	317/48	100/38	22/32
Matanuska	61.6°	118/42	339/42	892/28	1312/37	1607/42	1703/46	1508/49	1158/50	730/53	369/51	140/51	55/55
ARIZONA													
Page	36.6°	1106/18	1408/19	1939/13	2278/16	2562/16	2606/19	2507/20	2197/23	1902/21	1482/21	1143/20	896/27
Phoenix	33.4°	1020/31	1374/27	1813/22	2353/15	2674/13	2738/14	2485/21	2291/21	2014/20	1575/21	1150/27	932/32
Prescott	34.6°	1015/29	1334/27	1776/23	2274/18	2628/15	2761/14	2308/27	2090/28	1953/21	1542/21	1139/24	926/30
Tucson	32.1°	1098/29	1431/25	1863/22	2362/16	2670/13	2728/14	2340/25	2181/25	1978/22	1601/22	1207/25	995/31
Winslow	35.0°	984/30	1326/27	1779/22	2282/18	2593/16	2709/15	2345/25	2139/25	1927/21	1512/22	1118/25	894/31
Yuma	32.7°	1095/28	1442/24	1918/19	2411/14	2726/12	2812/12	2451/22	2327/20	2050/19	1622/20	1214/24	999/29
ARKANSAS													
Fort Smith	35.3°	743/47	999/45	1311/42	1615/41	1911/38	2088/34	2064/34	1876/34	1504/39	1200/38	851/42	682/47
Little Rock	34.7°	731/49	1002/45	1312/42	1610/42	1928/38	2105/34	2031/36	1860/36	1517/38	1228/37	847/44	673/49
CALIFORNIA													
Arcata	41.0°	528/53	793/48	1132/46	1586/40	1841/40	1960/39	1807/42	1578/44	1341/41	935/45	593/51	469/54
Bakersfield	35.4°	766/45	1101/38	1594/30	2093/24	2508/19	2748/14	2681/14	2419/16	1991/19	1457/24	941/37	677/47
Daggett	34.9°	957/32	1279/29	1772/23	2273/18	2590/16	2764/14	2602/18	2381/18	2007/19	1515/22	1084/28	875/33
Davis	38.5°	583/53	944/42	1482/31	1947/28	2345/23	2588/21	2544/19	2252/21	1836/22	1283/29	796/53	546/51
El Toro	33.7°	947/36	1235/33	1609/31	1928/31	2068/33	2193/31	2362/29	2154/25	1736/30	1356/32	1026/34	869/37
Fresno	36.8°	645/51	999/42	1524/31	1965/28	2308/25	2529/21	2524/20	2274/21	1871/22	1355/28	841/53	549/55
Inyokern	35.6°	1150/16	1545/13	2131/6	2584/6	2903/5	3082/4	2890/8	2721/5	2389/2	1784/6	1349/8	1087/14
Long Beach	33.8°	927/37	1214/34	1609/31	1936/30	2063/33	2139/33	2298/27	2098/28	1699/31	1325/33	1003/36	846/38
Los Angeles	33.9°	925/37	1213/34	1618/30	1950/30	2058/33	2118/33	2306/27	2078/28	1680/32	1316/33	1003/36	848/37
Mt. Shasta	41.3°	560/49	857/44	1250/40	1755/33	2185/29	2435/24	2576/18	2212/21	1734/24	1154/31	659/46	505/49
Needles	34.8°	984/30	1353/25	1824/20	2316/16	2650/14	2790/13	2540/19	2276/21	2013/19	1537/21	1123/25	913/30
Oakland	37.7°	707/45	1017/40	1456/33	1921/29	2210/28	2348/27	2321/27	2052/28	1700/29	1211/33	822/40	646/45
Pasadena	34.1°	925/36	1228/33	1618/29	1876/32	2097/32	2138/33	2337/25	2208/23	1777/28	1349/31	999/34	870/36
Point Mugu	34.1°	926/36	1220/33	1634/29	1950/30	2016/34	2053/36	2117/32	1934/33	1607/36	1295/34	1005/34	856/37
Riverside	33.9°	1014/30	1353/27	1762/24	1994/29	2297/25	2507/22	2481/21	2278/21	1972/21	1500/24	1176/24	995/27
Sacramento	38.5°	596/53	939/44	1457/33	2002/25	2433/21	2682/16	2687/14	2367/16	1906/19	1314/27	781/41	538/53
San Diego	32.7°	975/36	1265/33	1631/31	1935/31	2001/36	2061/36	2185/30	2056/29	1716/32	1373/32	1062/33	903/36
San Francisco	37.8°	707/45	1008/40	1454/33	1919/29	2224/28	2375/27	2390/24	2115/25	1741/27	1225/33	821/40	642/45
San Jose	37.3°	663/49	980/42	1301/41	1787/34	2115/31	2207/31	2247/29	1979/31	1691/29	1149/38	956/46	638/47
Santa Maria	34.9°	853/40	1140/37	1581/32	1920/32	2139/32	2347/27	2340/25	2105/27	1729/30	1353/30	973/36	803/38
Sunnyvale	37.4°	737/44	1036/39	1485/32	1943/29	2275/27	2451/24	2440/22	2165/24	1758/27	1248/32	843/39	660/45
COLORADO													
Boulder	40.0°	741/37	988/38	1478/30	1696/37	1696/45	1935/40	1917/39	1618/42	1519/34	1143/34	818/36	671/37
Colo. Springs	38.8°	890/28	1177/28	1549/28	1930/27	2127/31	2367/27	2210/30	2024/29	1758/25	1358/24	944/29	781/30
Denver	39.7°	840/33	1127/30	1530/29	1879/29	2134/30	2350/27	2272/27	2044/28	1726/26	1300/25	883/30	731/33
Eagle	39.6°	754/37	1077/32	1500/30	1931/28	2254/27	2507/22	2385/24	2083/27	1766/24	1307/25	868/32	690/36
Grand Junction	39.1°	791/34	1118/31	1552/28	1985/27	2378/22	2597/20	2464/22	2180/23	1833/22	1344/24	918/30	731/33
Grand Lake	40.3°	782/32	1154/27	1559/25	1888/29	2035/33	2330/28	2212/28	1862/30	1755/24	1331/23	863/31	678/36
Pueblo	38.3°	894/29	1171/30	1563/28	1955/28	2161/30	2433/24	2310/27	2101/27	1778/24	1360/24	953/29	782/31
CONNECTICUT													
Hartford	41.9°	477/56	714/53	978/53	1314/50	1567/48	1685/48	1648/47	1420/49	1154/49	852/48	497/58	384/60
DELAWARE													
Wilmington	39.7°	571/51	827/48	1148/46	1479/45	1709/45	1882/41	1822/42	1613/42	1317/44	984/44	644/50	489/55
DC													
Washington	38.8°	571/54	815/50	1124/48	1458/46	1717/44	1899/41	1817/42	1617/44	1340/44	1003/44	651/50	481/57
FLORIDA													
Apalachicola	29.7°	852/48	1125/45	1473/40	1877/34	2090/32	1997/37	1812/42	1686/42	1534/40	1370/36	1039/40	817/47
Daytona Beach	29.2°	958/42	1213/40	1547/37	1883/34	1966/38	1825/42	1783/42	1681/42	1477/44	1250/42	1035/41	870/45
Gainesville	29.6°	1025/38	1353/33	1640/33	1987/30	2160/30	2006/37	1917/39	1873/36	1637/37	1357/37	1172/32	936/40
Jacksonville	30.4°	899/45	1162/41	1521/37	1854/34	1955/37	1884/41	1801/42	1693/42	1441/44	1222/42	995/41	817/46
Miami	25.8°	1057/42	1313/39	1603/37	1858/36	1842/40	1707/46	1762/44	1629/45	1456/46	1301/42	1117/41	1019/41
Orlando	28.5°	999/41	1242/40	1581/36	1897/33	1987/36	1830/42	1800/42	1672/44	1495/42	1303/40	1095/39	925/42
Pensacola	30.5°	922/44	1183/40	1493/38	1876/33	2072/33	2094/34	1979/37	1876/36	1585/38	1452/31	1025/40	826/46
Tallahassee	30.4°	876/46	1136/42	1478/39	1828/36	1935/38	1882/41	1747/44	1674/42	1492/42	1317/38	1007/41	813/47
Tampa	28.0°	1010/41	1258/40	1593/36	1907/33	1997/36	1847/41	1751/44	1652/44	1491/44	1345/39	1107/39	935/42
GEORGIA													
Atlanta	33.6°	717/51	969/48	1302/44	1685/39	1853/40	1911/40	1811/42	1707/41	1421/42	1199/40	882/44	674/50
Augusta	33.4°	750/49	1014/46	1338/42	1728/38	1864/40	1903/40	1803/42	1666/42	1409/44	1219/39	916/41	720/48
Griffin	33.2°	877/41	1113/40	1430/39	1913/31	2127/31	2138/33	2061/34	1928/33	1611/36	1372/31	1062/32	774/44
Macon	32.7°	769/49	1019/46	1362/42	1734/38	1884/39	1918/40	1784/44	1716/41	1438/42	1246/39	939/41	728/48
Savannah	32.1°	907/41	1158/40	1486/38	1906/32	2075/33	2042/36	1976/37	1847/37	1486/41	1283/38	977/40	789/45
HAWAII													
Hilo	19.7°	1120/40	1246/40	1348/40	1434/40	1553/40	1658/40	1624/45	1592/45	1546/40	1372/40	1104/40	1019/45
Honolulu	21.3°	1180/40	1396/35	1621/35	1796/35	1949/30	2004/30	2002/30	1966/30	1810/30	1540/30	1766/35	1132/35
IDAHO													
Boise	43.6°	485/51	839/41	1302/34	1825/30	2275/25	2461/23	2611/16	2195/21	1736/21	1137/29	628/44	437/51
Pocatello	42.9°	539/48	881/39	1370/32	1819/30	2279/25	2478/23	2598/16	2238/20	1768/21	1202/25	689/39	476/48
Twin Falls	40.6°	601/48	885/44	1309/38	1703/36	2035/33	2183/32	2219/29	1991/29	1593/31	1054/39	649/48	483/54
ILLINOIS													
Chicago	42.0°	506/53	759/49	1106/46	1456/45	1788/41	2006/38	1942/38	1718/38	1353/40	969/41	565/51	402/58
Lemont	41.7°	630/42	855/44	1202/41	1438/46	1832/40	2038/37	1943/38	1792/36	1416/38	977/41	579/51	483/50

1. Source Data From Klein, Beckman and Duffie, "Monthly Average Solar Radiation on Inclined Surfaces, E. Report #42-2" University of Wisconsin, Revised 1978.

City	Lat.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Moline	41.4°	534/51	812/47	1117/46	1458/45	1752/42	1968/39	1937/38	1714/39	1356/40	995/40	594/50	432/56
Peoria	40.7°	601/47	840/46	1187/44	1556/41	1876/39	2112/34	2075/33	1851/34	1500/34	1102/36	682/45	512/50
Springfield	39.8°	585/50	860/46	1133/46	1514/44	1864/39	2096/34	2057/34	1804/36	1453/38	1067/39	676/47	490/54
INDIANA													
Evansville	38.0°	573/55	822/50	1150/47	1500/45	1781/42	1981/38	1919/39	1734/39	1403/41	1087/40	682/50	498/57
Fort Wayne	41.0°	455/59	697/55	981/53	1360/49	1670/46	1840/42	1786/44	1593/44	1272/45	924/46	516/58	369/64
Indianapolis	39.7°	495/58	747/54	1036/51	1397/48	1687/45	1866/42	1805/42	1642/41	1323/44	977/45	579/55	417/62
South Bend	41.7°	416/62	660/56	992/51	1387/47	1721/44	1921/40	1851/41	1665/40	1290/44	909/46	497/58	340/65
IOWA													
Ames	42.0°	642/40	933/38	1205/41	1486/44	1770/42	1994/38	1976/37	1696/39	1353/40	1010/39	689/41	527/46
Des Moines	41.5°	580/47	860/44	1180/42	1556/41	1866/39	2123/34	2096/33	1826/34	1433/37	1067/37	653/45	487/50
Mason City	43.1°	553/46	836/42	1167/41	1517/41	1894/38	2112/34	2083/33	1832/33	1404/37	1010/37	600/47	443/51
Sioux City	42.4°	568/47	841/44	1169/42	1577/40	1900/38	2122/34	2120/32	1844/33	1420/37	1037/37	642/45	469/50
KANSAS													
Dodge City	37.8°	826/36	1121/33	1476/32	1884/31	2089/32	2356/27	2294/27	2054/28	1685/29	1300/29	893/34	732/38
Manhattan	39.2°	708/41	973/40	1272/41	1596/40	1943/37	2031/37	1957/38	1939/31	1512/36	1077/39	837/36	575/48
Topeka	39.1°	681/45	940/42	1256/41	1640/39	1914/38	2125/34	2127/32	1909/32	1515/36	1146/36	771/41	583/47
Wichita	37.6°	783/40	1058/40	1405/35	1782/30	2035/35	2264/30	2238/28	2031/27	1616/30	1249/30	870/35	690/40
KENTUCKY													
Covington	39.1°	372/69	512/68	1036/51	1489/45	1873/39	2142/33	2470/21	2016/29	1471/37	866/51	516/60	299/73
Lexington	38.0°	545/57	779/54	1099/49	1478/46	1746/44	1896/41	1849/41	1685/41	1361/42	1043/42	657/51	485/56
Louisville	38.2°	545/57	789/53	1102/49	1466/46	1719/44	1902/41	1836/41	1679/41	1360/42	1042/42	652/51	488/57
LOUISIANA													
Baton Rouge	30.5°	785/51	1053/47	1378/44	1680/41	1870/39	1925/39	1744/45	1676/42	1463/42	1301/38	919/46	736/51
Lake Charles	30.2°	728/55	1009/49	1313/46	1569/45	1848/40	1969/38	1787/42	1656/44	1484/42	1380/34	916/47	705/54
New Orleans	30.0°	834/49	1111/45	1414/42	1779/38	1966/37	2002/37	1812/42	1715/41	1513/41	1334/37	972/44	779/49
Shreveport	32.4°	833/46	1028/46	1394/41	1721/39	2020/34	2006/37	2072/33	1917/34	1530/39	1312/36	896/45	730/49
MAINE													
Caribou	46.9°	425/50	726/44	1132/39	1407/44	1565/48	1749/46	1749/44	1486/45	1093/48	682/53	368/62	318/57
Portland	43.6°	450/55	682/53	969/51	1303/49	1567/48	1710/47	1658/47	1460/47	1157/47	822/48	459/56	363/59
MARYLAND													
Annapolis	39.0°	645/47	896/45	1254/41	1545/42	1799/41	2053/37	1998/37	1729/39	1411/40	1084/39	697/47	571/48
Baltimore	39.2°	586/51	839/48	1161/46	1487/45	1713/45	1878/41	1822/42	1598/44	1330/44	997/44	660/49	499/55
Silver Hill	38.8°	671/46	900/45	1253/42	1615/40	1891/38	2046/37	1902/39	1692/40	1463/38	1087/39	745/44	600/46
MASSACHUSETTS													
Amherst	42.2°	428/60	652/56	1106/46	1279/51	1589/48	1895/41	1902/39	1622/41	1217/46	922/44	564/51	457/53
Blue Hill	42.2°	575/46	792/47	1121/45	1397/47	1736/44	1906/41	1843/41	1600/40	1298/40	918/45	583/50	476/50
Boston	42.4°	476/55	709/53	1015/50	1325/49	1619/47	1816/44	1748/45	1486/47	1259/44	889/46	503/57	402/57
Lynn	42.5°	435/59	770/46	1106/48	1453/45	1674/45	1983/39	1987/37	1556/44	1253/44	852/48	490/57	369/60
Natick	42.3°	560/47	855/42	1202/41	1441/45	1843/39	1508/54	1891/40	1645/39	1323/41	962/41	542/54	494/48
MICHIGAN													
Detroit	42.2°	417/60	680/54	999/51	1398/47	1714/44	1865/42	1834/41	1574/44	1252/45	875/47	473/59	343/64
East Lansing	42.7°	446/57	774/47	1139/44	1323/49	1780/41	2016/36	1991/37	1718/38	1375/36	940/42	501/56	398/57
Flint	43.0°	383/63	636/56	956/53	1339/49	1657/46	1812/44	1795/42	1554/44	1195/46	829/49	429/62	309/66
Grand Rapids	42.9°	369/64	648/58	1014/49	1411/46	1754/42	1955/39	1913/39	1675/40	1261/44	858/47	446/60	311/66
Lansing	42.8°	498/53	785/46	1135/44	1320/49	1839/39	2038/37	2006/36	1773/36	1390/38	951/41	516/55	413/58
Sault Ste. Marie	46.5°	325/63	603/54	1028/45	1382/45	1687/44	1810/44	1834/41	1522/44	1049/50	673/54	331/66	253/66
Traverse City	44.7°	311/67	567/58	1000/48	1404/46	1728/44	1911/40	1908/39	1608/41	1165/46	754/51	377/64	256/69
MINNESOTA													
Duluth	46.8°	388/55	673/47	1034/45	1372/46	1631/46	1766/45	1853/40	1546/42	1095/48	725/50	380/59	291/60
Internat'l Falls	48.6°	356/54	662/45	1045/41	1442/41	1715/42	1852/42	1920/38	1618/39	1121/45	704/49	345/60	271/58
Minn.-St. Paul	44.9°	464/50	763/45	1102/44	1440/44	1736/42	1927/40	1969/37	1686/39	1254/42	859/44	480/54	353/57
Rochester	43.9°	476/51	752/47	1081/46	1409/46	1694/45	1900/41	1907/39	1661/40	1250/44	869/45	494/55	370/58
St. Cloud	45.6°	627/31	925/31	1349/29	1559/39	1839/39	1994/38	2046/34	1810/33	1327/38	888/41	538/47	453/44
MISSISSIPPI													
Jackson	32.3°	753/51	1026/46	1368/42	1707/39	1940/37	2023/37	1907/39	1780/39	1508/40	1271/38	901/45	708/44
Meridian	32.3°	743/51	1012/47	1327/44	1661/41	1859/40	1961/39	1822/41	1738/40	1453/44	1257/38	896/45	699/51
MISSOURI													
Columbia	39.0°	612/50	874/47	1178/46	1525/44	1878/39	2088/36	2114/32	1876/33	1449/38	1100/38	703/47	522/53
Kansas City	39.3°	647/47	894/45	1202/44	1574/41	1871/39	2078/36	2104/33	1862/34	1451/38	1092/36	737/44	561/49
St. Louis	38.7°	627/49	885/46	1204/45	1563/42	1870/39	2091/36	2048/34	1816/36	1458/38	1099/39	718/46	530/53
Springfield	37.2°	683/46	925/46	1235/45	1603/41	1881/39	2074/36	2061/34	1872/34	1479/38	1143/38	775/45	602/49
MONTANA													
Billings	45.8°	486/46	763/42	1189/38	1525/40	1912/37	2172/32	2382/23	2021/25	1469/31	986/33	561/44	421/47
Dillon	45.2°	526/44	845/37	1279/33	1638/36	1988/34	2142/33	2391/23	2022/25	1520/29	1022/32	601/41	450/45
Glasgow	48.2°	387/50	671/45	1104/39	1487/40	1826/39	2046/37	2192/29	1862/30	1339/34	877/37	478/46	333/50
Great Falls	47.5°	420/49	719/42	1169/37	1487/40	1847/38	2100/34	2327/25	1932/28	1377/33	924/34	498/46	335/53
Helena	46.6°	419/51	708/45	1145/39	1486/41	1859/38	2038/37	2333/25	1929/29	1412/33	925/37	521/48	364/51
Lewiston	47.0°	420/50	692/46	1128/39	1443/42	1806/40	2058/36	2286/27	1900/30	1371/34	904/37	502/47	363/50
Miles City	46.4°	457/47	745/42	1184/37	1541/39	1894/37	2144/33	2296/27	1976/27	1443/31	960/34	550/44	399/47
Missoula	46.9°	312/63	574/55	981/47	1382/45	1781/41	1932/40	2326/25	1880/30	1357/36	812/44	409/57	267/64
Summit	48.3°	450/42	597/50	988/45	1526/38	1703/44	1817/44	2065/33	1880/30	1305/36	796/42	376/57	280/58
NEBRASKA													
Grand Island	41.0°	660/41	917/40	1264/39	1692/37	1971/36	2241/30	2214/29	1938/31	1508/34	1137/33	738/40	569/44
Lincoln	40.8°	700/38	940/39	1279/39	1563/41	1829/40	2009/38	1979/37	1873/33	1519/33	1198/30	763/38	634/38
North Omaha	41.4°	633/42	891/41	1221/41	1558/41	1871/39	2121/34	2105/33	1857/33	1372/40	1049/38	644/47	511/49
North Platte	41.1°	692/38	958/38	1332/36	1723/34	1987/34	2265/30	2275/28	1988/24	1564/31	1176/30	759/38	605/40
Scotts Bluff	41.9°	675/38	950/37	1307/37	1667/37	1932/37	2235/31	2282/28	1998/29	1598/29	1145/31	723/39	575/41
NEVADA													
Elko	40.8°	689/39	1034/33	1462/30	1898/29	2302/24	2532/21	2621/18	2314/18	1891/18	1322/22	812/34	616/40
Ely	39.3°	819/32	1140/30	1605/25	2008/25	2309/24	2511/22	2445/22	2229/21	1934/19	1407/21	925/29	722/34

Appendix B

INSOLATION AND PERCENT DIFFUSE TABLES, CONTINUED

BTU per sq. ft. per day / **% DIFFUSE**

City	Lat.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Las Vegas	39.1°	977/28	1338/23	1822/19	2318/15	2644/14	2776/13	2587/18	2353/18	2036/16	1538/19	1085/25	880/30
Lovelock	40.1°	803/31	1165/27	1655/22	2164/19	2553/16	2747/15	2782/12	2482/12	2026/12	1450/16	929/27	714/32
Reno	39.5°	800/33	1149/29	1648/23	2158/20	2521/18	2700/16	2690/14	2404/15	1996/14	1430/19	911/30	705/34
Tonopah	38.1°	918/28	1273/23	1776/19	2250/18	2576/16	2786/13	2701/14	2437/14	2041/14	1520/16	1030/24	826/29
Winnemucca	40.9°	690/39	1027/33	1471/30	1966/25	2360/23	2568/20	2676/14	2347/16	1906/16	1321/22	809/34	618/39
NEW HAMPSHIRE													
Concord	43.2°	459/55	686/53	973/51	1316/49	1581/48	1704/47	1673/47	1455/47	1139/48	816/49	462/56	362/60
NEW JERSEY													
Atlantic City	39.4°	652/46	940/41	1419/33	1593/40	1817/41	2112/34	2094/33	1758/38	1445/38	1103/37	778/40	586/46
Lakehurst	40.0°	559/53	796/49	1108/48	1455/46	1671/46	1773/45	1702/46	1531/46	1260/46	955/45	621/51	475/55
Newark	40.7°	551/51	793/49	1108/47	1448/46	1686/45	1794/45	1758/44	1564/45	1272/45	950/45	596/51	454/56
Trenton	40.2°	638/45	900/42	1264/40	1563/41	1810/41	2013/38	1991/37	1729/39	1434/38	1084/38	719/42	571/46
NEW MEXICO													
Albuquerque	35.0°	1016/28	1341/25	1766/23	2227/20	2537/18	2677/16	2487/21	2289/21	1971/20	1545/20	1133/24	1927/29
Farmington	36.7°	944/29	1280/25	1692/24	2132/22	2450/21	2664/18	2477/21	2251/21	1933/20	1478/21	1046/27	837/31
Roswell	33.4°	1046/30	1372/27	1806/23	2216/21	2458/21	2608/19	2439/22	2240/23	1912/23	1526/23	1131/28	951/31
Zuni	35.1°	985/30	1296/28	1686/27	2165/22	2472/20	2600/19	2263/28	2077/28	1893/23	1495/23	1087/28	892/31
NEW YORK													
Albany	42.7°	502/53	766/48	1104/46	1493/42	1760/42	1950/39	1957/37	1699/39	1316/41	918/44	525/54	399/57
Binghamton	42.2°	386/64	575/62	860/58	1241/53	1493/51	1680/48	1658/47	1424/49	1131/49	778/53	414/65	297/68
Buffalo	42.9°	349/66	546/63	888/56	1314/49	1596/48	1806/44	1776/44	1512/46	1151/48	784/51	403/64	284/69
Ithaca	42.4°	450/57	748/49	1040/49	1283/51	1729/44	1987/38	1972/37	1696/39	1312/41	914/45	461/60	365/62
Massena	44.9°	431/54	692/49	1095/44	1500/41	1808/40	2006/38	1987/37	1687/38	1267/41	830/46	448/57	330/60
New York	40.8°	500/56	720/54	1036/50	1363/49	1635/47	1709/47	1686/46	1482/47	1213/47	895/48	533/57	403/60
Rochester	43.1°	364/65	569/62	903/55	1338/48	1605/47	1816/44	1780/44	1518/45	1159/48	781/51	403/64	281/69
Schenectady	42.8°	479/54	741/49	1010/50	1253/51	1526/50	1655/49	1637/48	1471/47	1106/50	807/50	476/58	383/58
Syracuse	43.1°	385/63	571/60	890/56	1323/49	1577/48	1777/45	1757/44	1502/46	1165/48	777/51	398/65	285/68
NORTH CAROLINA													
Asheville	35.4°	721/48	970/46	1305/42	1660/40	1803/41	1854/42	1775/44	1626/44	1360/45	1146/40	848/42	657/49
Cape Hatteras	35.3°	685/51	952/47	1325/41	1773/36	1960/37	2035/37	1919/39	1705/41	1470/40	1136/41	873/41	659/49
Charlotte	35.2°	719/49	970/46	1314/42	1694/39	1854/40	1920/40	1830/41	1694/41	1415/42	1173/39	865/42	672/50
Cherry Point	34.9°	756/47	1024/44	1386/39	1793/36	1923/38	1937/39	1828/41	1633/44	1433/42	1169/40	906/40	718/45
Greensboro	36.1°	715/47	969/45	1312/41	1682/39	1867/39	1952/39	1862/40	1695/41	1417/41	1140/40	838/42	658/47
Raleigh	35.8°	693/49	942/47	1275/44	1643/40	1807/41	1863/42	1774/44	1610/44	1376/44	1104/42	812/45	635/49
Raleigh-Durham	35.9°	793/42	1043/41	1379/39	1780/36	1905/38	1976/39	2038/36	1773/38	1463/40	1165/39	885/39	719/42
NORTH DAKOTA													
Bismarck	46.8°	467/46	775/39	1168/38	1458/42	1847/39	2059/36	2182/30	1876/31	1353/36	907/38	507/47	372/49
Fargo	46.9°	415/51	705/45	1097/41	1475/41	1833/39	1993/38	2119/32	1824/32	1303/38	874/39	457/51	337/54
Minot	48.2°	383/51	655/46	1043/42	1460/41	1845/38	1973/39	2097/32	1799/32	1276/38	849/39	439/50	310/54
OHIO													
Akron	40.9°	428/62	649/58	963/54	1356/49	1667/46	1838/44	1786/44	1595/44	1271/45	907/47	505/59	353/65
Cleveland	41.4°	388/65	601/60	922/56	1349/49	1680/45	1842/42	1826/41	1581/44	1239/46	866/48	466/62	318/68
Columbus	40.0°	459/60	676/57	979/54	1352/49	1646/49	1811/44	1754/45	1640/42	1279/45	949/46	537/57	387/64
Dayton	39.9°	489/58	725/55	1025/51	1402/48	1699/45	1872/42	1809/42	1644/41	1317/44	969/45	564/56	407/62
Put-in-Bay	41.6°	442/58	734/51	1077/48	1360/48	1821/40	1998/38	2090/33	1902/32	1471/34	1087/34	579/51	409/58
Toledo	41.6°	435/60	680/55	996/51	1383/48	1715/44	1877/41	1848/41	1615/42	1275/44	910/46	498/58	355/64
Youngstown	41.3°	385/65	586/62	889/57	1278/51	1585/48	1758/46	1733/45	1506/46	1193/48	851/49	456/63	315/68
OKLAHOMA													
Oklahoma City	35.4°	800/42	1054/41	1399/38	1724/38	1917/38	2142/33	2127/32	1949/32	1553/37	1232/36	901/39	725/44
Stillwater	36.1°	763/44	1054/40	1430/37	1681/39	1851/40	2186/32	2186/30	1998/30	1677/31	1268/31	947/34	752/40
Tulsa	36.2°	731/46	977/45	1305/42	1602/41	1821/41	2019/37	2029/36	1864/34	1471/39	1163/39	827/42	659/47
OREGON													
Astoria	46.2°	314/64	545/58	866/54	1252/50	1607/47	1625/49	1745/44	1498/45	1183/45	712/51	387/60	261/66
Burns	43.6°	490/51	792/45	1186/40	1648/37	2051/32	2278/29	2459/21	2082/24	1619/27	1042/34	593/46	431/51
Corvallis	44.5°	500/48	738/47	1027/47	1397/46	1671/45	1836/44	1770/44	1633/40	1310/40	989/36	588/45	432/49
Medford	42.4°	407/62	737/50	1132/45	1638/38	2032/33	2276/29	2473/21	2120/24	1588/29	981/40	504/56	336/65
North Bend	43.4°	439/57	704/50	1058/47	1508/42	1856/39	1993/38	2106/32	1785/36	1376/38	892/44	524/53	380/58
Pendleton	45.7°	348/62	613/54	1043/46	1501/41	1924/37	2143/33	2394/23	1993/27	1501/30	908/39	438/56	292/63
Portland	45.6°	310/66	554/58	895/54	1307/49	1662/45	1772/45	2036/34	1672/39	1216/44	723/51	387/62	260/67
Redmond	44.3°	490/49	774/45	1190/39	1682/34	2078/31	2286/29	2444/22	2068/24	1583/28	999/36	571/47	424/50
Salem	44.9°	332/65	587/57	947/51	1369/47	1796/42	1847/42	2141/31	1773/36	1328/39	769/50	410/60	277/66
PENNSYLVANIA													
Allentown	40.6°	527/54	763/51	1078/48	1409/47	1636/47	1776/45	1764/44	1545/45	1237/46	925/46	568/54	430/58
Avoca	41.3°	454/59	688/55	991/53	1338/49	1589/48	1758/46	1744/45	1512/46	1198/47	896/47	490/59	368/63
Erie	42.1°	345/68	577/62	919/55	1358/48	1645/46	1846/42	1832/41	1454/48	1200/47	827/50	416/65	277/71
Harrisburg	40.2°	535/54	770/51	1082/49	1410/47	1651/46	1803/44	1762/44	1550/45	1265/45	933/46	579/54	447/57
Philadelphia	39.9°	555/53	794/50	1108/48	1433/47	1659/46	1810/44	1757/44	1574/45	1280/45	958/45	619/51	470/56
Pittsburgh	40.5°	424/62	625/60	942/53	1316/50	1601/48	1761/46	1689/46	1510/46	1208/48	895/48	504/59	346/66
State College	40.8°	512/55	745/51	1095/48	1375/48	1721/44	2006/38	1947/38	1674/40	1331/42	1014/40	571/54	442/57
RHODE ISLAND													
Newport	41.5°	571/48	852/44	1217/41	1456/45	1803/41	1983/39	1817/39	1655/41	1401/38	1006/40	645/46	520/48
Providence	41.7°	506/54	738/51	1031/50	1373/48	1654/46	1774/45	1694/46	1498/47	1208/47	906/46	537/55	418/57
SOUTH CAROLINA													
Charleston	32.9°	744/50	995/47	1338/44	1731/38	1859/40	1843/42	1798/42	1584/46	1393/45	1192/41	933/41	720/48
Columbia	33.9°	761/48	1020/45	1354/41	1745/37	1893/39	1946/39	1840/41	1701/41	1438/42	1211/39	920/40	721/47
Grnvle.-Sptnbrg	34.9°	729/49	981/46	1328/41	1697/39	1838/39	1918/39	1830/40	1699/40	1405/42	1180/34	880/40	670/49
SOUTH DAKOTA													
Huron	44.4°	488/49	744/47	1113/44	1529/40	1870/38	2100/34	2181/30	1891/31	1417/34	988/37	577/46	405/53
Pierre	44.4°	529/45	794/42	1205/38	1613/38	1965/36	2193/32	2277/27	1991/28	1495/31	1051/32	623/41	442/48

City	Lat.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Rapid City	44.1°	542/45	826/41	1228/38	1588/38	1885/38	2130/33	2222/29	1961/29	1517/31	1063/32	646/40	476/45
Sioux Falls	43.6°	532/47	801/44	1152/42	1542/40	1892/38	2098/34	2149/31	1843/33	1409/36	1005/37	607/45	441/50
TENNESSEE													
Chattanooga	35.0°	630/53	858/53	1176/48	1549/44	1730/44	1830/42	1734/45	1629/44	1335/46	1108/42	772/48	580/55
Memphis	35.0°	682/51	944/48	1277/44	1638/41	1884/39	2043/37	1971/37	1823/37	1470/40	1204/38	816/46	628/51
Nashville	36.0°	601/65	882/59	1188/56	1638/49	1911/46	2081/43	2033/43	1845/44	1561/44	1199/46	808/57	605/60
Oak Ridge	36.0°	612/55	877/50	1202/47	1648/40	1898/38	2009/38	1921/39	1755/39	1537/37	1176/38	778/47	593/53
TEXAS													
Abilene	32.4°	923/40	1182/38	1575/33	1842/34	2036/34	2208/31	2138/32	1955/32	1596/37	1313/36	1007/38	863/39
Amarillo	35.2°	960/31	1242/31	1630/29	2017/27	2210/29	2392/25	2279/28	2102/27	1759/28	1403/28	1032/31	871/32
Big Spring	32.2°	988/36	1268/33	1718/28	2126/23	2109/32	2186/31	2035/34	1725/41	1928/23	1423/30	1073/33	958/33
Brownsville	25.9°	912/50	1135/47	1456/42	1736/40	1926/38	2114/32	2211/29	2026/31	1692/37	1438/37	1054/45	862/50
Corpus Christi	27.8°	897/48	1146/45	1437/42	1641/42	1865/39	2092/33	2184/30	1989/32	1686/36	1415/36	1072/42	844/48
Dallas	32.8°	821/46	1071/44	1421/40	1626/42	1887/39	2134/33	2120/32	1949/33	1586/37	1275/37	936/41	779/45
El Paso	31.8°	1124/28	1479/23	1908/20	2362/16	2599/16	2680/16	2449/22	2283/22	1986/22	1638/21	1243/24	1030/29
Fort Worth	32.8°	800/47	1063/44	1401/40	1610/42	1882/39	2145/33	2146/31	1972/32	1610/36	1276/37	926/42	757/46
Houston	30.0°	772/53	1034/48	1296/47	1522/47	1773/42	1897/40	1827/41	1685/42	1470/42	1275/40	924/47	729/53
Kingsville	27.5°	911/48	1161/45	1434/42	1662/42	1863/39	2035/36	2110/32	1921/34	1624/38	1389/37	1034/44	849/48
Lubbock	33.6°	1030/30	1331/29	1761/24	2166/22	2394/22	2543/21	2410/23	2207/24	1819/27	1467/27	1116/29	934/31
Lufkin	31.2°	793/50	1068/46	1375/42	1623/42	1865/40	2054/36	2005/36	1862/36	1529/40	1348/36	962/42	767/48
Midland	31.9°	1080/30	1382/29	1838/23	2191/22	2429/21	2561/20	2388/23	2208/24	1843/28	1521/27	1176/28	999/31
Port Arthur	29.9°	800/51	1070/47	1353/45	1609/44	1869/39	2009/37	1845/41	1735/41	1526/41	1321/38	952/45	754/51
San Angelo	31.4°	961/39	1207/38	1605/33	1849/34	2030/34	2185/31	2121/32	1965/32	1606/37	1336/36	1043/37	894/39
San Antonio	29.5°	895/46	1154/44	1449/41	1611/44	1893/39	2068/34	2120/32	1946/33	1634/37	1349/37	1008/42	846/46
Waco	31.6°	832/47	1095/44	1427/40	1611/42	1773/42	2111/33	2129/32	1957/33	1600/37	1301/37	956/42	802/45
Wichita Falls	34.0°	861/41	1122/39	1471/37	1762/37	2016/34	2220/31	2165/31	1968/32	1601/36	1291/34	956/38	799/41
UTAH													
Cedar City	37.7°	881/31	1179/30	1634/25	2091/23	2466/20	2704/16	2502/20	2240/21	1967/18	1459/21	992/28	785/33
Salt Lake City	40.8°	638/44	988/37	1453/30	1893/29	2361/23	2559/21	2588/18	2252/20	1842/20	1293/24	787/36	570/45
VERMONT													
Burlington	44.5°	425/56	678/51	1055/46	1449/44	1766/41	1949/39	1950/38	1672/39	1264/42	834/46	433/59	320/63
VIRGINIA													
Mt. Weather	39.1°	634/48	1010/38	1246/42	1526/44	1873/39	1935/40	1880/40	1585/44	1382/42	1036/41	745/44	619/44
Norfolk	36.9°	678/49	932/46	1280/42	1676/39	1886/39	1999/38	1852/41	1679/41	1395/41	1082/41	811/41	623/48
Richmond	37.8°	631/50	876/48	1210/45	1565/42	1761/42	1871/42	1773/44	1599/44	1347/44	1032/44	733/47	566/51
Roanoke	37.3°	660/49	899/47	1235/45	1581/42	1763/42	1881/41	1795/42	1619/44	1357/44	1080/41	764/45	590/50
WASHINGTON													
Olympia	47.0°	269/68	503/60	844/55	1255/50	1631/46	1692/47	1912/39	1548/42	1156/45	636/56	339/64	221/69
Prosser	46.2°	431/50	818/37	1294/31	1921/24	2271/24	2507/22	2606/16	2227/18	1689/20	1010/31	501/48	369/51
Pullman	46.7°	453/47	671/48	1095/41	1681/33	1998/33	2529/21	2603/16	2035/24	1578/24	944/34	542/44	354/53
Richland	46.3°	317/64	741/44	1228/34	1721/32	1902/37	2385/25	2124/32	2216/19	1430/32	844/42	457/53	365/53
Seattle	47.4°	288/65	501/59	973/47	1460/41	1847/38	1921/40	2090/32	1685/38	1209/41	697/51	391/57	236/67
Spokane	47.7°	314/62	606/51	1040/44	1494/40	1917/36	2082/36	2355/24	1941/28	1434/31	840/40	397/56	255/64
Tacoma	47.2°	262/68	495/60	849/54	1293/48	1713/42	1801/44	2246/28	1615/40	1146/45	656/54	337/64	211/71
Whidbey Is.	48.3°	293/65	532/55	917/50	1345/45	1760/40	1820/45	1981/35	1592/40	1173/40	655/53	357/60	233/67
WEST VIRGINIA													
Charleston	38.4°	498/60	706/57	1009/54	1355/50	1639/47	1774/45	1682/47	1514/47	1272/46	971/46	613/55	440/62
Parkersburg	39.3°	527/56	745/54	1113/48	1397/48	1795/41	1994/38	1939/38	1784/37	1453/38	1047/41	616/53	487/56
WISCONSIN													
Eau Claire	44.9°	452/53	746/46	1089/44	1425/45	1680/45	1870/42	1885/40	1619/41	1196/45	826/46	450/57	341/59
Green Bay	44.5°	451/53	725/48	1103/44	1438/44	1718/44	1906/41	1887/39	1621/41	1217/44	820/47	465/56	350/59
La Crosse	43.9°	481/51	764/46	1100/45	1426/45	1712/44	1904/41	1899/39	1665/40	1242/44	893/46	494/55	369/58
Madison	43.1°	515/50	803/45	1135/44	1397/46	1742/42	1947/40	1933/38	1707/38	1299/41	910/44	504/55	388/57
Milwaukee	42.9°	479/54	736/49	1088/46	1441/45	1767/42	1976/39	1960/38	1718/38	1309/41	907/44	524/54	378/59
WYOMING													
Casper	42.9°	682/34	1013/30	1441/29	1846/29	2202/28	2500/22	2533/19	2224/20	1749/21	1218/24	764/32	593/36
Cheyenne	41.1°	765/31	1067/30	1432/31	1769/33	1994/34	2257/30	2229/29	1965/30	1666/27	1241/27	822/32	671/33
Lander	42.8°	848/19	1183/19	1662/18	2038/22	2156/29	2488/23	2389/23	2138/23	1711/23	1312/19	874/23	726/22
Laramie	41.3°	826/25	1099/28	1563/24	1836/31	2020/33	2311/29	2186/30	1939/31	1548/32	1176/30	837/31	675/32
Rock Springs	41.6°	734/33	1088/28	1530/25	1943/27	2343/23	2573/20	2546/19	2238/20	1832/19	1305/22	826/31	650/34
Sheridan	44.8°	517/45	787/42	1204/38	1537/40	1882/38	2155/33	2327/25	2005/27	1500/31	1005/34	590/44	441/47
ALBERTA													
Edmonton	53.6°	328/39	649/32	1150/28	1522/34	1876/36	1891/41	1939/37	1508/41	1099/40	693/39	409/36	245/44
Lethbridge	49.6°	442/38	774/32	1253/29	1548/37	1917/36	2138/33	2249/28	1917/28	1364/31	885/33	516/37	332/46
BRITISH COLUMBIA													
Vancouver	49.0°	280/63	383/67	689/62	1264/48	1725/42	1777/45	2009/36	1467/45	929/54	590/56	350/58	206/67
MANITOBA													
Churchill	58.7°	240/23	553/23	1124/18	1640/24	1880/33	1954/38	1862/38	1401/42	829/49	424/53	221/45	129/42
Winnipeg	49.9°	483/31	829/27	1338/23	1618/33	1880/37	1935/40	2094/32	1740/34	1179/41	756/42	439/46	339/44
NEW BRUNSWICK													
Moncton	46.1°	369/58	664/51	1069/44	1401/45	1622/46	1659/48	1733/45	1512/45	1143/46	774/48	405/58	332/57
NEWFOUNDLAND													
St. Johns	47.5°	295/64	553/56	885/51	1180/53	1475/50	1585/50	1622/48	1253/54	1032/50	627/56	295/67	258/64
ONTARIO													
Ottawa	45.4°	531/42	841/37	1235/36	1486/41	1832/39	2057/36	2016/36	1729/37	1309/39	815/46	453/55	402/50
Sapuskasing	49.4°	405/45	700/39	1143/34	1364/45	1512/49	1770/45	1770/42	1475/45	995/50	590/56	295/64	295/53
Toronto	43.7°	446/55	682/51	1077/46	1372/47	1762/42	1917/40	1943/38	1600/42	1268/42	826/48	453/58	350/60
QUEBEC													
Montreal	45.5°	405/56	737/45	1180/38	1435/42	1733/42	1806/44	1880/40	1622/40	1143/47	737/51	369/64	295/63

Appendix C

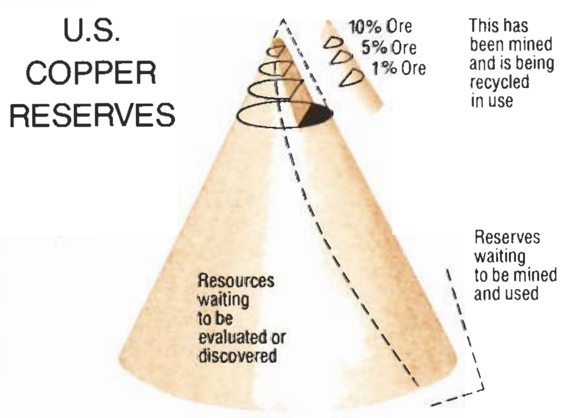
TABLE 12/COLLECTOR TILT FACTORS

		LATITUDE	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC
20% Diffuse	COLLECTOR TILT = LAT. – 15°	24°	1.13	1.09	1.04	1.00	0.97	0.96	0.97	1.00	1.04	1.10	1.12	1.15
		32°	1.34	1.24	1.11	0.99	0.93	0.94	0.92	0.98	1.11	1.28	1.34	1.42
		40°	1.67	1.41	1.23	1.01	0.90	0.90	0.89	1.02	1.21	1.42	1.73	1.76
		48°	2.18	1.64	1.51	1.10	0.96	0.80	0.95	1.08	1.43	1.73	2.26	2.56
	COLLECTOR TILT = LATITUDE	24°	1.31	1.21	1.08	0.95	0.87	0.85	0.87	0.94	1.08	1.21	1.28	1.37
		32°	1.56	1.39	1.16	0.97	0.79	0.76	0.78	0.96	1.15	1.45	1.56	1.71
		40°	1.95	1.55	1.28	0.98	0.75	0.75	0.74	1.00	1.25	1.57	2.05	2.10
		48°	2.53	1.80	1.57	1.08	0.90	0.74	0.89	1.05	1.49	1.90	2.63	3.04
	COLLECTOR TILT = LAT. + 15°	24°	1.40	1.25	1.06	0.80	0.70	0.67	0.70	0.79	1.05	1.27	1.36	1.50
		32°	1.69	1.45	1.13	0.89	0.59	0.55	0.58	0.88	1.12	1.54	1.68	1.89
		40°	2.11	1.60	1.25	0.91	0.67	0.65	0.66	0.92	1.23	1.63	2.24	2.30
		48°	2.72	1.85	1.54	1.00	0.79	0.65	0.78	0.97	1.45	1.98	2.84	3.34
40% Diffuse	COLLECTOR TILT = LAT. – 15°	24°	1.10	1.07	1.03	1.00	0.97	0.96	0.97	1.00	1.03	1.07	1.09	1.12
		32°	1.27	1.20	1.09	0.98	0.93	0.95	0.92	0.97	1.09	1.22	1.26	1.33
		40°	1.52	1.33	1.18	0.98	0.89	0.89	0.89	1.00	1.16	1.34	1.59	1.61
		48°	1.93	1.50	1.42	1.06	0.94	0.78	0.93	1.04	1.35	1.57	2.02	2.23
	COLLECTOR TILT = LATITUDE	24°	1.24	1.16	1.06	0.95	0.88	0.86	0.88	0.94	1.05	1.17	1.21	1.28
		32°	1.44	1.31	1.12	0.96	0.79	0.76	0.78	0.95	1.11	1.36	1.43	1.56
		40°	1.74	1.44	1.21	0.96	0.74	0.74	0.73	0.97	1.19	1.46	1.84	1.87
		48°	2.20	1.61	1.45	1.03	0.88	0.73	0.87	1.01	1.38	1.71	2.31	2.60
	COLLECTOR TILT = LAT. + 15°	24°	1.32	1.19	1.03	0.80	0.72	0.69	0.72	0.79	1.03	1.20	1.26	1.38
		32°	1.53	1.36	1.09	0.89	0.59	0.56	0.58	0.88	1.08	1.42	1.52	1.70
		40°	1.85	1.47	1.18	0.88	0.67	0.66	0.66	0.90	1.15	1.50	1.98	2.03
		48°	2.34	1.64	1.41	0.95	0.78	0.64	0.77	0.93	1.34	1.75	2.46	2.82
60% Diffuse	COLLECTOR TILT = LAT. – 15°	24°	1.07	1.05	1.02	1.00	0.98	0.97	0.98	0.99	1.02	1.05	1.06	1.09
		32°	1.20	1.15	1.06	0.97	0.93	0.95	0.92	0.96	1.06	1.17	1.19	1.25
		40°	1.38	1.25	1.13	0.96	0.88	0.89	0.88	0.98	1.12	1.26	1.45	1.46
		48°	1.69	1.35	1.33	1.02	0.92	0.77	0.91	1.00	1.27	1.42	1.77	1.90
	COLLECTOR TILT = LATITUDE	24°	1.17	1.11	1.04	0.94	0.89	0.87	0.89	0.93	1.03	1.12	1.13	1.20
		32°	1.31	1.24	1.07	0.94	0.79	0.76	0.78	0.94	1.07	1.26	1.30	1.41
		40°	1.53	1.32	1.14	0.93	0.73	0.74	0.73	0.95	1.12	1.35	1.63	1.65
		48°	1.87	1.42	1.34	0.99	0.86	0.72	0.85	0.97	1.28	1.51	1.98	2.16
	COLLECTOR TILT = LAT. + 15°	24°	1.22	1.13	1.00	0.80	0.73	0.71	0.73	0.79	1.00	1.13	1.16	1.25
		32°	1.37	1.26	1.04	0.88	0.59	0.56	0.58	0.87	1.03	1.30	1.36	1.50
		40°	1.60	1.34	1.10	0.86	0.66	0.66	0.66	0.88	1.08	1.37	1.72	1.76
		48°	1.96	1.43	1.29	0.91	0.77	0.64	0.76	0.89	1.23	1.52	2.09	2.31
80% Diffuse	COLLECTOR TILT = LAT. – 15°	24°	1.04	1.03	1.01	1.00	0.98	0.97	0.98	0.99	1.01	1.03	1.04	1.05
		32°	1.12	1.11	1.04	0.96	0.93	0.96	0.92	0.96	1.04	1.11	1.12	1.16
		40°	1.24	1.17	1.08	0.94	0.88	0.88	0.87	0.96	1.07	1.18	1.30	1.31
		48°	1.44	1.22	1.24	0.98	0.90	0.75	0.89	0.97	1.19	1.27	1.53	1.57
	COLLECTOR TILT = LATITUDE	24°	1.10	1.07	1.01	0.94	0.90	0.89	0.90	0.93	1.01	1.07	1.06	1.11
		32°	1.19	1.16	1.03	0.93	0.79	0.77	0.78	0.93	1.03	1.17	1.18	1.26
		40°	1.33	1.21	1.07	0.90	0.73	0.74	0.72	0.93	1.06	1.23	1.42	1.43
		48°	1.55	1.25	1.22	0.94	0.84	0.70	0.84	0.93	1.18	1.31	1.66	1.72
	COLLECTOR TILT = LAT. + 15°	24°	1.12	1.06	0.98	0.80	0.75	0.73	0.75	0.79	0.97	1.06	1.05	1.13
		32°	1.21	1.17	0.99	0.87	0.60	0.57	0.59	0.86	0.99	1.18	1.19	1.31
		40°	1.35	1.20	1.02	0.83	0.66	0.66	0.65	0.86	1.01	1.24	1.47	1.49
		48°	1.58	1.23	1.16	0.87	0.76	0.63	0.75	0.85	1.12	1.29	1.71	1.79

COPPER FACTS Supply • Sources • Energy

The future is bright for tomorrow's supply of copper. Copper is plentiful in the United States. Natural abundance plus recycling make the nation essentially self-sufficient in copper. Moreover, copper's production is energy efficient.

Visualize the copper on earth as a cone of resources. Up to now man has found, extracted and put into recycling use a slice off the tip of that cone. Below that slice are the



known reserves of copper waiting to be mined and used. Behind those reserves are the rest of the earth's copper resources, known to exist but which may not yet be precisely located or economically or legally recoverable. The most recent Bureau of Mines estimate is: copper in U.S. ore reserves, 202 billion pounds; copper in additional U.S. ore resources, 640 billion pounds. This total of 842 billion pounds of U.S. copper resources is about 250 times current annual U.S. requirements, which have averaged 3.2 billion pounds in the 1970's.

In addition to the plentiful supply of new copper, there is another naturally occurring copper resource that no other metal can match: ease of recycling. Today, almost half the copper in U.S. mill and foundry products comes from recycled scrap. During the 1970's, an average of 3.2 billion pounds came from newly-mined ore each year and 2.8 billion pounds (47% of total copper production) from U.S. scrap resources.

Although copper is mined around the world, the U.S. is essentially self-sufficient in copper. During the 1970's, the U.S. averaged nearly 92% in net total copper and copper alloy self-sufficiency, with a high of 97% reached in 1970 and again in 1975. No other engineering metal can make such a claim.

Copper is favorably situated among the metals when it comes to "energy cost." Based on mid-seventies technology, the production of copper from ore in the U.S. requires the equivalent of from 12.2 to 15.7 kilowatt hours per pound, depending on ore type and grade. This includes both direct energy usage and indirect energy requirements represented by equipment use and supplies consumed. It also includes losses due to the inefficiencies of energy conversion. Production from scrap is even more energy efficient.

It is interesting to calculate the energy cost of the material in a solar collector panel. That is, how much energy is required to produce from ore the metal in the fins and tubes that make up one square foot of absorber plate? The answer for copper is about 47,000 Btu. This means a copper collector installed in Tucson on January 1 can pay back its energy debt with useful heat by June 4 of the same year, based on data from an actual installation.

ENERGY COST OF METALS

PRIMARY PRODUCTION

	kwh per pound
Carbon Steel	3.4
Lead	3.8
Cast Iron	4.8
Zinc	9.1
Copper	12.2—15.7
Nickel	20.2
Aluminum	34.2
Magnesium	50.1
Titanium	57.1

COPPER BENEFITS Properties and Advantages for Solar Energy Systems

The copper metals, copper, brass and bronze, are uniquely suited for solar heating systems. Without copper, the outlook for solar energy in the U.S.A. would be nowhere near so bright as it is today.

- **Thermal conductivity–**unsurpassed among engineering materials, the key to cost-effective solar collectors and heat exchangers.
- **Corrosion resistance–**both in hot water and in glycol-water solutions, proven by decades of successful service.
- **Joinability and Ease of Fabrication–**in the factory and in the field, unsurpassed for solar heating system components.
- **Familiarity–**in building construction and throughout the plumbing, heating and cooling industry.
- **Availability–**abundant supply in the U.S.A., half of it from recycled scrap, both energy efficient sources.

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