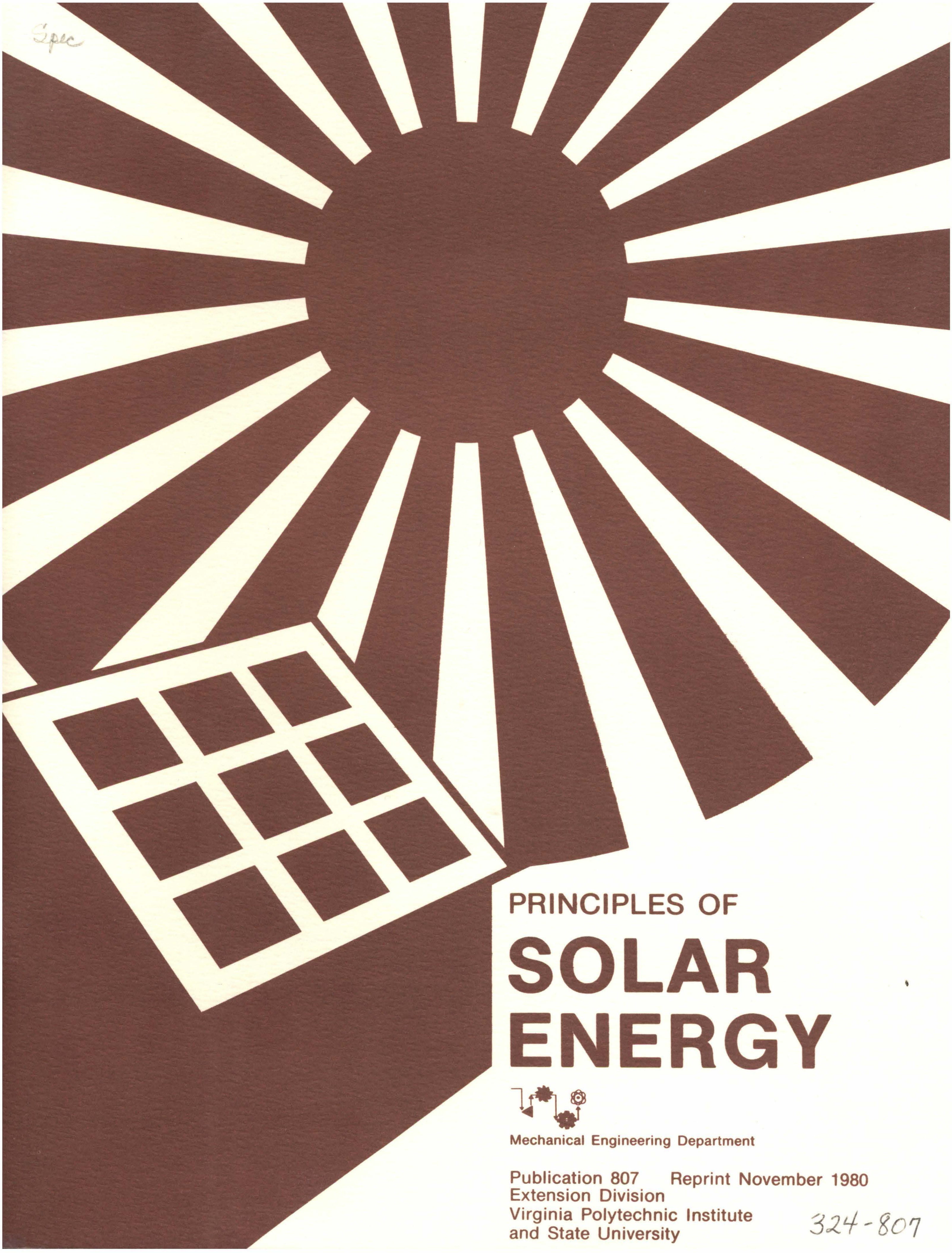

PRINCIPLES OF

SOLAR ENERGY

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PRINCIPLES OF SOLAR ENERGY

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INTRODUCTION

The purpose of this publication is to provide a basic understanding of the principles of solar energy systems, their uses and limitations, material selection, and good design practices. There are many options available in solar applications, and the selection process has to be an individual one based on knowledge, application, and investment capital.

It is strongly suggested that professional assistance be utilized if a system of significant size and financial investment is to be built. While the theory and concept is relatively simple, there are many pitfalls that can be avoided by someone who is technically competent and experienced in solar applications.

Since the level of technical knowledge will vary with readers, an appendix is included which defines many of the terms used in the text.

HOW MUCH ENERGY IS AVAILABLE

SOLAR ENERGY REACHING EARTH - If we were to go outside the earth's atmosphere - which is a distance of approximately 50 miles - and measure the amount of energy that is available, we would find that 429 BTU's/sq. ft./hr. would fall upon a surface that is normal to the sun's rays.[1] As this energy travels through the earth's atmosphere, some of it is lost to diffuse scattering, to reflection from clouds, and to absorption by moisture and gases in the earth's atmosphere, so when it finally reaches earth's surface, it has lost much of the amount that is available in outer space. The amount lost varies with the depth of atmosphere through which the rays must travel. Figure 1 depicts these losses of the sun's rays as they penetrate the earth's atmosphere.

In addition, the energy varies from season to season as the relationship of the angle of the sun to the earth changes. Figure 2 shows the maximum and minimum angles of declination from winter to summer. In winter, the sun moves to a low of 19° below a horizontal line represented by the equator. The winter sun comes in at a low angle through the earth's atmosphere to reach the North American continent and the rays are made to travel through a longer distance of the earth's atmosphere. For this reason, even though the sun is closer in winter (91,325,000 miles), the energy received by the North American continent is much less than in summer. As the sun moves to a high of 23° above the horizontal line represented by the equator in summer, it reaches a more perpendicular angle with respect

[1]Numbers refer to similarly numbered references in Bibliography at end.

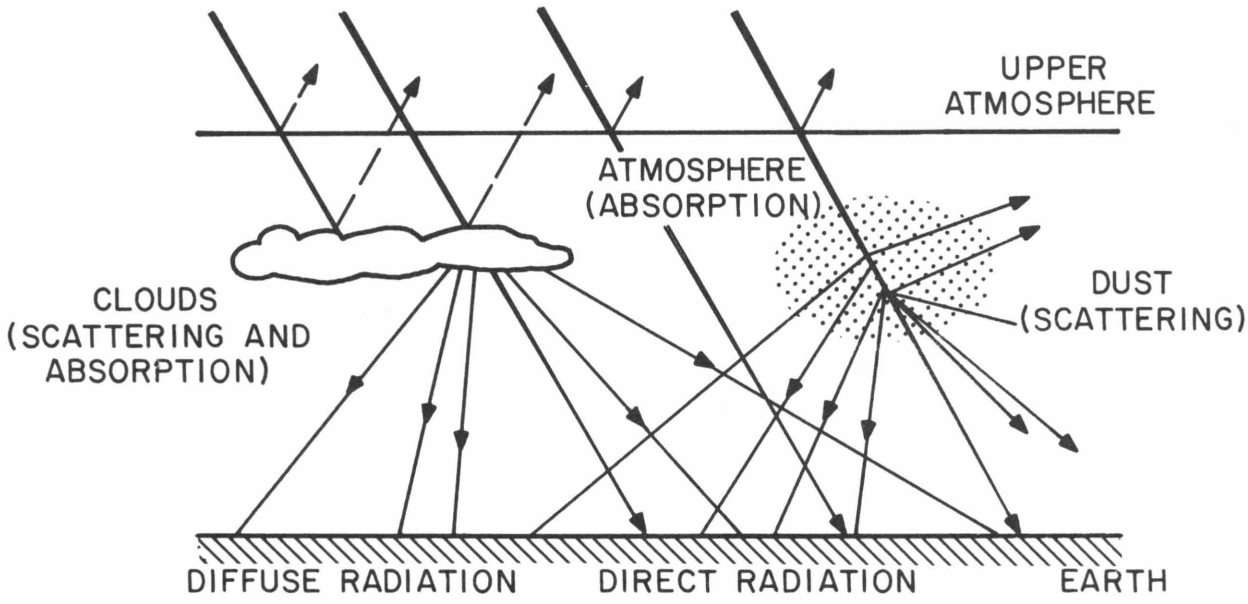


Figure 1: Losses of the Sun's Rays as they Penetrate the Atmosphere

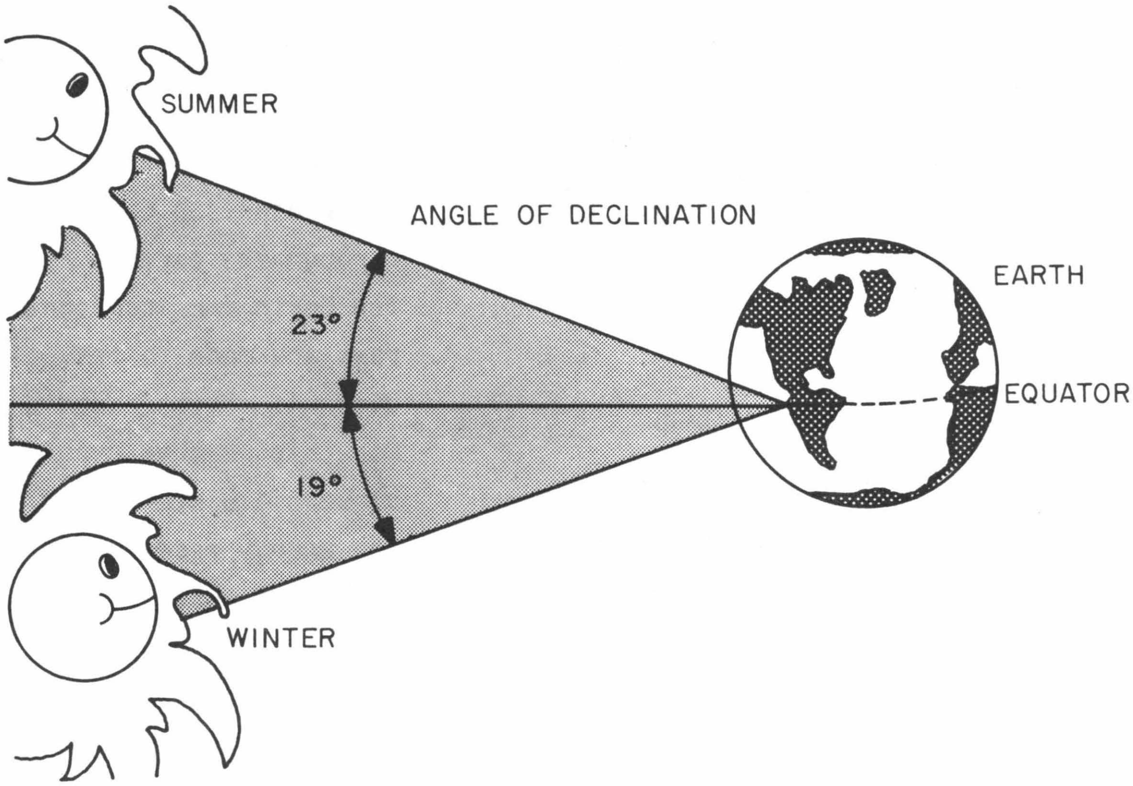


Figure 2: Sun's Position in Winter and Summer

to the North American continent causing the rays to have less distance to travel through the earth's atmosphere, thereby providing more energy.

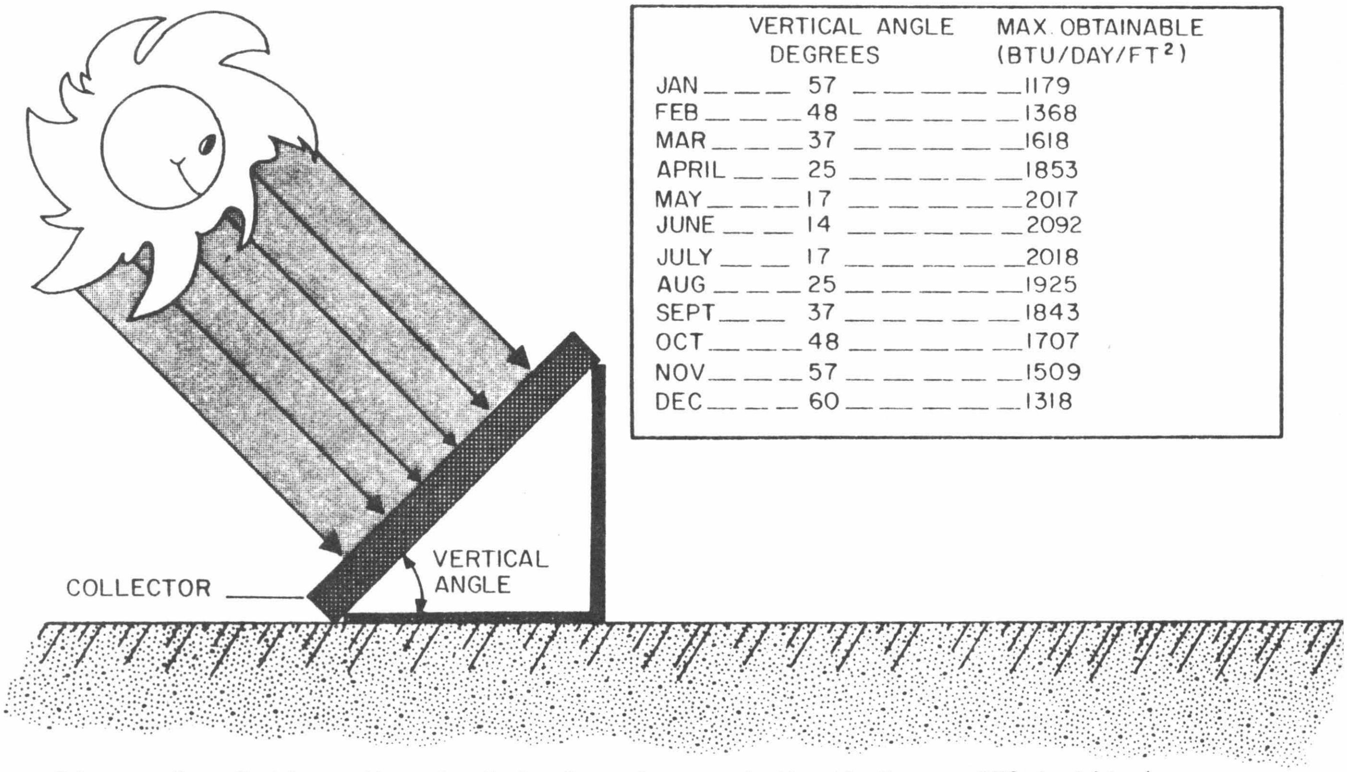
<u>COLLECTOR ORIENTATION</u> - A maximum amount of solar energy can be intercepted if the collector is perpendicular to the solar rays all day long. To do this would require tracking the sun. Collectors can be made to track, but many moving parts and flexible connections are required as well as some means to sense the position of the sun at all times. Tracking collectors are not practical for installations on houses, so collectors mounted at fixed angles are used.

The maximum intensity of direct radiation occurs at noon and because the distribution of radiation is symmetrical about noon, the collectors should be faced directly south then tilted to the desired vertical angle. If this is not possible or desirable because of the building design or other considerations, variations in collector orientation up to 30° from due south can be tolerated without serious reduction of the total solar energy collected during the day.

The optimum fixed vertical angle for collectors depends on the latitude and the primary function of the solar system. For heating purposes, maximum collection of solar energy is desired during the winter season, from about October until April or May. For hot water heating the system is in use the year round so the collector should be set to collect a near equal amount for all seasons. There are exceptions to this. For example, in some areas electrical rates are higher in summer, so collectors should be set to be most efficient during that period.

Figure 3 shows the optimum vertical angle for each month for a latitude of 37°. As can be seen, this angle approaches the vertical in winter and the horizontal in summer. In fact, a vertical mounted collector used for space heating in winter will collect approximately 15 percent less energy than one mounted at the optimum angle.

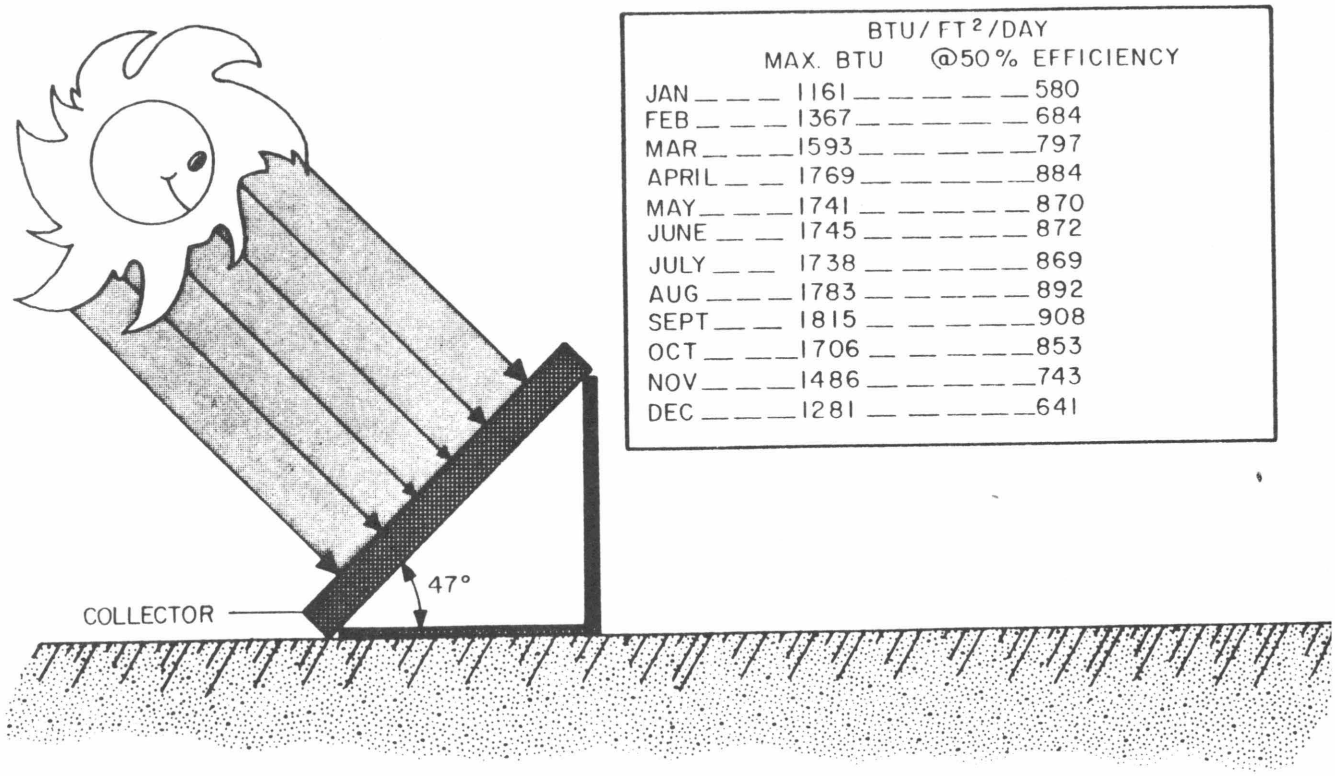
The second column in Figure 3 gives maximum obtainable solar energy in BTU's per day per square foot of collector and is typical for the state of Virginia. This amount is slightly more for Eastern Virginia and less for Western Virginia. These figures are obtained from Mean Daily Solar Radiation Charts produced by the U. S. Department of Commerce. The values from these charts are measured on a horizontal surface and are given in Langleys, which are calories per square centimeter. They are converted to BTU's per square foot per day by multiplying by 3.69. Correction must then be made for the vertical angle



MONTHLY OPTIMUM COLLECTOR ANGLES

	VERTICAL ANGLE DEGREES	MAX. OBTAINABLE (BTU/DAY/FT^2)
JAN	57	1179
FEB	48	1368
MAR	37	1618
APRIL	25	1853
MAY	17	2017
JUNE	14	2092
JULY	17	2018
AUG	25	1925
SEPT	37	1843
OCT	48	1707
NOV	57	1509
DEC	60	1318

Figure 3: Optimum Vertical Angles for each Month for a 37° Latitude



COLLECTOR AT LATITUDE + 10° (47°)

	MAX. BTU	BTU/FT^2/DAY @50% EFFICIENCY
JAN	1161	580
FEB	1367	684
MAR	1593	797
APRIL	1769	884
MAY	1741	870
JUNE	1745	872
JULY	1738	869
AUG	1783	892
SEPT	1815	908
OCT	1706	853
NOV	1486	743
DEC	1281	641

Figure 4: Average Energy Available Per Month at a Vertical Angle of 47°

selected. The values from these charts are average values which take into consideration cloudy days.

The second column of Figure 3 shows that in January, the amount of energy is 1,179 BTU's/day/sq. ft. To obtain the total amount of energy that could be expected in January, simply multiply this figure times the number of days in that month. Follow this procedure for each of the twelve months and the total amount of energy available on a yearly basis can be found.

Because solar collectors are rigidly mounted, it is not practical to consider changing this angle monthly. Therefore, an optimum angle for year-round operation is desired and has been determined to be latitude plus 10°. In Virginia, where the average latitude is 37°, the optimum angle for year-round operation would be 47°.

Figure 4 shows the amount of energy that is available to a collector that is mounted at 47°. The first column represents the amount of energy in BTU's/sq. ft./day that might be expected to fall upon a collector mounted at 47°. The second column represents the amount of usable energy available. This is obtained by taking an average efficiency of 50% for collectors and multiplying this by the maximum energy available. It is seen that this value ranges from a low in January from 580 BTU's/sq. ft./day to a maximum of 908 BTU's/sq. ft./day in September. If these monthly numbers are added together and averaged, then a rule of thumb value of 800 BTU's/sq. ft./day is developed as the yearly average that may be expected to be available in usable form.

COLLECTOR MATERIALS AND DESIGN

The technology of solar energy certainly is not new. Recorded history shows it going back several hundred years. It has been reported that as early as 1700, a concentrating solar collector was built that produced temperatures high enough to melt diamonds.[2] However, if useful systems are to be developed that will have a life expectancy longer than that necessary to provide an economic payback, then the development of solar energy really becomes a materials problem.

Materials react to solar energy in either one of three ways or a combination of these as shown in Figure 5. The incoming radiation is either transmitted, absorbed, or reflected. We wish to make maximum utilization of these characteristics in the various components of a solar collector.

It would be very desirable, then, to have a collector that would allow the sun's radiation to pass through and be absorbed into the collector

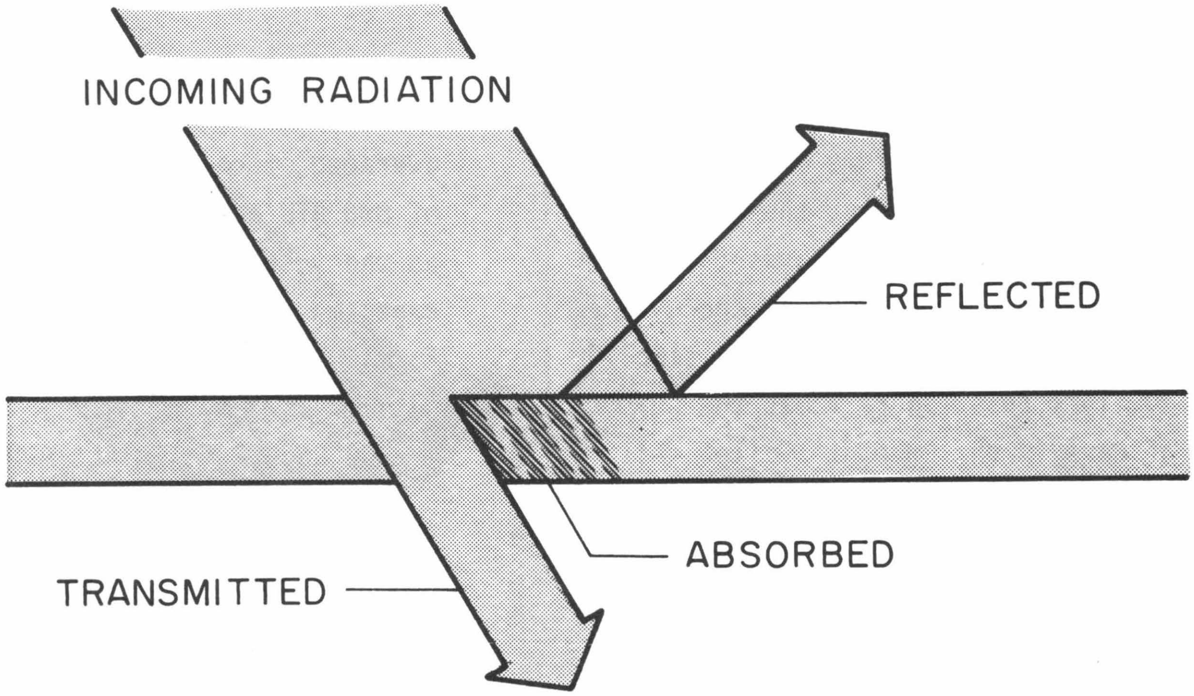


Figure 5: Material Reaction to Solar Energy

plate and then to have the longer or infrared waves produced by the collector plate to be trapped or reflected back to the plate. This is known as the greenhouse effect and occurs not only in a well-designed collector, but also in nature. For example, when the sun has been shining during the day and then is followed by a cloud cover at night, temperatures are higher because the cloud overcast reflects the infrared energy back to earth.

GLAZING - A material that is most effective in providing this trapping effect for a solar collector is glass. It has the characteristic of transmitting 90-95% of the sun's energy and then reflecting back 97-99% of the infrared waves or infrared radiation that is produced at the absorber plate. Glass exhibits this characteristic best of the available materials. Plastics transmit solar radiation but reflect back less of the infrared waves and, therefore, are less effective as a trap. Some glass materials are better than others. Low iron content glass transmits more of the solar energy and is identified by looking at the edge. If it is clear or blue, then it has low iron content. If it is green, the iron content is high.

Glass manufacturers have already

developed a high interest in the potential market for solar products and have developed glass materials that have a high transmission and, in addition, are much more shatterproof. While other materials such as fiber-glass and film plastics do not have the same trapping effect as glass, they do have other advantages such as low cost, low thermal expansion, and less susceptibility to breakage by thrown objects or natural phenomena such as hail storms. Because of the trade-offs then, glazing on commercially available solar collectors may consist of either glass, plastic, or fiber-glass impregnated materials.

ABSORBER PLATE - The next component of a solar collector is the absorber plate. This plate should be located from 1 1/2 to 2 1/2 inches below the glazing so that the glazing is not exposed to excessive temperatures. The absorber plate may be designed to heat either a liquid or air.

Liquid absorbers are made in a variety of designs. Many of them consist of tubing that is bonded to a flat metallic plate. This tubing can be either copper or aluminum. Copper is preferred since it is more compatible with tap water and does not require special corrosion inhibitors. Copper also is more compatible with existing copper plumbing.

The absorber plate may be steel, copper, or aluminum. The bonding of the tubing to the plate is critical because a high resistance at this point will prevent a good transfer of heat from the plate to the tubing and will reduce collector efficiency. Good bonds are made by brazing the tubing to the plate, press fitting it into matching grooves, or other similar techniques that provide good contact surfaces. Absorbent plates are also made by bonding two flat plates together with various techniques so that water flows in a controlled pattern between the plates

The amount of energy that the absorber plate will absorb is dependent directly upon the coating that is applied. Figure 6 shows the percent absorption for a variety of colors. Notice that flat black in this case is the highest--being in the 90% range--followed by red and grey. We would also expect that green would have a fairly high absorption since leaves are green and have the prime function of absorbing solar energy. Most materials that absorb radiant energy also emit it at about the same rate. However, since it is absorbed at a high frequency from the sun and emitted at a lower frequency from the absorber plate, there are some materials that have a significant spread in the absorptance and emittance. These are called selective

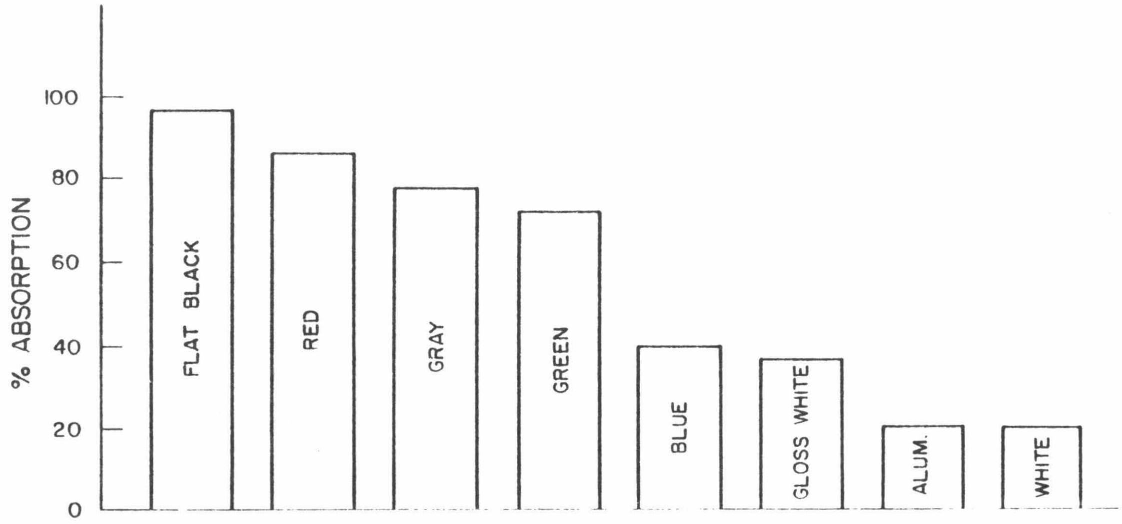


Figure 6: Per Cent Solar Absorption by Colors

surfaces. Black Chrome, for example, has a short wave absorptance of .87 - .93 and a long wave emittance of only .1. Other materials are under development but most selective surfaces are yet to prove their durability under long life conditions. Heat resistant flat black paint, which has a short wave absorptance of .94 - .98 and a long wave emittance of .89 - .97 is still one of the most common coatings used.[3]

INSULATION - The next component to be considered is insulation. In building a boxed structure that is going to be exposed continuously to the outside extremes of weather from year to year, it is realistic to assume that leaks are going to occur. Insulating materials made of closed cell material are best for prevention of moisture absorption. Temperature within a collector may go as high as 300°F, particularly under static conditions, so the insulating material should be able to understand this without deteriation.

Insulation should be along the side as well as behind the absorber plate, as this can be a significant area of energy loss.

FRAMING - Framing can be of aluminum, steel, or wood. If wood is used, it should never be in direct contact with the absorber plate which can get quite hot. Tests have shown that if wood is exposed to temperatures as low as 212°F for a long period of time, it is possible for combustion to occur.[4]

TYPICAL DESIGNS - Air collectors come in a variety of configurations as shown in Figure 7. All seem to work equally well. Air is, of course, the medium used to absorb and transport the absorbed energy, and the panel is designe to create a turbulent flow of air so as to cause a scrubbing effect on the

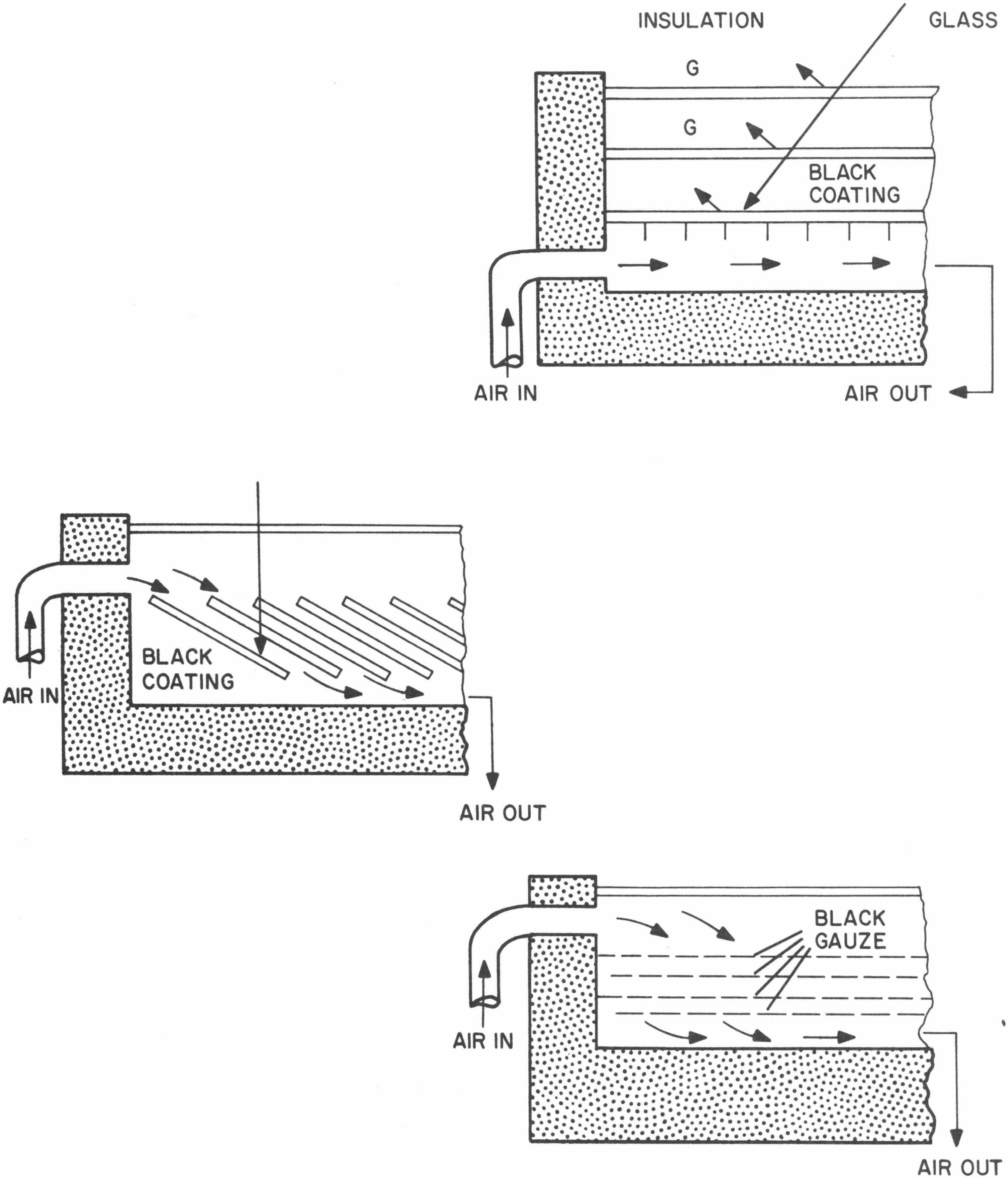


Figure 7: Typical Designs of Air Collectors

absorber plate and, thus, increase the efficiency.

Figure 8 shows a typical design of a liquid collector.

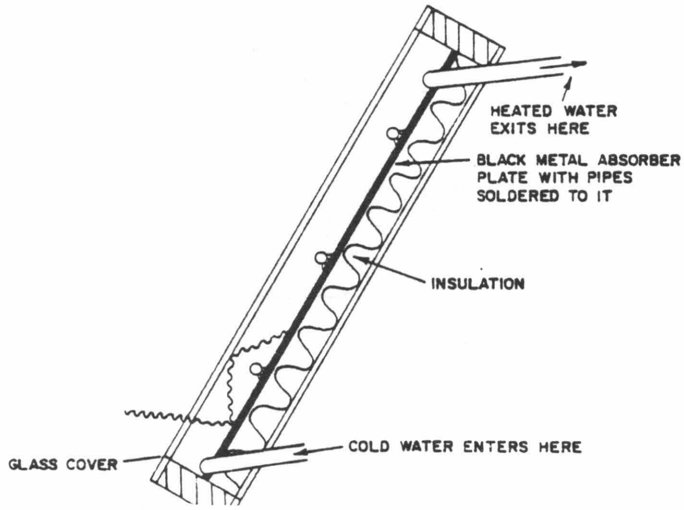


Figure 8: Typical Design of Liquid Collector

Concentrating collectors as depicted in Figure 9 and 10 may be used if higher temperatures are desired, but it should be pointed out that they do not increase the total amount of energy available. They simply heat a given quantity of liquid to a higher temperature. Designs like Figure 9 often are made to track the sun, so the focal point is always on the surface to be heated. The one in Figure 10 is not intended to track and is, consequently, less efficient. Concentrating collectors have been used for many years for a multitude of purposes such as cooking and for solar furnaces.

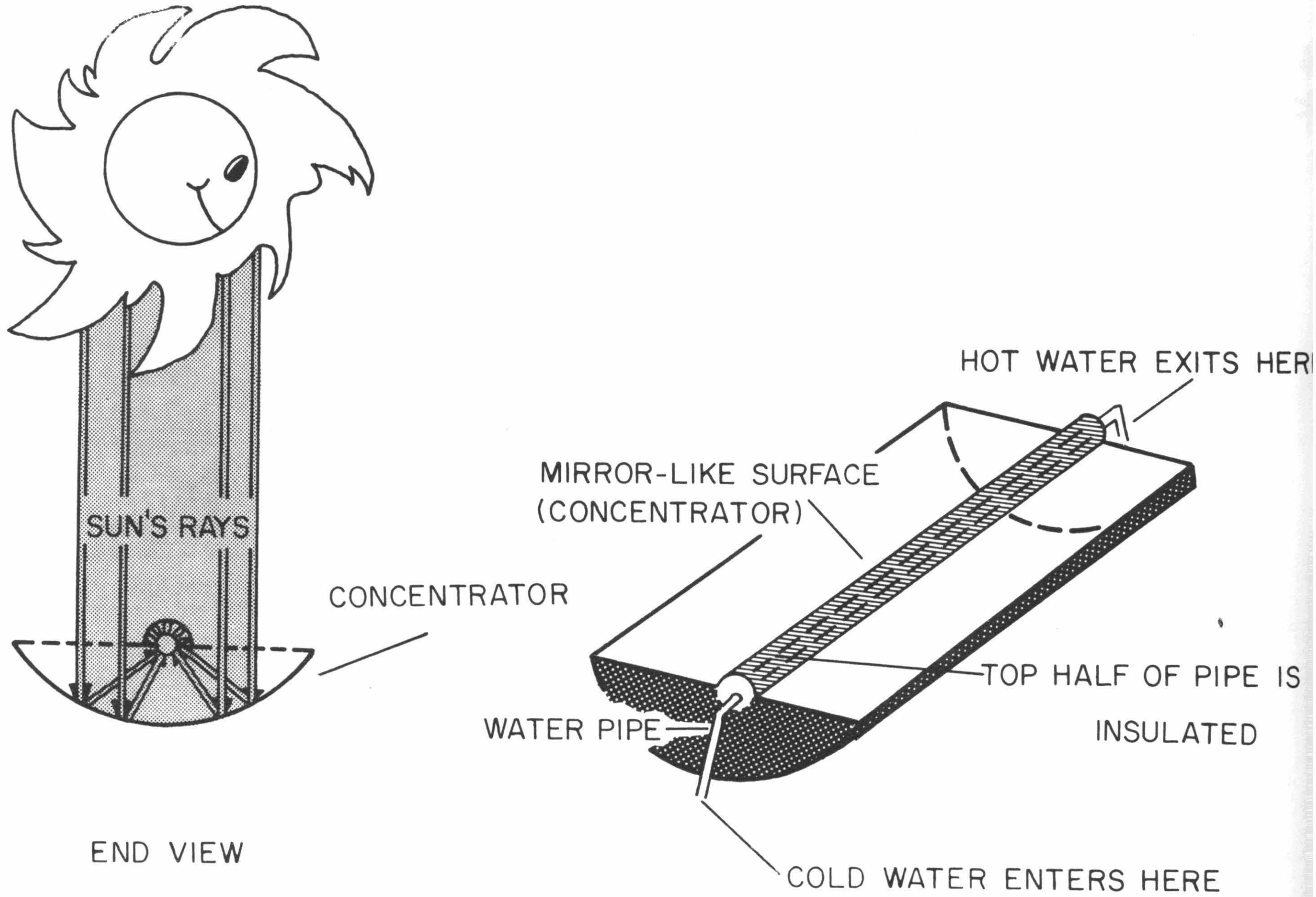


Figure 9: Concentrating Collector-Tracking

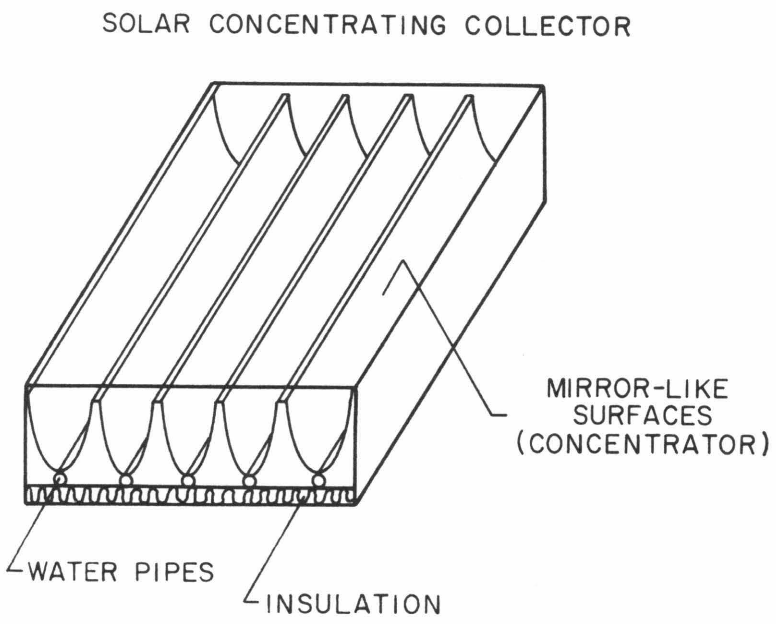


Figure 10: Concentrating Collector-Non-Tracking

COLLECTOR EFFICIENCY - Figure 11 is a curve of the efficiency of the collector vs. the temperature differential--that is, temperature out minus temperature in--of the fluid. This curve is typical for a great number of collectors. Notice that the higher the outlet temperature the lower the efficiency of the collector.

Efficiency can be improved by such things as double glazing, selective surfaces, excellent bonding and other good design characteristics. This curve shows that at a temperature differential of 80°, which is a typical operation, the efficiency of the collector would

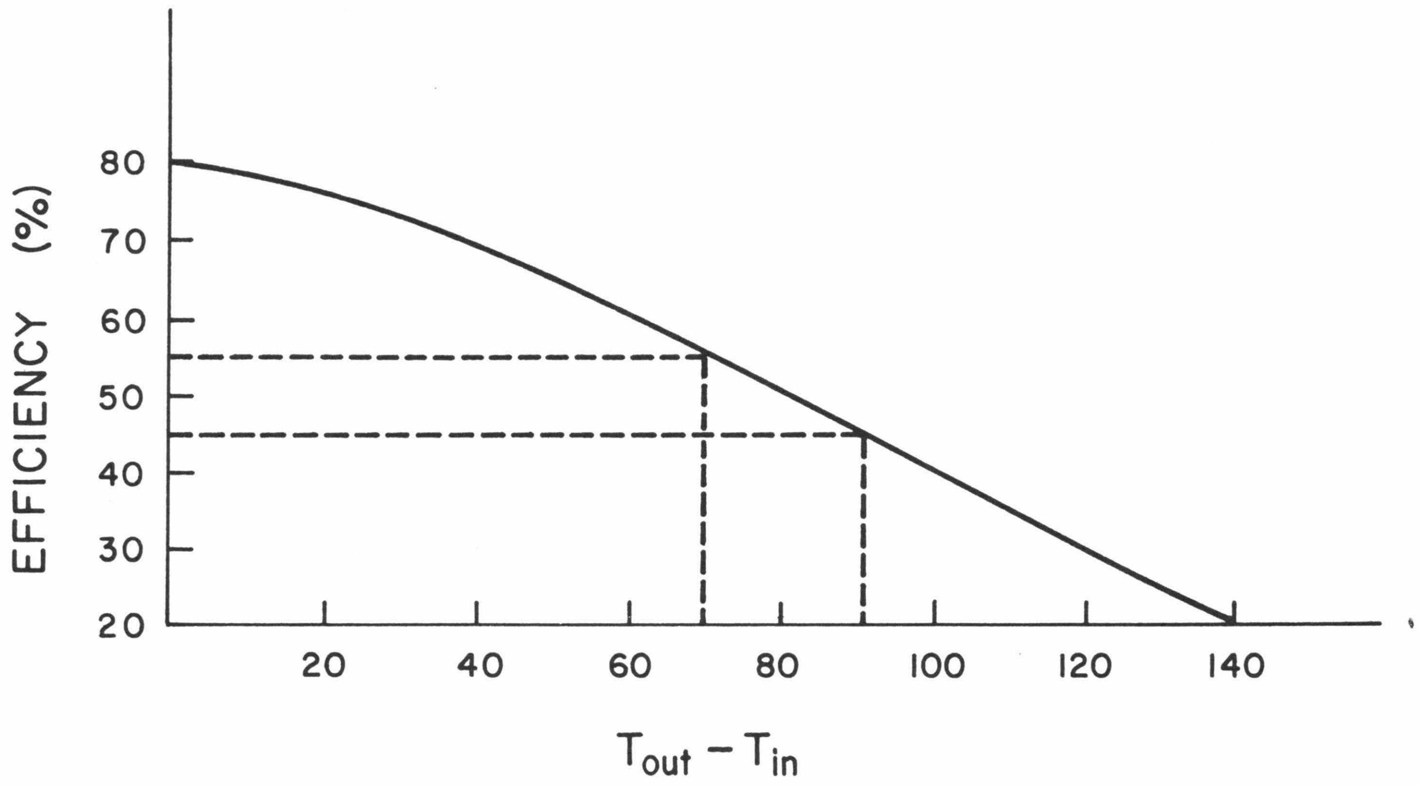


Figure 11: Effect of Operating Temperatures on Collector Performance

be 50%. Since this value varies constantly with the time of day and with the season, it is a rule of thumb number that can be used for a close approximation of the amount of energy available.

WATER HEATERS

Because they can be used for year-round operation, solar systems used to heat domestic water have the most economical benefit of any solar application. Such a system is basically simple once the technology is understood. A typical system with all of the necessary components is shown in Figure 12. These components are utilized to make the system both efficient and safe.

<u>SYSTEM COMPONENTS</u> - Because the pump is utilized just to circulate the water in the system, and is not required to pump against a significant head, it can be very small in size, even as low as 1/20th horsepower.

The differential thermostat controls the operation of the pump. There are two sensors associated with this unit, one located in the collector and the other in the storage tank. These sensors detect the temperature of these two units, and when the temperature of the collector exceed that in the storage tank by a preset amount, the differential thermostat turns the pump on.

The air vent is located at the highest point in the system and is used to purge the air out of the fluid

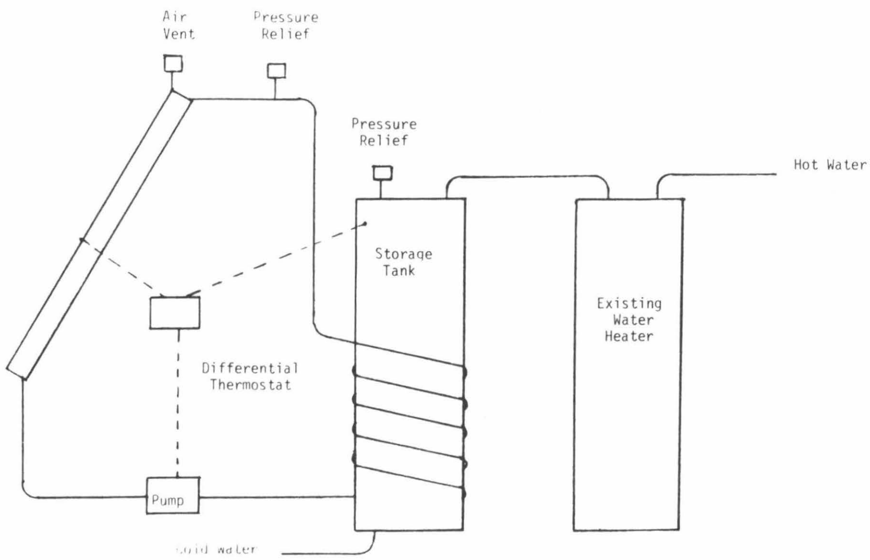


Figure 12: Typical Solar Water Heating System

and, thereby, prevents vapor locks which would disrupt the flow of fluid through the collector system.

The pressure relief valve is a safety device that prevents a build-up of excessive pressure if temperatures should become high enough to cause the fluid to boil.

The heat exchanger design depicted here has a double wall which is required in order to meet many building codes if nonpotable antifreeze is used in the primary circuit.

The storage tank for the solar heated water is in addition to the existing water heater. The cold water inlet is piped from the solar storage tank, so when the solar system is operating, hot or tempered water from this tank is supplied to the existing water heater where little or no additional energy must be supplied to bring the water up to the proper temperature.

FREEZE PROTECTION - In a liquid system, freeze protection is a major consideration. Several of the techniques used for freeze protection are discussed below:

• Antifreeze - One of the most common methods of freeze prevention is to use a system such as shown in Figure 13 with a proper amount of antifreeze added to the liquid flowing through the collectors. The disadvantage of this system is the added cost of the antifreeze plus the double wall heat exchanger that is required by building codes. Because of chemical degradation antifreeze may have to be replaced every few years.

• Drain Down - Figure 13 shows a system that simply allows the water to drain back down out of the collectors once the pump stops running. The major disadvantage to this system is that a pump with a higher head capacity is required. Care must be exercised to insure there are not low places to trap water.

• Dump Valves - Solenoid valves can be utilized in such a system such that when the temperature drops to near the freezing level they will automatically shut off the flow of water and drain the system. These valves are designed to automatically drain the system in case of power failure. This system is shown in Figure 14.

• Pump Control - By adding a control module to the system that turns the pump on when temperatures are near freezing, warm water from the storage tank is then circulated back through the panels. This has the disadvantage of cooling previously heated water and is not fail safe in case of power

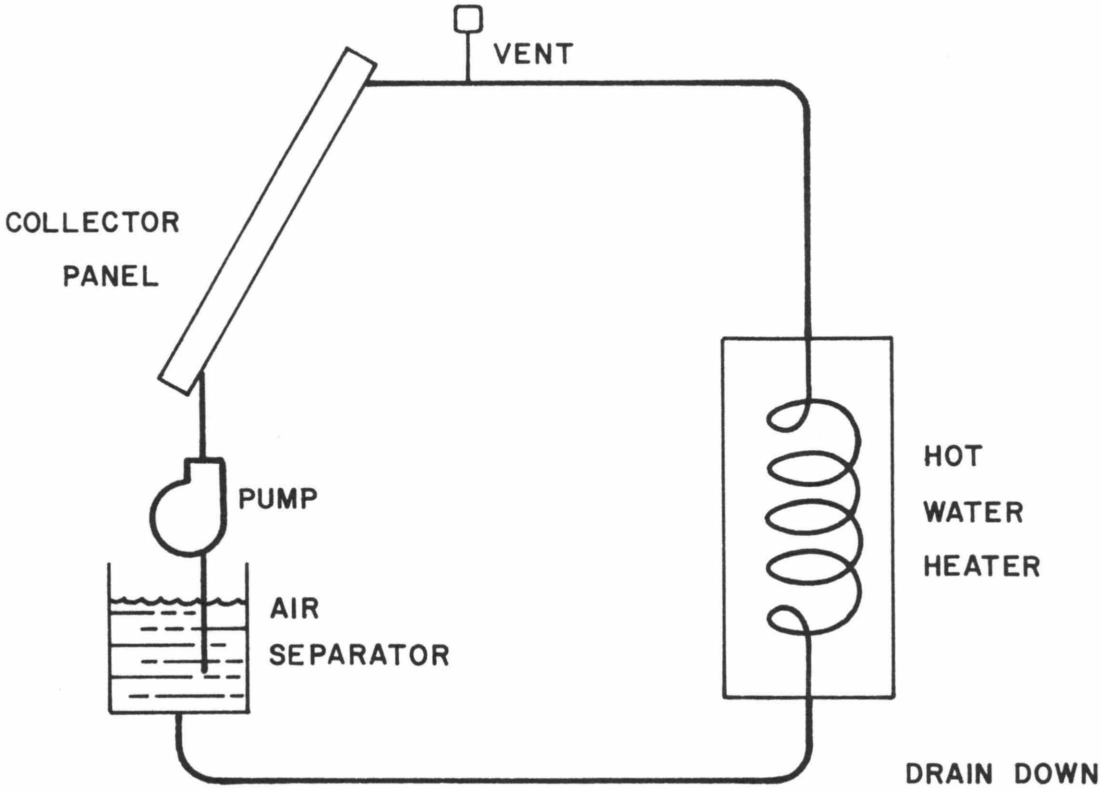


Figure 13: Drain Down System

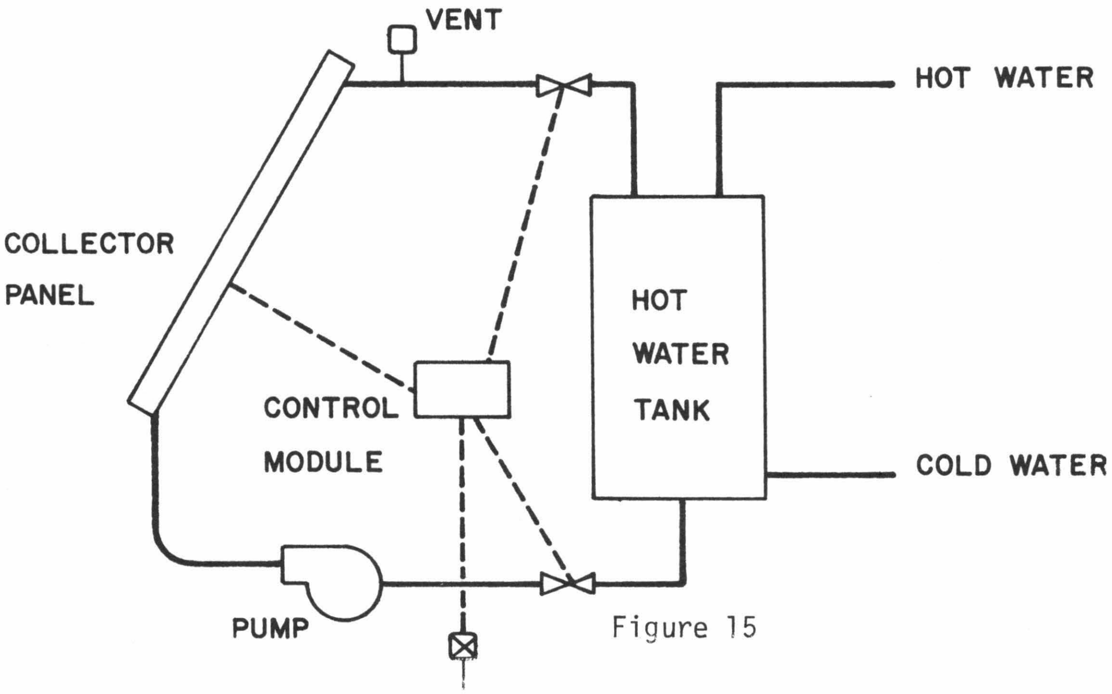


Figure 14: Dump Valve System

failure. However, experience indicates that except on the very coldest of nights a minimum of energy is required to prevent freezing.

· Air Panels - Another method of preventing freezing is to have an air collector blowing the heated air across an air-to-water heat exchanger with the system designed such that all plumbing is inside. Such a system has the advantage of being low cost, and the excess heat from the air can be dumped into the living space in the wintertime so as to provide some additional space heating. While skilled craftsmanship is required to build a liquid collector, air collectors are rather simple and can be built with a minimum of skill and tools. A schematic of an air-water heating system is shown in Figure 15.

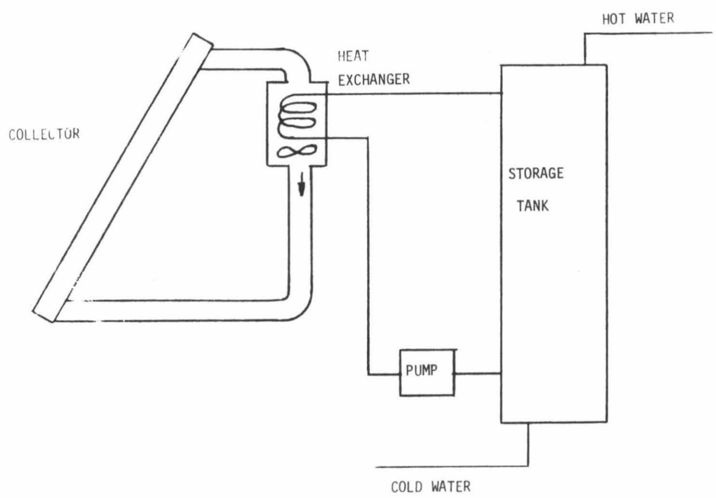


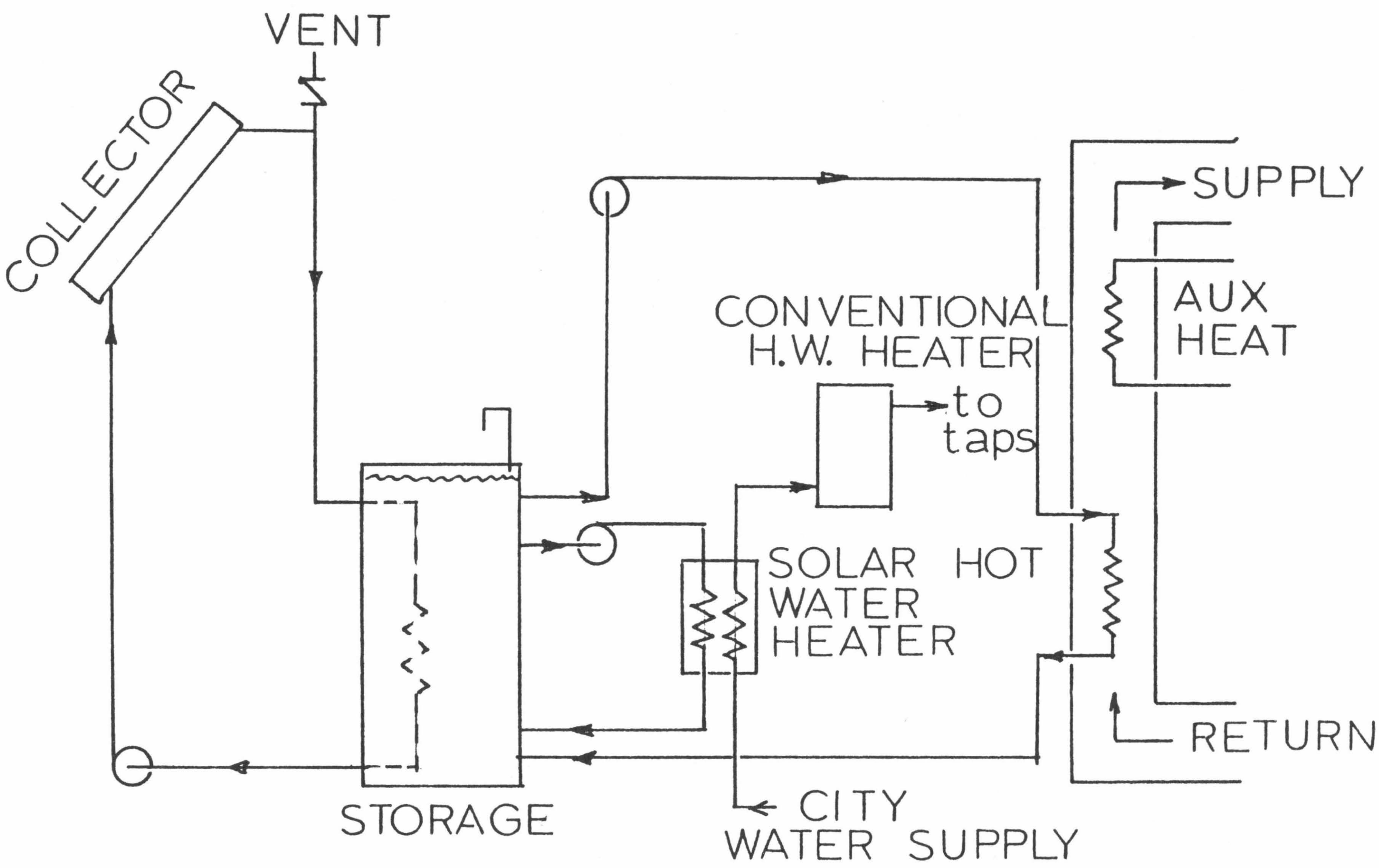
Figure 15: Air-Water Heating System

SPACE HEATING

Just as there are many options from which one may choose in designing a solar water heating system, there are even more available in the design of a space heating system. Only by understanding the basic technology of solar systems can one make intelligent decisions on the type best suited either for new construction or an existing home. The sun, of course, doesn't shine on one location twenty four hours a day. Neither does it shine every day. Therefore, a method for storing the energy collected when the sun is shining for use during night and overcast days is a vital part of a solar heating system. From an economic standpoint a storage capacity of three days without sunshine appears to be the upper limit. Since there are long periods of insufficient sunshine, a back-up heating system is required which adds to the total overall cost.

There are two basic systems utilized in space heating. One utilizes liquid and the other utilizes air. Each is discussed below.

Basic Liquid System - Figure 16 is a schematic diagram of a basic liquid system. The liquid is circulated by the pump up through the collector where energy is collected and



BASIC LIQUID SYSTEM

transferred to water in a large storage tank. Energy is then supplied from this large tank of water to two places. One goes to supplement the domestic hot water and the other is utilized in the space heating system. Any space heating system should also have provision for providing domestic hot water since this is utilized on a year-round basis and will improve the economics of the whole system. The energy from the stored water may at this point be utilized in a number of ways; such as having a heating coil directly in the heating duct line of an air system. The hot water may instead be passed through baseboard convectors, radiant panels, or conventional radiators.

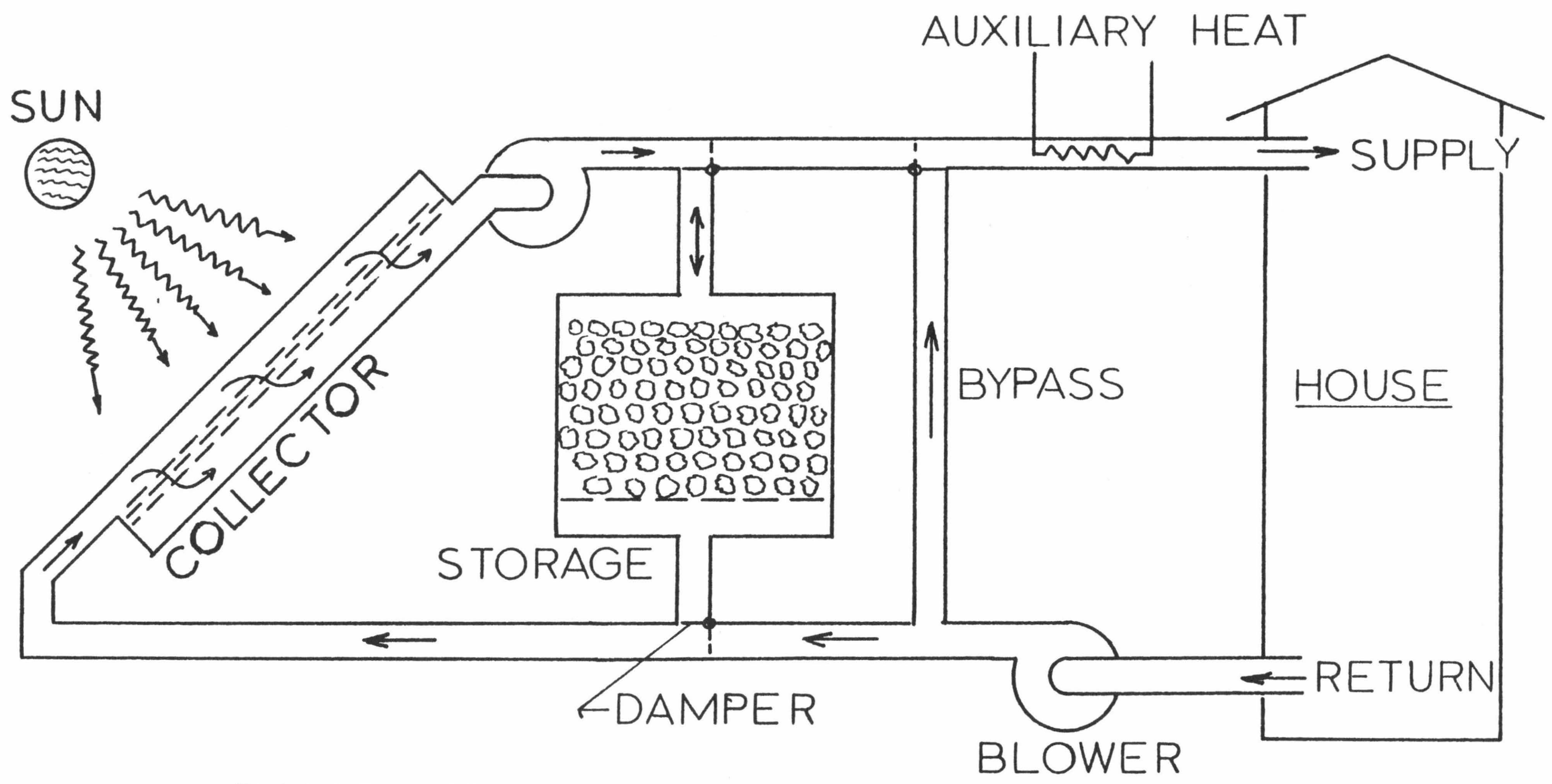
BASIC AIR SYSTEM - A schematic for a basic air system is shown in Figure 17. Rock storage is the most commonly used method of storing the collected energy. Provision for heating domestic water can be included by having either a tank or heat exchanger coils in the storage bin. Air systems are free from the freezing problems associated with liquid systems, but controlling and moving air is more difficult than liquid.

Air solar units without storage can be very economical if the price is kept to a minimum. Heat is provided, of course, only when the sun is shining. Window units are available commercially or can be built with limited skill, tools, and materials. These units can operate from a single window or from two windows. Figure 18 shows the details of a unit that is designed to mount vertically on a south wall of a two-story house. The fan is located inside a first floor window and the exhaust goes into an upstairs window. It can, of course, be utilized in other configurations such as between two windows on the same floor. A vertical mount causes approximately 15% less energy collection during winter as compared to mounting at an angle of latitude plus 10°, but mounting is easier and less conspicuous.

Individuals may wish to get into solar by first building themselves a simple window unit such as the one shown. This allows them to have a better conception of the energy available from solar and is an excellent method of testing materials and techniques that may later be incorporated into a larger system.

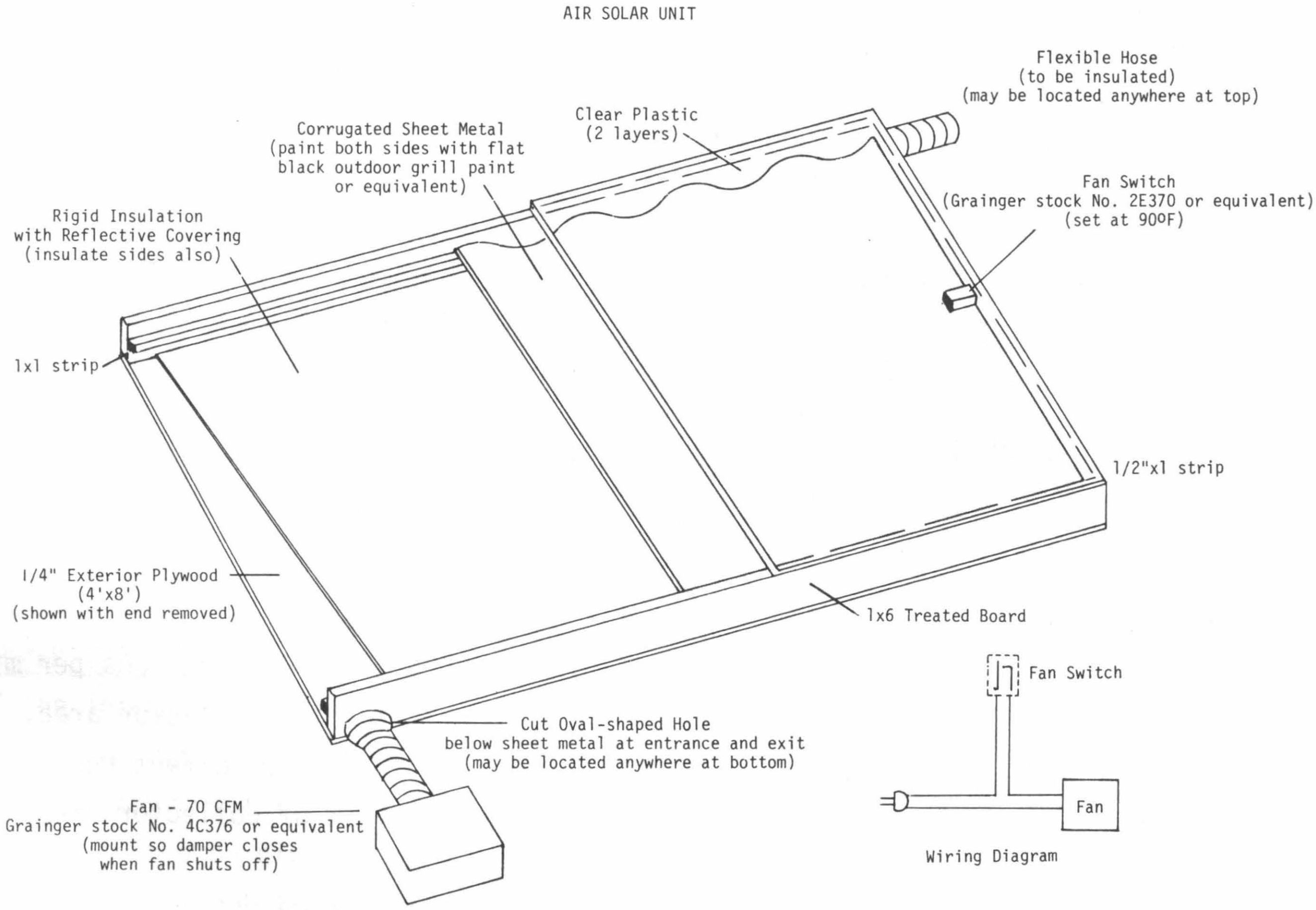
COSTS

Solar systems are expensive for two reasons. First, the basic materials used in them--such as aluminum and copper--are expensive. Increasing the production will not significantly lower the cost because so much of it



BASIC AIR SYSTEM

Figure 17



(W. D. Grainger, Inc., 2023 Salem Avenue, SW, Roanoke, VA 24016)

Figure 18: Window Air Collector

is in basic materials and will rise with inflation. At best, increased production may prevent a cost increase but not lower it. Second, because of the intermittent nature of available solar energy, a back-up system is required for space heating which causes the overall heating system cost to be expensive. As other energy costs continue to increase, the payback period for solar will decrease, but it is important that a good economic evaluation be made on any proposed solar system.

SIZING

Final sizing and design of a solar system should be done by a professional engineer with experience in solar system. Because the economics of space heating by solar is so marginal, any rule of thumb method which can easily be in error by 10 to 20 percent can have a serious effect on the economic analysis.

With this precaution, Chart I is given so that very rough estimate can be made for both space heating and domestic water heating.

CHART I

RULES OF THUMB FOR SOLAR DESIGN

SPACE HEATING

Recommend percent of energy to be supplied by solar = 50 - 80%.

Useful Energy Collected = 800 BTU's per sq. foot of collector area per day.

Collector Angle = latitude + 10°.

Water Storage Size = 1.5 - 2.5 gallons per square foot of collector area.

Rock Storage Size = 40 - 70 pounds of rock per square foot of collector area.

Collector Area Required = 25 - 40% of floor area.

FLOW RATES

Water = 0.02 gallons per minute per square foot of collector area.

Air = 2 cubic feet per minute per square foot of collector area.

DOMESTIC WATER HEATING

Collector Area = 12 square feet per person in household.

Water Storage = 20 gallons per person in household. (Recommended minimum design for 4 persons).

APPENDIX

DEFINITIONS

HEAT - Heat is a form of energy due to the rapid motion of molecules. All substances are composed of infinitesimally small units or particles called molecules which vibrate with great freedom when the matter is gaseous and with less freedom when it is liquid or solid. The temperature of a body is due directly to the vibration of these molecules. The more rapid they move, the higher is the temperature. If heat is applied to an open pan of water, the water molecules begin to vibrate at such a speed that they eventually break the surface tension of the water and boiling occurs.

TEMPERATURE - Temperature is an index of the intensity of heat. The Fahrenheit scale is the one presently and most commonly used in the United States. It is obtained by giving the value 32 to the freezing point and 212 to the boiling point of water. The Celsius scale, which is a part of the metric system, is being gradually introduced into our system and is based upon zero degrees as the freezing point and 100 degrees as the boiling point of water.

BRITISH THERMAL UNIT - The British Thermal Unit is more commonly known as a BTU and is the amount of thermal energy required to raise one pound of water, one degree Fahrenheit. This unit represents a definite and fixed quantity of thermal energy just as the foot is the unit of linear measure and a pound is a unit of weight. One BTU is approximately the amount of heat contained in a stick match. The average BTU content of some of the more common fuels are:[5]

COAL - 10,000 - 15,000 BTU's per pound

WOOD - 8,000 BTU's per pound

OIL - 140,000 BTU's per gallon (18,000 BTU's per pound)

GASOLINE - 20,000 - 20,500 BTU's per pound

NATURAL GAS - 900 - 1,400 BTU's per cubic foot

MANUFACTURED GAS - 500 - 600 BTU's per cubic foot

LIQUEFIED PETROLEUM GAS - 2,500 - 3,200 BTU's per cubic foot

KILOWATT-HOURS - Electrical energy is most often measured in kilowatt-hours. A watt is a unit of electrical power, and kilo equals one thousand. One kilowatt-hour of energy then means that 1000 watts of power was applied for one hour. This is equivalent to having ten one hundred watt light bulbs on for one hour. One kilowatt-hour also equals 3,413 BTU's.

K - COEFFICIENT OF THERMAL CONDUCTIVITY - The coefficient of thermal conductivity, most often represented as the letter, k is the number of BTU's transmitted per hour through one square foot of material an inch thick with the difference of one degree Fahrenheit between the two surfaces. In selecting a good insulating material, one would look for the lowest possible value of k. Some of the better insulating materials will have a value of 0.25 BTU/°F/Ft.^{2}/°F or less. Building materials will have a range of k values from 0.25 to 12.0.

RESISTANCE - Resistance is the term most commonly used to express the insulating value of materials. It is the reciprocal of thermal conductivity, so a material with a thermal conductivity of 0.25 then would have a resistance of 4. The greater the R value, the better the insulating value. The R value is normally indicated on the insulation material itself or in charts, and is either per inch of thickness of the material or for a listed thickness of material. R values for various building materials are as follows:

	R Per inch thickness
1. Bath and Blanket Insulation	3.1-3.7
2. Fill type Insulation	2.9-4.1
3. Building Materials	
Brick	0.11
Concrete	0.08

DEGREE DAY - If the thermostat for an average house is set for 72°F on a da when the temperature is 65°F outside, the house needs no additional heat be- cause heat from the occupants, appliances, lights, and other sources main- tain this comfort level. So, for suc a day, we say the number of heating d gree days accumulated for that day is zero. If the average temperature for the day is 64°F, then we have accumulated one degree day. For average temperature above 65°F no degree days are accumulated.

By adding the total number of degree days for all the days of the year with an average below 65°F we arrive at a measure of the need for energy for heating for a whole season The total number of degree days accum lated over a heating season are tabulated by the Weather Bureau and are available for several localities. Some averages across the state are given below:

LOCATION	DEGREE DAYS
Abingdon	4,000
Blacksburg	5,000
Charlottesville	4,200
Richmond	3,800
Norfolk	3,400

METHODS OF HEAT TRANSFER

Heat always seeks the lowest temperature level; therefore, the transfer of heat always takes place, or is said to flow, from a warmer to a colder body. This transfer may take place by one or more of three methods, namely;
(1) conduction, (2) convection, and
(3) radiation.

CONDUCTION - When heat is transferred by conduction it passes from one part of a body to another part without any relative displacement of the molecules of that body. The molecules which first receive the heat are vibrating more rapidly and give up a portion of their energy to the less rapidly moving molecules. In this way, the energy or heat is passed along during the collision process from one part of the body to another without any change in the exact position of the parts of the body. By placing one end of a metal bar or rod in a flame, a gradual increase of the temperature of the bar will be noted at all points along the bar. The heat then is being transferred through the bar by conduction. The transfer of heat through solid building materials takes place principally by conduction.

CONVECTION - The process of heat transfer by convection applies to liquids and gases. Convection is the transfer of heat by moving matter; for example, the heated air rising from a register of a warm air heating system. The heat has thus been transferred from one place to another by means of the actual transfer of a part of the air.

RADIATION - Radiation is a process by which heat is transmitted through space with or without the presence of matter. While heat is being transmitted in this way, it is called radiant energy and is not heat. This radiant energy is a form of electromagnetic wave motion, and is similar to light and electrical radio waves, the essential difference being in the wave length. The transfer of heat by radiation is analogous to a transfer of sound by radio. Sound is produced in a broadcasting studio and changed to radio waves by means of the sending apparatus of the broadcasting station. While these radio or electrical waves are being transmitted, they are not sound, but rather a form of radiant energy of various wave lengths. These waves are caught or absorbed by the aerial of the receiving set and reconverted to sound waves by means of the radio.

In a similar manner, heat is emitted from a hot surface or body in a form of radiant energy. This energy is then transmitted by waves until it comes in contact with colder surfaces or objects which are in a line of sight with the emitting surface. The receiving surfaces absorb a part of the radiant energy and convert it back to heat. All energy from the sun is received in the form of radiant energy. The amount of energy actually absorbed by a receiving surface is dependent upon the characteristics of that surface.

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