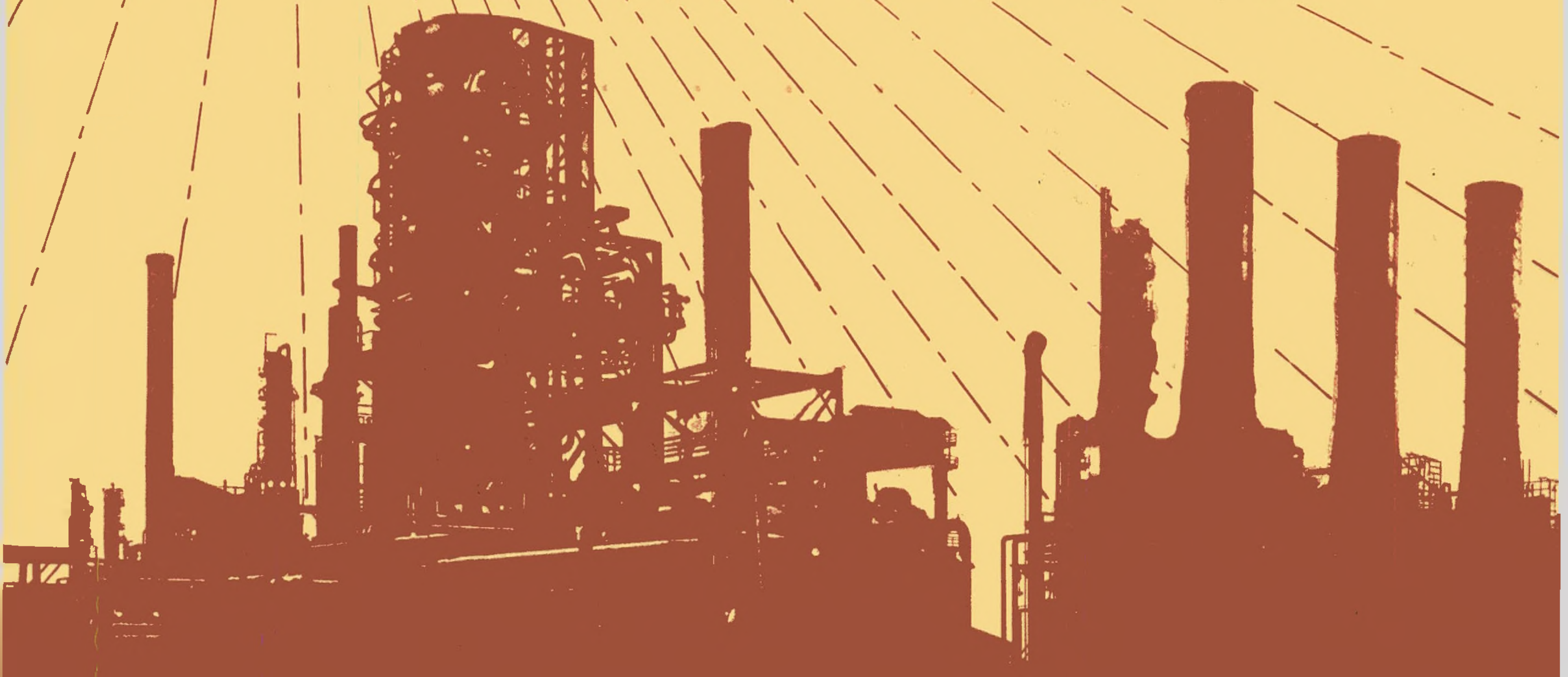
American Institute of Plant Engineers

Plant Engineers

SOLAR ENERGY HANDBOOK

Southern California Region



Department of Energy · United States of America

SOLAR TECHNOLOGY TRANSFER PROGRAM

LLL/M-087

PLANT ENGINEERS

SOLAR ENERGY HANDBOOK

SOUTHERN CALIFORNIA REGION

PREPARED FOR THE

SOLAR WORKSHOP FOR THE PLANT ENGINEER

MARCH 30, 1978

COSPONSORED BY

LOS ANGELES CHAPTERS OF THE

AMERICAN INSTITUTE OF PLANT ENGINEERS

U. S. DEPARTMENT OF ENERGY - SOLAR TECHNOLOGY TRANSFER BRANCH

DIVISION OF SOLAR TECHNOLOGY

UNIVERSITY OF CALIFORNIA
LAWRENCE LIVERMORE LABORATORY
TECHNOLOGY APPLICATIONS GROUP
LIVERMORE, CALIFORNIA 94550

NOTICE

ACKNOWLEDGMENTS

This handbook has been prepared by the Technology Applications Group (TAG), Lawrence Livermore Laboratory, Livermore, California, for the "Solar Workshop for the Plant Engineer," held at the Roger Young Center, Los Angeles, California, on March 30, 1978. The general coordination of the project has been by Herbert Newkirk (TAG). The compiling and subsequent editing of a greater part of the original text (handbook for the San Francisco Bay Area) were performed by Yvonne Howell, Technical Information Department, Lawrence Berkeley Laboratory, with the assistance of Harry Miller, Solar Energy Group, Lawrence Berkeley Laboratory. Editorial review and revision of the original text for use in this handbook for the Southern California Region were provided by Brian Jarman (TID) and Herbert Newkirk (TAG), Lawrence Livermore Laboratory, and the workshop speakers.

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AGENDA

SOLAR WORKSHOP FOR THE PLANT ENGINEER

DATE: March 30, 1978

PLACE: Roger Young Center
Los Angeles, CA

8:00 - 8:15 a.m.	REGISTRATION	
8:15 - 8:20 a.m.	WELCOME - Otto Bombach, President, Western Region No. 6, American Institute of Plant Engineers	

MORNING SESSION

8:20 - 8:30 a.m. INTRODUCTION

Herbert W. Newkirk, Technology Applications Group
Lawrence Livermore Laboratory

A brief review of the handbook contents, emphasizing information sources and service contacts.

8:30 - 9:00 a.m. NATURE OF THE SOLAR ENERGY SOURCE

Herbert W. Newkirk, Technology Applications Group, Lawrence Livermore Laboratory

Direct and diffuse radiation; seasonal, daily, and hourly variations in insolation; the effect of collector tilt and orientation; and solar data available for system design and analysis.

9:00 - 9:45 a.m. AN OVERVIEW OF COLLECTORS

James Senn, Sennergetics

Various collector types and applications - nonconcentrating and concentrating; the effect of glazing and absorber plate coatings on collector efficiency and performance; and heat transfer considerations.

9:45 - 10:00 a.m. COFFEE BREAK

10:00 - 10:30 a.m.	OTHER SOLAR SYSTEM COMPONENTS James Senn, Sennergetics Heat storage materials; storage tanks; heat exchangers; expansion tanks; differential thermostats; flow control; pumps and valves.
10:30 - 11:00 a.m.	UPDATE ON CODES, STANDARDS, AND LEGISLATION Howard Kraye, Conserdyne Corporation Testing, codes and standards, such as ASHRAE 93-77 and 94-77, affecting usage of solar energy; current tax credit legislation.
11:00 - 11:45 a.m.	SYSTEM CASE STUDY - RETROFIT INDUSTRIAL PROCESS (190°F) HOT WATER Jorgen Vindum, Acurex Corporation Campbell Soup Company Plant, Sacramento, California Experience, design, cost, installation and operation; lessons learned.
11:45 - 12:00	QUESTIONS AND DISCUSSION
12:00 - 1:00 p.m.	L U N C H
1:00 - 1:45 p.m.	SYSTEM CASE STUDY - RETROFIT HOT WATER DEMONSTRATION Eric Burnett, Aratex Services, Inc. Red Star Industrial Service Laundry, Fresno, California Experience, design, cost, installation and operation; lessons learned.

1:45 - 2:30 p.m.	SYSTEM CASE STUDY - NEW CONSTRUCTION: ENERGY CONSERVING FEATURES: HEATING, COOLING AND DOMESTIC HOT WATER Bruce Hunn, Los Alamos Scientific Laboratory National Security and Resources Study Center Los Alamos, New Mexico Experience, design, cost, installation and operation; lessons learned.
2:30 - 3:15 p.m.	SYSTEM CASE STUDY - THE SOLAR TOTAL-ENERGY TEST FACILITY James Leonard, Sandia Laboratories Solar Total-Energy Test Facility Division Albuquerque, New Mexico Experience, design, cost, installation and operation; lessons learned.
3:15 - 3:30 p.m.	COFFEE BREAK
3:30 - 4:15 p.m.	HOW BIG A SYSTEM? George Sauter, Technology Applications Group, Lawrence Livermore Laboratory A detailed explanation of a methodology for sizing collector systems and for analyzing the thermal performance of a typical solar system.
4:15 - 5:15 p.m.	DOES IT MAKE CENTS? George Sauter, Technology Applications Group, Lawrence Livermore Laboratory A detailed explanation of a methodology for the economic analysis of a typical solar system; differential life cycle costs and fuel savings.
5:15 - 5:30 p.m.	PANEL DISCUSSION
5:30 p.m.	ADJOURNMENT

TABLE OF CONTENTS

INTRODUCTION

Solar energy represents a huge and virtually inexhaustible resource that is widely available over the United States, including Southern California. Estimates indicate that it can supply 25% of the nation's future energy needs by 2020 if costs of collecting and using solar energy can be reduced substantially.

In support of national RD&D goals in this field, the Department of Energy (DOE), Solar Technology Transfer Branch, Division of Solar Technology, has organized and manages a program to effect the timely transfer of Solar RD&D results to researchers, users, businessmen, and industry through information and technology transfer activities. Selected DOE National Laboratories have been designed to function as regional field representatives for the Solar Technology Transfer Program (STTP) of DOE and to provide easy direct access to the program from the field. These information and transfer functions utilize commercial sector avenues (trade associations, professional and nonprofessional organizations, manufacturers, publishers, marketing organizations, media) to catalyze the growth of solar energy activities. This handbook is one example of the ongoing information dissemination efforts by DOE to facilitate an effective commercialization program. It was designed and developed by the Lawrence Livermore Laboratory (the Western Regional Representative for STTP) for the Southern California Region, specifically as a source of supplementary information for attendees at the "Solar Workshop for the Plant Engineer" held at the Roger Young Center, Los Angeles, California on March 30, 1978.

The purpose of this handbook is to provide plant engineers with factual information on solar energy technology and on the various methods for assessing the future potential of this alternative energy source.

Discussed in order after the introduction are solar components and systems (collectors, storage, service hot water systems, space heating with liquid and air systems, space cooling, heat pumps and controls); computer programs for system optimization; local solar and weather data; a description of buildings and plants in Southern California applying solar technology; current Federal and California solar legislation; standards, codes and performance testing information; a listing of manufacturers, distributors, and professional services available in the Southern California region; and information access. Finally, the last section provides solar design check lists for those engineers who wish to design their own systems.

Hopefully, the handbook provides enough information to prepare an in-depth analysis of the economic feasibility of solar heat utilization for a plant facility.

SOLAR COMPONENTS AND SYSTEMS

SOLAR COMPONENTS AND SYSTEMS

SUMMARY

In the Southern California area, the total solar energy striking the roof of a building during a year is adequate to supply all the space heating, hot water needs, and cooling of the building — it it could all be collected. Several types of solar collectors have been devised to catch a part of this energy and put it to work. These usually rely on a black energy-absorbing surface that heats up when the sun shines. The heat is transferred to water or air which carries the heat to where it is needed.

Since energy can be collected only on sunny days, any excess energy is transferred to a storage system (which can be water, rock, or chemicals) for use at night and during cloudy periods. Most solar systems include a back-up heater that uses conventional fuel, which takes over when the stored solar heat runs out.

A delivery system is needed between the collector or storage, and the water heater, the swimming pool, or the rooms of the building. Controls are usually necessary to regulate the flow of heat; these can be thermostats, valves, dampers, or shutters, and can be either hand-operated or automatic.

SOLAR COLLECTORS

The purpose of solar collectors is to intercept (collect) solar radiation and transform radiant solar energy into heat energy. For heating systems, the heat energy is then transferred to a fluid, transported into the building, and either used directly to heat service water and the building space or stored for later use. For space cooling systems, the heat energy is applied either directly or indirectly, depending on the type of system: refrigeration (direct), evaporative cooling (indirect), and radiative cooling (indirect).

A collector that has the same solar-energy intercepting area as absorbing area is called a flat-plate collector. A collector that concentrates direct radiation from a larger intercepting area to a smaller absorbing area is called a concentrating collector. Concentrating collectors are not yet considered practical for residential solar systems, although they hold promise for high-temperature applications in cooling. When very high-temperature over ($200^{\circ}F$) heat is required, to generate steam for process heat in industry or to operate steam turbines to develop mechanical power, concentrating collectors become more cost effective and are more generally used in these applications than are flat-plate collectors. For residential and small commercial solar-energy systems, flat-plate collectors can produce heat at sufficiently high temperatures to heat the building and operate the cooling unit. Many types of flat-plate collectors are being manufactured today and are available in quantity for commercial applications.

Flat-Plate Collectors: Basic Components

Absorber plate. A sheet of copper, aluminum, steel, or plastic, with a heat-absorbing coating, is used to collect the solar radiation, convert it to heat, and transfer the heat to the working fluid. Factors which affect the performance of absorber plates include the tube spacing, the thermal bond between tube and plate, and the materials used.

Cover plate(s). One or more transparent sheets of glass or plastic may be attached 1/2 to 1 inch above the absorber plate to retard radiative and convective heat loss. The glazing material must be transparent to shortwave sunlight but opaque to longer-wavelength heat which is reradiated from the absorber plate. Glass, fiber-glass reinforced plastics, Plexiglas, and thin plastic films have all been used successfully in this application. Criteria to be considered when selecting a glazing material include: transmissivity, cost, weight, resistance to ultraviolet degradation, tensile strength, and breakability.

Insulation. A material with high resistance to heat flow should be used to retard conductive heat losses through the back and sides of the collector. Selection criteria for insulation material are: stability at high temperatures (stagnation temperatures may reach as high as 450°F, causing some materials to outgas or deform) compatibility with dampness from condensation, and thermal resistance.

Collector Efficiency

The efficiency of solar collectors is generally defined as the *ratio of useful heat delivered from the collector over any time period to the incident solar energy over the same time period.* Typical flat-plate collector efficiencies may vary from 0 to 80%, depending upon fluid and ambient air temperatures and the insolation rate. When the rate of fluid flow through the collector is low, the fluid heats up to a high temperature, as does the absorber plate. Since heat loss is directly proportional to the difference (Δt) between the plate temperature and ambient temperature, high absorber-plate temperature leads to large heat losses from the collector, with consequential low collector efficiency. Conversely, with a high fluid-flow rate through the collector, the fluid and absorber plate temperatures are low, heat losses are low, and collector efficiencies are high. At normal fluid temperatures of 100 to 140°F in an operating system, efficiencies of 35 to 50% are typical for a flat-plate collector.

Number of covers. Collector efficiency is affected not only by fluid and ambient temperatures but also by the number of transparent covers and the type of black coating on the absorber plate. If the collector has only one transparent cover, the amount of solar radiation reaching the absorber plate will be greater than if it had two cover plates. However, in areas of the country with cold ambient air temperatures during the winter, heat losses from the absorber through the top cover plate are greater than the additional solar energy gain, making a collector with only one transparent cover less efficient at higher temperatures than if it had two covers. Adding a third cover plate further reduces the heat losses but reduces the solar energy reaching the absorber plate by a greater amount, with the net result that collector efficiency can be less. For swimming pool heating, unglazed collectors are usually less costly and can be used in summertime or, where winds are not severe, in wintertime.

Coatings. A flat-black paint absorbs a high percentage of the solar radiation incident on the absorber plate. Absorptances of 92 to 96% are typical; but such coatings also have a high emittance--generally almost equal to the absorptance. Thus when solar radiation is absorbed and converted to heat, the hot absorber plate radiates away a large amount of heat energy, the amount depending on the temperature of the plate. When high temperatures in a collector are important, a "selective" black coating is essential--such as black nickel, black chrome, or copper oxide--and the absorptance of solar energy remains high while the emittance of heat energy is low. With a selective coating on the absorber, the collection and conversion of solar energy to heat are high while heat loss by radiation is low, which increases collector efficiency. Many types of selective surface coatings are commercially available, but most involve processes that add substantially to the cost of manufacturing the collectors. Within the next few years, improvements in materials and methods of application may make selective surfaces more economical for flat-plate collectors.

Performance data. Most of the manufacturers of solar collectors provide performance data on their equipment. Some of this information is derived from measurements made by the manufacturer; other data, which also may be available, are procured by independent testing organizations. Since the efficiency of a solar collector is highly dependent on the test conditions, meaningful results require full specifications of the significant variables.

Collector tilt and orientation. The optimum tilt angle for solar collectors depends on site latitude and on application. The collector should be kept at an angle as close as possible to normal (perpendicular) to the incoming solar radiation. Since the average angle formed between the earth-sun line and a horizontal plane will be different for each latitude on a given day, optimum collector tilts will vary with latitude.

Most collectors are permanently mounted at a single angle to provide a secure, stable installation. The rules-of-thumb for the tilt angle for specific applications are as follows:

- Pool heating: latitude angle -10 to -15°. In the summer swimming season, the sun is high in the sky and the collector tilt angle is rather flat. In the winter swimming season, a higher tilt angle is required.
- Service water heating: latitude angle.
- Space heating: latitude angle +10 to +15°. The collector now faces the winter sun, which is lower in the sky.

A deviation of ± 10° from the optimal collector tilt angle will not result in a significant deterioration of performance in most applications. A deviation of ± 20° from the optimum collector orientation (due south) can be tolerated without a significant performance penalty.

Shading. Collectors should be mounted so that no adjacent building or landscaping can ever block any of the incident radiation from reaching the collector during the useful collection hours (9 a.m. to 4 p.m.). Moreover, when collectors are mounted in rows (or banks), care must be taken to avoid shading part of one row with the collectors in front of it. The usual design criterion is to arrange the collectors so that they are unshaded from 10 a.m. to 2 p.m., solar time, on December 21 when the sun is at its lowest position in the sky.

Liquid-Heating Collectors

In liquid-heating flat-plate collectors, heat is transferred from the hot absorber plate to the heat transport fluid by conduction and convection. The liquid flows through tubes that should be in good thermal contact with the absorber plate. Because the rate of heat conduction through the metal absorber is much greater than the rate of heat transfer into the fluid, it is sufficient to have the liquids flow through tubes spaced a few inches apart on the absorber plate. Tube spacing is a function of the thickness and material of the absorber plate. The tubes can be bonded to the plate, or passages can be incorporated into the plate. Figure 1 displays some common collector configurations.

An alternative method for heat transfer to a liquid is to trickle the liquid over the absorber plate. The disadvantage of this type of

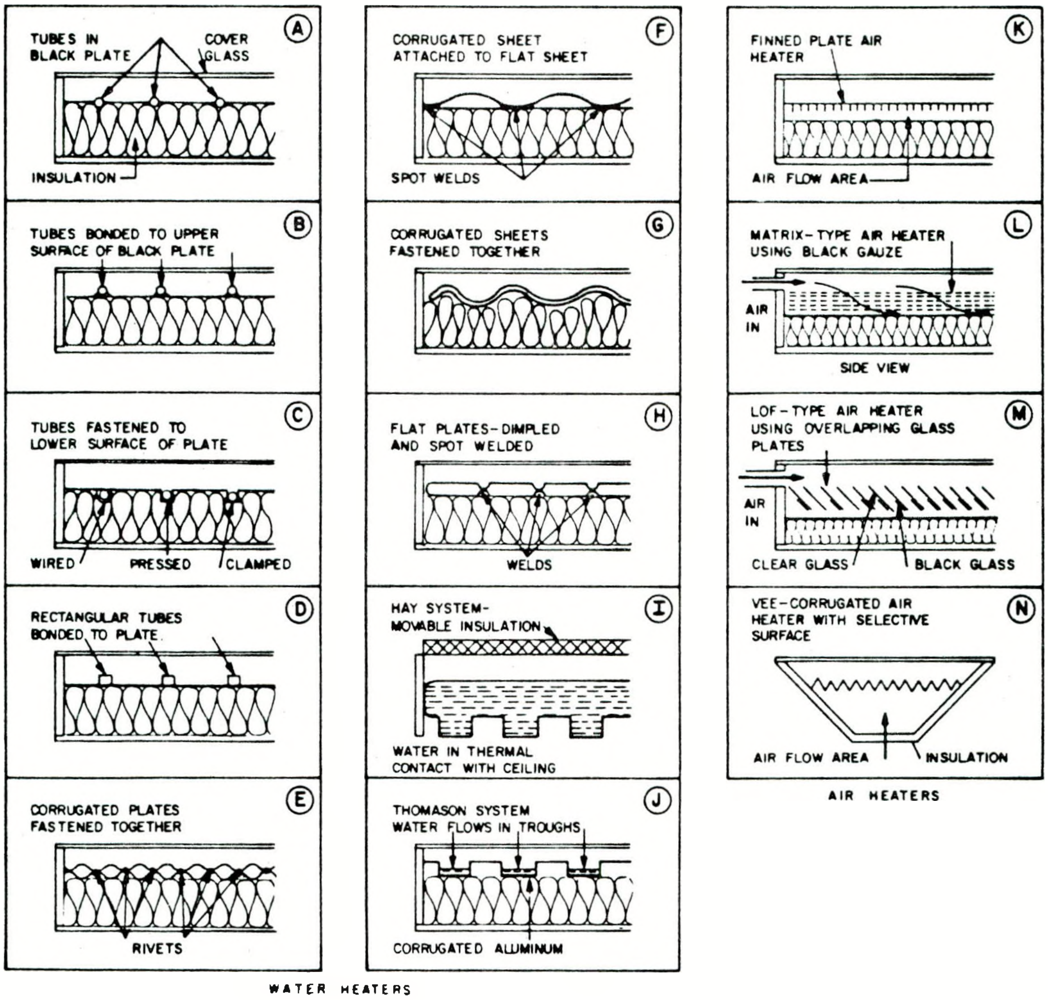

Fig. 1. Common collector configurations. (From John I. Yellott, "Solar Energy Utilization for Heating and Cooling," in the ASHRAE Applications Handbook.)

collector is that for a reasonable collector efficiency of about 30% the liquid temperature is limited to about $110^{\circ}F$; with higher temperatures the efficiency drops rapidly. The major advantage is that trickle-type collectors are self-draining, so freeze protection is not needed.

Freeze protection. Water is by far the most economical liquid to use in liquid-heating solar collectors. But since freezing occurs in both mild and cold climates, some sort of precaution must be taken to protect the collector from freezing.

Antifreeze. Propylene glycol is a satisfactory antifreeze additive and less toxic than ethylene glycol. A 30 to 40% solution will prevent freeze damage to collectors in most of the United States. The addition of propylene glycol also reduces the specific heat of the solution; but the reduction can be compensated by increasing the mass flow rate, with slightly greater expense for pumping.

When antifreeze solutions are used in a collector system, it is economically advantageous (and may be mandatory when interfacing with the potable water supply) to separate the fluid flowing through the collectors from the water flowing into the heat-storage tank, as shown in Fig. 2; a double-metal barrier between the antifreeze and the potable water is an absolute necessity. A counterflow heat exchanger transfers the heat from the collector loop to the storage loop. The volume liquid in the collector loop for domestic water heating will be about 10 gallons for a normal residential installation (while the volume in storage for space heating will be about 1000 gallons). Because freeze protection is required only in the collector loop, the quantity of antifreeze needed for a 40% concentration is 4 gallons. If the flow loops were not separated, the cost of the antifreeze needed for the large total volume would be prohibitive. It should be mentioned, however, that use of a heat exchanger will result in a loss of efficiency.

Drain-down. An alternative type of freeze protection is an automatic drainage arrangement whereby the water in the collector automatically drains into the storage tank whenever the pump is not operating. Air entering the collector increases corrosion rates, however; and the total drainage of the collector must be assured without fail.

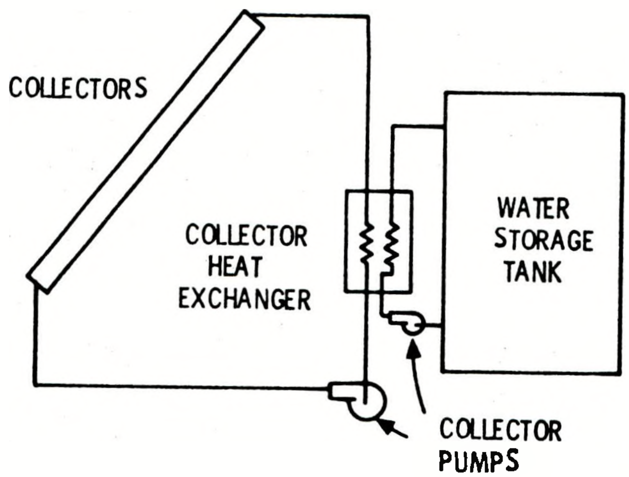

Fig. 2. Service hot-water system with heat exchanger. In systems where the heat exchangers is an integral part of the storage tank, a second pump is not required.

The drainage system shown in Fig. 3 is actuated by a temperature sensor either in the collector itself or in the atmosphere. When the sensor indicates a possibility of freezing, the drainage and vent valves open, draining the fluid and thereby providing protection. The temperature sensor can be of the vapor-pressure type with capillary-tube connections to mechanical valve actuators, or of the electrical type in which the valves are held open by electrical means, automatically closing either when electrical failure occurs or at low temperatures.

The collector can also be drained as shown in Fig. 4. In this unpressurized system, a float valve in the storage tank controls the admission of cold water to the tank; and a pump in the hot-water distribution system can furnish the necessary service pressure. This design permits air to enter the collector through a vent, draining the water into the storage tank whenever the pump is not operating.

Recirculation. Another freeze-protection scheme is to circulate heated water from storage through the collector. This is accomplished by use of a "freeze-cycle" on the differential controller, which will activate the pump when the temperature approaches freezing. When the absorber plate reaches a safe warm temperature, the pump is de-activated. The disadvantage is that the loss of stored heat could become significant in an environment which required frequent use of the freeze cycle. This can happen, even in mild climates, since at night the collectors can often be several degrees below the general ambient temperature.

Corrosion protection. Corrosion inhibitors should be added to the water if the absorber plate is aluminum or steel. If an antifreeze additive is used that does not provide for corrosion protection, or if pure water is used in the collector loop, corrosion inhibitors should be added (depending upon system metals).

Flow rates. The rate of useful heat delivered from the collector depends on the mass flow rate of the fluid through the collector. If the flow rate is constant, the temperature rise of the liquid through the collector will vary during the day as the solar radiation increases until midday and decreases afterwards.

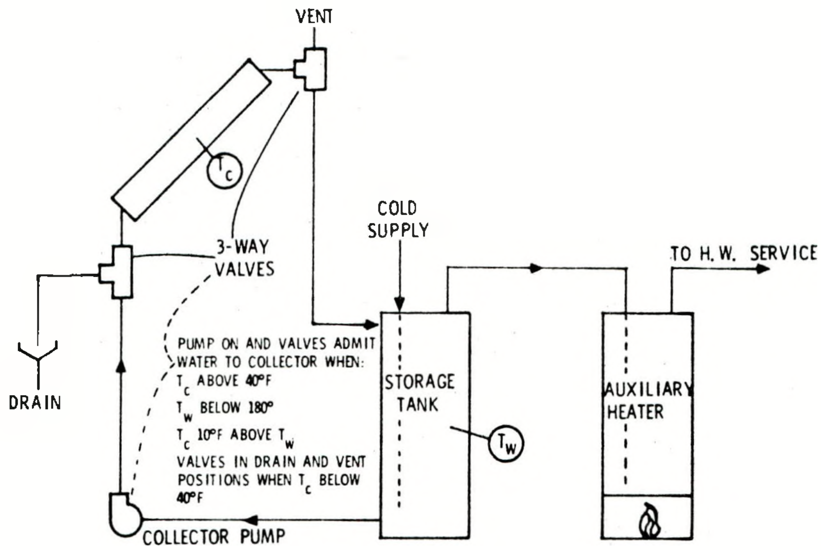

Fig. 3. Solar water heater with freeze protection by automatic collector drainage.

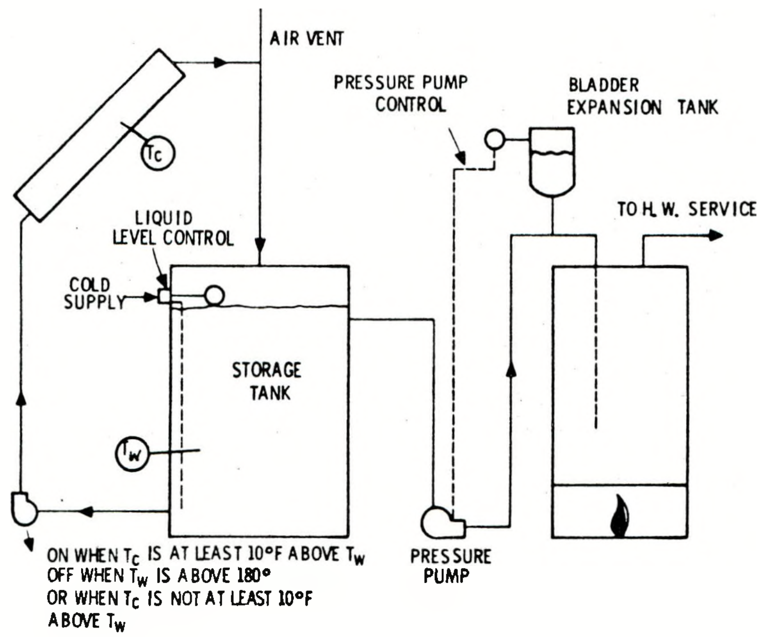

Fig. 4. Unpressurized vented solar water heater system.

A flow rate lower than 0.02 gal/min per square foot will create a greater temperature rise in the transport fluid and consequent reduction of collector efficiency; a flow rate greater than this value will result in a lower temperature rise and increased efficiency, but more pumping power will be required to circulate the fluid.

Air-Heating Collectors

In air-heating collectors, air circulates over and under (or through) the absorber plate, which is usually made of sheetmetal, glass, or metal screening (Fig. 5). Therefore heat transfer takes place over the entire surface area of the absorber.

Flow rates. If an air-heating collector is coupled with a stratified heat storage unit, such as a pebble bed, its efficiency is about equal to that of a liquid-heating system with a slightly smaller mass flow rate. To achieve high collection efficiencies, air flow velocities must be higher than 2 ft^3/min per square foot.

System comparison. Air-heating collectors have several advantages over water-heating collectors; in particular, there is no problem with freezing or corrosion. With no corrosion, the collectors have long lifetimes and maintenance is minimal. Also, minor leaks in the system cannot result in damage to the building or its contents (although they will hurt system performance). Air that is heated in the collector can be circulated directly to heat the building. The disadvantages of air systems are the need for greater storage volume and the lack of an effective space-cooling unit operable with hot air. In addition, duct-work for heat distribution is usually more expensive and bulkier than piping for a liquid system; and more mechanical energy is required to transfer the thermal energy through an air system.

High-Temperature Collectors

When temperatures above 180°F are required for applications such as process heat and solar cooling, some form of solar concentration is required, and the use of "advanced" flat plate collectors as nontracking concentrating collectors is generally more cost effective.

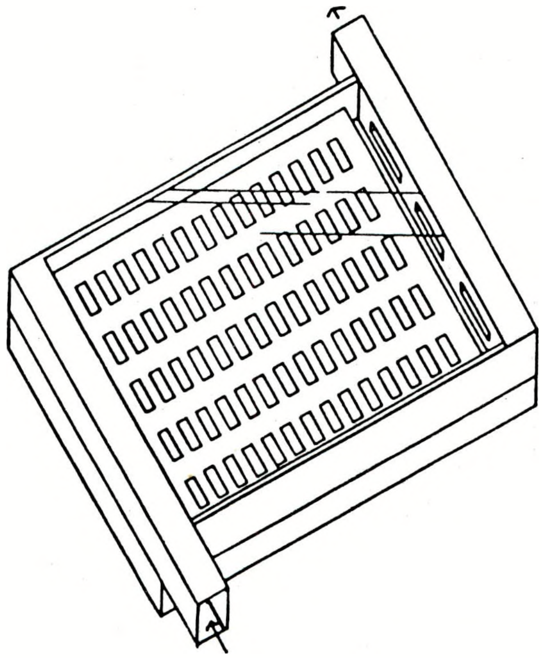

Fig. 5. Flat-plate air collector. (From HUD Minimum Property Standards.)

Flat plate evacuated-tube collectors. These collectors consist of a metal or glass absorber tube surrounded by an evacuated glass tube. The vacuum reduces convective heat loss and thereby increases efficiency. The transfer medium may be either liquid or gas. An evacuated-tube collector can utilize both direct and diffuse radiation. [See Solar Radiation Glossary, "Solar and Weather" Section.]

Concentrating (focusing) collectors. These collectors are designed to reflect or focus the radiation falling on a large area and to concentrate it onto a smaller absorber area. Some concentrating collectors also use a tracking mechanism to allow the collector to follow the sun's path throughout the day. Concentrating collectors utilize only direct radiation and consist of three basic parts: the lens or reflector, the absorber, and the housing.

Many configurations of concentrating collectors have been used successfully. Some of these are illustrated in Fig. 6. Generally, the combination of a concentrating collector and an evacuated-tube collector yields a higher efficiency than if the collectors were used separately.

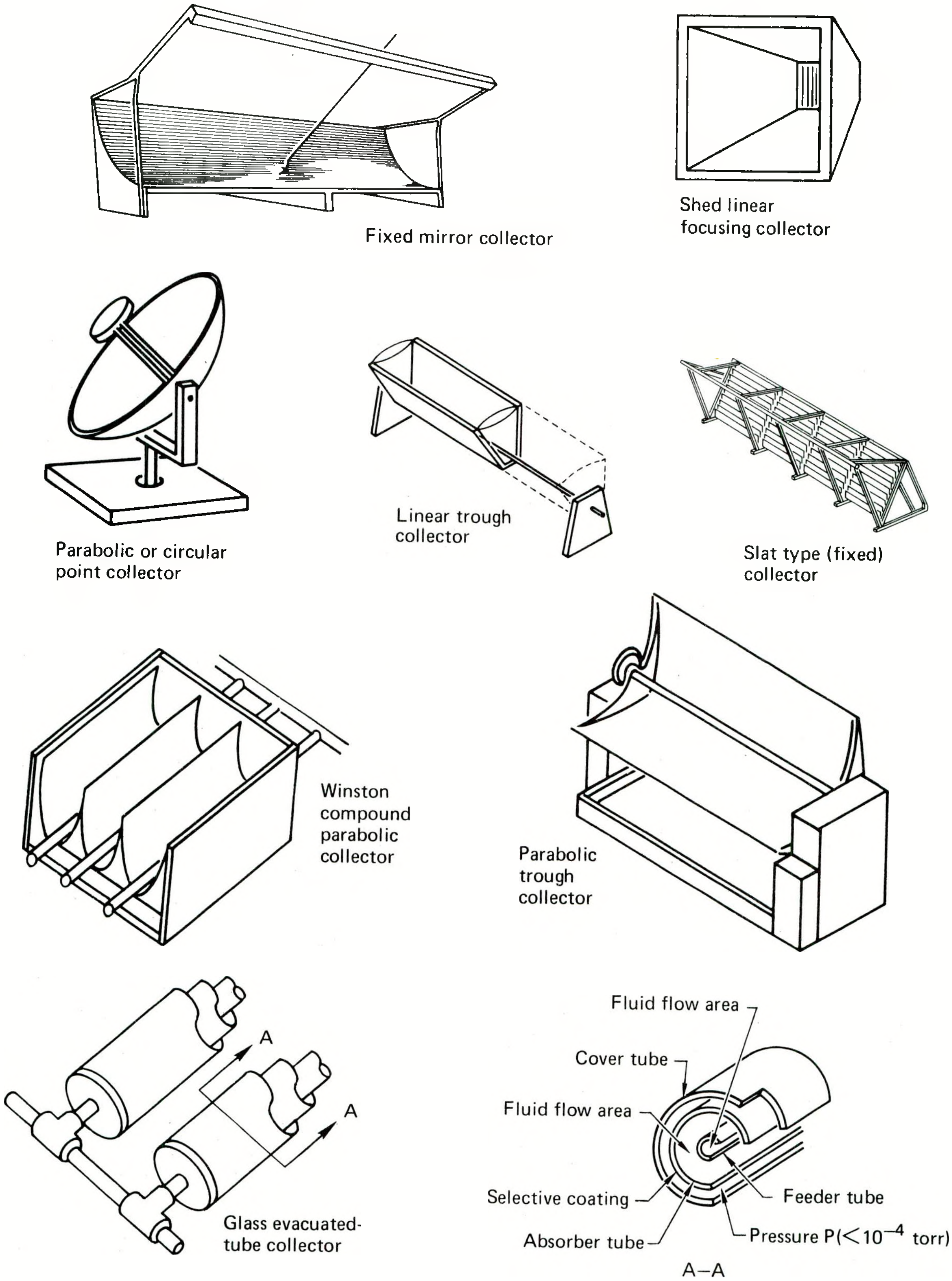

Fig. 6. Various types of concentrating collectors.

STORAGE

The purpose of thermal storage in a solar heating and cooling system is to provide heat at night and on cloudy days. Several factors, the most important of which is cost, suggest that storage should be designed to cover a period of 18 to 30 hours for a space heating or domestic hot-water application and that some other (supplementary) heat source should be used during an extended siege of cloudy weather.

Water and rock are the two principal storage media: heat is stored in water with "hydronic" systems, and in a rock bed with air systems. Both store sensible heat, which means that the quantity of heat stored is directly proportional to the temperature rise of the water or rocks. Both have the great advantage of being inexpensive.

Another type of heat storage system uses a chemical that melts at a convenient temperature, in the 100 to 150°F range. With such materials, large amounts of heat can be stored and released by the process of melting and solidifying without change in temperature. Their principal advantage is that a smaller storage volume is needed than for rock or water. However, several problems associated with these materials have not yet been solved; thus these systems are not considered practical at the present time.

Water Storage

Heat can be stored in a tank of water by circulating water from the tank through the collector loop and back to the tank--either directly, or by interfacing the tank and collector loop with a heat exchanger. By this means, the temperature of the entire tank is gradually increased. It is not unusual to have 30 to 40°F water stratification in the storage tank. A nonpressurized tank should be vented, and the system size should be designed to operate below boiling temperature. (Under most conditions, a pressurized tank is expensive and should not be considered for a normal residential heating and cooling system.) Water storage tanks should be insulated to prevent excessive heat losses.

Capacity. Water has a specific heat of 1 Btu/lb °F. On a volume basis, water can store 62.4 Btu/ft^3 (=1Btu/lb °F x 62.4 lb/ft^3) for each °F rise in temperature. One thousand gallons (134 ft^3) of water can store about 8360 Btu per °F rise(=134 ft^3 x 62.4 Btu/ft^3 °F). Thus if a 1000-gallon tank is at 195°F and the tank is drawn down to 95°F, the useful energy provided would be 736,000 Btu [=(195°F - 95°F x 8360 Btu/°F]. Suppose a house has a heating load of 16,000 Btu/°F.day. If the average ambient temperature is 14°F and the desired inside temperature is 68°F, then the heating load for a day would be 846,000 Btu [=16,000 Btu/°F•day x (68°F - 14°F) x 24 hr]. This storage tank would have sufficient capacity to carry the building load for about 21 hr [=736,000 Btu/846,000 Btu x 24 hr].

Temperature range. The minimum useful temperature in a water storage tank for direct heating systems is usually 90-100°F. For solar cooling systems, the minimum temperature is 170-210°F for a lithium-bromide water absorption cooler. These minimum temperatures, together with the boiling point, define the useful temperature range and are used to determine the tank size for the system.

Materials. The choice of a material for the liquid storage tank will be defined by environment and application. Selection criteria include: availability, weight, cost, ease of fabrication, interior or exterior corrosion, and leakage. Some materials that have been used successfully are: steel, aluminum, reinforced concrete, reinforced plastics, pipe sections (culverts), and wood. Regardless of the material used, the tank should be well insulated.

Rock-Bed Storage

Heat can be stored by circulating heated air from the collectors directly through a rock bed (Fig. 7). Because the rock bed is not heated uniformly, stratification results; thus the inlet end of a rock bed (usually the top) is close to the collector air temperature and the outlet end (bottom) of the rock bed is at ambient temperature. The advantages of stratification are:

- Cool air is returned to the collector from the bottom of storage making the collector operate more efficiently.
- When the house is heated from storage at night, the air temperature is always high since it is nearly the same temperature as when it

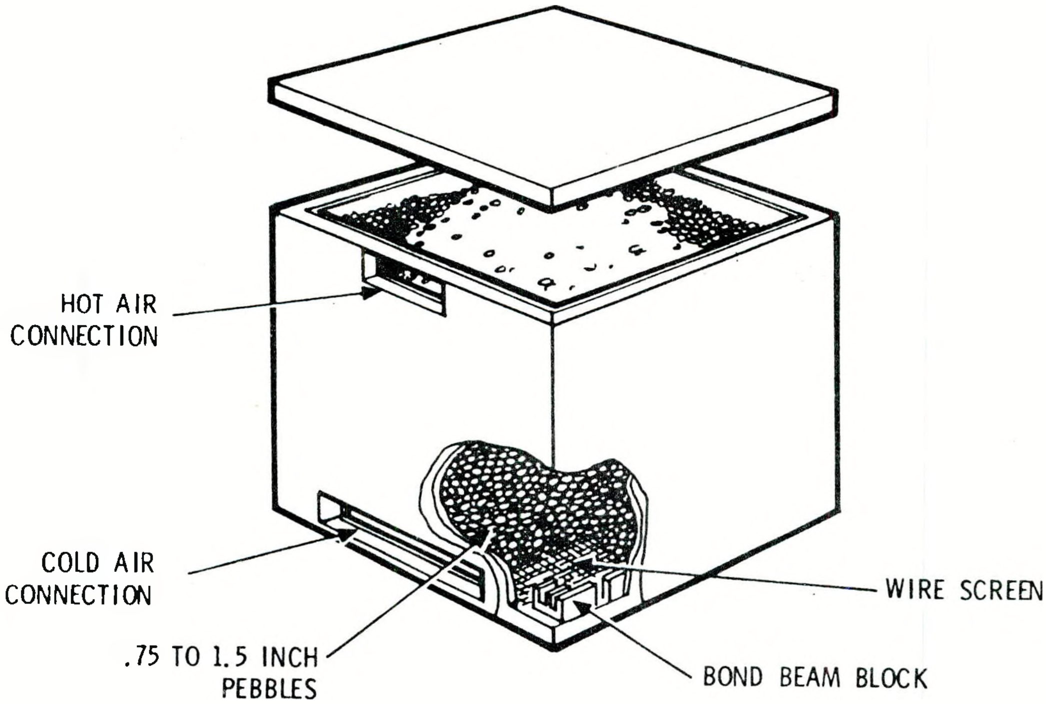

Fig. 7. Rock-bed heat-storage unit.

was delivered from the collector during the day.

Capacity. Commonly available rocks have a specific heat of about 0.21 Btu/lb°F. On a volume basis, the heat capacity is about 21 Btu/ft^3°F (=0.21 Btu/lb °F x 100 lb/ft^3) for nominal 1-inch diameter rock. This is about one-third the heat-storage capacity of water per cubic foot of volume (which is 62.4 Btu/ft^3°F). To have the same heat-storage capacity as a water tank, a rock volume will have to be three times as large. Because air passing through the pebble bed is circulated directly to the rooms without additional heat exchange, storage at room temperature (about 70°F) is still useful. Twenty tons of rock heated to a uniform temperature of 150°F can store about 672,000 Btu of useful heat [=21 Btu/ft^3 °F x 400 ft^3 x (150 - 70°F)]; for a house with a heat load of 16,000 Btu/°F•day and an average ambient temperature of 14°F, there is enough stored heat to last 19 hr [=672,000 Btu/16,000 Btu (70°-14°) /24 hr].

Pressure drop. A maximum depth of about six feet of pebbles is recommended for acceptable floor loading and air pressure loss. The pressure drop also depends upon the size and uniformity of the pebbles. At a typical air velocity of about 20 ft/min through 5 ft of 0.75- to 1.5-inch gravel, the pressure drop will be about 0.3 inch water gauge. As shown in Fig. 7, the pebbles are supported on a one-inch steel mesh material, such as "expanded metal," which in turn is supported on bond beam blocks for maximum free area to air flow in the lower plenum. Coverage of the bottom by the supporting blocks should be about 50% for lightweight screen support. If a heavy mesh of woven or welded wire screen is used, the block spacing can be greater.

Direction of air flow. Although horizontal flow has occasionally been used in pebble beds, the effectiveness of heat exchange is less than in vertical beds. Heat losses through the bottom can be appreciable, and channeling of air flow across the top of the rock can adversely affect performance. The tendency of warm air to flow through the upper part of the bed and cool air to seek the lower portion impairs effective heat transfer. If a horizontal design cannot be avoided, vertical baffles should be provided so that the air path is alternately up and down; in this case, more powerful blowers will need to be used.

CONTROLS

To provide maximum efficiency, the circulation of the working fluid through the collector should be limited to those times when heat can be collected. This is usually accomplished by using a differential thermostat which will activate the pump whenever the collector temperature (measured at the collector outlet) is 20°F higher than the storage temperature (measured at the bottom of the tank). Air systems normally require a 20°F temperature differential to activate the fan. A time lag is often built in to avoid excessive pump or fan cycling during periods of sporadic sunshine. Controls for liquid systems may include features to prevent freezing or pressure build-up resulting from very high temperatures.

The following description of differential thermostats is presented only to illustrate a common type of control used in a solar energy system. Several manufacturers can provide this (and other) types of controls.

RHO SIGMA

RHO SIGMA

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DIFFERENTIAL THERMOSTAT

APPLICATION NOTES

INTRODUCTION

The Differential Thermostat is designed to provide control functions for homes or other buildings employing solar heating and hot water systems. With the advent of solar heating and hot water systems, a new form of thermostat is required. The following discussion gives a brief description of the operation of a differential thermostat as compared to that of the thermostat used in conventional heating systems and/or hot water systems.

In the conventional house the thermostat is set at the desired room temperature, typically 70 degrees for heating and 140 degrees for hot water. When either temperature is below this setting the heating system is turned on. When the temperature rises above this setting the heating system is turned off. This cycle is repeated throughout the day and night always with reference to the 70 degree (or 140 degree) reference point setting.

Since the heat source in a conventional heating system always provides heat at a temperature substantially higher than desired temperature, the specific temperature of the burner output need not be known. Thus, the thermostat in a conventional system is required to sense only one temperature – room (or hot water) temperature – to perform the necessary control function. As will be shown, a single temperature measurement is not adequate for a solar heating system.

The basic solar system used in many installations includes a flatplate collector on the roof of the building supplying water to a storage tank, and a pump to recirculate water from the bottom of a storage tank back up to the collector. During most of the daylight hours, the sun's radiation incident on the collector will cause the temperature of the water at the collector to be higher than that at the storage tank. Under these conditions, the pumping and recirculating action achieves the desired objective of transferring heat energy into the storage tank for subsequent use in building or water heating.

At night, however, or under overcast daytime conditions, the collector water temperature will tend to fall below the storage tank water temperature. Continued pumping and recirculation under these conditions would be self-defeating, since heat energy would be removed from, not added to, the storage tank.

The pump could of course be manually turned on when it appears that the collector is capable of supplying heat energy to the storage tank and manually turned off when it is not. But this would be inefficient if the collector temperature and storage tank temperature are not accurately known and compared, and would also be burdensome and inconvenient to the user of a solar heating system. A much more effective solution is to employ the Rho Sigma Differential Thermostat to automatically sense and compare the collector and storage tank temperatures, and to control the daily on-off cycling of the pump in the optimum manner.

TYPICAL OPERATING CYCLE FOR A SOLAR HEATING SYSTEM

Figure 1 indicates a representative example of the sequence of events in a normal daily solar heating/hot water cycle under the control of the Differential Thermostat. The terms ΔT_{off} and ΔT_{on} which appear in the figure are defined as follows:

ΔT_{off} = temperature difference between collector exit water temperature and storage tank water temperature sufficient to turn pump off.

ΔT_{on} = temperature difference between collector exit water temperature and storage tank water temperature sufficient to turn pump on.

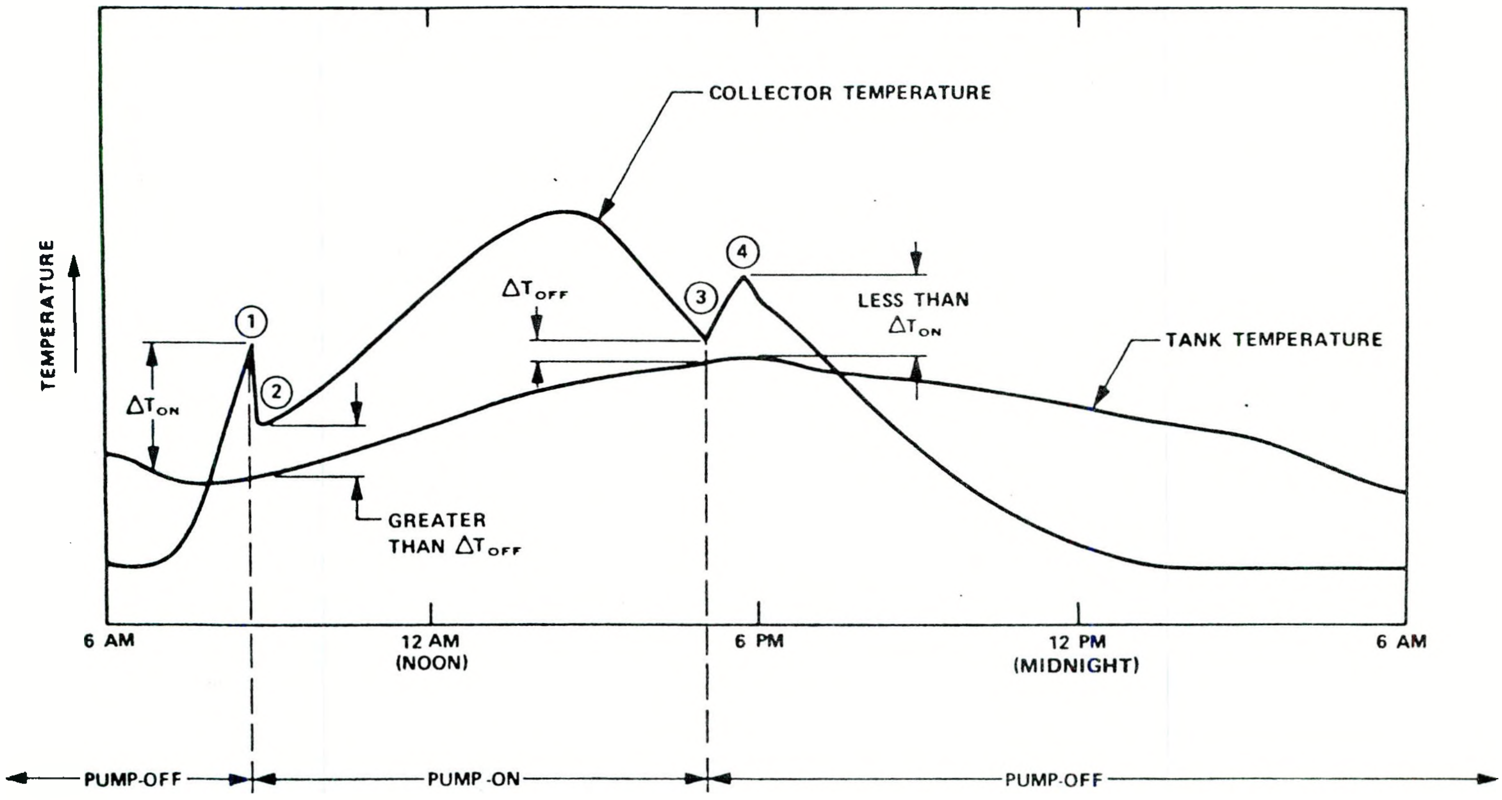

FIGURE 1 – PUMP CYCLING UNDER CONTROL OF THE DIFFERENTIAL THERMOSTAT

As shown in Figure 1, the pump is initially off. As the sun rises the collector temperature rises sharply above the tank temperature. This is shown as ΔT_{on}. This ΔT turns the pump on. The cooler tank water carries off the heat in the collector and causes the initial drop to the point marked 2. The ΔT at point 2 is however greater than the ΔT_{off} and the pump continues to operate.

As evening approaches, the collector temperature moves below the ΔT_{off} threshold at the point marked 3. The pump is turned off and due to the stagnation condition (i.e., the sun is heating the collector but the pump is not on) the temperature in the collector rises as shown at point 4. If ΔT_{on} is set sufficiently greater than ΔT_{off}, the pump will remain off. The adjustments of the threshold and hysteresis settings in the Differential Thermostat are correctly preset at the factory.

The hysteresis circuit is a special feature of the Differential Thermostat which prevents the pump from being unnecessarily turned on and off immediately following an initial pump turn-on or turn-off event. Without this circuit feature, the sharp peaks of temperature rise shown at points 1 and 4 would cause the pump to repeatedly switch on and off, causing unnecessary wear on the pump, pump motor, and relay contacts controlling pump operation, as well as reduced efficiency in transferring heat energy from the collector to the storage tank.

SOLAR HOT WATER SYSTEM APPLICATION OF DIFFERENTIAL THERMOSTAT

Figure 2 shows a typical solar hot water system installation. The 50 gal. storage tank operates as a pre-heat system for the conventional 30 gal. gas (or electric) system. With 40 to 50 square feet of collector area this system will supply 60%, or more, of the hot water needed for a family of four under most insolation (sun) conditions. During extended periods of cloud conditions, the 30 gal. gas water system functions as augmentation. During clear sunny days, even under low ambient temperature conditions, the storage tank water can rise to very high temperatures. To prevent scalding, it is suggested that a "high set" thermostat be used in the storage tank as shown. This thermostat should be set in the range of 160°F and connected in series with the pump motor. This will prevent the storage tank water from rising above this temperature. Without the "high set" thermostat, tank temperatures could exceed 180°F on clear sunny days. (For heating systems this "high set" thermostat would not be required.)

The Differential Thermostat can be installed at any convenient indoor location. (Ruggedized, weather-proof models can be furnished when outdoor installation is required.) Thermistor Sensor #1 is inserted in the collector exit water line as shown. A pair of wires run from this sensor to the Differential Thermostat. Similarly, at the exit line from the storage tank, a pair of wires from Thermistor Sensor #2 connect to the Differential Thermostat. Action of the Thermostat operates a set of relay contacts for controlling the pump motor. If desired, the pump motor control lines can be placed in series with the high set thermostat to prevent the pump from operating when the upper tank temperature is reached.

Connectors are provided on the Differential Thermostat for the 120 VAC, 60 cycle, required to operate the unit as well as for the two sensor inputs and the pump motor control lines.

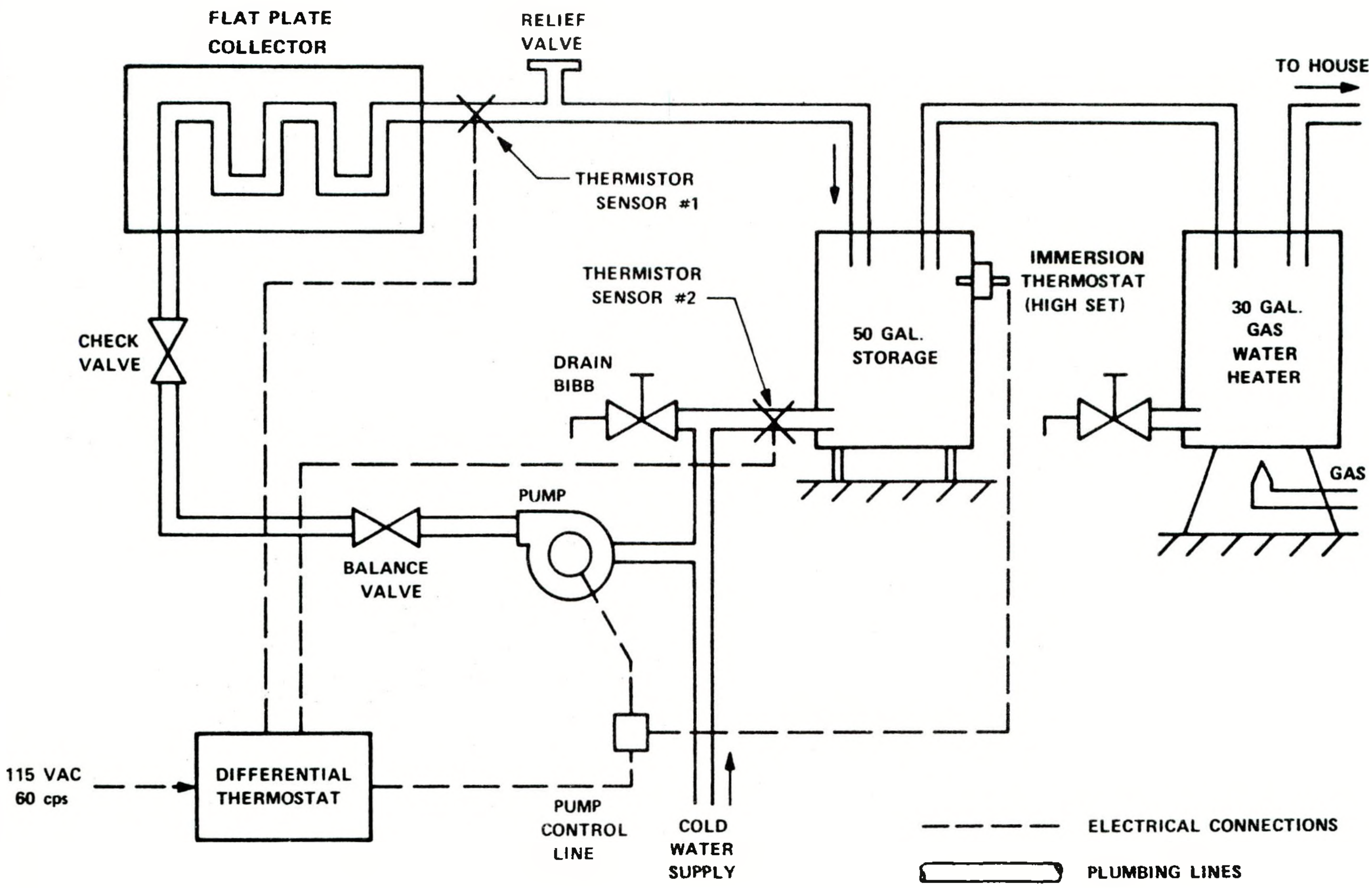

FIGURE 2 – TYPICAL SOLAR HOT WATER SYSTEM INSTALLATION

PUMPS AND VALVES

A pump is always required for water circulation in a solar energy system, if the collectors are located higher than the storage tank (which is usually the case). An appropriate flow of water through the collector (1 to 2 gal/hr per ft^2 of collector) can be achieved by a small circulating pump of 1/10 to 1/20 hp. A high quality pump should be used that will last the lifetime of the system. Many manufacturers make pumps that are suitable for this purpose.

Relief valves, check valves, drain valves, and tempering valves all have their place in controlling the flow through solar energy systems.

SERVICE HOT-WATER SYSTEMS

The oldest and simplest domestic use of solar energy is for heating water. Solar hot-water heaters were used in the United States at least 75 years ago, first in Southern California and later in Southern Florida. Although the use of solar water heaters in these regions has declined drastically during the past 40 years, their use in Australia, Israel, and Japan has risen, particularly in the last 15 years.

Thermosiphon Circulation

The simplest type of solar water heater, used almost exclusively in nonfreezing climates, is shown in Fig. 8. The collector, usually single glazed, may vary in size from 30 to 80 square feet; the insulated storage tank commonly holds 40 to 80 gallons. Hot-water requirements of a family of four can usually be met by a system in the middle of this size range, in a sunny climate.

Unpressurized operation is possible with a float valve in the storage tank or in an elevated-head tank; water then flows by gravity from the hot-water tank to the faucets. Operation at supply-line pressure can be provided if the system is designed for it. Plumbing systems and fixtures in the United States normally require a pressurized system.

Principles of operation. Placing the storage tank higher than the top of the collector causes circulation of cold water from the bottom of the tank to the bottom of the collector, where it is heated and rises to the top of the tank as a result of the density difference between cold and hot water. Temperature stratification in the storage tank permits operation of the collector under the most favorable conditions: water at the lowest available temperature being supplied to the collector, and that at the highest available temperature being provided to service. Circulation occurs only when solar energy is being received, so the system is self-controlling; the higher the solar radiation level, the greater the heating and the more rapid the circulation. In a typical collector under a full sun, a temperature rise of 15 to 20°F is commonly realized in a single pass through the collector.

To prevent reverse circulation and cooling of stored water when no solar energy is being received, the bottom of the tank should be

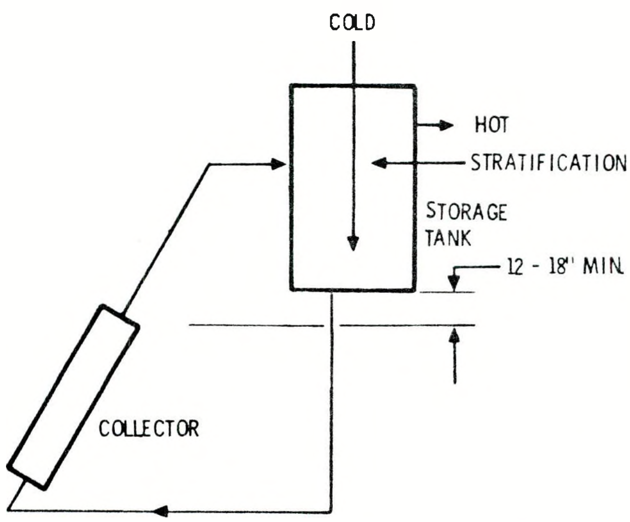

Fig. 8. Thermosiphon solar water heater.

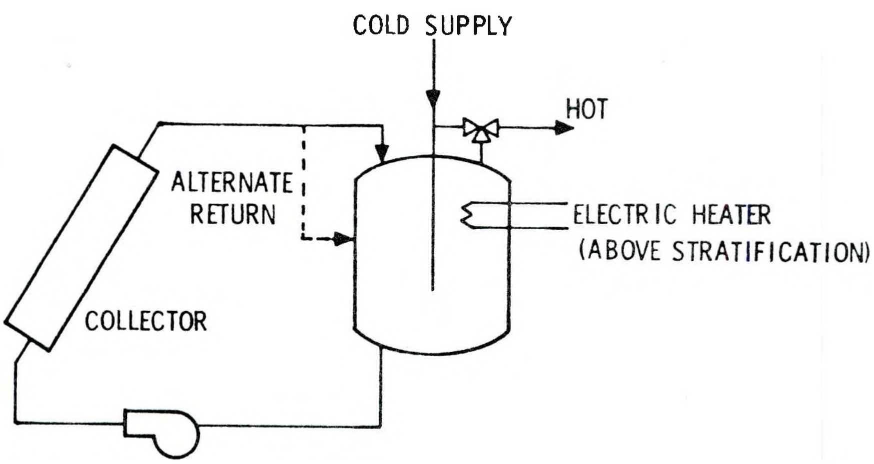

Fig. 9. Direct-heating, pump circulation solar water heater.

located above the top header of the collector. If the collector is on a roof, the tank may be either on the roof or in the attic space.

Freeze protection. The thermosiphon type of solar water heater can be protected from freezing by draining the collector. To avoid draining the storage tank as well, thermostatically controlled valves in the lines between collector and storage tank must close when freezing threatens; and collector drain and vent valves must open. Resumption of operation requires closure of the drain and vent valves and opening of the valves in the circulating line. The possibility of control failure or valve malfunction makes this complex system unattractive in freezing climates.

An inexpensive, alternative method of freeze protection on thermosiphon or gravity convection systems is the application of thermostatically-controlled heat tape to the collector. The heat tape is not fail-safe, however, since it will not operate during a simultaneous power failure and freeze.

Pump Circulation

Principles of operation. If placing the storage tank above the collector is inconvenient or impossible, the tank may be located below the collector and a small pump used to circulate water between collector and storage. This kind of water heater is usually more practical in the United States than the thermosiphon type because the collectors are often located on the roof with the storage tank in the basement. When the sun shines, a differential thermostat actuates a small pump which circulates water through the collector-storage loop. A schematic arrangement is shown in Fig. 9.

To prevent reverse thermosiphon circulation and consequent water cooling when no solar energy is being received, a check valve should be located in the circulation line. If this type of solar water heater is used in a cold climate, it must be protected from freeze damage when subfreezing temperatures are encountered. Several methods can be used. (See earlier section on Liquid-Heating Collectors.) Their common requirement is reliability, even when electric power is not available.

Heat-Exchanger Systems

By using a nonfreezing fluid to extract heat from the solar collector, and a heat exchanger (inside the building) to transfer heat from this fluid to the service water, one can eliminate the risk of freeze-damage.

Liquid-to-liquid. One method for solar water heating with a liquid heat-transfer medium is shown in Fig. 10. The liquid most commonly recommended is a solution of propylene glycol in water. A pump circulates this unpressurized solution and delivers it to and through a liquid-to-liquid heat exchanger. Simultaneously, another pump circulates domestic water from the storage tank through the exchanger and back to storage. The control system is essentially the same as before. If the heat exchanger is located below the bottom of the storage tank and if pipe sizes and heat exchanger design are adequate, thermosiphon circulation of water through the heat exchanger can be used. A small expansion tank needs to be provided in the collector loop, preferably near the high point of the system, with a vent to the atmosphere.

To meet most code requirements, the heat exchanger must be of a design such that rupture or corrosion failure will not permit flow from the collector loop into the domestic water, even if pressure on the water side of the exchanger drops below that on the antifreeze side. Parallel tubes with metal bonds between them, so that perforation of one tube could not result in liquid entry into the other tube, would be a suitable design. A finned tube air-to-liquid heat exchanger could also be used by circulating the two liquids through alternate rows of tubes, heat transfer being by conduction through the fins.

Air-to-liquid. Air-heating collectors can also be used to heat service water in an air-to-water exchanger. Figure 11 illustrates this concept. A solar air heater is supplied with air from a blower, the air is heated by passage through the collector, and the hot air is then cooled in the heat exchanger through which domestic water from a storage tank is either being pumped or is circulating by thermosiphon action. Air from the heat exchanger is recirculated to the collector.

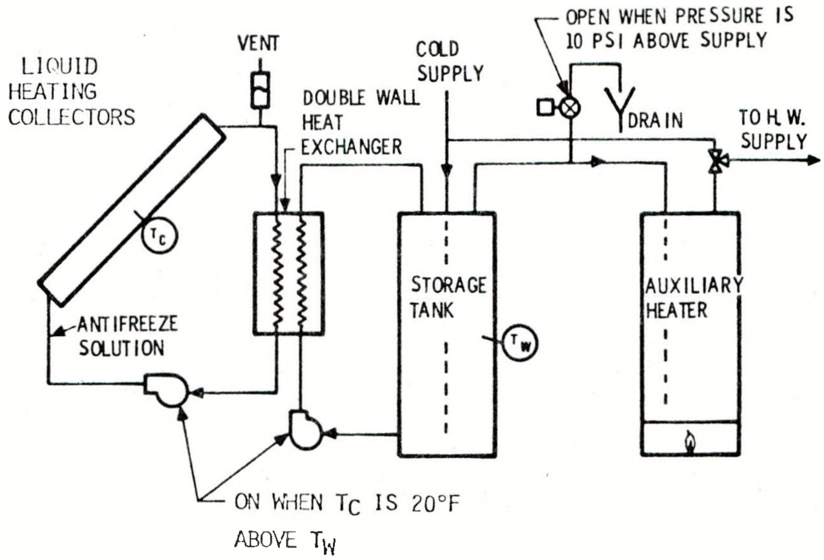

Fig. 10. Dual-liquid solar hot-water heater. In systems where the heat exchanger is an integral part of the storage tank, a second pump is not required.

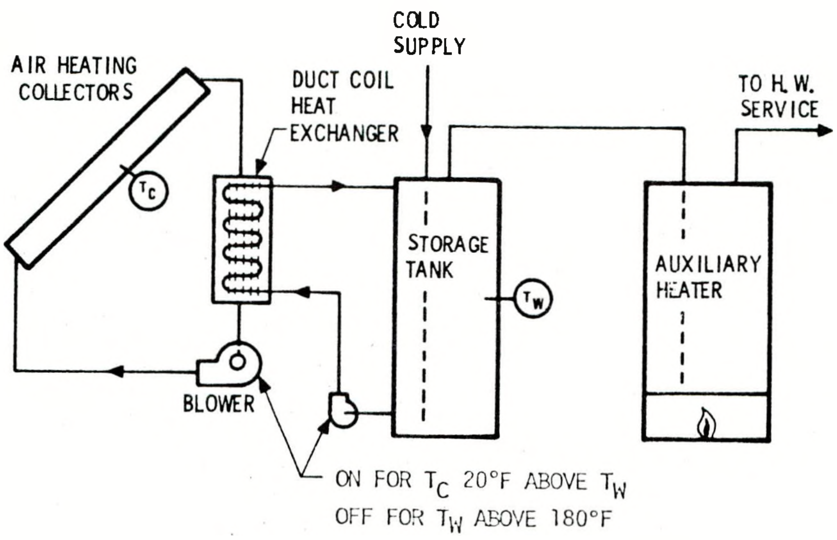

Fig. 11. Solar hot-water heater with air collectors.

Differential temperature control (between collector and storage) is used as before. Advantages of the air heat-transfer medium are the absence of corrosion in the collector loop, freedom from liquid leakage, and freedom from boiling and loss of collector fluid. Disadvantages are the larger conduit between collector and heat exchanger, higher power consumption for circulation, and slightly larger collector surface requirements.

Auxiliary Heat

A dependable supply of hot water usually requires auxiliary heat to supplement the solar source. The numerous methods of providing this heat vary in cost and effectiveness; but a general principle for maximizing solar supply and minimizing auxiliary use is to avoid direct or indirect auxiliary heat input to the fluid entering the solar collector. If auxiliary heat is added to the solar hot-water storage tank, so that the temperature of the liquid supplied to the collector is increased above that which the solar system alone would provide, efficiency is reduced because of higher heat losses from the collector. Thus auxiliary heat should be added at a point beyond (downstream from) the solar collector and storage system. Figures 10 and 11 show a conventional gas-fired hot-water heater being supplied with hot water from the solar tank (whenever a hot-water tap is opened). Any deficiency in temperature is made up by fuel in the thermostatted conventional heater.

Temperature stratification. Another way in which auxiliary heat can be used without reducing solar collection efficiency is by electric resistance heaters in the upper portion of the solar storage tank, as shown in Fig. 9. Temperature stratification in the tank, accomplished by bringing cold water from the main into the bottom and by circulating water through the collector from the bottom of the tank to the upper portion of the tank, thereby prevents auxiliary heat from increasing the temperature of the water supplied to the collector. Water returning from the collector may be brought into the tank well below the level of the resistance heater (as shown by the dashed line), so that the hot supply is always available at the thermostatted temperature.

SPACE HEATING AND COOLING

Space Heating: Liquid Systems

A liquid-heating solar system commonly uses water, with or without antifreeze and corrosion inhibitor additives, as the heat transfer and storage fluid. A basic solar space-heating system is shown in Fig. 12. The collectors supply heated water to an insulated storage tank from which heat is delivered to the house by conventional means. Auxiliary heat is furnished by a fuel-fired water boiler or a hot-air furnace (if the heat distribution system is a warm-air type).

A system more representative of most of the liquid types in use is shown in Fig. 13. It uses a dual-liquid collection and storage system, and provides service hot water as well as space heating. The system is controlled so that whenever the collector temperature at S1 is greater than the storage temperature at S2 by a preset amount, say 20°F, pumps 1 and 2 circulate the water around the collector and storage loops, respectively. Heat from the collector is thus delivered to storage. The thermostat in the conditioned space S3 controls pump 3 so that whenever heat is needed, hot water from storage is delivered to the fan-coil unit. For normal residential buildings, a single thermostat and a central air-distribution system are used; however, zoned control with two or more fan-coil units is also possible. In a solar system, a fan-coil unit is preferred to baseboard heat radiators and convectors because the building space can be heated effectively with water temperatures as low as 100°F. Baseboard radiators require water temperatures of about 150°F to be fully effective, and the higher temperature water requires the collectors to operate at higher temperatures with consequent loss of collection efficiency. Also, the higher storage and distribution pipeline temperatures will result in greater heat "losses," or uncontrolled heat flow, to the building space.

The preheating of service water will take place when the storage temperature S2 exceeds the temperature at S4 by a preset amount. Pumps 4 and 5 circulate the water from the storage tank and through a preheat tank, respectively. If the preheat tank reaches a maximum temperature, a thermostatic switch shuts off the pumps to prevent overheating of the

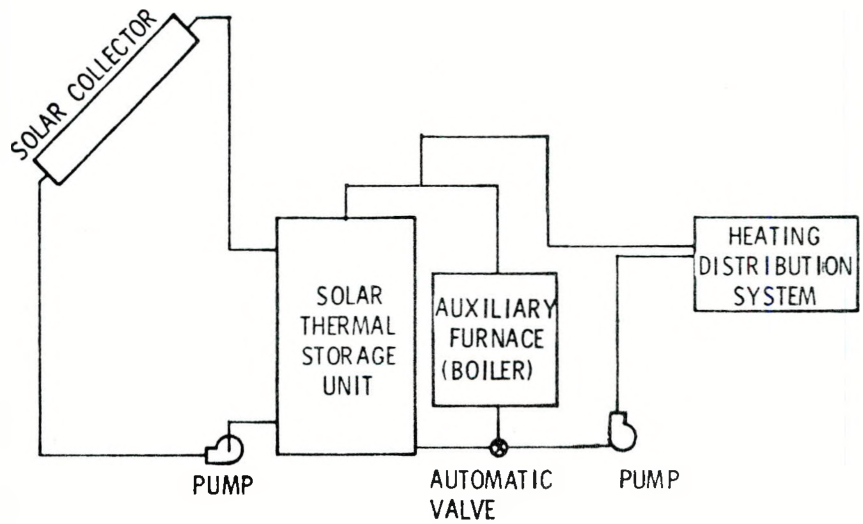

Fig. 12. An alternative solar heating system.

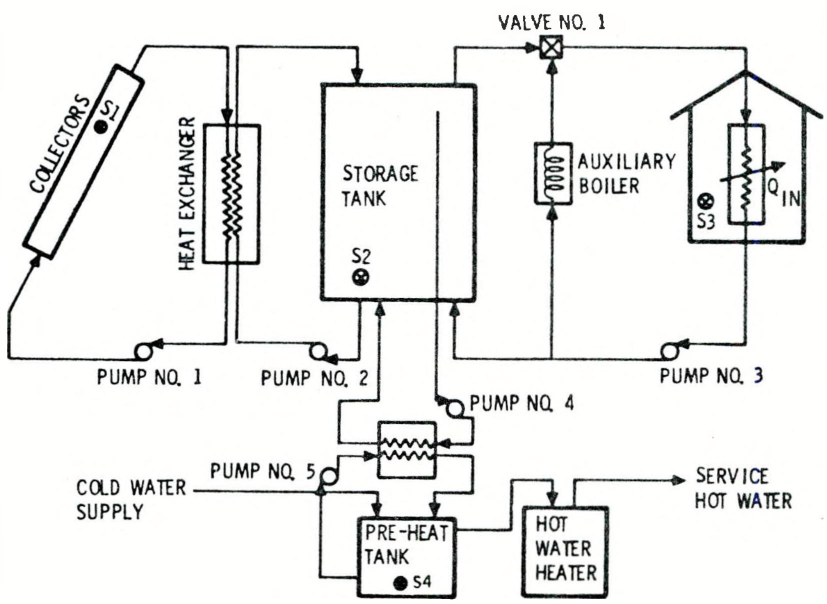

Fig. 13. Representative solar space heating and service hot-water system.

service water. If the preheat tank does not provide adequate temperature levels, a standard hot-water unit adds heat to raise the temperature to the level desired.

The auxiliary boiler in the space-heating circuit is connected in parallel with the solar heating loop. If the temperature of the water in the storage tank is not sufficient to provide the heat needed in the house, a second contact in thermostat S3 fires the boiler and operates valve 1 so that hot water circulates from the boiler to the building. When the heat demand in the house is met, the thermostat shuts off pump 3 and returns the valve to a normal solar heating mode.

The auxiliary boiler is connected in parallel rather than in "series" in the space-heating loop to avoid heating the storage tank with auxiliary energy. If the boiler were connected in series, the temperature of the water returning from the fan coil could be warmer than the storage water temperature; hence auxiliary energy would be unnecessarily used to keep the storage temperature above some minimum level. The auxiliary boiler should be sized to carry the total heating load in the house. This is necessary because the solar system will not be able to provide useful heat during cloudy periods.

Space Heating: Air Systems

In its simplest form, a solar air collector closely resembles the liquid-heating type. The essential difference is the circulation of air in contact with, and usually beneath, the black absorber plate. To enhance the heat transfer, the absorber surface may be extended by means of fins, corrugations, etc. It has been found that good performance is achieved with air collectors operating at approximately the same mass flow rate as in liquid collectors, about 10 lb/hr per square foot of collector surface, or roughly 2 ft^3/min per square foot. But because air has only about one-fourth the heat capacity of water, the temperature rise in the collector is about four times as great if efficiencies are equal. Typical midday air collector temperatures are 70°F at the inlet and 140°F at the outlet.

Easy retrofits. Over 50% of the single-family residences in the United States are provided with warm-air heating systems. The use of solar air collectors would permit direct heating of these buildings without need for heat exchange. Moreover, return air from rooms to the collector is always at a low temperature (about 70°F), which results in a higher collection efficiency than if hot air were being returned.

Rock-bed storage. For the best collection efficiency, heat storage in an air system should extract substantially all the useful heat from the hot air stream so that the return air can be at the same favorable low temperature as the returning room air. A highly stratified storage capability is therefore desirable. The thermal properties of loose solids, such as gravel of uniform size, are ideally suited to this application. Warm air at a temperature of 140 to 150°F is delivered to one end, usually the top, of a bin of gravel. The very large surface area of the pebbles and the high porosity of a bed of uniformly sized solids result in rapid transfer of heat. In a distance of 2 to 3 ft in the direction of air travel, the air temperature is reduced virtually to the previously existing rock temperature. Thus if the pebble bed is initially at a uniform temperature of 70°F, air entering at 140°F creates a continually enlarging zone of 140°F pebbles at one end of the bed, while it is being discharged from the other end at the rock temperature, 70°F. Unless the bed is "filled" with heat, the temperature of the air returning to the collector from the pebble bed is substantially the same as if it were returning from the rooms of the house. A practical quantity of storage material is about 50 lb (approximately 0.5 ft^3) of pebbles per square foot of collector.

Heat distribution. Supply of heat to the rooms from the storage unit is easily accomplished by circulating room air through the pebble bed in a direction opposite to that employed in the storing cycle. Room air is thus heated by contact with the heated rocks, leaving the pebble bed from the region of highest rock temperature. The resulting air temperature is within a few degrees of the temperature of the air that was originally used to heat the storage. Auxiliary heat can readily be used in this system by passing air either from the collector or from the storage through a furnace on its way to the rooms. Fuel or electricity is used to augment the solar heat as necessary.

A two-blower air-type solar system is comprised of four principal components: solar collector, heat storage unit, air blower, and auxiliary heater. By combining the blower and dampers into an "air handler" unit, construction and operation of the system can be simplified. Figures 14-17 show such a system in its several modes.

Most commercially available warm-air furnaces for residential use contain a blower for circulation of warm air through the building via the distribution ducts. In a typical all-air solar installation, the furnace blower is used in the normal manner for distributing warm air from either the collectors or storage. The solar system blower operates only when air is circulated through the collector.

Space Heating: Passive Systems

The "active" space-heating systems discussed above require mechanical energy to transfer thermal energy from the point of collection to the point of use. The collectors, storage, controls, and distribution of active systems are separate components.

An alternate approach to solar space heating, called "passive," is characterized by a reliance on natural convection, conduction, and radiation, and by heat collection and storage areas that are integrated into the living space rather than separated from it. Buildings heated by passive means are sometimes called "sun-tempered."

Since almost any building benefits from direct solar radiation, all can be said to be passively heated to some extent. But when direct solar energy use becomes a major objective of the architectural design of a building, and when solar energy thus supplies over half of the heating requirements, then one has a passive solar-heated building.

Although a passive solar heating or cooling system is defined as one in which the energy flow is entirely by natural means, designs that use motorized or manually operated insulation panels or shading devices once or twice a day are still considered passive, provided the thermal energy flow is by natural convection, conduction, or radiation.* System designs that use small fans to assist circulation should not be ruled out simply because they are not strictly passive; for often the use of a small amount of auxiliary energy can materially decrease the overall

*For more detailed definitions of passive systems, see "Passive Solar Heating and Cooling Systems," by John I. Yellott, ASHRAE Journal, p.60, January 1978.

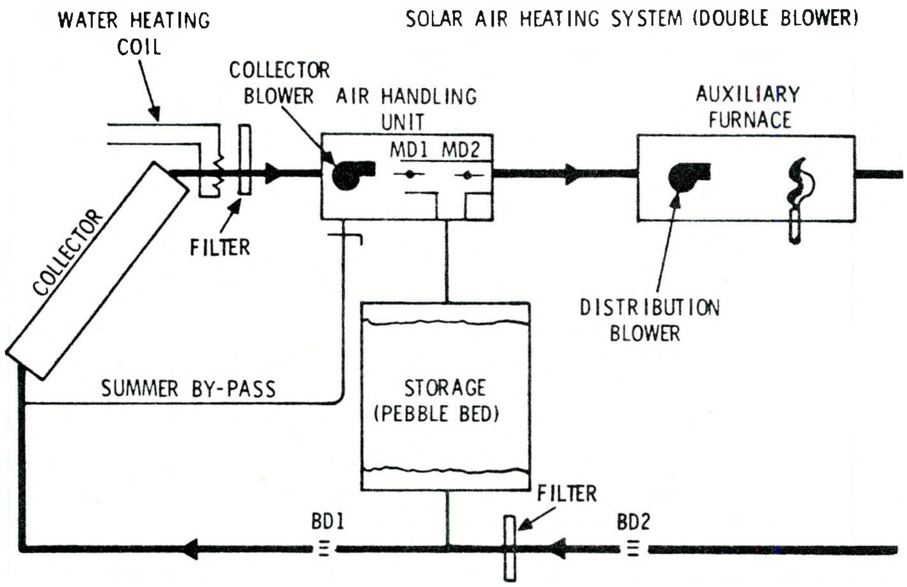

Fig. 14. Heating building directly from collectors.

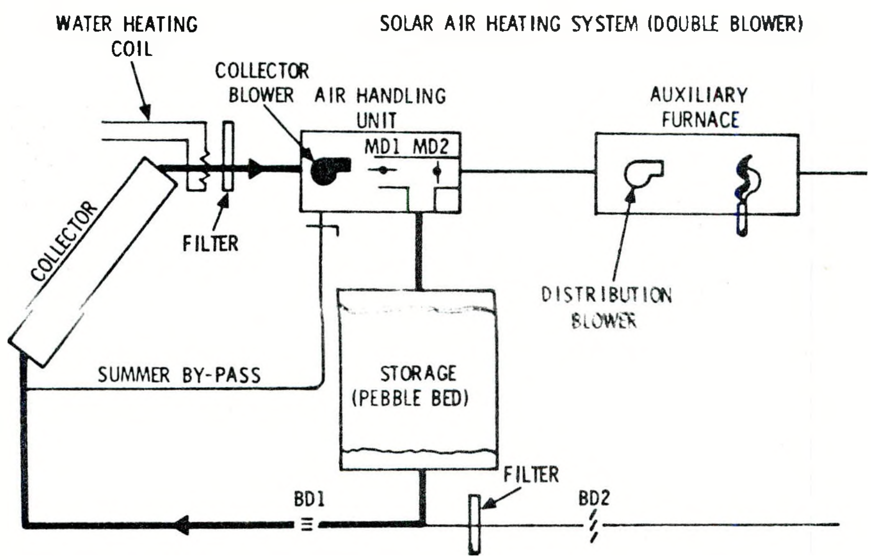

Fig. 15. Storing heat from collectors.

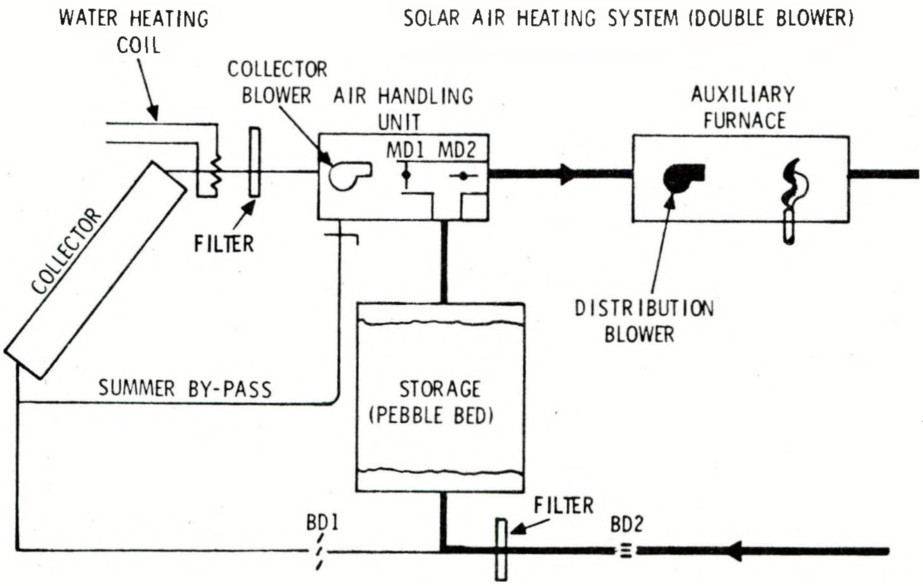

Fig. 16. Heating building from storage unit or from auxiliary furnace.

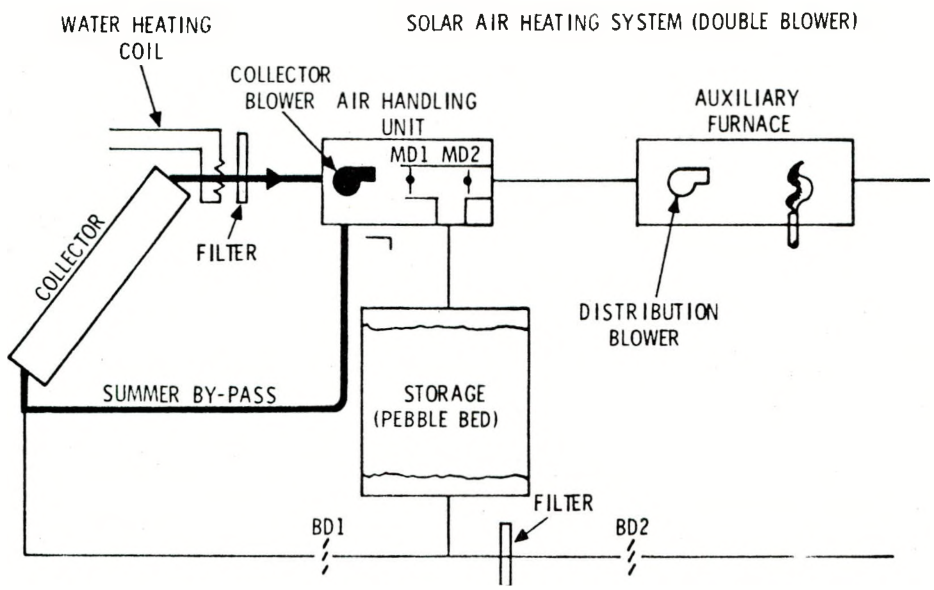

Fig. 17. Service hot-water heating (summer operation).

conventional heating or cooling requirements. In short, a passive design should seek to maximize the use of natural convection, conduction, and radiation processes while minimizing the use of mechanical devices powered by conventional fuels.

Design considerations. A number of passive solar-heating concepts have been built into structures and have received widespread attention for their apparent success in saving energy. Nevertheless, they have not yet been widely adopted--probably because of skepticism about their effectiveness and a lack of operating data and engineering criteria. At the present time, the growing interest among architects in passive concepts is still outpacing the establishment of thermal criteria to guide their use.

In quantifying passive designs, there is no problem in the area of collection. Calculation of solar gains through windows (which make efficient solar collectors) is well understood and documented. Adequate south-facing window areas combined with proper heat-conservation measures can take care of a large fraction of the heating load of a building. In a passive design, the surface receiving the solar flux and the thermal storage mass can be combined in a more or less integrated unit, as in the drum-wall system. Or the storage can be separate from the directly irradiated surface, as with massive internal walls not directly exposed to sunlight. Or there can be a combination of storage masses directly and indirectly heated by solar radiation--which is the usual case for a house that has large south-facing windows but which has floor areas, furniture, and some internal walls in shadow. In general, the arrangement in which the thermal-storage medium is directly heated by the solar flux will provide the largest fraction of passive solar heating and will minimize the problems of daytime overheating.

Moderately effective controls have been designed to deal with problems of heat gain and loss in passive designs; these include movable shading devices to control sunlight, movable insulation panels to reduce night-time heat losses, and ventilation ports to either augment or reduce daytime heating by means of natural convection.

<u>Passive design elements</u>. The following should be considered from both architectural and engineering viewpoints:

Design Element	Application
Thermal	Fixed thermal insulation is used to decrease natural energy flow and thus maintain building interior comfort; the insulation retains warmth in a cold environment and coolness in a warm environment. Movable insulation can be used to diminish natural energy flow through windows at desired times, while still allowing energy flow at other times.
Fenestration	Windows can be used to admit solar radiation into a structure, either for warmth or for lighting. When heat is desired, window orientation is extremely important: south windows receive maximum winter gains and minimum summer gains.
Shading	Roof overhangs and window awnings can be designed to admit the low winter sun and block out the high summer sun. Shading can be combined with insulation in drapes and shutters. Vegetation, both deciduous and evergreen, can also provide shade, with deciduous trees giving a natural seasonal control.
Reflectors	The use of diffuse or specular reflectors can significantly increase the total influx of solar radiation through a window. They also can function in a cooling mode, in which high-emittance exterior surfaces reflect visible radiation and radiate infrared heat.
Building Structural or Added Mass	Use of heavy, heat-retaining materials within a building provides natural thermal storage of sensible heat.

Thermal Radiation	Thermal radiation is absorbed directly or indirectly by the thermal-storage mass of the passive system. The energy is removed by radiation and convection from the storage mass to heat the interior of the building. In warm periods, thermal radiation and convection can be used to remove heat from both the building and the storage mass during the night.
Natural Convection	In passively heated systems, natural convection of air can be used to transport heat and to produce air movement (ventilation). Natural convection in liquid systems will also transport heat, as in a thermosiphon hot-water heater.
Conduction	Materials of high mass and low thermal diffusivity (such as ordinary masonry) can delay the arrival of a thermal wave until the heat can be used effectively.
Air Stratification	Warm air can be stratified at the ceiling and removed by natural convection through vents to reduce the air-conditioning load. Alternatively, stratification can be used to concentrate warm air for use elsewhere.
Evaporation	Static outdoor ponds (perhaps on the roof) can be cooled evaporatively and the remaining water used to cool the building. Spraying or cascading the water increases evaporative cooling and also has a pleasing esthetic aspect when it is architecturally integrated.
Heat-of-Fusion Storage Materials	Thermal masses normally store sensible heat. Heat-of-fusion or phase-change materials offer a possible alternative means of energy storage. Heat-of-fusion storage requires a smaller mass

and volume to store a given quantity of heat than sensible-heat storage does; it also stores heat without a change of temperature. In cooling, phase-change materials can be a good thermal heat sink. However, these materials have not yet been developed far enough to be of practical use in passive systems.

Use of passive design elements can be best demonstrated by studying buildings that have successfully incorporated them. The buildings discussed below are grouped according to type of passive solar heating: direct gain, thermal-storage wall, and roof pond.

Direct gain. The simplest approach to passive space heating is by direct gain of solar radiation through a south-facing expanse of glass (Fig. 18). This works best when the south window area is double glazed and when the building has considerable thermal mass such as concrete floors and masonry walls, insulated on the outside. The result, in effect, is a live-in solar-collector and thermal-storage unit. If the south-facing window area is vertical, seasonal temperature control is almost automatic since the interior space of the building is exposed to a maximum amount of solar energy in the cold winter months and to a minimum in the summer (when sun angles are high).

Thermal storage walls. The second type of passive system stores heat in a heavy wall set directly behind single or double south-facing glazing. The wall is usually painted black or other dark color for good absorptance; it can be made of masonry or of water-filled containers (e.g. 55-gal drums.)

In its heating mode, the drum-wall releases heat to the living space by radiation and convection. The heat capacity of such a system is easily calculated; allowing for filling volume, each drum gives up about 418 Btu for every 1°F drop in the water temperature (Fig. 19).

The massive south-facing concrete wall is used in the well-known Trombe-wall houses constructed in the solar community near Odeillo in the French Pyrenees by Felix Trombe and his colleagues (Fig. 20). The

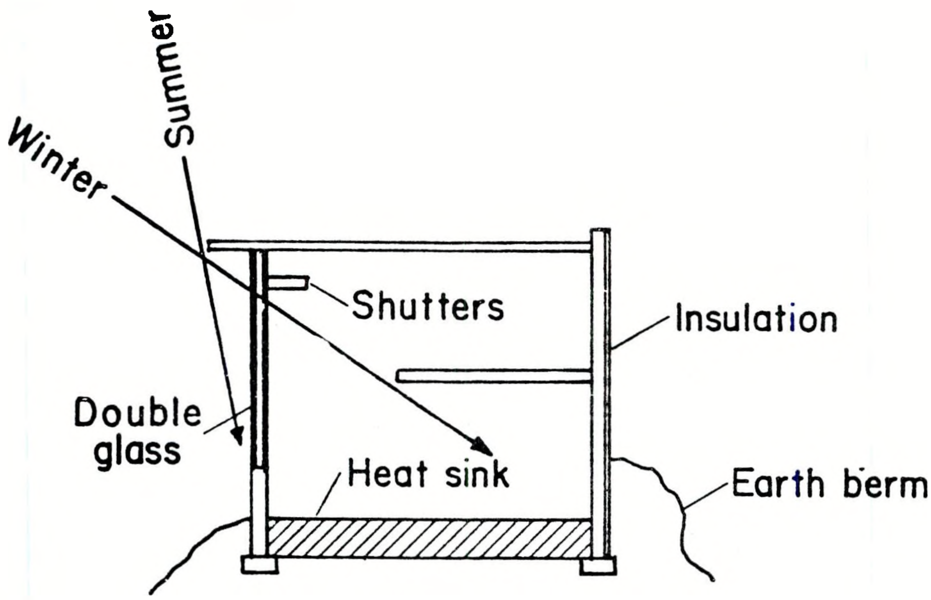

Fig. 18. Direct gain.

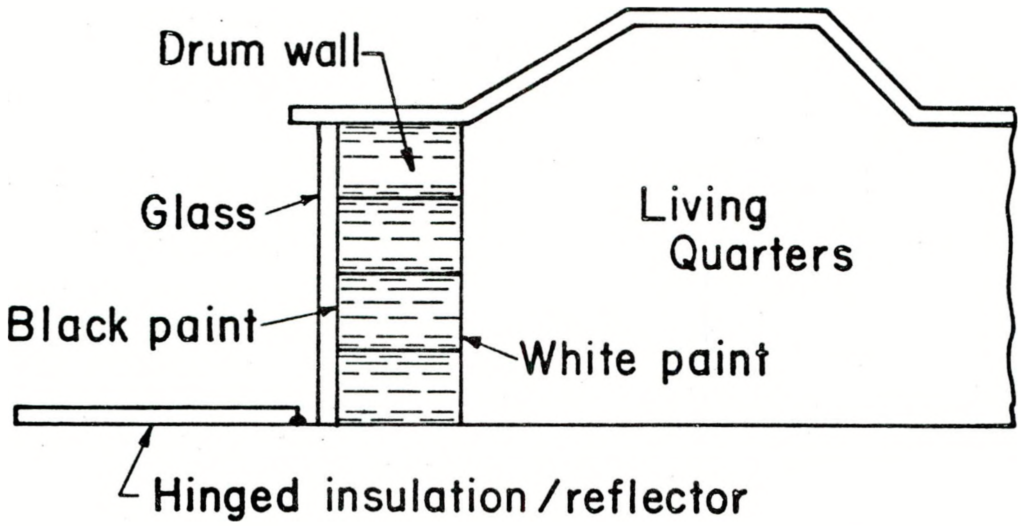

Fig. 19. Water wall (Steve Baer house).

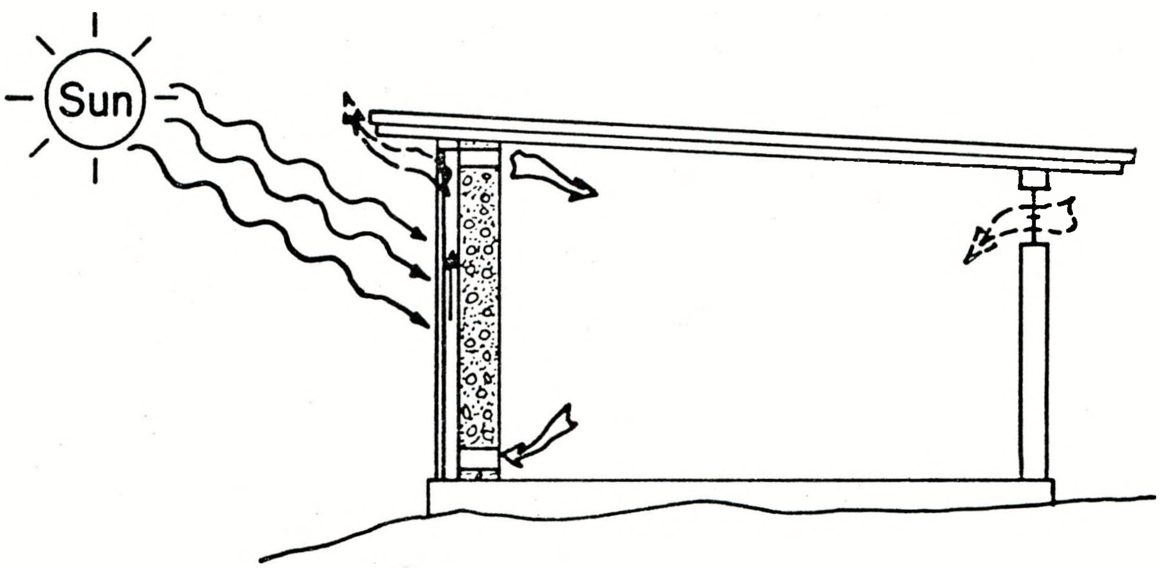

Fig. 20. Concrete wall (Felix Trombe house).

outward surface of the concrete, painted black, is located behind a double-glazed window so that an air passage is formed between glass and concrete; this air passage connects with the living space by means of openings in the concrete wall near the floor and ceiling. In the heating mode, solar radiation strikes and heats the black-painted concrete surface setting up a convective air flow in the space between the glass and the concrete. As cool air is drawn from the floor-level openings and hot air is discharged into the living space through the ceiling-level openings, a convective loop is established throughout the collection area and living space. The massive wall slowly accumulates thermal energy as solar heat which is not removed by convection diffuses into the concrete. At night the convective loop is closed off, and the concrete storage wall then acts as a low-temperature radiant-heating panel for the living space. Although the exterior face of the wall loses some heat to the outside environment, double glazing reduces these losses to an acceptable level.

Data taken from a Trombe-wall building constructed in 1967, in which the walls are 2-feet thick, indicate that roughly 36% of the solar radiation incident on the south wall during winter months is transferred into the house. Over the heating season, 70% of the heating load is provided by solar energy, with the remainder coming from a conventional thermostatically controlled auxiliary system; of this 70%, 20% is transported into the living space by convection through the vents and 50% by conduction through the wall.

In the summer, the overhanging roof shades the glazed concrete wall from the sun. Vents at the top of the glazing allow warm air to escape outside, thus setting up a convective circuit that ventilates the living space.

Roof ponds. In the roof-pond system, thermal storage takes place in water located on the roof of the building. The shift from vertical collection/storage to horizontal results in a system that can be used for summer cooling as well as for winter heating.

The Skytherm roof-pond system, first tested in one-room structures in Phoenix, Arizona, has recently been evaluated in a one-story residence designed especially for the system and built in Atascadero, California (Fig. 21). The flat steel roof of this house supports large black-plastic bags that contain about 7000 gal of noncirculating water (8 in. deep). The bags are in good thermal contact with the steel, which also forms the ceiling of the interior of the house.

On a sunny winter day, the bags are exposed to the sun, which warms the water; at night and during cloudy periods, panels insulated with polyurethane foam slide along tracks to cover the bags and prevent the water from losing its stored-up heat to the outside environment. The stored heat is then slowly transferred from the water through the steel and into the living space, via radiation and convection. On a summer day, the insulated shutters cover the bags to shade them from the hot sun; then at night, with the shutters rolled back, the water radiates its heat to the cool night sky, thus storing coolth for the coming day.

The shutters are stored over the carport when they are rolled back. They can be operated either by hand or by a thermostatically controlled ¼-hp motor.

The thermal performance of the Atascadero house is impressive. The system supplied 100% of the heating and cooling requirements of the building during the test months, and was able to keep the indoor temperature between 66°F and 74°F--except during special test periods and during prototype breakdowns. But even during these exceptional periods, the temperature never went below 60°F or above 80°F. The indoor temperature at the 5-foot level cycled less than 4°F daily. The vertical temperature stratification in the living space was usually less than 5°F in the winter, and less than 1°F in the summer. The largest monthly average heating load handled by the system was about 24,000 Btu/day in February; the largest monthly average cooling load was about 168,000 Btu/day during July. The system was operated with the thermoponds glazed with inflatable clear plastic covers, and also unglazed. The cover proved necessary to keep the indoor temperature up to the 66°F level during the winter months; without it, the indoor temperature dropped to around 60°F in the early morning hours.

The weight of the roof ponds create no major problems, even for a site located in an earthquake area. The design of Skytherm is amenable

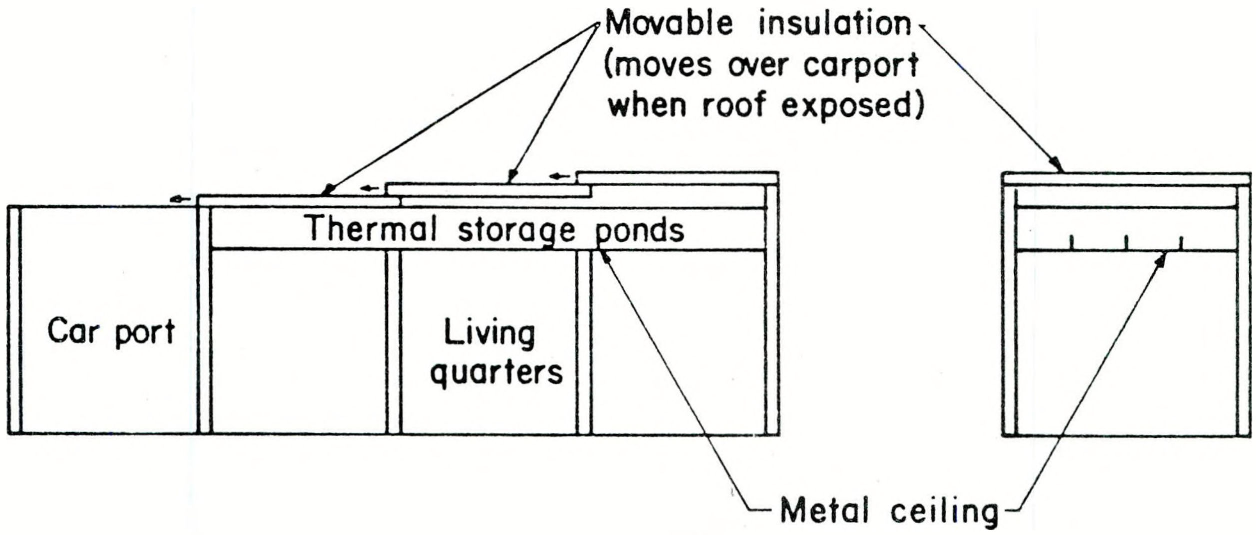

Fig. 21. Roof ponds (Harold Hay house).

to prefabrication, which would result in minimal on-site labor. Problems with roof leaks have been corrected, and additional water-tight roof designs are now being studied. However, there are some geographical limitations to this Skytherm system. In the South, for example, high humidity during the summer would hamper night radiation from the thermoponds to the sky. For high-latitude locations, some kind of vertical reflector is necessary to direct the low winter sun onto the horizontal ponds.

Space Cooling

There are three categories of space cooling for residential buildings: refrigeration, evaporative cooling, and radiative cooling. Solar energy is used directly only for the refrigeration method; and among several refrigeration machines, the lithium-bromide/water absorption unit is the only one in commercial manufacture in sizes suitable for residential buildings. Evaporative cooling and radiative cooling are indirectly related to solar energy in that they are dependent on climatic factors.*

Definition of terms. The capacity of a refrigeration machine to cool room air is customarily referred to in *tons of refrigeration*. A ton of refrigeration is the removal of heat at a rate of 12,000 Btu/hr.

Another often used term in connection with refrigeration equipment is the *coefficient of performance*, *COP*. The COP expresses the effectiveness of a refrigeration system as the ratio of useful refrigeration to net energy supplied to the machine. The COP is determined by the simple equation:

$$\text{COP} = \frac{\text{Heat energy removed}}{\text{Energy supplied from external sources}}$$

The COP of a mechanical vapor-compression refrigeration machine is characteristically about 2 and can be as high as 4. The COP of a lithium-bromide/water absorption refrigeration machine is usually rated at 0.65 and more often operates in the range from 0.45 to 0.55. A COP less than 1.0 means that the energy supplied to the machine is greater than the heat energy being removed from the room air. From the cooling capacity and COP, the rate of energy consumption by the machine to produce the cooling

*For interesting examples of buildings that use energy from the natural environment for cooling, see "Passive Cooling Systems in Iranian Architecture," by Mehdi N. Bahadori, Scientific American, p.144, February 1978.

effect can be determined by dividing the heat-removal rate by the COP. For example, the heat-removal rate for a 3-ton absorption air cooler is 36,000 Btu/hr. With a COP of 0.6, the quantity of heat needed at the generator is 60,000 Btu/hr (=36,000 Btu/hr ÷ 0.6).

Absorption refrigeration. An absorption refrigeration machine uses heat energy to provide cooling. When a liquid mixture of refrigerant and absorbent is heated, the refrigerant is driven out of solution. The refrigerant flows from the generator through a condenser, expansion valve, and evaporator, and then into an absorber where it recombines with the absorbent. In a lithium-bromide/water absorption machine, water is the refrigerant and lithium-bromide solution is the absorbent. An absorbent is a liquid that combines chemically with the refrigerant at low temperatures but will separate from the refrigerant at high temperatures; in the combination process, heat absorbed by the refrigerant is released.

The operating principle of a lithium-bromide absorption cycle can be explained with the aid of Fig. 22. The cycle begins when water in the liquid mixture in the generator is boiled off in superheated state by solar energy at temperatures between 170 and 210°F. Superheating of water is made possible by having very low pressure in the system. The superheated water vapor leaving the generator enters the condenser, where it is cooled to about 100°F by the cooling water from an outdoor cooling tower. The vapor condenses to a liquid and is then revaporized through an expansion valve which cools the vapor-liquid mixtures to a temperature of 40°F. The heat in the room air or water that is brought in contact with the evaporator is removed by the evaporating refrigerant. The refrigerant then passes to the absorber where it recombines with the concentrated lithium-bromide solution from the generator at a temperature of about 100°F.

In this recombination process, heat is released; and the heat is removed by the cooling water from the cooling tower. The dilute solution of lithium-bromide and water in the absorber flows by gravity, or is pumped, back to the generator and the cycle is repeated. The "recuperator" in the diagram is a heat exchanger that preheats the dilute solution as it flows from the absorber to the generator and at the same time cools

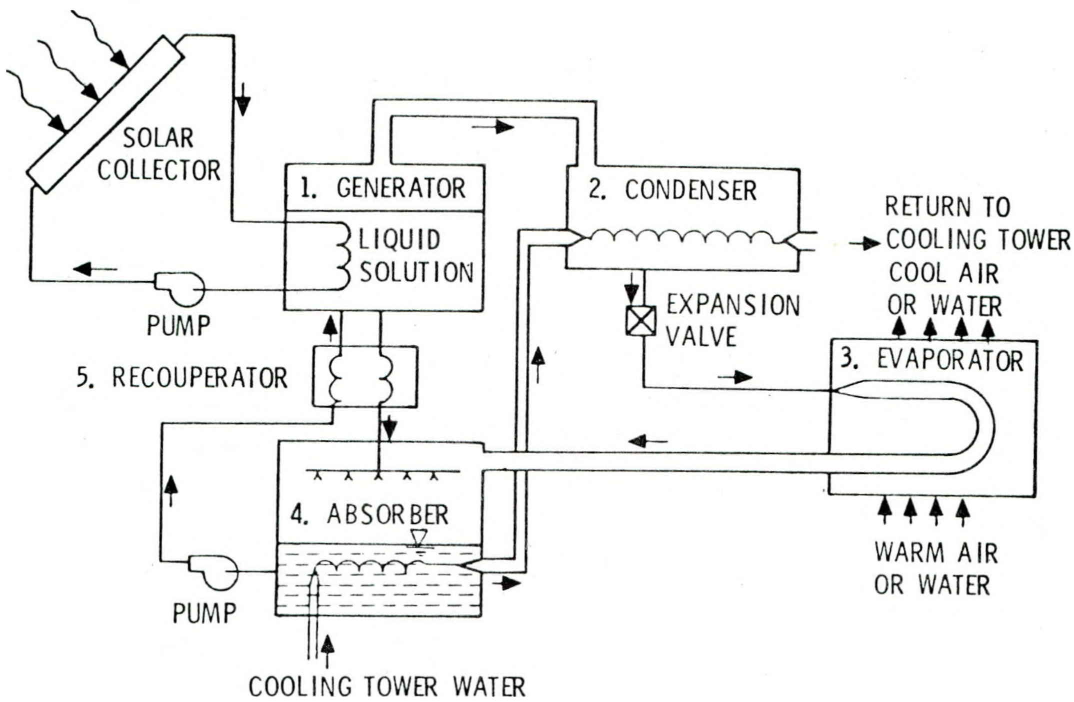

Fig. 22. Absorption air conditioner.

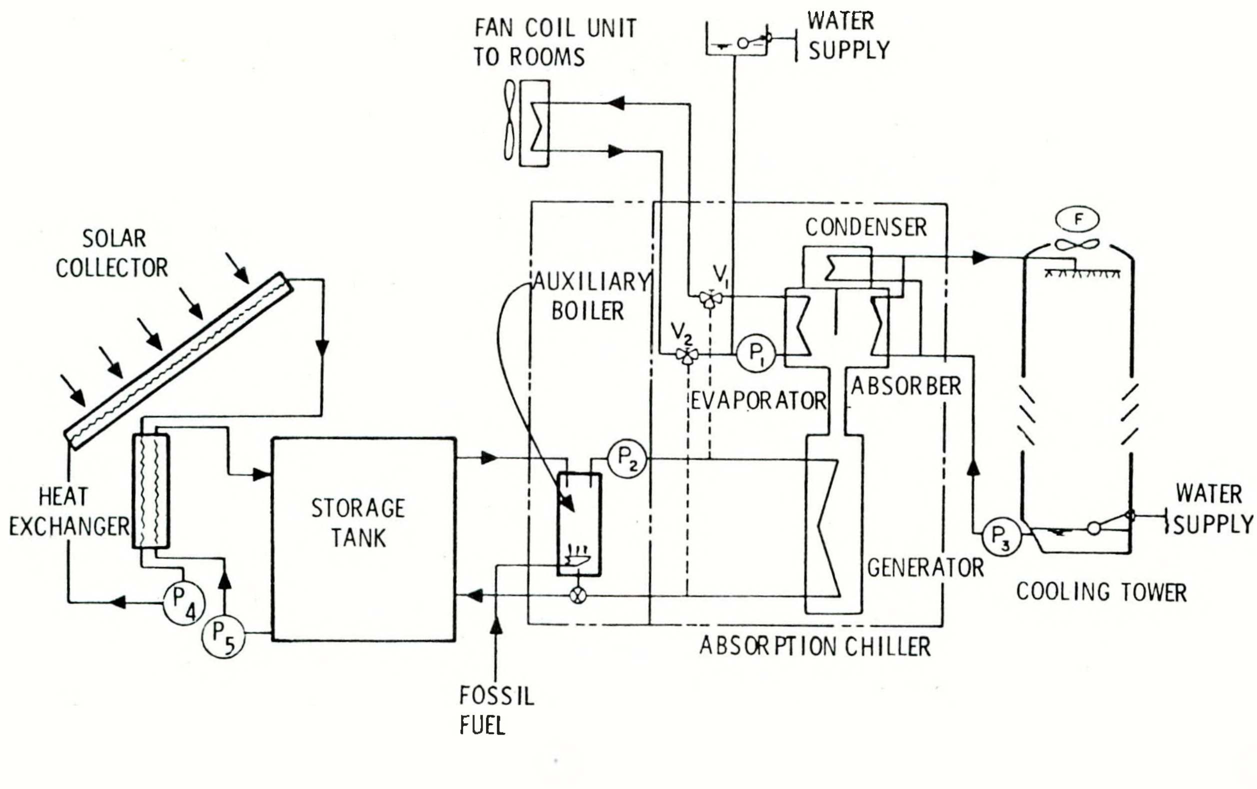

Fig. 23. Flow chart of a water chiller operation.

the hot concentrated solution that flows from the generator to the absorber. This makes the system thermodynamically more efficient.

The operating temperature range of the hot water supplied to the generator of a solar-operated, lithium-bromide/water absorption refrigeration machine is restricted to about 170 to 210°F. The heat input to the generator must be sufficiently high to boil the refrigerant water from the solution in the generator; and the hot water to the generator, which comes from storage, will be less than the boiling point of water at atmospheric pressure. Another limitation is the temperature of the concentrated lithium-bromide solution which flows from the generator to the absorber through the recuperator. If the temperature is too low in the recuperator, and the concentration of the lithium-bromide/water solution is high, the lithium-bromide will solidify in the outlet tube leading from the recuperator to the absorber (and eventually in the generator) as water continues to be boiled off. Only if temperature in the generator is between 170 and 210°F will the unit operate satisfactorily.

Solar Heating and Cooling Systems

A schematic diagram of a solar heating and cooling system with service hot-water heating is shown in Fig. 23. The components added to the heating system are:

- Absorption water or air chiller
- Wet cooling tower
- Pump to circulate cooling water from the chiller to the tower
- Pump to circulate chilled water
- Associated piping, valves, and controls.

Operation. The collector, with or without the heat exchanger, provides hot water to the storage tank. If a heat exchanger is not used in the collector loop, only one pump is needed to circulate the water from storage through the collector. The water is taken from the storage tank and is pumped through the generator of the absorption chiller by pump P2 and returned to the bottom of the tank. In this arrangement, the flow from the tank is through the auxiliary boiler, which allows the use of the same pump for circulating water both from the storage tank and through the auxiliary boiler. When the temperature in the storage tank is insufficient to operate the absorption chiller, the auxiliary boiler provides heat to the generator. When the auxiliary boiler is used, the three-way valve at the bottom of the boiler diverts the return water to circulate only through the boiler. In this way, auxiliary energy is not used to heat the storage tank. The size and head of pump P2 depend upon the flow rate and length of piping for the system. It is advantageous to place the absorption chiller as close to the storage tank as possible to minimize both the pressure drop and the heat losses from the pipeline.

A wet cooling tower is needed with the absorption chiller to discharge heat from the condenser and the absorber to the atmosphere. The size of the cooling tower needed depends on the size of the absorption machine (cooling capacity) and the wet-bulb temperature of the ambient air. The temperature of the cooling water from the tower will have a significant effect on the coefficient of performance (COP) of the machine. For example, a drop in COP from 0.7 to 0.6 can be expected if the wet-bulb temperature increases from 75 to 85°F. The pump P3 is needed to circulate the cooling water from the tower through the absorber and condenser of the absorption machine.

The chilled water from the evaporator is circulated by pump P1 to the fan-coil unit to cool the air in the rooms. The fan-coil unit may be the same central unit used for heating, or there may be individualized units for different zones within the building.

System characteristics. The flow rates of hot water from the storage tank, cool water from the cooling tower, and chilled water from the evaporator depend upon the cooling capacity. The details for determining the flow rates are complex, but the manufacturer will provide the information needed to size the pumps.

The operating characteristics will be described for a 3-ton unit having a COP of about 0.8. From the definition of COP, the heat input to the generator is 45,000 Btu/hr for the 3-ton unit. If the temperature of the hot water is (say) 195°F, this means the flow rate must be about 19 gal/min to the generator with a difference of 10°F between entering and exit temperatures from the generator. The heat removal rate at the condenser is about 38,000 Btu/hr, and at the absorber about 43,000 Btu/hr. The cooling water from the tower will be at a temperature near 75^{o}F and will return to the cooling tower at a temperature of about 90^{o}F. The flow rate should be about 12 gal/min. The heat rejection rate of the cooling tower will be 81,000 Btu/hr, which is equal to the cooling capacity (36,000 Btu/hr) plus the heat added to the generator (45,000 Btu/hr).

If a cooling water temperature of 75^{o}F cannot be achieved because of a rise in the wet-bulb temperature of the outside air, or because the tower is not sized properly, the performance of the system can be expected to go down. If the temperature rises to 85^{o}F, then the COP will change from 0.8 to about 0.7. The 3-ton unit will then provide about 2.5 tons of cooling with the same heat input to the generator. Also, if the heat input rate to the generator decreases, the performance of the cooling system will decrease. It is important to follow the manufacturer's sizing recommendations for cooling tower and pumps for a particular size of cooling unit at a given geographic location, because of the system's sensitivity to cooling-water temperature and to flow rates.

Another important factor in the operation and performance of a solar cooling unit may involve frequent on-off cycling, depending on the system design. When the cooling load is less than the cooling capacity of the unit, the unit will turn on as the temperature in the building rises above the threshold level. When the building cools to the desired comfort level, the unit will switch off. These on-off temperatures depend upon the thermostat settings, but they could be (for example) 80^{o}F and 75^{o}F, respectively. Because of the cooling unit's thermal capacity, a sizable quantity of heat is needed to start up the cooling equipment each time the building calls for cooling. It requires about 10 to 15 minutes before a unit begins to cool. Cycling can be a problem, particularly for air chillers, but it can be reduced for water chillers by providing chilled water storage, enabling the cooling unit to operate continuously. When cooling is not needed for the building, the chilled water can be stored. When it is needed, valves divert the chilled water to the fan-coil units. Cycling can also be reduced by increasing the dead-band of the thermostat. This will cause greater temperature excursions within the building; but these can be tolerated in residences, particularly if there is significant improvement in cooler performance.

Installation considerations. It has already been pointed out that the absorption unit should be placed as close to the storage tank as possible to reduce thermal and pressure losses in the pipelines. The cooling tower also should be located close to the system; however, esthetic considerations may dictate the choice.

The higher operating temperatures of water in the storage tank necessitate insulation of the storage tank, pipes, and solar equipment. If the surfaces are not well insulated, there will be heat flow into the building enclosure from the solar equipment, which will add to the cooling load. Some of the heat gain can be eliminated if the solar equipment, including the absorption chiller, is placed in an insulated room. During the cooling season, the room can be vented to the outside, and during the winter, the vents can be closed to take advantage of the heat gain in the building.

Evaporative Cooling with Rock-Bed Storage

Evaporative cooling is effective whenever there is a difference in vapor pressure between the water and the atmosphere. Warm air may be evaporatively cooled to a dry-bulb temperature that depends on the velocity of air and the wet-bulb temperature. As an example, outside air at $100^{\circ}F$ dry-bulb and $70^{\circ}F$ wet-bulb (relative humidity 22%) can be cooled by an air washer to about $77^{\circ}F$. Strictly speaking, evaporative cooling is not a solar energy system; but because the rock bed of an air-heating solar system can be used for storing "cool" air in the summertime, an evaporative cooling unit may be considered along with an air-heating solar system.

An evaporative cooler coupled with a rock-bed storage unit is shown in Figs. 24 and 25. Night air is evaporatively cooled and circulated through the rock bed to cool the pebbles in the storage unit; during the day, warm air from the building can be cooled by passing the air through the cool pebble bed.

An evaporative cooling system coupled to an air-heating system is shown schematically in Fig. 26. To cool the rock-bed storage, air is drawn from outdoors and evaporatively cooled by the EVC. All dampers

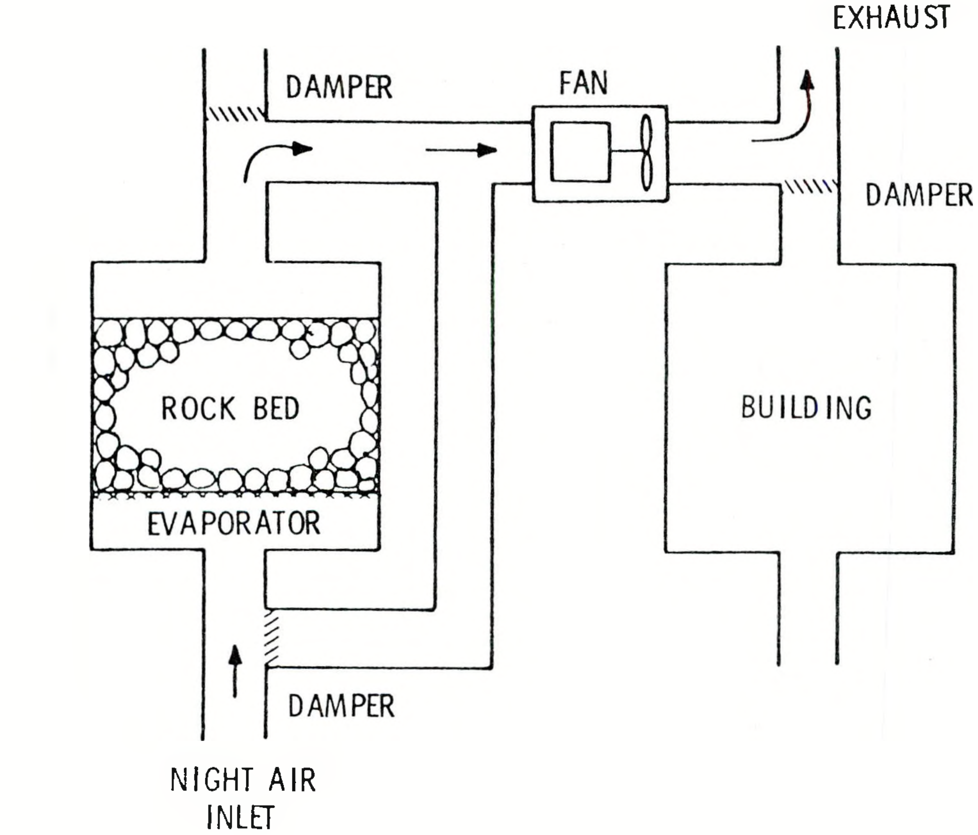

Fig. 24. Night charging of rock bed.

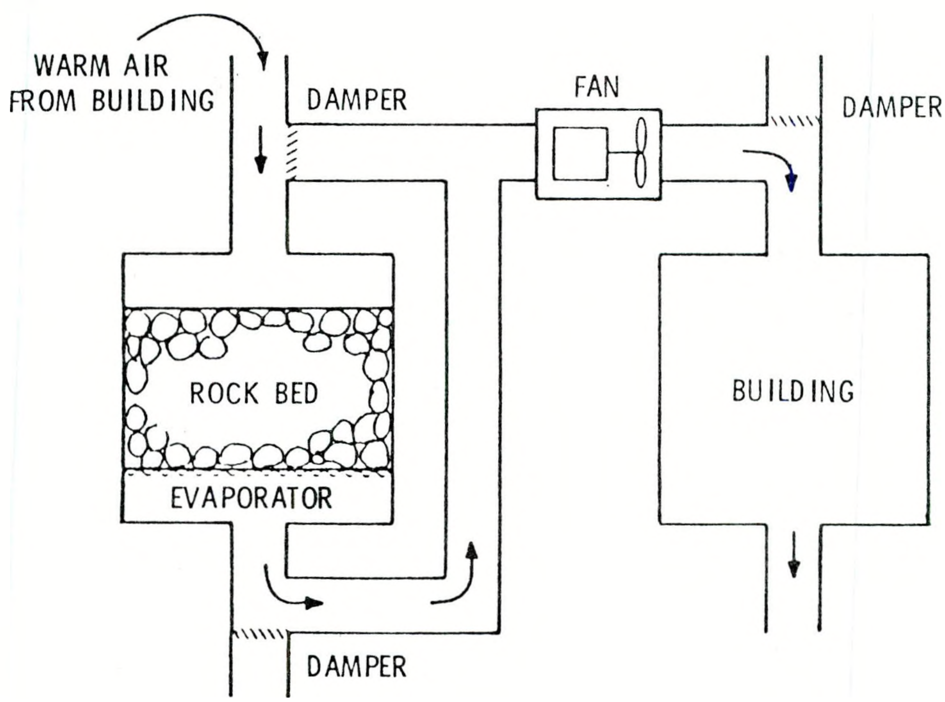

Fig. 25. Day cooling of building.

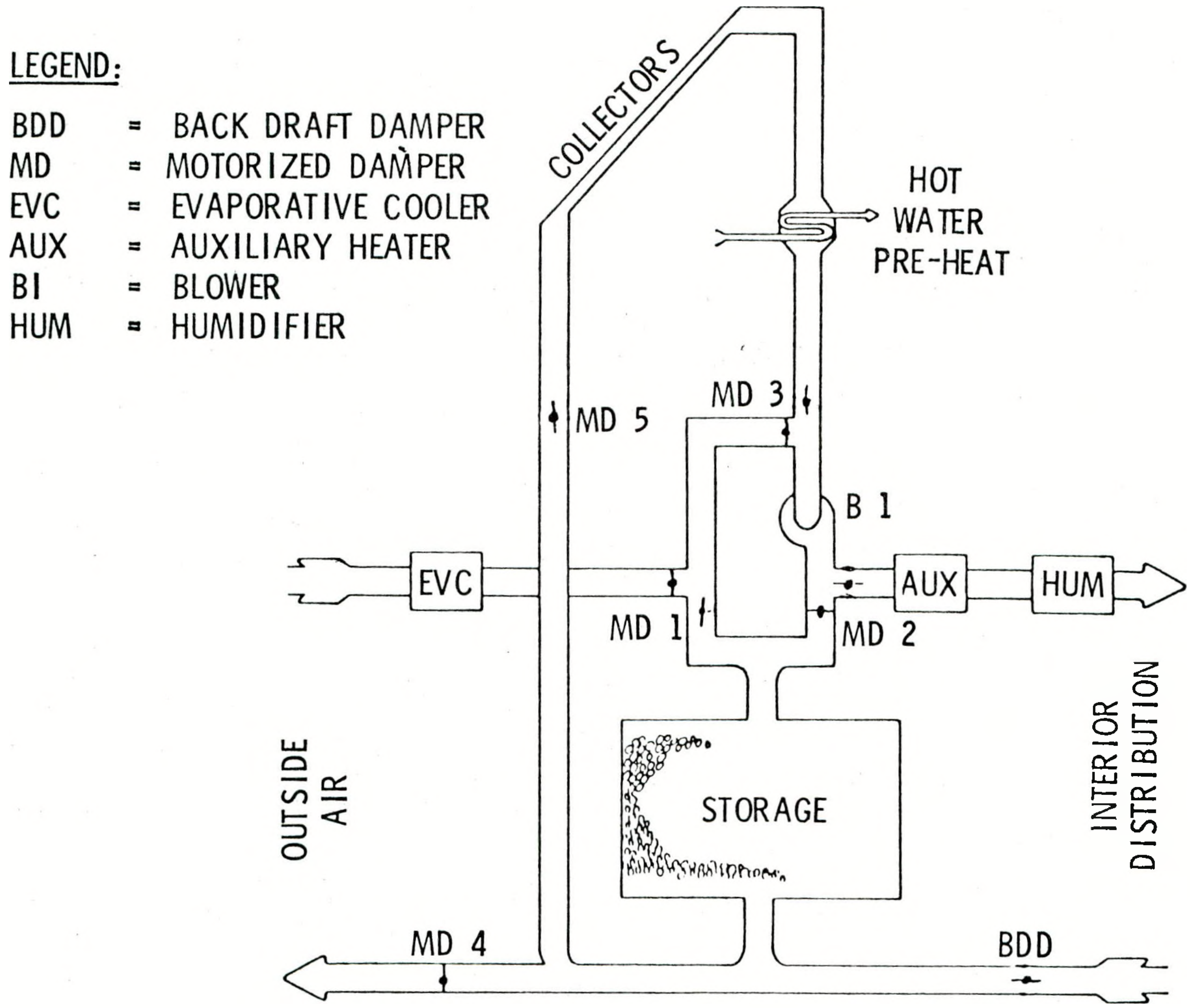

Fig. 26. Air-heating system with an evaporative cooler.

are positioned by the controller so that the cooled air is blown through storage (bottom to top) and discharged outdoors. The evaporative cooling of the rock-bed storage is accomplished during night-time hours. During the day when cooling is required in the building, the room air is drawn through the cool storage bed in a reverse direction (top to bottom), and is distributed back to the rooms. When the cooling capability of the rock bed has been depleted, the evaporative cooler may also be used directly to cool the building.

The installation of an evaporative cooler in the solar-heating system is relatively simple. There are no unusual features. As with all air systems, care should be exercised in installing dampers and ducts to ensure that tight closure can be achieved to prevent air leakage.

System performance example. The design guideline for sizing the rock-bed storage of a solar air-heating system is 0.5 to 1 ft^3 per square foot of collector. The air flow rate recommended is 2 ft^3/min per square foot of collector. Therefore (for this example) the volume of rocks and the air flow rate for 500 ft^2 of collectors on a house would be 250 to 500 ft^3 and 1000 ft^3/min, respectively.

Let's assume that the rock bed can cool down to 55°F at night with an evaporative cooler and that the desired temperature in the building is 75°F during the day. The rate of cooling provided by this system during the day is determined by :

Cooling rate = (air flow rate) x (air density) x (air heat capacity) x (temperature difference).

For this example, the cooling rate capability of the system is:

$$\text{Cooling rate} = (1000\ ft^3/min) \times (0.073\ lb/ft^3) \times (0.24\ Btu/lb°F) \times (75°F - 55°F) \times (60\ min/hr)$$

$$= 21{,}024\ Btu/hr$$

$$= 1.75\ \text{tons of cooling.}$$

The cooling capacity stored in the rock bed is determined by:

Cooling capacity = (volume of rock storage) x (specific weight of rocks) x (specific heat of rock) x (temperature difference).

For the example system with 250 ft^3 of rock bed:

$$\text{Cooling capacity} = (250\ ft^3) \times (100\ lb/ft^3) \times (0.21\ Btu/lb^\circ F) \times (75^\circ F - 55^\circ F) = 105{,}000\ Btu$$

At a cooling rate of 21,024 Btu/hr, about 5 hr (=105,000 Btu ÷ 21,024 Btu/hr) of cooling capability are provided by 250 ft^3 of rock-bed storage.

If the storage size is 500 ft^3, the cooling capability is increased from 5 hr to 10 hr; but the rate of cooling is the same (1.75 tons). It is therefore advantageous to consider the largest rock-bed storage permissible for the solar-heating system when thinking of coupling an evaporative cooling unit with it.

The size of the evaporator cooler is determined by the desired approach of the temperature to wet-bulb temperature. The flow rate through the EVC is effectively the same as for the heating mode, although a two-stage motor could be used to increase the flow rate for cooling. If the air flow rate is 1000 ft^3/min and the outdoor air temperature is 80°F, and cooling to 55°F is desired, then the EVC cooling rate is:

$$\text{Cooling rate} = (1000\ ft^3/min) \times (0.073\ lb/ft^3) \times (0.24\ Btu/lb^\circ F) \times (25^\circ F) \times (60\ min/hr) = 26{,}280\ Btu/hr.$$

The EVC is sized by the air flow rate in ft^3/min. But the performance of a given unit will vary with the outdoor dry- and wet-bulb air temperatures. If an oversized evaporative cooling unit is used, the approach to saturation is greater, which means the relative humidity of the cooled air will be high. A high moisture content will likely cause condensation on the pebbles in storage. The room air which is circulated through the rock bed will then be humid because moisture will be picked up from the rock bed. On the other hand, if the EVC unit is undersized, the approach to saturation will be less and the cooled air temperature will be higher than for a larger unit.

Evaporative cooling of the type described is effective only in arid and semiarid regions of the country where there are cool nights and low wet-bulb temperatures.

Heat Pumps*

A heat pump is a device that uses electrical energy to transform a low-temperature energy source--such as ambient air, ground water, or solar-heated air or water--to high-temperature energy suitable for heating buildings. The same device in a reversed operating mode can be used to cool building space. A heat pump is basically a reversible refrigeration machine, not unlike a household frostfree refrigerator, but much larger since its purpose is to heat and cool the entire building.

System description. A typical heat pump unit which uses the energy in the outside air is shown in Fig. 27. An electrically driven compressor compresses a refrigerant vapor to a high temperature. The heat is given up at the indoor coil to the room air and the refrigerant condenses to a liquid. As the liquid refrigerant is then expanded to form cold vapor in the outdoor section, heat energy is drawn into the cold refrigerant at the outdoor coil and circulated back to the compressor, where the cycle is repeated.

In the cooling mode, the cycle is reversed as shown in Fig. 28. The functions of the outdoor and indoor coils are reversed; thus the indoor coil draws heat from the room air, cooling the air, and the heat is rejected at the outdoor coil, just as it is in a standard refrigeration unit.

Figures 27 and 28 are shown for an *air-to-air* heat pump, but the cycle and principles of operation are the same for water-to-air and water-to-water heat pumps. For a *water-to-air* heat pump, the energy source at the "outdoor" coil in Fig. 27 would be water. If the water is heated by solar energy, the unit becomes a solar-assisted heat pump. In the cooling mode, a water-to-air heat pump would reject the heat in water; therefore it could be used to heat a swimming pool in the summer. A *water-to-water* heat pump uses low-temperature water as the energy source and heats the water for the indoor heat-distribution system.

Solar-assisted heat pumps. The concept of a solar-assisted heat pump is to supply low-grade solar-heated air or water to the heat pump. Because the temperatures are low, the solar collectors operate more efficiently than for direct solar space heating.

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*For additional information on heat pumps, see feature articles on pages 27, 32, and 36, respectively, in "Solar Engineering," Vol. 3, No. 2, February 1978.

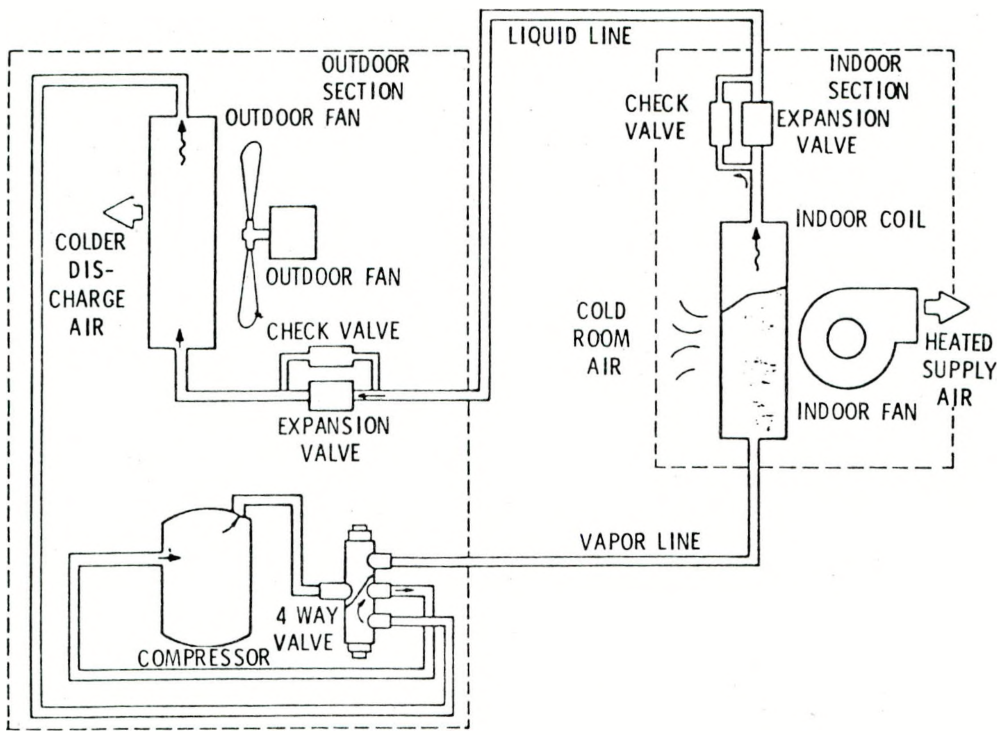


Fig. 27. Heat pump in a heating mode.

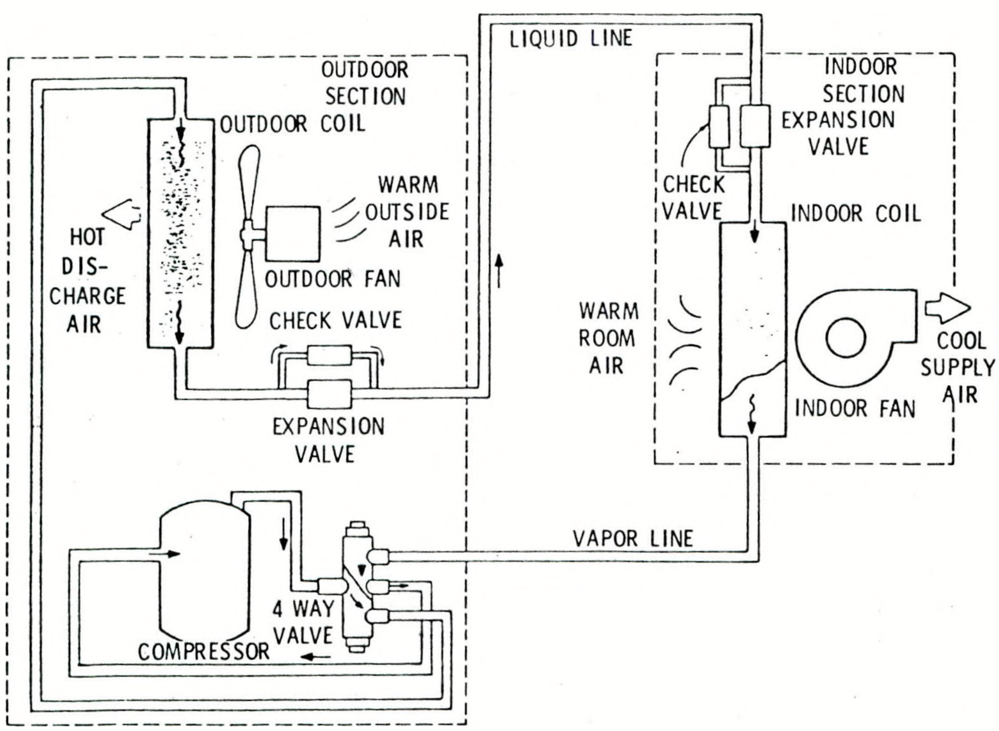


Fig. 28. Heat pump in a cooling mode.

The heat is usually stored on the low-temperature side of the heat pump because this results in less heat loss, and also because a smaller capacity heat pump is needed than for a "hot side" storage unit. The system is illustrated in Fig. 29. The collectors may be air-heating with a pebble-bed storage unit or liquid-heating with water or phase-change storage. Consequently, the heat pump may be any of the three types (air-to-air, water-to-air, or water-to-water).

It is not yet clear which heat-pump arrangement is going to prove best. With an air system, the heat pump can be used most advantageously if operated simply, as the auxiliary furnace normally would be used, to boost the temperature of the air coming from the pebble bed to the rooms. Outdoor air is used as the source. In the liquid systems, it is not obvious whether the heat pump should be used in a similar fashion or whether the source should be the solar storage tank. At this time, an engineer and the heat-pump manufacturer should be consulted to help in the design of a solar heat-pump combination.

The coefficient of performance (COP) of a typical heat pump in the space heating mode is shown below for various outside temperatures (interior temperature of 70°F is assumed).

Outside Temperature (°F)	COP
60	4.5
50	4.0
40	3.5
30	3.0
20	2.5
10	2.0
0	1.5

A COP of 3.0, for example, means that the heat pump moves 3 units of heat for 1 unit of electrical energy. By comparison, the COP of regular electric heating is 1.0, because 1 unit of heat is produced by 1 unit of electricity. In other words, a heat pump is much cheaper for space heating than is regular electric heating.

The advantage of a solar-assisted heat pump over a normal solar space heating system lies in the collector requirements. A small bank of collectors will have no trouble keeping the tank at 60° even in a very cold climate. On the other hand, a normal solar space heating system will require a very large bank of highly efficient collectors to keep the storage tank at, say 120°, in this same climate.

During the cooling season, a conventional heat pump moves heat from the inside of the house to the outside, and when the outside is very hot, the corresponding COP will be low. However, the corresponding COP for a solar-assisted heat pump will be higher, since its operation is analogous to a large storage tank, filled with cool water, serving as a heat sink.

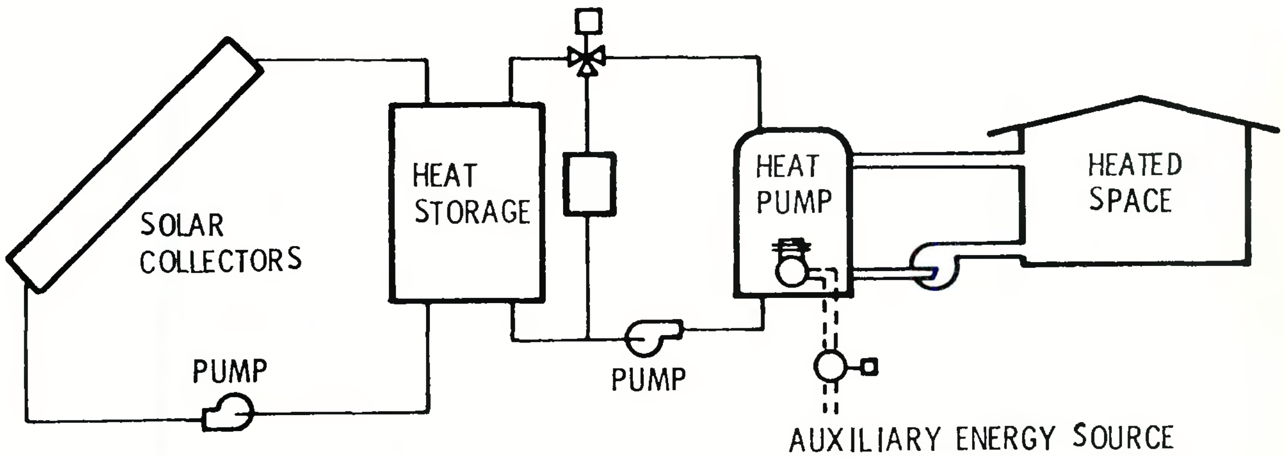


Fig. 29. Simplified diagram of a solar-assisted heat-pump system, series arrangement.

SWIMMING POOL HEATING

Using solar energy to heat swimming pools is an appropriate and relatively simple application. Among the several factors that make solar pool heating attractive is the increasing unavailability of natural gas for this purpose. Heating a pool often requires more fuel than heating a home, and thus will have a low priority as supplies of natural gas decrease.

Because solar collectors for swimming pools operate at a relatively low temperature, they lose little heat to their surroundings (unless it is windy) and need neither glazing nor insulation (except for winter use). Since the collectors can be unglazed (which prevents damaging heat build-up) and since the working fluid is not potable water, collectors for pool heating can be made of inexpensive plastics--provided the material has been impregnated with chemicals to reduce damage from exposure to the sun's ultraviolet radiation. Absorber plates of copper have also been used successfully, but they are more expensive.

The water of the swimming pool itself provides the thermal storage for the solar heater; and the pool's already-existing pump and distribution network simplify the installation of the system. Existing pumps usually have sufficient head to move the water fast enough to keep collector temperature down and collection efficiency up.

The rule-of-thumb for sizing pool collectors is that the collector area should be equal to at least one-half of the pool surface area. If one wants to extend the swimming season into the spring or autumn, it may be necessary to have the collector area equal to that of the pool surface. Any deviation of the collectors from optimum tilt or orientation may also require increasing the collector area.

In order to determine the optimum size (or output) of the solar collectors, it is necessary to calculate the rate of heat loss from the pool--or more precisely, the amount of heat required to maintain the desired pool temperature. Heat can be lost in several ways:

- *Convection:* Moving air takes heat with it as it passes over the pool.
- *Evaporation:* Heat is used up in vaporizing the surface layer of water.
- *Radiation:* The warm pool gives off heat to the colder sky.

- Conduction: Heat is lost through the bottom and sides of a pool. However, the amount of this loss is small because of the relatively poor thermal conductivity of the surrounding soil; it is usually ignored.

Heat loss calculations are discussed, with examples, in *How To Design And Build A Solar Swimming Pool Heater* by Francis de Winter (see Bibliography in the Information section). The calculations are not too difficult; but since convective heat loss is very sensitive to wind speed, it may be hard to get sufficiently accurate weather and wind data.

Pools should be covered when not in use! Many types of pool covers are now commercially available; their use will cut heat loss by as much as 50%, depending on the climate. In addition, covers save chemicals and water which would otherwise be lost by evaporation. Convective heat losses can be further reduced by planting or erecting windbreaks as close to the pool as practical--which also adds to the comfort of the swimmers.

System operation. A solar swimming pool heating system is represented schematically in Fig. 30. During operation of the solar system, the gate valves are open and the bypass valves closed. (The purpose of these valves is to isolate the collectors for repair without interrupting the operation of the differential thermostat.) When the differential thermostat senses that the solar collectors are warmer than the pool water, it closes the automatic valve, causing the water to flow from the pool through the collector loop. If the solar system is not collecting enough heat, a thermostatically controlled auxiliary heater can be used to maintain the desired pool temperature.

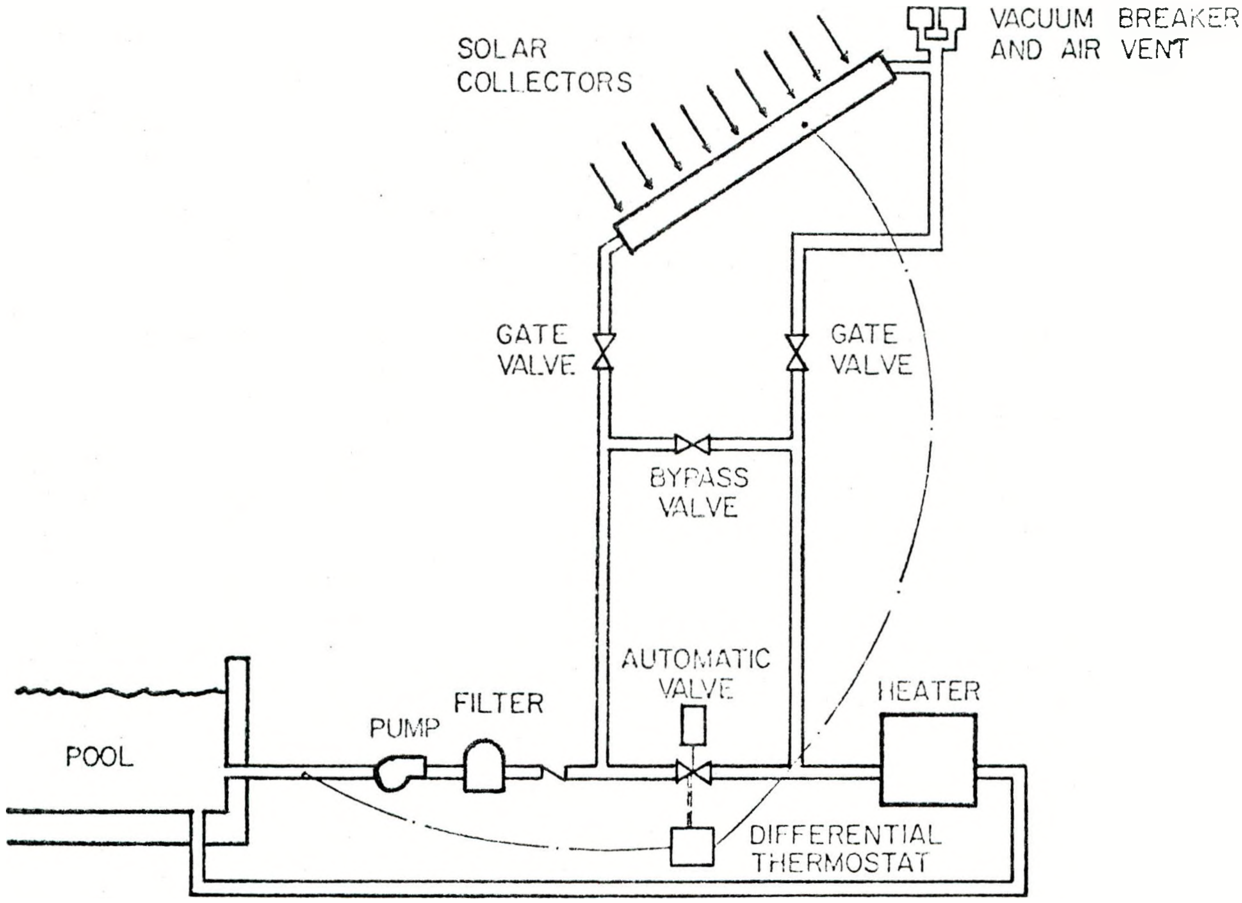


Fig. 30. Solar pool-heating system with automatic valve.

SOLAR PONDS FOR INDUSTRIAL PROCESS HEAT

A shallow solar pond (SSP) is a special type of horizontal, flat-plate collector used to heat water to 150°F. Costs are minimized by building large area modules from polymeric materials to replace metal and glass used in conventional flat-plate collectors.

Figure 1 shows the basic design features of two types of SSP's, one being more capital-intensive than the other. The selection of a particular design depends on a detailed economic study and acquisition of accurate life-expectancy data for materials.

The basic design consists of a plastic water bag with a black bottom situated over two inches of polyurethane foam. A plastic window is supported over this assembly either mechanically (A), or with air (B). Solar radiation is transmitted through the upper cover and is absorbed by the water and black pond bottom. The convective losses are minimized by the cell of air, and radiation losses in the infrared region are minimized by the cut-off characteristic of the cover.

In one industrial application at a uranium milling and mining complex, three full-size SSP modules of different designs, cold and hot water storage reservoirs, and instrumentation to measure heat collection, provide indistrial hot water for leaching operations. The plant requires 400,000 gallons of water per day, heated to 140°F. Oil burners are to be supplemented by preheating water in ponds similar to those shown in Figure 1A. As presently conceived, each pond module is a long, narrow, clear plastic bag (200 by 12 feet) containing slowly flowing water two to four inches deep. On sunny days, hot water is used directly from the ponds; storage reservoirs, constructed underground, retain useful quantities of heat overnight or through cloudy periods of a few days.

In this field, the U.S. Department of Energy is sponsoring R&D aimed at reducing the cost of the ponds and finding other applications for the concept: crop drying, solar-heated air, hot water, space heating, and air-conditioning for buildings and plants, and to make steam economically.

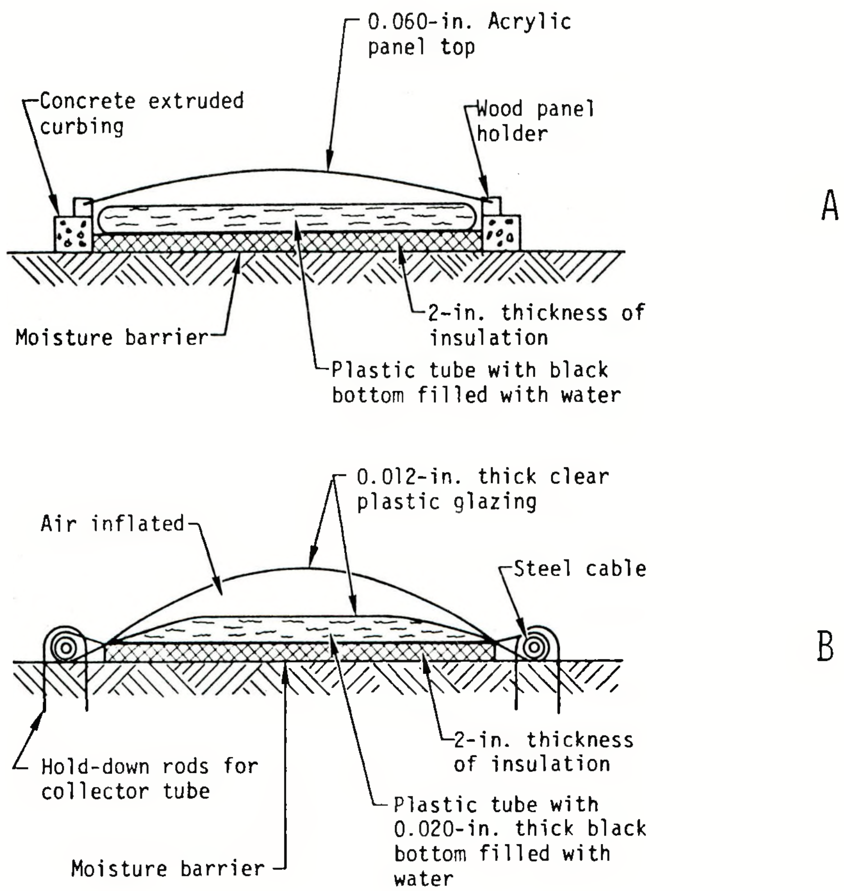
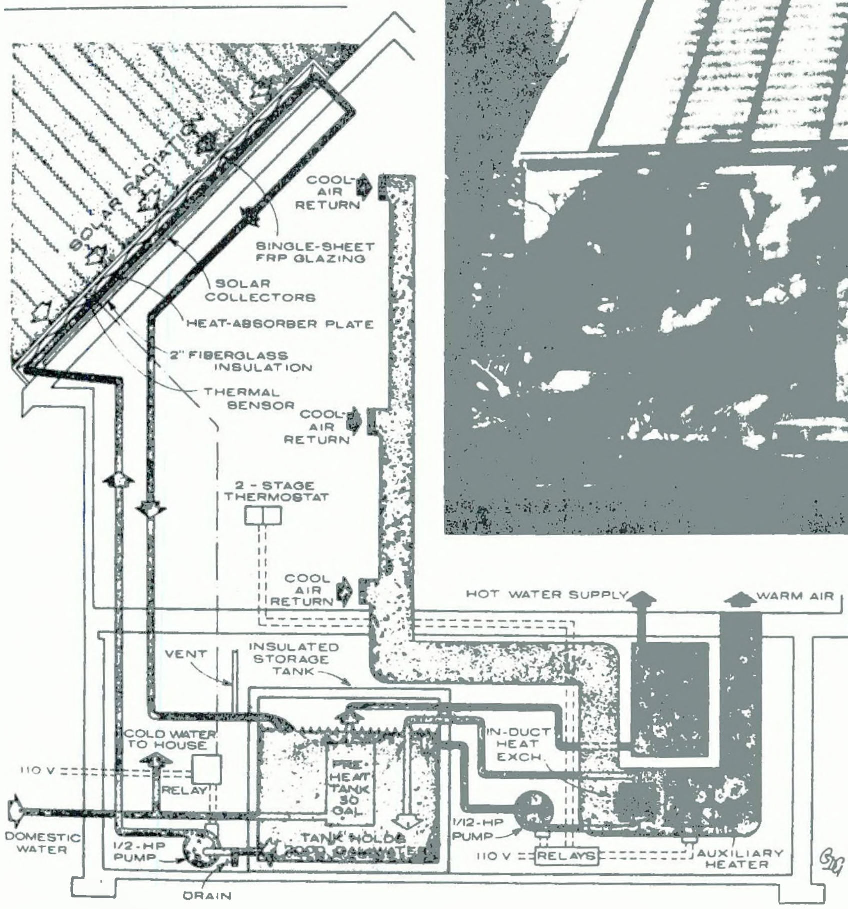
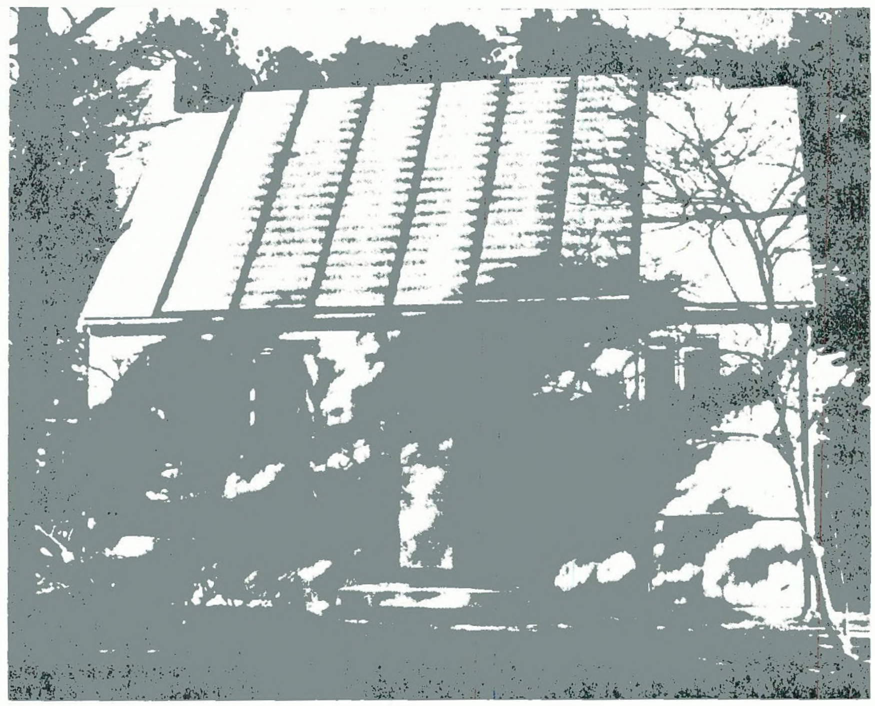


Fig. 1 Basic design features of two types of shallow solar ponds

PS update: the newest
solar-heating equipment

High heat bills and proposed tax breaks tempt you to buy? Now may be the right time





Acorn Sunwave 420 Energy System is designed for company's factory-built homes, garages. Copper tubes are clamped to aluminum absorber plate in 4-by-20-ft. collectors; glazing is fiberglass-reinforced plastic. Untreated water is pumped through collectors to vinyl-lined plywood storage tank; collectors self-drain in subfreezing temperatures. Installed cost of complete six-panel (420-sq.-ft.) system: $7200.

By RICHARD STEPLER

Suddenly, it seems everyone's talking about sun power. It makes newspaper headlines and television specials. Even your next-door neighbor may be talking about putting solar collectors on his roof.

Why suddenly? Much of the interest was sparked by the brutal winter of 1976-77, which shocked many Americans with its record high heating bills. Perhaps the catalyst was provided by President Carter's proposal for solar tax credits, included in his energy message last April. In any case, the public's interest in solar energy is at an all-time high. And a record number of manufacturers are now able to provide the most reliable and economical solar-heating equipment ever.

Bigger companies are now producing solar hardware. The names should be familiar:

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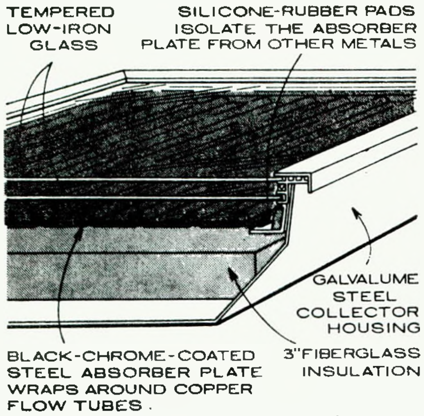
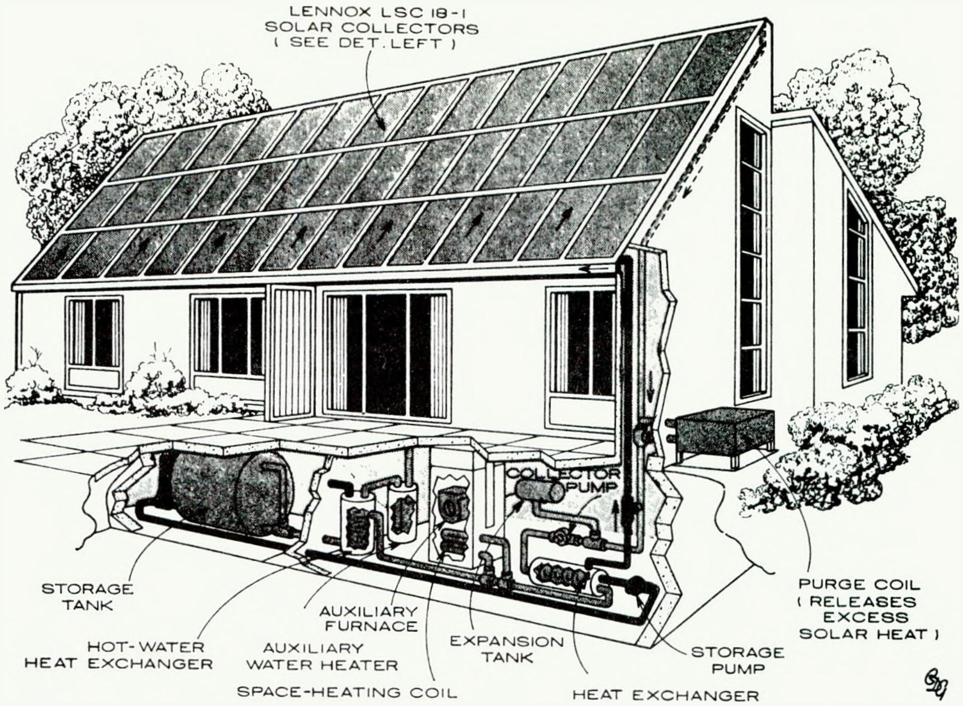




Lennox Solarmate space- and water-heating system uses transfer fluid to carry heat from collectors to space-heating coil, storage tank, and water heater. Backup is oil- or gas-fired Lennox furnace or heat pump, plus water heater. Collector's steel absorber plate (detail, above) is formed around copper flow tubes and sealed with solder filler. Complete system will be offered later this year; hot-water system (available now) costs from $1200 to $3000, installed.

• Iowa-based Lennox Industries, in cooperation with Honeywell, will market a complete solar-heating package (see drawing) through Lennox's 6000 dealers. Already available is a domestic hot-water system (average installed cost: $1500). A dealer-training program covering the design, installation, and servicing of solar-heating systems began this summer.

• General Electric, which initially offered a flat-plate collector with its solar-assisted heat-pump system (see drawing), has now developed an advanced evacuated-tube collector. GE plans to have the units in production at its Valley Forge plant about the time you read this.

• ITT's Fluid Handling Division offers pumps, heat exchangers, and valves for solar heating systems. The company also provides a design manual to help contractors and engineers plan solar projects.

• Glass manufacturers—Owens-Illinois and Libbey-Owens-Ford—are joining rival PPG in the solar field. O-I is putting its Sunpak evacuated-tube collector on the market this year (see last month's cover story for a description of two prototype systems). LOF has taken a more conventional approach with its Sun Panel—a double-glazed flat-plate collector.

• Westinghouse's new Solar Heating and Cooling Division offers a solar-assisted air-to-air heat pump, using air-type collectors made by Sunworks (see drawing). Al Weinstein, division manager, says a system costs about $10,000.

• And giant automaker GM, through its Harrison Radiator Division, plans to develop and market a solar hot-water system in 1978.

New, small companies are introducing some of the most exciting innovations, however:

• Daystar Corp., founded only two years ago, has developed a flat-plate collector that features an ultrathin polymer structure between the cover glass and absorber plate. It both enhances solar transmission, says Daystar, and reduces heat loss due to radiation and convection. At least one independent engineering firm rates Daystar's collector above all others tested.

• A new idea in control systems is complete prepackaging. Ecosol Ltd. offers an energy-recovery system that includes pumps, valves, electronic controls, an air handler, and a backup heat pump in a unit that very much resembles a conventional oil- or gas-fired furnace. That's no accident. "New trades are not going to be installing solar heating systems," says Ecosol vice-president Bruce Rodin. "We wanted a unit that would be familiar to electricians, plumbers, and heating contractors." Price of Ecosol's model 101 system: $3900 to $4200.

• And Minnesota-based Sunsource Systems Corp. has developed a "black-liquid system"—the collector structure itself is transparent extruded plastic with a reflective backing; a blackened heat-transfer fluid is the absorber.

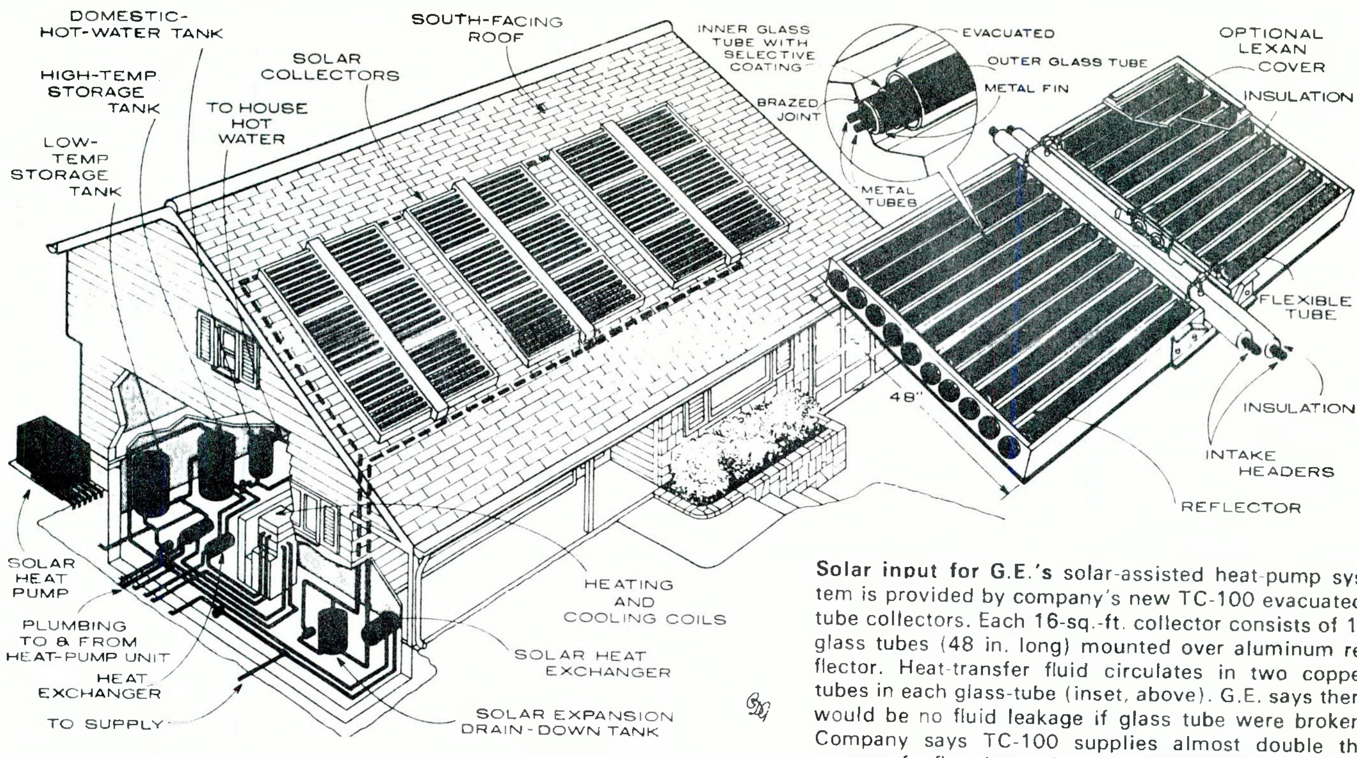
Solar basics

A solar heating system consists of collectors, storage (water tank or rock pile), interconnecting pipes and/or ductwork, pumps and/or blowers, controls (differential thermostats, sensors), plus auxiliary heat source(s)—oil, gas, or electric furnace or heat pump. The latter are needed because no solar heating system can supply 100 percent of your needs and be economically competitive with conventional sources. Most systems aim for 50 to 75 percent of total heating requirements. (If a solar heating system were designed to supply *all* your heating requirements in the coldest months, it would be oversized for the balance of the heating season.)

The heart of any solar heating system is the collector; most often, these are flat-plate collectors—glass- or plastic-covered boxes that contain a metal absorber plate—usually copper, aluminum, or steel, or a combination of these metals. Other types of solar collectors include evacuated-tube collectors [PS, July; also see the G.E. schematic on the facing page] and concentrating collectors [PS, Oct. '76].

The sun's rays heat up the collector's absorber plate, and a heat-transfer medium—a liquid or air—carries off this heat for heating either space or water directly; or to storage for later use—at night or during cloudy weather.

An insulated pile of rocks is the storage medium in air-type systems; a water tank stores heat in liquid systems. A variation is the system developed by Dr. Harry E. Thomason, which uses a combination rock bed and water tank [PS, Mar. '74]. The systems are usually capable of storing enough heat to carry a house through three to five days of



Solar input for G.E.'s solar-assisted heat-pump system is provided by company's new TC-100 evacuated-tube collectors. Each 16-sq.-ft. collector consists of 10 glass tubes (48 in. long) mounted over aluminum reflector. Heat-transfer fluid circulates in two copper tubes in each glass-tube (inset, above). G.E. says there would be no fluid leakage if glass tube were broken. Company says TC-100 supplies almost double the energy of a flat-plate collector. Price: about $20/sq. ft.

Meanwhile, some companies are expanding their lines of solar systems and components:

- PPG, which offered a "Baseline" solar collector with an aluminum absorber plate two years ago, now offers three different models: "standard" collectors with copper or aluminum absorber plates; a "Pool Plus" collector for swimming-pool or domestic-water heating; and a box-type collector for higher-temperature space-heating purposes.
- Grumman, the aerospace company, has been marketing solar space- and water-heating systems since late 1975 [see "Solar Water Heaters You Can Buy Now," May '76]. The company's Sunstream collectors were originally all-aluminum; now there's a version with copper tubing (see drawing).
- Solaron, maker of the air-type space-heating system first reported in our March '75 cover story, now offers a domestic hot-water system, also with air as the heat-transfer medium (see drawing). Solaron reports that it now has distributors in 42 states.
- Sunworks, a small independent company two years ago, has since been purchased by Enthone division of Asarco. In addition to its all-copper liquid-type Solector collector, the company now has an air version.
- Revere, another company covered in our March '75 issue, has introduced its Sun Pride water-heating system, as well as a new "Tube-in-Strip" collector absorber plate (see drawings). Revere offers collectors for both new construction and retrofitting, plus a special collector for swimming-pool heating.
- About a year ago, State Industries, the water-heater manufacturer, introduced a solar water-heating system that featured two aluminum collectors, Dow Corning's silicone heat-transfer fluid, an 82-gallon storage tank with backup electric element, plus controls. Price: $1895. A second-generation model recently unveiled uses a porcelain- and enamel-finished steel absorber plate with distilled water as the heat-transfer fluid. If temperatures drop below freezing, an air pump forces the water out of the collector. Price of the new system, which carries a 10-year warranty: $895.
- Rho Sigma, a company that specializes in solar controls, has introduced a proportional control, which, instead of merely providing "all-on or all-off" control of solar collection, turns the heat-transfer fluid on and off gradually, according to the temperature differential between collectors and storage. This has advantages on days of low insolation, claims Rho Sigma's president Robert Schlesinger.

Solar builders

The housing industry is hardly taking second place in all this activity:

- Acorn Structures, the precut-

Continued

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cloudy weather before the auxiliary heating system comes on.

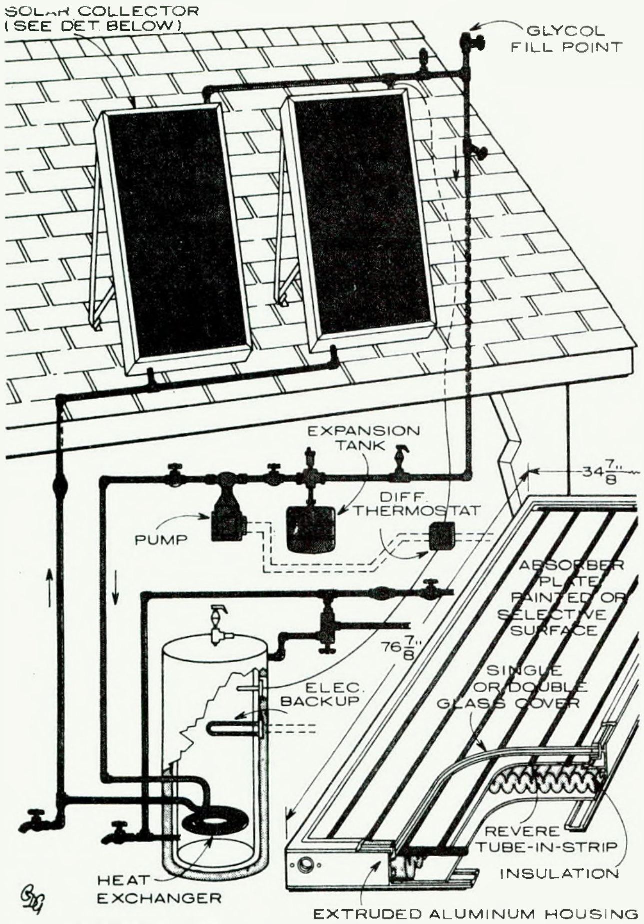
How much collector you'll need depends on how much space (or water) you plan to heat. Rules of thumb: Collector area should equal one-third to one-half the square footage of the space to be heated; or one square foot of collector for every gallon of water to be heated daily.

Air systems, while not subject to the leaking, freezing, and corrosion problems of the liquid systems, do require bulkier storage (rocks require up to twice the volume to hold the same amount of heat as water); also, ductwork takes up much more space than piping. These may be primary considerations in retrofit installations. And air systems are not as well suited as liquid systems for heating domestic water. (Solaron, however, claims to have overcome this disadvantage with its domestic system.)

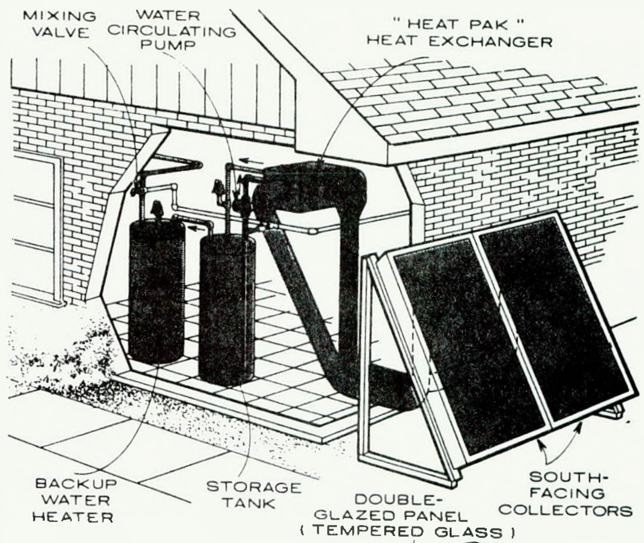
Liquid systems deal with freeze-up problems in one of two ways:

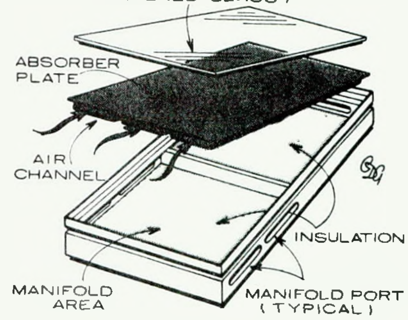
- The collectors and all exposed pipes automatically drain when the temperature drops to freezing.
- The heat-transfer fluid contains an antifreeze or is a special liquid with a low freezing point. Dow Corning, for example, claims that its silicone-based fluid prevents freezing, boiling, and corrosion problems. It can operate, says Dow, from −50° F to +600° F.

A differential thermostat keeps a solar system working—collecting heat when the sun's shining, and storing it when it's not. This device turns on a pump or blower when a sensor mounted at the collectors indicates that the collectors are hotter than storage. When the collectors are *cooler* than storage, the differential thermostat stops the circulation until the next sunny day.



Revere now offers Sun Pride, a complete water-heating system with a glycol/water heat-transfer fluid. Price of components, including two collectors and a storage tank, is $950. The company estimates installed price of $1500.





Solaron has added an air-type hot-water system to its line of solar products. There are no freeze-up or corrosion problems with this type of system, which uses water pump, blower, air-to-water heat exchanger. Price, about $1100.

home company, manufactures a complete solar space- and water-heating system designed to fit its line of contemporary homes (see drawing).

- American Timber Homes has commissioned Donald Watson (architect for our March '75 cover home) to design two solar-house packages. The Solartran homes use Sunworks collectors for space and water heating, plus a greenhouse for passive solar heating.
- Stanmar, another maker of precut houses, says it will custom-design solar homes for its clients, using off-the-shelf hardware.
- A California builder, Blue Skies Radiant Homes, recently sold out its first solar subdivision. Price range of the homes: $37,900 to $46,400.

All this activity adds up to some impressive statistics:

In the March '75 issue, PS listed 33 manufacturers of solar equipment; a recent survey by PS staffers revealed nearly 200 companies—too many, in fact, for a complete listing in this issue. (To get your copy of the PS Solar Manufacturers' Index, see the last paragraph of this article.)

Solar-collector production, which totaled 136,000 square feet in 1974, reached nearly two million square feet in 1976. Richard Stoll, with the Federal Energy Administration's Task Force for Solar Commercialization, estimates that more than four million square feet will roll off the assembly lines in 1977. Those figures do not include low-temperature (under 100° F) collectors for swimming-pool heating, such as Fafco's [PS, April]. According to Stoll, 3.875 million square feet of this type of collector alone were manufactured in 1976.

And earlier this year, Harvard's William A. Shurcliff issued the 13th and *final* edition of his "Solar Heated Buildings: A Brief Survey." Shurcliff says he's quitting now "because the number of solar-heated buildings is increasing so fast, and duplicate designs are becoming increasingly common." Shurcliff's survey shows that by the end of 1970, there were 24 such structures in the U.S. By the end of 1976, the number had climbed to 286. "The number of solar-heated buildings completed in the U.S. in 1976—namely 146—exceeds the total number completed in all preceding years—namely 140," he adds.

Federal, state, and local action

Government participation and encouragement is proceeding apace, though not with the vigor some solar advocates would like to see.

While no legislation to benefit solar installations has been enacted at the federal level yet, at least 35 states have already passed or are considering solar-related laws. These range from property- and sales-tax exclusions to so-called sun-rights laws. The latter would prevent your neighbor from planting a tree or building a fence or other structure that would shade a solar collector already installed on your property. (The city of Los Alamos, N.M., has the first such ordinance, which prohibits casting a shadow on a solar collector between 9 a.m. and 4 p.m.)

Federal agencies are stepping up their solar-promotion programs. ERDA recently added 80 projects to 32 already selected in a five-year solar-demonstration program for nonresidential buildings. HUD has just announced grants in its third-cycle residential demonstration program. Grants in cycles one and two went to projects involving more than 1500 housing units.

How's business?

In a word: booming. Grumman's Joe Dawson described it recently as "unreal—one of our dealers in upstate New York just sold solar systems for three homes, a library, and a medical building in one week." At last count Grumman had more than 70 dealers in 24 states and Canada.

G.E. says it has already sold out its production of evacuated-tube collectors through the end of this year. And that was before the company had even begun making them.

Bill Heidrich of Revere says that in the first quarter of 1977 business doubled over the same period in 1976. Heidrich sees a growing number of commercial and industrial installations. "Initially, all our systems went into residential construction; now we're installing the equipment in schools and hospitals," he says.

Ray Williamson, Solaron's marketing administrator, says that the company sold more solar gear in the second quarter of this year than it did in all of 1976. "If we didn't have access to extra manufacturing capability," says Williamson, "we couldn't keep up with demand."

And the price?

The initial investment in solar hardware is substantially higher than that for conventional space- and water-heating equipment. A typical solar water-heating system --with two or three collectors, storage tank, and controls—will run from $1000 to a little over $2000, installed. Add space heating, with more collectors and larger storage, and you're in the $5000 to $10,000-plus bracket.

Charles Pesko, Daystar's marketing manager, says that at present fuel prices Daystar's solar equipment has a payback period of eight to 10 years. (That's the time it takes fuel savings to cover the cost of the solar hardware.) Daystar's prices: $2000 for a water-heating system; $8000 for a space- and water-heating system with 210 sq. ft. of solar collectors. "We really need to get the payback period down to under five years to get into the mass market," says Pesko. "Now --honestly—we're selling to an elite, first-on-the-block type of market."

John Dixon, of Dixon Energy Systems, a New England-based solar manufacturer, puts it this way: "Certainly, solar space heating in northern climates is not yet cost-effective. Solar water heating, however, is much better, and we think that payback periods of the order of 10 years are reasonable. Claims of much shorter payback periods, we think, are simply wishful thinking and will not be realized until oil and electricity prices have increased considerably. This, of course, is very likely to happen over the next decade or so, and then solar energy will be very cost-effective."

Dixon feels that solar equipment isn't going to come down in price, however: "The manufacture of collectors is largely a matter of cost of materials, not labor. The installation, of course, is labor-intensive. But we don't expect that the materials used in solar collectors are going to get less expensive. Nor do we expect the cost of installation to decrease. Rather, all these costs are likely to increase along with normal inflation."

Two recent government-sponsored reports reflect the consensus on the present state of solar economics:

In a study prepared for ERDA, the Mitre Corp. indicated that solar could already compete with electric heating in New York and in 12 other cities—including Atlanta, Los Angeles, and Seattle. But Mitre concluded that solar would be competitive with oil and gas only if the cost of installing the solar equipment was reduced 50 percent, or if these conventional fuels rise in price.

A computer team from the University of New Mexico predicts that solar will be cheaper than oil or gas in 26 states by 1985. In a study prepared for Congress' Joint Economic Committee, the team also concluded that solar is already cheaper than electric heat for new homes in 30 states.

Should *you* go solar?

Some factors to consider before you opt for solar: your space- and water-heating requirements; climatic zone; availability of sunshine; present fuel costs and what they're likely to be in 10 years—if that fuel is still available; means of financing the solar equipment (a high-interest loan could cut deeply into any projected savings); and whether there's a suitable location for solar collectors and other equipment on your home or property. Armed with these facts (the sources listed at the end of this article will help you determine them), you're ready to talk to dealers and get quotes on systems.

To get your copy of the PS Solar Manufacturers' Index, send a stamped, self-addressed envelope to: Solar Index, Popular Science, 380 Madison Ave., New York, N.Y. 10017. PS

FOR FURTHER INFORMATION

Have a question on solar heating you want answered fast? You can dial the National Solar Heating and Cooling Center toll-free: (800) 523-2929; in Pennsylvania, call (800) 462-2983.

"Buying Solar," a booklet put out by the FEA, will help you decide if solar will work for you. It's $1.85 from the Superintendent of Documents, U.S. Govt. Printing Office, Washington, D.C. 20402. (stock no. 041-018-00120-4).

"Energy: The Solar Prospect," by Denis Hayes, ought to fire up even the solar pessimist. The booklet is $2 from the Worldwatch Inst., 1776 Massachusetts Ave., N.W., Washington, D.C. 20036 (Worldwatch Paper 11).

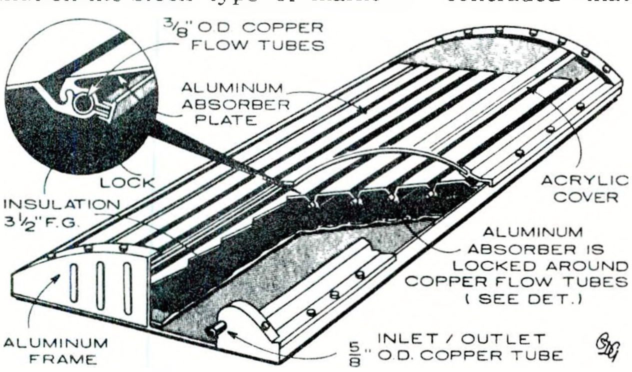
Designing and Building a Solar House, by Donald Watson. This well-illustrated book is $8.95 (paper), $12.95 (hard cover) from Garden Way Publishing, Charlotte, Vt. 05445.

The Solar Home Book by Bruce Anderson (see review in "Shop Talk," Jan. '77). $7.50 from Cheshire Books, Church Hill, Harrisville, N.H. 03450.

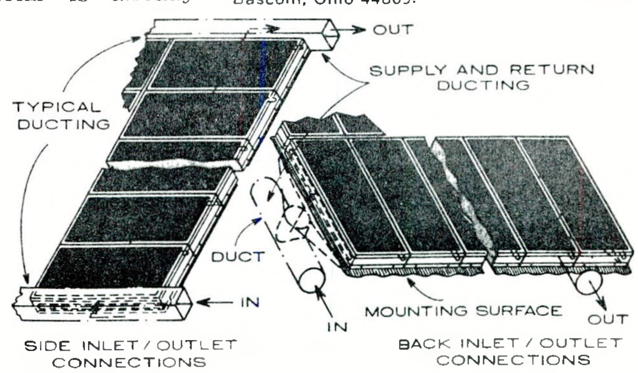
Solar Heated Buildings: A Brief Survey, 13th ed., by William A. Shurcliff. Capsule descriptions of the solar heating systems in 319 buildings in the U.S. and abroad. $12 from Wm. Shurcliff, 19 Appleton St., Cambridge, Mass. 02138.

"Economic Analysis of Solar Water and Space Heating," Div. of Solar Energy, ERDA. $1.85 from Superintendent of Documents, U.S. Govt. Printing Office, Washington, D.C. 20402 (no. 060-000-00038-7).

"The 1977 SUN Catalog," a 126-page catalog of solar components from various manufacturers. $2 from Solar Usage Now, Box 306, Bascom, Ohio 44809.

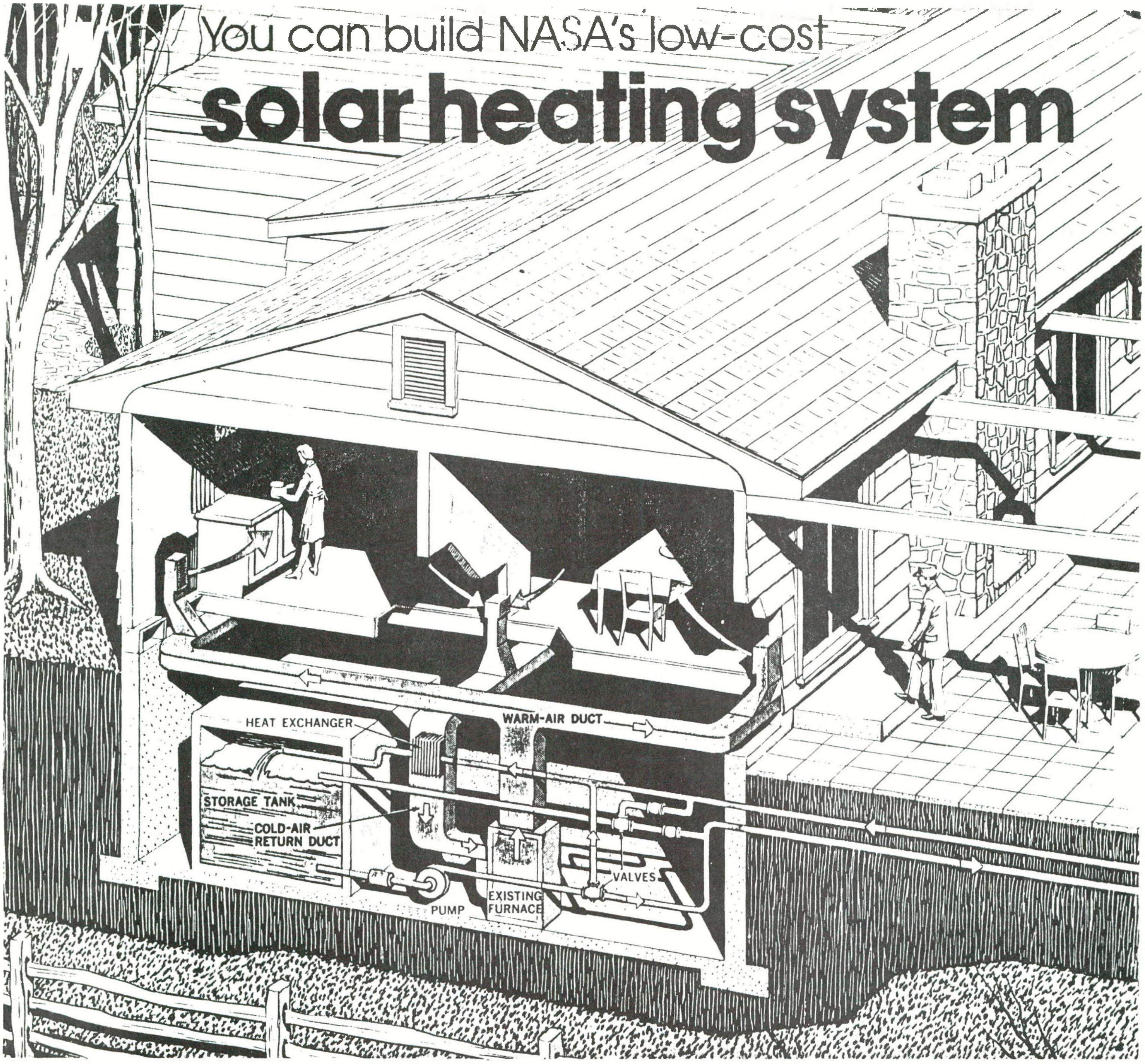


Grumman's Sunstream division offers Finplank, a collector with copper flow tubes locked into aluminum absorber plate (inset). Price of 27-sq.-ft. model 60F collector: $300. Original model 60A, with aluminum absorber: $275.



Sunworks, maker of all-copper liquid-type collector, also offers an air-type model, which the company recommends for space heating. Absorber is selectively coated copper sheet. Collector (3 by 7 ft.) costs $12-14 a square foot.

You can build NASA's low-cost solar heating system



NASA's technical expertise, low-cost materials, plus your DIY labor could make solar heat practical for your home

By GRAHAM GROSS

If you're like most Americans, you paid dramatically more to heat your home last winter. In fact, it's safe to say that fuel for home heating will cost more each year, and there may be shortages.

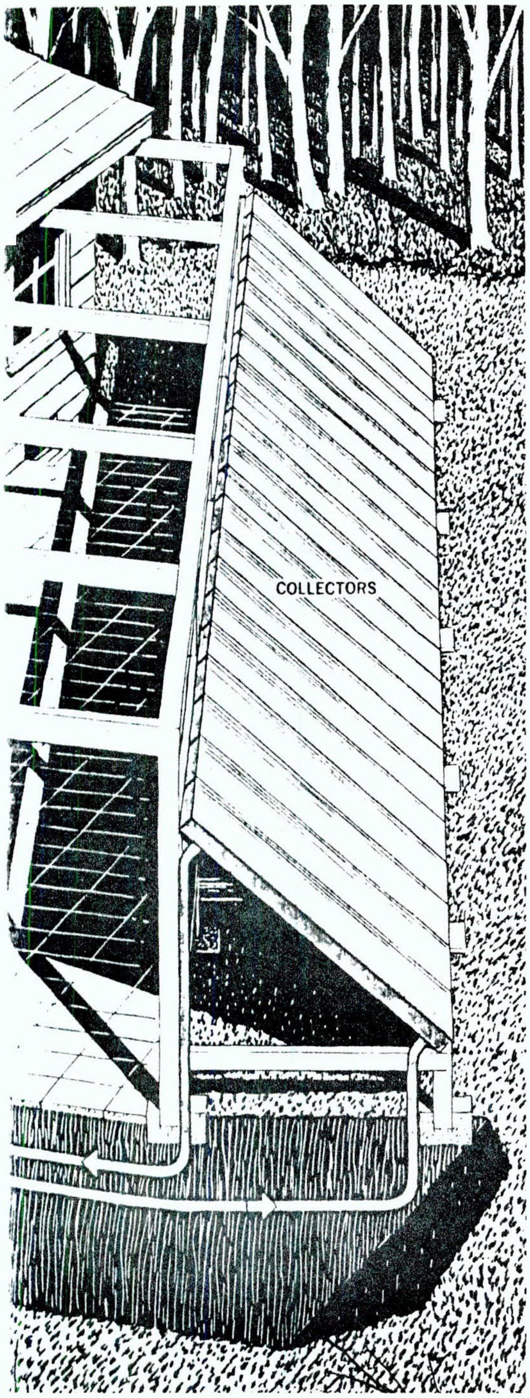
Of course, sunshine is one inflation-free alternative that is available daily, or at least intermittently. But aren't solar heating systems too expensive to compete with conventional fuels? Perhaps—for factory-built and dealer-installed systems. But for about $2000—as compared with the $5000 to $10,000-plus of the ready-built systems—you can build your own solar heating system.

Engineers at NASA's Langley Research Center in Hampton, Va., have written a do-it-yourself handbook for homeowners. It describes how to build and install a solar heating system that could cut 40 percent from the heating bill of a house insulated to 1974 FHA minimum standards.

Most of the parts are off-the-shelf items that can be bought locally. The piping is PVC, and no unusual tools are needed. NASA's handbook gives step-by-step instructions, lists parts and manufacturers, and shows you how to figure how cost-effective the system can be for you.

The collectors can be mounted on your roof or set up in a sunny spot in your backyard. On a sunny day, even in the winter, water in the collectors will reach 150° F. The heated water is stored in a 1000-gallon concrete septic tank. Hot water from the tank is then used to heat air just before it goes to your existing furnace.

Since the incoming air is hotter, the furnace has to do less work. And less work means it burns less fuel. After dark, or during cloudy periods, the hot water in the storage



"An Inexpensive Economical Solar Heating System for Homes" (NASA TM X-3294), by Johnny W. Allred, Joseph M. Shinn Jr., Cecil E. Kirby, and Sheridan R. Barringer, costs $4.25 from the National Technical Information Service, Springfield, Va. 22161. Order by referring to accession number N76-27671.

tank continues to preheat the air entering the furnace.

No part of NASA's system is different from the devices solar engineers have been developing for several years. What *is* different is that the NASA system can be built *now*, by anyone reasonably adept with tools, and at a cost that should make it worthwhile when matched against potential fuel-cost savings.

Dr. Cecil Kirby, one of the NASA engineers who designed and built the system, says that they were able to do this by sacrificing some of the efficiency theoretically possible. In making the system simpler, it doesn't work as well as it might. But in this case, simpler also means easier to install—and inexpensive enough that, depending on a lot of factors, you should be able to recover the cost of installation within eight to 10 years.

There are a number of factors to consider before deciding to undertake this project. One is time. Engineer Joe Shinn, who helped design the test model at Langley, estimates that it will take about four weeks of solid work to build and install the system. That adds up to a lot of weekends.

Another point: Since most areas have no specific solar heating codes, NASA designed its system to conform to Hampton's building codes. But codes vary, and you should check out your local code for any conflicts before you begin work. Dr. Kirby also suggests that you have the more critical components, such as the plumbing and electrical controls, checked out by a contractor or some other professional.

The collector

NASA's test system uses 20 three-by-eight-foot aluminum roll-bond absorber plates. Purchased, they would have run $700 in 1975; now they cost just under $800.

Construction details for a DIY version that's made from extruded aluminum tubing are also included in NASA's handbook. Parts for this absorber plate ran about $400. Painted black, the plates are mounted in a 2-by-4 frame over a bed of fiberglass insulation 1½ inches thick.

Aluminum exposed to untreated water corrodes very quickly. Since NASA used aluminum absorber plates in the collector, it is *essential* that the water in the system be treated with a corrosion inhibitor. This extends the lifetime of the system, says NASA, from three months to many years. NASA used sodium dichromate at a concentration of 250 parts per million. A local water-treatment company can give you recommendations for your area.

It's important to note, however, that sodium dichromate is toxic. Some local codes specify double-walled heat exchangers if a toxic liquid is used to heat potable water. This consideration will only affect those who wish to preheat their domestic water in the storage tank, however.

Of course, you could use copper roll bond and avoid the aluminum corrosion problem. But be prepared to pay. Olin Brass's 1977 price for 20 three-by-eight-foot copper roll-bond panels runs to just over $1750; that's almost $1000 more than the cost of aluminum.

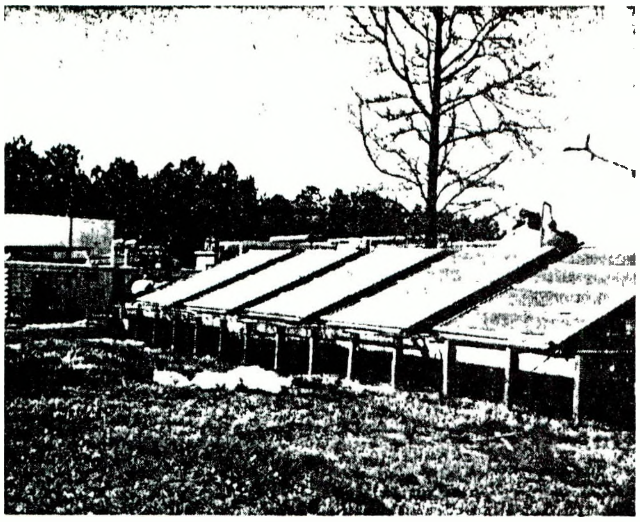
The collector frame can be covered with plastic film or glass. NASA originally recommended PVC or PFV film such as Tedlar because it was less expensive, lighter, and easier to work with. But recently there's been some criticism of the use of these materials as collector covers because they may degrade when exposed to the sun's ultraviolet rays for an extended period of time. It may be cheaper to change the film periodically (every five years is NASA's estimate), but Joe Shinn of Langley recommends you use glass. Be sure it has a low iron content, however, or it will filter out much of the infrared radiation. Glass with too much iron has a greenish tinge on its edge.

How much collector?

NASA used 480 square feet of collector in its test model to supply 40 percent of the heat requirements of its hypothetical 1500-square-foot house. How much collector area you'll need depends on several factors: how well-insulated your home is; what its heat requirements are; and how much sunshine your site gets. Climatic data are available from the U.S. Weather Bureau. Your home's past heating bills will provide the raw data for determining its heating needs [see table, "Cost of Fuel per Btu," in "Window Heat Loss," PS, Jan.]. Adding extra insulation and weather stripping—recommended in these days of rising energy costs anyway—is especially important if you're considering going solar. Cut your heating load, and you'll be able to reduce the size—and cost—of a solar heating system.

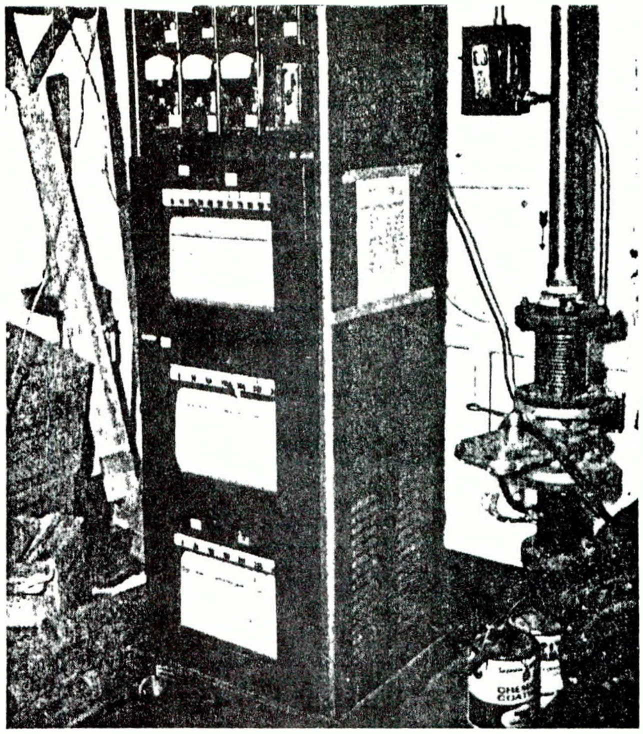
For good results, the collector should be mounted on a south-facing roof, though a variation of up to 20 degrees from due south won't significantly affect performance. Pitch does affect performance, but it isn't critical. Generally, roof pitches from 3:12 to almost vertical are acceptable.

Continued



Solar collectors in NASA's test model are mounted in racks near building to be solar-heated. The collectors are in five bays, with four panels in each bay.

NASA's data-recording equipment is shown at right. Air temperature, wind velocity, solar radiation, collector and storage temperatures were among the variables measured.



Another consideration is the collector's weight: Filled with water, collectors weigh 2.6 pounds per square foot. Dr. Kirby believes most roofs can support the added weight, but he suggests you have a pro check your roof structure first.

You might consider mounting the panels in your backyard on a frame such as the patio screen depicted in the illustration. That way, you can slightly improve performance by setting the tilt at the optimum angle for your area (your latitude plus 15°).

NASA recommends a 1000-gallon concrete septic tank because these are readily available and relatively inexpensive. Rule of thumb for storage in liquid systems is 1½ gallons of water per square foot of collector. Thus a solar heating system with 500 square feet of collector would require 750 gallons of water.

The storage tank is insulated with six inches of fiberglass on all sides, and may be placed in the basement, garage, or outdoors above or below ground. If you install the tank outdoors, you should waterproof the insulation with roofing cement. If the tank is above ground, make sure it's strong enough; many septic tanks are built for below-ground use only.

A single ⅓-horsepower pump moves the water through the system. Horizontal pipes are slightly tilted so they will drain automatically when the system shuts down at night, during cloudy weather, and in power failures. This prevents freeze-up.

Flow is controlled by a differential-temperature flow controller (DTFC) and a pair of three-way valves. Thermistors sense the temperatures of the collector and the hot-water tank; the DTFC compares them.

When the collector is 10° hotter than the water in storage, the DTFC energizes the two thermomechanically operated valves. Water from the tank is pumped through a heat exchanger in your furnace's return-air duct, and back to storage (see drawing). As the tank heats up to within five degrees of the collectors, the DTFC de-energizes the valves, and the collectors automatically drain. Since the system is in the drain-down mode in the de-energized stage, it is fail-safe in a power failure.

The payoff comes when the hot water from the collector or storage tank heats the air in your house. You do this by installing a heat exchanger in the return-air duct just before it goes to the furnace. When the home's thermostat calls for heat, the pump circulates heated water through the heat exchanger, warming the return air almost to the temperature of the water.

The type of heat exchanger you use depends on the overall size of your system. NASA provides guidelines for selecting the right one.

Payback

In 1975-76, NASA figured payback on a system designed for a 1500-square-foot house to be a little more than 10 years. Calculations were based on a 40 percent saving for a home using 1200 gallons of oil per year. Oil cost was computed at 36.9 cents/gallon with a 10 percent increase each year. Equipment costs were based on 1975 levels and are higher now. However, so is the cost of fuel oil (50 cents/gallon now is not uncommon). Payback could be around eight years if you build your own absorber plates rather than buy ready-made ones. If your home uses more expensive electric heating, payback is even faster.

Dr. Kirby estimates that the use of a domestic water preheater in the system will add $400 to the total cost, but would reduce the payback period to seven years. Another point worth considering is the tax break that a number of states now give for using solar energy. You can substitute your own heating costs and requirements in NASA's cost study to determine payback for your own home.

NASA's handbook can be ordered from the National Technical Information Service (see box). ▪

MATERIALS COST ESTIMATE (March 1975)

Collector:	
Aluminum roll-bond panels (480 sq. ft.)	$ 700
Polyvinyl fluoride (PVF) film collector cover	100
Fiberglass insulation	50
Flat black paint	30
Flashing and sealing	30
Wood (2-by-4 framing)	100
Hose, screws, paint, misc.	90
Subtotal	1100
Storage, controls, etc.:	
Heat exchanger	$ 175
Heat-exchanger adapter	75
Pump	100
Storage tank	180
Fiberglass insulation for storage tank	50
Controls	260
Piping	100
Subtotal	940
Total	2040

The shopping list above shows NASA's costs at the time the system was designed and the components were purchased. The prices can't be expected to be the same today, but any increases are probably more than offset by additional savings due to the rapid rise in fuel costs since the original study.

Domestic Hot Water

The New England Electric System Project: A Learning Experience

By Robert O. Smith and John Meeker

Robert Grant

When news of the results of the New England Electric System Solar project broke on the front page of the Wall Street Journal *and in newspapers across the country last year, the shining image of solar energy use received a severe setback in the popular mind. Ten percent of your yearly hot water heating bill saved—at a cost of $2,000? Leaks? Freezes? Heat actually going out? Guess I should forget about solar hot water.*

But as one reporter who attended the follow-up press conference said, "the project had trouble—but for all the right *reasons." The criticism under which N.E.E. has smarted was largely unjustified. The study has gone on. N.E.E. completed its own evaluation, and then an independent engineering firm, Robert O. Smith & Associates, under contract to Brookhaven National Laboratory and supported by ERDA, made an independent report. That report, condensed, is here, and to fill out the story* Solar Age *spoke with Mr. Smith and with Dr. John Meeker, solar energy consultant to the New England Electric subsidiaries, who inherited administration of the solar project and who says, a little wryly, "it was a learning experience for us all."*

The Study.

In 1973 the price of fuel oil to The New England Electric System rose from about $3.50 a barrel to $11 a barrel in [illegible] months; thereafter, the contracted supply was cut off absolutely, requiring the purchase of spot oil. Although New England Electric converted to coal at the request of the Federal Energy Office, the Environmental Protection Agency delayed the use of coal by two months. This brought N.E.E. to a fuel crisis.

New England Electric System is a holding company composed of Massachusetts Electric Company, distributing electricity in Massachusetts; Narragansett Electric Company, distributing electricity in Rhode Island; Granite State Electric Company, distributing electricity in New Hampshire; and some non-distribution companies — the New England Power Company that generates electricity and sells it in bulk, the New England Power Service Company that provides accounting, billing, and legal services to affiliated companies; and New England Energy, Inc. that explores for domestic fuel supplies used to generate electricity. The distributing companies have, taken together, about one million customers in the three contiguous states, Massachusetts, Rhode Island and New Hampshire.

N.E.E. has about 179,000 customers with electric hot water heaters. These heaters typically have at least one 4 to 4.5-kilowatt heating element. N.E.E. also has a wintertime and evening-hour peakload that appears amenable to reduction by use of load-sheddable water heaters. Arranging such sheddable loads could avoid or postpone the need for new generating stations.

The typical electric water heater used by Massachusetts Electric, Narragansett Electric, and Granite State Electric for off-peak service has two heating elements. During off-peak hours the complete tank is brought to design temperature using first the top element, then the bottom element. During other than off-peak hours only the top element is available, and the bottom element is locked out. As hot water is removed from the top of the tank it will be displaced by cold water entering the bottom of the tank. Thermal stratification tends to minimize mixing between the hot water and cold water, and most of the hot water heated at off-peak times is available at design temperature for use during on-peak hours without requiring any additional heating. However, as the level of cold water reaches the top element, it will operate as a demand heater. The solar-electric water heater system should have potential for load management capabilities equal to or greater than those achieved with conventional off-peak water heaters.

A solar water heater project offered the potential for gaining knowledge of load management, operational experience with solar equipment, diverse regional data, economic competitiveness, consumer benefits, and good public relations. The available solar

Typical installations were in suburban New England houses with four occupants and clear southern exposure. Savings for the 100 systems were expected to average 40% this winter.

system options were described to N.E.E. officials as

1. water medium with electric resistance heating for freeze protection;
2. anti-freeze medium - toxic;
3. anti-freeze medium - non-toxic;
4. air medium;
5. water medium with drain back to tank. In all cases, dual or single tanks were possible.

The budget for the project was originally set at $250,000, excluding salaries of the twenty-five to thirty N.E.E. field workers who read the monitoring equipment each week, and the salary of the administrator of the project, but including purchase costs of the equipment and salaries of N.E.E. engineers and fees to consultants who were involved in the project. This budget has had to be enlarged to nearly twice the original figure.

The project was to start in September of 1975 and finish in September of 1977 (it has since been extended to October 1978). In September of 1975 a purchasing specification was issued for procurement of the first thirty systems. Seventeen suppliers attended a September 1975 bidders' briefing in Boston. Most suppliers then offered to make the installations complete within three weeks of receipt of order. About sixty requests for quotations were issued for the procurement of the first thirty units. Purchase orders were issued in November but the winter was at hand, and it was agreed with some suppliers to delay installation until the following spring when the weather moderated. Other systems were installed during the winter. The last of the thirty units was installed by May of 1976.

A second set of requests for quotations was issued in March of 1976 for the remaining seventy units. A new specification, twenty-seven pages of text and ten diagrams, was isued for this procurement. By July of 1976 purchase orders had been issued, and most of the remaining units were installed by November. A year earlier the consulting firm, Arthur D. Little, Inc., had interviewed nine manufacturers of solar water heaters and obtained estimates of installed cost and lead times from the factories. On this basis ADL advised N.E.E. that the systems could be procured and installed quickly. It turned out to be otherwise. Also, of the original nine manufacturers, one withdrew his offer after receiving a purchase order, and three others were unresponsive to solicitations for bids.

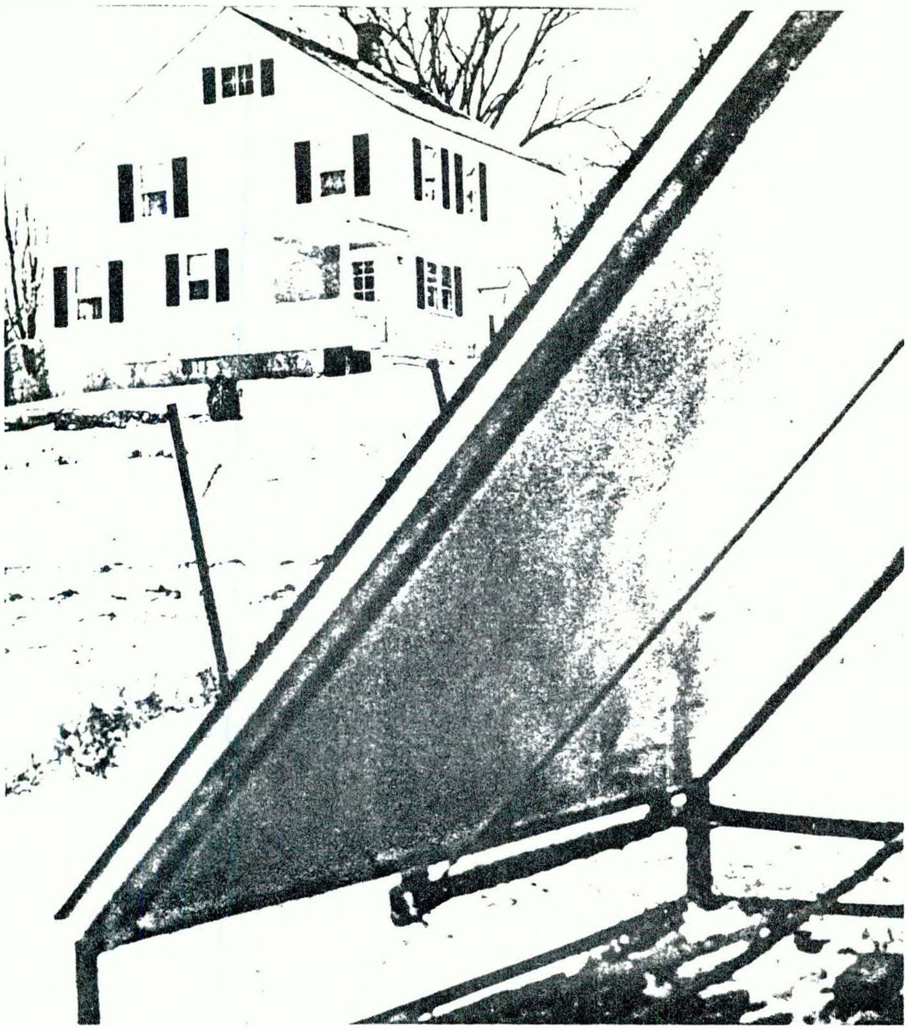
New England Electric explicitly left to each supplier the decisions to select

1. size and type of collector array
2. insulation materials and thicknesses
3. make and model of controller and all components
4. make and model of heat exchangers and tank and size
5. antifreeze chemicals and concentrations
6. collector temperature sensor and location.

N.E.E. specified, though not in writing, that collectors should be oriented true south and tilted up to the latitude angle plus five degrees. In systems requiring two tanks, the electric water heater tank used as an auxiliary to the solar heater was selected and provided by N.E.E., and the cost of this was not charged to the solar system. The installation was done by the solar system installer.

The consultant recommended instrumenting the systems to measure water

Meeker: We have totally replaced 26 systems, the twenty-six worst. It has been a joint venture if you will, because three or four manufacturers have replaced about fourteen. These were manufacturers whose systems were under 15 percent, most of them under 10 percent efficient—or people we kicked out of the program because they were not living up to the one-year warrantee. The manufacturers still remaining in the program have completely modified about thirty systems. Approximately fifty-six units are completely different from what they were the first year. If everything goes right this winter, I would expect that the savings, instead of averaging between 17 and 20 percent, would average between 35 and 40 percent, for all 100 units. The original average included a bunch of dogs that didn't belong there. Unfortunately, those dogs are still on the market. That's part of the problem. It's nice to say that the consumer is a little more educated than he was back in the 40s and 50s but really, all he has to go on is what he's told. There are all kinds of good collectors on the market. We have a lot of them in the program. But even with a very good system, if a butcher puts it in, it will only give you 15 to 20 percent efficiency instead of 40 or 50 percent.



A sticky legal problem developed in a Western Massachusetts town, when occupants of the house in the background objected to glare from their neighbor's solar collector. The town zoning board subsequently closed down this project by forcing removal of the panels, which were built too close to the neighbor's property line.

temperature, water flow, and electric power usage and timing. New England Electric required the furnishing of a water meter by each supplier of solar heating systems and, further, furnished at its own expense the following instruments now installed on all 100 systems:

- thermometer installed on the cold side,
- thermometer on hot output side,
- on two-tank systems only, a thermometer in the storage tank,
- a pressure gauge on closed-loop systems,
- on single-tank systems only, a thermometer on the supply and on the return lines to the collector array,
- an electric two-dial watt meter on heating element circuit, combined with circulating pump circuit; the two meter dials distinguish consumption during peak times from consumption during off-peak times,
- a second electric watt meter measures only the solar circulator and control energy and any freeze-protection resistance heaters,
- a running time (hour) meter on the solar circulator pump energizing circuit.

Running time meters were not originally installed. In ten cases where they were first tried they revealed so many problems with pump controllers and pumps that N.E.E. has since installed these running time meters on all systems. The cost of instrumentation has not been added to the base cost of the solar system for evaluation purposes.

The Participants.

A public announcement soliciting interest was issued in newspapers and on radio. This brought over 5,200 responses in less than two weeks. Respondees were sent a questionnaire. Eliminated were those who:
wouldn't pay $200, weren't owners-and-occupants of single family houses, weren't in N.E.E. service areas, and those whose site had south shading, no south exposure, or no space for a collector on the ground. Twenty five hundred respondents were left.

N.E.E. field workers were given a six-hour training course in how to locate collectors and how to appraise total suitability of sites, taught by an experienced

Q: The New England Electric System study stands as a kind of landmark—or perhaps a stumbling block—in the recent history of solar development. What happened?

Smith: Somehow or other, perhaps from the utility, the press got hold of more information than was ready to be released at that point in history. Of course they did what they usually do: they tried to sell papers by making big headlines, and headlines are made of conflict, tragedy, or trouble. This appeared in the *Wall Street Journal* on the front page, and other places. All they played up was the trouble. New England Electric was immediately accused by people in the solar field of trying to scuttle solar—which rather hurt, because the people running the program were not thinking that way, to my knowledge. Nobody ever mentioned that there were some very good systems running in this program of 100 systems. But time has gone by and more information has come to the surface. Important lessons were learned from the experience by all who were involved in it, from every angle.

Q: It seems that the key mistake was to make the installers responsible for certain design and installation decisions. Is that true?

Smith: At that time they were not capable of bearing that responsibility. But I think the participants were not aware of what they did not know. Even the most experienced among them had very thin experience, and most of them had none prior to these jobs. New England Electric had no more experience. They proceeded with sincere but innocent intentions. They learned, the hard way. It was considered obvious, for instance, to orient the collectors south, so it was not specified. Frequently people had not taken a compass out to the site and really checked what the magnetic direction was, then corrected it for true south. Of course, you can deviate from true south by 10 or 15° before you really get in trouble—though there are some new subtleties coming in the horizon now. Gordon Tully will tell you that it's better to look to the east a little because your tank is cool in the morning and gives you better collection efficiency then.

Q: How much of the higher-than-anticipated cost is attributable to prototype design?

Smith: The first-time installation costs certainly were large compared with subsequent installation costs. They had a lot to learn. But everybody's always praying that economies of scale will make these things cheaper. I don't see that labor, or copper, or anything else is getting cheaper. I'd guess that it's going to be close to an average $2,000 in cost.

Q: Why weren't the systems efficient?

Meeker: Any installation that didn't produce 10 percent efficiency was sick. It's wrong. We expect 40 percent efficiency. We didn't get it in most cases. Even the fifteen good ones are still being upgraded, and the bottom ones are being weeded out and replaced, in place.

Q: Isn't fifteen good systems out of 100 a very bad average?

Smith: It certainly is lower than the people at New England Electric ever expected when they signed up for a hundred. It did reveal that a lot of people, including them, had a lot to learn. They strove mightily to do it right by drawing up specifications first and using a consultant to help them do it. They also trusted their suppliers and manufacturers to know what they were about — which is reasonable to do. About twenty-three were involved.

Q: Even for these "best" systems, it's going to be a very long time before the savings they achieve equal the cost of the system, isn't it?

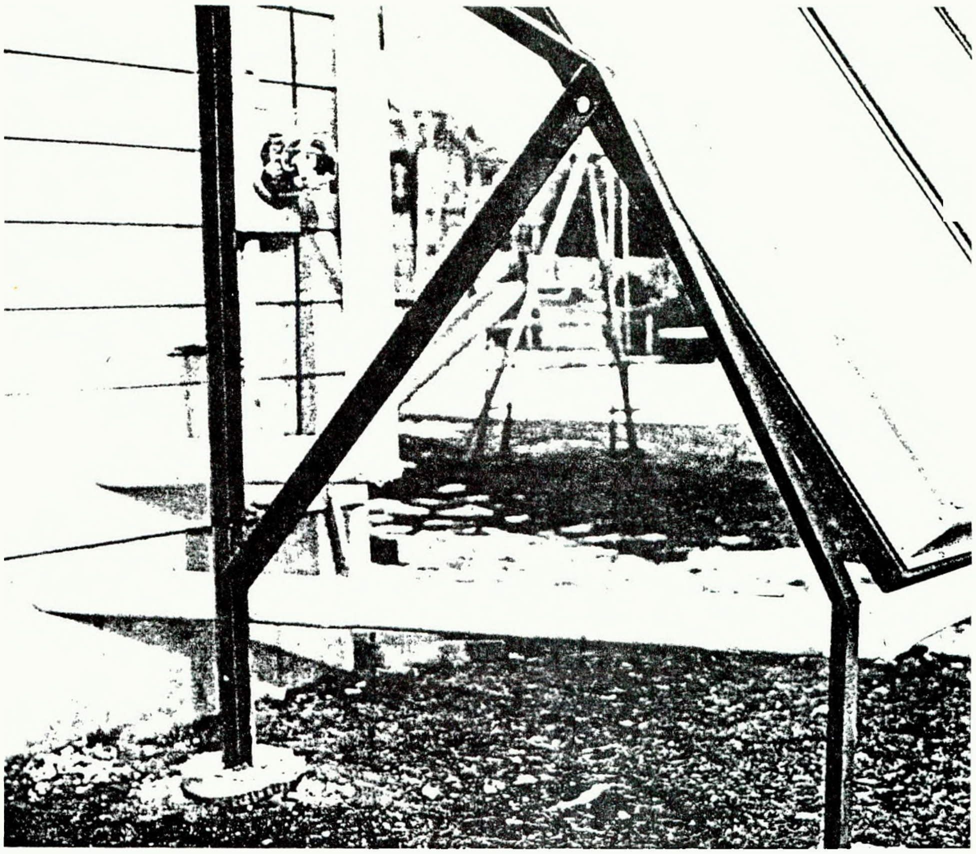
Smith: That's right, if fuel costs hold still with no escalation. So what do we need? Systems that cost half as much and do a little better.

Q: You're not contradicting the reports that came out in the newspapers.

Smith: The people who want to go solar are the people who either have exorbitant fuel costs, wherein their payback is much better than these look, or they are people who speculate against the future crisis of energy, feeling that the escalation rates predicted by the government economists—8 percent for electricity — are too gentle, and they're going to beat the system by going into solar now. Damn the incompetence of beginners, go ahead. Usually they're in a tax bracket where they can play games like that.

Q. What are the most important benefits of the experiment?

Meeker: The most important is that we identified, early in the game, just what the major problems were, and worked with the manufacturers to help them correct those problems. Talking as a Monday-morning quarterback, it has made the manufacturers aware that it doesn't cost $150 to $300 to install one of these units. Especially in the northeast, I think the experience has brought the solar community together. It might sound strange—but now there is dialog among manufacturers, contractors, distributors, unions, utilities, and the professional community. Once you've admitted a problem exists, you can correct it.



Well insulated feeder pipe with short line run proved essential to an efficient system. This installation, in central Massachusetts, was the best, peaking at 70% savings.

solar engineer on loan from a prominent collector manufacturer. N.E.E. sent 100 people to inspect the 2,500 sites and to fill out a three-page checkout questionnaire with a sketch of the building and a sketch of the sun track. This reduced the number of those eligible to about 1,200.

The 100 units were rationed among the twenty-two N.E.E. retail company service districts in proportion to customer meter population count. Districts received, in consequence, between one and nine solar heating systems to install. A lottery was held publicly in each district by which the customers were selected to receive solar water heaters. In districts where many customers were eligible, the lottery was held in two stages. Customer agreement forms were issued for customer signatures after the first-stage lottery. (In some cases customers signed agreements to cut down trees.)

Ground-mounting of collectors was specified because:

• liability to repair roofs would be costly;

• repair of damaged collectors would be more costly and inaccessible if roof mountings were used;

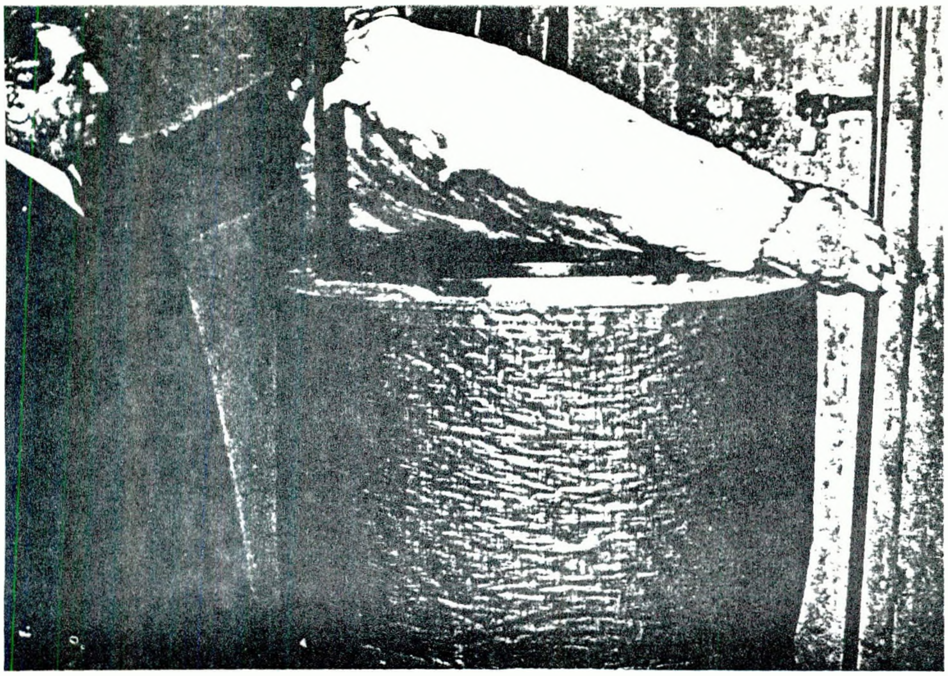
• workingmen's compensation insurance premiums for N.E.E. personnel would be higher if they had to go onto roofs to inspect systems; and

• the consultant advised N.E.E. that there would be no difference in performance between ground and roof mounted collector systems.

Some suppliers have complained that this requirement was a handicap because the pipelines between the collector and store were made longer than normal, the buried lines were costly to install, and necessary special support structure on prepared concrete footings caused considerable extra cost, not found in making roof installations. Others were indifferent to ground mounting because they associated long pipe runs and costly rigging and roofing work with rooftop installations.

The view of this firm is that concrete footings and burial of pipes may create an unfairly costly basis for making comparisons of economics of solar heating systems. On the other hand, it also costs money to rig, fasten and plumb an array of collectors on any steeply-sloped second or third-floor roof and preserve the watertight integrity of that roof afterwards. System efficiency of ground-mounted systems shouldn't be notably different from roof-mounted ones. Pumping energy, for one thing, may be lessened with ground-mounting of collectors because the static head is lower. On the other hand if the pipe runs are longer, this advantage can be reduced or lost.

At the bidders' conference the state building inspector permitted single-wall heat exchangers for anti-freeze.



Six inches all around the storage tank was found to be adequate insulation. Here Robert J. Hunt, Consumer Services Manager at Massachusetts Electric, (a New England Electric subsidiary) examines a tank in Northampton, Massachusetts.

The Costs.

[Installed cost figures exclude the costs to procure and install instruments.]

Prices submitted to the consultant in the fall of 1975 by five firms had risen 159 percent to 294 percent by the time the systems were in place in 1976. Even today these manufacturers' prices for installed systems are 134 percent to 200 percent higher than their 1975 original estimates.

New England Electric set up a logical program of measurements and calculations to determine how much of the electrical energy usually devoted to heating domestic hot water was being saved by the solar systems. Energy used by the solar system pumps, blowers, solenoid valves, and controllers was duly charged in these calculations. Power consumed by any instrumentation was excluded. The savings realized by solar systems are larger in the summer than in the winter, so to be precise they should be computed for the entire year. Fairness in comparing alternatives compel this. Many of the N.E.E. systems had not been in action for a full twelve months as of July 1977, so caution is indicated in interpreting N.E.E. performance figures until data is in hand for twelve months, even though extrapolations for missing months can be made to obtain reasonable approximations.

The savings can be expressed as either the percent of electricity saved or as the absolute number of dollars saved from electric bills. It should be noted that families using large quantities of hot water show large absolute dollar savings even though a large usage tends to make

Savings of Some of the Best Systems

Number of Persons	gallons per week	gals. used per week Mar.	July	Dec.	System type
3	307	303	250	368	AF
2	576	729	400	600	DO
5	862	733	860	993	AF
5	493	576	440	465	DO
4	387	394	362	405	DB
7	600	558	620	623	AF
4	310	280	330	320	AF

Months of Data Sample	Total Net Percent	Period Savings Dollars	Gal. per Year	Savings ¢ per gal. Year Average
12	47	96	15.964	0.61
15	43	139	29.969	9.37
14	44	99	44.824	0.19
16	35	115	25.670	0.17
12	39	60	20.124	0.30
12	38	61	31.217	0.19
14	32	48	16.120	0.26

Q: In your contract with homeowners. New England Electric listed a series of questions it wanted to answer. Do you have answers, or preliminary answers, yet?

Meeker: Preliminary answers. The first question was, how it is going to interface with our peak. We just got twenty additional digital pulse recorders to give us a little better idea of what it is doing to our peak. That potential is there, or we wouldn't have gotten involved in the first place. I think we have a fairly good idea of what it's going to cost to install the units. Almost everybody around here agrees that it's going to cost between $2,000 and $2,500 for the package installed. I don't think you can get a good system for much less than that. The labor costs are tremendous. Some very good people were saying $2,200 two or three months ago. Now they're saying $2,900—though that may be gilding the lily. One thing we've found is that it's cost-effective to insulate the pipes and the tanks thoroughly, to an R-value of at least 4, whether they're gas or electric. The difference is dramatic. New England Electric and some of our members are working with the manufacturers that supply our water-heating tanks to come up with a better design, and with the insulating packages that we are now offering to the customers. That has to be done nation-wide.

Smith: Do you attempt to get a system that will save you 80 percent, or do you stick with the 40 to 50 percent range? I feel the lower one is the feasible range; talking electricity, not gas or oil, that's maybe $100 a year. For $2,000, that's a twenty year payback—if you sell it that way, which is a mistake, I think. I think you sell it for energy independence and energy conservation. Eighty or 90 percent is valid in Arizona or southern California, but up here a twenty-year payback doesn't make much sense, for the average person. Should the average person be buying solar right now? I don't know.

Q: With these hundred systems, has New England Electric made a commitment that it is going to continue?

Smith: N.E.E. is staying on these 100 water heaters—they haven't lost faith — and is upgrading them in many ways. The worst performers have been ripped out and replaced, in some cases by the same manufacturer who put them in in the first place. These people have said "hey, we've all learned a lot, haven't we? Let me just take that away, and pretend you never saw it." These men should be given every chance, because they are going somewhere in the field. That's exactly why we have refused to identify the manufacturers involved. Some of them had troubles originally but they haven't let go. They have made vast improvements.

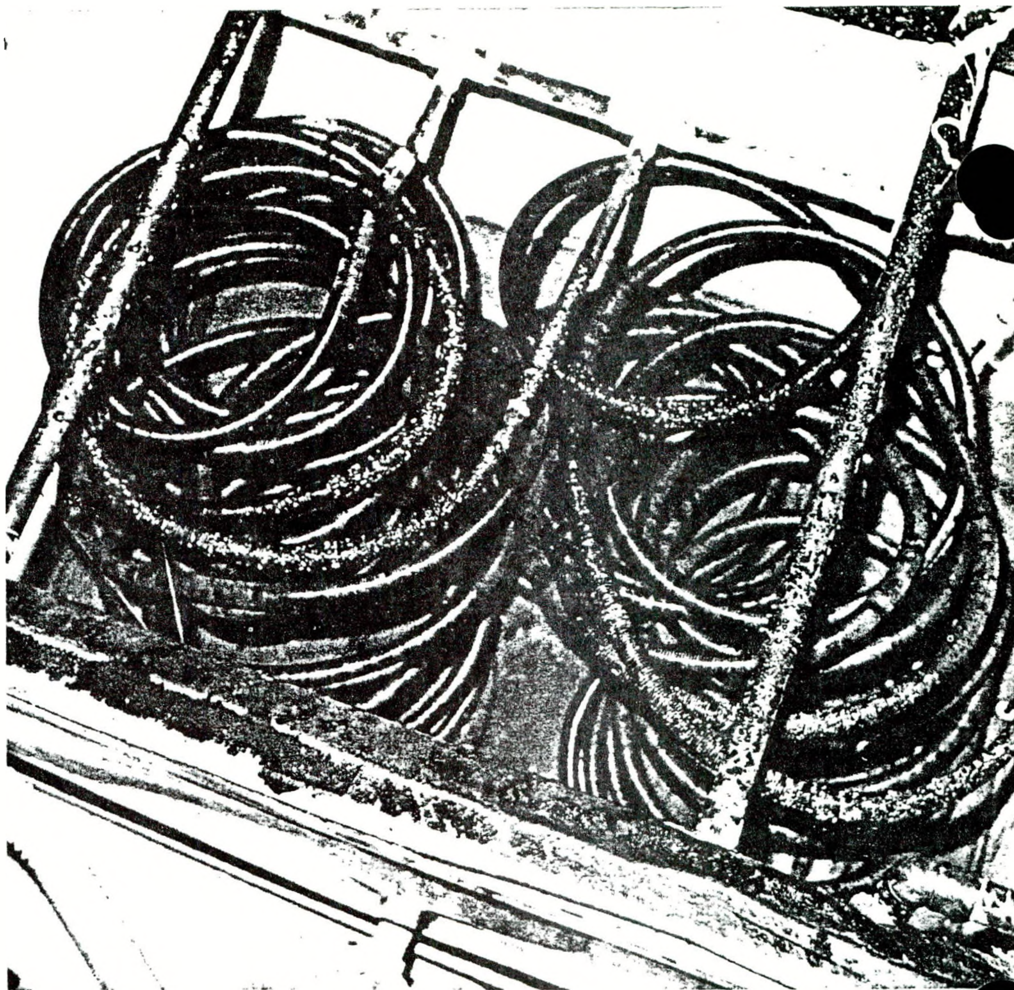
Meeker: The experiment was supposed to end in September. We could have justified almost anything after that. We ran into a lot of problems, and it really took a lot of thought, but we made the commitment to stick with it, at least through October 1978, and to try to work with the manufacturers as much as possible to correct the systems. We decided to remove some manufacturers from the program and install what we consider to be much better units. We have asked our customers to sign an agreement that would carry it through the winter of 1979, because we see a remarkable turn-around. When the average system savings comes out around 40 percent, it's a completely different ballgame. If, unfortunately, things happen the way they did last winter, then I'd see a case for prudence. Personally, I don't believe that's going to happen.

Q. What have you found out about setting off-peak rates for solar-assisted systems?

Meeker: It depends, partly, on what the traffic will bear. If you're a solar customer and install a unit with the idea that you'll get a special rate for the electric backup, with the understanding that during the peak hours you won't have any electricity for the backup and that two or three days of cloudy weather might see you with very little hot water—how much will you tolerate? That's something we have yet to find out because of all the malfunctions last year.

Q. Has this experiment prompted other utilities to do similar experiments?

Meeker: More than a hundred gas and electric utilities are doing solar experiments now. Certainly the fuel oil dealers are into it. At the recent Federal Trade Commission symposium on competition in solar I think it was almost a unanimous opinion: don't keep the utilities out. They're the people who are going to make the early investment, and they know it. That's important to understand. The private utilities have been prohibited from doing this sort of experiment—installing units and making deals with customers—in California, although municipal utilities like Santa Clara's can do it. As far as homeowners go, at least two or three times a week we get calls asking if people can still participate in the program. The answer, unfortunately, is "no." [N.E.E. has put out a *Solar Consumer's Guide,* however, a pamphlet available free from them at 20 Turnpike Rd., Westborough, Mass., 01581].



The single best installation was this closed loop water drain down system with 70 square feet (6.5 square meters) of heat transfer surface. Looking down into the empty storage tank, the large amount of surface area for heat transfer can be seen. Temperatures in this tank reached over 155°F (74°C) before a mixing valve was installed.

for a diminished percentage of savings. The opposite results occur to those who use small amounts of hot water.

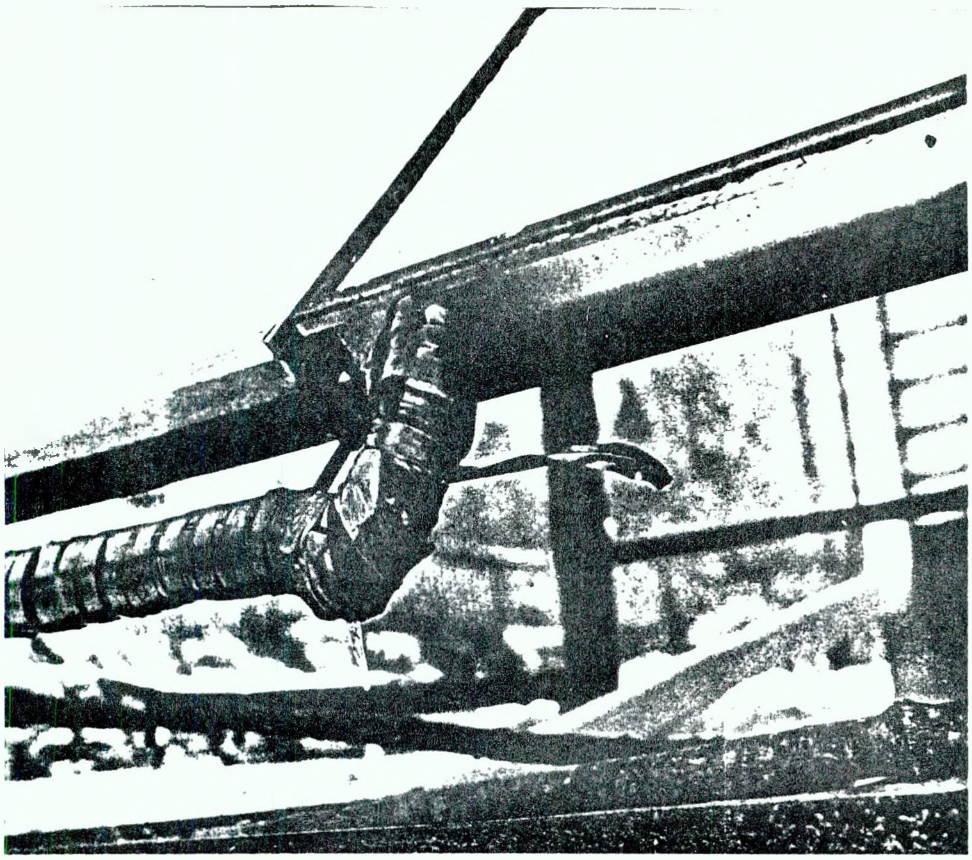
We expect that these savings are likely to be increased somewhat in the future as improvements are made in control of pumping speeds and times, insulation, and as users become more perceptive in timing of hot water usage. Also, setting the required delivery temperature as low as possible raises the solar fraction of total energy supplied.

Costs of Systems

Generic Type of System	Number of Manufacturers Participating	Number of Units Installed	Average Installed Cost
Water Drain-down	6	26	$1984
Closed Loop Water	1	22	1960
Closed Loop Anti-Freeze	10	48	2207
Air	3	4	2782

The Fifteen Best Systems

Generic type	Number used in experiment	Number found in the best systems	Percent of the best systems
Antifreeze	48	11	73.3
Drain back	2	1	6.7
Drain out	24	3	20
Heated pipe	22	0	0
Air	4	0	0
Totals	**100**	**15**	**100**



The Troubles.

Conclusions from statistics of mechanical troubles described on the weekly inspection reports of N.E.E. field workers must be drawn cautiously. Most of the troubles encountered in this project are due to flaws in installation, secondarily to flaws in the selection of component sizes and types, and thirdly to lack of inspections and adjustments after installation. Some problems can be associated with generic type of system.

These statistics fail to indicate that there are many very successful systems running in this project. Of the 100 installations, fifteen functioned well, twenty-three including these fifteen had no serious breakdowns, the rest had at least one major stoppage or breakdown requiring technicians to repair, and about twenty gave severely interrupted unreliable service. Among the poorer systems, twenty-seven produced very low savings of electrical energy or none.

Among the fifteen best systems were eleven anti-freeze, one drain back, and three drain out types. Generic type selections made by N.E.E. seem to have been the result of what information was avail-

Q: Aren't these recommendations rather stringent?

Smith: Yes. Almost impossible. They would have to be compromised by anybody who makes a practical installation. An intelligent overseer of a project could do it safely. The installers that we have growing up with this project are pretty sharp, and won't be terrified by these recommendations. Novice installers should be petrified, and probably sent away.

Recommendations For Consumers

Planning Stage

- Study the design and construction of solar water heaters. Literature on this is available from the National Solar Heating and Cooling Information Center, P.O. Box 1607, Rockville, MD., 20850.
- Compare offerings of several supplier-installers.
- Inspect existing systems installed by the installers you are planning to solicit.
- Seek an experienced supplier who provides everything, installs it, and guarantees it.
- Seek a long-term warranty covering labor and parts, e.g., five years.
- Seek a long financing term and low rate.
- Set modest goals for economic performance, and be prepared for a lengthy startup and adjustment period when performance may be below expectations.
- Provide indoor drains large enough to carry away water from pipes around the equipment if any should, accidentally burst.

Cost Estimating Stage

- Try to forecast all costs over a long period of ownership, e.g., ten years.

Contract Negotiating Stage

- Get legal assistance in writing your own terms into the purchase contract.
- Hold back some of the total payment for twelve months to see that the system is satisfactory in all seasons. Perhaps the greatest difficulty will be getting prompt repair service after the initial installation is made. A substantial holdback is about all that seems useful in this matter.
- Write into the contract that it is the seller's responsibility to provide the kind of equipment and installation arrangement and workmanship that will be approved by the local building officials.
- Specify that the installer is responsible for all plumbing, carpentry, electrical, painting, roofing, masonry, and landscaping work, and for procurement of all code permits and approvals of work.
- Be sure that the employees of the installer are covered by Workingmen's Compensation Insurance. Obtain and inspect this insurance policy.
- Make clear that the installer is required to restore disturbed roofing, siding, building insulation, and lawn and plants following the completion of the installation.
- Limit the duration of the installation project to some time such as two weeks to avoid a drawn-out job, and limit the permissible interruption of hot water service to some time such as one day.
- Avoid having the installation made during freezing weather when work proceeds more slowly than in non-freezing weather.
- Specify design temperatures and gallons per day in the performance requirements.
- Get a complete description of freeze-protection provisions in the system.
- Get a complete description of future maintenance work needed for long-term operation.
- Get a complete description of the procedures for vacation shutdown and startup.
- Get a neat, legible set of drawings describing the piping and wiring of the individual system. Have any standard drawing set marked to show how the completed system as actually built differs from it.
- Get a list of all major components with name, count, make, model, size, and capacity of each. This should include all valves, motorized dampers, temperature sensors, controllers, pumps, blowers, motors, heat

83 (Solar C&S)

able and what offers were received in 1975 at N.E.E. The manufacturers of the fifteen were among those with the most actual experience with solar installations. The installers were among the more experienced with solar systems and the more meticulous in attention to detail and follow up.

New England Electric officials and their consultant took care to write a sound specification for purchase of the systems but all parties concerned found themselves in a learning experience with solar water heaters. None of the installation work received New England Electric surveillance by an experienced solar system engineer. Few of the twenty manufacturer-suppliers had any prior solar water heater installations. The most experienced among them had experience which was modest in scope. This is also true of the installation contractors, and of the consultant. Some of the consequences of this joint inexperience were that collector area was almost always undersized for four-person demand: Collector areas furnished were between 30 and 60 square feet-net whereas in this climate at least 80 square feet of average-efficiency flat plate collector is indicated for four people—the usual family size found in this program.

In anti-freeze or other closed-loop systems the heat exchanger coils were almost all undersized at about 8 square feet of surface. Heat delivery from collector to domestic water was inhibited. A figure of between 20 and 40 square feet is in order here.

Problems with piping, valves, and controllers were many and can be attributed to both inadequate reliability of valves and controllers as received at the site.

It is reasonable to set target savings for successful installations at 50 percent or more of annual water heating electrical energy. No system had met this target over an average of twelve months by July 1977, but improvements made in many of these systems during the summer of 1977 show promise of producing this target saving in the next twelve months.

Q: You stated in the report that one must be careful not to identify problems with generic types of collectors. Nevertheless—can some problems be attributed to some designs?

Smith: I think differently today. Some *are* identifiable with generic types. Freezeups can occur in almost any kind of collector except an air collector. It was not always apparent what caused them and it was hard to find out—the men in the field making these reports every week are not solar engineers—but there were some patterns. The drain-out types had freezeups frequently. The solenoid valves on the supply lines are triggered into the panic mode when the temperature hits, say, 37°F. They dump the system and hold back the city water that normally floods through. If the valves don't work, or if they get frozen, you've got trouble. When you pump the system up again, the air valves have to work to vent air from the system.

Meeker: If the thermostat operates 99 percent of the time—there can still be a problem. All it needs is one night to freeze. Even in our second go-round these problems have not been surmounted, and this type of failure — unless the consumer has a warrantee — could cost him $300 to $400 if the collector goes. If you're saving $100 a year, it's not worth it.

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exchangers, tanks, collectors, and any other main components. These may have to be repaired or replaced at any time.

- Specify that a mixing valve shall be installed and adjusted to prevent final delivery temperatures from exceeding 140°F.
- Specify where and by what means the collectors and the main pipe or duct runs to them shall be mounted and fastened.
- Some instrumentation is needed to determine whether the system is making the most of the sunshine. The principal item is a running time meter on the collector circulation motor. Thermometers and flow meters are a further help in determining whether the controller set points combined with the pump flow rate are set to capture the most heat from the sun.
- Closed-loop systems should be equipped with a way to detect loss of the anti-freeze solution. Either a pressure gauge in a readable location in the anti-freeze loop, or a sight gauge tube on the side of the reserve supply tank should be installed.
- Reserve the right to inspect every part before it is installed and to reject any that do not meet contract terms.
- Demand that the system pass pressure tests on the collector loop, e.g. 25 psi for twenty-four hours, and on the domestic water loop, e.g. 120 psi for twenty-four hours, to appropriate values for appropriate durations before startup.
- If possible, obtain the services of an experienced solar engineer or solar system installer to act as an inspector at the time of startup. The system may have been installed by very inexpert workmen with inadequate supervision.
- Be careful to learn what insulation will be provided, both the kind of material and the thickness at collector backing, pipe (or duct) runs outdoors, and pipe (or duct) runs indoors.
- Where anti-freeze is used, HUD requires two walls of pipe or tank—two distinct layers of sealed metal—separating the anti-freeze solution from the domestic water. Most codes require this now.
- Get the city plumbing inspector actually to inspect the job for conformance with the plumbing code before the pipes are insulated or buried. He is employed to safeguard consumers' interests.

Recommendations for Industrial Practices

It appears from this project that solar equipment manufacturers can avoid bad publicity when they:

- Control and train installation subcontractors;
- As a result of training, can offer long warranties and sole-reponsibility for complete systems;
- Build a reputation for prompt attention to trouble calls from customers;
- Pre-package as much of the system plumbing and wiring as possible;
- Pay a great deal of attention to air venting and to liquid draining pathways, both in design and installation;
- Provide installers with very clear drawings and parts lists made for installation use;
- Tell customers clearly what they will have to do to maintain their systems correctly;
- Wherever double loop systems are offered, use much larger heat exchanging surfaces than the 8 square foot surfaces in common use in the N.E.E. project;
- Have improvements made in pipe insulation for exterior and underground applications. This refers to U-value, durability, ease of installation, and assurance of retention in place.

Interviews with several installation contractors who were involved in this project yielded many ideas, among them these, without comment:

- Promote licensure laws for solar installation technicians.
- Get plumbing inspectors to look carefully at each job before the pipes or wires are covered.
- Manufacturers of solar equipment know very little about construction costs. They have seriously underestimated these in bids, then tried to complete the jobs anyhow within the contracted price. This causes skimping that leads to bad performance and bad publicity.
- Financially weak manufacturers have been very slow and evasive about paying installers.
- The training of new installers and solar equipment manufacturers costs time and money that should be budgeted into jobs.
- A reputation for neat work and quick response to trouble calls is very valuable.

Smith: The biggest problems were not traceable to generic type, but to bad plumbing thought. The lines didn't pitch downward so they would drain, for example. In this particular experiment there was so much trouble at the installer level that it practically obscures a precise analysis of trouble by generic type. To identify trouble that way is worth doing — but you need some solar engineers out there to figure out whether it *is* generic trouble.

Q: Are there generic types of troubles with installers? Can you classify them?

Smith: Yes. Just run down the table. Freezing or low economy: could be pump settings or water seepage, both installer problems. Leaks in pipes are installer problems. There were sixty leakage problems noted—and probably more that weren't noted—surely blameable on the installer. Valving: a lot of valves were faulty when they were purchased—it seems to be the nature of the valve hardware industry to slip in a few in the course of a lot—and the plumbers throw them right on in. Half the time, when you put a faulty valve on a non-solar system, nobody knows the difference for years. It doesn't matter much. In solar work it's critical. Some valves were omitted or mislocated. That's the installer. A pump was installed backward. That's the installer, thank you. Excessive pump noise: the usual motor speed, 1,750 rpm, is a fairly quiet motor. But when you have a lot of height between the pump and the collector you resort to a motor that's built differently and goes twice that speed, and it is a screamer, by nature. Sensors: one was only attached to the absorber plate with tape. That's criminal. They should be bolted to the upper portion of the absorber plate. Controllers: in twenty-six cases they ran continuously or excessively. In other words, they weren't controlling. In two cases, controllers were wired backwards, so systems were pumping heat outside. We don't know why the controllers broke down so frequently, exactly, but many were thrown out as "bad" internally. Antifreeze solution was too weak in one case—again, installers. To generalize, installers did the job to standards that were good enough for other things, but not good enough for solar. Standard plumbing practice is too casual. I've speculated that the best tradesmen for this work are probably the refrigeration and air conditioning installers, who know something about insulating pipes and making them very tight at the connections.

Trouble Analysis

Type of trouble	Number of troubled systems	Breakdown by type				
General systems		Anti-freeze	Drain-down	Drain-out	Heated pipe	Air
Water hammer noise	9	1		6	2	
Froze	30	1		19	10	
Below 10 percent economy	27	10		8	8	1
Water seepage into house	3	2		1		
Collectors						
Leak at known joint	9	2		2	5	
Leak, unspecified	5	1		2	2	
Burst pipe	1			1		
Outer cover cracked	1			1		
Damaged by wind	3	3				
Wrong insulation, material or thickness	1	1				
Buckled casing	1	1				
Inner cover broken	2	1		1		
Piping						
Leak at known joint	16	3		6	7	
Leak, unspecified	5	2		3		
Drainout reservoir overflow	3			3		
Water hammer	1			1		
Not pitched properly	15			15		
Became airbound	14	1		3	10	
Wrong insulation	6	2		2	1	1
Valving						
Leak at known place	3	2		1		
Frozen or stuck	5	1	1	3		
Relieved too often	3	3				
Fault in valve	4	2		2		
Omitted or mislocated	6	1		3	3	
Tank, heat exchanger, electric heater						
Leak at known place	2	1		1		
Leak, unspecified	1	1				
Failed electrical element	1	1				
Failed elec. heater thermostat	1	1				
Temperature control relay fault	2	2				
Pump or blower and motor						
Leak in pump	2	2				
Motor malfunction	3	3				
Pump installed backward	1	1				
Excessive noise	5	1		1	2	1
Pump didn't move water	2			1	1	
Overheated	7	1			6	
Temperature sensors						
Fault in sensor	3	2	1			
Sensor became detached	4	2		1	1	
Controller						
Ran continuously or cycled excessively	26	11		12	2	1
Wired backwards	2	1		1		
Freeze protection setting too low	3			3		
Setting not optimal or in range	2	1		1		
Miscellaneous						
Antifreeze too weak	1	1				
TOTALS	**241**	**73**	**2**	**102**	**60**	**4**
PERCENTAGES	**100**	**30**	**1**	**42**	**25**	**2**

Q: What do the homeowners who participated say?

Meeker: It varies, according to how they were treated. If they think they got the shaft from the manufacturer or the contractor, then they're upset. A homeowner will call up the field director to say he or she has a problem, or the field director will notice the problem when he goes weekly to take the reading, and will inform the homeowner who will notify the contractor. If the contractor says he'll be there at 9 in the morning, and doesn't show, and the homeowner has taken the day off to meet him, we call him—but we really have no control over him. In some cases it took the headlines to get the people back to make repairs. This type of bad will hangs on. The entire solar community is affected by it. On the other hand you have people who really were abused early in the game and still—for their $200 investment—are happy now. When the repairs were made, instead of 10 to 15 percent savings they're up to 35 or 40 percent. If it's done correctly, the thing will work. I don't think anybody disputed that, anywhere along the line.

Atlanta (Towns) Solar Experiment: The lessons we learned

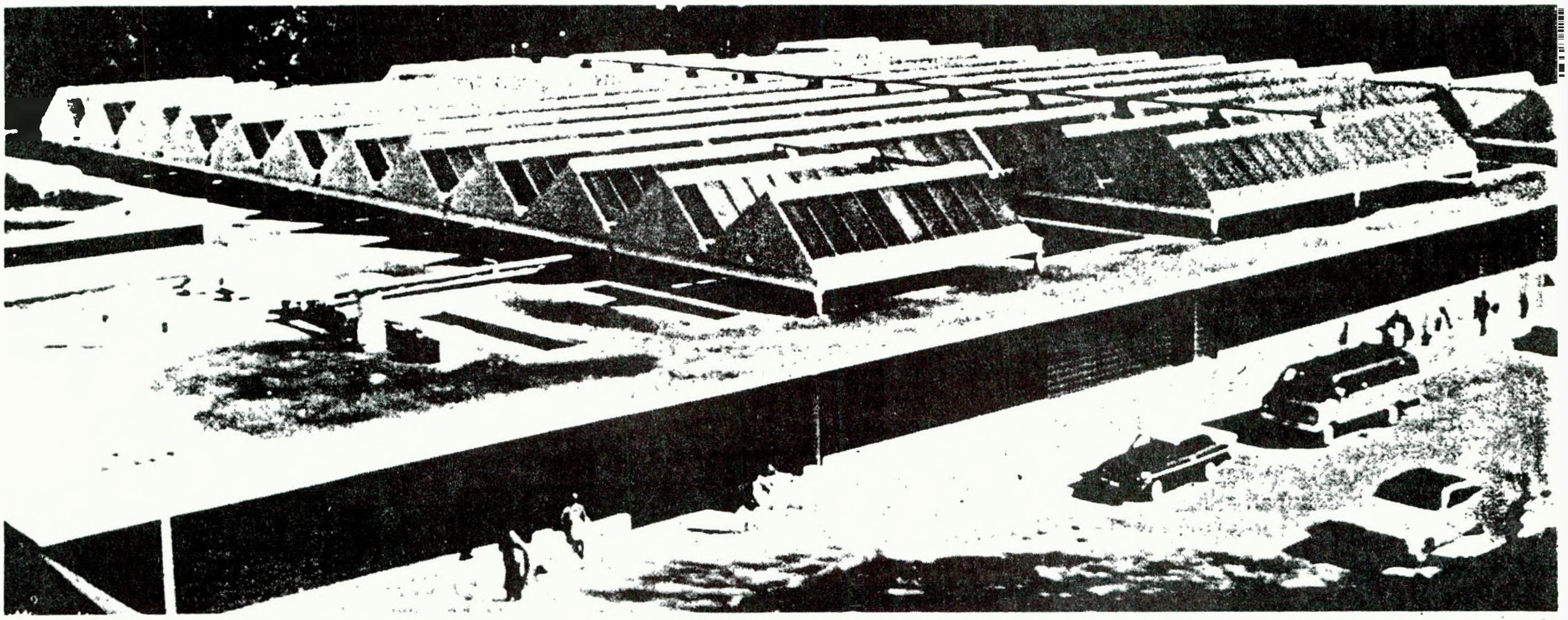

Fig. 1 Towns Elementary School

A large-scale solar heating and cooling system experiment was designed and constructed for the Towns Elementary School, Atlanta, GA. This system involved 10,360 sq. ft. of flat-plate collectors, 10,800 sq. ft. of flat reflectors and a 100-ton absorption chiller. Lessons learned and the systems' performance in the heating mode are described.

ALBERT WEINSTEIN
Member ASHRAE

RICHARD T. DUNCAN

WILLIAM C. SHERBIN

IN 1974 we conducted a comprehensive study of the feasibility of solar heating and cooling of buildings for the National Science Foundation. It was concluded that although economic considerations are the principal barriers to widespread commercial use of solar systems, the most difficult technical problem is that of cooling by solar heat. Authorization was subsequently received to design, construct, test, and analyze an experimental large-scale solar heating and cooling system for the Towns Elementary School in Atlanta. This site was selected because it had a significant cooling and heating demand and was climatically representative of the large southeast region of the country.

Construction and analysis phases of this program were carried out under the sponsorship of the U.S. Energy Research and Development Administration by our firm and its associated team members: Burt, Hill & Associates, Architectural Engineers, Butler, PA.; Dubin-Mindell-Bloome Associates, Mechanical Engineers, New York, NY.; Georgia Institute of Technology, Instrumentation, Atlanta, GA.

As an experiment of the first large-scale solar heating and cooling system, it had several implicit objectives:

- Investigate technical feasibility of a large-scale solar heating and cooling system.
- Validate design data and techniques.
- Determine system and subsystem reliability and performance under field conditions.
- Identify unpredictable problems.

Construction of the solar system began in April, 1975. It was dedicated on November 26, 1975. Fig. 1 shows the collector layout. After a period of debugging and shakedown, performance data monitoring was begun on February 1, 1976.

A detailed report on the system's design was prepared and is availabl through the National Technical Ir formation Service (NTIS).[1] The initia phase of this experiment was described in the March 1976 issue of ASHRAE JOURNAL and, in addition, several papers have been published by the principal participants of the project.[2,3,4] This paper is an interim report of the problems encountered and performance test results of the solar heating mode. When results on solar cooling become available they will be reported in a subsequent paper.

CONSTRUCTION

It was the policy to utilize commercially available components and standard techniques to the maximum degree possible. Similarly, it was the policy to employ small business subcontractors, local to Atlanta, to perform the actual construction.

The sum total of the competitive bids proved to be considerably higher than estimates made six months earlier. This increase was largely attributable to very sharp increases in costs of piping and fittings.

COLLECTORS

Analysis by the architectural engineers established that treated wood would be more economical than steel or aluminum for the collector array support. These truss-like structures were produced off-site and then assembled on a steel frame bed, two

The authors are with the Special Systems Div., Westinghouse Electric Corp., Baltimore, MD.

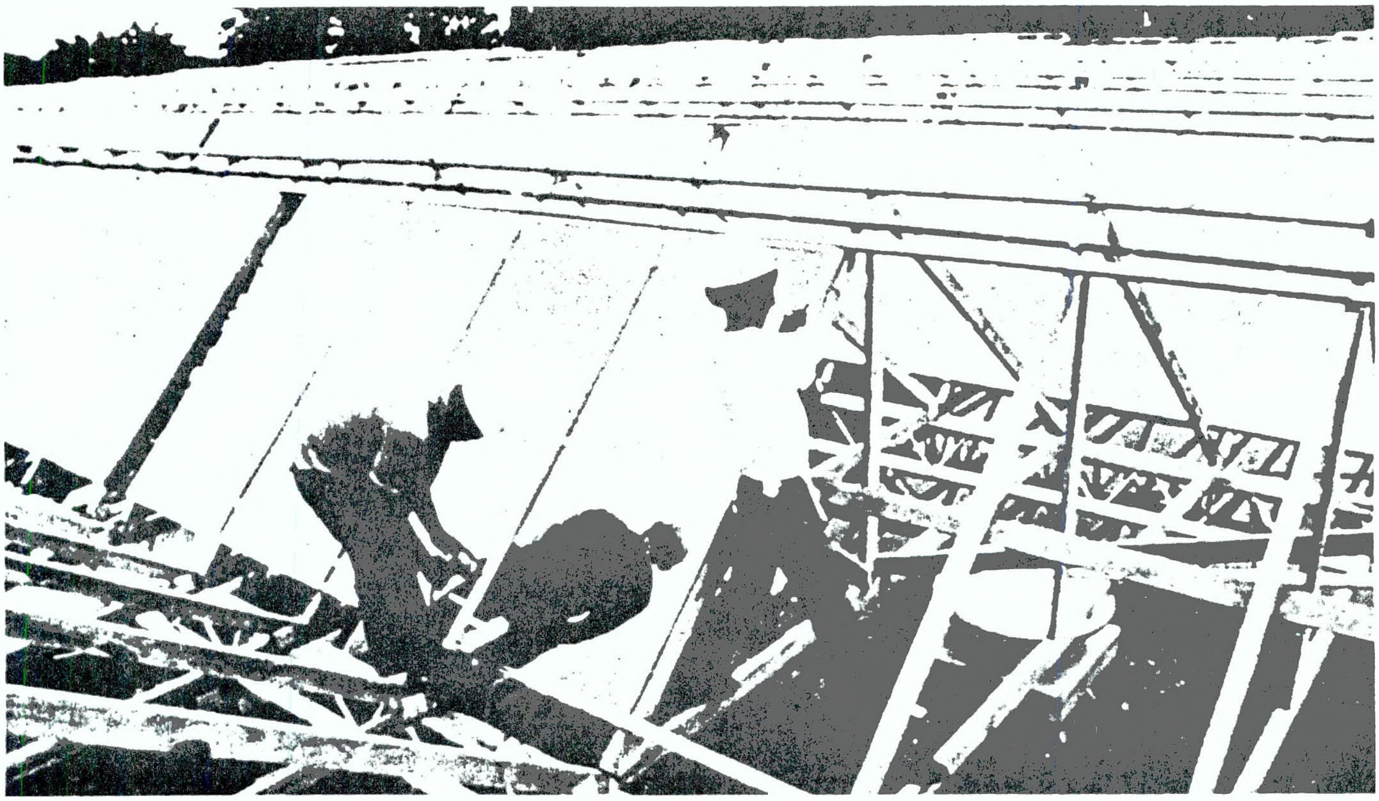

Fig. 2 Collector installation

feet above the flat roof as required by the Atlanta Public School system. Fig. 2 shows installation of 576 collectors on the wood frame support at a tilt angle of 45°. During installation, 22 collectors became inoperative for various causes as indicated in Table 1. Due to thermal stresses the problem was corrected by substituting heat strengthened glass for the inner cover while retaining tempered glass for the outer cover.

The saw tooth configuration of the collector array support made it possible to physically mount "mirrors" on the rear section that connects the top of one collector row to the bottom of the next row at a slope of 36 degrees. These "mirrors," made of a commercially available aluminized reflective plastic, serve to capture the energy that would otherwise be lost when the sun's altitude angle exceeded 51° and reflect it into the next row of collectors. Calculations indicated that these mirrors would add about 30% more energy at the peak of the cooling season and that higher temperatures, required to drive the absorption machine in the summer, could be achieved. In effect, the reflectors constitute a low cost, low ratio "concentrator." The glint shown from one row of collectors in Fig. 3 is a striking qualitative indication of its effectiveness. A more quantitive analysis of the performance of the reflector subsystem is provided further on.

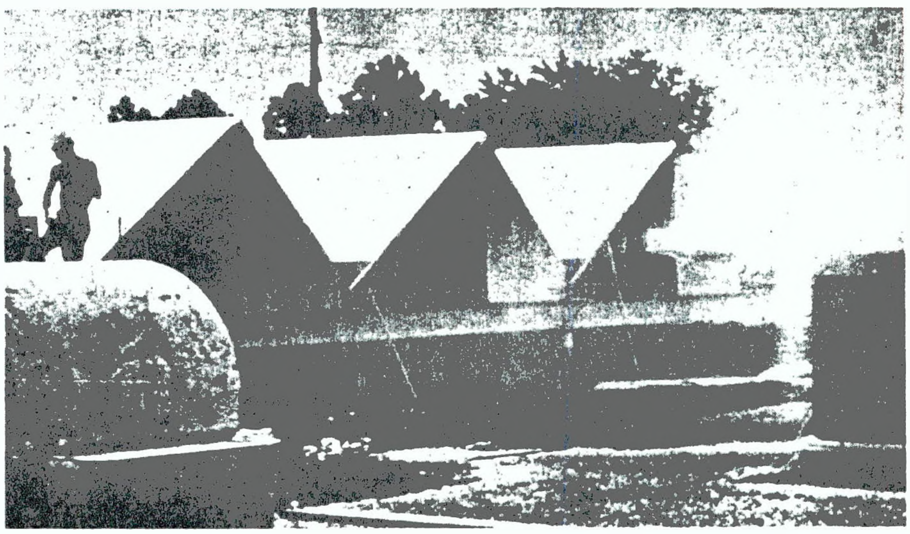

Fig 3 Aluminized reflectors

Table 1 Collector Failure Statistics

		% of 586
Collectors Purchased Initially (includes 10 spare)	586	100.00
Packing/Shipping Faults	2	0.34
Glass Broken During Installation	3	0.51
AFTER START OF OPERATION:		
Inner Glass Thermal Breaks	12	2.05
Outer Glass Thermal Breaks	2	0.34
Vandalism/Foreign Object Breaks	0	0
Absorber Plate Leaks	3	0.51
FIRST YEAR TOTAL	22	3.75

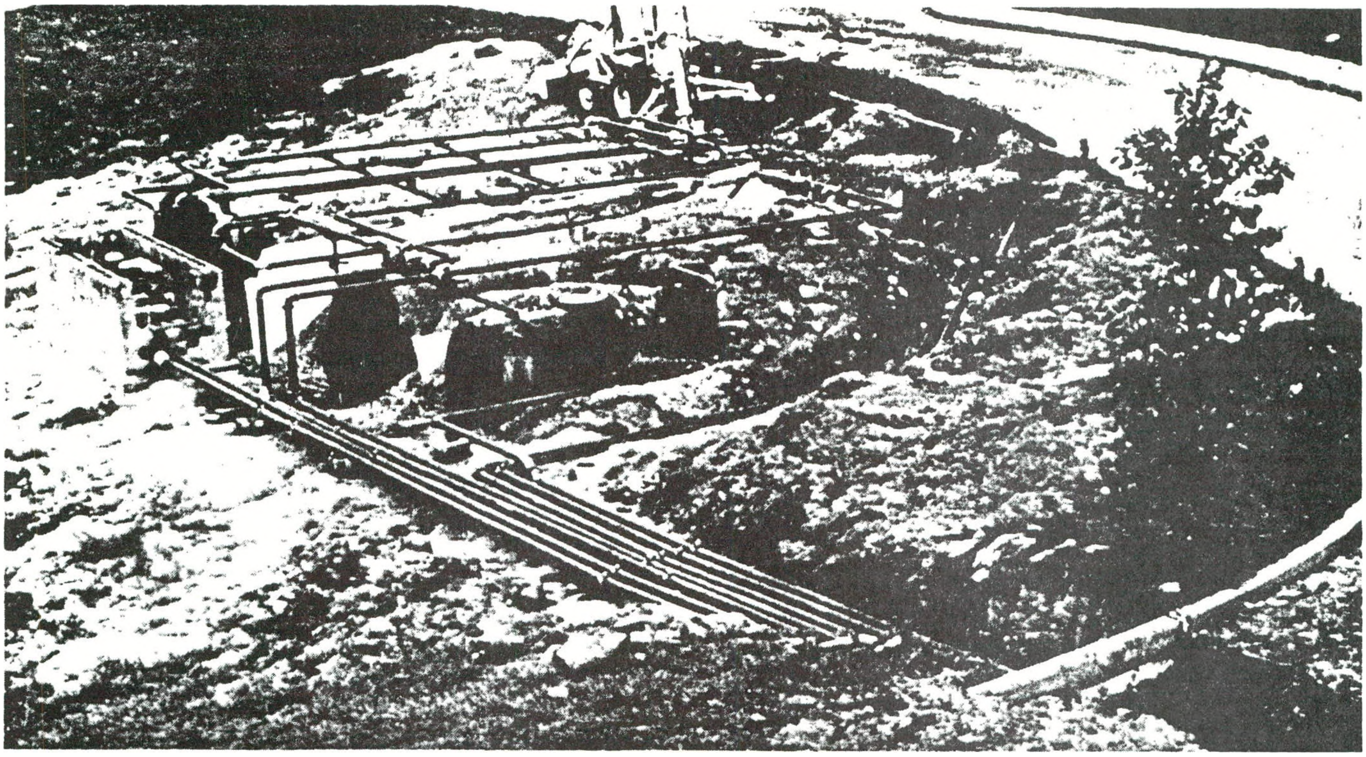

fig. 4 Storage tank farm

STORAGE & PIPING

A "farm" consisting of three 15,000 gal. steel storage tanks and one 1,600 gal. drain-down tank was located 125 ft. in front of the building as shown in Fig. 4. The tanks are imbedded in 2-in. size crushed rock without insulating jackets over an 18-in. rock bed with piped drainage. A four-in. thick wall of beadboard insulation serves to insulate Tank 1 from Tanks 2 and 3. This is necessary for summer operations when Tanks 2 and 3 contain hot water at temperatures up to 200F and Tank 1 is used to store chilled water at 45F-55F. Two layers of 2-in. beadboard insulation, a 4-mil vinyl sheet and 3 ft. of topsoil, dome shaped for watershed, covers the tank farm to minimize heat loss upwards and prevent rain water from seeping down onto the tanks.

Underground valve pits are located at each end of the tank farm. One contains 9 valves that control the flow of water from the collector to storage and the other contains 4 valves that control the water from storage to the room unit ventilators or absorption chiller as directed by the control logic unit.

Fig. 4 also graphically shows a section of the piping and fittings associated with the system, all of which are insulated. There is over a mile of piping and several thousand fittings in the system. The cost of piping and fittings proved to be almost three times that of the solar collectors. The sharp increase in piping and fitting costs constitute one of the painful lessons learned.

To achieve the flexibility desired in the experiment required a sophisticated control system involving 27 control valves. The characteristics of several of the valves proved to be very important. In accordance with conventional practice, commercial grade poppet-type valves were specified and installed. Although the valve manufacturers describe them as "tight-closing" capable of withstanding a 35 psi differential water pressure, a slow leakage in the reverse direction was experienced. This would have been of little consequence in an ordinary system, but it was intolerable in the collector drain-down subsystem. It was found that higher pressure hot water from the storage tanks seeped past the isolating valves and, over a period of several days, filled the drain-down holding tanks to capacity. Under this condition, the collectors could not automatically drain-down completely and they become vulnerable to possible freezing. As a temporary fix it was necessary to periodically manually drain the holding tank; as a permanent fix these valves were replaced with bi-directional "bubble-tight" butterfly valves.

Another problem, associated with the drain-down system, related to the pump that fills the collectors by drawing from the holding tank. The pump is in the machinery room and is located 150 ft. from the holding tank and 15 ft. above it. Because the appropriate valve did not close "bubble-tight" when commanded by the sensors, all the water in the pipes connecting the collector fill pump to the holding tank would drain down into the holding tank. When the pump was turned on to fill the collectors, it would suck nitrogen and was frequently unable to pull water suction and fill the collectors. To correct the problems, the pump was exchanged for a submerged impeller pump and moved to the holding tank. The associated valves were replaced by bubble-tight valves.

During initial system checkout the water flow rate from the storage tank was considerably below that anticipated. It was subsequently discovered that a "normally open" control valve and a "normally closed" control valve had been mislabeled by the supplier and so had been interchanged during installation. Such incidents, which are not unique to solar systems, are very frustrating and time consuming.

PERFORMANCE

Comprehensive analysis of the system's performance began on February 1, 1976. The monitoring instrumentation, designed, installed, and monitored by Georgia Institute of Technology, involved 60 data points. These included collector plate temperatures, inlet and outlet temperatures of the water to the collectors, storage tank temperature and flow rates at all critical points. Since only a few months of data is available and, in view of the problems encountered, the system could not be maintained in continuous automatic operation. It is, therefore, not possible to present at the time of this interim report a conclusive overall system performance evaluation. However, by analyzing appropriate data, a reasonable indication of the system's performance can be obtained.

Fig. 5 (data for April 23, 1976) provides a good indication of the reflectors' performance.

A comparison of measured heat production for a clear day (February 20, 1976) to that predicted in our computer program is shown in Fig. 6. Integrating over the entire day, the measured value exceeds the prediction by 1.4%. The fact that the measured value was below prediction during the early morning is attributed to inadequate accounting in the computer program for the thermal lag of the collectors.

LESSONS LEARNED

Subject to further data and analysis, the principal lessons learned to date are:

- The design data and techniques are valid and slightly conservative.
- The "reflectors" function somewhat better than anticipated and are a low-cost means of augmenting solar performance.
- A drain-down system has thermodynamic merit but adds to the control system complexity.
- Field tests of large-scale collector arrays are essential to uncover production and installation problems.
- The solar system is operating at or slightly better than design predictions in the heating mode.
- Piping, fittings, and valves are major cost items (three times collector cost).
- Improved flat-plate collectors with two low iron glass plates and a black chrome selective surface would require about 30% less collector installed area for the same energy output when compared to the existing panels in Atlanta. (These improvements in collector technology were not commercially available in 1974).

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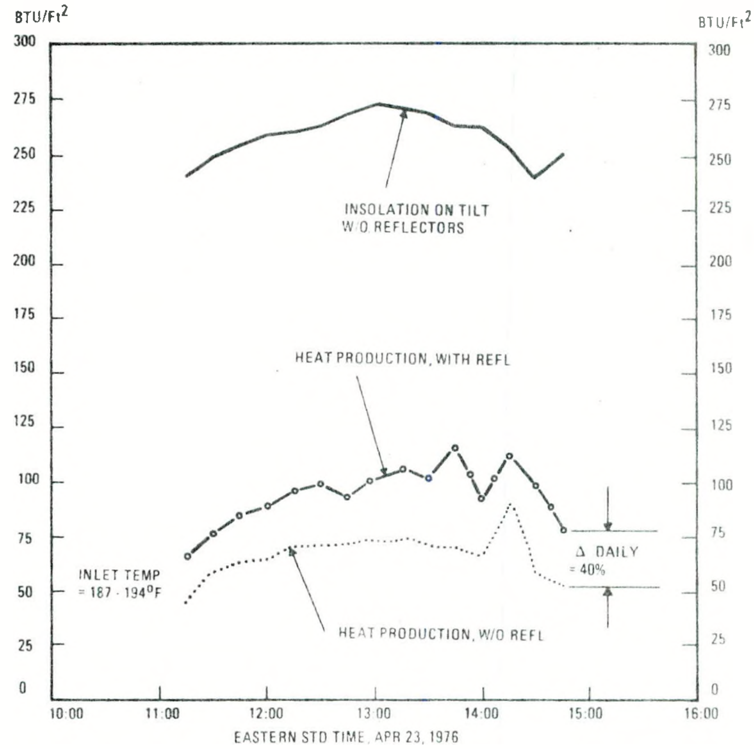


Fig. 5 Reflector performance

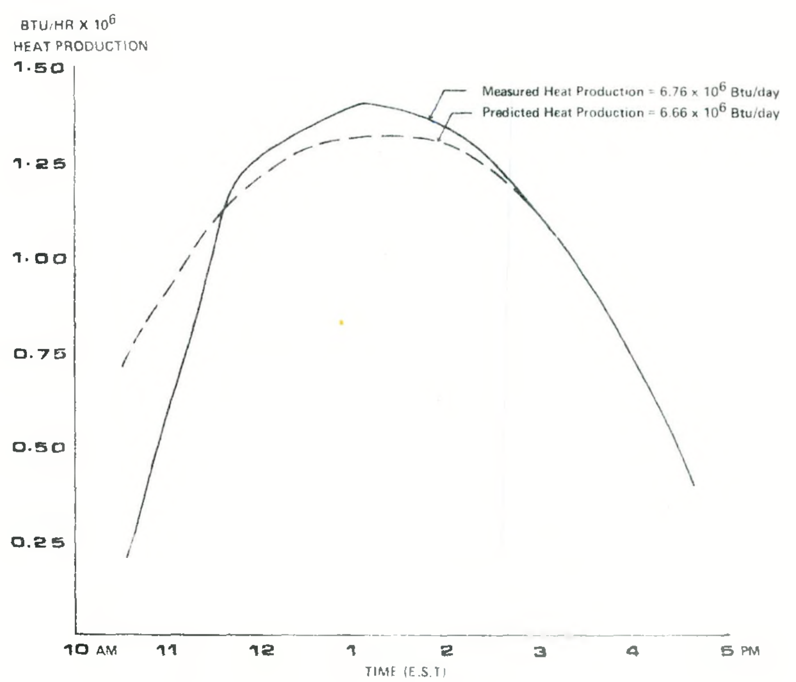


Fig. 6 Predicted and actual collector heat production at Towns School (Feb. 20, 1976)

Problems, anyone?

Seven HUD grantees, pioneers in Cycle 1, single out some difficulties

If you can expect problems with any solar system installation, it seems almost axiomatic to assume that retrofit installations will have even more problems. The boundaries are less flexible, the limitations more absolute. Nine retrofit projects were funded under the first cycle of solar demonstration grants from the Department of Housing and Urban Development. Most of them are now complete, or nearing completion, and so might be expected to have found whatever problems lie in wait. *Solar Age* asked the architects or designers two questions: what was your biggest difficulty? How did you overcome it? Their answers touched most of the troublesome areas that had been predicted—but yielded surprisingly few that were more than serious irritations.

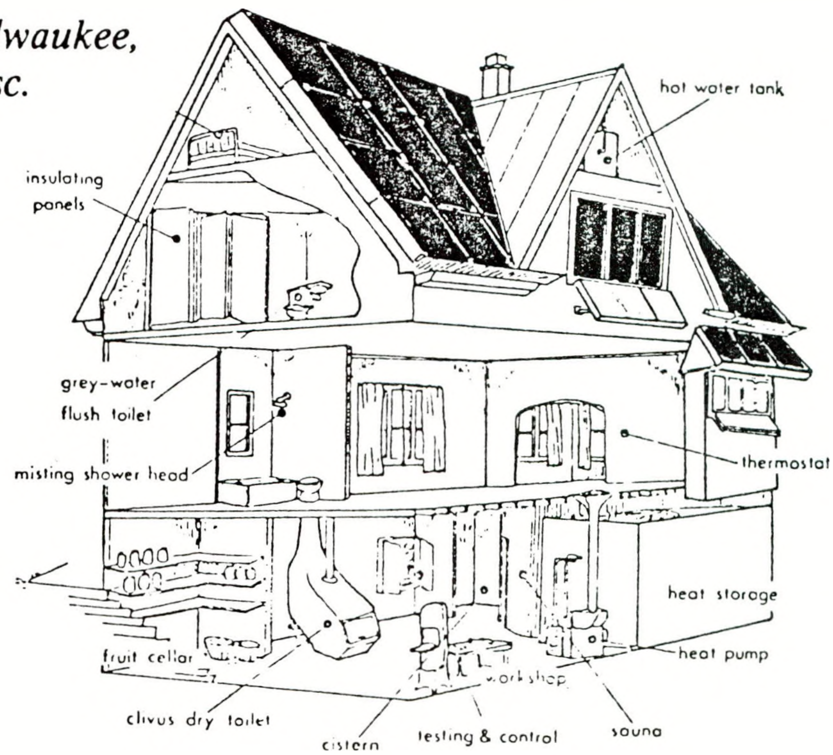
The University of Wisconsin at Milwaukee is putting 600 square feet of air-cooled flat plate collectors on the roof of a two-story 2,400 square foot wood frame house, to provide space heat and domestic hot water. But the installation of the Solaron collectors is only part of the project. John Schade of the University School of Architecture, head architect for the project, says:

The first issue is conservation. If you can reduce consumption by a significant amount you can reduce the capital investment required by the solar system by cutting down the square footage of necessary collectors. We reduced the energy consumption by at least 55 percent with a series of changes. First, Insulation, blown-in cellulose fiber throughout. Second, and this is probably one of the most cost-effective changes we made, was the addition of a three-function control system to the existing gas hot air system, consisting of a direct-ignition pilot, an automatic night cutback system, and an automatic damper control that closes the damper when the furnace is turned off. That has a fail-safe mechanism so that it could pass the American Gas Association standards, and it is estimated to save about 28 percent of the initial heating cost. We tested it independently on another house, and it saved more than 25 percent—and it cost only about $300. Third, we put in insulating shutters on most of the windows. They can be opened during the day and closed at night, which makes the house somewhat of a collector itself. Fourth, very elaborate weatherstripping. We also used something called InsulShade, a kind of passive solar treatment of the south facing windows.

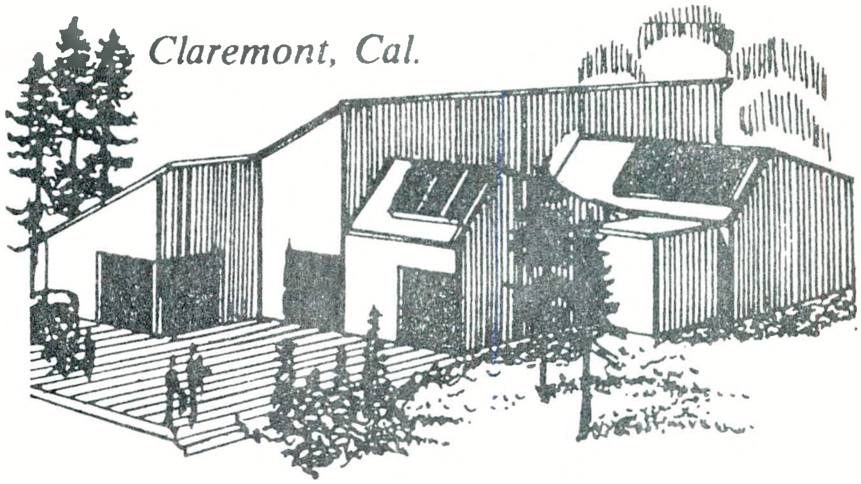
The other major problems were the typical problems. When you deal with a retrofit situation, the costs of ductwork and mounting the collectors are considerably higher, by a factor of two or maybe three—who knows, maybe four—than they are in new construction. The first bids were simply out of this world. The second bids were too high. The third bids were coming down. We feel that's largely a function of communication with the bidders. It's very important to sit down with them and take the aura of mystery and novelty away from solar, because technically and industrially it's not mysterious. It's sheet metal work and, in our case, we use an air system that's quite conventional. Communication helps, but you still have to expec higher costs because you're workin with an existing structure where yo have to go through the building, and you have to make allowances for interior cosmetics. In our case, we had to build support for the collectors on the roof.

HUD provided $13,800, $9,000 for

Milwaukee, Wisc.



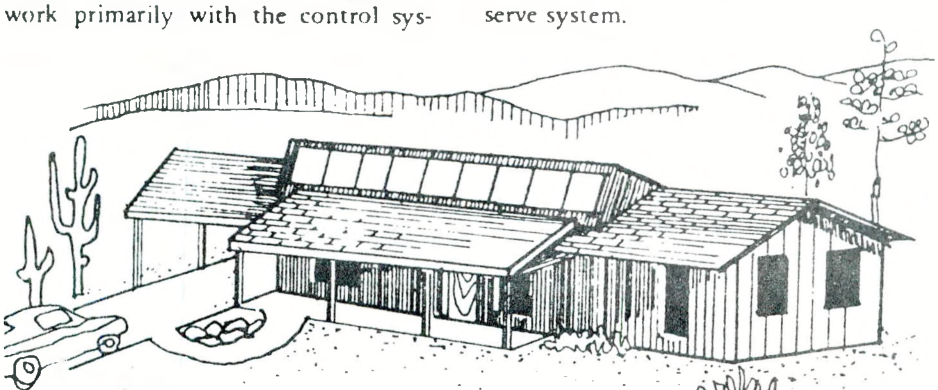
the hardware and $4,800 for the installation, even after three bids, it's much higher, and is being picked up by an agency of the city of Milwaukee. We've been negotiating for the extra money for nearly a year. Meantime, the conservation work is done, and we have documented a year and a half's worth of data. We feel that the 55-percent figure is probably conservative.


Claremont, Cal.

The Creek Nation Housing Authority in Tulsa, Okla., is connecting five single-story, single-family houses to a single solar heating and hot water preheat system. Two hundred thirty four square feet of Raypak liquid-cooled collectors in an ancillary structure will serve approximately 5,250 square feet of living space. The HUD grant was $39,935. A. Leon Ragsdale, of architects Ragsdale and Christensen, says:

I would say that one of the greater problems was the integration of the existing heating mechanical systems. In our case, we were dealing with three different fuels, electric, gas, and butane. How do you tie the solar system in, and control the systems so you get the optimum operating efficiency from the solar? In new construction you can design the backup system to fit and the integration would be done at the time it was installed. We had to resolve the ways to get them to work in harmony, with electronic controls to create that concert. We aren't using standard mechanisms, thermostats, or controls. We're working with time-delay mechanisms and temperature-sensing devices, and the workings of these things were a question of getting the kinds of expertise that probably no one individual has. We had to bring in a number of people who were experts in various fields, and an electronics expert to work primarily with the control system. For example, when the temperature in the house is such that it demands heat, we had to work it out so that water is released from storage or directly from the collector to go to the heat exchange unit inside the floor of the house; that required working the thermostat inside the house, calibrated one way, through a heat-sensing device that is calibrated in another way to monitor the temperature of the water in both places. And that had to be worked in such a way that we could use a time-delay mechanism to get the hot water to the heat exchanger. We have now designed a digital computer that works with this system so that it's much simpler than the original system. All of the collectors are installed; the control systems are built and some of them are in operation now. We're just making the final checkout.

The most important thing, in the use of solar, is of course that you get the most use out of it that you can. So many of the systems we have reviewed did not control the system in a way that gets the optimum use out of it. They use the backup system too much. We are trying to be sure that we are getting every Btu of heat from that collector before we switch over to the reserve system.


Tulsa, Ok.

The Armstrong Development Corp. in Claremont, Cal., was to have modified an existing building design to include solar energy space heat. The project was abandoned. Architect Robert King says:

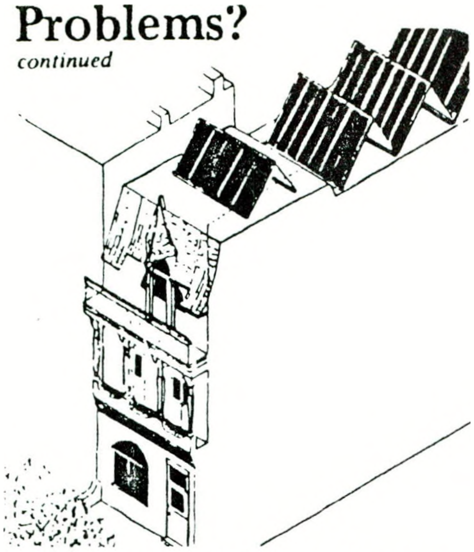
The major problem was being able to make the changes we wanted to make. You couldn't change a beam size or anything else without getting approvals from all over the country. The contractor concerned didn't want to take the time to do it that way. When HUD approved the project, they were putting out money and they wanted—rightfully—to know what to expect. In order to do so, they had to approve every minor modification. It just didn't work out.

The University of Pennsylvania project ($12,980) involved modifying a three-story Philadelphia townhouse for solar preheating and domestic hot water. Existing ductwork was used to circulate heat collected by 584 square feet of PPG collectors (transferred through a water-to-air heating coil in the ductwork) to the 3,942-square-foot house. Sidney Shore of the University's department of engineering says:

One difficulty, probably characteristic to our university setup, was that on our staff in the department of civil and urban engineering we don't have plumbers and riggers. The major problem was not in the design of the system but in the physical question of moving tanks and getting collectors up. We licked it, but we had to design everything that had to be hoisted. We had to make our own hoist. In a row house, like the one we are retrofitting, getting the ratio of the collector area to the need is a problem. You can't increase the size of the roof on a house that is already built, a row house in particular. We had to optimize the space so that on a year-round basis we would collect the maximum amount of energy even

Continued

Problems?
continued



Philadelphia, Penn.

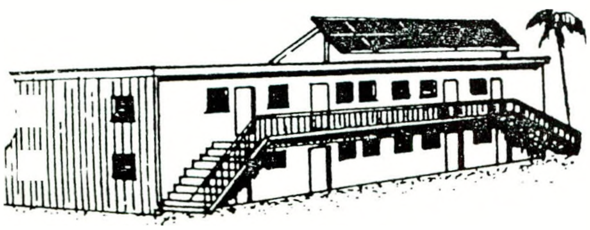
though we might have some snading of a collector some time during the day, some time during the year. We went to HUD data for the insolation, then we went through the various spacing and angles at which a collector could be set and figured the collection over the year.

[redacted]

The City of St. Petersburg, Fla., got $9,428 from HUD to integrate a domestic hot water system into an existing two-story apartment building. The 144 square feet of collector were manufactured by Gulf Thermal Corp. Brady Crawford, of the architectural firm of Reynolds, Smith, and Hills, says:

One of the major problems was adequate information on solar collectors. They haven't been tested enough really to verify comparisons. So we tried to go with the one we had the most knowledge of, ourselves, a collector we had been investigating for some time, manufactured here in Florida and familiar to one of my men who is a graduate student under Dr. Erich Farber. The other problem we had was wind loading on the collectors themselves. We hadn't really thought about the wind problem much. It hit us more or less out of the blue, you might say—and it's a problem we should consider here in the state of Florida, providing an adequate structure to overcome the hurricane-force winds that could come up. The structural engineer solved it by putting in some concrete blocks attached to the structure itself, heavy enough to hold the collectors down.

St. Petersburg, Fla.

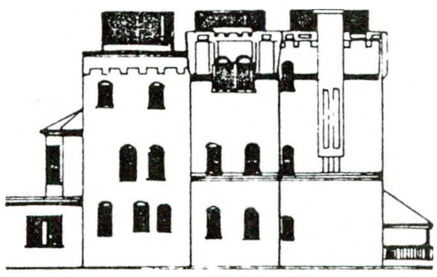


It was actually a fairly small job, just a domestic hot water heater, and I think we should see a lot more of it. The Florida Solar Energy Center is doing a great job of testing collectors now, so that adequate information will be available.

[redacted]

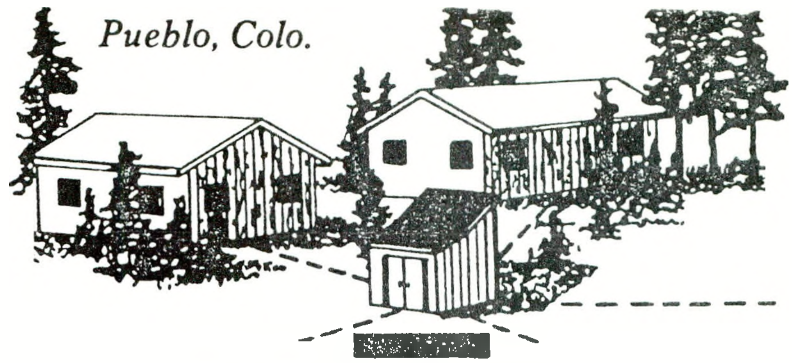
Drexel University also installed solar-heated hot water, in a five-unit apartment building. The grant, $6,780, covered 270 square feet of PPG collectors that preheat water circulated through an oilfired boiler to bring it up to 150°F. Architect Donald C. Larson says:

Most of our problem was associated with the roof support. It was an older building, an eighty-year-old three-story apartment, and it had a very old roof. We had to put beams across, and this ran the cost up more than we thought it would. The additional estimates for the support were about as high as the total grant, but then instead of using steel beams we were able to use wood to span the 12-foot roof. I asked for more money from HUD repeatedly—we went from aluminum to copper, and I asked for more there—but they weren't able to make any changes from the original requisition. We were able to get additional funds from Drexel, and we have two mechanical engineering senior design groups actually doing the installation of the system—it's primarily a student effort; a lot of the design of the system is being done by students, and the testing as well—so this is a way we're saving money. We've also been able to experiment with one of the three banks of collectors.



Philadelphia, Penn.

Pueblo, Colo.



[redacted]

A central hot water system to serve five existing houses was funded ($16,000) for the City of Pueblo, Colo., Housing Authority. A central shed houses 144 square feet of Raypak collectors and hardware; insulated pipes carry the hot water to booster heaters in each house. Half the array Is intended for maximum summer efficiency, half for maximum winter efficiency. Project coordinator Joseph Acedes says:

We put this up on a public housing project. Getting officials to cooperate, getting the people involved, was no problem. But we did run into contractor problems that were significant and should be taken into account. For example, when we let the bid out for construction we got bids from various contractors and subcontractors and everything seemed fine, but when we started to build one of the plumbing contractors pulled out. Perhaps he could see that he had his bid wrong, or he didn't want to get involved because it was something new—I don't know what the problem was. We were delayed some time and we had to get another contractor to finish the job. Other problems? We stipulated, when we ordered components, that one company supply all the solar components, the pumps, the valves, everything, so that we could have one person responsible rather than having to deal with a number of different routes. The project was completed by the end of July and went into operation the first of August. We ran into a minor problem in December when we had some very cold weather and one of the panels had a little failure. We corrected it, replaced the absorber plate in the field. But the point is that trying to assess the responsibility for the leaky electromagnetic valve, designed to actuate when they sense the cold temperature and to drain the system, whether the valve manufacturer, or the plumber, or the full collector is responsible, is difficult.

There were no structural problems at all. We had what I would consider was a good general contractor who was responsible for the complete construction, and it went very smoothly, very quickly.

Absorbent	Working fluid in an absorption cooler that has the power to separate the more volatile refrigerant.
Absorber	A black plate or surface which transforms radiant solar energy to heat energy.
Absorptance	Ability of a surface to absorb solar radiation. Expressed as the ratio of solar energy absorbed to total incident radiation.
Absorption	The process of absorbing or being absorbed. In a cooling system, a refrigerant is expanded into gas in evaporating coils; the expanded gas is absorbed by another fluid (called the absorbent) and used again after the absorbent is evaporated.
Active System	A solar energy system that uses mechanical energy to effect thermal transfer.
Altitude	Angular distance between the sun and the horizon.
ASHRAE	Acronym for the American Society of Heating, Refrigeration and Air-conditioning Engineers.
Azimuth	Angle formed between the projection in the horizontal plane of the earth-sun line and the south-north line in the same plane.
Beadwall	A simple method of insulating double-glazed walls by pumping styrofoam beads into the air space between the glazings. The beads are pumped out to allow heat flow through the glazing (either solar radiation in, or space heat out).
Biofuels	Renewable energy sources derived from living (biological) things. All forms of life, their by-products, and wastes can be converted to organic fuels.
Bioconversion	Conversion of solar energy to fuel by plants, algae; methane gas production, etc.
British Thermal Unit (Btu)	The amount of energy required to heat one pound of water one degree Farenheit at standard physical conditions.

Boiler	A closed vessel in which a liquid is heated or vaporized.
Calorie	The amount of heat needed to raise the temperature of one gram of water one degree Celsius.
Coefficient of Heat Transfer (U-value)	Rate of heat loss (in Btu/hr • ft^2•°F) through a building surface from outdoor to indoor air.
Coil	A cooling or heating element made of pipe or tubing.
Collector	Any device that collects solar radiation and converts it to heat energy.
Collector Efficiency	Ratio of useful heat output from a collector to incident solar energy.
Collector Tilt	Angle formed between the slope of the collector and the earth's surface.
Compressor	A machine for reducing the volume of a given refrigerant vapor.
Concentrating Collector	A device using reflectors or other optical devices to concentrate the energy entering through an aperture upon a heat absorber smaller in surface area than the aperture.
Condenser	A vessel or arrangement of pipe or tubing in which a vapor (gas) is liquefied (changes state) by removal of heat.
Conduction	Transfer of heat through matter by communication of kinetic energy from particle to particle.
Conductivity	The measure of the capability of conducting heat.
Convection	Transfer of heat by movement of fluid (liquid or gas).
Convection, Forced	Heat transfer resulting from forced circulation of a fluid, as by a fan, jet, or pump.
Convection, Natural	Circulation of gas or liquid (usually air or water) due to density differences resulting from temperature differences.

Cooling Tower, Water	An enclosed device for evaporatively cooling water by contact with air.
Coverplate	Sheet of glass or plastic which is used to retard radiative and convective heat loss in a collector.
Delta-t (Temperature Differential)	Difference in temperature between two substances or surfaces. Controls the rate of heat flow.
Design Heat Load	The total heat loss from a building (which must be compensated for by heat gain from a heating system) at design temperatures for a given location.
Design Temperature (Outdoor, Winter)	A temperature near the minimum temperature that is likely to occur at a given location. Design temperatures are established by ASHRAE.
Dry-Bulb Temperature	The temperature of a substance as indicated by an ordinary thermometer. Indicates the sensible heat content.
Duct	A passageway made of sheetmetal or other suitable material, not necessarily leak-tight, used for directing movement of air or other gas at low pressures.
Emittance	The ratio of the amount of heat radiated by a surface to the amount which would be radiated by a black body at the same temperature.
Eutectic Salts	A group of salts that melt at low temperatures, absorbing large quantities of heat as they do so. Heat is released as the salts solidify. Useful for storing latent heat.
Evaporation	Change of state from liquid to vapor.
Expansion Valve	A valve through which liquid or gas, under pressure, is allowed to expand to a lower pressure and greater volume.
Fan	An air-moving device comprised of a wheel or blade, plus housing plate.
Filter	A device to remove solid material from a fluid.

Flat-Plate Collector	A panel of metal or other suitable material that converts sunlight into heat. The solar radiative absorbing surface is essentially flat and the aperture and absorber are similar in area and geometr
Fresnel Lens	A lens that has a surface consisting of a concentric series of simple lens sections so that a thin lens with a short focal length and a large diameter is possible. Can be used to concentrate solar energy.
Furnace	That part of a boiler or warm air heating device in which combustion takes place. Also, a complete heating unit for transferring heat from fuel being burned to the air supplied to a heating system.
Generator	An apparatus in which vapor or gas is formed from a liquid or solid by heat or a chemical process.
Glauber's Salt (Sodium sulfate decahydrate)	A hydrated salt (melting point = 90°F; absorbs 104 Btu/lb as it melts).
Glazing	Windows or collector coverplates.
Gravity Convection	See Convection, Natural.
Header	A conduit into which a number of smaller conduits open. A pipe which runs across the top or bottom of an absorber plate (or a bank of collectors), collecting or supplying the working fluid from the risers; the array of pipes that runs across the absorber plate (or from the collector outlets in the case of a bank of collectors).
Heat	The form of energy that is transferred by virtue of a temperature difference.
Heat Capacity	The quantity of heat required to raise the temperature of 1 ft^3 of the material 1°F.
Heat Exchanger	A device specifically designed to transfer heat between two physically separated fluids.
Heating System, Hydronic Space	A heating system in which water with supply temperatures less than 250°F is used as a medium to transfer heat from a central boiler, through a piping system, to suitable heat-distributing means.

Heat Pump	A device for transferring heat energy from a low-temperature locality (heat source) to a high-temperature locality (heat sink) by mechanical means involving the compression and expansion of a fluid (as in mechanical refrigeration).
Heat Sink	A medium or container to which heat flows (and in which heat is stored).
Heat Source	A medium or container from which heat flows.
Heliostat	An instrument consisting of a mirror mounted on an axis, which tracks the sun so that a sunbeam is steadily reflected in the same direction throughout the day. So named because it seems to make the sun stand still.
Indirect System	See Active System.
Infiltration	Movement of air from outside into the heated space of a building through cracks around doors, windows, walls, roofs, and floors.
Infrared Radiation	Thermal radiation having wavelengths longer than those of visible light.
Insolation	Total amount of solar radiation incident upon a surface exposed to the sky. Measured in $Btu/hr{\cdot}ft^2$ or in langleys.
Insulation (Thermal)	A material having a relatively high resistance to heat flow and used principally to retard heat flow.
Integrated system (Hybrid)	A solar heating and/or cooling system which uses a combination of active and passive systems.
Kilowatt	One thousand watts of power; equal to about 1-1/3 horsepower.
Langley	A unit of measurement of insolation (one langley equals one gram-calorie/cm^2 or 3.69 Btu/ft^2); named for American astronomer Samuel P. Langley.
Latitude	Angular distance north (+) or south (-) of the Earth's equator, measured in degrees of arc.
Magawatt	One million watts or one thousand kilowatts; about 1300 horsepower.

Methane Digester	Insulated, airtight container that speeds up the breakdown of organic wastes to produce methane gas, for use as biofuel.
Nocturnal Cooling	Cooling of a body or building by night time radiation, convection, and evaporation, of excess heat to the cool sky.
Normal	In geometry, a word meaning perpendicular.
Panel Installation Angle	See Collector Tilt.
Passive System	A solar heating and/or cooling system which does not rely on mechanical energy to effect the transfer of thermal energy.
Photolysis	Chemical decomposition caused by radiation, including solar radiation, such as the decomposition of water to hydrogen and oxygen.
Photosynthesis	Synthesis of chemical compounds with the aid of light, sometimes including the near infrared or near ultraviolet; the conversion of solar energy to chemical energy by the action of chlorophyll in algae and plants
Photovoltaic	The direct conversion of radiant energy into electricity by means of thin wafers of various semiconductor materials.
Radiant Panels	Heat distribution devices with integral passages for the flow of a working fluid. Heat is conducted from the fluid to the panel and radiated to the space.
Radiation	Transmission of energy by means of electromagnetic waves.
Reflected Radiation	Solar radiation that is reflected from the surrounding terrain or buildings onto a receiving surface exposed to the sky.
Refrigerant	Working fluid in a refrigeration cycle, absorbing heat from a reservoir at low temperature and rejecting heat at a higher temperature.
Relative Humidity	A measure of the degree of saturation of the air at any dry-bulb temperature.

<u>Resistance (Thermal-R-Value)</u>	Tendency of a material to retard heat flow.
<u>Retrofitting</u>	Installation of a solar energy system on an existing building.
<u>Risers</u>	Pipes or conduits which transport the working fluid vertically (as up the surface of the absorber plate).
<u>Rock Storage</u>	A bin, pit, or other container filled with rock to act as a heat reservoir for an air-type solar energy system.
<u>Seasonal Efficiency</u>	Collector efficiency averaged over an entire heating season.
<u>Selective Surface</u>	A special coating applied to solar collectors to give a surface that will absorb solar radiation and suppress infrared (heat) radiation.
<u>Shading Coefficient</u>	Ratio of solar radiation passing through a specific glazing system to the solar radiation passing through a single layer of double strength glass.
<u>Solar Cell</u>	A device, often made of silicon, that converts sunlight directly into energy. Also referred to as a photovoltaic cell.
<u>Solar Constant</u>	Amount of solar radiation per minute on a surface normal to the sun's rays beyond the Earth's atmosphere at the average earth-sun distance. This is just under 2 Langleys per minute.
<u>Solar Cooker</u>	Device such as a reflector or oven for cooking with sun heat.
<u>Solar Furnace</u>	A device using mirror reflectors or lenses to produce very high temperatures at a focal point or "hot spot." Small ordinary furnaces generate temperatures as high as 2000°F; the largest can reach over 5600°F.
<u>Solarimeter</u>	A simple solar radiation measuring instrument using solar cells.
<u>Solar Pond</u>	A special type of horizontal flat-plate collector in which polymeric materials are generally used to replace metal and glass in conventional flat-plate collectors. The basic design consists of a plastic water bag with a black bottom and transparent top.

Solar Pump — A device using solar energy to run a steam engine or electric motor to do useful work.

Solar Still — Equipment using the sun's heat to distill water. Used in desalting and purification of sea water.

Solar Time — A time system in which the sun is at its highest point in the sky at noon.

Specific Heat — Process of heating a vapor after it has been completely boiled from the liquid to the vapor state.

Steam — Water in the vapor phase.

Sun Chart of Sun Path (Diagram) — See Sky Chart in the Solar Radiation Glossary at the end of the Data section.

Superheat — Heating a liquid above its boiling without converting it to vapor. (Due to unusual low-pressure conditions.)

Thermal Capacity — Quantity of heat required to warm a collector to its operating temperature.

Thermal Cement — A material which can be used to make metal-to-metal seals that have both high mechanical strength and good thermal conductivity.

Thermal Mass (Thermal Inertia) — Heat storage capacity of a building; the tendency of a building with a large amount of materials having high specific heats to fluctuate in temperature very slowly, if at all.

Thermosiphoning — See Convection, Natural.

Trickle-Type Collector — System whereby liquid flows down open channels in black corrugated sheet-metal absorbers.

Ultraviolet Radiation — Electromagnetic radiation having wavelengths shorter than visible light but longer than x-rays.

Wet-Bulb Temperature — The lowest temperature recorded by an ordinary thermometer (whose bulb is wrapped in a wet wick with water) when the thermometer is placed in a moving current of air.

COMPUTER PROGRAMS FOR SYSTEM OPTIMIZATION

COMPUTER PROGRAMS FOR SYSTEM OPTIMIZATION

SUMMARY

Collector area is the most important factor in the performance of solar energy systems. Its relationship to system performance can be determined by two general types of computational procedures: sophisticated computer simulations and simplified methods.

Sophisticated computer simulations are expensive to use, but they yield realistic results. They optimize the system by determining the collector area that will minimize cost. Two such computer procedures are available to the user: TRNSYS and Cal-ERDA.

TRNSYS is best suited for simulating multicomponent systems and is adaptable to a wide variety of computers. It offers several options for handling heating and cooling loads, whether general or detailed. It can also accommodate more than 100 different types of building construction. TRNSYS requires meteorological data supplied by the user for the place and period of interest.

Cal-ERDA, in simulating system performance, use four programs. One calculates a building's hourly heating and cooling loads for the year, based on each thermally unique space in the building. A second program simulates equipment operation for distributing and controlling heating and cooling. A third program simulates the operation of the energy conversion plant. The remaining computer program calculates life-cycle costs of alternative designs of the solar energy system.

Users interested in small buildings of standard design can turn to simplified methods for determining the relationship between collector area and system performance . Such methods predict average (long-term) performance of a given solar energy system. The best known, perhaps, is the "f-chart" method - a basic procedure for predicting the performance of a liquid system and an air system. The heat-loading fraction (f) provided by a given solar collector is determined from a performance chart.

A computer program version of the "f-chart" is also available to the user for predicting life-cycle costs and finding out the appropriate collector area that will minimize costs. In addition, work sheets and

step-by-step instructions provide the user with a virtually self-contained method of predicting savings in fuel costs and in solar energy systems for heating buildings and domestic hot water. Intermediate, minimum property standards (safety aspects, corrosion, material lifetimes, seismic and hail loads, etc.) for the latter type of systems can be calculated in a step-by-step approach.

A similar, but generally easier, approach is the LASL method, which uses an "x-factor," including built-in parameters of a "standard" solar system, to relate the heating load fraction (supplied by solar energy) to the collector area. However, with some exceptions, the LASL method cannot be used to examine system performance.

SOLCOST, a batch-process computer program, differs from the "f-chart" and LASL methods: it performs a detailed simulation for an "average day" for each month. Although not fully developed, SOLCOST yields an accurate solution for reasonable computer costs.

If you are unable to decide whether solar energy makes sense to you, you can use RSVP, a computer program that estimates the economics of a solar energy system for domestic water heating in either new or existing homes. Computer output is in the form of a personal summary report.

Synopses of the "f-chart," LASL, and SOLCOST methods are tabulated in this section.

INTRODUCTION

The performance of a solar energy system is defined as the fraction of the building's heating or cooling load that is supplied by solar energy over the long term. It must be related to the climatic conditions at the site, the end use of the energy, and the design and control strategy of the specific solar system being considered.

The most important factor in system performance (for a given load and reasonable tilt angle of the collector) is the area of the collector. Several computational methods have been developed for determining the relationship between performance and collector area, most of which allow the user to investigate the performance for different tilt angles, types of collectors, storage-tank volumes, etc. Many provide a formula to calculate costs (e.g. life-cycle costs) for a given performance.

There are two general types of procedures: sophisticated computer simulations which use hourly solar and weather data and require detailed specification of the system (collectors, storage tank, building construction, etc.); and simplified methods which demand less detail and use monthly totals (or averages) of solar and weather data.

DETAILED SIMULATION METHODS

The detailed computer-simulation methods yield more reliable results but require considerable effort and expense. Their use may be warranted for large complex buildings, for many buildings of a similar design or location, or for novel systems not treatable via the simplified methods. Computer-based methods will "optimize" the system by determining the collector area that will minimize costs. Two such methods are described below.

TRNSYS

This computer program is geared to performance calculations of multicomponent systems; costs are not treated. It was developed by the University of Wisconsin with NSF and ERDA support and has been used extensively for several years. Written in standard FORTRAN IV (with a few minor exceptions), it has been run on a wide variety of machines with very little or no modification. No serious problems should be anticipated in setting up the program, provided core requirements are met.

TRNSYS has several options in the way heating and cooling loads can be handled. If a detailed load calculation is not required, one should use the simple "degree-hour" load model. When a more exact determination of the dynamics of a particular building is required, transfer function "walls," "roofs," and "rooms" can be assembled to model almost any structure; ASHRAE provides transfer function coefficients for over a hundred different construction types. Finally, TRNSYS can accept hourly loads generated by even more sophisticated load programs, such as those available from NBS.

The program requires card image records of meteorological data at short and regular intervals (e.g. hourly), which the user must supply for the place and period of interest.

The basic method is described in the book: J. A. Duffie and W. A. Beckman, *Solar Energy Thermal Processes* (Wiley, New York, 1974). The best reference to the program is the operating manual: S. A. Klein, et al., *TRNSYS, A Transient Simulation Program*, Engineering Experiment Station Report #38; it is available from:

TRNSYS Coordinator
Solar Energy Laboratory
1303 Engineering Research Laboratory
University of Wisconsin
1500 Johnson Drive
Madison, WI 53706

Cal-ERDA

This program features a special language that facilitates the user's description of the building being analyzed. It was developed for application to energy conservation strategies by a collaboration of the Lawrence Berkeley Laboratory, Consultants Computation Bureau, Argonne National Laboratory, Los Alamos Scientific Laboratory, National Bureau of Standards, and Construction Engineering Research Laboratory; however, active solar systems can also be treated.

The LOADS program calculates the hourly heating and cooling loads of the building throughout the entire year, using external temperature, wind speed and direction, pressure, and solar radiation data. These loads are calculated for each thermally unique space within the building. ASHRAE algorithms are used throughout.

The SYSTEMS program simulates the operation of the equipment and systems that distribute and control the cooling and heating. This simulation is done on an hour-by-hour basis in conjunction with the output of the LOADS program. The results give the final indoor temperatures and reflect the actual loads that must be satisfied by the plant.

The PLANT program simulates the operation of the energy conversion plant (i.e., boiler, chiller, public utility, etc.). It uses the hour-by-hour output of SYSTEMS to determine plant capacity required to meet actual building loads.

The ECONOMICS program calculates the life-cycle cost for each alternative design examined. The output is in terms of first cost, fuel cost, and operation and maintenance cost throughout the expected life of the building.

The best source of information is the *Cal-ERDA User's Manual* which can be obtained from:

Robert Graven
Building 362
Argonne National Laboratory
Argonne, IL 60439

For the computer program, contact:

Frederick Winkelmann
Lawrence Berkeley Laboratory
University of California
Berkeley, CA 94720

SIMPLIFIED METHODS

By specifying the details of the solar energy system and the end use of the energy, simplified design procedures have been set up. These methods are usually intended for small buildings of standard design — such as a home with roof-mounted collectors, water as the working fluid, a storage tank, and a forced-air heating system.

Given monthly solar and weather data that have been averaged over several years (sometimes called "long-term" or "historic" data), one can use the simplified methods to predict the average (long-term) performance of a solar energy system. Even if these methods were exact, the actual performance for a given month or year would usually differ from the prediction; and if solar and weather data for a short period of time are used, the long-term prediction will usually be in error.

F-Chart Method (University of Wisconsin)

The f-chart method can be used to predict the performance of two "standard" systems for space and domestic water heating: a liquid system and an air system. The heart of the method is a performance chart (the f-chart) that allows the user to determine the fraction f of the heating load provided by solar by a given solar collector. The f-chart is applied after the user has specified the space heating and domestic hot water load, a few parameters of the solar system (such as collector efficiency), the monthly total solar radiation, and the monthly mean temperature and heating degree-days.

The f-chart method was developed from detailed considerations of solar energy systems for buildings by Klein, Beckman, and Duffie; the actual parameters of the chart were generated empirically from some 300 detailed simulations based on TRNSYS. The basic method and its application to liquid systems are described in: S. A. Klein, W. A. Beckman, and J. A. Duffie, "A Design Procedure for Solar Heating Systems," *Solar Energy*, Vol. 18, No. 2, p.93, 1976. This paper includes a prescription for calculating the "annual dollar savings" of the solar system as compared with a conventional system. The prescription also explains how to determine the collector area that maximizes the savings. The extension of the method to air systems is given in: S. A. Klein, W. A.

Beckman, and J. A. Duffie, "A Design Procedure for Solar Air Heating Systems," in the *Proceedings of the International Solar Energy Society Joint Conference*, Vol. 4, p.271, 1976.

The application of an f-chart using these papers is not completely straightforward and requires a knowledge of solar energy fundamentals and a good grasp of mathematics. Most users will find it more convenient to use one of the following approaches for applying the basic method.

FCHART. This is an interactive computer program version of the f-chart method of the original papers. The program is accompanied by some descriptive material but a knowledge of solar energy fundamentals is still helpful. However, FCHART handles all the calculations and provides pre-set (default) values for all the various input parameters. The user needs only to change those parameters that are different for his own system. The solar and weather data are built into the program for 100 locations (7 in California). FCHART will perform a life-cycle cost analysis and, at the option of the user, determine the collector area that minimizes the costs. The *University of Wisconsin Interactive Solar Heating Design Program* can be obtained from:

Shirley Quamme (phone 608/263-1586)
or
Patrick Hughes (phone 608/263-5626)
Solar Energy Laboratory
1303 Engineering Research Building
University of Wisconsin
1500 Johnson Drive
Madison, WI 53706

Solar heating of buildings and domestic hot water. This approach to f-chart is nearly self-contained in that, for many applications, all the necessary information (except weather data) is in the report. Cost methods are provided to estimate the "dollar value of fuel saved per year," "the present worth of 15 years of fuel savings," and the cost of the solar energy system. Worksheets and step-by-step instructions guide the user in preparing the input to the performance and cost analyses. Two complete examples are given: one for a residence and the other for a dental dispensary.

Although weather data are not provided, the report does contain tables of solar radiation on a horizontal surface for 52 locations

(7 in California), as well as descriptive material and numerical information on many aspects of solar energy systems including: types of flat plate collectors, collector heat losses, selective surfaces, storage methods, maintenance, temperature rise through collectors, and architectural considerations.

This approach is described in E. J. Beck, Jr. and R. L. Field, *Solar Heating of Buildings and Domestic Hot Water*, Technical Report R835, sponsored by Naval Facilities Engineering Command. The original version, which treated only liquid systems, is now out of print. A revised version which includes air systems may be ordered as a Xerox copy from NTIS (#AO-21862). An improved version is also available for $5.95 (plus 36¢ tax) from:

SOLPUB Company
1831 Weston Circle
Camarillo, CA 93010

Intermediate minimum property standards for solar heating and domestic hot water systems. This document gives a step-by-step approach to using f-chart. The space-heating step requires reference to another HUD report; otherwise, the report is largely self-contained. A complete example for a residence is included. There is no cost analysis. Solar data and mean temperatures (but not degree-days) are given for 80 locations (6 in California). Although the language is "government-ese," there is a wealth of descriptive and numerical information. Topics include: safety considerations, corrosion, material lifetimes, seismic and hail loads, condensation in collectors, absorptive coatings, storage methods, ducts and pipes, heat transfer fluids, and sealing compounds.

The document was prepared by the National Bureau of Standards for HUD. It is available as: *Intermediate Minimum Property Standards for Solar Heating and Domestic Hot Water Systems, NBSIR 76-1059*, from:

Solar Energy Program
Office of Housing and Building Technology
Center for Building Technology, IAT
National Bureau of Standards
Washington, D.C. 20234

Department of Housing and Urban Development
Office of Policy Development and Research
Division of Energy, Building Technology and Standards
Washington, D.C. 20410

		Reference
Computation level:	Hand calculator with trigonometric functions.	(a)
	Interactive computer program. Hand calculator.	(b,c,d)
Units:	Metric. Engineering. Either system.	(a,c,d,b)
Solar system types:	Liquid flat-plate collector, heat exchanger to storage tank, w/wo domestic hot water; or	(a,b,c,d)
	air flat-plate collector, pebble bed storage, w/wo domestic hot water.	(a,b,c,d)
Solar data needed:	Monthly total radiation on tilted surface; or	(a,c,d)
	monthly total radiation on horizontal surface and tilt calculation.	(a,b,c,d)
Tilt calculation:	Equation for any tilt angle, south orientation.	(a)
	Built-in for any tilt angle, south orientation.	(b)
	Graph for latitude +10°, south orientation.	(c)
	Tables for latitude, latitude ±15°, vertical, south orientation.	(d)
Weather data needed:	Monthly average ambient temperature and degree days.	(a,b,c,d)
System parameters:*	Slope and intercept of collector efficiency curve.	(a,b,c,d)
	Effectiveness of collector-tank heat exchanger.	(a,b,c,d)
	Various heat capacity flow rates.	(a,b,c,d)
	Storage tank volume per unit collector area.	(a,b,c,d)
Space heating input:	Building load in energy units per month; or	(a,b,c,d)
	constant characterizing of the load in units of energy per degree day.	(a,b,c,d)
Hot water input:	Domestic hot water load in energy units; or	(a,b,c,d)
	constant characterizing of the demand, water main temperature, minimum acceptable temperature.	(a,b,c,d)
Cost analysis:	"Annual Dollar Savings" based on $\$/m^2$ of collector (installed), fixed costs, \$/unit capacity storage, annual charge on capital investment, auxiliary fuel costs.	(a)
	"Life-Cycle" based on collector area dependent costs, fixed costs, down payment, interest, term of mortgage, discount rate, insurance, maintenance, present cost of fuel, and rate of increase.	(b)
	"Dollar Value of Fuel Saved" based on cost of fuel and furnace efficiency.	(c)
	"Present Worth of 15 Years of Fuel Saved" based on inflation rate and discount rate (estimates provided).	(c)
	"Cost of Solar System" based on cost/ft^2 of collector, storage, auxiliary heating installed, miscellaneous, and contractor fees.	(c)

(a) Original papers of Klein, Beckman, and Duffie (1976).
(b) Interactive computer program, FCHART (1976).
(c) *Solar Heating of Buildings and Domestic Hot Water*, Beck and Field (1976).
(d) *Intermediate Minimum Property Standards for Solar Heating ...*, NBS/HUD (1976).

* These parameters can often be ignored; they are used in a correction factor that is 1.0 for systems without heat exchangers and very close to 1.0 for efficient systems with exchangers.

LASL Method (Los Alamos Scientific Laboratory)

Basically, the LASL method is similar to f-chart. An "x-factor" is defined that relates the fraction of the heating load supplied by solar to the collector area. The parameters of the x-factor were determined empirically by a detailed simulation analysis of 25 U.S. and Canadian cities. The factor applies to air or liquid heating systems using flat-plate collectors.

In contrast to f-chart, the x-factor has the parameters of a "standard" solar system built in. Thus,the LASL method is generally easier to apply than f-chart; but (with some exceptions given below) it cannot be used to examine the performance, which depends on collector efficiency, tilt angle, and storage capacity per unit collector area. Another difference is that the LASL method calculates the fraction of the *annual* load supplied by solar, while f-chart can be used to obtain either the *monthly or the annual* fraction.

The original approach and a step-by-step explanation of its application can be found in J. D. Balcomb and J. C. Hedstron, "A Simplified Method for Calculating Required Solar Collector Array Size for Space Heating," *Proceedings of the International Solar Energy Society Joint Conference*, Vol. 4, p.281, 1976. This report utilizes solar and weather data for 85 cities (7 in California). The data themselves are not given but rather have been used (along with the x-factor) to calculate a quantity called "LC." Once the user has specified the heating load in Btu's per degree-day, the tabulated values of LC can be used to calculate in a very simple way the required collector area for 25%, 50%, and 75% of the annual load to be supplied by solar. A cost analysis is not included.

Although the knowledgeable solar energy user should not have any difficulty using either LC or the x-factor as presented in the paper, the following approach is much more informative and somewhat more versatile.

ERDA's Pacific regional solar heating handbook. The step-by-step approach used in this document is essentially the same as in the original paper. LC, now called the Load-Collector ratio, is tabulated for the 18 cities (out of the original 35) that are in the Pacific region. Six of these cities, including Santa Maria and Fresno, could supply hourly data available and are given special attention. The Load-Collector ratios are calculated from detailed simulations rather than from the x-factor. Graphs show how the solar fraction depends on many design considerations such as collector type (single or double glazing), orientation and tilt, and storage capacity. Strictly speaking, the graphs apply only to the six special cities; however, they can be used for most locations to judge the significance of variations in design.

A "cost of solar heat" analysis is included that computes the cost per million Btu of the energy supplied by solar. A nomograph enables one to estimate the break-even point for solar (in $\$/ft^2$ of collector) for various assumptions about future fuel costs. The handbook also contains descriptive material on heating systems, and has short sections on domestic hot water heating, swimming pool heating, and passive systems.

A copy of ERDA's *Pacific Regional Solar Heating Handbook*, prepared for ERDA (now DOE) San Francisco Operations Office by the Los Alamos Scientific Laboratory, may be obtained for $3.25 by requesting Stock #060-000-0024-7 from the Superintendent of Documents, Washington, D.C. 20402. It is also available at the bookstores in the Federal buildings in Los Angeles.

Synopsis of the LASL Method

		Reference
Computation level:	Hand calculator for LC (Load-Collector) ratio.	(a,b)
	Hand calculator with trigonometric functions for x-factor.	(a,b)
Units:	Engineering	
Solar system types:	Liquid flat-plate collector, heat exchanger to storage tank, w/wo domestic hot water, forced air heat; or	(a,b)
	air flat-plate collector, rock bed storage, w/wo domestic hot water, forced air heat.	(a,b)
Solar data needed:	Monthly total radiation on tilted surface; or	(a,b)
	monthly total radiation on horizontal surface and tilt calculation.	(a,b)
Tilt calculation:	Equation for latitude +10°, south orientation.	(a,b)
Weather data needed:	Monthly degree-days.	(a,b)
System parameters:	For basic method (any location); none.	(a,b)
	For six special cities with hourly solar data, graphs show liquid-system performance dependence on: type of collector (single vs. double glazing, selective surface); collector orientation, tilt, cover glass transmissivity, surface absorptance and emittance, coolant flow rate, heat transfer coefficient, back insulation, and heat capacity; distribution pipe insulation, heat exchanger effectiveness; thermal storage heat capacity and heat losses; design water temperature.	(b)
	For air systems, graphs show dependence on: collector heat-transfer effectiveness, air flow rate, thermal storage capacity, and rock-bed temperature distribution.	
Space heating input:	Building load in Btu per degree-day.	(a,b)
Hot water input:	Estimated load.	(a,b)
Cost analysis:	"Cost of Solar Heat" in dollars per million Btu's based on: system installation cost/ft^2; annual capital fixed charge rate; and annual operating, maintenance, and repair cost.	(b)
	"Break-Even Point" in dollars/ft^2 of collector based on: alternate energy cost and forecasted annual increase; and useful solar energy delivered per year per ft^2 of collector.	(b)

(a) Original paper by Balcomb and Hedstrom (1976).
(b) *ERDA's Pacific Regional Solar Heating Handbook*, ERDA-SAN/LASL (1976).

SOLCOST (Martin Marietta Method)

SOLCOST is a batch-process computer program developed for ERDA by Martin Marietta in Denver. It differs from f-chart and the LASL method in that it performs a detailed simulation for an "average day" for each month. According to its authors, "this approach provides an accurate solution while keeping computer costs to a reasonable value." SOLCOST, when fully developed, will be able to handle hot-water systems, absorption-cycle air conditioners, solar-assisted heat pumps, and some passive features, as well as air and liquid space-heating systems. A variety of methods, ranging from monthly fuel bills to transient simulations, can be used to specify the load. Collectors may be flat plates, evacuated tubes, or one- or two-axis concentrators.

The weather data required are minimum and maximum temperatures, heating degree-days, and (for cooling only) minimum and maximum relative humidity; the solar data needed are percent possible sunshine (PP) and "clearness number." The program uses a recipe to compute the solar radiation for a clear day (Q_{clear}) and for a cloudy day (Q_{cloud}). It then forms the sum:

$$Q_{average\ day} = PP \cdot Q_{clear} + (1 - PP) \cdot Q_{cloud} .$$

The only location-dependent ingredient in Q_{clear} or Q_{cloud} is the clearness number which is related to the average atmospheric transmission on clear days. This number is generally not available experimentally; as a default, the program uses the Clearness Number Contour Map of Threlkeld and Jordan, found in Chapter 59 of the ASHRAE Applications Handbook (1974). The weather and solar data are built into the program for 124 cities (7 in California). A life-cycle cost analysis can be performed relative to a reference (conventional) system. At the user's option, the program will compute the collector area that minimizes this cost.

A technical description of the method is given in: M. Connolly et al., "Solar Heating and Cooling Computer Analysis — A Simplified Sizing Design Method for Non-Thermal Specialists," *Proceedings of the International Solar Energy Society Joint Conference*, Vol. 10, p.220,

1976. However, application of the method requires the computer program and the user's manual: *SOLCOST, Solar Energy Design Program for Non-Thermal Specialists, Part I, User's Guide*, which is available from:

Dr. C. Byron Winn
P.O. Box 1914
Fort Collins, CO 80522
(phone, 303/491-7683)

Plans call for the program to be available on the CYBERNET and GEIS timesharing networks.

Synopsis of SOLCOST

Computational level:	Batch process computer program.
Units:	Engineering
Solar system types:	Space and domestic hot-water heating systems with air or liquid collectors; or absorption-cycle air conditioning; or solar-assisted heat pumps; or systems with some passive features.
Collector types:	Flat-plate, evacuated-tube, one- or two-axis trackers.
Solar data needed:	Percent possible sunshine and clearness number (default value of clearness number supplied by program from contour map).
Tilt calculation:	Built in for any tilt and orientation.
Weather data needed:	Minimum/maximum temperature. Heating degree-days. Minimum/maximum relative humidity (solar cooling only).
System parameters:	Collector efficiency parameters from efficiency curve. Storage capacity per collector area (liquid systems only). Fuel type, efficiency of auxiliary heat source. COP for solar-assisted heat pump (heat pump application only). Various flags to specify collector type.
Heat/cool input:	Building load in energy units; or monthly fuel bills and description of existing HVAC system (retrofit only); or building dimensions for buildings meeting ASHRAE standard 90-75; or UA (u-factor) in Btu/hr °F; or detailed specification of building for steady-state calculation; or detailed specification for transient calculation (recommended by the authors for buildings with passive features).
Hot water input:	Hot-water load in energy units.
Cost analysis:	"Life-cycle" relative to a reference system. The following types of information are used: Reference system: initial installed cost and maintenance. Solar system: fixed cost, installed cost per unit collector area, liquid storage installed cost per gallon, maintenance cost. Finance/tax data: scenario indicator (residence, business, nonprofit), loan interest rate, loan term, loan down payment, insurance, property tax rate, income tax rate, various depreciation factors for businesses. Fuel costs: dollars per unit; escalation rate; heat content per unit for any natural gas, electricity, fuel oil, LPG, coal.

Reference: *SOLCOST User's Guide*, Martin Marietta (1977).

RSVP (Residential Solar Viability Program)

The HUD Residential Solar Viability Program (RSVP) is a computer program for estimating the economics of a solar energy system for domestic water heating in either new or existing homes. Based on data you supply on a standard form (concerning building and solar system, back-up system, taxes, and financing), RSVP will provide economic estimates to help you decide whether solar makes sense for you. This information is presented in the form of a personal summary report.

The economics of a solar energy system will differ depending on whether the system is purchased in cash or financed. If you indicate that a solar energy system will be purchased in cash, your personal summary report will contain the following information for a range of different solar system sizes:

- Collector Area. The solar system size expressed in square feet of collector area.
- Annual Percent Solar. The estimated percent of your annual domestic water heating requirements which will be supplied by the solar energy system.
- Initial Cost of System. An estimate of the total installed cost for the solar energy system.
- Energy Savings 1st Year ($). The estimated energy savings in dollars to be expected in the first year of solar system operation. This amount will increase in future years as energy prices escalate.
- Years to Recover System Cost. The number of years until the total cumulative savings from the solar energy system equals the estimated initial purchase price.
- Net Life-Cycle Value Over 20 Years: The estimated net total of savings less costs attributable to the solar energy system over a twenty-year period. Savings are based on projected energy savings. Costs include initial installation, maintenance and real estate taxes, if applicable.

If you indicate that a solar energy system will be financed, your summary report will contain all of the above items except that Net Life

Cycle Value Over 20 Years will also include estimates of income tax savings and financing costs, and Years to Recover System Cost will be replaced by the following two estimates:

- Loan Costs 1st Year. The total of principal and interest attributable to the financing of the solar energy system to be repaid during the first year. In most cases, this will remain the same for each year of the loan term.
- Years for Annual Savings to Exceed Annual Costs. The number of years until the value of energy and income tax deduction savings from the solar energy system during the year equals or exceeds the loan and other costs during the year.

For both cases,(cash purchase or financing),the summary report will separately indicate the system size which represents the best estimated value over a twenty-year period.

For more information, contact:

National Solar Heating and Cooling Information Center
P.O. Box 1607
Rockville, MD 20850
(800) 523-2929

LOCAL SOLAR AND WEATHER DATA

LOCAL SOLAR AND WEATHER DATA

SUMMARY

Full realization of the potential for solar energy applications requires adequate characterization of the solar resource. Outside the earth's atmosphere at the mean distance of the earth from the sun, the amount of solar radiation received per unit time and unit area on a surface normal to the sun is called the "solar constant." The presently accepted value of this constant is 1370 watts/meter^2, or 434 Btu/ft^2•hr. Small variations in this amount that result from yearly changes in the earth-sun distance can be readily calculated to within 2%

The solar flux reaching the earth's surface is considerably less than the solar constant, however, because the sun's radiation is both scattered and absorbed by the earth's atmosphere. Thus the solar energy actually available to us depends on various atmospheric and weather variables, including cloud cover and the amount of water vapor, dust particles, ozone, and other molecules present in the air.

The amount of usable solar energy at a particular site is best determined by long-term collection of solar and weather data at that site or at a nearby location. But in most cases, site-specific measurements have never been made (and are not even practical). Therefore, designers of solar systems--and the users of this Handbook--should select the solar and weather stations that are situated closest to the location of interest, and use the data therefrom. However, if the nearest station is separated from the user's location by a mountain range, it is better to use data from a more distant station in the same air basin.

The data tables in this Handbook, which cover the Southern California region as well as present information allows, are taken from the "California Solar Data Manual," a document produced by the Solar Energy Group of the Lawrence Berkeley Laboratory in Berkeley, California. The work that resulted in the manual involved a survey and evaluation of all solar data records in California and a compilation of those data judged to be of acceptable quality.

Variation of Solar Radiation Intensity

As the tables indicate, the intensity of solar radiation at a given location on the earth's surface will vary from hour to hour, day to day, month to month, and year to year. Because of these variations, solar collector sizes for a particular building or plant system cannot be determined by simply choosing solar radiation data for a particular hour, day, month, or even a year. Collector size and solar system design must be based on long-term averages of solar radiation data and weather conditions, particularly ambient air temperature. The long-term average, monthly, total solar radiation falling on a horizontal surface for each month of the year at different stations in Southern California is listed in the tables. Also listed are fractions of the maximum solar radiation possible at a station (if there were no clouds to reduce the sunshine), average daily air temperatures for each month, and the average heating degree days.

Solar energy striking a horizontal surface at any location on earth, when averaged over a month, varies from month to month. This variation is caused by both the seasonal changes in weather, which affect the cloud cover, and the changing angular relationship between the sun and the horizontal surface. In the winter, the sun is lower in the sky than in the summer, and the resultant angle between the sun and a horizontal surface reduces the portion of radiation intercepted by the surface. The solar radiation on a horizontal surface varies from day to day because of clouds, dust, and atmospheric pollution. Daily variations are important because they affect the quantity of heat that a solar system can deliver to the building or plant in a given day. An engineer can do little to change the deliverable heat quantity, however, because the size of a solar system on a building or plant is fixed.

Hourly variations in available solar energy at a given location are caused by the earth rotating about its own axis and about the sun. In the early morning and late afternoon, the sun is at a very low angle and the solar rays pass through a larger thickness of atmosphere than at noon. This reduces the amount of solar energy that reaches the earth's atmosphere. Peak radiation intensity occurs at noon.

Tilt Angle

It is advantageous to tilt a solar collector from the horizontal because more solar radiation can be intercepted by a given collector area. As the season changes, the most effective tilt angle changes. The optimum, fixed tilt 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 cooling purposes, maximum collection is desired from June to October. For a combined heating and cooling system a compromise needs to be made for winter and summer seasons.

The maximum intensity of direct radiation occurs at noon and its distribution is symmetrical. Consequently, the plane of collectors at any tilt angle should be oriented to fall directly south. If this is not possible or desirable because of the building design or other considerations, variations in collector orientation from due south can be tolerated without seriously reducing the total solar energy collected during the day.

Effect of Collector Orientation

The solar radiation striking a unit area of collector for various collector orientations and collector tilt angles (slopes) at various sites in Southern California is listed in the tables. To illustrate the effect of collector orientation let us use the table for China Lake, Inyokern. The average monthly total radiation in January, falling on a collector tilted 45° from the horizontal with the collector plane oriented due south, is 53,000 Btu per square foot. If the collector faces 45° east or west from due south, the average monthly total radiation is 41,000 Btu per square foot--a 17% reduction of incident solar radiation. With this orientation, it may be desirable to make up the reduction by additional collector area.

Use of Degree-Day Values

The heat requirements of a particular building depend most heavily on atmospheric temperature. Data on hourly, daily, average monthly, and other temperature variations are regularly recorded by the U.S. Weather

Service at several Southern California stations. The average atmospheric temperatures or degree-day values in the tables represent seasonal requirements and are used in sizing solar heating systems.

The "degree days of heating" in a particular location is a quantity that is proportional to the total heat required by a particular building, during a designated interval, at a particular location. It is based on a time-weighted average of the temperature difference between inside and outside the building, whenever the daily atmospheric temperature is below 65°F. The degree days in a particular month, for example, are computed by substracting the daily mean temperature (one-half the sum of the maximum and minimum hourly temperature readings during a 24-hour period from 65°) and totaling these 30 or 31 numbers.

If the mean temperature on a January day is 25°, 65° - 25° = 40 degree-days of heating are computed. For the month, possibly 90 degree-days may result, and for the year, perhaps 5000. The tables show values of monthly average atmospheric temperature and monthly degree-day totals for each station in this data collection; they also list additional heating degree days.

Values in the tables are given in engineering units; conversion to SI (metric) units can be accomplished by using the conversion tables that directly follow the solar and weather data. Unfamiliar terms are defined in the Solar Radiation Glossary.

More information on solar and weather data can be found in the following documents:

(1) Monthly Normals of Temperature, Precipitation, and Heating and Cooling Degree Days 1941-70--California Climatography of the United States No. 81 (by state) U.S. Department of Commerce, NOAA

which is available from:

National Climatic Center
Federal Building
Asheville, North Carolina
$0.25 (check/money order made payable to "Commerce, NOAA"

(2) World Distribution of Solar Radiation
College of Engineering, The University of Wisconsin
Engineering Experiment Station,
Report No. 21, by George O. G. Lof, John A. Duffie, Clayton O. Smith

which is available from:

Solar Energy Laboratory
The University of Wisconsin
Madison, Wisconsin 53706

(3) California Solar Data Manual
Solar Energy Group
Lawrence Berkeley Laboratory
Berkeley, California 94720

which should be available early in 1978.

(4) Aerospace Corp. 1974. Solar thermal conversion mission analysis: Vol. III Southwestern U.S. Insolation Climatology. Aerospace Corp. Report ATR-74 (7417-16-)-1.

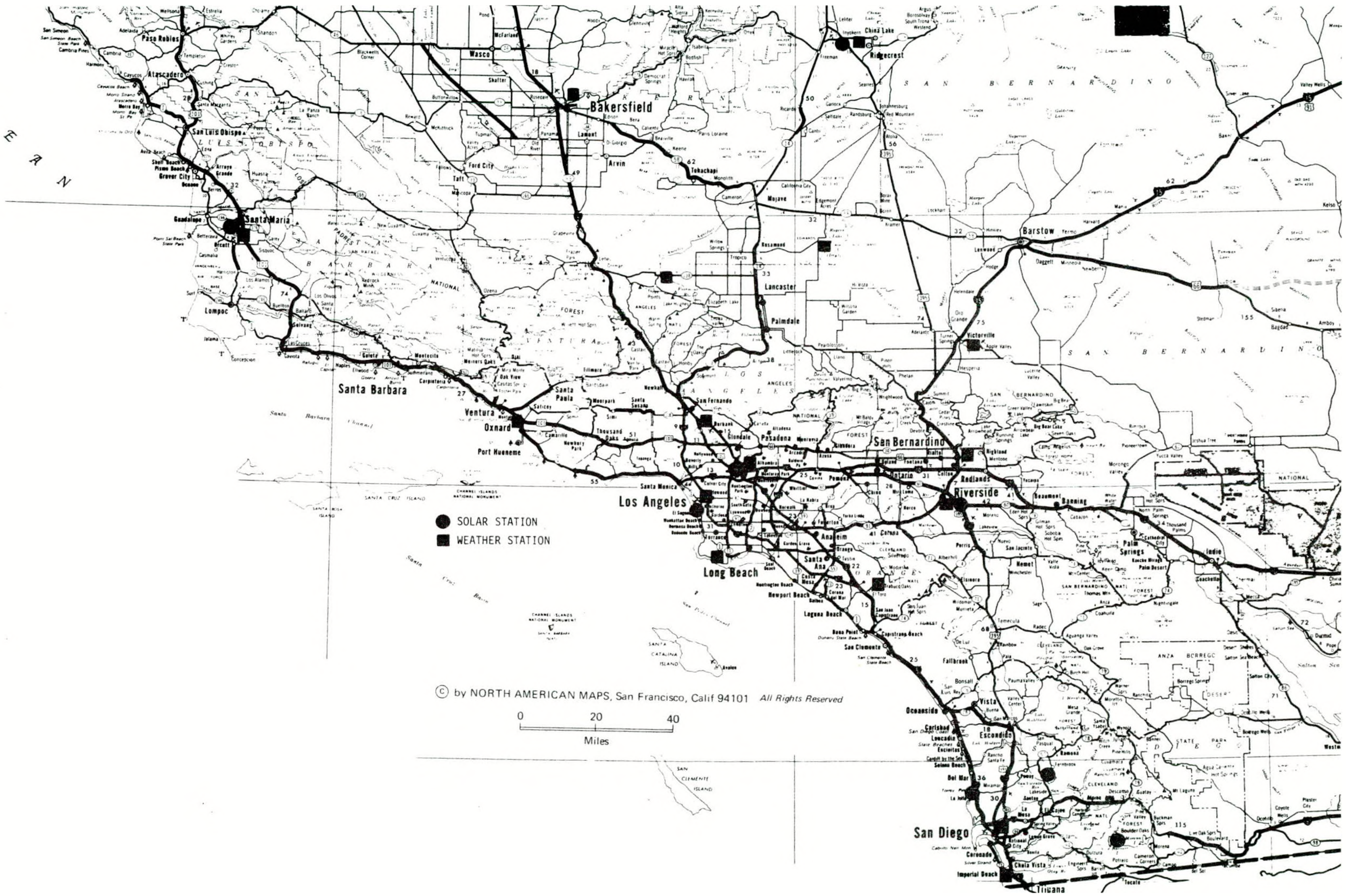
MAP OF DATA STATIONS

To help you choose the most suitable data, the accompanying map shows the locations of all the selected data-collecting stations:

- ● is a solar station
- ■ is a weather station

Following the map, data are presented separately for each solar station and each weather station. The stations are arranged by latitude, from north to south.

8 (Solar & Weather)



CHINA LAKE/INYOKERN

MONTHLY SOLAR RADIATION DATA FOR CHINA LAKE/INYOKERN

Latitude: 35.65° Longitude: 117.67° Elevation: 2186'	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
SOLAR RADIATION (kWh/m^2 per month)													
horizontal surface	98	115	177	213	246	249	243	224	186	146	106	91	2094
direct beam (normal incidence)	182	181	249	272	297	297	285	272	248	218	190	179	2570
SOLAR RADIATION (KBtu/ft^2 per month)													
horizontal surface	31	36	56	68	78	79	77	71	59	46	34	29	664
direct beam (normal incidence)	58	57	79	86	94	94	90	86	78	69	60	57	909
PERCENT OF POSSIBLE SUNSHINE*	n/a												
MEAN CLOUD COVER (in tenths)*	4	4	3	3	3	1	2	1	1	2	3	3	3
FRACTION OF EXTRATERRESTRIAL RADIATION (K_T)	.64	.65	.70	.72	.72	.73	.70	.70	.70	.67	.66	.64	.69

AVERAGE MONTHLY TOTAL RADIATION ON A TILTED SURFACE FOR INYOKERN (CALCULATED VALUES)

UNITS ARE KBTU/SQFT PER MONTH

DIRECT BEAM + DIFFUSE (GROUND REFLECTION EXCLUDED)

SURFACE ORIENT-ATION	ANGLE OF TILT (DEGREES FROM HOR-IZONTAL)	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
SOUTH	15	41	45	64	71	77	77	76	73	65	55	43	39	724
SOUTH	30	48	50	67	70	73	70	70	70	66	60	51	47	740
SOUTH	45	53	52	66	65	63	59	60	63	64	61	55	52	713
SOUTH	60	54	51	62	55	51	46	47	52	57	59	55	53	643
SOUTH	75	52	47	53	43	36	31	32	39	47	53	52	52	536
SOUTH	90	46	40	41	28	20	15	17	24	35	43	46	47	402
SE, SW	15	38	42	61	69	77	77	76	72	63	52	40	36	702
SE, SW	30	42	45	63	68	73	71	71	69	63	55	45	41	705
SE, SW	45	44	45	61	63	66	63	63	63	60	54	46	43	672
SE, SW	60	44	43	56	56	56	52	53	55	54	51	45	43	607
SE, SW	75	40	39	48	46	44	40	41	44	46	45	41	40	514
SE, SW	90	35	32	38	34	31	28	29	32	35	37	35	35	402
E, W	15	30	36	55	66	76	77	75	69	58	45	33	28	649
E, W	30	29	34	52	62	71	72	70	65	54	43	32	27	612
E, W	45	27	32	48	56	64	65	63	59	50	40	29	25	558
E, W	60	25	28	42	49	56	56	55	51	44	35	27	23	491
E, W	75	21	24	36	41	46	46	45	43	37	30	23	20	413
E, W	90	17	20	29	33	36	36	35	34	29	24	19	16	327

MONTHLY SOLAR RADIATION DATA FOR SANTA MARIA

Latitude: 34.93° Longitude: 120.42° Elevation: 234'

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
SOLAR RADIATION (kWh/m^2 per month)													
horizontal surface	89	104	157	185	207	212	221	202	159	131	94	83	1844
direct beam (normal incidence)	149	149	199	211	221	225	239	225	188	178	149	148	2282
SOLAR RADIATION ($KBtu/ft^2$ per month)													
horizontal surface	28	33	50	59	66	67	70	64	50	42	30	26	585
direct beam (normal incidence)	47	47	63	67	70	71	76	71	60	56	47	47	723
PERCENT OF POSSIBLE SUNSHINE*													
MEAN CLOUD COVER (in tenths)*	5	5	5	5	5	4	3	3	4	4	4	5	4
FRACTION OF EXTRATERRESTRIAL RADIATION (K_T)	.56	.58	.62	.62	.61	.62	.64	.63	.60	.60	.57	.57	.60

Recording interval: 1952-1975

AVERAGE MONTHLY TOTAL RADIATION ON A TILTED SURFACE FOR SANTA MARIA (CALCULATED VALUES)

UNITS ARE KBTU/SQFT PER MONTH

DIRECT BEAM + DIFFUSE (GROUND REFLECTION EXCLUDED)

SURFACE ORIENT-ATION	ANGLE OF TILT (DEGREES FROM HOR-IZONTAL)	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
SOUTH	15	36	39	56	61	65	65	68	65	54	48	37	35	630
SOUTH	30	42	44	58	60	61	59	63	62	55	52	43	41	640
SOUTH	45	45	45	57	55	53	51	54	56	53	53	45	45	613
SOUTH	60	46	44	52	47	43	40	43	47	47	50	45	46	551
SOUTH	75	43	40	45	37	31	27	30	35	39	45	43	44	459
SOUTH	90	39	34	35	25	18	15	16	22	28	37	37	39	345
SE,SW	15	33	37	54	60	65	65	68	64	53	46	35	32	613
SE,SW	30	37	40	54	58	61	61	64	62	53	48	38	36	612
SE,SW	45	38	40	53	54	55	54	57	56	50	47	39	38	581
SE,SW	60	37	38	48	47	47	45	48	49	45	44	38	37	522
SE,SW	75	34	33	41	39	37	35	37	39	38	39	34	34	441
SE,SW	90	29	28	33	29	27	24	26	29	29	31	29	30	345
E,W	15	28	32	49	57	64	65	68	62	49	41	29	26	571
E,W	30	26	31	46	54	60	61	64	59	47	39	28	25	538
E,W	45	25	28	42	49	54	55	57	53	43	36	26	23	491
E,W	60	22	25	37	43	47	48	50	46	37	32	23	21	431
E,W	75	19	22	32	36	39	39	41	38	31	27	20	18	362
E,W	90	16	18	25	28	30	30	32	30	25	22	16	15	287

LOS ANGELES (Civic Center)

MONTHLY SOLAR RADIATION DATA FOR LOS ANGELES (Civic Center)

Latitude: 34.05° Longitude: 118.23° Elevation: 540'	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
SOLAR RADIATION (kWh/m^2 per month)													
horizontal surface	83	98	146	167	184	188	217	197	160	121	91	80	1732
direct beam (normal incidence)	130	130	173	177	180	184	232	215	186	151	137	134	2031
SOLAR RADIATION (KBtu/ft^2 per month)													
horizontal surface	26	31	46	53	58	60	69	62	51	38	29	25	549
direct beam (normal incidence)	41	41	55	56	57	58	74	68	59	48	44	42	644
PERCENT OF POSSIBLE SUNSHINE*	69	72	73	70	66	65	82	83	79	73	74	71	73
MEAN CLOUD COVER (in tenths)*	5	5	5	5	5	4	3	3	3	4	4	4	4
FRACTION OF EXTRATERRESTRIAL RADIATION (K_T)	.52	.53	.56	.56	.54	.55	.63	.61	.60	.54	.54	.53	.56

Recording interval: 1952–1974

AVERAGE MONTHLY TOTAL RADIATION ON A TILTED SURFACE FOR LOS ANGELES CIVIC (CALCULATED VALUES)

UNITS ARE KBTU/SQFT PER MONTH

DIRECT BEAM + DIFFUSE (GROUND REFLECTION EXCLUDED)

SURFACE ORIENT-ATION	ANGLE OF TILT (DEGREES FROM HOR-IZONTAL)	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
SOUTH	15	33	36	51	55	58	58	67	63	54	44	36	33	587
SOUTH	30	38	40	53	53	54	53	62	60	55	47	41	38	593
SOUTH	45	41	41	52	49	47	45	53	54	52	47	43	41	565
SOUTH	60	41	39	47	42	38	36	42	45	47	45	43	42	506
SOUTH	75	39	36	40	33	28	25	29	34	38	39	40	40	420
SOUTH	90	34	30	31	22	17	14	16	21	28	32	35	36	314
SE, SW	15	31	35	49	54	57	58	67	63	53	42	34	30	573
SE, SW	30	34	36	50	52	54	54	63	60	53	43	36	34	569
SE, SW	45	35	36	48	48	49	48	56	55	50	42	37	35	538
SE, SW	60	34	34	43	42	41	40	47	47	45	39	36	34	482
SE, SW	75	31	30	37	35	33	31	36	38	37	34	32	32	406
SE, SW	90	26	25	29	26	24	22	26	28	29	28	27	27	317
E, W	15	26	30	45	52	57	58	67	61	50	37	28	25	536
E, W	30	25	29	43	49	53	54	63	57	47	35	27	24	505
E, W	45	23	27	39	44	48	49	56	52	43	33	25	22	461
E, W	60	21	24	34	39	42	42	49	45	37	29	22	20	404
E, W	75	18	20	29	32	35	35	40	37	31	24	19	17	339
E, W	90	14	16	23	25	27	27	31	29	25	20	16	14	268

LOS ANGELES (International Airport)

MONTHLY SOLAR RADIATION DATA FOR LOS ANGELES (International Airport)

Latitude: 33.93° Longitude: 118.38° Elevation: 126'	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
SOLAR RADIATION (kWh/m^2 per month)													
horizontal surface	86	102	149	182	195	188	217	199	154	123	90	79	1764
direct beam (normal incidence)	135	138	179	204	199	184	232	218	175	157	133	133	2086
SOLAR RADIATION (KBtu/ft^2 per month)													
horizontal surface	27	32	47	58	62	60	69	63	49	39	29	25	559
direct beam (normal incidence)	43	44	57	65	63	58	74	69	56	50	42	42	661
PERCENT OF POSSIBLE SUNSHINE*													
MEAN CLOUD COVER (in tenths)*	5	5	5	5	5	5	4	4	4	4	5	5	5
FRACTION OF EXTRATERRESTRIAL RADIATION (K_T)	.53	.55	.58	.61	.57	.55	.63	.62	.57	.55	.53	.53	.57

Recording interval: 1951-1975

AVERAGE MONTHLY TOTAL RADIATION ON A TILTED SURFACE FOR LOS ANGELES AIRPORT (CALCULATED VALUES)

UNITS ARE KBTU/SQFT PER MONTH

DIRECT BEAM + DIFFUSE (GROUND REFLECTION EXCLUDED)

SURFACE ORIENT-ATION	ANGLE OF TILT (DEGREES FROM HOR-IZONTAL)	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
SOUTH	15	34	38	52	60	61	58	67	64	52	45	35	32	598
SOUTH	30	39	42	54	58	57	53	62	61	53	48	40	38	604
SOUTH	45	42	43	53	54	50	45	53	55	50	48	42	41	575
SOUTH	60	42	41	48	46	40	35	42	45	45	46	41	42	514
SOUTH	75	40	37	41	36	29	25	29	34	37	40	39	40	426
SOUTH	90	35	31	32	23	17	14	16	21	27	33	33	35	318
SE,SW	15	32	36	50	59	61	58	67	63	51	43	33	30	583
SE,SW	30	35	38	51	57	57	54	63	60	51	44	35	33	579
SE,SW	45	36	38	49	53	51	48	56	55	48	44	36	35	548
SE,SW	60	35	36	45	46	44	40	47	47	43	40	35	34	490
SE,SW	75	32	32	38	38	34	31	36	38	36	35	31	31	413
SE,SW	90	27	26	30	28	25	22	26	28	28	28	26	27	321
E,W	15	27	32	46	56	60	58	67	61	48	38	28	25	546
E,W	30	25	30	44	53	56	54	63	58	45	36	27	24	515
E,W	45	24	28	40	48	51	49	56	52	41	33	25	22	469
E,W	60	21	25	35	42	44	42	49	45	36	30	22	20	411
E,W	75	18	21	30	35	37	35	40	38	30	25	19	17	345
E,W	90	15	17	24	28	29	27	31	30	24	20	15	14	273

RIVERSIDE

MONTHLY SOLAR RADIATION DATA FOR RIVERSIDE

Latitude: 33.97°	Longitude: 117.33°	Elevation: 1050'											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
SOLAR RADIATION (kWh/m^2 per month)													
horizontal surface	88	106	157	182	198	209	224	205	171	132	102	88	1562
direct beam (normal incidence)	142	149	194	203	204	219	244	229	208	175	164	156	2290
SOLAR RADIATION (KBtu/ft^2 per month)													
horizontal surface	28	34	50	58	63	66	71	65	54	42	32	28	590
direct beam (normal incidence)	45	47	62	64	65	69	77	73	66	56	52	50	725
PERCENT OF POSSIBLE SUNSHINE*													
MEAN CLOUD COVER (in tenths)*	4	5	5	5	4	3	2	2	2	3	4	4	4
FRACTION OF EXTRATERRESTRIAL RADIATION (K_T)	.55	.58	.61	.61	.58	.61	.64	.64	.64	.59	.60	.59	.60

*Data for March AFB 35°54'N, 117°15'W, Elevation 1543'
Recording interval: 1952-1975

AVERAGE MONTHLY TOTAL RADIATION ON A TILTED SURFACE FOR RIVERSIDE (CALCULATED VALUES)

UNITS ARE KBTU/SQFT PER MONTH

DIRECT BEAM + DIFFUSE (GROUND REFLECTION EXCLUDED)

SURFACE ORIENTATION	ANGLE OF TILT (DEGREES FROM HORIZONTAL)	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
SOUTH	15	36	40	55	60	62	64	69	66	59	48	41	37	635
SOUTH	30	41	44	57	58	58	58	64	63	59	52	46	43	643
SOUTH	45	44	45	56	54	51	50	55	56	56	52	49	47	615
SOUTH	60	44	44	51	46	41	39	43	47	50	50	49	48	551
SOUTH	75	42	40	44	35	29	26	29	35	41	44	46	46	458
SOUTH	90	37	33	34	23	17	14	16	21	30	36	40	41	342
SE,SW	15	33	38	53	59	62	64	69	65	57	46	38	34	618
SE,SW	30	36	40	54	57	58	60	65	62	57	48	41	38	616
SE,SW	45	37	40	52	53	52	53	57	57	54	47	42	39	584
SE,SW	60	36	38	47	46	44	44	48	49	48	44	41	39	524
SE,SW	75	33	33	40	38	35	34	37	39	40	38	37	36	441
SE,SW	90	28	27	32	28	25	24	26	29	31	31	31	31	344
E,W	15	27	33	49	56	61	65	69	63	53	41	32	27	576
E,W	30	26	31	46	52	57	60	65	59	50	39	30	26	543
E,W	45	24	29	42	48	52	54	58	54	46	36	28	24	495
E,W	60	22	26	37	42	45	47	50	47	40	32	25	22	434
E,W	75	19	22	31	35	37	39	41	39	34	27	21	19	364
E,W	90	15	18	25	28	29	30	32	30	27	21	17	15	288

SAN VICENTE RESERVOIR

MONTHLY SOLAR RADIATION DATA FOR SAN VICENTE RESERVOIR

Latitude: 32.92°	Longitude: 116.92°	Elevation: 660'											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
SOLAR RADIATION (kWh/m^2 per month)													
horizontal surface	107	112	162	184	212	242	238	209	180	144	112	102	2004
direct beam (normal incidence)	187	156	202	204	227	280	271	235	222	196	185	190	2557
SOLAR RADIATION (KBtu/ft^2 per month)													
horizontal surface	34	35	51	58	67	77	75	66	57	46	35	32	633
direct beam (normal incidence)	59	50	64	65	72	89	86	75	70	62	59	60	810
PERCENT OF POSSIBLE SUNSHINE*	71	72	70	65	58	56	68	69	68	67	73	71	67
MEAN CLOUD COVER (in tenths)*	5	5	5	5	6	6	5	4	4	4	4	5	5
FRACTION OF EXTRATERRESTRIAL RADIATION (K_T)	.64	.59	.62	.61	.62	.71	.69	.65	.66	.63	.64	.66	.64

*Data for San Diego 32° 44' N 117° 10' W. Elevation 13'

Recording interval: 1957-1959

AVERAGE MONTHLY TOTAL RADIATION ON A TILTED SURFACE FOR SAN VICENTE RESEVOIR(CALCULATED VALUES)

UNITS ARE KBTU/SQFT PER MONTH

DIRECT BEAM + DIFFUSE (GROUND REFLECTION EXCLUDED)

SURFACE ORIENT-ATION	ANGLE OF TILT (DEGREES FROM HOR-IZONTAL)	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
SOUTH	15	44	42	57	60	66	74	73	67	61	53	45	43	684
SOUTH	30	51	46	59	59	62	67	67	64	62	57	51	51	693
SOUTH	45	55	47	58	54	54	56	57	57	59	57	54	55	662
SOUTH	60	55	45	53	46	43	43	44	47	52	54	54	56	592
SOUTH	75	52	41	45	35	30	28	30	35	43	48	50	54	490
SOUTH	90	46	34	34	23	17	13	15	21	30	39	44	48	364
SE,SW	15	41	40	55	59	66	74	74	66	60	50	42	39	666
SE,SW	30	45	42	56	57	62	69	68	63	59	52	45	44	663
SE,SW	45	46	42	53	53	56	60	60	58	56	51	46	46	628
SE,SW	60	45	39	48	46	47	49	50	49	50	48	45	46	563
SE,SW	75	41	35	41	38	37	38	39	40	42	41	40	42	473
SE,SW	90	35	28	32	28	26	26	27	29	32	33	34	36	368
E,W	15	33	35	50	57	66	75	74	65	56	45	35	32	621
E,W	30	32	33	48	53	61	70	69	61	52	42	33	30	584
E,W	45	30	30	43	48	55	63	62	55	48	39	31	28	532
E,W	60	27	27	38	42	48	54	53	48	42	34	27	25	466
E,W	75	23	23	32	35	40	44	44	40	35	29	24	22	390
E,W	90	19	18	26	28	31	34	34	31	28	23	19	18	308

LA JOLLA

MONTHLY SOLAR RADIATION DATA FOR LA JOLLA

Latitude: 32.83°	Longitude: 117.25°	Elevation: 85'											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
SOLAR RADIATION (kWh/m^2 per month)													
horizontal surface	94	102	150	171	198	180	195	179	148	125	102	85	1729
direct beam (normal incidence)	149	135	178	181	203	170	195	183	162	156	159	140	2010
SOLAR RADIATION (KBtu/ft^2 per month)													
horizontal surface	30	32	48	54	63	57	62	57	47	40	32	27	548
direct beam (normal incidence)	47	43	56	57	64	54	62	58	51	49	50	44	637
PERCENT OF POSSIBLE SUNSHINE*	71	72	70	65	58	56	68	69	68	67	73	71	67
MEAN CLOUD COVER (in tenths)*	5	5	5	5	6	6	5	4	4	4	4	5	5
FRACTION OF EXTRATERRESTRIAL RADIATION (K_T)	.56	.54	.57	.57	.58	.53	.56	.56	.55	.55	.59	.55	.56

Recording interval: 1929-1942
*Data for San Diego 32°44', 117°10' W, Elevation 13'

AVERAGE MONTHLY TOTAL RADIATION ON A TILTED SURFACE FOR LA JOLLA (CALCULATED VALUES)

UNITS ARE KBTU/SQFT PER MONTH

DIRECT BEAM + DIFFUSE (GROUND REFLECTION EXCLUDED)

SURFACE ORIENT-ATION	ANGLE OF TILT (DEGREES FROM HOR-IZONTAL)	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
SOUTH	15	37	38	52	56	62	55	60	57	50	45	40	35	588
SOUTH	30	43	41	54	54	58	50	55	54	50	48	46	40	594
SOUTH	45	46	42	53	50	50	43	48	49	48	48	48	43	566
SOUTH	60	46	41	48	42	40	34	38	40	42	45	48	44	508
SOUTH	75	43	37	41	33	29	23	26	30	34	40	44	42	422
SOUTH	90	38	30	31	22	16	13	15	19	25	32	28	37	316
SE,SW	15	35	36	51	55	62	55	60	57	49	43	38	32	573
SE,SW	30	38	38	51	53	58	51	56	54	48	45	41	35	569
SE,SW	45	39	37	49	49	52	45	50	49	46	44	41	37	538
SE,SW	60	38	35	44	43	44	38	42	42	41	40	40	36	482
SE,SW	75	35	31	38	35	35	27	33	34	34	35	36	33	406
SE,SW	90	29	25	30	26	25	21	23	25	26	28	30	28	317
E,W	15	29	32	47	53	61	55	60	55	46	39	32	26	536
E,W	30	28	30	44	50	57	52	57	52	43	37	30	25	505
E,W	45	26	28	40	45	52	47	51	47	40	34	28	23	460
E,W	60	23	25	35	39	45	40	44	41	35	30	25	21	403
E,W	75	20	21	30	33	37	33	36	34	29	25	21	18	338
E,W	90	16	17	24	26	29	26	28	27	23	20	17	15	267

EL CENTRO

MONTHLY SOLAR RADIATION DATA FOR EL CENTRO

Latitude: 32.8°	Longitude: 115.67°	Elevation: 12'											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
SOLAR RADIATION (kWh/m^2 per month)													
horizontal surface	112	126	179	220	250	248	232	223	192	155	120	103	2160
direct beam (normal incidence)	201	190	237	276	302	292	260	262	247	221	206	192	2888
SOLAR RADIATION (KBtu/ft^2 per month)													
horizontal surface	36	40	57	70	79	79	74	71	61	49	38	33	685
direct beam (normal incidence)	64	60	75	88	96	93	82	83	78	70	65	61	915
PERCENT OF POSSIBLE SUNSHINE*	85	88	91	94	96	97	90	91	94	92	86	82	91
MEAN CLOUD COVER (in tenths)*	4	4	4	2	2	1	3	2	1	2	3	4	3
FRACTION OF EXTRATERRESTRIAL RADIATION (K_T)	.67	.67	.68	.73	.73	.73	.67	.69	.71	.68	.69	.66	.69

Recording interval: 1963-1975

*Data for Yuma, Ariz. 32° 40' N, 114° 36' W, elevation 194'

AVERAGE MONTHLY TOTAL RADIATION ON A TILTED SURFACE FOR EL CENTRO (CALCULATED VALUES)

UNITS ARE KBTU/SQFT PER MONTH

DIRECT BEAM + DIFFUSE (GROUND REFLECTION EXCLUDED)

SURFACE ORIENTATION	ANGLE OF TILT (DEGREES FROM HORIZONTAL)	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
SOUTH	15	46	48	63	72	78	75	72	71	66	57	48	43	740
SOUTH	30	54	53	66	71	72	68	65	68	66	62	55	51	751
SOUTH	45	58	55	64	65	62	57	56	61	63	62	59	56	717
SOUTH	60	59	53	59	55	49	43	43	50	56	59	59	57	641
SOUTH	75	56	48	50	42	34	28	29	36	46	52	55	54	529
SOUTH	90	49	40	38	26	17	13	15	21	32	42	48	49	391
SE,SW	15	43	45	61	71	78	76	72	71	64	54	45	40	719
SE,SW	30	47	48	62	69	73	70	67	68	64	57	49	45	717
SE,SW	45	49	48	59	64	65	61	59	61	60	56	50	47	680
SE,SW	60	48	45	54	55	55	50	49	53	54	52	49	46	609
SE,SW	75	44	40	46	45	42	38	38	42	45	45	44	43	512
SE,SW	90	37	33	36	33	30	26	27	31	34	36	37	37	397
E,W	15	35	39	55	68	77	76	72	69	59	48	37	32	668
E,W	30	33	37	52	64	72	71	67	65	56	45	35	31	629
E,W	45	31	34	48	58	65	64	60	58	51	42	33	29	572
E,W	60	28	30	42	50	56	55	52	51	45	37	29	26	501
E,W	75	24	26	35	42	46	45	43	42	37	31	25	22	419
E,W	90	19	21	28	33	36	35	33	33	30	25	20	18	331

MONTHLY SOLAR RADIATION DATA FOR BARRETT RESERVOIR

	Latitude: 32.68°			Longitude: 116.67°				Elevation: 1623'					
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
SOLAR RADIATION (kWh/m^2 per month)													
horizontal surface	98	116	163	206	224	239	228	212	178	145	100	91	2000
direct beam (normal incidence)	159	164	203	247	249	275	251	241	218	198	151	154	2510
SOLAR RADIATION (KBtu/ft^2 per month)													
horizontal surface	31	37	52	65	71	76	72	67	56	46	32	29	634
direct beam (normal incidence)	50	52	64	78	79	87	80	76	69	63	48	49	795
PERCENT OF POSSIBLE SUNSHINE*	71	72	70	65	58	56	68	69	68	67	73	71	67
MEAN CLOUD COVER (in tenths)*	5	5	5	5	6	6	5	4	4	4	4	5	5
FRACTION OF EXTRATERRESTRIAL RADIATION (K_T)	.58	.61	.62	.69	.66	.70	.66	.66	.66	.63	.57	.58	.64

Recording interval: 1959-1961

*Data for San Diego 32°44' N 117° 10' W, Elevation 13'

AVERAGE MONTHLY TOTAL RADIATION ON A TILTED SURFACE FOR BARRETT RESERVOIR (CALCULATED VALUES)

UNITS ARE KBTU/SQFT PER MONTH

DIRECT BEAM + DIFFUSE (GROUND REFLECTION EXCLUDED)

SURFACE ORIENT-ATION	ANGLE OF TILT (DEGREES FROM HOR-IZONTAL)	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
SOUTH	15	39	43	57	68	70	73	70	68	61	53	39	37	678
SOUTH	30	45	48	59	66	65	66	64	65	61	57	44	43	683
SOUTH	45	48	49	58	60	56	55	55	58	58	57	46	47	648
SOUTH	60	48	47	53	51	45	42	43	47	52	54	46	47	575
SOUTH	75	46	43	45	39	31	27	29	35	42	48	43	45	472
SOUTH	90	40	36	34	25	17	13	15	21	30	39	37	40	346
SE, SW	15	37	41	55	67	70	73	70	67	59	51	37	34	661
SE, SW	30	40	43	56	65	66	68	65	64	59	52	39	38	656
SE, SW	45	41	43	54	60	59	59	58	58	55	51	40	40	618
SE, SW	60	40	41	49	52	49	49	48	50	49	48	38	39	551
SE, SW	75	36	36	41	42	39	37	37	40	41	42	35	36	461
SE, SW	90	31	29	32	31	27	26	26	29	32	33	29	30	357
E, W	15	30	36	51	64	69	74	70	66	55	45	31	28	619
E, W	30	29	34	48	60	65	69	66	62	52	42	30	27	583
E, W	45	27	31	44	54	58	62	59	56	47	39	27	25	530
E, W	60	24	28	38	47	51	53	51	48	41	34	24	22	464
E, W	75	21	24	32	39	42	44	42	40	35	29	21	19	387
E, W	90	17	19	26	31	32	34	33	31	27	23	17	16	306

■ *CHINA LAKE/INYOKERN*

CLIMATOLOGICAL DATA FOR CHINA LAKE/INYOKERN

Latitude: 35° 41' Longitude: 117° 41' Elevation: 2293'

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
TEMPERATURE(°F)													
average monthly	44	50	55	64	71	80	87	85	78	67	53	45	65
average daily max/min	57/30	63/36	68/41	78/49	85/56	95/65	102/72	100/69	94/62	82/51	68/38	59/31	79/50
extreme max/min	77/6	81/14	86/22	97/28	107/38	114/42	113/55	110/53	110/40	100/32	86/20	75/8	114/6
DEGREE DAYS													
heating (base 65°F)	614	392	267	127	10	0	0	0	0	43	316	601	2370
cooling (base 65°F)	0	0	10	115	262	483	741	682	450	145	0	0	2388
WIND													
Mean speed (mph)	7	8	10	10	10	10	9	9	8	7	6	6	8
Max. speed* (mph)	77	79	81	74	82	77	60	58	69	68	67	71	82
Prevailing direction	SW	SW	SW	SW	SW	SW	SW	SW	SW	SW	SW	SW	SW
FREEZE DAYS PER MONTH	19	9	4	<0.5	0	0	0	0	0	<0.5	7	19	58
PRECIPITATION (in. water)													
average	0.5	0.4	0.2	0.1	0.1	T	T	0.1	0.3	0.1	0.3	0.4	2.5
max/min	0.9	0.9	0.9	0.9	1.0	0.3	0.2	0.6	0.9	0.8	1.0	0.9	1.0
RELATIVE HUMIDITY(%)													
4 AM	63	59	52	46	42	36	32	35	38	45	55	65	47
1 PM	37	32	26	21	18	15	15	16	17	21	30	37	24

*"fastest mile", speed is fastest observed 1 minute value.

**Data for Trona 35° 47' N 117° 23' W, Elevation 1695'

■ *EDWARDS AFB*

CLIMATOLOGICAL DATA FOR EDWARDS AFB

Latitude: 34° 55' Longitude: 117° 54' Elevation: 2302'

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
TEMPERATURE(°F)													
average monthly	44	48	52	59	66	74	83	81	74	63	51	44	62
average daily max/min	57/30	61/34	66/38	73/44	81/51	90/58	99/66	97/64	91/57	79/47	66/36	57/30	76/46
extreme max/min	83/4	80/14	87/19	97/27	105/32	112/41	113/50	112/47	109/34	99/20	85/13	84/7	113/4
DEGREE DAYS													
heating (base 65°F)	620	459	400	245	84	29	0	0	7	113	380	592	2929
cooling (base 65°F)	0	0	0	44	90	260	502	459	286	78	5	0	1724
WIND													
Mean speed (mph)	7	8	10	12	13	13	12	10	8	7	7	6	9
Max. speed* (mph)	59	67	74	58	62	59	51	60	75	75	55	58	75
Prevailing direction	W	SW	WSW	SW	SW	SW	SW	SW	SW	SW	SW	W	SW
FREEZE DAYS PER MONTH	20	12	6	1	<0.5	0	0	0	0	1	10	21	71
PRECIPITATION (in. water)													
average	0.8	0.8	0.5	0.3	T	T	T	0.1	0.1	0.2	0.6	0.7	4.1
max/min	3.3	4.4	2.3	1.5	0.3	0.3	0.4	1.0	1.1	1.7	3.5	3.7	4.4
RELATIVE HUMIDITY(%)													
4 AM	71	69	66	64	59	52	42	45	50	55	63	71	59
1 PM	40	36	32	27	24	20	17	17	19	24	34	42	28

*Peak gust speed.

**Data for Palmdale 34° 44' N 118° 06' W, Elevation 2596'

BAKERSFIELD

CLIMATOLOGICAL DATA FOR BAKERSFIELD

Latitude: 35° 25' Longitude: 119° 03' Elevation: 475'

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
TEMPERATURE(°F)													
average monthly	47.5	52.4	56.6	62.7	69.8	76.9	83.9	81.6	76.6	66.9	56.0	47.9	64.9
average daily max/min	58/37	63/41	69/45	76/50	84/56	92/62	99/69	97/67	91/62	81/53	68/44	57/38	78/52
extreme max/min	79/24	80/27	92/31	98/38	107/41	111/48	113/56	111/57	108/49	98/29	90/30	75/25	113/24
DEGREE DAYS													
heating (base 65°F)	543	353	266	140	22	0	0	0	0	55	276	530	2185
cooling (base 65°F)	0	0	6	71	171	362	586	515	348	114	6	0	2279
WIND													
Mean speed (mph)	5.2	5.7	6.6	7.2	8.0	8.0	7.2	6.8	6.2	5.6	5.1	4.9	6.4
Max. speed* (mph)	35	44	38	40	38	41	25	30	30	31	30	35	44
Prevailing direction	NW	ENE	NW	NW	NW	NW	NW	NW	WNW	NW	ENE	ENE	NW
FREEZE DAYS PER MONTH	5	1	<0.5	0	0	0	0	0	0	<0.5	<0.5	5	12
PRECIPITATION (in. water)													
average	0.96	1.03	0.83	0.85	0.19	0.06	0.02	0.01	0.08	0.26	0.69	0.74	5.72
max/min	2.82/T	4.42/0.03	4.61/T	2.65/0.0	2.39/0.0	1.11/0.0	0.30/0.0	0.17/0.0	0.83/0.0	1.82/0.0	3.04/0.0	1.80/T	4.61/0.0
RELATIVE HUMIDITY(%)													
4 AM	83	77	70	64	55	51	47	51	55	63	76	85	65
10 AM	75	65	54	45	37	35	32	34	39	46	65	77	50
4 PM	61	49	40	32	24	23	20	22	26	33	50	64	37
10 PM	78	69	60	52	39	36	33	36	42	52	70	80	54

*"fastest mile", speed is fastest observed 1 minute value.

SANTA MARIA

CLIMATOLOGICAL DATA FOR SANTA MARIA

Latitude: 34°54' Longitude: 120°27' Elevation: 236'

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
TEMPERATURE(°F)													
average monthly	50.5	52.0	52.8	54.9	57.1	59.6	62.1	62.3	62.6	60.4	56.1	51.8	56.9
average daily max	63	64	64	66	67	70	72	72	74	73	69	64	68
average daily min	38	40	41	44	47	50	52	53	51	48	43	39	46
extreme max	84	84	85	95	100	102	87	93	99	100	92	84	102
extreme min	22	22	24	31	31	38	43	43	39	26	27	21	21
DEGREE DAYS													
heating (base 65°F)	450	364	378	303	245	167	112	102	94	159	270	409	3053
cooling (base 65°F)	0	0	0	0	0	5	22	18	22	17	0	0	84
WIND													
Mean speed (mph)	6.7	7.2	8.3	8.0	8.3	7.9	6.5	6.2	5.9	6.2	6.6	6.4	7.0
Max speed* (mph)													
Prevailing direction	WNW	WNW	WNW	WNW	WNW	WNW	WNW	W	W	W	WNW	WNW	WNW
FREEZE DAYS PER MONTH	7	5	2	1	<0.5	0	0	0	0	<0.5	1	7	24
PRECIPITATION (in. water)													
average	2.25	2.40	1.98	1.30	0.19	0.04	0.03	0.02	0.10	0.52	1.36	2.05	12.25
max	7.09	9.69	5.08	4.24	1.03	0.26	0.62	0.11	1.57	2.07	4.74	4.82	9.69
min	0.01	T	T	T	T	T	0.00	0.00	T	T	0.00	0.13	0.00
RELATIVE HUMIDITY(%)													
4 AM	81	84	86	88	91	92	88	93	91	85	78	79	86
10 AM	64	63	64	60	62	64	64	66	64	55	60	63	62
4 PM	61	61	65	61	62	62	61	63	63	60	64	62	62
10 PM	81	83	84	87	87	88	86	91	89	85	77	79	85

*"fastest mile"; speed is fastest observed 1-minute value.

■ *SANDBERG*

CLIMATOLOGICAL DATA FOR SANDBERG

Latitude: 34° 45' Longitude: 118° 44' Elevation: 4517'

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
TEMPERATURE(°F)													
average monthly	40.2	42.2	43.6	49.2	55.7	64.0	74.0	73.0	68.9	58.8	48.3	41.9	55.0
average daily max/min	46/34	49/35	52/36	58/40	66/46	75/53	85/63	84/62	79/59	68/50	55/41	48/36	64/46
extreme max/min	71/3	72/13	80/15	85/22	94/26	99/30	102/40	102/40	98/35	89/21	80/21	72/11	102/3
DEGREE DAYS													
heating (base 65°F)	769	638	663	474	288	116	7	10	33	212	501	716	4427
cooling (base 65°F)	0	0	0	0	0	86	286	258	150	20	0	0	800
WIND													
Mean speed (mph)	17.0	16.4	16.7	16.4	15.9	15.1	12.8	12.6	12.9	14.9	16.1	16.4	15.3
Max. speed* (mph)	64	77	74	64	59	64	46	40	45	53	62	53	77
Prevailing direction	ENE	N	NNW	NNW	NNW	NNW	NNW	NNW	NNW	NNW	ENE	ENE	NNW
FREEZE DAYS PER MONTH	13	11	11	6	2	<0.5	0	0	0	1	5	11	59
PRECIPITATION (in. water)													
average	2.15	2.45	1.33	1.12	0.25	0.03	0.03	0.06	0.21	0.34	2.05	1.95	11.97
max/min	10.6/0.0	11.4/0.02	6.18/0.0	4.11/0.0	1.13/0.0	0.54/0.0	0.49/0.0	0.65/0.0	3.40/0.0	3.55/0.0	9.80/0.0	10.3/T	11.4/0.0
RELATIVE HUMIDITY(%)													
4 AM	51	56	65	67	64	58	42	45	47	55	57	62	56
10 AM	56	57	57	52	46	36	26	27	30	39	47	54	44
4 PM	56	50	52	50	47	38	28	29	33	42	50	59	44
10 PM	58	56	63	62	59	51	38	41	45	52	55	63	54

*"fastest mile": speed is fastest observed 1-minute value.

■ *VICTORVILLE (George AFB)*

CLIMATOLOGICAL DATA FOR VICTORVILLE (George AFB)

Latitude: 34° 35' Longitude: 117° 23' Elevation: 2885'

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
TEMPERATURE(°F)													
average monthly	45	48	52	59	65	73	81	80	75	65	52	47	62
average daily max/min	57/33	60/36	64/39	72/45	79/50	88/58	96/66	95/64	90/59	79/50	65/39	59/34	75/48
extreme max/min	80/9	79/18	85/24	94/31	100/35	110/41	108/50	106/49	107/38	95/31	85/20	86/17	110/9
DEGREE DAYS													
heating (base 65°F)	688	512	446	250	101	25	0	0	13	156	444	660	3295
cooling (base 65°F)	0	0	0	19	77	217	434	403	220	57	6	0	1433
WIND													
Mean speed (mph)	8	9	10	10	10	10	8	8	8	8	8	7	9
Max. speed* (mph)	62	52	71	56	53	87	58	45	44	51	59	64	87
Prevailing direction	SSE	W	W	W	S	S	S	S	S	SSE	SSE	SSE	S
FREEZE DAYS PER MONTH	14	9	5	1	0	0	0	0	0	<0.5	5	12	46
PRECIPITATION (in. water)													
average	0.9	0.6	0.5	0.3	0.1	T	0.1	0.2	0.2	0.2	0.4	0.6	4.1
max/min	1.7	1.9	1.1	0.4	0.3	0.1	0.7	0.5	1.4	0.6	1.6	1.5	1.9
RELATIVE HUMIDITY(%)													
4 AM	65	64	63	62	58	51	40	45	48	53	61	63	56
1 PM	36	33	30	26	22	18	16	18	19	24	30	34	26

*"fastest mile": speed is fastest observed 1-minute value.

*Peak gust speed.

**Data for Victorville Pump Plant 34° 32' N 117° 18' W, Elevation 2858'

OXNARD (Oxnard AFB)

CLIMATOLOGICAL DATA FOR OXNARD (Oxnard AFB)

Latitude: 34°13' Longitude: 119°05' Elevation: 94'

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
TEMPERATURE(°F)													
average monthly	53	54	54	57	59	62	66	67	66	63	57	55	60
average daily max/min	64/41	65/43	65/43	67/46	68/49	71/53	75/57	76/57	76/55	74/51	69/45	67/43	70/49
extreme max/min	87/25	89/30	89/30	97/31	95/36	101/42	94/45	96/46	105/43	101/35	97/31	93/27	105/25
DEGREE DAYS													
heating (base 65°F)	351	297	304	242	180	116	68	51	56	109	202	310	2286
cooling (base 65°F)	0	6	0	0	0	14	74	69	53	38	10	0	264
WIND													
Mean speed (mph)	6	6	6	6	6	5	5	5	5	5	6	7	5
Max. speed* (mph)	54	51	49	41	41	26	25	24	37	51	58	52	58
Prevailing direction	ENE	ENE	WSW	WSW	WSW	WSW	WSW	WSW	WSW	WSW	ENE	ENE	WSW
FREEZE DAYS PER MONTH	2	1	<0.5	<0.5	0	0	0	0	0	0	<0.5	1	4
PRECIPITATION (in. water)													
average	2.5	2.7	1.4	1.3	0.1	0.1	T	T	0.1	0.1	1.9	1.5	11.7
max/min	4.2	4.2	2.0	2.0	0.4	0.6	T	0.1	0.6	0.5	1.7	2.2	4.2
RELATIVE HUMIDITY(%)													
4 AM	71	77	82	87	88	90	91	91	89	82	75	66	82
1 PM	50	51	56	57	58	62	62	63	59	54	51	47	56

*"fastest mile"; speed is fastest observed 1-minute value.

**Data for Oxnard 34°12'N 119°11'W Elevation 49'

BURBANK

CLIMATOLOGICAL DATA FOR BURBANK

Latitude: 34° 12' Longitude: 118° 22' Elevation: 724'

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
TEMPERATURE(°F)													
average monthly	53.6	55.2	57.9	61.2	64.4	68.0	73.8	74.1	72.6	66.3	60.4	55.6	63.6
average daily max/min	65/42	66/44	69/47	72/50	75/54	79/57	86/61	87/62	86/60	79/54	74/47	68/44	75/52
extreme max/min	83/33	85/32	83/36	95/36	95/40	99/47	96/53	106/54	97/49	100/45	88/34	84/34	106/32
DEGREE DAYS													
heating (base 65°F)	366	277	239	138	81	18	0	0	6	43	177	301	1646
cooling (base 65°F)	5	10	12	30	52	123	289	301	240	99	18	0	1179
WIND													
Mean speed (mph)	4.5	5.1	5.6	5.9	5.8	5.7	5.9	5.4	4.8	4.4	4.3	4.3	5.1
Max. speed* (mph)													
Prevailing direction	NW	S	S	S	S	S	S	S	S	S	S	NW	S
FREEZE DAYS PER MONTH	0	1	0	0	0	0	0	0	0	0	0	0	1
PRECIPITATION (in. water)													
average	3.14	3.22	2.16	1.21	0.18	0.05	T	0.05	0.27	0.49	1.05	2.71	14.53
max/min	13.4/T	13.8/T	10.2/0.	5.7/T	1.2/T	0.4/T	0.04/0.	0.7/0.	6.6/0.	2.4/T	10.6/0.	8.1/T	13.8/0.0
RELATIVE HUMIDITY(%)													
4 AM	62	56	72	78	81	83	82	84	81	67	76	73	74
10 AM	45	37	50	53	53	63	50	57	55	45	59	62	52
4 PM	37	31	46	48	46	52	38	46	45	37	51	52	44
10 PM	57	53	67	68	71	76	73	77	75	62	72	68	68

*"fastest mile", speed is fastest observed 1 minute value.

SAN BERNARDINO (Norton AFB)

CLIMATOLOGICAL DATA FOR SAN BERNARDINO (Norton AFB)

Latitude: 34°06' Longitude: 117°14' Elevation: 1166'

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
TEMPERATURE(°F)													
average monthly	51	53	55	61	65	70	77	77	75	66	57	52	64
average daily max/min	63/38	66/40	68/42	74/47	78/51	85/55	94/60	94/60	91/58	81/51	71/43	65/39	78/49
extreme max/min	86/20	87/26	89/26	99/32	100/36	112/42	109/47	110/46	113/42	105/35	93/27	85/25	113/20
DEGREE DAYS													
heating (base 65°F)	403	311	283	167	65	22	0	0	13	52	206	369	1891
cooling (base 65°F)	0	9	7	35	72	193	409	409	301	108	14	0	1557
WIND													
Mean speed (mph)	5	5	5	5	5	5	5	5	3	3	3	3	3
Max. speed* (mph)	79	63	54	54	46	55	45	64	69	66	59	74	79
Prevailing direction	E	E	SW	SW	WSW	WSW	WSW	WSW	WSW	WSW	E	E	WSW
FREEZE DAYS PER MONTH	7	4	2	<0.5	0	0	0	0	0	0	1	4	18
PRECIPITATION (in. water)													
average	2.1	1.9	1.7	1.3	0.4	0.1	0.1	0.1	0.4	0.4	1.4	1.7	11.6
max/min	4.0	1.9	1.5	1.6	1.2	0.5	0.3	0.9	1.9	0.9	2.0	2.4	4.0
RELATIVE HUMIDITY(%)													
4 AM	74	77	80	82	83	82	77	77	74	74	71	72	77
1 PM	42	41	43	41	41	37	28	30	31	34	36	41	37

*"fastest mile", speed is fastest observed 1-minute value.

**Data for San Bernardino County Hospital 34°08'N 117°16'W, Elevation 1125'

LOS ANGELES (Urban)

CLIMATOLOGICAL DATA FOR LOS ANGELES (Urban)

Latitude: 34°03' Longitude: 118°14' Elevation: 270'

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
TEMPERATURE(°F)													
average monthly	56.7	58.1	59.2	61.7	64.7	68.0	73.2	74.1	72.7	68.4	62.7	58.1	64.8
average daily max/min	67/47	68/49	69/50	71/53	73/56	77/60	83/64	84/64	83/63	78/59	73/52	68/48	74/55
extreme max/min	95/28	91/34	94/38	99/39	102/46	106/50	103/54	103/53	110/51	104/41	100/39	89/32	110/28
DEGREE DAYS													
heating (base 65°F)	268	207	190	124	60	25	0	0	5	35	113	218	1245
cooling (base 65°F)	10	14	10	25	51	115	258	282	236	140	44	0	1185
WIND													
Mean speed (mph)	6.8	6.9	7.0	6.6	6.3	5.7	5.4	5.3	5.3	5.7	6.4	6.6	6.2
Max. speed* (mph)	49	40	47	40	39	32	21	24	27	48	42	44	49
Prevailing direction	NE	W	W	W	W	W	W	W	W	W	W	NE	W
FREEZE DAYS PER MONTH	<0.5	0	0	0	0	0	0	0	0	0	0	<0.5	<0.5
PRECIPITATION (in. water)													
average	3.00	2.77	2.19	1.27	0.13	0.03	0.00	0.04	0.17	0.27	2.02	2.16	14.05
max/min	14.9/0.00	12.4/T	8.14/0.00	6.02/0.00	1.43/0.00	0.32/0.00	0.03/0.00	0.39/0.00	1.80/0.00	1.53/0.00	9.68/0.00	6.57/T	14.9/0.00
RELATIVE HUMIDITY(%)													
4 AM	63	71	74	78	81	85	84	84	78	76	61	62	75
10 AM	51	54	52	53	56	59	54	56	52	55	45	45	53
4 PM	50	52	52	54	55	56	53	55	54	56	49	50	53
10 PM	67	70	72	74	75	78	79	79	76	74	62	62	72

*"fastest mile"; speed is fastest observed 1-minute value.

LOS ANGELES (International Airport)

CLIMATOLOGICAL DATA FOR LOS ANGELES (International Airport)

Latitude: 33°56' Longitude: 118°24' Elevation: 97'

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
TEMPERATURE(°F)													
average monthly	54.5	55.6	56.5	58.8	61.9	64.5	68.5	69.5	68.7	65.2	60.5	56.9	61.7
average daily max/min	64/45	64/47	64/49	66/52	68/55	70/59	75/62	76/63	76/62	73/58	70/51	67/47	69/54
extreme max/min	87/30	92/37	88/39	95/43	96/45	92/50	92/55	91/58	110/55	106/43	101/38	88/32	110/30
DEGREE DAYS													
heating (base 65°F)	331	250	267	195	114	71	19	15	23	77	158	267	1819
cooling (base 65°F)	5	7	0	9	17	56	127	154	134	83	23	0	615
WIND													
Mean speed (mph)	6.7	7.3	8.0	8.4	8.2	7.8	7.6	7.5	7.1	6.8	6.6	6.6	7.4
Max. speed* (mph)	48	57	62	59	45	32	29	33	28	46	55	49	62
Prevailing direction	W	W	W	WSW	WSW	WSW	WSW	WSW	WSW	W	W	W	W
FREEZE DAYS PER MONTH	<0.5	0	0	0	0	0	0	0	0	0	0	<0.5	<0.5
PRECIPITATION (in. water)													
average	2.52	2.32	1.71	1.10	0.08	0.03	0.01	0.02	0.07	0.22	1.76	2.39	11.59
max/min	9.60/0.00	11.1/T	5.98/0.00	4.52/0.00	0.56/0.00	0.29/0.00	0.15/0.00	0.30/0.00	4.39/0.00	2.34/0.00	7.92/0.00	6.57/T	11.1/0.00
RELATIVE HUMIDITY(%)													
4 AM	68	73	78	79	82	85	86	85	83	79	75	70	79
10 AM	54	58	61	60	65	70	68	68	65	58	58	55	62
4 PM	59	62	66	63	66	68	68	69	67	64	64	61	65
10 PM	69	71	75	76	79	83	83	83	81	77	74	70	76

*"fastest mile"; speed is fastest observed 1-minute value.

■ *RIVERSIDE (March AFB)*

CLIMATOLOGICAL DATA FOR RIVERSIDE (March AFB)

Latitude: 33°54' Longitude: 117°15' Elevation: 1543'

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
TEMPERATURE(°F)													
average monthly	51	52	55	59	64	70	76	76	74	66	58	53	63
average daily max/min	62/39	64/40	67/42	72/46	77/50	84/55	92/60	92/61	89/58	80/51	71/44	66/40	76/49
extreme max/min	85/18	87/22	92/27	97/32	103/36	110/43	109/48	107/47	110/44	103/36	93/26	90/23	110/18
DEGREE DAYS													
heating (base 65°F)	406	312	283	168	74	22	0	0	5	62	212	375	1919
cooling (base 65°F)	6	7	7	27	68	160	341	347	257	96	8	0	1324
WIND													
Mean speed (mph)	5	5	6	6	6	6	6	6	5	5	5	5	6
Max. speed* (mph)	53	49	47	44	39	45	49	40	45	45	46	56	56
Prevailing direction	NW	NW	NW	NW	NW	NW	NW	NW	NW	NW	NW	NE	NW
FREEZE DAYS PER MONTH	6	3	1	<0.5	0	0	0	0	0	0	1	3	14
PRECIPITATION (in. water)													
average	1.8	1.6	1.4	1.0	0.1	T	T	0.1	0.3	0.3	1.0	1.5	9.1
max/min	3.1	1.6	1.8	1.6	0.5	0.2	0.2	1.3	1.9	0.8	2.1	2.7	3.1
RELATIVE HUMIDITY(%)													
4 AM	73	78	82	85	84	83	74	75	74	76	71	71	77
1 PM	39	41	42	41	39	36	28	29	30	32	34	38	36

*"fastest mile": speed is fastest observed 1-minute value.

**Data for Riverside Fire Station #3, 33°57'N 117°23'N, Elevation 840'

LONG BEACH

CLIMATOLOGICAL DATA FOR LONG BEACH

Latitude: 33°49' Longitude: 118°09' Elevation: 25'

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
TEMPERATURE(°F)													
average monthly	54.2	55.5	57.2	60.6	64.1	67.3	72.2	73.3	71.8	66.9	60.6	55.5	63.3
average daily max/min	65/43	66/45	68/47	71/51	74/54	77/58	83/62	84/63	83/60	78/56	73/48	67/44	74/53
extreme max/min	89/25	91/33	88/33	99/38	103/40	108/47	100/51	105/56	110/50	111/39	101/35	85/31	111/25
DEGREE DAYS													
heating (base 65°F)	339	273	247	148	71	23	0	0	7	48	155	295	1606
cooling (base 65°F)	0	7	0	16	43	92	226	260	211	107	23	0	985
WIND													
Mean speed (mph)	5.6	6.2	7.0	7.5	7.3	7.0	6.7	6.5	6.1	5.9	5.7	5.3	6.4
Max. speed* (mph)	37	40	35	44	30	21	23	23	23	37	35	39	44
Prevailing direction	WNW	W	W	W	S	S	WNW	WNW	WNW	WNW	WNW	WNW	WNW
FREEZE DAYS PER MONTH	<0.5	0	0	0	0	0	0	0	0	0	0	<0.5	1
PRECIPITATION (in. water)													
average	2.26	2.16	1.50	0.89	0.07	0.04	0.00	0.02	0.09	0.19	1.38	1.65	10.25
max/min	11.2/0.00	7.88/0.00	4.20/0.00	4.42/T	0.67/0.00	0.52/0.00	0.05/0.00	0.22/0.00	1.31/0.00	2.08/0.00	6.05/T	5.98/T	11.2/0.00
RELATIVE HUMIDITY(%)													
4 AM	72	76	77	78	79	81	80	80	81	80	78	76	78
10 AM	57	60	60	56	61	64	61	60	60	57	59	60	60
4 PM	51	52	54	49	54	56	52	52	54	52	54	53	53
10 PM	70	72	72	71	75	76	75	75	76	75	74	73	74

*"fastest mile"; speed is fastest observed 1-minute value.

■ *SANTA ANA (El Toro MCAS)*

CLIMATOLOGICAL DATA FOR SANTA ANA (El Toro MCAS)

Latitude: 33°40' Longitude: 117°44' Elevation: 383'

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
TEMPERATURE(°F)													
average monthly	54	55	56	59	62	66	71	72	71	66	60	56	63
average daily max/min	64/44	65/45	66/45	69/49	72/52	76/56	82/60	82/61	82/59	77/55	71/49	66/46	73/52
extreme max/min	93/25	88/30	88/32	101/33	101/39	103/44	103/48	102/47	116/44	108/38	97/35	93/30	116/25
DEGREE DAYS													
heating (base 65°F)	372	298	279	177	94	38	0	0	9	64	195	341	1867
cooling (base 65°F)	0	7	0	9	29	77	181	209	165	70	12	0	759
WIND													
Mean speed (mph)	6	6	6	6	6	6	6	6	6	6	6	6	6
Max. speed* (mph)	67	75	61	53	55	33	54	41	49	52	72	69	75
Prevailing direction	E	E	W	W	W	W	W	W	W	W	E	E	W
FREEZE DAYS PER MONTH	1	<0.5	<0.5	0	0	0	0	0	0	0	0	<0.5	1
PRECIPITATION (in. water)													
average	2.4	1.8	1.9	1.3	0.2	0.1	T	0.1	0.2	0.3	1.5	1.9	11.7
max/min	5.2	2.1	2.5	2.2	0.5	0.3	0.3	0.7	1.2	0.7	2.8	2.4	5.2
RELATIVE HUMIDITY(%)													
4 AM	70	74	81	85	86	88	88	83	82	79	70	69	80
1 PM	52	53	55	55	55	56	52	53	51	51	48	51	53

*"fastest mile", speed is fastest observed 1-minute value.

**Data for Tustin Irvine Ranch 33°44'N 117°47'W, Elevation 118'

SAN DIEGO

CLIMATOLOGICAL DATA FOR SAN DIEGO

Latitude: 32°44' Longitude: 117°10' Elevation: 13'

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
TEMPERATURE(°F)													
average monthly	55.2	56.7	58.1	60.7	63.3	65.5	69.6	71.4	69.9	66.1	60.8	56.7	62.9
average daily max/min	65/46	66/48	66/50	68/54	69/57	71/60	75/64	77/65	77/63	74/58	70/52	66/47	70/55
extreme max/min	86/31	85/38	85/39	91/44	91/48	90/51	92/57	90/58	111/56	107/43	97/38	88/36	111/31
DEGREE DAYS													
heating (base 65°F)	314	237	219	144	79	52	6	0	16	43	140	257	1507
cooling (base 65°F)	10	0	0	15	26	67	149	201	163	77	14	0	722
WIND													
Mean speed (mph)	5.6	6,3	7.2	7.6	7.6	7.5	7.1	7.0	6.7	6.3	5.7	5.5	6.7
Max. speed* (mph)	39	35	46	37	27	26	23	23	25	31	51	34	51
Prevailing direction	NE	WNW	WNW	WNW	WNW	SSW	WNW	WNW	NW	WNW	NE	NE	WNW
FREEZE DAYS PER MONTH	<0.5	0	0	0	0	0	0	0	0	0	0	0	<0.5
PRECIPITATION (in. water)													
average	1.88	1.48	1.55	0.81	0.15	0.05	0.01	0.07	0.13	0.34	1.25	1.73	9.45
max/min	6.26/T	5.31/0.00	5.89/T	3.58/T	0.95/0.00	0.38/0.00	0.13/0.00	0.87/0.00	1.90/0.00	2.90/0.00	5.82/0.00	7.60/0.03	7.60/0.00
RELATIVE HUMIDITY(%)													
4 AM	68	72	74	74	76	80	81	80	78	74	73	70	75
10 AM	54	56	59	58	64	69	69	67	65	58	57	55	61
4 PM	55	57	59	58	63	67	66	66	64	61	63	57	61
10 PM	68	71	72	71	74	78	79	78	77	73	73	70	74

*"fastest mile"; speed is fastest observed 1-minute value.

■ *REAM FIELD (Imperial Beach NAS)*

CLIMATOLOGICAL DATA FOR REAM FIELD (Imperial Beach NAS)

Latitude: 32°34' Longitude: 117°07' Elevation: 33'

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
TEMPERATURE(°F)													
average monthly	55	55	57	59	62	64	68	70	68	65	59	55	61
average daily max/min	64/45	63/47	64/49	65/52	67/56	68/59	72/63	74/65	74/62	72/57	68/50	64/46	68/54
extreme max/min	83/27	83/35	84/35	88/42	92/44	89/48	84/53	85/56	108/52	105/43	98/36	85/31	108/27
DEGREE DAYS													
heating (base 65°F)	384	314	304	216	144	81	27	13	38	94	209	338	2162
cooling (base 65°F)	0	0	0	0	0	15	76	115	95	32	0	0	333
WIND													
Mean speed (mph)	7	7	7	8	7	7	6	6	6	6	7	7	7
Max. speed* (mph)	55	44	41	55	32	31	31	30	35	38	59	46	59
Prevailing direction	E	E	W	W	W	W	W	W	W	W	E	E	W
FREEZE DAYS PER MONTH	<0.5	0	0	0	0	0	0	0	0	0	0	<0.5	<0.5
PRECIPITATION (in. water)													
average	1.5	1.1	1.0	1.1	0.2	0.1	T	T	0.2	0.3	1.4	1.1	8.0
max/min	1.6	1.1	1.6	1.2	0.5	0.4	0.1	0.1	1.1	0.6	1.9	1.4	1.9
RELATIVE HUMIDITY(%)													
4 AM	77	82	84	86	84	87	88	87	86	83	79	78	83
1 PM	61	64	67	68	68	71	73	72	71	69	61	61	67

*"fastest mile"; speed is fastest observed 1-minute value

**Data for Chula Vista 32°36'N 117°06'W, Elevation 9'

CONVERSION FACTORS

	From	To	Multiply by
TIME:	years	hours	8760
	years	seconds	3.16×10^{7}
	days	seconds	86,400
LENGTH:	meters	feet	3.2808
	meters	inches	39.3701
	km	miles	0.62137
AREA:	m^2	ft^2	10.7639
	m^2	in^2	1550
	km^2	$mile^2$	0.3861
	km^2	acres	247.105
ENERGY:	kWh	Btu	3410.08
		kJ	3600
		kcal	859.326
		erg	3.6×10^{13}
	Btu	kWh	2.928×10^{-4}
		kJ	1.0548
		kcal	0.251996
		erg	1.0548×10^{10}
		therm	10^{-5}
		quad	10^{-15}
ENERGY DENSITY:	kWh/m^2	Btu/ft^2	316.815
		kJ/m^2	3600
		J/cm^2	360
		cal/cm^2 (langley)	85.935
	Btu/ft^2	kWh/m^2	3.1517×10^{-3}
		kJ/m^2	11.3538
		J/cm^2	1.13538
		cal/cm^2 (langley)	0.27125
POWER:	kW	Btu/h	3414.43
		Btu/min	56.8253
		cal/min	1.43197×10^{4}
		cal/sec	238.662
		kcal/h	859.2
		hp	1.3410
	Btu/h	kW	2.931×10^{-4}
		Btu/min	0.01667
		cal/min	4.1999
		cal/sec	0.0700
		kcal/h	0.251996
		hp	3.9275×10^{-4}
POWER DENSITY:	kW/m^2	Btu/ft^2-h	317.21
		kJ/m^2-h	3600
		W/cm^2	0.1
		langley/sec	0.23901
		langley/min	14.3406
	Btu/ft^2-h	W/m^2	3.1524
		kJ/m^2-h	11.348
		W/cm^2	3.1524×10^{-4}
		langley/sec	7.5347×10^{-5}
		langley/min	4.5208×10^{-3}

Actinograph	See Pyranograph.
Black and White Pyranometer	A thermopile pyranometer manufactured by Eppley Laboratory that is intermediate in quality between a PSP and a Light Bulb Pyranometer.
Cavity Radiometer	A type of pyrheliometer with a black cavity as the radiation absorber. These instruments provide the most accurate measure currently available of the Direct Beam (Normal Incidence) radiation.
Cloud Cover	A measure of the fraction of the sky covered with clouds. A human observer rates the cover on a scale from 0 (no cover) to 10 (completely overcast).
Cooling Degree-Days	Each degree that the mean daily temperature is *above* 65°F is called a cooling degree-day unit. The monthly value of cooling degree-days is then the sum of the degree-day units for the days in the month. Cooling degree days are not a particularly good measure of a building's cooling requirements since they do not include relative humidity effects.
Declination Angle (δ)	Consider a person standing on the equator at solar noon. The solar declination is then the angle between the sun and the local vertical. The angle varies from -23.45° at winter solstice to +23.45° at the summer solstice, where a positive angle means that the sun is to the north of the equator.
Direct Beam	The solar radiation coming directly from the sun.
Direct Beam (Normal Incidence)	The direct beam radiation incident upon a surface held normal (perpendicular) to the beam. This surface must be rotated as the sun moves across the sky. Measured by a pyrheliometer.
Diffuse Radiation	The light incident upon a surface, from the sky as opposed to directly from the sun. This light was originally from the sun but was scattered by clouds, air molecules, dust, etc. May be measured by a shadow-band pyranometer or by an ordinary pyranometer and pyrheliometer in combination.

ETR	See Extraterrestrial Radiation.
Extraterrestrial Radiation	The solar radiation received at the top of the atmosphere.
Global Radiation	Same as Total Horizontal Radiation.
Heating Degree Days	Each degree that the mean daily temperature is *below* 65°F is called a heating degree-day unit. The monthly value is then the sum of the degree-day units for the days in the month. Degree days are a fairly good measure of a building's heating requirements, for buildings of conventional construction.
Hour Angle	An angle that describes the number of hours that the sun is away from Solar Noon. Each hour corresponds to 15° of angle; positive values in the afternoon.
Insolation	Strictly speaking, the Total Horizontal Radiation. The term is often used more loosely, however, to refer to all types of solar radiation.
Isotropic	Uniformly distributed. When applied to Diffuse Radiation, refers to the assumption that (except for the sun itself) the sky is uniformly bright.
K_T	The ratio of Total Horizontal Radiation to Extraterrestrial Radiation on a horizontal surface.
Light Bulb Pyranometer	See 180° Pyrheliometer.
NIP	For Normal Incidence Pyrheliometer. A commonly used pyrheliometer manufactured by Eppley Laboratory. The sensor is a thermopile. A black surface is the radiation absorber.
Percent Possible Sunshine	The percent of the time between sunrise and sunset that the sun is shining (not obscured by clouds). Measured by a Sunshine Switch.
PSP	For Precision Spectral Pyranometer. An advanced type of thermopile pyranometer manufactured by Eppley Laboratory. "Spectral" refers to the potential use of the instrument with a colored filter to measure a portion of the solar spectrum.

Pyranograph	A type of pyranometer in which a bimetallic strip senses the temperature difference between a black surface and a white or reflecting surface. These instruments are not as accurate as thermopile pyranometers.
Pyranometer	An instrument used to measure Total Radiation. Usually mounted horizontally, but sometimes tilted.
Pyranometer (Thermopile Type)	A pyranometer with a black radiation absorbing surface. A thermopile senses the temperature difference between this hot surface and a cooler surface that is either painted white or shaded from the sun.
Pyrheliometer	An instrument used to measure the Direct Beam (Normal Incidence) Radiation. A collimator (long tube) shields the sensor from most of the diffuse sky light. Must be mounted on a sun-tracking mechanism.
180° Pyrheliometer	Archaic name for a thermopile pyranometer manufactured by Eppley Laboratory. The instrument looks like a light bulb. It is no longer manufactured. Modern pyranometers are generally considered superior.
Shadow Band Pyranometer	A pyranometer with a metal strip that shades the sensor from the direct beam radiation. Used to measure the diffuse radiation.
Sky Chart	A graph used to locate the position of the sun in the sky for any hour of the day, for any month of the year.
Solar Constant	A measure of the radiation received from the sun at the top of the earth's atmosphere.
Solar Noon	Refers to 12:00 noon in a time system (Solar Time) in which the sun is most directly overhead at noon.
Solar Time	A time system in which the sun is at its highest point in the sky at noon.
Sun Chart	See Sky Chart.

SOLAR BUILDINGS AND PLANTS
(SOUTHERN CALIFORNIA)

SOLAR BUILDINGS AND PLANTS
(SOUTHERN CALIFORNIA)

DESCRIPTIONS

The following are descriptions of solar heating and cooling systems now in operation on various buildings, mostly in the Southern California region. Though it is far from complete, this collection does represent a cross section of today's efforts to harness solar energy in simple and practical ways. Many solar buildings are presently being monitored with precision instruments to determine the performance of their solar heating and cooling systems over long periods of time.

PROJECT:	Neighborhood Central Plant San Bernardino, California
SPONSOR:	U. S. Department of Housing and Urban Development
TYPE OF SYSTEM:	Central plant to provide space and domestic water heating for a 10-house complex and space heating for a greenhouse
DESIGNER:	Solarcoa (Ken Parker) Long Beach, California
CONTACT:	Nate Rekosh San Bernardino West Side Community Development Company San Bernardino, CA

This unique system features 75 flat-plate collectors (4' x 8' each), with 5000 gallons of thermal storage capacity located centrally to provide space heat and domestic hot water for 10 houses. Fan coils at each house distribute the space heat. In addition, the solar system provides environmental control through a combination of forced air and radiant heating for a community food-growing facility.

The system is fully instrumented for data acquisition, and performance records will be available in the future. The designers estimate that the solar system will provide 100% of the heating load for seven months of the year and 70% of the yearly average load.

PROJECT:	Project SAGE Timbers Apartment Complex El Toro, California
SPONSORS:	Southern California Gas Company U.S. Energy Research and Development Administration (now part of U.S. Department of Energy) National Science Foundation
TYPE OF SYSTEM:	Hot-water system
DESIGNER:	Jet Propulsion Laboratory Pasadena, California
CONTACT:	SAGE Project Director Southern California Gas Company P. O. Box 3249 Terminal Annex Los Angeles, CA 90051 (Note: For detailed performance and economics information, request CCMS Solar Energy Pilot Study.)

Project SAGE (Solar-Assisted Gas Energy) is a hot-water heating system that is retrofitted to the plumbing system of a 32-unit apartment complex. The system has a two-fluid, two-loop configuration connected to the conventional central hot-water supply.

One loop connects a bank of solar collectors and heat exchangers in an expansion tank. Treated water is used in this loop to minimize corrosion. The second loop links the hot-water storage tank, a tempering tank, the natural gas boiler, and the hot-water system of the apartments.

PROJECT:	El Camino Real Elementary School Irvine, California
SPONSOR:	U.S. Energy Research and Development Administration (now part of U.S. Department of Energy)
TYPE OF SYSTEM:	Retrofit heating and cooling to a four-year old building
DESIGNER:	McCaughey & Smith Tustin, California
CONTACT:	Dave King Irvine Unified School District Irvine, CA (714) 556-4900

The El Camino Real School is an existing modern building, air-conditioned by a conventional heating and cooling system. The system has been solar-augmented as a retrofit to provide approximately 50% of building demands for heating and cooling.

Five thousand square feet of high-performance collectors are used to provide the temperatures needed for both heating and cooling. Cooling demands are met as much as possible during the portion of the day when the radiation levels are high enough to drive the chiller directly.

PROJECT:	Torrance School District West High School/South High School Torrance, California
SPONSOR:	Torrance School District
TYPE OF SYSTEM:	Space heat and domestic hot water for high school gymnasiums
DESIGNER:	Donnelly, Bundy Los Angeles, California
CONTACT:	Roy Donnelly Donnelly, Bundy Los Angeles, CA (213) 273-5255

West High School:	2340 sq. ft. of Revere collectors/ 2700 gallon storage
South High School:	2484 sq. ft. of Revere collectors/ 2700 gallon storage

System construction completion date: November 1, 1977.

Designers predict that this retrofit/raw-construction combination project will provide 60 to 70% of the yearly average space heating and domestic hot water energy demands.

PROJECT: American National Housing
Chino, California

TYPE OF SYSTEM: Domestic hot water

DESIGNER: Conserdyne (Howard Kraye)
Glendale, CA
(213) 846-8408

CONTACT: Same

Three model homes (single-samily dwellings) are outfitted with solar domestic hot water systems. Each house has one 3 x 10 collector and 66 gallons of storage. A mineral oil fluid flows through the collector loop and is passed through a heat exchanger in the tank. The collectors are stainless steel with a selective coating covered by 3/16-inch tempered glass.

PROJECT: Cal West Development
Buena Park, California

TYPE OF SYSTEM: Domestic hot water

DESIGNER: Conserdyne (Howard Kraye)
Glendale, CA
(213) 846-8408

CONTACT: Same

In this project, a 16-unit apartment complex meets its domestic hot water needs through use of a solar system consisting of 180 sq. ft. of collector and 322 gallons of thermal storage. A closed system is used in which a mineral oil fluid is circulated through the collectors and through a heat exchanger in the storage tank. Stainless steel collectors with a selective coating and a 3/16-inch tempered glazing are used.

PROJECT:	Gagnon Construction Long Beach, California
TYPE OF SYSTEM:	Space heat and domestic hot water
DESIGNER:	Conserdyne (Howard Kraye) Glendale, CA (213) 246-8408
CONTACT:	Same

An open solar system (water is the circulating fluid so no heat exchanger is needed) provides space heat and domestic hot water for a 12-unit apartment complex. The system consists of 630 sq. ft. of collectors and 1500 gallons of thermal storage.

PROJECT: SGD & E Solar Demonstration House
Spring Valley, California

SPONSOR: San Diego Gas & Electric Company

TYPE OF SYSTEM: Commercial flat-plate collectors providing space conditioning and domestic hot water

DESIGNER: SDG & E and Solar Utilities Company

CONTACT: Carl Welti
SDG & E
P. O. Box 1831
San Diego, CA
(714) 232-4252

The value of the solar system in this house is approximately $17,000. Under an agreement with the owners, the system is being monitored and evaluated by SDG & E for a period of two years.

The solar climate control system utilizes a two-tank system for hot and cold water storage. Auxiliary heating in winter is provided off-peak by an electric water heater. Cooling last summer was provided by nighttime circulation of water through solar collectors and by a chiller running during off-peak periods. Double-glazed windows reduce energy loss and help maintain interior temperature.

Objectives

The first objective is to demonstrate the level of performance that can be expected from this and similarly designed solar energy systems. The second objective is to demonstrate that all solar standby energy can be supplied during utility off-peak periods without inconveniencing residents of the solar house.

First-Year Operation

After the first year of operation, the solar energy system provided 98.4% of the space heat and 96.9% of the domestic hot water requirements, exceeding the predictions of 70 to 80% of the energy supply. Temperatures during the winter of 1976-77 were 60% warmer than usual.

Monitoring of the system by SDG & E will continue for another year. At the end of that time, the equipment becomes the property of the homeowners.

Other data compiled after the first year's operation include:

- Compared with electric resistance heating, the solar system supplied the equivalent of 10,941 kilowatt-hours (net) of energy. Based on replacing the solar energy with electric resistance heating, annual savings amount of approximately $480.
- Estimated solar savings, using a heat pump as the alternative space heating system, would be approximately $300 annually.
- The average monthly electrical input for the pumps was 54 kilowatt-hours, a cost of $2.30.
- The overall system coefficient of performance is 18 to 1, which means that for each unit of energy input to the solar system, 18 units of energy output were delivered to the house.
- The nocturnal cooling system provided 10% of the cooling, which did not reach the predicted 20% of space cooling. The nocturnal cooling has subsequently been discontinued.

Heating

During daylight hours, water gains heat from the sunlight by circulating through the rooftop solar collector. The heated water is stored in a 1900-gallon underground storage tank. Hot water from the storage tank is circulated through a fan coil unit within the house that extracts heat from the water and distributes it throughout the home. The system is similar to standard central heating and cooling systems, except that the heat source is provided by solar-heated hot water rather than by gas or electricity.

An auxiliary system is provided for use during periods of prolonged cloudy weather when solar heating is unavailable from the collectors. The auxiliary system, a 20-gallon hot water tank, heated by electricity, is automatically activated when the temperature in the hot-water storage tank drops below the level required to provide home heating. The water from the auxiliary tank circulates through the same fan coil system as the water heated by the solar collectors.

Cooling

During the night hours, water from a cold-water storage tank is circulated through the solar collector for cooling and then stored in the 1900-gallon underground tank. The stored cold water circulates through the fan coil unit which then distributes the cool air throughout the house. Because nocturnal cooling does not provide adequate amounts of cooling for all the daytime air-conditioning cycle, an electric chiller unit is provided to further chill the nocturnally cooled water.

Hot Water System

Tap water is piped through the solar-heated underground water storage tank before it enters the domestic hot-water tank. Supplemental heating is provided by an electric heating element in the domestic hot water tank which activates automatically as required to maintain the desired hot water temperature.

Solar Collector

The Revere solar absorber panel was selected for use in the SDG & E solar demonstration house because of its high thermal performance characteristics and because its cost, construction, and durability best met the requirements of the SDG & E system.

The Revere collector consists of rectangular copper tubes bonded to a copper absorber sheet that has been laminated to a plywood panel. Its overall size is 34 x 72 inches. Twenty-seven collectors were built into the roof of the house and covered with a single-glazed water white glass, 5/32-inch thick. Double-glazing is not being utilized because it would not significantly increase heat collection efficiency at the normal operating temperature of the system.

PROJECT:	Solar Hot Water Demonstration Project Red Star Industrial Service Laundry Fresno, California
SPONSORS:	U.S. Energy Research and Development Administration (now U.S. Department of Energy) California Energy Resources Conservation and Development Commission ARATEX Services, Inc. (formerly Work Wear Corporation)
PROJECT STATUS:	Complete - operational since July 1977
TYPE OF SYSTEM:	Integrated wastewater heat recovery/solar preheat system - retrofit industrial process water
DESIGNER:	Eric S. Burnett Director - Energy and Pollution Control ARATEX Services, Inc. (formerly Work Wear Corporation) (213) 995-2518
CONTRACTORS:	Ying Manufacturing Corporation Gardena, California (solar collectors, tank, and controls) Clarke Mechanical, Inc. Long Beach, California (mechanical installation) Home Electric Company Fresno, California (electrical installation) Heat Recovery Systems Paramount, California (wastewater heat reclaimer and controls)

The system is an integrated hot water preheating system that includes a wastewater heat recovery subsystem and a flat plate solar collector subsystem with storage. It was installed retroactively at the Red Star Industrial Service Laundry in Fresno, California, during the first half of 1977. It is designed to preheat approximately 60,000 gallons a day of city water at a temperature of between 70 and 80°F to between 125 and 135°F. The system operates in a direct, pass-through mode with no intermediate working fluid in the solar system.

The wastewater heat recovery subsystem consists of a three-section, stainless steel tube-and-shell heat reclaimer with back-flush valves and controls. Incoming city water from dual zeolite water softeners is passed through the heat reclaimer during hot water demand cycles, where it is heated to within 10°F of the wastewater temperature (typically 115 to 125°F) prior to entering the solar hot water tank. This tank has a capacity of 12,000 gallons. It is constructed of fiberglass, coated on-site with 3-in. foamed polyurethane insulation. During normal operation, water from this tank is circulated at 200 gpm through the solar array continuously, whenever the temperature differential between the solar collectors and the stored water exceeds 4.5°F.

Operation of the solar circulating loop is automatic. It depends only on the differential temperature between the array and the stored water, with time delays for shutdown and restart which obviate premature shutdown under transient cloudy conditions. Excess heat generated during weekend operation in the summer months and holidays, when the hot water demand is zero, is transferred to the wastewater sump - using reverse flow in the heat reclaimer.

The solar array consists of 140 single-glazed flat-plate collectors, each 12 ft in length by 4 ft in width, for a total nominal area of 6500 ft^2. The glazing material is Lexan 110, with a thickness of 0.020 in. Stainless steel tubes are used for the waterways and headers, while the remainder of the plumbing is copper, with dielectric isolation between collectors and the main header and return lines.

Flow equalization is provided by individual automatic flow controllers, with automatic venting of the collectors for draindown freeze protection and reduction of losses from nocturnal cooling.

Total cost of the system, including the storage tank and wastewater heat recovery subsystem, but excluding the IBM instrumentation, was $233,000. The combination of the wastewater heat-recovery subsystem and the solar subsystem is expected to reduce the natural gas requirements for hot water heating in the plant by at least 50%. The solar subsystem alone is expected to contribute between 16 and 20% to the savings in natural gas consumption, while the heat reclaimer will contribute approximately double that amount.

Before installation of the system, one therm heated 78.3 gallons of water to the desired temperature. The wastewater recovery system part of the project increases this value to 138.5 gallons. Solar energy further boosts this figure to 175.7 gallons.

The performance of the system is being monitored at the NASA installation in Huntsville, Alabama, through use of a mini-computer at the Red Star Industrial Service Laundry. This unit is linked by a WATS line to the main computer at Huntsville.

SOLAR LEGISLATION

SOLAR LEGISLATION

CALIFORNIA SOLAR LEGISLATION

Existing

(1) Legislative Number = CH. 670
Date of Action = 1976

Authorizes any city or county to require new buildings that are subject to state housing law to be constructed so as to permit installation of solar devices.

Sponsor: Senator Donald Grunsky
Senate of California
Sacramento, CA 95814

Contact: Relevant City Council or Board of Supervisors

(2) Legislative Number = CH. 168
Date of Action = 1976

Provides for income tax credit up to $1000 or 10% of the cost of a solar system in a residential or commercial structure. (superseded by AB 1558)

Sponsor: Senator Alfred Alquist
Senate Committee on Public Utilities, Transit and Energy
State Capitol
Sacramento, CA 95814

Contact: Franchise Tax Board
P. O. Box 1468
Sacramento, CA 95814
(916) 355-0370

(3) Legislative Number = S.B. 150
Date of Action = 1977

Would require governmental agencies to make a cost analysis of at least two energy systems, one of which must be solar, before construction of any building with more than 35,000 sq. ft. of floor area.

Sponsor: Senator Alfred Alquist
Senate Committee on Public Utilities,
Transit and Energy
State Capitol
Sacramento, CA 95814

(4) Legislative Number = CH. 1082 (AB 1558)
Date of Action = 1977
Signed = September 26, 1977

Provides a tax credit up to the lesser of $3,000 or 55% of the cost of a residential solar installation. For commercial or multifamily residential applications, a tax credit up to the greater of $3,000 or 25% of the cost of the solar system (per system installed). Covered under this law are acquisition and installation charges, as well as energy conservation measures taken in conjunction with the solar system. The tax credit is applicable on any installation made between January 1, 1977 and January 1, 1981. Taxpayers whose credit will exceed their tax liability may carry over the remainder of the credit and apply it against their tax liabilities for future years until the entire credit is taken, even past 1981. If and when a Federal solar tax credit is enacted, the combined State and Federal credit will not exceed 55%. In 1977, any system which uses solar energy to heat, cool or produce electricity, and which had a useful life of at least 3 years will be eligible. The State Energy Commission will establish guidelines for eligibility for future years.

Sponsor: Assemblyman Gary Hart
State Capitol
Sacramento, CA 95814

(5) Legislative Number = AB 1512
Date of Action = 1977
Signed = September 26, 1977

Requires the State Energy Commission to establish a testing and certification program for manufacturers of solar equipment (see Standards/Codes section of this Handbook). Also mandates the development of design specifications and design manuals for passive solar systems.

Sponsor: Assemblyman Vic Fazio
State Capitol
Sacramento, CA 95814

Proposed

(1) Legislative Number = SB 146
Date of Action = 1977

Exempts solar equipment attached to residential or nonresidential building or swimming pool from property taxation. Dependent upon passage of a constitutional amendment (on June 1978 ballot).

(2) Legislative Number = SCA 15
Date of Action = 1977

Would propose to voters in the 1978 Primary Election that the Legislature have the authority to exempt solar systems from property taxes (on June 1978 ballot).

Sponsor: Senator Alfred Alquist
Senate Committee on Public Utilities, Transit and Energy
State Capitol
Sacramento, CA 95814

EDMUND G. BROWN JR.
GOVERNOR

STATE OF CALIFORNIA

OFFICE OF THE SECRETARY
Business and Transportation Agency
1120 N STREET, P.O. BOX 1139
SACRAMENTO 95805

DEPARTMENTS
ALCOHOLIC BEVERAGE CONTROL
BANKING
CALIFORNIA HIGHWAY PATROL
CALIFORNIA HOUSING FINANCE AGENCY
CORPORATIONS
HOUSING AND COMMUNITY DEVELOPMENT
INSURANCE
MOTOR VEHICLES
REAL ESTATE
SAVINGS AND LOAN
TRANSPORTATION

CALIFORNIA SOLAR INCOME TAX CREDIT

(Subject to Minor Changes)

Passage of AB 1558 (Hart, 1977) permits California taxpayers to claim as an income tax credit up to 55% of the cost of purchasing and installing solar energy systems, under the following conditions:

1. The taxpayer must own the property at the time the solar system is installed.
2. The solar system must be installed between January, 1977, and December, 1980.
3. Any of the following solar applications will qualify (partial list):
   a. Solar water heater in new construction.
   b. Solar-assisted heat pump.
   c. Water-heater insulation and/or pipe insulation, if in conjunction with solar water heating.
   d. Hot water conservation measures (reduced flow devices).
4. The tax credit must be claimed the year of the solar installation and can be carried forward until used up.

As of January 1, 1978, interim criteria <u>may also</u> apply these requirements in claiming the solar tax credit*:

1. <u>Performance</u>. The solar system must either provide 55% of the annual heating load <u>or</u> be cost-effective over its life-cycle (including the benefits of the tax credit).
2. <u>Minimum Warranties</u>. Five-year parts warranty on collector, storage tank, and heat exchanger, <u>and</u> one-year warranty on entire system.
3. <u>Certification Standards</u>. The State Energy Commission expects to have, by about April 1978, criteria for certification of collectors acceptable for the tax credit. A solar system may be eligible for the tax credit, pending certification of testing results, as long as:

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*Draft regulations covering these issues will be made public in late November and final regulations will be issued by January 1, 1978.

a. The product installed is on the waiting list to be tested, or is not of a type to be tested; and

b. The product installed receives temporary approval, which can be attained through:

- The manufacturer's or dealer's guarantee to refund an amount equal to the applicable tax credit (if the system is not certified); or
- The Energy Commission's acceptance of "proof of performance" data provided by the manufacturer, including addresses of collector/system installations in California. (California Department of Housing and Community Development will assist in this task.)

The solar installation must meet existing building codes and be authorized by a building permit as per those codes.

Limits of the California solar tax credit are as follows:

1. According to the purchase-plus-installation costs of each solar system:

   a. Up to $6,000, credit equals 55%, to $3,000 maximum.

   b. Beyond $6,000, credit equals 25% or $3,000, whichever is greater.

2. Owners of apartments or condominiums with solar systems costing more than $12,000 are eligible only for a 25% credit, except condominium owners can claim the 55% credit if a separate solar system is installed for each unit.

3. Any federal solar income tax credit will deduct an equivalent amount from the available California credit. That is, the combined federal and state credits granted cannot exceed that allowed by the state. The federal credit would be used first.

Information Sources

Solar Energy Advocates
P. O. Box 876
Sacramento, CA 95814

SUNRAE
P. O. Box 915
Goleta, CA 93017

California Energy Resources Conservation and Development Commission
Public Information Office
1111 Howe Avenue
Sacramento, CA 95814
(800) 852-7516

FEDERAL SOLAR LEGISLATION

Existing

(1) Public Law No: 93-409, enacted, 9/3/74
Brief Title: Solar Heating and Cooling Demonstration Act of 1974
Original Bill No: HR 11864, introduced, 12/10/73
Sponsor: McCormack

Purpose: To provide for the early commercial demonstration of technology for solar heating and combined solar heating and cooling (funds through NASA, HUD, NSF, GSA). Authority of the Act was transferred to ERDA when that agency was activated 1/19/75.

(2) Public Law No: 93-383, enacted, 8/22/74
Official Title: Community Development Assistance Act
Original Bill No: S 3066, introduced, 2/27/74
Sponsor: Sparkman

Purpose: To consolidate, simplify, and approve laws relative to housing. To provide federal funds for community development.

(3) Public Law No: 93-438, enacted, 10/11/74
Brief Title: Energy Reorganization Act of 1974

Purpose: Created the U.S. Energy Research and Development Administration (ERDA) and the Nuclear Regulatory Commission (NRC).

(4) Public Law No: 93-473, enacted, 10/26/74
Official Title: Solar Energy Research, Development, and Demonstration Act of 1974
Original Bill No: S 3234, introduced, 3/26/74
Sponsor: Humphrey

Purpose: Authorizes a vigorous federal program of R&D, provides for the development of suitable incentives for rapid commercialization. In addition, the Act provides for an NSF program of education in solar engineering, establishes a Solar Energy Research Institute and a Solar Energy Information Data Bank. Authority for this Act also transferred to ERDA on 1/19/75.

(5) Public Law No: 94-187, enacted, 12/31/75
Brief Title: ERDA Authorization
Original Bill No: HR 3474
Sponsor: Price

Purpose: Authorizes appropriations to ERDA (including solar budget).

(6) Public Law No: 94-385, enacted, 8/14/76
Brief Title: Energy Conservation and Production Act
Original Bill No: HR 12169, introduced, 2/25/76
Sponsor: Staggers

Purpose: Amends the Energy Policy and Conservation Act to authorize appropriations for FEA functions (i.e., development of a National plan for accelerated commercialization of solar). Establishes a residential solar and energy conservation demonstration program with HUD. Establishes, through FEA, a states loan guarantee program.

(7) Public Law No: 94-431, enacted 9/30/76
Brief Title: Military Construction Authorization Act
Original Bill No: HR 14846, introduced, 7/26/76
Sponsor: Ichord

Purpose: Authorizes certain construction at military installations. Mandates use of solar energy on these installations whenever economically feasible.

(8) Public Law No: 95-39, enacted, 6/3/77
Brief Title: Energy Research
Original Bill No: S 36, introduced, 1/10/77
Sponsor: Jackson

Purpose: Authorizes appropriations to ERDA

(9) Public Law No: 95-82, enacted, 8/1/77
Brief Title: Military Construction Authorization Act
Original Bill No: S 1474, introduced, 5/9/77
Sponsor: Hart

Purpose: Authorizes certain construction at military installations.

Proposed

Throughout the many recently introduced Federal Solar Bills there is a common objective: market penetration for solar applications. It is universally accepted that hindrances must be removed and incentives established if solar energy is to displace a significant amount of fossil fuel in the near future. Many solar bills were introduced in 1977 which are intended to overcome the hindrances; the status of these bills changes frequently. This Handbook presents a survey of the legislative approaches currently being taken and a few sources of further information.

Incentives for Consumers

Tax credits. To offset the high initial cost of a solar installation, an individual might claim an income tax credit for a portion of solar expenditures; businesses could claim an investment tax credit. A combination of State and Federal tax credits could return as much as 55% of the initial cost, helping to bring solar into cost-competition with fossil fuels.

Amortization schedule. Consumers would be allowed to extend the amortization schedule for solar expenditures.

Property and sales tax exemptions. Solar energy equipment or systems would neither increase the property tax assessment of the building on which they are installed nor be subject to State sales tax.

Low interest loan/loan guarantees. Low interest or federally guaranteed loans would be provided for solar installations. These programs could be administered through various existing agencies such as VA, FHA, SBA, DOE, etc., or through a newly-created "Solar Loan Administration."

Sun rights. Any new construction that would interfere with solar radiation falling on existing solar heating and cooling systems or equipment would be prohibited.

Community leasing programs. Grants would be provided for the establishment of community programs to purchase solar equipment and lease it to local residents at low cost.

Incentives for Agricultural Applications

Research and development. Funds would be provided for investigation of solar-driven irrigation, and solar heating and cooling of farm buildings and homes.

Information dissemination and demonstrations. An agricultural solar information network would be established to provide design data and technical assistance. A series of solar demonstration farms could be included as part of this program.

Family farms. Assistance would be provided for solar heating and cooling of buildings located on family-owned farms.

Advancement of the Solar Industry

Solar utilization on federal buildings. Outfitting of new and existing government buildings with solar heating and cooling equipment and photovoltaics would be mandated. Federal buildings would be subject to energy audits and would be brought up to maximum thermal efficiency.

Solar utilization on state and city facilities. Federal matching funds would be provided to assist states and localities in providing solar energy systems for public buildings.

Solar for hospitals. Loans and grants would be provided to allow hospitals to utilize solar space and water heating.

Developing nations. Cooperative programs would be established with less developed countries for the advancement of appropriate, nonconventional technologies.

Solar inventions and businesses. A program of grants, loans, and loan guarantees would be set up to assist inventors (individuals and small businesses) as well as small businesses involved commercially in solar energy.

Department of Energy (DOE)

General solar funding. The amount of appropriations to DOE that are earmarked for solar would be increased; specific projects/programs would be funded through DOE.

Energy extension service. As a branch of DOE, the Energy Extension Service would provide technical assistance and training on a grassroots level.

Interfuel Competition

It would become unlawful for any integrated company to own or control any coal, oil shale, tar sands, uranium, geothermal steam or solar energy asset.

Information Sources on Federal Legislation

Solar Energy Intelligence Report
P. O. Box 1967
818 Roeder Road
Silver Springs, MD 20910

Washington Energy Monitor
Washington News Services, Inc.
9908 Hillridge Drive
Kensington, MD 20795

Solar Energy Industries Association
1001 Connecticut Avenue, N.W.
Washington, D.C. 20036

Susannah Lawrence
Consumer Action Now
317 Pennsylvania Avenue, S.E.
Washington, D.C. 20003

J. Glen Moore
Library of Congress Research Service
Washington, D.C. 20003

Weekly Energy Report
1238 National Press Building
Washington, D.C. 20004
(202) 638-4260

STANDARDS/CODES AND TESTING

STANDARDS/CODES AND TESTING

SUMMARY

Solar equipment will have to be approved according to conventional building and mechanical codes, as well as by codes specifically designed to regulate solar installations. In Southern California, as well as in other western states, the most commonly used code is the International Conference of Building Officials (ICBO) Uniform Building Code (UBC). This code is fairly restrictive in that it does not allow the building official a great deal of discretion in approving alternative materials or methods. At present, the UBC mandates that heating systems capable of maintaining a 70°F temperature three feet above the floor be installed in all habitable rooms in residences. Solar systems and associated distribution (piping and ducting) are also required to comply with the Uniform Mechanical Code and the Uniform Plumbing Code, which are adjuncts of the UBC. (For an up-to-date report on national certification, see "Where are the Standards?", page 7, Solar Engineering, February 1978.)

LOS ANGELES SOLAR GUIDELINES

Minimum guidelines are now in effect in Los Angeles for solar systems to meet the building and safety codes. The guidelines present the building permits and operating requirements for the installation of solar systems. If there is noncompliance, it is stated that the solar devices installed are subject to penalty, fines, and/or removal.

The approval of the Mechanical Testing Laboratory of the Department of Building and Safety is required for all hydraulic solar heating and/or solar cooling systems. Evaluation and approval is based on the total recommended solar system installation, not on its component parts. In addition, a list of approved materials has been cited by the Laboratory. For absorber plates, these are type K, L, or M copper tubing with brazed water-ways, galvanized steel piping, or stainless steel. Other materials must be evaluated for fire resistance, corrosion resistance, toxicity, and suitability for intended use.

Metal frames are approved materials, whereas wood or other combustible materials are subject to further approvals. If the frames are an integral part of the roof, the materials must meet existing building codes.

Impact resistant glass is preferred for glazing; however, plastic is acceptable. Materials that are not impact-resistant are limited to areas where breakage could not be harmful to people.

Connections and joints are subject to the plumbing codes and should be designed to allow for necessary contraction and expansion. Test pressures in swimming pool systems, other than the trickle type, will be 50 psi gauge at normal operating temperature. Potable water systems will be tested at 150 psi gauge, and indirect systems will be tested at one and one-half the working pressure rated by the manufacturer.

Tanks in the system are required to be constructed to current ASME, AGA, UL, or other commonly accepted criteria. Those in contact with potable water should be constructed of nontoxic materials. A separation is required between potable water and nonpotable systems.

Heat exchangers will be evaluated for corrosion and performance in accordance with pressures, temperatures, fluids, and/or gases used in the proposed system. In addition, the heat exchanger must have an exposed area where leaks in the system can be seen. If a nontoxic fluid is used, single wall separation is acceptable.

Approved piping materials are copper tubing, galvanized steel, and certain plastics. Others must be approved. Copper water tubing must be of Type K or L. Type M may be used above grade at working pressures of less than 100 psi. Plastic piping is approved for underground cold water use only. Plastic piping in contact with potable water will be tested by the National Sanitation Foundation or other appropriate agency to assure nontoxicity. Plastic pipe is allowed for swimming pool use at temperatures up to 120°F and 35 psi gauge maximum pressure.

Backflow or antisiphon valves are required to separate potable water piping and nonpotable piping or swimming pool systems.

Control devices must be approved by the Laboratory or other acceptable testing agency. Electrical equipment and hookups should conform to electrical code requirements. Pneumatic and hydraulic control devices will be evaluated for possible cross connections, toxicity, and pressure and temperature ratings of the device in contact with the operating fluids.

The Laboratory requires that manufactueres supply curves showing head-loss versus flow for panel or panel array, calculated or tested stagnation pressure and temperature values under maximum exposure, and a sample collector panel for evaluation of workmanship.

The guidelines also establish fees for Laboratory approval: Mechanical: $275, initial submission; $110, yearly renewal. Electrical: $140, initial; $85, renewal. Building: $275, initial; $110, renewal.

Complete instructions on system operations and manuals must be sited within a 40 mile radius of the Laboratory.

Copies of the guidelines--which follow in this handbook--may also be obtained from the Los Angeles Department of Building and Safety Approval, 402 City Hall, Los Angeles, CA 90012.

CITY OF LOS ANGELES

CALIFORNIA

TOM BRADLEY
MAYOR

DEPARTMENT OF
BUILDING AND SAFETY
402 CITY HALL
LOS ANGELES, CALIF. 90012

MEMORANDUM OF GENERAL DISTRIBUTION - #21 (revised)
February 17, 1977

GUIDELINES FOR SUBMITTING AND INSTALLING SOLAR DEVICES FOR LOS ANGELES DEPARTMENT OF BUILDING & SAFETY APPROVAL

The guidelines listed below are designed to facilitate the approval, installation, and inspection of solar devices installed within Los Angeles City. As with any new technology and devices, there are many questions and procedures that still have to be answered and developed. The purpose of these guidelines is to help answer some of these questions and insure speedy processing of projects using solar devices. These guidelines are designed so that the applicant can provide the Department of Building and Safety with the information needed to evaluate and inspect a solar system installation.

If you have any questions or need additional information, contact the Energy Coordinator, Richard Whitson, of the Department of Building and Safety at (213) 485-2320.

NEW CONSTRUCTION OR SOLAR ADDITIONS TO EXISTING STRUCTURE

When submitting plans that incorporate solar devices, the following information is the minimum that should be included in the plans and specifications:

1. Electrical Schematics for all electrical items in the total solar installation, including the control system and all control system interfaces: Electrical equipment shall be in a weather proof enclosure and approved low energy cable shall be used for all open wiring of sensing units. Class II wiring (24 volts or less) which is not concealed within a building shall be installed as required for Class I systems.

2. Complete plans and substantiating design calculations including wet and dry weights per square foot on all roof mounted solar collectors: Detailed information on how any roof mounted devices will be secured and information regarding wind loading for roof mounted

devices shall also be provided. These two items are not required for collectors with a filled weight of less than two pounds per square foot of panel area or where they do not provide shelter for human occupancy. For roof mounted collectors under two (2) pounds/square foot or where not providing shelter for human occupancy there should be sufficient mounting hardware to insure they will not blow away in the event of high winds or other natural causes. Where one-hour roof construction is required, combustible panels shall be limited to 20% of the roof area over which they are installed. Access passageways conforming to 91.3601(e) shall be provided for buildings other than one family dwellings.

3. Plumbing runs and heat exchange fluids if any are used: Plans must provide protection against the siphoning or pumping of water out of the storage tank (or swimming pool) in the event of a leak in the solar device.

4. Fire District Information: Combustible collector units, i.e. plastics, are not permitted in Fire Districts No. 1 or No. 2. Plastic collector units may be used in the Mountain Fire District and Fire Buffer Zone when approved for such use by the Building Research Division.

5. Zoning Information: The collectors may be installed on a roof of a building or in any vacant area where a main or accessory building is permitted, provided they conform to the same height and yard restrictions as for a building. Solar heater accessory equipment may be located with the same limitations as specified in RGA 12-71 (Allowable Projections and Improvements in Required Yards).

6. Permits: Building and plumbing permits are required, and electrical permits may be required, on all installations. For building permits, use a #3 application when heaters are to be a part of an existing structure or a #1 application when on detached ground supported racks. The valuation shall be not less than $5.00 per square foot for the first 150 square feet or fraction thereof of solar heater area, and $3.00 per square foot for that area exceeding 150 square feet.

Minimum supporting wood framing is included in these valuations.

Solar devices installed without the necessary permits are subject to penalty fines and/or removal. In addition, legal action can be taken against the owner of the property.

A solar heater system is installed with a new swimming pool is included on the #7 application. Installations for comfort heating or for exisiting swimming pools require separate building and mechanical permits. Mechanical permit fees should be code fees, such as $5.00 for pool piping.

7. Grading Information: Preinspection in a "hillside area" will only be required where installations are located on lot slopes, grading is involved or where the drainage pattern is changed. Plans must indicate location of ground-mounted devices with respect to slopes.

8. Material Information: The solar collector panels may be of either incombustible materials such as metal piping or of combustible materials such as plastic-formed products. Plastic heater units must be constructed of plastics which have been approved by the Building Research Division for this use.

9. Mechanical Testing Laboratory Approval: Approval of the Mechanical Testing Laboratory is required for collectors.

   EXCEPTION: Mechanical Testing Laboratory approval is not required where the collector piping is of materials approved by the Plumbing Code (i.e. galvanized pipe, copper tubing, etc.) and the hydraulic characteristics may be determined by engineering analysis.

During the construction phase of the project, the solar devices will be inspected as any other item is by the Department of Building and

Safety. They will be inspected for compliance with approved plans and specifications. If there is a minor deviation from the approved plans, the building inspector may authorize the change. If there is a major change, the revised items must be resubmitted through Plan Check.

APPROVED

R L Hohman

R. L. HOHMAN, Chief
Engineering Research and
Development Bureau

Read By:

Adolphe
Kreeger
Newswanger
Russell

Approved for release by Jack M. Fratt

CITY OF LOS ANGELES

CALIFORNIA

TOM BRADLEY
MAYOR

DEPARTMENT OF
BUILDING AND SAFETY
402 CITY HALL
LOS ANGELES CALIF 90012

R. J. WILLIAMS
GENERAL MANAGER

MEMORANDUM OF GENERAL DISTRIBUTION - #25
February 17, 1977

GUIDELINES FOR LABORATORY APPROVAL OF SOLAR SYSTEMS

PURPOSE

The guidelines specified in this Memorandum are designed to acquaint the solar system and device manufacturers with the submittal requirements and type of testing that the Los Angeles Mechanical Testing Laboratory will require before granting approval of the system.

As with any new technology these tests will be updated and revised as more knowledge and experience is gained with solar equipment. The purpose of these guidelines is to set forth the minimum standards equipment must meet for Los Angeles Code approval. Manufacturers are encouraged to have additional testing performed on their equipment and to submit the results of the testing to the Testing Laboratory as part of their submittal. However, the additional testing is not mandatory for Testing Laboratory approval.

If you have any questions, or need additional information, contact the Director of the Mechanical Testing Laboratory, John Meacham, Department of Building and Safety at (213) 485-2314.

APPLICATION

All hydraulic solar heating and/or solar cooling systems intended for installation within the City of Los Angeles are required to be approved by the Mechanical Testing Laboratory of the Department of Building and Safety in accordance with the guidelines specified herein and the requirements of the Los Angeles Municipal Code.

The Mechanical Testing Laboratory evaluation and approval is to be based on the total recommended solar system installation. Evaluation and approval of component parts will be considered only within the context of a total recommended or actual system.

COLLECTOR REQUIREMENTS

A. Materials: The Laboratory will review the collector materials and manufacturing procedures used in assembling the collector. The following criteria will be used in evaluating the collector:

1. Absorber: Type K, L, or M copper tubing with brazed water ways, galvanized steel piping or stainless steel are approved materials. Other materials will be evaluated for fire resistance, corrosion resistance, toxicity and suitability for intended use by the Laboratory or other appropriate agency.

2. Frames: Metal frames are approved materials. Wood or other combustible materials shall require Building Research Division approvals. Where the collector is to be an integral part of the roof, the materials used in the collector shall be approved as an acceptable roofing material as defined in the Building Code.

3. Glazing: Impact resistant glass is the preferred material, however, plastic glazing is acceptable. Non-impact resistant materials will be limited in their location applications, i.e. they cannot be in areas where any resulting breakage may be harmful to people.

B. Connections:

1. All connections between collector panels and to the associated piping systems shall be designed to allow for necessary contraction and expansion.

2. All other joints and connections shall be made in accordance with the Los Angeles City Plumbing Code.

C. Test Pressures:

1. Swimming pool systems other than trickle type shall be tested at 50 psi gauge at normal operating temperatures.

2. For direct potable water systems the collector and system shall be tested to 150 psi guage.

3. Indirect systems shall be tested at one and one-half the working pressure rated by the manufacturer.

D. Head Loss: The manufacturer shall supply curves showing head loss versus flow for panel or panel array.

E. Stagnation Values: The manufacturer shall supply calculated or tested stagnation pressure and temperature values under maximum solar exposure.

F. Sample: The manufacturer shall supply the Testing Laboratory with a sample collector panel for evaluation of workmanship.

STORAGE TANK REQUIREMENTS

A. General: Tanks shall be constructed to current ASME, AGA, UL or other commonly acceptable criteria.

B. Potable Water Systems: Tanks in contact with potable water shall be constructed of non-toxic materials.

C. Non-Potable Systems: Separation between potable water and non-potable systems shall be maintained in accordance with Chapter 10 of the Los Angeles City Plumbing Code.

HEATING EXCHANGER REQUIREMENTS

A. General: Heat exchangers will be evaluated for corrosion and performance in accordance with the pressures, temperatures, fluids, and/or gases to be used in the proposed system.

B. Heat Exchangers Containing Potable Water: Double wall separation is required between any toxic fluids and the potable water supply. In addition, the heat exchanger must have an exposed area where leaks in the system can be seen. Only single wall separation is required if a non-toxic fluid is used. However, the system must be under manufacturer's control to guarantee that no toxic fluid will be used in the system. Evidence shall be provided that a quality assurance program is employed by the manufacturer. If the system is not under manufacturer's control, the Testing Laboratory will not approve single wall systems.

C. Space Heating and Cooling Systems: Consult with the Mechanical Testing Laboratory for space heating and cooling systems to be used in specific installations.

PIPING REQUIREMENTS

A. General: Copper tubing, galvanized steel and some plastics are presently approved piping materials. Other piping materials will be evaluated in accordance with its intended application and use.

B. Metallic Pipe: Copper water tube must be of Type K or L. Type M tubing may be used above grade at working pressures of less than 100 psi.

C. Non-Metallic Pipe: Plastic piping is approved for underground cold water use only. Plastic piping in contact with potable water shall be tested by the National Sanitation Foundation or other appropriate agency to assure non-toxicity.

Plastic pipe is allowable for swimming pool use at temperatures up to 120°F. and 35 psi gauge maximum pressure.

D. Back Flow or Anti-Siphon Valves: Any direct connection between potable water piping and non-potable piping or swimming pool systems shall be separated by an approved back flow and/or anti-siphon valve listed by the Los Angeles City Testing Laboratory. (See Chapter 10 of the Los Angeles City Plumbing Code.)

CONTROL DEVICE REQUIREMENTS

A. General: Control devices will be evaluated in accordanc with the requirements of the proposed system. All devices must be approved by the Los Angeles City Testing Laboratory or other acceptable testing agency.

B. Electrical Control Device: Electrical equipment and hook-ups shall be of approved types and shall conform to the Electrical Code requirements. When such approval does not permit exterior exposure, a weather proof enclosure shall be provided. Low-energy cable shall be used for open wiring of sending units. Class II wiring (24 volts), which is not concealed in the building, shall be installed as per Class I requirements. Systems with manual controls rather than automatic controls will be evaluated on an individual basis.

C. Pneumatic and Hydraulic Control Devices: Pneumatic and hydraulic control devices will be evaluated for possible cross connections, toxicity, and pressure and temperature ratings of the device in contact with the operating fluids.

INFORMATION REQUIRED WITH APPROVAL APPLICATION

The following information should accompany the request for Mechanical Testing Laboratory approval:

1. Completed application along with appropriate fees as required by ordinance.

SCHEDULE OF FEES

Approval	Initial Submission	Yearly Renewal
Mechanical	$275	$110
Electrical	140	85
Building	275	110

2. Engineering drawings and flow diagrams of the total system to be considered.

3. Written instructions for the installation operation and maintenance of the system.

4. Statement as to recommended and non-recommended areas of use.

5. Manufacturer statement as to safety devices and/or design features incorporated to prevent system damage from over pressuring, extreme temperature conditions, freezing and other extreme operating conditions.

6. Samples of identification or labeling of the total system and components and materials used in the system.

7. Location of a complete operational system that is available for inspection and within 40 miles radius of Testing Laboratory.

APPROVED

R L Hohman

R. L. HOHMAN, Chief
Engineering Research and
Development Bureau

le/mp

Read By

Adolphe
Kroeger
Newswanger
Russell

APPROVED BY ______________________
JACK M. FRATT DATE

Existing building codes affect solar hvac system installation

Most states and municipalities do not have building codes that deal specifically with the installation of solar hvac systems.

However, many states do follow recognized model building codes such as those established under the Uniform Building Code in the western states, the Basic Building Code in the mid-western and northeastern states, the Southern Standard Building Code in the southeastern and southern states and the National Building Code, no particular region. If a state does not enforce a statewide mandatory or voluntary building code, the responsibility is left up to the local municipality or major cities within the state.

Since these codes do not contain special sections applying to solar energy hvac systems, the existing general provisions will be applied to such systems. In a 1976 survey, the General Electric Company indicated that these existing codes have an impact on the installation and operation of solar hvac systems.

The General Electric survey demarked several areas of concern:

Existing codes may affect the economics and increase the cosεs of such systems in the following areas:

- the application of requirements for safety devices such as energy shutoffs, pressure relief devices and temperature relief devices;
- the application of fire ratings intended for combustion devices and equipment operating at higher temeratures than solar systems;
- sizing procedures for water heaters which result in drastically oversized water heating systems;
- the special location of mechanical equipment rooms when ammonia is used in refrigeration systems, such as absorption systems;
- an increase in the solar system requirements with stringent requirements for the construction and inspection of unfired pressure vessels and the interpretation of the catagory of boiler or pressure vessel type in which a solar collector system might be classified.

Codes affecting installation and the design of systems in the following areas:

- requirements that fired or powered equipment is not located in occupied or habitable space;
- provisions for clearances around fired or unfired pressure vessels to permit service access, which could affect the layout of solar collectors;
- requirement for fire resistive enclosures around all vertical shafts or ducts which penetrate the floor to prevent the spread of smoke or flames;
- applications of structural requirements for roof mounted signs to solar collectors in regard to appearance, materials and structure;
- prohibitions against the use of toxic and flammable refrigerants in air conditioning systems or procedures for disposing of waste materials and liquids which might be used in solar systems.

Approvals on materials

In some codes, the materials of construction and installation for hvac systems are specified for various classifications of buildings by occupancy or use groups, fire zone location and the type of construction.

Approvals may also be required for the use of materials or methods of construction not specifically defined within the code. Equivalency tests for alternatives may be prescribed in terms of quality, strength, effectiveness, fire resistance, durability and safety.

In addition, state legislative activities may influence the use of solar systems. Several states have laws that standardize the design and installation of solar energy systems. Other state legislation may affect the economics by reduced property assessments, tax deductions, tax incentives and special utility rates on solar energy systems.

Report recommendations

With the wide variety of state building code policies, the General Electric report concludes that it is difficult to predict the exact effect of existing codes. Since a wide variety of interpretations is possible, the report urges the national model code associations to establish special solar energy regulations apart from the existing building codes since the majority of the states with state building codes follow the national model codes.

The survey of existing statewide codes on solar hvac systems, commercial buildings, was sponsored by the Energy Research and Development Administration Division of Solar Energy. It is available from the National Technical Information Service, U.S. Department of Commerce, Springfield, Va. 22161. Paper copy, $6.75, domestic; $9.25, foreign: microfiche, $3, domestic, and $4.50, foreign.

Recommended installation procedures now available

Several organizations and government agencies have already proposed installation procedures, which are being considered for adoption by states and municipalities in several areas. These are:

HUD Intermediate Minimum Property Standards Supplement (1977 Edition), Solar Heating and Domestic Hot Water Systems, prepared by the Department of Housing and Urban Development and the National Bureau of Standards. Available from the General Printing Offices, HUD No. 4930.2. Price: $12.00.

Heating and Air Conditioning Standards for One and Two Family Dwellings and Multifamily Housing Including Solar, prepared by the Sheet Metal and Air Conditioning Contractors National Association, Inc. Copies may be obtained by writing SMACNA, 8224 Old Courthouse Road, Vienna, Virg. 22180. *(Please note this correction to SMACNA's address as given in the June issue of Solar Engineering Magazine, page 11).*

The Uniform Solar Energy Code, prepared by the International Association of Plumbing and Mechanical Officials (IAPMO). Copies may be obtained from IAPMO, 5032 Alhambra Ave., Los Angeles, Calif. 90032.

Installation comparisons

A comparison of the HUD, IAPMO and SMACNA requirements for installations and materials appears on pages 36–39. The summary was prepared for *Solar Engineering Magazine* by William B. Davis, of Travis-Braun & Associates, Dallas, Houston and San Antonio.

Recommended installation procedures

HUD Intermediate Standards	SMACNA Installation Standards	IAPMO Solar Code
Section 1. Collectors		
A. Performance Evaluation *S-515-2.1.2:* Recommends use of ASHRAE 93-77 for uniform basis in comparison of collector performance.	None	*Page 43, section 701H:* Requires listing by an approved agency.
B. Absorber Plate *S-515-2.3 (also tables S-515-2.3.2 and S-515-2.3.3):* Lists materials and their acceptable use condition.	None	*Page 43, section 701 and pages 22-23, table A:* Lists acceptable materials and their use.
C. Insulation *S-515-11:* Recommends "flame retardant materials which are treated to sustain high temperature without out-gassing.	None	*Page 43, section 701F:* Plastic used in collector construction shall be suitable for that application.
D. Glazing *S-515-2.2 and S-601-7:* Recommends the use of tempered glass and impact resistant plastic with edge grinding or treatment.	None	*Page 43, sections 701 and 702:* Surfaces shall be of tempered glass or suitable plastic.
E. Absorber Surface *S-515-2.4:* Recommends materials tested in accordance with ASTM methods for life expectancy.	None	*Page 43, section 701A:* Materials in exterior locations shall be suitable for that application and protected from corrosion.
Section 2. Heat Transfer System		
A. Piping *S-615-10:* Refers to local plumbing code.	*Pages 3-2:* Outlines basic design information; no codes or standards given.	*Page 36, section 402B:* Non-potable water lines must be posted "Danger Unsafe Water." Other pages list acceptable piping.
B. Duct Work *S-615-13:* Refers to ASHRAE Guide and manuals of NESCA and ARI.	*Pages 3-1, 2:* Ducts may be of sheet metal or fibrous glass. Also outlines good practice in duct design.	*Page 47, section 802 and page 49, section 901:* Refers to Mechanical Code of ICBO.
C. Hangers and Supports *S-615-3:* Shall be done in accordance with local codes.	None	*Pages 27-28, section 306:* Horizontal piping (screwed pipe) shall be supported each 10 feet, copper tube each 6 feet.
D. Pumps *S-515-6 and S-615-5:* Shall be in compliance with the requirements of the Hydraulic Institute.	*Page 4-2:* Pump capacity must match the required head and gpm.	*Page 25, section 301:* Components shall conform with applicable codes, rules, regulations and ordinances.

Abbreviations: **AASHTO**—American Association of State Highway and Transportation Officials; **ANSI**—American National Standards Institute, **ARI**—American Refrigeration Institute, **ASHRAE**—American Society of Heating, Refrigerating and Air Conditioning Engineers; **ASTM**—American Society for Testing Materials; **ICBO**—International Conference of Building Officials; **MPS**—Minimum Performance Standards; **NBS**—National Bureau of Standards; **NESCA**—National Environmental Systems Contractors Association; **NFPA**—National Fire Protection Association; **TEMA**—Tubular Exchangers Manufacturers Association; **UL**—Underwriters Laboratories.

HUD Intermediate Standards	SMACNA Installation Standards	IAPMO Solar Code
E. Valves *S-515-5 and S-615-4 (also appendix tables B-4 and B-5):* Provides useful standards.	None	*Page 37, section 403:* Up to 2 inches shall be copper alloy; over 2 inches, valves may be iron with alloy parts.
F. Fluids *S-515-8:* Selected fluid must match maximum and minimum temperature requirements. Toxic materials must be isolated from potable water.	None	*Page 35, section 402:* Recommends cross-connection control between potable and non-potable water supplies.
G. Gaskets *S-515-10:* Must be compatible with their use and the substrate to which they are exposed.	None	*Pages 39-40, chapter 5:* Covers compatability of piping and materials in detail.
H. Controls, Liquid *S-615-14:* System must have pressure relief valves and over temperature controls.	*Pages 6-1 through 6-6:* Over temperature controls thermostats, differential thermostats.	*Page 37, section 405:* Requires pressure and/or temperature and pressure relief devices in closed systems.
I. Controls, Air *S-615-14:* See Controls, Liquid above.	*Pages 7-1, 2, 3, 4:* Relates common accepted practice in air distribution control.	*Page 49, section 901:* Refers to mechanical codes for acceptable practices.
J. Corrosion Control *S-515-2.3.2.3 and table S-515-2.3.1:* Lists the various metals and their most appropriate use.	*Pages 18-1, 2:* Recommends the use of galvanic anodes, protective coatings and isolating of dissimilar metals.	*Pages 41-43, chapters 6 and 7:* Tanks and collectors. *Page 36:* Water piping; *Pages 26-27, section 305:* Corrosion control.
K. Domestic water heating *S-615-1.4:* Establishes minimum daily use of 50 gallons (75 with dishwasher).	*Page 19-1:* An expansion tank must be used in closed system.	None
L. Expansion Tanks *S-615-7.3.2:* Must take 1½ times the system design pressure; for sizing refer to ASHRAE Guide.	None	*Page 42, section 602:* Covers open and closed expansion tanks, including capacity.

Section 2a. Heat Transfer Fluids

A. Separation *S-615-10.1.1:* Systems must have minimum 2 walls between potable and non-potable water.	None	*Pages 35-36, sections 401 and 402:* Direct connections between potable and non-potable lines.
B. Types *S-615-8:* Any toxic solution used must carry a strong non-toxic dye or other means of leak detection.	*Page 8-1:* A double wall heat exchanger is mandatory with toxic fluids.	None
C. Toxic Materials *S-615-8:* Same as (B) Types, above. Systems must be rendered child proof.	None	*Page 36, section 402B:* Non-potable lines posted "Danger Unsafe Water" if can be mistaken for drinking purposes.

HUD Intermediate Standards	SMACNA Installation Standards	IAPMO Solar Code
D. Identification *S-615-8.1.3:* All systems containing toxic fluids must be clearly marked.	None	Same as previous listing

Section 3. Heat Storage Systems

A. Heat Exchanger *S-515-9 and S-615-12:* Manufacturing by TEMA requirements. Double wall between potable and non-potable liquids.	*Page 4-2:* Must be manufactured to comply with TEMA requirement.	*Page 37, section 403E:* Copper tube heat exchanger bundle shall be constructed of not less than Type L copper tube.
B. Storage Vessels *S-601-12:* Must be designed to withstand 1½ times the designed working pressure.	*Pages 11-1:* Tank should be located in dwelling, be equipped with pressure relief valves and be treated to reduce corrosion.	*Page 41, chapters 6 and 7:* Shall be designed to local standards.
C. Expansion tanks *S-615-10.9:* Must be provided for system fluid thermal expansion, sized according to ASHRAE Guides.	None	*Page 42, chapters 6 and 7:* Required only when design uses pressure or is closed system.
D. Insulation *S-515-11.2.3:* Indicates material waterproofing and vapor barrier requirements.	None	*Page 47, chapters 6 and 7:* Two per cent loss of heat energy in 12 hours.
E. Location *S-601-12.3.1:* Above ground tanks must be sheltered. Below ground tanks must conform to AASHTO H 20-44 standards.	*Pages 11-1:* Tank should be located within a dwelling to prevent freezing.	*Pages 41-42, section 601A, B, C:* Covers above and below ground tanks.
F. Sizing *S-615-7.3.1:* 500 Btu per square foot collector (active system). 1,000 Btu per square foot (passive systems).	*Page 11-1:* 2 gallons or ½ cubic foot rock storage per square foot collector.	None
G. Filling-Draining *S-615-7.4 and S-615-7.5:* Tank must have filling and draining provisions.	None	*Page 41, section 601A-8:* Provides for drainage and overflow openings.
H. Pebble Bins *S-615-7.8:* Consider size, shape and cleanliness of storage pebbles when designing the thermal performance and pressure drop.	*Pages 1-2; 11-1, 2:* ½ cubic foot of ½ inch diameter pebbles per square foot collector. 20 to 30 fpm across bed.	None
I. Over Pressure Control *S-615-7.9 and S-615-14.1.1:* Provision for automatic release during periods of overpressure.	None	*Pages 37-38, section 405:* Pressure shall be limited to 80 psi except in pipes and then only with relief valve rated to pipe strength or 150 psi, whichever is less.

Section 4. Installation of Components

A. Flashing *S-515-2. 1.4:* Designed to prevent water penetration and to permit minor repairs to collector without distrubing roof membrane.	None	*Page 43, section 701C:* Panel installation at ground level or on the roof surface.

HUD Intermediate Standards	SMACNA Installation Standards	IAMPO Solar Code
B. Weatherstripping None	None	*Page 43, section 701, B,D:* Weatherproofing
C. Pipe Hangers *S-515-4.3 and S-615-3:* Hangers should be placed to avoid damage to pipe insulation.	None	*Page 27, section 306:* Screwed type pipe supports each 10 feet, copper, each 6 feet.
D. Collector Support *S-515-4.1; S-515-4.2; and S-601-11:* Collectors shall be placed in such a manner as not to harm the roof membrane.	None	*Page 43, section 701A,B:* Panels anchored to the roof surface shall be made to maintain water integrity of the roof covering.
E. Structural Support for Storage *S-601-6.2:* Tables and charts showing design compliance for seismic requirements.	None	*Page 41, section 601:* Buried tank shall be capable of withstanding 300 psf. Tank foundation minimum 2,500 psi concrete.
F. Undergound Piping *S-615-10.13:* Refers to MPS 615-35.	None	*Page 26, section 305:* Protection of piping materials and structures.
G. Insulation of Piping and Equipment *S-615-7. 3.4:* Storage: provide insulation. *S-515-3. 3.3:* Ducts should be insulated.	*Page 9-1, 2:* 1" for 1 inch pipe up to 200°F. 1½ inch for 2" pipe, 2 inch for 4 inch pipe.	*Pages 45-48, chapter 8:* Minimum heat loss of 50 Btu per lineal foot of piping.
H. Safety Controls *S-615-1.8 and S-615-14.1:* There shall be provision for automatic emergency shut down.	*Page 6-2:* Over temperature freezing and and over pressure provision are required.	*Page 37, sections 404 and 405:* Over pressure control on tanks (80 psi), pipes (150 psi) or design pressure, whichever is less.
I. Pipe-Duct Sizing *S-515-3.3:* Duct sizing according to ASHRAE Guide or application manuals of NESCA, SMACNA and ARI.	*Pages 3-1, 2; 7-1, 2, 3; 8-1, 2, 5:* Sizing and installation guide. Ducts sized for 0.1 inch sp. Piping 0.75 per 100 feet of pipe.	*Page 49, chapter 9:* Refer to local mechnical code.
J. Type of Piping *Appendix table B-4:* Typical standards.	None	*Pages 22, 23, table A, chapter 2:* Ferrous, non-ferrous, non-metallic piping and fittings.
K. Filters *S-515-3.3.2:* Shall conform to UL 900 (ANSI B 124.1-1971).	*Page 13-1:* Face velocity not to exceed 300 fpm.	None
L. Gaskets *S-515-10:* Are to be compatible both chemically and physically with their substrates.	None	Same as previously mentioned.
M. Piping Installation *S-515-10*	*Pages 8-1, 2:* Do not use galvanized pipe with glycol anti-freeze solutions.	*Pages 35, 36, 38, chapter 4:* No cross connection allowed. Non-potable lines noted "Danger Unsafe Water."
N. Connections and Fittings *Appendix table B-4:* Typical standards.	*Page 3-2; 8-1:* Rubber hosing may be used on solar loop. Copper tubing to be brazed or soldered with 95.5 tin-antimony.	*Pages 36-40, chapter 5:* Two-inch and below copper alloy and iron with non-corrosive material and automatic air vents.

CALIFORNIA'S SOLAR ENERGY TEST AND INSPECTION PROGRAM

Early in 1978, a new Solar Equipment Testing and Inspection program sponsored by the State Energy Commission will begin to provide California consumers with reliable and comprehensive information on the quality of solar energy products in the market place. This program will assist the practicing architect and engineer by providing a concise, comprehensive set of criteria, standards, and validated test results that will characterize both the solar equipment and the total installed system.

Adding to the thermal performance criteria that is already available, the Testing and Inspection Program will determine further performance aspects which concern reliability, durability, maintainability, and safety. A State certification will be awarded as a result of tests performed by independent laboratories. The data compiled will be directed to all sectors: homeowners, builders, designers, inspectors, vendors, lenders, and insurers. The finalized program for implementation has three objectives:

- The program will protect the consumer from fraud and promote the solar industry by mitigating the worries about solar equipment that could impede market growth. To accomplish this, minimum criteria will be established so that solar collectors that do not meet basic reliability, durability, maintainability, and safety criteria will not receive a certification label in the State of California. The manufactuere will be told of the deficiencies and will be given the opportunity to reapply for certification after appropriate changes have been made.

- The program will contribute to an improvement in the state of the art of solar equipment. Since the results of tests will be made public in a general way, the individual manufacturer who is accredited can see from his own data how his product compares with others. This information should stimulate product improvement. It is integral to the program that publishing of comparative data be handled fairly and with integrity and respect for the rights of all.

- The program will provide the technical information needed as a basis for government actions in accelerating solar implementation. The establishment of incentives in the form of financial rewards or tax rebates requires rational criteria. The program can establish conditions of confidence about the products which will encourage early legislative approval.

A complete paper on the Solar Test and Inspection Program was presented by G. W. Rhodes Associates at the Solarcon 77 Solar Energy Conference and Exposition held in August in San Francisco. For more information, please contact:

Rhodes Associates
25630 Elena Road
Los Altos Hills, CA 94022
(415) 948-3456

PUBLISHED STANDARDS, CODES, AND PERFORMANCE CRITERIA
(Solar heating and cooling)

1 1. "Interim Performance Criteria for Solar Heating and Combined Heating/Cooling Systems and Dwellings," January 1, 1975, prepared for HUD by NBS. Order by SD Catalog No. C13.6/2:504, price $1.90 per copy; from Superintendent of Documents, Government Printing Office, Washington, D.C. 20402.

2. "Interim Performance Criteria for Solar Heating and Cooling Systems in Commercial Buildings," November 1976, prepared for ERDA by NBS. Order No. PB-262-114, price $5.50 per copy: from NTIS, 5285 Port Royal Road, Springfield, VA 22161.

3. "Intermediate Minimum Property Standards for Solar Heating and Domestic Hot Water Systems," March 1977, prepared for HUD by NBS. Available from GPO as NBSIR-77.

4. "Heating and Air Conditioning Systems Installation Standards for One and Two Family Dwellings and Multifamily Housing Including Solar," Third edition, February 1977. Prepared by Sheet Metal and Air Conditioning Contractor's National Association, Inc., 8224 Old Courthouse Road, Tysons Corner, Vienna, VA 22180. Price $10.00 to individuals, $6.00 to A/E firms, educational institutions, public libraries, federal, state, and local government agencies and departments.

5. ASHRAE Standard 93-77, Methods for Testing Thermal Performance of Solar Collectors." ASHRAE, 345 East 47th Street, New York, NY 10017; price $8.35 per copy.

6. ASHRAE Standard 94-77, "Methods for Testing Thermal Storage Devices Based on Thermal Performance." ASHRAE, 345 East 47th Street, New York, NY 10017; price $6.35 per copy. (Note: Both ASHRAE Standard 93-77 and ASHRAE Standard 94-77 are available together for $10.35.)

7. "Florida Solar Energy Center Test Methods and Minimum Standards for Solar Collectors," November 1976. Florida Solar Energy Center, 300 State Road 401, Cape Canaveral, FL 32920; no charge.

8. Uniform Solar Energy Code, 1976 Edition. International Association of Plumbing and Mechanical Officials, 6032 Alhambra Avenue, Los Angeles, CA 90032; price $6.00 per copy. Note: The Uniform Solar Energy Code is the subject of a severe criticism in an appendix to the report "Legal Barriers to Solar Heating and Cooling of Buildings." Environmental Law Institute, 1346 Connecticut Avenue, N.W., Suite 620, Washington, D.C. 20036.

9. Los Angeles Guidelines (reproduced herein).

10. "Title 24, Energy Conservation Standards for New Nonresidential Buildings," State Energy Resource Conservation and Development Commission, 1111 Howe Street, Sacramento, CA 95814.

11. "Provisional Flat Plate Solar Collector Testing Procedures," National Bureau of Standards Document IR 77-1305, September 1977. United States Government Printing Office, Washington, D.C.

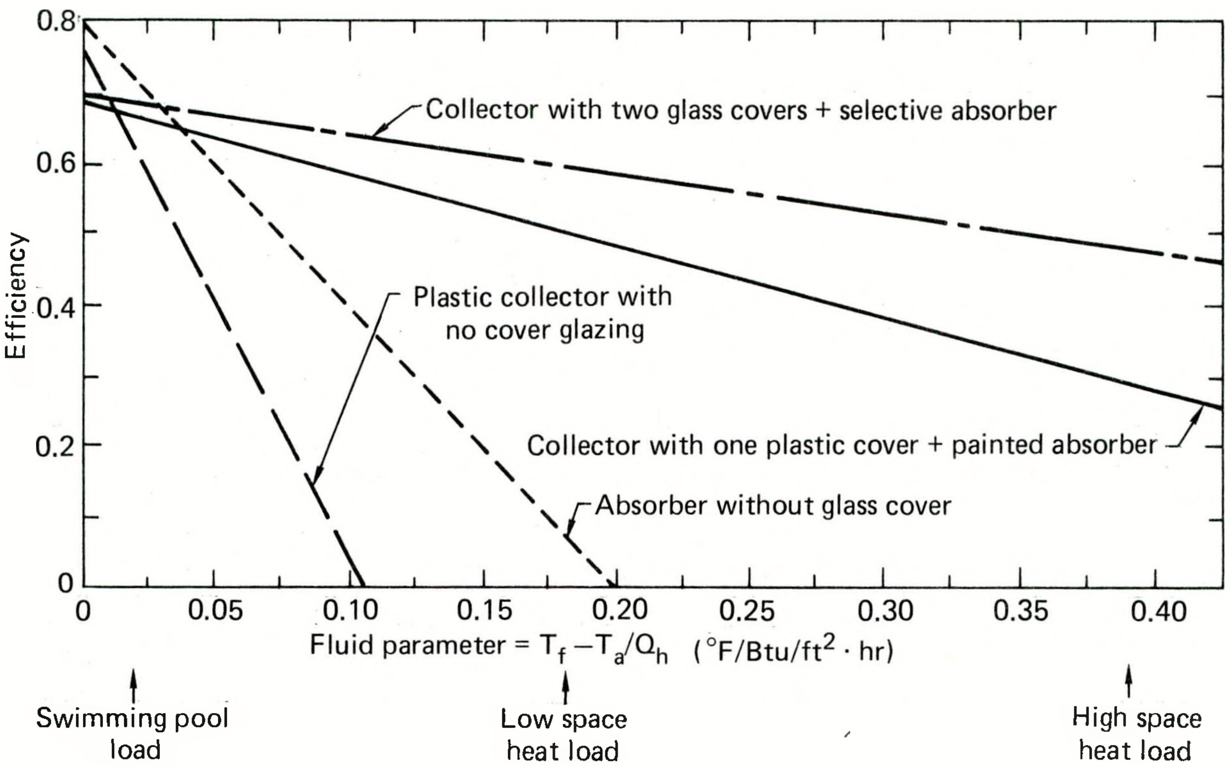
MEASURING THERMAL PERFORMANCE*

Thermal performance of solar collectors can be rather precisely measured and predicted in different situations as a result of the excellent work done in the past. The present sharply defined NBS test methods, documented in ASHRAE Standard 93-77, provide well-examined and correlated ways of measuring the ability of a collector to capture solar energy.

The "instantaneous" performance of a collector during a short period under quasi-steady state conditions is routinely evaluated in independent laboratories and is normally provided by a number of manufacturers. It is typically displayed as shown in the accompanying figure. The vertical axis shows efficiency--the energy extracted from the collector by the thermal transport fluid divided by the solar energy falling on the collector. The horizontal axis shows the fluid parameter $(T_f - T_a)H$, where T_f = temperature of the fluid in the collector; T_a = temperature of ambient air around the collector; and H = insolation, or solar energy falling upon the collector.

One can think of this horizontal parameter as a measure of relative "load" that needs to be carried (i.e., the temperature difference the collector must provide). The arrows pointing up indicate the normal operating region of various typical loads in California. The lowest load is that of a typical swimming pool; the higher relative loads are for winter space heating in different climates. Generally, the cost of an adequate collector is proportional to the relative load. The curves showing the performance of collectors of varying construction indicate that for low loads it is more economic to use the plastic swimming pool collector than when the ambient temperature is 35° below that of the pool in bright sunlight (at maximum, H = 350 Btu/hr ft^2, $T_f - T_a = 35^o$; efficiency = 0).

The use of efficiency curves based on actual test data permits fair comparison (with all other factors equal and properly considered) of alternate collectors and different operating conditions. It also permits a comparison of performance versus price. Unfortunately, predicting price performance over an entire year requires more computation than comparing instantaneous collector efficiency curves because of the number of varying factors involved in a total heating sense. But, the collector efficiency curve concept is the fundamental base for all credible analysis.



*This material was derived from "California Government Program to Accelerate Implementation - Solar Energy Test and Inspection Program," by G. W. Rhodes; paper for Solarcon 77 Solar Energy Convention and Exposition, August 19-21, 1977, San Francisco, California.

SOLAR TESTING FACILITIES

The Air Conditioning and Refrigeration Institute Foundation, Inc., (ARI Foundation) is preparing a list of recommended qualified solar testing laboratories for the National Bureau of Standards.

The ARI Foundation has been working under a contract with the NBS to identify laboratories for a forthcoming ERDA collector testing program. Robert Evans of the ARI Foundation says that after surveying about 150 firms there will probably be from 10 to 15 laboratories on the list.

In the process of assembling the list, ARI Foundation is establishing criteria for assessing a laboratory's capability to test collectors, evaluating questionnaire information submitted by the testing laboratories, and making visits to potentially qualified laboratories. All qualified laboratories have to be able to test solar collectors in accordance with ASHRAE Standard 93-77, "Methods for Testing the Thermal Performance of Solar Collectors."

A continuing part of the contract involves the ARI Foundation in developing a draft of rating standards for solar collectors as well as draft documentation for a certification program for solar collectors. The need for standardized testing and rating procedures has been emphasized by NBS since these procedures provide a means of evaluating and comparing equipment in a meaningful and consistent way and provide an equitable basis for competition among manufacturers. They also will serve as a basis for selection of equipment by consumers.

Anyone interested in more information on the selection of qualified laboratories or on the rating program may contact Robert Evans, ARI Foundation, 1815 North Fort Myer Drive, Arlington, VA 22209. Phone: (703) 524-8800.

In the meantime, a short list of a few of the established solar testing facilities is presented on the following page.

SOLAR TESTING FACILITIES

Name	Address	Phone	Item Tested
AETL (Approved Engineering Testing Laboratories)	20988 W. Golden Triangle Road Saugus, CA 91350	(805) 259-8184	Solar collectors
Desert Sunshine Exposure Tests, Inc.	P. O. Box 185 Black Canyon Stage Phoenix, AZ 85020	(602) 465-7846 (602) 465-7521	Solar devices Solar materials Radiometer calibration
Florida Solar Energy Center	300 State Road 401 Cape Canaveral, FL 32920	(305) 783-0300	Solar devices
Lockheed Research Laboratory	3251 Hanover Street Palo Alto, CA 94304	(415) 493-4411 Ext. 45193	Solar collectors
New Mexico State University Physical Science Laboratory	P. O. Box 3548 Las Cruces, NM	(505) 522-4400	Collectors
Solar Energy Laboratory University of Florida Dept. of Mech. Engr.	University of Florida Gainesville, FL 32611	(904) 392-0801	Solar collectors
University of Texas at Arlington Mech. Engr. Dept.	University of Texas Arlington, TX 76019	(817) 273-2561	Collectors
Wyle Laboratories Scientific Services and Systems Group	P. O. Box 1008 Huntsville, AL 35807	(205) 837-4411	Flat-plate collectors, air or liquid

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SOLAR FIRMS (Southern California)

SOLAR ENERGY SERVICES (Southern California)

Name	Address	Phone	Product
Alternative Energy Resources	8959 Complex Drive San Diego, CA 92123	(714) 560-1122	Design and marketing Installation
Aratex Services Inc.	P.O. Box 3000 Encino, CA 91316	(213) 995-2500	Design and marketing Installation
Ayres Associates	1180 S. Beverly Dr. #600	(213) 553-5285	Design and engineering Computerized energy analysis
Blue Skies Radiant Homes	40819 Park Ave. Hemet, CA 92343	(714) 658-2070	Building
Brentwood Electrical Contractors	2129 Pontius Ave. Los Angeles, CA 90025	(213) 477-2944	Contractors
California Architects	9378 Santa Monica Blvd. Beverly Hills, CA 90210	(213) 455-1814	Residential architecture
Colt, Inc.	71-590 San Jacinto Dr. Rancho Mirage, CA 92270	(714) 346-8033	Design and engineering
Conserdyne Corporation	4437 San Fernando Road Glendale, CA 91204	(213) 246-8409	Design and construction
Continental Solar Systems, Inc.	1901 Ave. of the Stars Suite 600 Century City, CA 90067	(213) 552-0003	Installation
Daniel Enterprises, Inc.	P. O. Box 2370 La Habra, CA 90631	(213) 943-8883	Computer optimization Energy system analysis
L. M. Dearing Associates, Inc.	13424 Ventura Blvd. Studio City, CA 91604	(213) 769-2521	Commercial design Swimming pool systems
Donnelly, Bundy	9220 Sunset Blvd. Los Angeles, CA 90069	(213) 273-5255	Architecture

Name	Address	Phone	Product
Energy Management Consultants, Inc.	6380 Wilshire Blvd. Suite 1407 Los Angeles, CA 90048	(213) 658-7088	Architecture and design
Joseph Farber	1605 Sherrington Place Suite Y 212 Newport Beach, CA 92660	(714) 642-6993	Solar consulting
Fredericks Development Corp.	9 Brook Hollow Drive Santa Ana, CA 92705	(714) 549-4822	Contracting
Gluth & Quigley Architecture	662 State Street San Diego, CA 92109	(714) 236-9385	Architecture
Harrison, Beckhart & Mill Architects	844 W. Colorado Blvd. Los Angeles, CA 90041	(213) 254-7141	Architecture
Hayakawa Associates	1180 S. Beverly Dr. #701 Los Angeles, CA 90035	(213) 879-4477	Consulting engineer Design
Hellman & Lober Mechanical Engineers	6380 Wilshire Blvd. #1506 Los Angeles, CA 90048	(213) 658-8811	Design and engineering
Jacobs Engineering Co.	251 South Lake Ave. Pasadena, CA 91101	(213) 449-2971 Ext. 201	Design and construction
Jacowitz and Associates	55 Empty Saddle Road Rolling Hills Estates, CA 90274	(213) 377-3849	System design consulting
Howard R. Lane	16633 Ventura Blvd. Encino, CA 91316	(213) 788-4560	Architecture
Leaverton-Beck, Inc.	16721 Hale Ave. P. O. Box 17118 Irvine, CA 92713	(714) 979-3880	Plumbing contractor

Name	Address	Phone	Product
Maroko & Snyder Associates,	12517 Chandler Blvd. North Hollywood, CA 91607	(213) 877-0981	Consulting engineers
Mitchell-Webb Associates, Inc.	1911 Fifth Avenue San Diego, CA 92101	(714) 238-1522	Design
Fred Rice Production, Inc.	48-780 Eisenhower Drive P. O. Box 643 La Quinta, CA 92253	(714) 564-4823	Design and construction
San Bernardino West Side Community Development	1736 W. Highland Ave. San Bernardino, CA 92411	(714) 887-2546	Design, building, contracting
Skytherm Processes & Engineering	2424 Wilshire Blvd. Los Angeles, CA 90057	(213) 389-2300	Design and construction Engineering
Solar Broker	405 N. Johnson El Cajon, CA 92020	(714) 562-2666	Solar sales training service
Solarcoa, Inc.	2115 E. Spring St. Long Beach, CA 90806	(213) 426-7655	Solar engineering and design: residential, industrial, commercial, and institutional
Solar Energy Centers	1534 Newport Blvd. Costa Mesa, CA 92627	(714) 631-2860	Design and installation
Solargenics, Inc.	9713 Lurline Avenue Chatsworth, CA 91311	(213) 998-0806	Residential, industrial Commercial solar System design, Engineering, and construction Management

Name	Address	Phone	Product
Solar Home Center	1938-A So. Anaheim Blvd. Anaheim, CA 92805	(714) 973-9104	Design and installation
Solar Resources, Inc.	5401 McConnell Ave. Los Angeles, CA 90066	(213) 397-2879	Architecture and engineering Energy consultants
Solar Utilities	2850 Mesa Verde Dr. Suite J Costa Mesa, CA 92626	(714) 557-7125	Design and installation
Solar West Construction Co.	23939 Ventura Blvd. Calabasas, CA 91302	(213) 888-7896	Design and engineering Installation
Southwest Air Conditioning, Inc.	7268 E. Cajon Blvd. San Diego, CA 92115	(714) 462-0512	Installation
Southwest Energy Management	8290 Vickers, Suite B San Diego, CA 92111	(714) 292-5185	Design
E. J. Stanley Enterprises	2730 E. Broadway Long Beach, CA 90803	(213) 434-5151	Consulting engineers Sizing
Warren Steele	153 S. La Peer Drive Beverly Hills, CA 90211	(213) 278-3062	Mechanical engineering
Garrett G. Steinbeck & Co.	1609 Westwood Blvd. Los Angeles, CA 90024	(213) 879-0320	Solar contractor's and manufacturers insurance
The Thomas Co.	12910 Haster St. Garden Grove, CA 92640	(714) 971-0690	Installation
TWR-Energy Group	1 Space Park Redondo Beach, CA 90278	(213) 535-2871	Design and engineering

Name	Address	Phone	Product
Universal Heritage Investments Corp.	21535 Hawthorne Blvd. Wells Farbo Plaza Torrance, CA 90503	(213) 370-8531	Energy-related investment counseling
Urban Innovations Group	1063 Gayley Ave. Westwood, CA 90024	(213) 477-9595	Design and architecture
Ying Manufacturing Corp.	1957 W. 144th St. Gardena, CA 90249	(213) 327-8399	Design and construction

MANUFACTURERS AND DISTRIBUTORS OF SOLAR PRODUCTS (Southern California)

Name	Address	Phone	Product
Advanced Solar Systems	3440 Wilshire Blvd. Los Angeles, CA 90010	(213) 383-0035	Flat-plate collectors
American Appliance Mfg. Corp.	2425 Michigan Ave. Santa Monica, CA 90406	(213) 870-8541	Domestic hot water heaters (Mor-Flo Industries) Storage tanks
American Solar Energy Systems	20866 Kelvin Place Woodland Hills, CA 91367	(213) 884-1800	Distributor
American Sun Industries	3477 Old Conejo Rd. Newbury Park, CA 91320	(805) 498-9700	Medium temperature collectors System for domestic hot water and pools in kit form
Applied Sol Tech, Inc.	P. O. Box 9111 Cabrillo Station Long Beach, CA 90810	(213) 426-0127	Heating and cooling
Aztec Solar Distributors	1326 West Betteravia Rd. Santa Maria, CA 93454	(805) 928-1731	Flat-plate collectors
Bostik-Finch, Inc.	20846 S. Normandie Ave. Torrance, CA 90502	(213) 320-6800	Coatings and glazings
Brannon Contractor's Supply	1650 Harbor Ave. Long Beach, CA 90813	(213) 437-0828	Medium temperature collectors
Calexico Building Supply Co.	441 Emerson Calexico, CA 92231	(714) 357-1631	Distributor of Solargenics collectors and systems
California Enertech	7872 Convoy Court San Diego, CA 92111	(714) 279-1703	Flat-plate collectors
Cal-Pacific Energy Systems	7020 Hayrenhurst Ave.-D Van Nuys, CA 91406	(213) 787-3833	Distributor (Olin collectors)

Name	Address	Phone	Product
Cal Suntrol	875 Kempton Avenue Monterey Park, CA 91754	(213) 573-5280	Coatings and glazings Reflective film
CaTel Manufacturing, Inc.	243 W. Maple Avenue Morovia, CA 91016	(213) 359-2593	Swimming pool heaters
Century Fiberglass	P. O. Box 6069 Anaheim, CA 92806	(213) 589-6788	Storage Tanks
Chronomite Laboratories	21011 S. Figueroa Carson, CA 90745	(213) 320-9452	Eng. & mfg. collectors Collector panels Solar booster heater
Colt, Inc. of Southern California	71-590 San Jacinto Dr. Rancho Mirage, CA 9227	(714) 346-8033	Flat-plate collectors
Conserdyne Corp.	4437 San Fernando Rd. Glendale, CA 91204	(213) 246-8409	Domestic hot water heaters Pools and spas Space heating
Dearing L.M. Associates, Inc.	12324 Ventura Blvd. Studio City, CA 91604	(213) 769-2521	Pool covers
Del Manufacturing Co.	905 Monterey Pass Rd. Monterey Park, CA 91754	(213) 264-0860	High temperature collectors
Dutcher Industries, Inc.	7617 Convoy Court San Diego, CA 92111	(714) 279-7570	Solar refrigeration Solar engines
EGL Sales, Inc.	837 E. Sandhill Ave. Carson, CA 90746	(213) 770-6053	Domestic hot water heaters (American Heliothermal)
El Camino Solar Systems	5330 Debbie Lane Santa Barbara, CA 93111	(805) 964-8676	Space heating systems Domestic hot water heaters Pool heaters Components, controls

Name	Address	Phone	Product
Energy Systems, Inc.	4570 Alvarado Canyon Rd. San Diego, CA 92101	(714) 280-6660	Glazed and unglazed collectors
	4569 Mission Gorge Pl. San Diego, CA 92120	(714) 563-1940	
Environmental Energy	121 Broadway, Suite 535 San Diego, CA 92101	(714) 239-1439	Medium temperature collectors
Fabco	809 E. 18th St. Los Angeles, CA 90021	(213) 749-5244	Coatings and glazings
Fafco LA, Solar Energy Assoc.	1976 S. Sepulveda Blvd. Los Angeles, CA 90025	(213) 879-1440	Swimming pool heaters
Familian Corp.	12353 Wilshire Blvd. Los Angeles, CA 90025	(213) 820-2641	Domestic hot water heaters (Mor-Flo Industries) Wholesale distributors
Farwest Corrosion Control Co.	17311 S. Main St. Gardena, CA 90248	(213) 532-9524	Solar electric and energy storage
Fedmart	8001 Othello San Diego, CA 92111	(714) 292-3220	Collector panels
Filon, Division of Vistron Corp.	1233 S. Van Ness Ave. Hawthorne, CA 90250	(213) 757-5141	Coatings and glazings
Fleming Lumber Co.	3250 San Fernando Rd. Los Angeles, CA 90065	(213) 254-7201	Domestic hot water heaters (Grumman/Sunstream)
Forest Lumber Co.	38265 N. Sierra Hwy Palmdale, CA 93534	(805) 947-3165	Distributor for Solargenics collectors and systems

Name	Address	Phone	Product
Garden Grove Pipe & Supply, Inc.	10612 Stanford Avenue Garden Grove, CA 92640	(714) 534-6325	Flat-plate collectors Storage tanks Plumbing supplies
Warren W. Gibbons Co.	12064 Caminito Campana San Diego, CA 92128	(714) 487-5168	Medium temperature collectors
Glasteel, Inc.	1727 Buena Vista Duarte, CA 91010	(213) 357-3321	Coatings and glazings
J. Gregory & Co.	3187-G Airway Avenue Costa Mesa, CA 92626	(714) 751-3850	Medium temperature collectors
Grumman Energy Systems	999 N. Supulveda Blvd. Suite 510 Los Angeles, CA 90049	(213) 640-2490	Flat-plate collectors
Grundfos Pumps Corp.	2555 Clovis Avenue Clovis, CA 93612	(209) 299-9741	Stainless steel pumps
Haldeman, Inc.	2845 Supply Avenue Los Angeles, CA 90040	(213) 726-7011	Domestic hot water heaters (Solarcon)
Hamilton Supply	4937 Market Street San Diego, CA 92102	(714) 263-7723	Collector panels
Hayward Lumber Co.	709 E. Main Street Barstow, CA 92311	(714) 256-5918	Distributor of Solargenics collectors and systems
Hayward Lumber Co.	127 South Main Street Blyth, CA 92225	(714) 922-4891	Distributor of Solargenics collectors and systems

Name	Address	Phone	Product
Hayward Lumber Co.	1215 High Street Delano, CA 93215	(805) 725-2551	Distributor of Solargenics collectors and systems
Heaslett Sales	3103 Falcon Street San Diego, CA 92103	(714) 298-6851	Medium temperature collectors
Heliotrope General	3733 Kenora Drive Spring Valley, CA 92077	(714) 460-3930	Space heating and cooling Domestic hot water heaters Pool heaters Components, storage
Hy-Cal Engineering	12105 Los Nietas Rd. Santa Fe Springs, CA 90670	(213) 698-7785	Controls and instruments
Imperial Valley Lumber Co.	401 E. Main Street Imperial, CA 92251	(714) 355-1141	Distributor of Solargenics collectors and systems
International Solar	1071 Industrial Place El Cajon, CA 92020	(714) 442-9876	Flat-plate collectors (Solar Shingle)
Jack Janofsky & Assoc.	P. O. Box 48415 Los Angeles, CA 90048	(213) 931-5562	Coatings and glazings for heat reflection
J. G. Johnston Co. Solar Division	33458 Angeles Forest Hwy. Palmdale, CA 93550	(805) 947-3791	Air heating systems
Kedco, Inc.	9016 Aviation Blvd. Inglewood, CA 90301	(213) 776-6636	Collectors
Lennox Industries	1400 Manhattan Avenue Fullerton, CA 92631	(714) 956-8201	Medium temperature collectors

Name	Address	Phone	Product
Link Solar Products	3258 E. Willow Street Long Beach, CA 90806	(213) 424-1334	Medium temperature collectors, sales and installation
Lovz Enterprises	1241 W. Avenue "I" Lancaster, CA 93534	(805) 948-8368	Will be marketing hot water heaters (Energy Systems of San Diego; A to Z Solar Products) Building homes
LTC Solar Energy Co.	7908 W. 4th Street Los Angeles, CA 90048	(213) 651-3873	Flat-plate collectors
Meterology Research, Inc.	P. O. Box 637 Altadena, CA 91001	(213) 791-1901	Controls and instruments
M. C. Nottingham Co.	P. O. Box 7007 890 S. Arroyo Parkway Pasadena, CA 91105	(213) 681-1173	Storage tanks
Olin Brass	520 N. Brookhurst Suite 230 Anaheim, CA 92801	(714) 635-8370	Flat-plate absorber panels
Owen Enterprises	436 N. Fries Avenue Wilmington, CA 90744	(213) 835-7436	Heating and cooling Concentrating and flat-plate collectors
Owens-Corning Fiberglass Corp.	5933 Telegraph Road Los Angeles, CA 90040	(213) 724-5383	Glazings and high temperature insulation
Panel-Air Corp.	1571 W. MacArthur Blvd. Costa Mesa, CA 92626	(213) 924-9454	Medium temperature collectors

Name	Address	Phone	Product
Piper Hydro Corp., Inc.	2895 East La Palma Anaheim, CA 92806	(714) 630-4040	Solar heating systems Domestic hot water heaters Flat-plate collectors Pool heaters
Powell Brothers, Inc.	5903 Firestone Blvd. South Gate, CA 90280	(213) 869-3307	Heating systems Domestic hot water heaters Flat-plate collectors
Quality Energy Systems	7668 Lemon Avenue Lemon Grove, CA 92045	(714) 464-3733	Medium temperature collectors
Raypak, Inc.	31111 Agoura Road Westlake Village CA 91359	(213) 889-1500	Heating systems Domestic hot water heaters Flat-plate collectors Pool heaters
RDX Corp.	110 S. Euclid, Suite 200 Pasadena, CA 91101	(213) 681-3451	Domestic hot water heaters (Solar Eye Products, Inc.)
RDX Corp.	8133 Engineer Road San Diego, CA 92111	(714) 278-6863	Collector controls
RDX Corp.	1287 Lawrence Station Rd. Sunnyvale, CA 94086	(408) 734-4500	Collector controls
A. O. Reed & Co. Solar Division	4777 Ruffner San Diego, CA 92111	(714) 565-4131	Space heating and cooling Domestic hot water heaters Agricultural drying Water distillation Storage tanks
Revere Copper & Brass	2107 S. Garfield Ave. Los Angeles, CA 90022	(213) 726-3300	Flat-plate collectors

Name	Address	Phone	Product
Reynolds Metals Co.	5670 Wilshire Blvd. Los Angeles, CA 90054	(213) 937-3680	Domestic hot water heaters
Reynolds Metals	2315 Dominguez Torrance, CA 90509	(213) 328-7421	Space heating and cooling Domestic hot water heaters Collectors
Rho Sigma, Inc.	11922 Valerio St. No. Hollywood, CA 91605	(213) 982-6800	Controls and instrumentation
Rising Sun	P. O. Box 1027 Westminster, CA 92683	(714) 892-2668	Flat-plate collectors
Robertshaw Controls, Grayson Division	100 W. Victoria Street Long Beach, CA 90805	(213) 636-8301	Space heating and cooling controls, solar water heater controls
RUUD Mfg. Co. (Rheem)	14300 Alondra Blvd. La Mirada, CA 90638	(213) 868-0701	Storage tanks
Sennergetics	18621 Parthenia Street North Ridge, CA 91324	(213) 885-0323	Solar products and components
Sharp Solar Industries, Inc.	7917 Lester Ave., #1 Lemon Grove, CA 92045	(714) 464-1411	High temperature collectors
Shaw Pump Co.	P. O. Box 3336 9660 East Rush Street South El Monte, CA 91733	(213) 283-5156 (213) 443-1784	Water pumps Al-wrapped PVC pipe Solar components
Skytherm Processes and Engineering	2424 Wilshire Blvd. #704 Los Angeles, CA 90057	(213) 389-2300	Solar heating and cooling Solar hot water

Name	Address	Phone	Product
Solarbeam Industries, Inc.	118 N. Almansor Street Alhambra, CA 91801	(213) 282-8451	Flat-plate collectors
Solar-Cal South Inc.	P. O. Box 1099 Pomona, CA 91769	(714) 622-0067	Air collectors Eutectic salt storage
Solar City	116 East Olive Burbank, CA 91502	(213) 843-4204	Medium temperature collectors
Solarcoa	2115 E. Spring Street Long Beach, CA 90806	(213) 426-7655	Collectors, storage Hot water heaters All applications
Solar Contact Systems	1415 Vernon Street Anaheim, CA 92805	(714) 991-8120	Collectors
Solar Control Systems	650 W. Latham Hemet, CA 92343	(714) 652-2922	Medium temperature collectors
Solar Energy Equipment Co.	2925 College Avenue Costa Mesa, CA 92626	(714) 540-3475	Distributor of Solargenics collectors and systems
Solar Energy Systems, Inc.	2492 Banyan Drive Los Angeles, CA 90049	(213) 472-6508	Space heating, controls Hot water heaters Pool heaters, components
Solar Enterprises	9803 E. Rush Street South El Monte, CA 91733	(213) 444-2551	Pool heaters Flat-plate collectors
Solar Enterprises	P. O. Box 3355 Santa Barbara, CA 93105	(805) 682-2316	Medium temperature collectors

Name	Address	Phone	Product
Solargenics, Inc.	9713 Lurline Ave. Chatsworth, CA 91311	(213) 998-0806	A. O. Smith tanks and boilers Space heaters Hot water heaters Flat-plate collectors Complete solar systems
Solargenics, Inc.	808 Grena Green Way, #6 Los Angeles, CA 90049	(213) 998-0806	Medium temperature collectors
Sola Heat	1200 E. 1st Street Los Angeles, CA 90033	(213) 263-5823	Flat-plate collectors
Solar Hydro	765 S. State College Rd. Fullerton, CA 92631	(714) 992-4470	Solar heating systems Flat-plate collectors Pool heaters
Solar Research Systems	3001 Red Hill Ave.#I-105 Costa Mesa, CA 92626	(714) 545-4941	Pool heaters, flat-plate collectors, low-temperature liquid collectors for swimming pools and domestic hot water pre-heaters Controls
Solar Sales	207 N. Broadway Santa Ana, CA 92701	(714) 547-6623	Flat-plate collectors
Solarsave	10533 Ellis Avenue Fountain Valley, CA 92708	(714) 964-1636	Flat-plate collectors
Solar Supply, Inc.	9163 Chesapeake Drive San Diego, CA 92123	(714) 292-7811	Medium temperature collectors

Name	Address	Phone	Product
Solartec Corp.	Mercury & Engineer Roads San Diego, CA 92111	(714) 560-8434	Low temperature collectors Medium temperature collectors High temperature collectors Heating/air conditioning Electronic controls
Solar Technology International	9701 Lurline Avenue Chatsworth, CA 91311	(213) 998-0667	Space heating and cooling Solar water pumps Photovoltaic panels
Solar-Tronics, Inc.	31149 Via Colinas #608 Westlake Village CA 91361	(213) 991-3200	Flat-plate collectors
Solar West	2711 Chicago Avenue Riverside, CA 92507	(714) 684-1555	Concentrating collectors
Solarwest Associates	646 E. Commonwealth Fullerton, CA 92631	(714) 992-6983	Flat-plate collectors
Solar World	9380 Activity Drive Suite G San Diego, CA 92126	(714) 578-4900	Concentrating collectors
Spectran Instruments	P. O. Box 891 La Habra, CA 90631	(213) 694-3995	Solar heating and cooling Hot water heating Instruments
Spectrolab, Inc.	12484 Gladstone Avenue Sylmar, CA 91342	(213) 365-4611	Solar cells

Name	Address	Phone	Product
STG Import Export Co.	262 S. San Gabriel Blvd. San Gabriel, CA 91776	(213) 287-9984	Medium temperature collectors
Stillman's Solar Heating	1240 N. Highway 101 Leucadia, CA 92024	(714) 753-4583	Medium temperature collectors
Sun Check Solar Screen	35572 Via Desco Valencia, CA 91355	(213) 367-3131	Coatings and glazings
Sundu Co.	3319 Keys Lane Anaheim, CA 92804	(213) 799-2011 (714) 828-2873	Pool heaters Flat-plate collectors
Southwest Energy Management	8290 Vickers, Suite B San Diego, CA 92111	(714) 292-5185	Medium temperature collectors
Southwest Supply Co.	P. O. Box 82896 San Diego, CA 92138	(714) 280-9411	Hot water heaters (Solarcon) Solar heating
State Industries	20721 Annalee Avenue Carson, CA 90745	(213) 639-3923 (800) 262-1544	Medium temperature collectors
Sun Power Solar Engineering	4032 Helix Street Spring Valley, CA 92077	(714) 464-5322	Heating and cooling systems Hot water heaters Solar drying Solar distillation Concentrating solar collectors
Sun Ray Energy	1523 E. Valley Parkway Escondido, CA 92027	(714) 463-3480	Medium temperature collectors
Sunrise Solar, Inc.	7359 Reseda Blvd. Reseda, CA 91335	(213) 881-3164	Flat-plate collectors

Name	Address	Phone	Product
Sunwater Energy Products	1488 Pioneer Way, #17 El Cajon, CA 92020	(714) 579-0771	Hot water heaters Pool heaters, components Solar distillation
Sun Water, Inc.	18754 Parthenia Street Northridge, CA 91324	(213) 886-3620	Solar panels
Swan Solar	6909 Eton Street Unit G Canoga Park, CA 91303	(213) 884-7874	Flat-plate collectors
Teco	P. O. Box 707 Rancho Sante Fe CA 92067	(714) 756-2700	Medium temperature collectors
Teledyne Controls	200 N. Aviation Blvd. El Segundo, CA 90245	(213) 675-7111	Controls and instruments
Temperature Instrument Equipment Co.	P. O. Box 4627 Inglewood, CA 90307	(213) 673-5198	Controls and instruments
Total Solar Control	P. O. Box 2114 Rancho Sante Fe, CA 92067	(714) 481-0855 (714) 231-6978	Distributor of Solargenics collectors and systems
Transparent Products Corp.	3410 S. La Grenega Los Angeles, CA 90016	(213) 938-3821	Coatings and glazings
Transparent Shade Co.	501 N. Figueroa Street Los Angeles, CA 90012	(213) 627-0851	Solar control shades and films
Unitspan Architectural Systems	9419 Mason Avenue Chatsworth, CA 91311	(213) 998-1131	Medium temperature collectors

Name	Address	Phone	Product
Vanguard Solar Systems	2727 Coronado Street Anaheim, CA 92806	(714) 871-8181	Flat-plate collectors
Ying Manufacturing Corp.	1957 W. 144th Street Gardena, CA 90249	(213) 327-8399	Hot water heaters Space heating Flat-plate collectors
ZZ Corporation	10806 Kaylor Street Los Alamitos, CA 90702	(213) 598-3220	Concentrating collectors

INFORMATION ACCESS

INFORMATION ACCESS

SOLAR INFORMATION SERVICES

- Department of Energy
  Division of Solar Technology
  Technology Transfer Branch
  600 E Street, N.W.
  Washington, D.C. 20545
  (202) 376-9118

- Fred Boercher
  Union Carbide Nuclear Division
  P.O. Box X
  Oak Ridge, TN 37830
  (615) 483-8611, Ext. 3-1486

- William L. Graves
  Solar TTP
  Brookhaven National Laboratory
  Upton, L.I., NY 11973
  (516) 345-3326

- R. C. Maninger, Head
  Technology Applications Group
  Lawrence Livermore Laboratory
  P.O. Box 808 L-790
  Livermore, CA 94550
  (415) 422-6902

- John J. Purcell
  Director, Chicago Operations Downtown Office
  Department of Energy
  175 West Jackson Room A 1136
  Chicago, IL 60604
  (312) 968-9368

- Robert P. Stromberg
  Sandia Laboratories
  P.O. Box 5800
  Albuquerque, NM 87115
  (505) 264-8170

- E. V. Werry
  Battelle Pacific Northwest Laboratories
  Battelle Boulevard
  Richland, Washington 99352
  (509) 946-2345

- National Solar Heating and Cooling Information Center
  P.O. Box 1607
  Rockville, MD 20855
  Call Toll Free (800) 523-2929

  Answers mail and phone requests for solar information from an extensive national and international computerized data base. No charge. The following standard files are available, some of them by geographic region:

  Manufacturers
  Governmental actions
  Solar contacts
  Solar buildings
  Distributors
  Demonstration projects
  Climatological data
  Education
  Speakers bureau
  Conferences
  Film/slide collection
  Associations
  Testing, evaluation, and standards
  Financial institutions

- DOE Technical Information Center (TIC)
  P.O. Box 62
  Oak Ridge, TN 37830
  (615) 483-8611, Ext. 4161

  This is the national solar energy information bank for all reports prepared under funding derived from the National Solar Heating and Cooling Demonstration Program. Publishes "Solar Energy Bibliography" and its continuation "Solar Energy Update"; also "Energy Research Abstracts."

- Energy Bookstores
4525 Comber Ave.
Encino, CA 91316
(213) 789-1073

  Provides mail order service for books on solar and alternate energies. Send $1 for catalog (applied toward first book purchase).

- Federal Energy Administration (FEA)
3660 Wilshire Blvd., Suite 800
Los Angeles, CA 90010

  Compiles sales data for the solar energy industry.

- Solar Energy Research Institute (SERI)
Denver West Office Building #4
1536 Cole Blvd.
Golden, CO 80401
(303) 234-7171

  Still in the infancy stage (as of December 1977). Will be doing research in solar applications. Get on their mailing list now to stay informed of their research projects.

- California Energy Resources Conservation and Development Commission
Office of Information and Education
1111 Howe Avenue
Sacramento, CA 95825
(916) 322-4251
(800) 852-7516

  Has information about solar utilization in California. Publishes the "State Energy Commission News," a monthly newsletter available at no charge.

- National Energy Information Center (NEIC)
Federal Building FEA
1200 Pennsylvania Ave., N.W.
Washington, D.C. 20461
(202) 556-9820

- Documentation Associates

11720 West Pico Boulevard
Los Angeles, CA 90064
(213) 477-5091

2215 M Street, N.W., Suite 203
Washington, D.C. 20037
(202) 223-6939

Data base searching by computers quickly and precisely produces a bibliography of citations pertinent to a topic. Although each data base appears under only one heading, many contain information relevant to multiple subject areas.

- Western Regional Information Service Center (WRISC)

Lawrence Berkeley Laboratory
Bldg. 509, Room 139
Berkeley, CA 94720
(415) 843-2740 or FTS 451-6308

Offers computerized search services to the public in energy-related information. WRISC has access to ERDA energy data bases, covering scientific journals as well as all energy-related government reports, conferences, patents, etc. These data bases are updated regularly.

- Agricultural Research Service (ARS)

U.S. Department of Agriculture
Beltsville Agricultural Research Center
Room 219 B-005
Beltsville, Maryland 20705

Does research and development in support of economically feasible agricultural applications of solar energy. The ARS solar program is now focused on grain drying, systems for curing certain agricultural products, greenhouse heating, livestock applications, food processing, and wind energy conversion systems.

- U.S. Forest Service

Information Office
Department of Agriculture
Washington, D.C. 20250

Is responsible for national leadership in forestry and is authorized to conduct basic research in its Forest Service Laboratories throughout the country. Work includes genetics, nutrition, improved methods of harvesting, fire prevention, better processing methods for forest products, recreation, and environmental improvement.

- Bureau of Domestic Commerce
  Office of Business Research and Analysis
  Domestic and Internal Business Administration
  U.S. Department of Commerce
  Washington, D.C. 20230

  Provides business assistance and advice to the Nation's business community. Collects, analyzes, and maintains factual data on U.S. industries including domestic and international data in categories such as production, pricing, inventories, marketing, labor, financing, taxation, and location and size of companies, and provides a working forum for business and the Federal Government on domestic business issues. Maintains an Office of Ombudsman for Business, which receives and handles complaints, suggestions, inquiries, and information on Federal programs of interest to the business community. Is responsible for coordinating consumer affairs activities.

- Bureau of International Commerce
  Domestic and International Business Administration
  U.S. Department of Commerce
  Washington, D.C. 20230

  Provides economic, commercial, and marketing information on export prospects and methods of marketing. Conducts development activities to increase national awareness of export opportunities improves Government/business cooperation, and assists U.S. firms on specific major export projects.

- Patent and Trademark Office
  Office of Technology Assessment and Forecast
  Washington, D.C. 20231

  Since October 1973, will (on request) advance for examination those patent applications which contribute to the development of energy resources and their conservation and utilization. Publishes reports on patent activity in various energy-related technologies.

- Government Printing Office
  Superintendent of Documents
  Washington, D.C. 20402
  (202) 783-3238

  Publishes "Monthly Catalog of United States Government Publications." This catalog can be reviewed in depository libraries.

- Office of Consumer Affairs
  U.S. Department of Health, Education and Welfare
  Washington, D.C. 20201

  With respect to solar energy, the Office is primarily interested in informing and protecting the consumer while supporting efforts for greater solar usage.

- NASA Industrial Application Center
  University of Southern California
  901 Exposition Boulevard, Room 205
  Los Angeles, CA 90007
  (213) 741-6132

  Provides for a relatively small fee, citations and abstracts on the following topics:

  Residential solar heating & cooling
  Solar collector design
  Solar energy storage techniques
  Solar energy concentrators & reflectors
  Solar energy generators & furnaces
  Solar energy utilization
  Windpower utilization
  Windpower design
  Solar cell design & manufacture
  Geothermal resources
  Geothermal energy conservation
  Energy vs. buildings, general
  Energy vs. buildings, conversion
  Solar energy computer programs.

ASSOCIATIONS AND SOCIETIES

- <u>International Solar Energy Society (ISES)</u>
  c/o Florida Solar Energy Center
  300 State Road 401
  Cape Canaveral, FL 32920
  (305) 783-2740

  The international professional organization dedicated to information exchange about solar. Publications include Solar Energy Journal, Sunworld, and a newsletter. American section publications include Solar Age and a membership directory.

- <u>Southern California Solar Energy Association (SCSEA)</u>
  City Administration Building 11-B
  202 C Street
  San Diego, CA 92100
  (714) 232-3914

  A regional chapter of ISES.

- <u>Solar Energy Industries Association (SEIA)</u>
  1001 Connecticut Avenue, N.W.
  Washington, D.C. 20036
  (202) 293-1000

  This organization represents the manufacturers, distributors, contractors, and some design professionals in the solar industry. Publications include Solar Industry and Solar Engineering.

- <u>Cal-SEIA</u>
  Frank Ames, Membership Chairman
  7926 Convoy Court
  San Diego, CA 92111

  This is a regional chapter of the above Solar Energy Industries Association.

- <u>American Society of Heating, Refrigerating, and Air Conditioning Engineers (ASHRAE)</u>
  Research and Technical Services
  345 East 47th Street
  New York, NY 10017

- American Institute of Architects (AIA)
  Southern California Chapter
  304 South Broadway
  Los Angeles, CA
  (213) 625-6561

- National Association of Home Builders (NAHB)
  NAHB Research Foundation, Inc.
  P. O. Box 1627
  Rockville, MD 20850
  (301) 762-4200

- Alternative Consumer Energy Society
  c/o Public Education Services
  Jet Propulsion Laboratory
  4800 Oak Grove Drive
  Pasadena, CA 91103
  (213) 354-4321

- Solar Energy Institute of America
  P. O. Box 6068
  Washington, D.C. 20005
  (202) 667-6611

- Southern California Gas Company
  P. O. Box 3249
  Terminal Annex
  Los Angeles, CA 90051
  (213) 689-2345

- Copper Development Association
  (L. Lane Adams)
  P. O. Box 3159
  Torrance, CA 90502
  (213) 325-4363

- Los Angeles Building and Construction Trades Council
  1626 Beverly Blvd.
  Los Angeles, CA 90026
  (213) 483-4222

- Los Angeles Department of Water and Power
  (Joseph Perlmutter, Solar Coordinator)
  111 North Hope Street, Room 1116
  Los Angeles, CA 90051
  (213) 481-5800

- Technology Transfer Society
  11720 West Pico Boulevard
  Los Angeles, CA 90064
  (213) 477-5081

COLLEGES AND UNIVERSITIES
WITH SOLAR-RELATED COURSES (Southern California)*

Institution	Address	Phone
California Institute of Technology Department of Engineering	Pasadena, CA 91103	(213) 795-6811
California State University Department of Engineering	1811 Nordoff St. Northridge, CA 91330	(213) 885-2183
Cerro Coso Community College	College Heights Dr. Ridgecrest, CA 93555	—
Fullerton College	321 E. Chapman Ave. Fullerton, CA 92635	(714) 871-8000
Grossmont Adult Education Santanna High School	9915 Magnolia Ave. Santee, CA	(714) 448-5500
Northrup University Department of Energy Science	1155 W. Arbor Vitae Inglewood, CA 90306	(213) 641-3470
San Diego Community College District Department of Vocational Education	3375 Camino Del Rio South San Diego, CA 92108	(714) 280-7610
University of California, La Jolla Engineering Department Energy Center	La Jolla, CA 92037	(714) 452-2230
University of California at Los Angeles Energy and Kinetics Department College of Engineering and Applied Science	10995 Le Conte Ave. Los Angeles, CA 90024	(213) 741-2311
University of California at Los Angeles Extension Division: Continuing Education in Engineering and Mathematics	10995 Le Conte Ave.	(213) 741-2311
University of Southern California School of Architecture and Fine Arts: Interdisciplinary Research Program	University Park Los Angeles CA 90007	(213) 741-2725

*Compiled from "Colleges and Universities in California with Solar Sources," National Solar Heating and Cooling Information Center, P. O. Box 1607, Rockville, MD 29850.

CATALOG SUMMARY

EDUCATIONAL GUIDE FOR SOLAR ENERGY AND ENERGY CONSERVATION

AT CALIFORNIA UNIVERSITIES AND COLLEGES

JANUARY 1978

SCHOOL	COURSES
Department of Engineering CALIFORNIA INSTITUTE OF TECHNOLOGY Pasadena, CA 91103	DEPT. OF ENG: Offer basic engineering courses related to solar: heat transfer, fluid mechanics, etc. Undergrads take engineering & applied sciences courses; graduate students take courses in applied mechanics, mechanical engineering, etc. RESEARCH: Some projects in heating & photovoltaics graduate students can work on.
Department of Physics CALIFORNIA POLYTECHNIC STATE U. San Luis Obispo, CA 93407	PHYSICS DEPT: Offer two courses in energy which include study of solar energy (undergraduate).
School of Natural Sciences CALIFORNIA STATE COLLEGE 5500 State College Parkway San Bernardino, CA 92407	NATURAL SCIENCES: Offer "Energy & Its Utilization by Man"-includes solar; emphasis on principles & requirements. Also offer "Solar Energy" extension course which covers basic principles of solar energy.
School of Engineering CALIFORNIA STATE POLYTECHNIC U. 3801 West Temple Avenue Pomona, CA 91768	SCHOOL OF ENG: Offer "Solar Thermal Engineering" for undergrads; "Direct Energy Conversion I" for graduate students; and, "Solar Energy for Home Owners"-a workshop offered on occasion.
CALIFORNIA STATE UNIVERSITY, CHICO Chico, CA 95929	SCHOOL OF NATURAL SCI: Offer "Energy Systems" course-overview including solar; "Basic Methods in Alternate Energy"-hands on course in designing alternative energ devices including solar collectors, etc; "Energy in the Human Environment" course-examines alternative energy sources & their environmental impact. DIV. OF ENG: Offer "Thermal Enrivonmental Engineering" which includes solar radiation fundamentals & solar system design. SCHOOL OF APPLIED SCI: Offer "Alternate Energy Housing course which includes solar. SCHOOL OF BEHAVIORAL & SOCIAL SCI: "Pro-Seminar in Geography, Planning & Development Corporation" course focuses on increasing community involvement with solar SCHOOL OF AGR. & HOME EC: "Graduate Seminar" in Agricultural Mechanics" which includes solar energy.
Department of Mechanical Eng. CALIFORNIA STATE UNIVERSITY Fullerton, CA 92634	DEPT. OF MECH.ENG: "Solar Energy & Engineering Applications" course covering collectors, storage, etc.
Physical Sciences Department CALIFORNIA STATE COLLEGE, STANISLAUS Turlock, CA 95380	PHYS.SCI. DEPT: Offer two solar courses -"Solar & Other Alternative Energies"-introductory course for jrs & srs on solar energy utilization (theory), and "Solar Energy Today"-survey of solar energy applications.

SCHOOL	COURSES
CALIFORNIA STATE UNIVERSITY Long Beach, CA Attn: Dr. Boyd A. Davis Director of Academic Planning	DEPT. OF MECH.ENG: Offer "An Introduction to Applied Solar Energy"-for seniors; "Solar Energy, Its Immediate & Direct Uses"-for adults interested in learning how to build a solar collector; and "Energy Selection & Conversion"-includes solar study.
School of Engineering CALIFORNIA STATE UNIVERSITY 5151 State University Drive Los Angeles, CA 90032	DEPT. OF MECH.ENG: Offer "Solar Energy Applications" course-covers collectors, storage, power plants, photovoltaics, solar heating & cooling systems.
Dept. of Engineering CALIFORNIA STATE UNIVERSITY 18111 Nordoff Street Northridge, CA 91330	DEPT. OF ENG: Offer non-credit course - "Solar Energy for Homeowners." (offered on occasion)
Industrial Technical Department CHAFFEY COMMUNITY COLLEGE 5885 Haven Avenue Alta Loma, CA 91701 Attn: Dean of Occupational Services	IND/TECH DEPT: Offer "Solar Energy I"-introduction to solar heating and cooling systems; and "Solar Energy II"-construction & installation of solar energy devices
Civil/Mechanical Engineering Tech. COGSWELL COLLEGE 600 Stockton Street San Francisco, CA 94108	CIVIL/MECH. ENG. TECH: Offer "Solar Energy Applications workshop for designers, builders, etc. on design & construction of sun & wind-powered systems.
Dept. of Eng. & Technology COLLEGE OF THE DESERT 43-500 Monterey Avenue Palm Desert, CA 92260	DEPT. OF ENG. & TECH: Offer "Introduction to Solar Energy" for undergraduates.
COLLEGE OF MARIN Kentfield, CA 94904 Attn: D. Sartor	ADULT EDUCATION COURSE on Energy Efficient Design & Alternative Energy Sources for professionals & laymen (includes solar)
COLLEGE OF THE REDWOODS Eureka, CA 95501	ENVIRON. SCI. DEPT: Offer "Man's Use of Energy" and laboratory course which includes solar. IND. TECH. DEPT: Offer "Solar Heating Systems" course on design & construction of active solar systems - for vocational/technical majors.
Natural Science Department COLLEGE OF THE SISKIYOUS 800 College Avenue Weed, CA 96094	NATURAL SCI. DEPT: Offer "Frontiers of Science - Energy for Consumers"-examines alternate energy sources that can be used by homeowner.
Dept. of Environmental Design COSUMNES RIVER COLLEGE 8401 Center Parkway Sacramento, CA 95823	DEPT. OF ENVIRON. DESIGN: Offer "Alternate Energy Systems" course-emphasis on solar design.
Biological Science Dept. DIABLO VALLEY COLLEGE 321 Golf Club Road Pleasant Hill, CA 94523	BIO. SCI. DEPT: Offer course in "Conservation Lifestyles" which includes solar heating.

SCHOOL	COURSES
FULLERTON COLLEGE 321 E. Chapman Avenue Fullerton, CA 92635	Offer one course in Solar Heating.
Physics Department GROSSMONT COLLEGE 8800 Grossmont College Drive El Cajon, CA 92020	PHYSICS DEPT: Offer introductory course in Solar Energy (theory).
Department of Engineering HUMBOLDT STATE UNIVERSITY Arcata, CA 95521	DEPT. OF ENG: Offer "Solar Energy Thermal Processes"-theory of solar energy collection; "Whole Earth Engineering" -includes solar; and, "Energy Resources"-includes solar.
Physical Science Department LAKE TAHOE COMMUNITY COLLEGE 2659 Lake Tahoe Blvd. P.O. Box 14445 South Lake Tahoe, CA 95702	PHYSICAL SCI. DEPT: Offer "Solar Energy" course which covers utilization of solar energy and mechanics of various systems.
LOS ANGELES PIERCE COLLEGE 6201 Winnetka Ave. Woodland Hills, CA 91371	PHYSICS/ENG. DEPT: Offer course in "Energy & Power"-includes physical principles of solar power. DEPT. OF LIFE & EARTH SCI: Offer course which includes solar energy - "Man & His Environment: Physical Processes."
Continuing Education MIRACOSTA COLLEGE One Barnard Drive Oceanside, CA 92054	CONT. ED. DEPT: Offer "Community Service" course which deals with energy conservation for consumers. Plan to offer courses in designing solar heating systems in future.
Engineering Dept. MT. SAN JACINTO COLLEGE 21400 Highway 79 San Jacinto, CA 92383	ENG. DEPT: Offer "Solar Energy Applications" course-semi-technical on applications and design of collectors
Department of Energy Science NORTHROP UNIVERSITY 1155 W. Arbor Vitae Street Inglewood, CA 90306	DEPT. OF ENERGY SCI: Offer bachelors degree in Energy Science. Provides general education, environmental issues, training in energy conservation & fundamental principles in solar, fossil & synthetic fuels, geothermal, nuclear & wind. (theory & practical applications). Offer nine solar-related courses. In process of establishing a Center for Energy Research & Technology Applications. (as of 6/77)
Technology Division ORANGE COAST COLLEGE 2701 Fairview Road Costa Mesa, CA 92626	TECHNOLOGY DIV: Offer "Energy Sources" course-survey energy sources from scientific & engineering viewpoint; and "Solar" course-system design & application of solar heating & cooling equipment. Planning complete program to include designing equipment, construction methods, and fabrication of solar devices.

SCHOOL	COURSES
Science Department OXNARD COLLEGE P.O. Box 1600 Oxnard, CA 93032	SCI DEPT: Offer "Energy Conservation & Alternate Energy Sources" course-includes solar. Possibility of offering occupational training in solar energy maintenance & installation.
Dept. of Eng. & Technology PASADENA CITY COLLEGE 1570 E. Colorado Blvd. Pasadena, CA 91106	DEPT. OF ENG. & TECH: Offer "Solar Energy for the Consumer"-basic principles of solar energy utilization; and "Energy Sources, Resources & Uses" which includes solar.
SAN DIEGO CITY COLLEGE Air-Conditioning & Refr. Dept. 12th & Russ Streets San Diego, CA	AIR-CONDITIONING & REFRIGERATION DEPT: Offer two course in "Solar Energy Maintenance & Technology" as part of their A.S. degree program.
SAN DIEGO MESA COLLEGE 7250 Mesa College Drive San Diego, CA 92111	PHYS. SCI. DEPT: Offer "Scientific Concepts Applied to Alternate Energy Sources"-includes solar. CONSTRUCTION TECH. DEPT: Offer "Utilization of Solar Energy"-covers types of solar equipment & lab.
School of Science SAN FRANCISCO STATE UNIVERSITY 1600 Holloway Avenue San Francisco, CA 94132	SCHOOL OF SCI: Offer engineering course-"Introduction to Solar Energy Systems"; and "Design of Solar Energy Systems" course. Also offer solar-related physics course - "Seminar in Science & Society."
Physics Department SAN JOAQUIN DELTA COLLEGE 5151 Pacific Avenue Stockton, CA 95207	PHYSICS DEPT: Offer "Energy Conservation & Alternatives" course which includes solar energy. Plan to offer two other solar energy courses in the future.
Solar Technology Department SAN JOSE CITY COLLEGE 2100 Moor Park Avenue San Jose, CA 95128	SOLAR TECH. DEPT: Offer two-year program in solar energy leading to associate degree & certificate under div. of air-conditioning & refrigeration. Courses cover residential solar design, installation & maintenance and industrial solar application. Provides students wit knowledge to become solar technicians.
Environmental Studies SAN JOSE STATE UNIVERSITY Building U San Jose, CA 95192 Attn: Program Information	ENVIRONMENTAL STUDIES PROGRAM: B.A. and B.S. degrees. Degree "emphasis" offered in solar energy theory & experience. Several solar energy projects on-going. Solar program open to area residents through Continuing Education Programs.
SIERRA COMMUNITY COLLEGE 5000 Rocklin Road Rocklin, CA 95677 Attn: Dean of Voc/Career Ed.	DEPT. OF WOOD TECH: Offer "Solar Energy Housing" course which covers solar energy systems as means of conserving home energy.
SOLAR TECHNICIAN TRAINING PROGRAM 1322 "O" Street Sacramento, CA 95814 Attn: JoAnn Trujillo Program Coordinator	Six-month course offered by Office of Appropriate Technology (CA). Job training program offering working skills in all facets of solar hot water systems -mainly installation. (program for low income individuals/ acceptance in program by application).

SCHOOL	COURSES
Solar Heating Technician Skills Training Program SONOMA STATE COLLEGE 1801 East Cotati Avenue Rohnert Park, CA 94928 Attn: Gayla Mote	TRAINING PROGRAM sponsored by Sonoma & a C.E.T.A. grant (15 trainees in 1977). Instruction covers design sizing, building & installing collectors, distribution and storage systems. Also energy conservation techniques, contractor licensing law, uniform mechanical code, marketing.
School of Engineering STANFORD UNIVERSITY Stanford, CA 94305	DEPT. OF MECH.ENG: Offer two courses in "Solar Energy" one graduate, one undergraduate; offer other related courses in energy conservation & policy. DEPT. OF CIVIL ENG: Offer graduate course-"Small Scale Energy Systems" in solar, as well as "Environmental Impact of Power Generation" which includes solar.
Energy & Resources Program UNIVERSITY OF CALIFORNIA Room 100, Bldg. T-4 Berkeley, CA 94720	ENERGY & RESOURCES PROGRAM: Interdisciplinary program leading to M.A., M.S., Ph.D. Several courses on solar, most in engineering. (some open to undergrads). SOLAR RESEARCH ongoing.
UNIVERSITY OF CALIFORNIA, DAVIS Davis, CA 95616 Attn: College of Engineering or Div. of Environ. Studies	COLLEGE OF ENGINEERING: Offer 5 solar-related courses: "Thermal Radiation," "Conductive & Radiative Heat Transfer," "Advanced Energy Technology," "Energy, Society & the Environment," and "Unit Operations in Agricultural Processing." DIV. OF ENVIRON. STUDIES: Offer "Energy, Man & the Environment" which includes solar.
School of Eng. & Applied Science UNIVERSITY OF CALIFORNIA Los Angeles, CA 90024	ENG. & APPLIED SCI: Offer B.S. & M.S. in "Energy Conservation & Utilization." One specific course in solar-"Solar Energy Use & Control" as well as many engineerin courses which include solar. SCHOOL OF ARCHITECTURE & URBAN DESIGN: Offer "Introduction to Energy Conserving Design" which includes application of solar technology to architectural design Other energy conservation courses offered as well.
Continuing Education in Eng'g & Mathematics UCLA - Extension 10995 Le Conte Avenue Los Angeles, CA 90024	CONT. EDUCATION PROGRAM: Offer short courses in solar energy on occasion.
Energy Center UNIVERSITY OF CALIFORNIA La Jolla, CA 92037	ENGINEERING DEPT: Have an energy center which offers courses in energy to graduate and undergraduate students.
College of Natural & Agricultural Sciences UNIVERSITY OF CALIFORNIA Riverside, CA 92521	COLLEGE OF NATURAL & AGR. SCI: Offer courses which cover theory & principles of energy technologies; some include solar energy.
UNIVERSITY OF CALIFORNIA Santa Cruz, CA 95064	ENVIRON. STUDIES: Offer Student Directed Seminar in Alternative Energy Sources (includes solar). OAKES COLLEGE: Offer "The Sun" course which covers several solar-related topics.

SCHOOL	COURSES
College of Arts & Sciences UNIVERSITY OF REDLANDS Redlands, CA 92373	DEPT. OF ENG: Offer "Energy Alternatives-Priorities & Policies" course which examines energy problems of nation, and alternatives including solar.
Natural Science Department UNIVERSITY OF SAN FRANCISCO San Francisco, CA 94117	NAT. SCI. DEPT: Offer course in "Design of a Solar Energy Collector" for small group of students.
Mechanical Engineering Dept. UNIVERSITY OF SANTA CLARA Santa Clara, CA 95053	MECH. ENG. DEPT: Offer "Solar Energy Thermal Processes course-introduction to use of solar for heating & cooling-covers collector and storage system design.
School of Architecture & Fine Arts UNIVERSITY OF SOUTHERN CALIFORNIA University Park Los Angeles, CA 90007	INTERDISCIPLINARY COURSE: "Energy for Urban & Suburbar Growth & Maintenance" - to examine policy & implicatic of using solar in new & existing structures. (two units)

GENERAL BIBLIOGRAPHY

• Nontechnical Books

DIRECT USE OF THE SUN'S ENERGY, F. Daniels (Ballantine Books, Inc., Westminster, MD 21157, 1964) 271 pp, $1.95.
Covers all aspects of solar energy research and application; provides a general introduction to the subject.

SOLAR HOME BOOK, B. Anderson and M. Riordan (Cheshire Books, Harrisville, NH 03450, 1976) 297 pp, $8.50.
Covers all aspects of solar home heating including architectural, direct and indirect systems, do-it-yourself water heating, retrofitting, and social and cultural implications.

SOLAR HEATED BUILDINGS: A BRIEF SURVEY (13th edition, January 1977), W. A. Shurcliff (19 Appleton St., Cambridge, MA 02138, 1977) 306 pp, $12.00 prepaid.
Contains descriptions of 319 buildings which are partially or fully solar heated; includes buildings that did exist, do exist, or are expected to exist very soon. Permits comparison of characteristics and performances of a wide variety of solar-heated buildings.

TOTAL ENERGY MANAGEMENT--A PRACTICAL HANDBOOK ON ENERGY CONSERVATION AND MANAGEMENT (National Electrical Manufacturers Association, 155 E. 44th St., New York, NY 10017).
Not on solar, but a "must" for commercial building operators.

BUYING SOLAR, Federal Energy Administration, Stock #041-018-00120-4 (Superintendent of Documents, Government Printing Office, Washington, D.C. 29492, June 1976) 71 pp, $1.85.
Guide to factors a homeowner should consider when buying solar systems.

• Technical Books

SOLAR ENERGY THERMAL PROCESSES, J. A. Duffie and W. A. Beckman (John Wiley & Sons, New York, NY 10016, 1974) 396 pp, $18.00.
How to understand and predict the performance of solar collectors and solar photothermal systems for heating and cooling buildings and for heating water and air; comprehensive and coherent treatment for professionals, and especially for engineers.

SOLAR ENERGY HANDBOOK, edited by Paul A. Fleck (paperback, 92 pp, $3.95). A small but tightly packed collection of the numbers, conversion factors, equivalents, and definitions needed by the serious experimenter, builder, architect, or engineer. The established solar reference book.

- ASHRAE Solar Publications

The following publications can be obtained from:

ASHRAE Publications Sales Dept.
345 East 47th Street
New York, NY 10017

SOLAR ENERGY AND THE FLAT PLATE COLLECTOR (S-101), $10.00.
A 31-page bibliography which discusses and cites available information on the flat-plate collector.

SOLAR ENERGY APPLICATIONS (MO-74-1), 52 pp, $10.00.
Clear-day isolation data, applications of solar energy to large institutional buildings, use of the heat pump in connection with solar collectors, developments in the field of thermal storage, and an overview of National Science Foundation programs.

SOLAR HEATING AND COOLING OF BUILDINGS (NSF-RA-N-74-125), 164 pp, $12.50.
Feasibility studies and reports on solar experiments presented at the 1974 Washington, D.C. Workshop sponsored by the National Science Foundation.

SOLAR ENERGY STORAGE SUBSYSTEMS, (NSF-RA-N-75-041), 191 pp, $12.50.
A review of thermal energy storage from the 1975 Charlottesville, Virginia Workshop sponsored by the National Science Foundation.

APPLICATIONS OF SOLAR ENERGY FOR HEATING AND COOLING BUILDINGS.
An expanded and revised version of "Low Temperature Engineering Application of Solar Energy." Thirteen chapters are divided into three sections: environmental evaluation and solar assessment, system component performance and rating, and direct application information.

LOW TEMPERATURE ENGINEERING APPLICATION OF SOLAR ENERGY, 78 pp, $8.00.
A series of authoritative technical treatments needed in the engineering of low-temperature level solar-energy applications particularly related to flat-plate collectors.

SOLAR ENERGY REPRINTS.
Fourteen articles reprinted from the November 1975 issue of ASHRAE Journal.

ENERGY CALCULATIONS 1, 182 pp, $10.00.
Algorithms for building heat-transfer subroutines.

ENERGY CALCULATIONS 2, 96 pp, $10.00.
Procedures for simulating the performance of components and systems for energy calculations.

ENERGY CALCULATIONS 4, 308 pp, $18.00.
Load profiles and energy requirements for heating and cooling of buildings.

HOW TO DESIGN AND BUILD A SOLAR SWIMMING POOL HEATER, Francis de Winter (Copper Development Association, New York, 1975) 46 pp. Free.
Note: Request the sample calculations appendix.

SOLAR HEATING AND COOLING: ENGINEERING, PRACTICAL DESIGN, AND ECONOMICS, J. F. Kreider, and F. Kreith (McGraw-Hill Book Co., New York, NY 10036, 1975) 342 pp. $22.50.
Designed as a how-to handbook with emphasis on economically feasible heating and cooling systems; contains considerable technical detail and extensive tables of reference data.

ERDA's PACIFIC REGIONAL SOLAR HEATING HANDBOOK, prepared for ERDA San Francisco Operations Office by the Los Alamos Scientific Laboratory's Solar Energy Group. The handbook may be obtained for $3.25 by requesting Stock #060-000-0024-7 from Superintendent of Documents, Washington, D.C. 20402. This handbook should also be available at the bookstores in the Federal buildings in Los Angeles and San Francisco.

SOLAR HEATING OF BUILDINGS AND DOMESTIC HOT WATER, E. J. Beck, Jr. and R. L. Field. Technical Report R8356, sponsored by Naval Facilities Engineering Command. The original version, which treated only liquid systems, is now out of print. A revised version that includes air systems may be ordered as a Xerox copy from NTIS (#AO-21862). An improved version is also available for $5.95 (plus 36¢ tax for California residents) from SOLPUB Company, 1831 Weston Circle, Camarillo, CA 93010.

SOLAR HEATING SYSTEMS DESIGN MANUAL (International Telephone & Telegraph Corp., Fluid Handling Division, 8200 N. Austin Avenue, Morton Grove, IL 60053, 1976) 100 pp, $2.50.
Brings together technical data, procedures, and designs necessary to install a solar hydronic heating system; based on system installed at ITT's training facility in Morton Grove.

GUIDELINES FOR SAVING ENERGY IN EXISTING BUILDINGS--Engineers, Architects, and Operators Manual, F. S. Dubin, H. L. Mindell, and S. Bloome (Dubin-Mindell-Bloome Associates, New York, 1975). Available from NTIS, $10.00.
Intended for engineers, architects, and skilled building operators who are responsible for analyzing, devising, and implementing comprehensive energy conservation programs. It includes energy conservation measures that can result in energy savings of 15 to 20% with an investment cost that can be recovered within 10 years through lower operating expenses.

ENERGY CONSERVATION IN COMMERCIAL, RESIDENTIAL, AND INDUSTRIAL BUILDINGS, 343 pp, $20.00.
Proceedings of the 1974 Conference held at Ohio State University.

BIBLIOGRAPHY ON AVAILABLE COMPUTER PROGRAMS, 87 programs with indexes, $4.00.
Lists and describes computer programs in the general area of heating, refrigerating, air conditioning, and ventilating.

INTERNATIONAL DAY BULLETIN (ID-AC-75), 86 pp, $10.00.
Presentations made by international authorities concerning energy conservation and metrication.

- AIA Research Corporation Publications

The following publications are available from:

AIA Research Corporation
1785 New York Avenue, N.W.
Washington, D.C. 20006

ENERGY CONSERVATION IN BUILDING DESIGN, 156 pp, $5.00.
Considers the various aspects of the technological and social impacts of energy supply and consumption. Charts and tables as well as text outline the basic design considerations for energy-efficient architecture. Includes descriptions of existing and planned structures.

HERE COMES THE SUN-1981, Joint Venture, Inc., 98 pp, $11.00.
Considers the advantages, differences, and compatibility of various solar mechanical systems, energy conservation measures, and multi-family concepts. Illustrates the feasibility of integrating these systems into multifamily dwellings and the resulting opportunities for architects.

SOLAR-ORIENTED ARCHITECTURE, Arizona State University, 142 pp, $12.50.
Contains summaries and drawings of 70 dwellings utilizing solar energy for heating and cooling, detailed descriptions (with 10 full sets of drawings) depicting buildings which illustrate the four principal methods of using solar radiation. Provides analysis of the basic principles of solar space heating and evaluation of design implications.

SOLAR ENERGY AND HOUSING DESIGN, Giffels Associates, 145 pp, $15.00.
Presents a systematic process for selection of solar energy systems applicable to four climatic regions of the continental U.S., and the incorporation of these systems into low-rise, multifamily dwellings. Includes a survey of solar collection and storage components.

SOLAR CONTROL AND SHADING DEVICES, Olgvay and Olgvay, 202 pp, $7.50. "No other text exists which discusses solar control and shading devices in such intimate relationship with contemporary architecture. This work will be an extremely valuable addition to the architectural library."-*Progressive Architecture*.

CRITERIA FOR THE PRELIMINARY DESIGN OF SOLAR-HEATED BUILDINGS, E. M. Barber and D. Watson (Sunworks, Inc., 669 Boston Post Road, Guilford, CT 06437, 1974) 54 pp, $10.00.
This paper outlines criteria for solar heated buildings. It is intended for architects, builders, and potential owners of such buildings. Included are most of the major architectural and construction considerations that must be dealt with in the design of these buildings.

- Economics-Related Books

AN ECONOMIC ANALYSIS OF SOLAR WATER AND SPACE HEATING, Energy Research and Development Administration, Stock #060-000-00038-7 (Government Printing Office, Washington, D.C. 20403, November 1976) 26+ pp, $1.85.

THE POVERTY OF POWER: ENERGY AND THE ECONOMIC CRISIS, Barry Commoner (A. Knopf, New York, NY 10022, 1975) 320 pp, $8.95.
The energy crisis as seen by an environmentalist; covers the use and misuse of fossil and nuclear energy, current government and industrial opposition to alternative energy sources, and recommendations for the future.

SOLAR HEATING AND COOLING IN BUILDINGS: METHODS OF ECONOMIC EVALUATION, Rosalie T. Ruegg (National Bureau of Standards, May 1975).
Available from National Technical Information Service, Springfield, VA 22151; ask for Report #COM-75-11070.

HOME MORTGAGE LENDING AND SOLAR ENERGY, D. Barrett et al,, Stock #023-000-00387-2 (Government Printing Office, Washington, D.C. 20402, 1977) 31 pp, $1.40.
Results of a series of interviews with mortgage loan officers at financial institutions in New England. Main focus was on mortgage financing for new housing with solar energy space-heating systems.

MARKET STATISTICS AND FORECASTS, in *Survey of the Emerging Solar Energy Industry*, J. A. Bereny (Solar Energy Information Services, P. O. Box 204, San Mateo, CA 94401, 1977) 395 pp, $60.00.

- LIFE CYCLE COSTING EMPHASIZING ENERGY CONSERVATION: GUIDELINES FOR INVESTMENT ANALYSIS, Reynolds, Smith, and Hill (National Technical Information Service, U.S. Department of Commerce, 5285 Port Royal Road, Springfield, VA 22161, September 1976) $6.00.

- AN ECONOMIC ANALYSIS OF SOLAR WATER AND SPACE HEATING, Mitre Corporation (Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402, Stock # 060-000-0038, November 1976) $1.40.

- SOLAR LIFE CYCLE CASH FLOW ANALYSIS, Sheldon H. Butt (Solar Energy Industries Association, 1001 Connecticut Avenue, Suite 800, Washington, D.C. 20036) $1.50.

- SOLAR HEATING AND COOLING IN BUILDINGS: METHODS OF ECONOMIC EVALUATION, Rosalie T. Ruegg (Building Economics Section, Center for Building Technology, Institute for Applied Technology, National Bureau of Standards, Washington, D.C. 20234, July 1975, NBSIR 75-712).

- SOLAR HEATING AND COOLING, Jan Kneider and Frank Kneith (McGraw-Hill, New York, NY 1975).

* Periodicals

SOLAR ENERGY (Pergamon Press, Inc., Maxwell House, Fairview Park, Elmsford, NY 10523), bimonthly, $100.00/yr. Included with membership in International Solar Energy Society. Contains scientific and engineering papers on all aspects of solar energy and technology, theory, and applications.

SUNWORLD (Pergamon Press, Inc., Maxwell House, Fairview Park, Elmsford, NY 10523) quarterly, $12/yr. Semitechnical articles on worldwide developments in solar energy. Included with membership in International Solar Energy Society.

SOLAR AGE (Solar Vision, Inc., 200 E. Main St., Port Jarvis, NY 12771) monthly, $20.00/yr. Brief articles on developments in solar energy applications, with emphasis on solar heating and cooling. Included with membership in American Section of the International Solar Energy Society.

SOLAR ENERGY INTELLIGENCE REPORT (Business Publishers, Inc., P. O. Box 1067, Silver Spring, MD 20910) biweekly, $90.00/yr. Covers the Washington beat in solar energy. Also new developments, markets, and meetings.

SOLAR ENGINEERING (Solar Engineering Publishers, Inc., 8435 N. Stemmons Freeway, Suite 880, Dallas, TX 75247) monthly, $15.00/yr. Short descriptions of activities and developments in the field of solar energy, particularly in the private sector and in the U.S.

SOLAR HEATING AND COOLING (Gordon Publications, P. O. Box 2126-R, Morristown, NJ 07960) bimonthly, $6.00/yr. Short articles on solar heating and cooling issues, developments and equipment. Oriented to builders, developers, and manufacturers.

SOLAR ENERGY DIGEST (CWO-4, W. B. Edmondson, P. O. Box 17776, San Diego, CA 92117) monthly, $28.50/yr. Concise summaries of solar energy developments, on-going research and publications, both U.S. and foreign.

SUNRAE NEWSLETTER (Solar Utilization Now for Resources and Employment, P. O. Box 915, Goleta, CA 93017) monthly, $5/yr.

SOLAR ENERGY ADVOCATES NEWSLETTER (Solar Energy Advocates, P. O. Box 876, Sacramento, CA 95814) monthly, $5/yr. Follows legislative and governmental activity in solar energy in Sacramento.

SPECIFYING ENGINEER (Subscription Service, 270 St. Paul St., Denver, CO 80206) $16/yr. Highly technical journal for building and plant engineers; often has practical solar engineering articles.

ENERGY ACTION NEWS & VIEWS (Citizens for Energy Conservation and Solar Development, Inc., P. O. Box 49173, Los Angeles, CA 90049). Send donation to receive this citizen action newsletter to further energy conservation and solar energy. CECSD is trying to become a strong public voice to further solar energy.

ENERGY REPORTER (Federal Energy Administration, Washington, D.C. 20461).
A free monthly that includes miscellaneous tidbits from the FEA. A "citizen newsletter" with energy conservation tips, etc., in a readable format. The one-page summary of available publications in each issue is very useful.

- Government Programs

NATIONAL PROGRAM FOR SOLAR HEATING AND COOLING OF BUILDINGS: PROJECT DATA SUMMARIES, Vol. 1- COMMERCIAL AND RESIDENTIAL DEMONSTRATIONS, (Stock #060-000-00012-3, 1976) 163 pp, $2.35; Vol. 2- DEMONSTRATION SUPPORT, (Stock #060-000-00042-5, 1976) 61 pp, $1.25; Vol. 3- RESEARCH AND DEVELOPMENT (Stock #060-000-0018-2, 1976) 96 pp, $1.90. (Systems Consultants, Inc., Superintendent of Documents, Government Printing Office, Washington, D.C. 20402).
Brief abstracts of projects funded by ERDA (DOE) and conducted under the National Program for Solar Heating and Cooling of Buildings through July 1976. Volume 2 reports on development support for the demonstration program, and Volume 3 describes all research and development projects in the areas of collectors, thermal energy storage, solar heat pumps, solar cooling systems, and controls.

SOLAR HEATING AND COOLING DEMONSTRATION: A DESCRIPTIVE SUMMARY OF HUD SOLAR RESIDENTIAL DEMONSTRATIONS, CYCLE 1, AIA Research Corporation Stock #023-000-00338-4 (Superintendent of Documents, Government Printing Office, Washington, D.C. 20402, 1976) 59 pp, $1.15.
Project summaries of 53 projects in the first cycle of residential demonstration awards. Each description includes background and climatic data, a brief discussion of the dwelling's physical characteristics and energy conservation features, and information on the components of the solar energy system.

A DESCRIPTIVE SUMMARY OF HUD SOLAR RESIDENTIAL DEMONSTRATIONS, CYCLE 2, Fall 1976. AIA Research Corporation (Superintendent of Documents, Government Printing Office, Washington, D.C. 20402, 1977) $2.30. Describes solar grant projects selected from the second-cycle grant applications in the HUD solar heating and cooling demonstration program. Includes renderings of building elevations and schematic drawings of each solar system.

A GUIDE TO FEDERAL PROGRAMS OF POSSIBLE ASSISTANCE TO THE SOLAR ENERGY COMMUNITY, Congressional Subcommittee on Science and Technology (Superintendent of Documents, Government Printing Office, Washington, D.C., 1977) 529 pp. Federal financial assistance and funding programs, import-export information, services offered to the solar community by various agencies, procedures for bidding on Government installations and selling to Government agencies.

- Directories

INFORMAL DIRECTORY OF THE ORGANIZATIONS AND PEOPLE INVOLVED IN THE SOLAR HEATING OF BUILDINGS (2nd edition), W. A. Shurcliff (19 Appleton St., Cambridge, MA 02138, 1976) 178 pp, $7.00.
Selective coverage of institutions and individuals involved in all aspects of solar heating of buildings; main emphasis is on U.S. but some foreign groups are included.

SOLAR AGE CATALOG, 1977, prepared by Solar Age (SolarVision, Inc., 200 E. Main St., Port Jarvis, NJ 12771) 232 pp, $8.50.
Includes product descriptions and general articles on building design; passive solar heat; greenhouses; components; subsystems; systems; photoconversion; measurement and data collection; and data tables and performance curves. Has a listing of 126 solar manufacturers and over 200 architects, engineers, designers, builders, and information sources.

1977 SOLAR ENERGY & RESEARCH DIRECTORY (Ann Arbor Science Publishers, Inc., P. O. Box 1425, Ann Arbor, MI 48106) 386 pp, $22.50.
Lists 700 private, nonprofit, and government groups in the following categories: energy conservation; solar component manufactueres; total system manufactueres; solar distributors; design and construction; solar research. Indexed also by subject and by component and subsystem. Includes both U.S. and foreign companies.

SOLAR ENERGY SOURCE BOOK, C. W. Martz, editor (Solar Energy Institute of America, P. O. Box 9352, Washington, D.C. 20005, 1977) 712 pp, $12.00.
Loose-leaf guide to manufacturers and organizations; periodic updates provided to members.

SOLAR INDUSTRY INDEX (Solar Energy Industries Association, 1001 Connecticut Avenue, N.W., Suite 632, Washington, D.C. 20036, 1977) 381 pp, $8.00.
Comprehensive guide to manufacturers and service organizations; also includes chapter on operations and economics of solar systems.

SURVEY OF THE EMERGING SOLAR ENERGY INDUSTRY, 1977, Justin A. Bereny (Solar Energy Information Services, P. O. Box 204, San Mateo, CA 94401) 406 pp, $60.
Gives an overview of solar technology in the U.S.: heating and cooling, solar thermal electric, photovoltaics, wind energy, ocean thermal, and bioconversion. Covers present technology, role of government, interface with utility companies, market facts and forecasts. Directories of 408 public and private companies, their products and services, 165 nonprofit research groups, and a 12-page bibliography.

- Bibilographies

SOLAR ENERGY-A BIBLIOGRAPHY, U.S. Energy Research and Development Administration (Technical Information Center, U.S. Department of Commerce, Springfield, VA 22161).

SYNERJY (Synerjy, P. O. Box 4790, Grand Central Station, New York, NY 10017). Semiannual updated bibliography on alternative sources.

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ASHRAE Report S-101
November 1975

Solar Energy and the Flat Plate Collector

An Annotated Bibliography

by

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February, 1975

Abstract

The literature on the flat plate collector covers a number of decades and involves many journals and books. To date there seems to be no single source in which the significance of the literature is discussed in some detail. This annotated bibliography constitutes an attempt to do this for the flat plate collector itself, and for the solar input quantities which must be used for performance calculations. The possible uses of the flat plate collector are not discussed in detail.

Acknowledgement

The need for this bibliography became apparent in preparing the proceedings of a Solar Cooling Workshop organized for the National Science Foundation under Grant No. AG-502. The preparation of the bibliography was completed under sponsorship of the Copper Development Association Inc., of 405 Lexington Avenue, New York.

Any views expressed in this bibliography are my own, and do not necessarily reflect the views of the Copper Development Association Inc., or of the National Science Foundation.

SOLAR ENERGY AND THE FLAT PLATE COLLECTOR - AN ANNOTATED BIBLIOGRAPHY

by Francis de Winter

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I. INTRODUCTION

The flat plate collector has for many years been the most popular device to collect solar heat at modest temperatures. It has been used, almost to the exclusion of other devices, for the heating of domestic water. It is the most frequently considered device for use in the heating or cooling of buildings with solar energy. It has been coupled to heat engines and other devices in hundreds of published hardware and paper studies.

Concentrating collectors are the main alternatives to the flat plate collector. These can only collect direct solar energy, and a small fraction of the diffuse solar energy which happens to be at angles close to the sun.* Concentrating collectors generally need continuous tracking control, a more expensive (pivoting) mounting structure than the flat plate collector, and reflective surfaces which require regular cleaning. At temperatures below perhaps 140^{o}C there seems to be general agreement that the flat plate collector is likely to be more economical than concentrating collectors.

The energy crisis and the subsequent revival of solar energy has made it necessary for many to search through a literature which stretches over a number of decades, involves many journals, books and conference proceedings, and includes papers of a wide range of usefulness. There is no single source of information on the flat plate collector in which the understanding of its operation, and the significance of the literature, is discussed in some detail. Hopefully this annotated bibliography will be useful in these areas.

It was decided not to limit the discussion to the flat plate collector itself. The flat plate collector is quite dependent on solar inputs. The available measurements on solar inputs are sketchy, and many necessary data are not readily available or not available at all. The basic interactions between solar radiation and the atmosphere remain a mystery to many involved in solar energy work. Because of the importance of this topic, it was covered in some depth.

There have been a number of areas in which time and space have made a thorough treatment impossible. The discussion of the early historical development of the flat plate collector has not considered most of the patent literature (see Daniels and Duffie, 1955), or most of the other primary sources (for references, see for example Jensen, 1959, or the Jordan chapter in Zarem and Erway, 1963). The discussion has been restricted primarily to the most commonly treated liquid-heating collectors, and no attempt has been made to cover the dozen or so other types which have been discussed in the literature. Finally, the literature on usage, including

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*The new concentrators of Winston (1970) have a large field of view and can collect sizable amounts of diffuse solar energy.

heating, cooling, power production, storage and other topics is so vast that no attempt has been made to go into it in detail.

There is little question but that readers will find oversights and other errors in the material that has been covered. I would appreciate receiving suggestions for future editions of this bibliography. It should be noted that any opinions expressed in this bibliography are my own, and do not necessarily reflect the views of the Copper Development Association or of the National Science Foundation.

2. THE FLAT PLATE COLLECTOR

Several aspects of the flat plate collector are discussed below. The mode of operation is discussed in qualitative terms. The significant developments in the design of the collector, and in the understanding of its operation, are presented for the most commonly used types of liquid-heating collectors. Several other types are discussed briefly. Finally some references are given on usage and economics.

It should be noted that the discussion has not, to date, included the Russian or the Japanese literature, although in both of these countries solar energy has had a long history of involvement by highly competent technical people.

2.1 Flat Plate Operation, Features, and Components

Figure 1 shows an exploded view of a flat plate collector with typical components. In the flat plate collector a flat plate with a black (solar-absorbing) frontal coating serves to collect the solar energy and convert it to heat. This plate then transmits the heat, by conduction, to the fluid to be heated. The flat plate itself can have several forms, of which the most common are probably a sheet with fluid-carrying tubes fastened to it spaced at regular intervals, or a double-walled geometry with internal flow passages. At temperatures close to ambient nothing else is needed, and a simple,

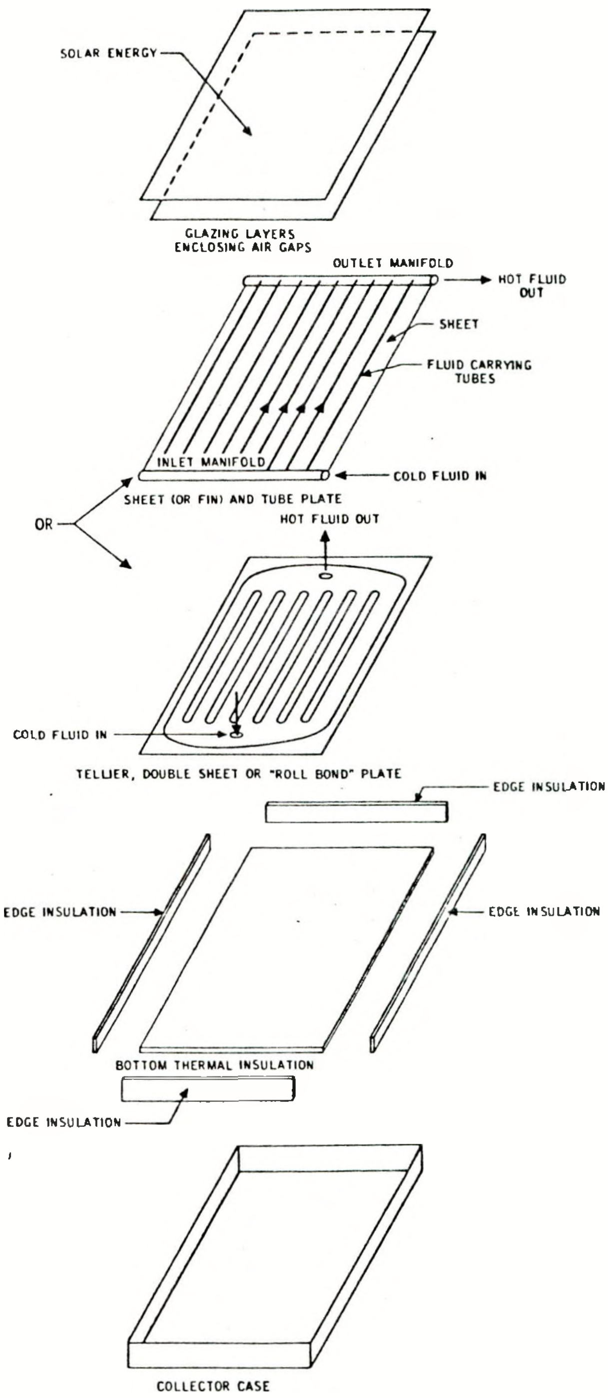

Figure I Exploded View of Standard Flat Plate Collector bare flat plate collector system can be used as is for such purposes as heating swimming pools.

In operation fluid is made to flow into one side of the flat plate, and withdrawn on the other side after having been heated to temperatures ranging from ambient up to perhaps 150^{0}C, depending on the design. Flat plate collector designs can be made for temperatures somewhat higher than this, but concentrating collectors at some point become more cost effective.

At increasingly higher temperatures of collection the heat losses get out of hand unless measures are taken to minimize them. Thermal insulation can be installed behind the flat plate, and at the edges. One or more layers of glass or plastic (enclosing relatively stagnant air spaces up to about 2-3 cm thick) may be used on the front side. While such layers of glazing filter out and reflect some of the incoming solar energy, the reduced heat losses can greatly outweigh this effect. Most of the heat loss reduction is due to the formation of blankets of relatively stagnant air. Direct wind convection losses are eliminated altogether, and if the glazing is spaced at the right distances, natural convection effects inside the glazing system are not excessive and losses are perhaps only 2-3 times higher than those corresponding to stagnant gas conduction alone.* Some** of the heat loss reduction is due to the interception of infrared radiation by the glass, which is quite opaque to the infrared. Plastics are generally not as opaque, and hence less effective in this regard.

Heat losses can be reduced further by using a selective black surface, which has a low emissivity for the infrared but still has a high absorptivity for the solar energy spectrum. This can probably only be considered in glazed collectors, in which the weathering requirements on the selective coating are minimized. A "good" selective coating can replace roughly one glass layer.

Flat plate collectors are generally fastened rigidly at an angle which will yield a maximum heat output during the whole year or in a particular season. For maximum year-round collection they should be tilted towards the equator at an angle slightly (say 5^{0}) greater than the latitude of the site. For summer collection the best angle is roughly latitude minus 10 or 15 degrees, for winter collection latitude plus 10 or 15 degrees. Even when the optimum angle is not used in installing a collector,*** the fixed mounting yields a number of cost benefits compared to the concentrating collector.

*This is the case for a 2-3 cm clearance at a collector inclination of 45° with reasonable temperature differences. Not much is to be gained by going beyond 2-3 cm clearance in this case. See Tabor (1958a) for detailed results.

**The so called "greenhouse effect" is a relatively minor effect even in greenhouses (Zarem and Erway, 1963 p. 298).

***The penalties for slight off-optimum orientations are surprisingly modest.

2.2 Development of Design and Understanding

According to Ackermann (1915), the flat plate collector was invented by H.B. de Saussure, the Swiss alpinist and scientist, in the second half of the 18th century. De Saussure used a wooden box, with a blackened collection surface, covered by 2 layers of glass.

Sir John Herschel in 1837 performed experiments near Cape Town with a flat plate collector, and found that with two glass plates he could get to 120^{o}C (Ackermann, 1915). On one occasion he amused himself and some bystanders by cooking food.

Tellier (1885) used a flat plate collector without glazing, in Paris, as an ammonia (water solution) boiler for a heat engine driving a water pump. The collection plate consisted "of two sheets of iron riveted together on all their edges, and separated slightly with filling pieces," with the fluid flowing in the space between the sheets. A similar design is the subject of an early U.S. patent of Molera and Cebrian (1880).

Willsie and Boyle, starting in 1902 used a number of double glazed flat plate designs in Olney, Illinois; Hardyville, Arizona; St. Louis, Missouri; and Needles, California, as heat sources for Rankine cycles using ammonia or sulfur dioxide as a working fluid (Ackermann, 1915; Abbot, 1938). The Willsie and Boyle collectors were horizontal, using water flowing in an open trough (under the double glazing). The water was then used to evaporate the engine working fluid. They continued work for several years, ultimately reaching a 15 HP output.

Shuman in 1907 built a 3 1/2 HP ether Rankine cycle, using a 1200 ft^2 flat plate collector containing parallel blackened pipes and covered with a single glazing. In 1911 he built a flat plate collector with two glazings and a Tellier-type collecting plate close to Philadelphia, with reflecting mirror boosters giving an effective solar concentration of 2 to 1. With a total area of 10,296 ft^2 he was able to produce 816 lbs. of steam per hour (Ackermann, 1915, Abbot, 1938). The Shuman collectors, with their fore and aft mirror boosters, constituted a trough which ran East and West. Shuman adjusted the inclination of his collector system about every 3 weeks so as to be normal to the solar rays at noon.

Collectors with a sheet-and-tube configuration were built in the 1920's and 1930's (see Farrall, 1929; Day & Night, 1930).

Carnes (1932) also built a flat plate collector featuring tubes with side fins soldered to them. For his final material he used corrugated (28 gage galvanized) steel, but he also considered the use of copper. An interesting aspect of his work is that he found solder necessary to get a good enough bond for an acceptable efficiency, a fact confirmed by modern understanding (see, for example, Whillier, 1964b, or Khan, 1967).

Brooks (1936) gives extensive results of operation of flat plate collectors in a manual aimed at the do-it-yourself market. Brooks worked primarily with heaters consisting of close arrays of pipes esentially blanketing the collection area. Some results were given for a "flat tank" (Tellier) type of collector, but only a brief mention was made of the possibility of using fins between the tubes.

Hottel and Woertz (1942) made the first real attempt to understand the operation of the flat plate collector from first principles.* The transmission, reflection, and absorption of solar energy in multiple glazing systems were examined in detail using the methods of Stokes (1860-1862), and simplified relations were presented describing these effects. A rigorous solution was obtained for the fin efficiency of a collection sheet spanning the space between fluid-carrying tubes. A model was made of the convection and radiation losses up through the glazing, and this model was fitted to experimental results. The effect of temperature variation along the flow length was estimated. Steady state solutions were found to be adequate for the description of collector performance, particularly since good collector design requires a low thermal inertia.**

A thorough review of the literature and history of solar water heating up to the time was published shortly after the Hottel and Woertz paper by Veltford (1942).

Hawkins (1947) wrote a do-it-yourself solar heating manual in which the tube and sheet geometries recommended involved a cost-optimized fin thickness and length.

Whillier (1953) and Hottel and Whillier (1955) obtained a rigorous solution for a "flow factor" which can be used to predict the collector overall efficiency, accounting for the effect of temperature variation along the flow length. They also derived several equations describing the effect of plate-to-tube contact coefficient, plate-to-tube contact width, heat transfer coefficient of the heat transfer fluid, and similar characteristics of the typical cross section of the collection plate. These factors might be called the "cross-section efficiency." More such factors were derived by Bliss (1959) in a study in which he presented an organized derivation and discussion of flat plate efficiency factors.

Tabor (1955 a,b,c) revived interest in the use of selective surfaces in flat plate collectors. The concept of these was not new, indeed Brooks (1936) has extensive tables of the absorptivity

*Shuman, Willsie and Boyle, Carnes, and Brooks all made efficiency determinations based on estimated or measured insolation values. There does not however seem to be any attempt in these studies to relate efficiency accurately to specific design and operation parameters.

**In the discussion of their paper, Hottel and Woertz (1942): "believe it probable that many of the (then-existent-commercial) California solar heaters have a heat-capacity loss equal to at least 15 per cent of the useful collection."

and emissivity of surfaces, and a discussion of their significance. Most selective surfaces that were known were however only able to get a low emissivity at the cost of a significant penalty in absorptivity, and this made them worse (despite the fact that some had high values of α/ϵ), than non-selective surfaces of high absorptivity and emissivity.* Tabor showed the incentives for using selective surfaces, using as examples a number of possible surface designs tailor-made to solar energy requirements. As a result of these Tabor papers, and of one by Gier and Dunkle (1955), new work was directed at selective surface development and evaluation (Unger, 1958), (Hottel and Unger, 1959), (Edwards et al, 1960, 1961, 1962), (Tabor et al, 1961, 1962, 1963), (Close 1962a).

The selective surface with the best radiation properties to date is probably "nickel black" or "chrome black." Both of these were first developed by Tabor (1962, 1963, see also Tabor chapter in Jordan, 1967), and have recently been studied extensively by NASA (Lowery, 1974; McDonald, 1974).

The use of a selective surface in an experimental collector led Tabor (1958a) to a revision of the convection and radiation heat loss equations originally proposed by Hottel and Woertz (1942), and used by virtually everyone since, including Whillier (1953), Unger (1958), and Tabor (1955a). The original equations had proved adequate for gray surfaces but led to excessively low heat loss predictions in collectors featuring selective coatings.

There are a number of other aspects of the design and operation of flat plate collectors which are not really important enough to consider in a strictly historical context. Some of these are discussed below.

The heat losses through the sides and the bottom of the collector are normally handled based on steady state conduction models, depending on the thermal insulation and the configuration used. Simple guidelines for the losses through the bottom of approximately optimized collectors are given by Whillier in a report edited by Jordan (1967). Determinations of the edge losses can become quite complex, particularly if one wants to understand things well enough to optimize the edge insulation design. Tabor (1958) examined this problem using conduction solutions of Langmuir, and found that edge losses can be surprisingly large unless one takes care to minimize them.

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*It should be noted in this regard that the term "α/ϵ" is meaningless in the description of a surface, except for a surface delivering no useful heat, and having neither convection nor conduction losses. This case is of absolutely no interest in terrestrial solar energy. In order to characterize a surface one must specify α and ϵ. For a discussion of quality criteria of selective surfaces, including an "absorptance of merit," see Edwards et al (1960, 1961, 1962). For earlier discussions, see also Gier and Dunkle (1955), and Tabor (1955a).

Convection heat transfer to the atmosphere (from the outside glass layer) is normally handled with standard heat transfer correlations such as those given in McAdams (1954). Bliss (1961a) did a thorough analytical study directed at establishing an effective sky temperature for the calculation of infrared radiation losses. This sky temperature can be used in describing the radiation heat losses from the collector.

The heat transfer requirements of the bond between the tubes and the collection sheet (fin) have been investigated by Whillier (1964b) and by Khan (1967).

Tabor (1958b, 1966) explored the potential of mirror boosters, including those of the Shuman type. Winston (1970, 1974) proposed an interesting new booster concept which has less critical pointing requirements.

The heat transfer coefficient of the fluid flowing through the collector passages is rarely controlling. If forced circulation is used, generally very little pumping power is needed* to obtain negligible fluid heat transfer resistances and a low temperature rise of the fluid (hence a high collector efficiency). Standard heat transfer correlations (McAdams, 1954) can be used. Collectors can also be used with natural circulation, or "thermosiphon" operation, using a storage tank located above the collector, with collector and tank connected by a circulation loop. This was used by Farrall (1929), Day & Night (1930), Carnes (1932), and Brooks (1936), and studied in detail by Close (1962) by Gupta and Garg (1958), by Yellott and Sobotka (1964) and by Tabor (1969). Thermosiphon systems generally lead to low flowrates through the collector with the fluid undergoing a large temperature rise; as a result, one would expect the collector efficiency to suffer.** Because of the low flowrate and high temperatures, hard water can lead to clogged passages (Yellott and Sobotka, 1964). The heat transfer at these low flow-rate conditions has been studied analytically for inclined tubes by Iqbal (1966), and experimentally for horizontal tubes by Baker (1967). Cheng and Hong (1972) corrected and extended the results of Iqbal by using recently developed calculation techniques.

Calculations on collector performance are still generally performed for the steady state case. Duffie and Beckman (1974a) (see also Klein et al, 1973), after extensive computer modelling work to examine the steady state assumptions, determined that: "The Hottel-Whillier-Bliss collector model is quite adequate for almost all flat plate collector calculations, and the

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*The main drawback of a forced circulation system is equipment and control cost and reliability.

**Tabor (1969) has however shown that low flowrate and high flowrate thermosiphon systems have virtually the same efficiency. In the low flowrate case the exit temperature is high even when input temperatures are low. In the high flowrate case, the temperature in the collector may be uniform, but in the afternoon it tends to be uniformly high since the same water may have been heated already several times by the collector.

availability of computing capability does not justify the use of more complicated models." This is particularly true since weather data are available at most at hourly intervals, and since the transient time constants of collectors (and of collector nodes in analytical computer-models) are of the order of minutes.*

The direct use of water in a flat plate collector poses several problems. The water can freeze in cold weather, damaging the collector, unless special care is taken to prevent it. It is probably best to drain the collector completely in cold weather as recommended by Farrall (1929) and Brooks (1936). It is easy to design an automatic system for doing this, particularly if one has a system using forced circulation of unpressurized water (Whillier, 1953; de Winter and Lyman 1973, de Winter 1974a). Unless one is quite certain this problem has been solved with water, it is necessary to go to a double loop system, with an antifreeze solution in the collector, and with a heat exchanger between the antifreeze solution and the water to be heated. Heat exchanger optimization criteria were developed by de Winter (1975). Brooks (1936) describes such a double loop system sold commercially in California by the Day and Night Water Heater Co. Ltd. of Monrovia (see also Day & Night, 1930). The antifreeze solution should preferably be cheap, non combustible, non corrosive, and non toxic. There seems to be no ideal fluid. Many are too expensive. Most are too viscous, or too volatile. Many have poor heat transfer properties. Ethylene glycol, the normal automotive antifreeze, is highly poisonous, but propylene glycol is not (McFarland, 1972). The glycols however need corrosion inhibitors.

Water also makes it virtually mandatory to use corrosion-resistant tubing. Copper tubing has been used in most of the studies on solar water heating quoted here, and is becoming increasingly popular in potable water systems in general (Obrecht, 1973), although on a first-cost basis it is more expensive than most competing materials.

Glass for flat plate collectors should preferably be low in iron. With Fe_2O_3 concentrations greater than about 0.15% the solar transmissivity goes down fairly rapidly (see Dietz Chapter in Hamilton, 1950; or in Zarem and Erway, 1963). Glass high in iron has a dark green edge (Hottel and Woertz, 1942) whereas low iron glass of high transmissivity has an edge of a light bluish color (Farber, 1972).

Most glazing support systems have been designed for vertical glass, rather than horizontal or inclined glass. There has been a lot of broken glass in the history of the flat plate collector, due to faulty support systems or structures, excessive thermal expansion or temperature differences, or crack propagation from irregularly cut edges. In hail-free areas, single strength

*Remember: Good collector design involves the use of low thermal inertia!

glass can be adequate even under hurricane conditions (Robbins, 1974). Screens with 1/2" mesh of 22 S.W.G. galvanized wire stretched 12" above the collector have been used for hail protection in Australia in areas of "exceptionally severe hailstorms" (Morse, 1956), but can lead to performance reductions of up to 12%. Yellott and Sobotka (1964) have found that unprotected glazing can sometimes survive hailstorms with individual stones weighing up to 1 lb. each, if impacts are not at right angles to the glass.

Whillier (see his chapter in Jordan, 1967) has an approximate guide on how many layers of glass to use for a most cost-effective collector at any given temperature level. Calculations have been made for as many as 9 glass layers by Hottel (Zarem and Erway, 1963, p. 145).

Most plastic glazing materials do not stand up under ultraviolet light for long (Talbert et al, 1970). Polyvinyl fluoride, sold under the tradename "Tedlar" by Dupont, seems to be relatively good in this regard. It is often used as a coating on corrugated fiberglass reinforced plastic (FRP) panels for greenhouses, with guaranteed "light" (see below) transmissivity values-subject to regular cleaning - for periods up to 20 years (Filon, 1973).

There are several problems with plastics. The coefficients of thermal expansion are relatively high, and the support structure must take this into account. Tedlar is not recommended by Dupont for continuous use at temperatures above 107°C (Dupont Bulletin TD-2). It is hence probably best not to use it for internal layers of a glazing system, <u>unless</u> one is sure it will stay within temperature specifications. Finally, although Tedlar can have solar transmissivity* values as high as the best types of glass, most plastics (including Tedlar) have infrared transmissivity values as high as 30%, whereas glass has an infrared transmissivity of essentially zero (Whillier, 1963). In view of this, a particularly worthwhile concept for a flat plate collector design might involve one plastic glazing and a good selective coating.

Until recently the results most often used on "dirt factors" due to the dirtiness of glass on collectors were those of Hottel and Woertz (1942), which though measured at 30° inclination in a fairly sooty area in Cambridge, Massachusetts, seemed to indicate dirtiness was a very minor factor. Recently, Garg (1974) published comprehensive results obtained for glass inclined at a number of angles. In dry and dusty weather, it took roughly one month in Roorkee, India, for the dirtiness factors to become constant. The reduction of transmissivity was found to

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*Beware of solar transmissivity values! Many values given in the greenhouse literature refer to transmissivity of that fraction of the spectrum useful to photosynthesis (as measured by ASTM-D-1494-69), <u>not</u> to the transmissivity for the full solar spectrum (as measured by ASTM-E-424-71). There can be a significant difference in the two values. In Tedlar covered FRP materials, the total solar energy transmissivity seems to be about 8-10% <u>lower</u> than the "light" transmissivity.

be higher in Roorkee than in Cambridge, it was greater for plastics than for glass, and it was found to be much less at angles of inclination above about 40°, than for more horizontal panels. Dust inside of multiple glazing systems can be a significant problem (Whillier, 1953).

The best single source for the description of the performance of flat plate collectors is probably the report of Jordan (1967). For a while it was out of print. A new version is being prepared.

2.3 Different Types of Flat Plate Collectors

This discussion has stressed the flat plate collector used for heating liquids,* which is generally either of the Tellier (double-sheet) type, or of the sheet and tube type. There are however perhaps at least a dozen other varieties, several of which are discussed very briefly below.

Francia (1962, 1968) developed a collector concept in which the multiple glazing (normally used to prevent frontal heat losses) is replaced by a honeycomb structure normal to the plate. The honeycomb structure can serve to produce relatively stagnant air conditions, limiting convection losses. It can also limit infrared radiation losses by being made of walls essentially black to the infrared. The honeycomb concept works best when the panel is pointed at the sun, so that sunlight is streaming into the honeycomb with no shadowing. With a glass** honeycomb, however, this is not strictly necessary, since sunlight will go through the walls. Honeycomb type of collectors have been studied by a number of other investigators, including Hollands (1965), Bifano (1968), Buchberg et al (1968, 1971), Sparrow et al (1971), and Charters and Peterson (1972). The honeycomb collector can be used for heating liquids (Hollands 1965), or gases (Buchberg et al, 1971), or for evaporating liquids (Francia, 1962, 1968). Francia (1968) also includes a discussion of extensive experimental work done in the 1960's with his collector in Europe, and gives 37 references. Buchberg et al (1971) mentions some work done on honeycomb structures in the 1920's, and gives a number of references on basic heat transfer investigations in cellular structures.

There are several other types of collectors often used for heating air. Löf (see Löf et al, 1946; Löf, 1950; Löf and Nevens, 1953; Löf, 1954; also Löf in Daniels and Duffie, 1955) was the principal developer*** of a collector which uses "overlapped-glass-plates."

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*The Tellier type of collector can be used for gases, so long as the flow passages are large enough to yield reasonable pumping power levels.

**Or other material transparent to solar radiation and opaque to infrared.

***The concept was first described by K.W. Miller in a U.S. Government memo in 1943 (see Löf, 1950), and was also the subject of a later patent by Miller (1954).

A collector cross-section is shown in Figure 2. In this collector, air is fed upwards at about 30 cm/sec velocity through a box, about 10 cm deep, with a blackened back and covered with one or more glazings. As the air close to the back of the box is warmed, a clear glass sheet is inserted in the flow to keep it from mixing with the colder air above. After a short distance, another clear sheet is inserted above the first sheet, with a flow passage between the two. Successive glass sheets are overlapped in this way in a staircase fashion. The leading edges of the glass sheets are clear, the back parts of the glass sheets are blackened so as to heat the adjacent air, already flowing between glazings.

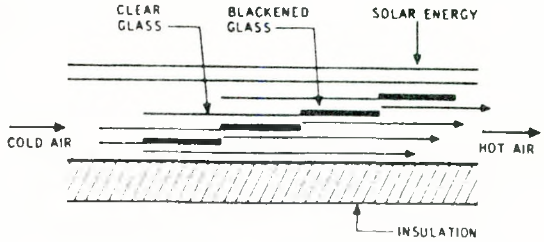

Figure 2 Cross Section of Löf Air Heating Collector

Compared to the liquid heating collectors, the theory of operation of the Löf-Miller air heaters is quite complex. Besides the Löf references given, these heaters have been studied by Whillier (1953, 1964a) and analyzed mathematically by Selcuk (1971).

Bliss (1956) used an air heater in which air was drawn down through a blackened screen in a glazed box, as shown in Figure 3. Suction through the screen prevented hot convection currents from reaching the glass. This type of heater has also been studied by Whillier (1964a), Gupta and Garg (1967) and Chiou et al (1965).

Some other air heaters are considered by Close (1963) and Whillier (1964a).

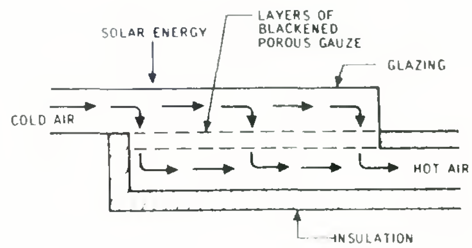

Figure 3 Cross Section of Bliss Air Heating Collector

2.4 Usage and Economics

As mentioned earlier, the literature on the use of the flat plate collector is so large that it is impractical to present a detailed and complete discussion based on specific references. The most that can be done is to mention general references, which anyone can then use as a starting point for literature searches in specific areas.

The heating and cooling of buildings has been described most recently by Yellott (1973, 1974) and Allen (1974), the cooling of buildings alone by de Winter (1974b). Most other topics have not had as specific recent coverage, and recourse must be had to more general literature.

The best books on solar energy are probably Zarem and Erway (1963), Daniels (1964), and Daniels and Duffie (1955). Jensen (1959) has a very thorough review of the literature as of 1959 (2916 references), and a discussion of current research and development activities. Conference proceedings include the July 1973 UNESCO Conference in Paris: "The Sun in the Service of Man;" the August 1961 U.N. Conference in Rome: "New Sources of Energy and Energy Development;" the November 1955 World Symposium on Applied Solar Energy in Phoenix, Arizona; the October - November 1955 Conference on the Use of Solar Energy: The Scientific Basis, in Tucson, Arizona; and the August 1950 Course - Symposium: "Space Heating with Solar Energy" at M.I.T. (see Hamilton, 1950). One report of great usefulness is one by Jordan (1967).

Much of the current flood of material does not add significantly to the above. Books which are bound to be worthwhile are in preparation at the Univ. of Wisconsin by Duffie and Beckman,* and at M.I.T. by Hottel.

Technical journals which can be consulted include "Solar Energy," "Heliotechnology" (translated from the Russian language), and the Bulletin of the "Cooperation Mediterraneene pour l'Energie Solaire" (COMPLES). The ASME Transactions and the ASHRAE Journal often have solar energy papers. Conference proceedings which generally have solar energy papers include those of the Intersociety Energy Conversion Engineering Conference (IECEC).

Almost any use of the flat plate collector requires storage of solar energy for use at night or during short periods of bad weather. Design of storage requires a knowledge of sequential weather patterns, and such information is not readily available, or not available at all for many locations. Optimization of storage capacity invariably leads to a storage capacity of a few days only. Periods of longer bad weather are so infrequent that larger storage capacity can not be justified economically. Solar systems that are required to be always ready for use almost invariably require a full capacity backup system.** Thermal storage can be provided by water, by rocks, or by salts (heats of fusion).

The economics of the flat plate collector involves balancing off the normal costs of capital equipment (depreciation, interest, taxes, and maintenance) and the alternate fuel or power costs. The lack of commercial success of solar energy to date is due at least in part to the fact that society encourages the wanton use of energy (through the use of a depletion allowance, rather than a depletion tax, through tolerance of pollution, and other means), and penalizes solar energy (through real estate taxes on the total value of buildings, through lending practices by mortgage institutions, through lack of protection against shading by a neighbor, etc.).

It is possible to enhance the economics of the flat plate collector by building one which also fulfills a roofing function, since in this case there is a mutual subsidy (see Tybout

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*Recently published (Duffie and Beckman, 1974b).

**If one is willing to economize warm water, or dispense with a shower when the weather is bad, a solar domestic water system for example needs no backup.

and Löf, 1970; or Löf and Tybout, 1973). Bliss (1961b) was probably the first to do this on a significant scale, although Brooks (1936) shows a design which can do this for water heating. Böer (1973), de Winter and Lyman (1973) and de Winter (1974a) have presented recent concepts for such dual purpose collectors. It should be noted that at high latitudes this may become a dubious proposition. If the roof has to be angled up very significantly to collect solar energy, then one must decrease the subsidy accordingly.

One other way to enhance the economics and to promote the use of the flat plate collector is through the preparation of a do-it-yourself manual. Normally the homeowner does not charge himself for his own labor, but considers it free or therapeutic in nature. Manuals for the building of domestic solar water heaters have included Brooks (1936), Hawkins (1947), Sinson (1965), Morse (1966), and Whillier (1969). Manuals for solar heaters for swimming pools include Whillier (1965b) and de Winter (1974a).

There has been significant commercial success of the flat plate collector for the heating of water in a number of locations. Between 1910 (see Bailey, 1910) and the 1930's (see Day & Night, 1930; Brooks, 1936) there was a considerable market in California. Hottel noted that in 1951 it was estimated there were 50,000 solar water heaters in the city of Miami (see Zarem and Erway, 1963, p. 299). Tanashita (1955, 1961, 1970) discusses commercial solar water heating in Japan, where it originally was able to flourish because the alternative fuel was in many cases rice straw. In Australia and in Israel solar water heating became widespread because the alternative was electrical heating, or heating with fuel which had to be carried in (see Morse, 1956).

3. SOLAR INPUTS FOR SOLAR ENERGY EQUIPMENT

One of the difficulties involved in the use of solar energy is the fact that the incoming solar flux at the surface of the earth is a quite random quantity, predictable only in a statistical way, because of the random nature of the weather. The solar flux outside of the atmosphere, the effect of the atmosphere on sunlight, and the solar flux at the surface of the earth, are discussed separately below.

3.1 Solar Flux, or "Solar Constant" Outside of the Atmosphere

Outside of the earth's atmosphere the solar flux is quite predictable. When the earth is furthest away from the sun* the incoming flux on a surface normal to the sun's rays is about 130.9 milliwatts/cm^2, when it is closest about 139.9 m W/cm^2, and on the average it is about 135.3 m W/cm^2 (429.1 Btu/hr ft^2), according to Thekaekara (1973). Superimposed on this annual cycle there are very small additional variations caused by variations in solar weather and by solar cycles.

Curiously enough, the current best guess at the value of the average "solar constant" -- now estimated by Thekaekara (1973) to be 135.3 m W/cm^2 -- has fluctuated significantly during the last 30 years or so, and is now back very close to the level it was thought to have about 100 years ago by John Ericsson. Ericsson, the famous engineer of the U.S. Civil War years, spent some £20,000 of his own money on R & D work in solar energy, concluded in 1876 that the solar constant was 134.5 m W/cm^2, and said: "In view of the completeness of the means adopted in measuring the energy developed and the ample time which has been devoted to the determination of the maximum intensity, it is not probable that future labors will change the result of our determination," as quoted by Ackermann (1915).**

Abbot, based on extensive measurements made by the Smithsonian Institution during the first decades of this century, arrived at a value of 134.6 mw/cm^2 (Thekaekara, 1965). Because of an error thought to exist in Abbot's results, Moon (1940) adjusted the value downward to 132.2 mw/cm^2, and this value became widely accepted in the 1940's. Several upward adjustments of the data were made later, so that at least in the U.S. the most popular value during much of the 1950's and 1960's became 139.4 mw/cm^2 (442 Btu/hr ft^2).*** Now, based on the latest measurements (Thekaekara, 1973), we are back to 135.3 mw/cm^2, quite close to the value of Ericsson.

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*The orbit of the earth around the sun is not exactly circular but is an ellipse with the sun at one focus. The earth is furthest away from the sun in July, and closest in January.

**For more on the measurements of Ericsson, see the Chapter by Yellott in the ASHRAE report of Jordan (1967).

***Much of the literature (including the report of Jordan, 1967) is still based on this high value. One must be careful.

Sunlight is of course not truly parallel. If the sun -- like most other starts -- were so far away as to look like a point, the light would be parallel. As it is, the sun is quite large when seen from the earth. On the average throughout the year the solar disk subtends approximately 32 minutes of arc across a diameter. The brightness of the disk is not completely uniform, but trails off significantly close to the edges. The effect depends on the wavelength of interest, and is documented by Ångström and Ångström (1971), based on measurements made by Abbot early in this century.

The position of the sun depends on the time of the day and year. The daily solar motion is caused by the constant rotational speed of the earth, and the somewhat variable speed of the earth around the sun. The seasonal solar motion is due to the fact that the axis of the earth is not perpendicular to the plane of the ecliptic,* but has a tilt of about 23°27'. This causes the sun to have a varying "declination" (maximum elevation in the sky) during the year, and causes the seasons, since it causes a variation in solar inputs. The solar input is highest (barring clouds) when the sun is highest in the sky at the summer solstice (June 22 in the Northern hemisphere, and December 22 in the Southern), and lowest when the sun is lowest at the winter solstice (December 22 in the Northern hemisphere, and June 22 in the Southern).

The exact position of the sun, apparent size of the sun and other information on the solar system can be found in The American Ephemeris and Nautical Almanac (1974). Most of the information of this type really needed in solar energy work is also included in solar energy sources such as Jordan (1967) or Robinson (1966).

3.2 Effect of Atmospheric Constituents on Solar Energy

Once the solar energy enters the atmosphere, it gets absorbed, scattered, and bent by a series of phenomena involving gases, water vapor and droplets, and suspended particles or materials. The following overview is based mainly on Kondratyev (1969).**

Denser air (closer to the earth) has a higher index of refraction. Because of this, sunlight entering the atmosphere at an angle is bent downward, much like sunlight passing through a water surface. The sun is hence always lower in the sky than it appears to be, but the effect is small except at dusk and dawn (when the sun's rays are bent downward some 34' of arc), and the size of the sun is not affected.

Turbulence (swirls) due to high air velocity (e.g., the jet stream) can also lead to significant density differences. This leads to an erratic bending effect which accounts for the

*The plane in which the earth moves around the sun.

**For another good book on the subject, see Robinson (1966).

scintillation of stars, and also causes some (but not much) scattering of solar radiation.

The random motion of air molecules leads to significant fluctuations of air density on a scale small compared to the wavelength of light. This causes very localized fluctuations in the dielectric constant, which in turn cause "Rayleigh scattering" of solar radiation, by which "diffuse" light is emitted in all directions.* The Rayleigh scattered light is highly polarized,** and has a different spectral distribution than direct sunlight, with intensity peaks at wavelengths close to 0.4 micrometers (μ) being responsible for the blue color of the sky.

Water droplets small compared to the wavelength of light would also cause a scattering of the Rayleigh type.*** Those water drops which are of a size comparable to or larger than the wavelength of light exhibit "Mie scattering," in which most of the scattering is in the forward direction. Mie scattering is responsible for the apparent enlargement of the sun when it is behind a cloud, and for the circumsolar (or lunar) aureole observed also occasionally when there is a lot of moisture in the sky and there are many suspended droplets but no distinct clouds. Since Mie scattering does not shift the light spectrum very much, the light spectrum coming through clouds is quite similar to direct sunlight (i.e., clouds are white, not blue!).

When drops are very large compared to the wavelength of light, the drops can act like lenses, and can exhibit geometrical reflection and refraction phenomena such as the rainbow.

Smoke, dust, and other opaque aerosols serve mainly to reduce sunlight. When the particles are small compared to the light wavelength or roughly the same size, the reduction of radiation is due mainly to scattering. Large particles also cause direct shadowing. Sunlight is also absorbed by water vapor (and water droplets), by carbon dioxide and monoxide, by ozone, oxides of nitrogen and hydrocarbons. Some sunlight is absorbed by oxygen. However, neither oxygen nor nitrogen (together 99% by volume of air) are of real importance in the atmospheric absorption of sunlight.

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* Rayleigh originally attributed this to the individual air molecules. It has now been shown (Kondratyev, 1969) that local condensation and rarefaction mechanisms involving many molecules are responsible.

**Particularly the light scattered sideways.

***The surface tension (or energy) of water however makes such small droplets unstable, hence unlikely to exist. A droplet of a diameter of 0.1μ, which would scatter in the Rayleigh regime, would for example have an over-pressure of nearly 30 atmospheres due to the effect of surface tension. A droplet of a diameter of 1μ still has an over-pressure of 3 atmospheres, but is already in the Mie regime. Hygroscopic salt particles (aerosols) acting as condensation nuclei can help some but not much; typical aerosols produce droplet distributions with very f droplets below a diameter of about 3μ (Fitzgerald, 1974).

The absorption process by gases in the atmosphere generally affects specific wavelength bands, so that the radiation reaching the earth has been very significantly depleted in many parts of the spectrum. The net arriving spectrum is shown by Moon (1940) and by Threlkeld and Jordan (1957).*

The net effect of all this is erratic but straightforward. Whenever there appears to be a relatively clear sky and the sun is casting well defined shadows, the sun looks much the same as it would if we had no atmosphere, except that it is weaker. Only Mie scattering and atmospheric turbulence serve to distort the image of the sun. The turbulence effect is very small, and the Mie effect is only of significance when the sky is so charged with water vapor and water droplets that there is little solar energy to begin with.

In a clear sky some sunlight has been filtered out, some scattered over wide angles by Rayleigh scattering. From the whole rest of the skydome we get diffuse energy which was scattered locally, all of which, (in the absence of reflection from clouds) is at a very low intensity. At angles close to the sun, the intensity of diffuse light is somewhat higher than elsewhere (Kondratyev, 1969), but it is still of very low intensity compared to that of direct sunlight. It is only when integrated over the total skydome that the contribution of diffuse sunlight becomes significant. On a "clear day" 80-85% of the sunlight received at the surface of the earth might be direct, and the remaining 15-20% diffuse.

There are several unknowns in this picture which make prediction of solar inputs on the earth difficult. Water vapor content of the atmosphere, and cloudiness varies in a random fashion with the weather, and can cause the solar flux to vary very significantly. Dust, smog and smoke, and other forms of air pollution are also quite unpredictable, and these can reduce the solar flux in cities between 20% and 80% depending on the wavelength of interest (Try, 1972). In a number of cities in Europe, the total solar inputs have been found to be about 20% lower than in the surrounding countryside (Kondratyev, 1969). Dust storms of the "dustbowl" type have on occasion reduced solar inputs to 1% of normal values (Brooks, 1936), and flocks of passenger pigeons or swarms of locusts have darkened the sky.

Some efforts at calculating "insolation" (i.e., solar flux) results on the surface of the earth, and the available data on solar inputs, are described in the next subsection.

There is an enormously rich literature in this field. Kondratyev (1969) provides a basis for exploring the Russian literature. There are a number of journals which can also provide a good starting point for a literature search, such as the "Journal of the Atmospheric Sciences,"

*Also in Kondratyev (1969) and in Robinson (1966).

the "Journal of Atmospheric and Terrestrial Physics," "Applied Optics" (see particularly the Andrew J. Drummond Memorial Issue, March 1974), the "Journal of Geophysical Research," and the "Journal of the Optical Society of America."

3.3 Insolation Values at the Surface of the Earth

The performance possibilities of flat plate collectors can not really be evaluated properly except if one has good results on the insolation one can expect at a location of interest. Ideally one should have "good" results measured at close enough distances so one is always close to a measuring station exposed to roughly the same solar conditions as the proposed panel. In some cases, close to mountains, coasts, or other such influences, weather and insolation can change drastically in perhaps 5 miles or less. There are probably very few locations in which there are not significant changes in 50 miles. On the average a gridwork of measuring stations should perhaps be located at distances of at most 20 miles. This would require some 7000 stations in the U.S., which seems like an enormous number until one considers that there are some 600,000 oil wells.

One should have not only average values, but one should have a sufficiently long series of instantaneous measurements so one can have a good statistical idea of the lengths of "good" and "bad" insolation conditions, and of their frequency and sequential behavior. This is necessary for the optimization of storage, and of overall system design. Insofar as conditions from year to year can vary significantly, one should know roughly what one can possibly expect, and what one is likely to get. One should have values of wind conditions, temperature, relative humidity, precipitation, and insolation measured on horizontal surfaces, on vertical surfaces facing in various directions, on a surface facing the sun, and on tilted surfaces facing the equator.

This is of course a somewhat utopian ideal, but the real situation has been pathetically far removed from this ideal, and the literature on the flat plate collector can only be understood properly if this is kept in mind. At the time of the Hottel and Woertz (1942) paper, there were only 18 measuring stations in the U.S., so that the mean distance between stations was some 400 miles. Presently the situation is better, but not very significantly better. Bennett (1965) had to base his results on 59 U.S. stations at which insolation had been measured, and 113 U.S. stations at which it had not been measured but at which cloudiness results were available. The accuracy of available measurements is pretty poor.

Three distinct topics are discussed briefly below. The first concerns the calculation of insolation values and spectra from first principles. The second concerns the available measurements and correlations. The third concerns the adaptation of insolation results specifically for use in flat plate collector calculations.

3.3.1 Calculation of Insolation Values and Spectra from First Principles

As might be expected from the earlier discussion, one can obtain only limited results from calculations. One can not possibly get a complete 3-dimensional description of the cloudiness, dustiness, etc. of the atmosphere at any one time and it is not possible to make a prediction of atmospheric conditions in the future.*

Nevertheless, calculations of insolation levels on earth can yield very useful results. Moon (1940) was the first to perform thorough calculations for a standard clear sky, containing reasonable amounts of water vapor, of other gaseous atmospheric constituents, and of dust. His final results consisted of complete solar spectra one might expect at sea level, on a surface normal to sunlight, for various path lengths through the atmosphere, corresponding to various solar elevations. Moon's spectral curves, for "air-mass" 1, 2, 3, 4, 5,** have been for long a standard in the illumination industry, in the evaluation of selective surfaces, and in many other solar applications.

Moon's clear sky results have recently been updated by Elterman (1967), who used the detailed understanding which had been obtained on atmospheric constituents, dust, aerosols, and water vapor content through the use of sounding rockets and other modern methods. Elterman's final results are in the form of tables of scattering and attenuation coefficients as a function of altitude and wavelength. These coefficients are most useful for a computer program built to calculate the modern day equivalent of Moon's "air-mass" spectra. The actual spectra are however not given. There is at present much activity on the definition of aerosol sizes and distributions in a clear sky. The aerosol model used by Elterman is no longer accepted as being very accurate, and refinements in this area are continually being made (Willson, 1973).

3.3.2 Available Measurements and Correlations of Terrestrial Insolation Values

Bennett (1965), the U.S. Weather Bureau (1964) and Löf et al (1966), have prepared maps showing the monthly means of the daily totals of solar radiation (direct plus diffuse radiation incident on a horizontal surface). The Bennett (1965) work is based on relatively long term (1950-1962) data available for some 59 stations, plus estimated results-based on cloudiness

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*It is unlikely that one would get very far, even if one had a complete description of cloudiness, dustiness, etc. A Monte Carlo ray tracing program would probably be needed in the calculations, and computation times and costs would probably be excessive for anything but limited results (Noon, 1974).

**The numbers correspond to the effective atmospheric mass traversed by the sunlight. When the sun is directly overhead, one has air-mass 1, when it goes through twice as much air because the sun is lower in the sky, air-mass 2, etc.

determinations-on another 113. The U.S. Weather Bureau (1964) values are based only on insolation measurements for 104 stations, of which many had only short periods of measurement. Bennett (1965) discusses the calculation techniques, and compares his results with those of the U.S. Weather Bureau (1964). Bennett (1969) also has a later paper on correlation techniques. The Löf et al (1966) results are based on measurements, supplemented by values calculated from data on mean monthly hours of sunshine. In all three references results are shown in Langleys,* with isolines at 50 Langley intervals being shown on the map.

It should be noted that the degree of cloudiness or hours of sunshine can at present not be used for determination of instantaneous insolation values. Reflection from clouds can lead to very high and erratic values. On one occasion measured insolation values on earth exceeded extraterrestrial values for more than half an hour (Norris, 1968).

Statistical frequency results on daily horizontal insolation values during the months of June and December in "Anglo North America" are given by Bennett (1967). These results however give no indication of the possible sequences of bad days and of good days one might expect, which is needed for the design of thermal storage and for the evaluation of the performance of complete systems (Tybout and Löf, 1970). Atlas and Charles (1964) have detailed tabulated statistics of the frequency of horizontal insolation values for all months of the year for 27 cities, but again there are no sequential or serial results. Such serial values can generally only be obtained through personal contacts with weather stations or meteorological organizations, as was done by Tybout and Löf (1970), and Duffie and Beckman (1973a, 1973b, 1974a). In this way weather tapes can be obtained covering long periods with measurements made hourly, but only for relatively few locations. The trouble with such detailed weather information is that it may be too expensive to use all of it in calculations (see Duffie and Beckman, 1974a), and that it is unlikely to represent a representative year.

Daily insolation values on horizontal surfaces can be converted to fairly accurate hourly insolation values on horizontal surfaces with a correlation first made by Whillier (1953), and extended by Liu and Jordan (1960) (see also Whillier, 1965a, Jordan 1967).

Average hourly insolation values can be used to calculate hourly insolation values on inclined surfaces if one knows how much of the energy is direct solar energy, what is the average position of the sun, how much is diffuse, and what is its angular distribution in the sky. The most commonly used method for this calculation process is probably that of Liu and Jordan (1961), which uses the relationships between direct, diffuse and total radiation described in

*A Langley is a gram-calorie/cm^2, equal to 3.69 Btu/Ft^2.

Liu and Jordan (1960). The calculation method is also included in Liu and Jordan (1963), and in Jordan (1967).

3.3.3 Adaptation of Insolation Results to Flat Plate Calculation Requirements

If only average daily insolation values are available for a flat plate collector site, one has no alternative but to use these for projected performance calculations. If one has detailed local weather and insolation information, one can then use this to determine the average collector performance over long periods of time, as was done quite accurately already by Hottel and Woertz (1942) who not only tested collectors but also measured insolation. There is however one problem: how does one use detailed weather and insolation information to make comparative predictions of the average long term performance of many different collector designs, inclinations, operating temperature, and so on? This problem was obviously of more crucial importance in the days before the advent of the high speed computer, but its solution has led to some very interesting weather correlations, explained below, which can now be applied also to average insolation information where no hourly or daily statistical values exist. These correlations are bound to be of lasting usefulness.

In a flat plate collector it takes a certain critical solar input to overcome the parasitic heat losses (and the pumping costs) and to start producing useful energy at some temperature level. In a forced circulation system, a control* can be used to turn the system off unless the solar input is above this level. In a thermosiphon system this will happen more or less automatically.

If all days are identical, and hence equal to an average day, then flat plate collector performance can be based on the daily insolation profile of an average day. If there is a sufficient variation in climate so that sometimes, during times of normal collection, the insolation drops below the critical values, then this has to be taken into account. Just using average insolation values would imply negative collection rates at times when insolation drops below critical values. In fact there probably would be a zero collection at such times, and the average collection is thus better than one might think based on average insolation values.

Whillier (1953) (see also Hottel and Whillier, 1955), was the first to exploit this phenomenon in the development of a new way to correlate weather information in terms of a set of hourly "utilizability" curves. This was based on a statistical analysis of weather information in a number of locations, elimination of those times during which the insolation was below the critical level required, and then characterizing the "utilizability" of the remaining solar

*Commercial control equipment is available for this purpose.

input as a function of the critical level.

For those locations in which daily insolation values, but not hourly insolation values were available, Whillier (1953, see also 1965a) made a correlation of hourly insolation values versus daily total values (both on a horizontal surface). This correlation was extended to higher latitudes by Liu and Jordan (1960). It can be used, in conjunction with statistical values of daily total insolation, to produce hourly utilizability plots which are nearly as good as if statistical values of hourly insolation had been available (Whillier, 1953).

The hourly horizontal insolation values can be used to predict values on an inclined flat plate collector through the use of geometrical factors which account for the relative amounts of diffuse and direct radiation (Whillier, 1953, see also Liu and Jordan, 1961). Such corrections should be based on the behavior of "better-than-average days only," since the geometrical factor on poor days is of no consequence if there can be no useful collection anyway (Whillier, 1953).

The direct and diffuse solar energy should be handled separately in flat plate calculations, because of the effect of angle of incidence on the interaction of radiation with the glazing. The angle of incidence of direct sunlight can be calculated in a straightforward way (Jordan, 1967). If a uniform sky model is used for the diffuse energy, an average angle of incidence of 58° (from the normal) should be used (Hottel and Woertz, 1942), for a real sky in which the diffuse energy is brighter in the vicinity of the sun, an average angle of incidence of 50° is fairly accurate (see Whillier, in Jordan, 1967).

Liu and Jordan (1963) made a significant extension of the Whillier utilizability technique. They found that the statistical variability of insolation is directly related to the reduction of insolation in the atmosphere. Where the average insolation is close to what one might expect locally if the earth had no atmosphere, there is little variability in the insolation values. Where the average insolation value is low compared to the maximum possible (with zero atmosphere), there is more variability. In places with relatively little sunshine, one does not generally have low insolation levels; often there is less than average, and sometimes one can get much higher than average values. The statistical distribution of daily inputs can be correlated to the average reduction.

This allowed Liu and Jordan (1963) to obtain "generalized utilizability" curves based only on average local insolation results, and hence to make it possible to make reasonable performance projections with a minimum of input data. Finally, Liu and Jordan (1963) give the necessary radiation and average ambient temperature data for 80 cities in the U.S. and Canada (these are also included in Jordan, 1967), and show some sample calculations. A very surprising result which is shown quite simply, is that a 2 or 3 glass plate collector can collect more energy at 110°F in January in Winnipeg, Canada, than either in Fresno, California, or in Blue Hill , Massachusetts.

The Whillier-Liu-Jordan utilizability technique has obvious limitations. It relates only to average flat plate performance at some specific temperature level, and is not directly related to real energy consumption. It can not answer precise questions on storage requirements. On days with very high solar inputs, the technique includes energy one may never be able to use. For such questions one must use other techniques. For intercomparing locations or intercomparing flat plate designs, the Whillier-Liu-Jordan technique is however bound to have lasting value.

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SOLAR DESIGN CHECK LISTS

SOLAR DESIGN CHECK LISTS

PROJECT SUMMARY DATA

A. PROJECT

1. NAME: ______________________

   ADDRESS: ______________________

   ____

2. BUILDING OWNER

   NAME: ______________________

   MAILING ADDRESS: ______________________

   ____

3. TYPE OF APPLICATION (Bldg. Use) ______________________

4. NEW ☐ RETROFIT ☐

5. LAND STATUS ______________________ (Option, Owned, Leased)

6. TYPE OF SOLAR SYSTEM

HEATING & COOLING	☐	HEATING, COOLING, HOT WATER	☐
COOLING	☐	COOLING & HOT WATER	☐
HEATING	☐	HEATING & HOT WATER	☐
HOT WATER	☐	AUGMENTATION OF EXISTING SYSTEMS	☐

7. CONTACT FOR ADDITIONAL INFORMATION

	BUSINESS	TECHNICAL
NAME	______________	______________
ADDRESS	______________	______________
	______________	______________
TEL. NO.	______________	______________

B. BUILDING SUMMARY

1. BUILDING FLOOR AREA ________ SQ. FT.

2. SOLAR CONDITIONED AREA ________ SQ. FT.

3. ANNUAL DESIGN LOAD (10^6 BTUs)

HEATING ________ COOLING ________ HOT WATER ________ TOTAL ________

4. PRESENT OR PROJECTED CONVENTIONAL (WITHOUT SOLAR) ENERGY COSTS/YR* $ ________

5. BACKUP ENERGY SYSTEM (Type and Commercial ID)

HEATING ________

COOLING ________

HOT WATER ________

C. SOLAR ENERGY SYSTEM

- SOLAR COLLECTOR

1. TYPE:
   - [ ] LIQUID
   - [ ] AIR
   - [ ] FLAT PLATE
   - [ ] EVACUATED TUBE
   - [ ] OTHER (Specify) ________

2. COMMERCIAL ID ________

3. TOTAL COLLECTOR AREA** ________ FT.^{2}

4. EFFECTIVE COLLECTOR AREA ________ FT.^{2}

5. ABSORBER COATING ________

6. NO. OF COVER PLATES ________

7. ABSORBER MATERIAL ________

8. TILT ANGLE ________

9. AZIMUTH ________ (State in degrees East or West of due South)

*Based on July 1977 Rates

**Total Collector Area refers to gross solar panel size. Effective collector area refers to the absorber aperture area.

- ENERGY TRANSPORT

10. FLOW RATE ________ GPM ________ CFM

FOR LIQUID ENERGY TRANSPORT STATE:

11. TYPE ________________________________

12. COMPOSITION ________________________________

- ENERGY STORAGE

13. TYPE: Tank(s), Box(s), None, etc. ________________________________

14. NUMBER HOT ________ 15. NUMBER COLD ________ 16. TOTAL ________

17. GROSS CAPACITY: HOT ________ (GAL); (CU FT)

COLD ________ (GAL); (CU FT)

18. METHOD OF POTABLE WATER PROTECTION ________________________________

____

- SOLAR HEATING SUBSYSTEM (INCLUDING AUXILIARY)

19. TYPE ________ 20. CAPACITY ________ BTUH

- SOLAR COOLING SUBSYSTEM (INCLUDING AUXILIARY)

21. TYPE ________ 22. CAPACITY ________ BTUH

D. CLIMATIC DATA

1. LATITUDE ________ 2. ALTITUDE ________ FT.

3. HEATING DEGREE DAYS ________ /YR. 4.* COOLING DEGREE DAYS ________ /YR.

5. AVERAGE TEMP. WINTER ________ ^{o}F SUMMER ________ ^{o}F

*Use 65^{o}F reference for heating and 75^{o}F reference for cooling.

		WINTER	SUMMER
6.	DAILY AVERAGE INSOLATION	________ BTU/FT^2	________ BTU/FT^2

7. YEARLY SUNSHINE ________ %   8. SOURCE OF DATA ________

9. AVERAGE ANNUAL TOTAL INSOLATION, UPON COLLECTOR SURFACE, BTU/FT^2 - YR

____

10. STATE BASIS FOR CALCULATION ________

E. ENERGY UTILIZATION

1. ANNUAL UNIT SOLAR ENERGY COLLECTED, BTU/YR - FT^2 ________

2. TOTAL SOLAR ENERGY COLLECTED, BTU/ YR ________

		ANNUAL SOLAR USAGE (10^6 BTU)	ANNUAL ENERGY CONSUMPTION (10^6 BTU)	AUXILIARY ENERGY CONSUMED (10^6 BTU)
3.	HEATING DEMAND SATISFACTION	________	________	________
4.	HOT WATER DEMAND SATISFACTION	________	________	________
5.	COOLING DEMAND SATISFACTION	________	________	________
6.	TOTAL DEMAND SATISFACTION	________	________	________

7. TOTAL YEARLY COST OF OPERATING SOLAR SYSTEMS $________

F. FUNDING AND COST-SHARING SUMMARY (FOR RETROFIT, FILL IN ITEM F.3 ONLY)

1. TOTAL CONVENTIONAL BUILDING COST (for new buildings) $ ________

2. TOTAL BUILDING COST WITH SOLAR ENERGY SYSTEM (for new buildings) $ ________

3. SOLAR SYSTEM COST DIFFERENTIAL (for new or retrofit bldgs.) $ ____________

4. COST SHARING POSSIBILITIES

____________________ ____________________

$__________________% $__________________%

(Proposed Cost sharing of Solar System Cost Differential stated in Line 3.)

5. SOLAR SYSTEM COST EFFECTIVENESS:

a. ANNUAL ENERGY COST WITH CONVENTIONAL SYSTEM $__________

b. ANNUAL ENERGY AND OPERATING COST WITH SOLAR SYSTEM $__________

c. ANNUAL SAVINGS (Line a minus Line b) $__________

6. FIXED COST TO ANNUAL SAVINGS RATIO __________
(Line 3, Solar Systems Cost Differential; divided by Line 5c, Annual Savings)

*Based on December 1977 Utility rates

PROJECT COST DATA

PROPOSER ______________________________

PROJECT LOCATION ______________________________

A. SOLAR ENERGY SYSTEM COSTS (Material only)

o SOLAR COLLECTORS

	Type of Quote	Amount
1. TOTAL AREA __________ SQ. FT.		
2. UNIT COST $ __________ PER SQ. FT.	( )	
3. COLLECTOR COST	( )	$ __________
4. SHIPPING & DELIVERY COST	( )	$ __________
5. TOTAL DELIVERED COST (A3 + A4)		$ __________

o ENERGY TRANSPORT

	Type of Quote	Quantity	x Unit Cost	=	Amount
6. PIPING, VALVES, PUMPS, FILTERS	( )	________	______		$ __________
7. HEAT TRANSFER FLUID (If Applicable)	( )	________	______		$ __________
8. HEAT EXCHANGER(S)	( )	________	______		$ __________
9. OTHER (Specify) ______________	( )	________	______		$ __________
10. TOTAL COST OF ENERGY TRANSPORT (A6 through A9)					$ __________

o STORAGE

		Type of Quote	Quantity	x Unit Cost	= Amount
11.	STORAGE TANKS(S), FILTERS	( )	______	______	$ ______
12.	STORAGE MEDIUM	( )	______	______	$ ______
13.	INSULATION, LINING, FINISH	( )	______	______	$ ______
14.	OTHER (Specify) ______	( )	______	______	$ ______
15.	TOTAL COST OF STORAGE (A11 through A14)				$ ______

o SOLAR COOLING SYSTEM

		Type of Quote	Quantity	x Unit Cost	= Amount
16.	TYPE: ______	( )	______	______	$ ______
17.	OTHER (Specify) ______	( )	______	______	$ ______
18.	______	( )	______	______	$ ______
19.	TOTAL COST OF SOLAR COOLING SYSTEM (A16 through A18)				$ ______

o CONTROLS & SAFETY DEVICES

		Type of Quote	Quantity	x Unit Cost	= Amount
20	CONTROLS	( )	______	______	$ ______
21.	SAFETY DEVICES	( )	______	______	$ ______
22.	OTHER (Specify) ______	( )	______	______	$ ______
23.	TOTAL COST OF CONTROLS & SAFETY DEVICES (A20 through A22)				$ ______

o OTHER RELATED COSTS

	Type of Quote	Quantity	x	Unit Cost	=	Amount
24. OTHER SOLAR SYSTEM RELATED COSTS List and (Specify) ______________________	( )	________		_____		$ __________
25. TOTAL OTHER SOLAR COSTS						$ __________

o TOTAL SOLAR SYSTEM COSTS

26. TOTAL SOLAR ENERGY SYSTEM COSTS
(A5+A10+A15+A19+A23+A25) $ __________

B. SOLAR SYSTEM DESIGN & INSTALLATION COSTS (labor only)

o DESIGN COST (A&E)

	Type of Quote	Labor hours	x	Labor Rate	=	Amount
1. SCHEMATIC DESIGN PHASE	( )	______		______		$ ______
2. DESIGN DEVELOPMENT PHASE	( )	______		______		$ ______
3. CONSTRUCTION DOCUMENT PHASE	( )	______		______		$ ______
4. ON SITE SUPPORT	( )	______		______		$ ______
5. OTHER (Specify) ______		______		______		$ ______
6. TOTAL SYSTEM DESIGN COSTS (BI through B5)						$ ______

o INSTALLATION COSTS

	Type of Quote	Labor hours	x	Labor Rate	=	Amount
7. COLLECTOR INSTALLATION (i+ii)	( )	______		______		$ ______
i) TRADE ______ (e.g., plumbing, ironwork, etc.)	$ ______					
ii) TRADE ______	$ ______					
8. ENERGY TRANSPORT	( )	______		______		$ ______
9. STORAGE	( )	______		______		$ ______
10. SOLAR COOLING SYSTEM (incremental costs over conventional unit) ______	( )	______		______		$ ______

	Type of Quote	Labor hours	x	Labor Rate	=	Amount
11. CONTROLS & SAFETY DEVICES	( )	______		______		$ ______
12. STRUCTURAL & INSTALLATION COST ______	( )	______		______		$ ______
13 OTHER (Specify) ______	( )	______		______		$ ______
14. ______	( )	______		______		$ ______
15. TOTAL INSTALLATION COST (B7 through B14)						$ ______ $ ______
16. TOTAL DESIGN & INSTALLATION COSTS (B6 + B15)						$ ______

C. OTHER

1. MAINTENANCE MANUAL PREPARATION COST $ ______

2. OTHER PROJECT COST (List)

______

______

______

______

______

3. TOTAL OTHER COST $ ______

D. TOTAL COST OF SOLAR SYSTEM
(A26 + B16) $________________

E. TOTAL SOLAR PROJECT COST
(D + C3) $________________

F. TOTAL AMOUNT TO BE COST SHARED BY OFFEROR $________________

G. TOTAL FUNDS REQUESTED
(E less F) $________________

PROJECT COST DATA

A. SOLAR SYSTEM ANNUAL OPERATION & MAINTENANCE (O&M) COSTS

o SOLAR SYSTEM OPERATING COST

1. TYPE OF ENERGY CONSUMED ____________________
e.g., gas, electricity, etc.

2. UNIT OF ENERGY CONSUMED ____________________
e.g., cu. ft, kwh, etc.

3. ANNUAL SYSTEM OPERATING COST

________ x ____________________ = $__________/yr
rate per unit* | annual energy requirements

o BACK-UP ENERGY COST

4. TYPE OF ENERGY CONSUMED ____________________
e.g., gas, electricity, etc.

5. UNIT OF ENERGY CONSUMED

6. ANNUAL BACK-UP ENERGY COST

________ x ____________________ = $__________/yr
rate per unit* | annual energy requirements

o OTHER SOLAR SYSTEM COSTS

7. ANNUAL MAINTENANCE COST $__________

8. INSURANCE & TAXES $__________

9. OTHER (Specify) ____________________ $__________

*Based on December 1977 rates.

PROJECT COST DATA

o TOTAL SOLAR SYSTEM O&M COSTS

10. TOTAL ANNUAL O&M COSTS (A3+A6+A7+A8+A9) $__________

B. CONVENTIONAL SYSTEM ENERGY COSTS

1. TYPE __________

2. UNIT __________

3. ANNUAL FUEL COSTS* $__________

C. SOLAR SYSTEM ECONOMICS

1. NET ANNUAL BENEFIT OF SOLAR SYSTEM (B3-A10) $__________

2. FIXED COST TO SAVINGS RATIO; TOTAL INSTALLED COST/NET ANNUAL BENEFITS $__________

*Based on December 1977 Rates

SUBSYSTEM PERFORMANCE/TECHNICAL DATA

A. COLLECTOR

COMMERCIAL BRAND NAME : ____________________ MODEL: ______________

TESTED BY AND METHOD: ______________________________________

EST. DELIVERY TIME: ____

APPROVED BY: ____

1. TYPE OF COLLECTOR ☐ LIQUID ☐ AIR

a. FLAT PLATE: ____________

b. TUBULAR: __________ EVACUATED: __________ NON-EVACUATED __________

c. CONCENTRATOR: TRACKING: ____________ NON-TRACKING: __________

TRACKING MODE: ______________________________________

CONCENTRATION RATIO: ____________ :1 TYPE: ____________

d. OTHER: DESCRIBE IN DETAIL ______________________________

____

____

____

____

2. TRANSPARENT COVER

a. NUMBER OF COVERS: ______________

b. MATERIALS: OUTER: ______________ INNER: ______________

c. THICKNESS: OUTER: ____________ (IN) INNER: ____________ (IN)

d. SOLAR SPECTRUM TRANSMISSIVITY: OUTER: ________ INNER: ________

e. WEIGHT: OUTER: ________ LBS/FT^2 INNER: ______________ LBS/FT^2

3. ABSORBER PLATE

a. ABSORPTIVE COATING

1. MATERIALS

a. TYPE: ____________________

b. ALLOY: ____________________

2. SOLAR SPECTRUM ABSORPTIVITY: ____________________ %

3. INFRARED EMISSIVITY: ____________________ %

b. BASE PLATE

1. MATERIALS

a. TYPE: ____________________

b. COMMERCIAL IDENTIFICATION: ____________________

c. FLUID PASSAGES

1. MATERIALS

a. TYPE: ____________________

b. COMMERCIAL IDENTIFICATION: ____________________

d. BONDING MATERIALS BETWEEN BASE PLATE AND FLUID PASSAGES

1. TYPE (BRAZED, SOLDERED, ADHESIVE, MECHANICAL, ETC.) __________

2. COMPOSITION: ____________________

3. COMMERCIAL IDENTIFICATION: ____________________

4. OTHER ____________________

e. **INLET AND OUTLET TYPE, SIZE, AND MATERIAL**

1. **EXTERNAL:** ______ ______ ______

2. **INTERNAL:** ______ ______ ______

4. INSULATION MATERIAL

a. TYPE: ____________________

b. COMPOSITION: ____________________

c. COMMERCIAL IDENTIFICATION: ____________________

d. THICKNESS: BACK ______ IN. SIDES ______ IN.

e. R FACTOR: BACK ______ SIDES ______

5. OUTER ENCLOSURE OR SHELL MATERIALS

a. TYPE: SIDES ____________________ BACK ________________________

b. THICKNESS: SIDES __________________ BACK _____________________

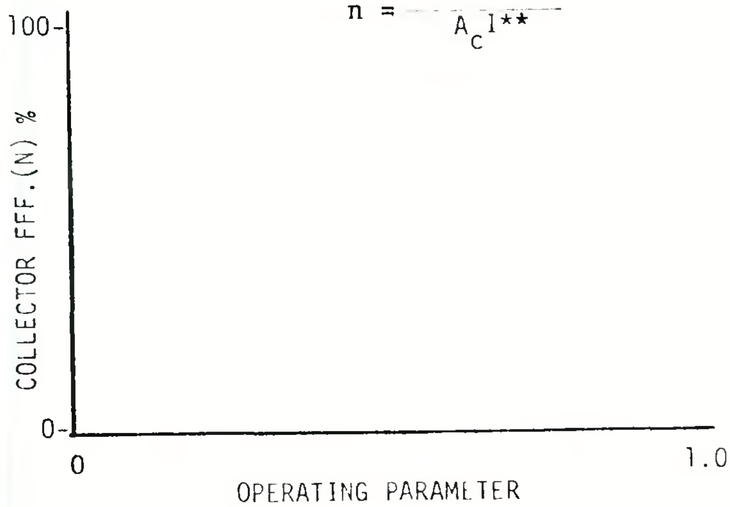
c. COMMERCIAL IDENTIFICATION: SIDES __________ BACK _____________

6. COMPOSITE COLLECTOR

Performance Data -- Test or Performance Analysis Data along with information detailing the conditions under which the data were generated. [NBS "Method of Testing for Rating Solar Collectors Based on Thermal Performance," (Document NBSIR 74-365)[1], ASHRAE "Methods of Testing to Determine the Thermal Performance of Solar Collectors" (ASHRAE Standard 93-77)[2], or other procedures which provide similar performance information.]

A GRAPH OF COLLECTOR EFFICIENCY (n) VERSUS THE PARAMETER $\frac{Tc-Ta^*}{I}$

where $n = \frac{MC_p(To-Ti)}{A_c I^{**}}$



$\frac{Tc-Ta^*}{I^{**}}$ $(^{o}F/BTU/hr\text{-}ft^2)$

1 Available from DOE, Technical Information Center, P.O. Box 62, Oak Ridge, Tennessee 37830.

2 Available from ASHRAE Inc., 345 East 17th St., New York, N.Y., 10017, $4.00 Member, $8.00 Non-Member, plus $0.35 shipping.

T_o = Collector transport media outlet temperature (°F)

T_i = Collector transport media inlet temperature (°F)

*T_c = 1/2 (T_o + T_i)

T_a = Ambient Temperature (°F)

**I = Solar Insolation on the Collector Plane (BTU/HR-FT^2)

M = Transport Media mass flowrate (lb/hr.)

C_p = Specific heat of transport media (BTU/LB°F)

***A_c = Area of Collector (ft^2)

*The ASHRAE procedure uses Ti=Tinlet rather than Tc=average of inlet and outlet temperatures. Either method is acceptable but state which is being used.

**For tracking collectors this value should be only the beam or direct component for the solar radiation.

***Define Ac as gross or net;Ac is gross collector area for ASHRAE 93-77, net aperture area for NBSIR 74-365.

7. MAXIMUM EXPECTED TEMPERATURE UNDER NO FLOW CONDITIONS ____________

8. DISCUSS PROVISIONS FOR PROTECTING COLLECTOR UNDER NO FLOW CONDITIONS ______

____

____

____

9. PROVISIONS TO ACCOMMODATE DIFFERENTIAL THERMAL EXPANSION BETWEEN COLLECTOR, SUPPORT STRUCTURE, PLUMBING ____________

____

____

____

10. COLLECTOR DIMENSIONAL CHARACTERISTICS

a. GROSS AREA ________ FT^2/PANEL ____________

b. APERTURE AREA ________ FT^2/PANEL ____________

c. WEIGHTS OF FILLED COLLECTOR ____________ LBS/FT^2

d. ESTIMATED WEIGHT OF SUPPORT STRUCTURE ________ LBS/FT^2

B. SOLAR STORAGE*

1. TYPE (TANK, ROCK BED, ETC.) ______

2. MATERIALS

   a. TYPE: ______

   b. FINISHES OR COATINGS: INTERIOR ______ EXTERIOR ______

   c. COMMERCIAL IDENTIFICATION: ______

   d. INSULATION (TYPE/THICKNESS): ______

   e. R FACTOR: ______

3. PHYSICAL DIMENSIONS:

   a. HEIGHT: ______

   b. WIDTH: ______

   c. LENGTH: ______

   d. DIAMETER: ______

   e. DEPTH (if buried) ______

   f. WATER TABLE DEPTH (if buried) ______

4. OPERATING TEMPERATURE RANGE: ______ °F

5. OPERATING PRESSURE RANGE: ______ PSI

6. BURST PRESSURE OR ASME RATING: ______ PSI

C. HEATING SUBSYSTEM

1. SOLAR

   a. TYPE: ______ FIN COIL, RADIATOR, ETC.

   b. COMMERCIAL UNIT

      1. TYPE: ______

      2. SIZE & BTU RATING (CAPACITY): ______

      3. COMMERCIAL IDENTIFICATION: ______

2. CONVENTIONAL

   a. TYPE ______ GAS, OIL, ELECTRIC, ETC.

*If a phase change system, list type, heat capacity, and temperature of phase change.

b. COMMERCIAL UNIT

1. SIZE: ____________________

2. COMMERCIAL IDENTIFICATION: ____________________

c. COEFFICIENT OF PERFORMANCE: IF APPLICABLE, THE COP VERSUS PERTINENT OPERATING CONDITIONS (AMBIENT TEMPERATURE, ETC.) ____________________

____

____

d. TOTAL HEATING CAPACITY: ____________________ BTU

D. HOT WATER SUBSYSTEM

1. SOLAR UNIT

a. TYPE: ____________________

b. SIZE: ____________________

c. COMMERCIAL IDENTIFICATION: ____________________

d. HEAT EXCHANGER TYPE:* ____________________

2. CONVENTIONAL UNIT

a. TYPE: ____________________ (GAS, OIL, ELEC. STEAM, ETC.

b. SIZE: ____________________ VOL. OR BTU

c. COMMERCIAL IDENTIFICATION: ____________________

d. CODE & SAFETY STD. CERTIFIED UNDER: ____________________

E. COOLING SUBSYSTEM

1. SOLAR

a. TYPE: ____________________

b. SIZE: ____________________ TONS

*Proposers are referred to the IPC for measures necessary to isolate potable and non-potable water systems.

c. COMMERCIAL UNIT IDENTIFICATION: ____________________

d. COP VS. CHILLED AND CONDENSING WATER TEMPERATURE TABLES:

____

2. CONVENTIONAL

a. TYPE: ____________________ RECIP, CENTRIFUGAL, ABSORPTION

b. COMMERICAL UNIT

1. TYPE: ____________________

2. SIZE: ____________________

3. IDENTIFICATION: ____________________

4. COP VS. TEMPERATURE TABLE: ____________________

F. TRANSPORT BETWEEN SUBSYSTEMS

	COLLECTOR TO STORAGE	STORAGE TO LOAD
1. PIPING DETAILS		
a. INNER DIAMETER:	in	in
b. OUTER DIAMETER:	in	in
c. LENGTH OF RUN TOTAL:	ft	ft
d. MATERIALS:		
2. PIPING INSULATION		
a. TYPE:		
b. THICKNESS:	in	in
c. 'U' FACTOR:		
3. TRANSPORT MEDIA		
a. TYPE:		
b. ADDITIVES		
1. COMMERCIAL IDENTIFICATION:		
2. TYPE:		
c. QUANTITIES OF FLUID IN SUBSYSTEM		
1. FLUID:		%
2. ADDITIVE:		%

	COLLECTOR TO STORAGE	STORAGE TO LOAD
3. pH:		
4. ION CONTENT:		
5. MINERAL CONTENT:		
6. DURABILITY (SERVICE LIFE):	MONTHS	MONTHS
d. SPECIFIC HEAT:		
e. FLOW RATE (LIQUID):	GPM	GPM
FLOW RATE (AIR):	SFCM	GPM
f. SPECIFY PRESSURE DROP BETWEEN COMPONENTS:	PSI	PSI
4. HEAT EXCHANGERS		
a. TYPE (CROSS OR COUNTERFLOW):		
b. FLOWRATE:	GPM	GPM
c. OVERALL UA FACTOR:	BTU/OF	BTU/OF

5. PROVIDE FLOW DIAGRAM FOR PROPOSED SOLAR ENERGY SYSTEM, GIVING SUBSYSTEM COMPONENTS LOCATION AND IDENTIFICATION AND FLOW DIRECTIONS.

G. CONTROL SYSTEM

SHOW FOR EACH MODE OF OPERATION A DESCRIPTION OF COMPONENTS AND VERBAL DESCRIPTION OF CONTROL SYSTEM; INTEGRATED SOLAR AND CONVENTIONAL SYSTEM(S)' OPERATIONS.

PROVIDE A SCHEMATIC OF CONTROL SYSTEM (MAY BE INTEGRATED WITH F.5.

ELECTRICAL POWER

1. OPERATING REQUIREMENTS

a. THE ELECTRICAL ENERGY REQUIRED TO DRIVE THE SOLAR COLLECTION PORTION OF THE SYSTEM IS ______ kw

1. PUMPS ______ kw FUNCTION ______

2. FANS ______ kw FUNCTION ______

3. CONTROLS ______ kw FUNCTION ______

4. OTHER ______ kw FUNCTION ______

b. THE ELECTRICAL ENERGY REQUIRED TO DRIVE THE STORAGE TO LOAD PORTION OF THE SYSTEM IS ______ kw

1. PUMPS ______ kw FUNCTION ______

2. FANS ______ kw FUNCTION ______

3. CONTROLS ______ kw FUNCTION ______

4. OTHER ______ kw FUNCTION ______

2. DESIGN LOAD DATA:

INCLUDE LOAD DUE TO VENTILATION REQUIREMENTS

BUILDING LOAD TABLE

MONTH	HEATING (BTU)	HOT WATER (BTU)	COOLING (BTU)
January			
February			
March			
April			
May			
June			
July			
August			
September			
October			
November			
December			
YEARLY TOTAL			
DESIGN PEAK (BTUH)			

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SOLAR SYSTEM ARRAY PERFORMANCE

COLLECTOR TYPE: ______________ LOCATION: ______________________

ARRAY AREA: ____________ FT^2; LATITUDE: ____________ °; TILT ANGLE FROM HORIZONTAL: ______________ °; AZIMUTH: ____________ +=West 0=Due South -=East

LINE	DESCRIPTION		MONTH											
		UNITS	J	F	M	A	M	J	J	A	S	O	N	D
(1)	Number of days		31	28	31	30	31	30	31	31	30	31	30	31
(2)	Average Temp. - (Tamb)*	°F												
(3)	Max Average Temp (Tmax)*	°F												
(4)	Average Ambient (Ta)1/2 (2) + (3)	°F												
(5)	Clearness Factor	—												
(6)	Average Collector Temp - (Tc) = 1/2(Tin+Tout)	°F												
(7)	Collector Efficiency	—												
(8)	Clear Air Daily Insolation on Tilted Collector Surface	BTU/ft^2												
(9)	Percentage Sunshine*													
(10)	Monthly Probable Insolation	BTU/ft^2												
(11)	Collected Energy (Qc)	Million BTU												
(12)	Q Loss (Piping & Losses)	Million BTU												
(13)	Q Usable	Million BTU												
(14)	Total Load Bld (Solar Conditioned)	Million BTU												
(15)	Auxiliary Energy Required	Million BTU												
(16)	% Solar Contribution													
(17)	Time of Collector Operation	Hours												
(18)	Electric Power for Collection Subsystem	KWH												
(19)	Electric Power for Storage to Load Subsystem	KWH												
(20)	Total Solar System Electric Power	KWH												

*Source of Data to be Specified: ______________

PLANT ENGINEERS SOLAR ENERGY WORKSHOP - FEEDBACK
SOUTHERN CALIFORNIA REGION

This workshop for Plant Engineers is a service cosponsored by the American Institute of Plant Engineers, Los Angeles Chapters, and the U.S. Department of Energy, Solar Technology Transfer Branch, Division of Solar Technology. We will appreciate your response, suggestions, criticisms, and comments in order to design improved workshops for the future. Please return the questionnaire to the workshop coordinator, Dr. Herbert W. Newkirk, Technology Applications Group, L-790, Lawrence Livermore Laboratory, P.O. Box 808, Livermore, CA 94550.

1. WHAT IS YOUR INTEREST IN SOLAR ENERGY?

ENGINEER ____
GENERALLY INTERESTED IN ENERGY ____
OTHER ____

2. WHAT WAS YOUR OVERALL EVALUATION OF THE WORKSHOP?

VERY USEFUL ____
INTERESTING ____
UNINTERESTING ____

COMMENTS:

3. WAS THE PROGRAM AGENDA APPLICABLE TO YOUR PROFESSIONAL RESPONSIBILITIES?

CRITICAL	____	LIMITED	____
IMPORTANT	____	NOT AT ALL	____
AVERAGE	____		

COMMENTS:

4. WAS THE WORKSHOP MATERIAL TOO SPECIFIC? _____
ABOUT RIGHT? _____
TOO GENERAL? _____

COMMENTS:

5. PLEASE COMMENT ON WHICH PARTS OF THE WORKSHOP WERE MOST (LEAST) INTERESTING FOR YOU. WHAT WAS MISSING FROM THE WORKSHOP AGENDA?

MOST ______________________________

____

LEAST ______________________________

____

MISSING ______________________________

____

6. a. WERE THE ORAL PRESENTATIONS CLEARLY PRESENTED?

OVERLY CLEAR _____ ABOUT RIGHT _____ UNCLEAR _____

b. WAS ENOUGH TIME DEVOTED TO THE AGENDA TOPICS?

YES _____ NO _____

COMMENTS ______________________________

____

7. AS A RESULT OF ATTENDING THE WORKSHOP, ARE YOU MORE OR LESS CONFIDENT IN EVALUATING A SOLAR ENERGY SYSTEM THAN BEFORE YOU TOOK THE WORKSHOP?

MORE CONFIDENT ____
NO CHANGE IN CONFIDENCE ____
LESS CONFIDENT ____

COMMENTS:

8. THE WORKSHOP INCLUDED A METHODOLOGY FOR THE THERMAL ANALYSIS OF SOLAR SYSTEMS. COULD YOU USE THE WORKSHEETS TO EVALUATE THE THERMAL PERFORMANCE OF A SYSTEM ON YOUR OWN? YES ____ NO ____

9. DO YOU BELIEVE THAT THE ECONOMIC EVALUATION METHODOLOGY PRESENTED IS A VALID WAY TO DECIDE THE ECONOMIC WORTH OF A SOLAR SYSTEM?

YES ____ NO ____

10. COULD YOU USE THE ECONOMIC EVALUATION METHODOLOGY PRESENTED IN THE WORKSHOP ON YOUR OWN? YES ____ NO ____

11. WILL THE HANDBOOK FROM THIS WORKSHOP BE A USEFUL REFERENCE FOR YOU?

CRITICAL ____ LIMITED ____
IMPORTANT ____ NOT AT ALL ____
AVERAGE ____

12. SHOULD THE FEDERAL GOVERNMENT SPEND/DO MORE OR LESS ON SOLAR ENERGY?

SPEND/DO MORE ____
ABOUT RIGHT ____
SPEND/DO LESS ____

COMMENTS:

FEEDBACK - 4

13. WERE THE WORKSHOP ARRANGEMENTS SUITABLE?

EXCELLENT ______ SATISFACTORY ______ MARGINAL ______

14. DID YOU HAVE ENOUGH ADVANCE NOTICE OF THE WORKSHOP?

YES ______ NO ______

15. OTHER COMMENTS OR QUESTIONS ABOUT THE WORKSHOP. (Please comment freely.) THANK YOU.

____

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