DOE/CS-0011

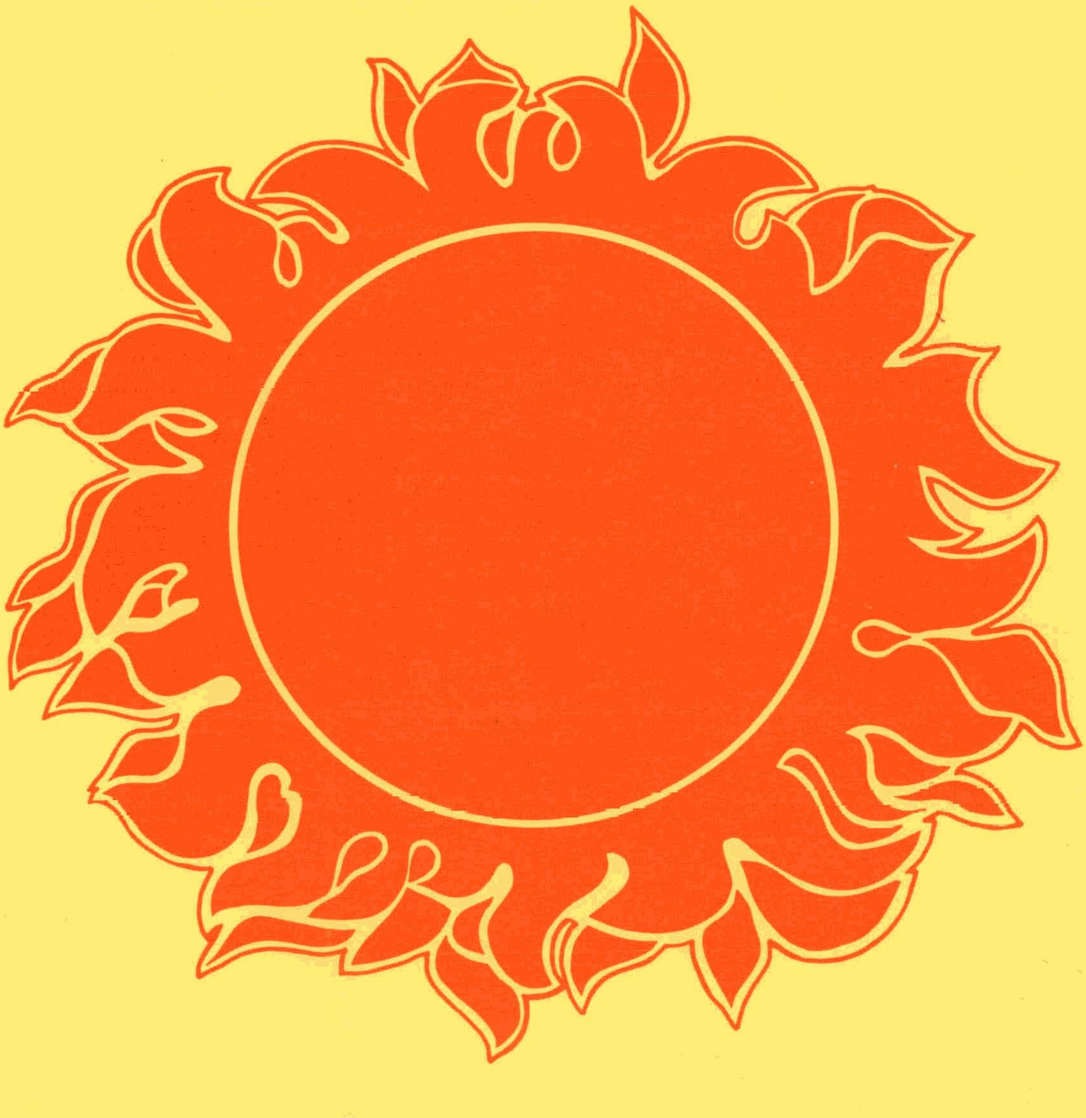
U.S. Department of Energy

August 1978

Assistant Secretary for Conservation
and Solar Applications
Office of Solar Applications

Introduction to Solar Heating and Cooling Design and Sizing

MASTER



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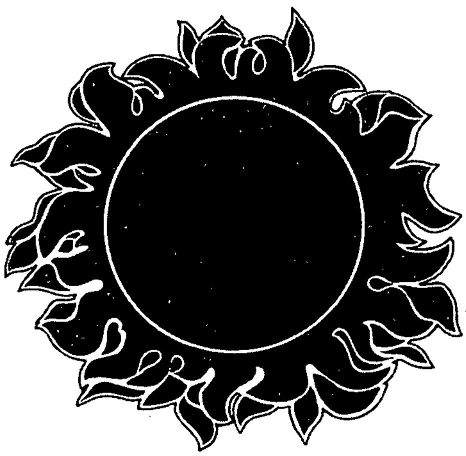

FOREWORD

This manual is designed to introduce the practical aspects of solar heating/cooling systems to HVAC contractors, architects, engineers and other interested individuals. It was developed as part of a two-day course presented in conjunction with the federal Transportable Solar Laboratory project, which travelled to all the continental 48 states from 1974 to 1978, first under the auspices of the National Science Foundation, then under a grant from the Energy Research and Development Administration and the Department of Energy. The text, prepared by noted solar energy developers, is arranged to support an introductory short course that may be adapted by vocational training organizations. It enables readers to assess potential solar heating/cooling applications in specific geographical areas, and includes tools necessary to do a preliminary design of the system and to analyze its economic benefits.

Contributors to this project:

The Energy Resources Center Honeywell Corporation Minneapolis, MN 55413	Project management under DOE Grant EY-76-G-02-2606
Solar Applications Laboratory Colorado State University Fort Collins, CO 80523	Overall text preparation
Beckman, Duffie & Associates 4406 Fox Bluff Road Middleton, WI 53562	f-chart sizing methodology
Total Environmental Action Church Hill Harrisville, NH 03450	Passive solar systems

Note: (Reference pages 2-12 to 2-134) Updated solar radiation information may be obtained from:

Climatological Analysis Division
National Climatic Center
National Oceanic & Atmospheric Administration
Asheville, NC 28801

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ENERGY PROBLEM/AVAILABILITY OF SOLAR

The United States, well known for its high standard of living, rates high on the energy consumption list in comparison to the other countries (Figure 1-1). The consumption of "cheap" energy plays a significant role in the high gross national product in the USA as well as other industrialized countries of the world.

It was not until the energy crunch in 1972 that people started realizing that there is not an endless energy supply (Figure 1-2). It took the closed gas stations and high gas bills for the public to become concerned about energy and to start doing something about it.

This rapidly depleting energy supply has led to the accelerated search for alternative methods of providing energy. Energy does not come only in the forms of coal, gas and oil. There are many others, such as nuclear, hydro-power, geothermal and solar. The most abundant, clean and inexhaustible form, of course, is Solar Energy.

There are many factors that have contributed to this so-called energy crisis, in addition to the increase in demand. The events that have occurred since the Arab-Israeli war of October 1973 have had many wide-ranging effects. The quadrupling of world oil prices over a three-month period due to the oil embargo, merely anticipated price levels that would have been reached a decade or so later, in any event. Whatever else it may have done, the Organization of Petroleum Exporting Countries (OPEC) action served as a timely reminder that even the fabulously productive oil fields of the Middle East are exhaustible and that plans must be made for an orderly transition to

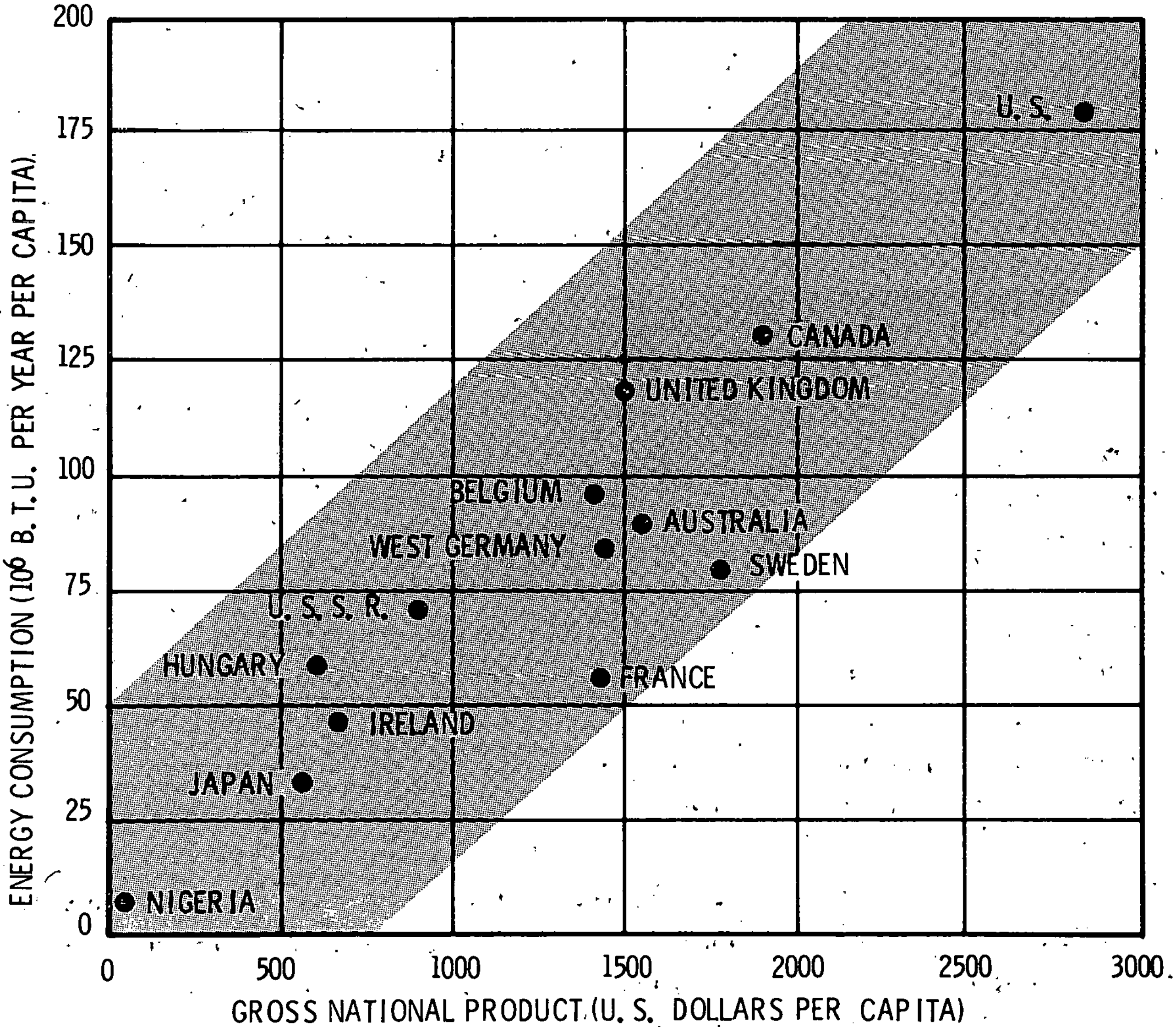

Figure 1-1. Comparison of Energy Consumption

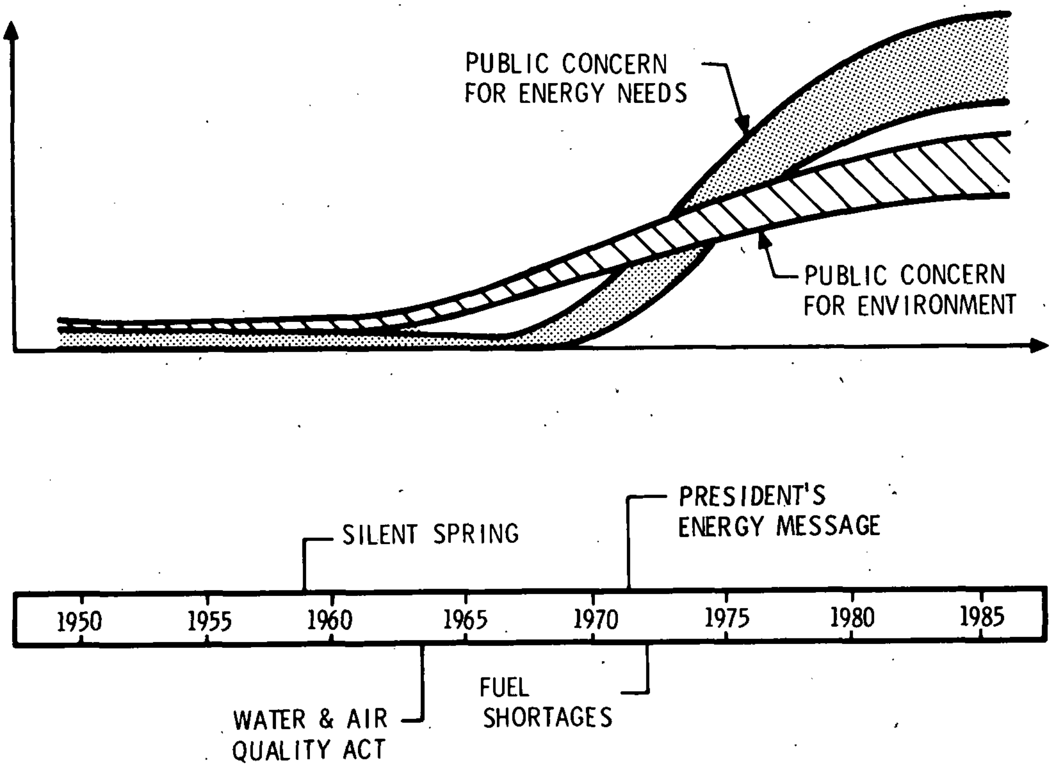

Figure 1-2. Energy and Environmental Concerns

other sources as the inevitable process of depletion makes oil progressively more scarce and costly. The timing and course of transition depend heavily upon relative availability of the various energy sources. It must be kept in mind that historically there has been a 50 to 75 year waiting period to bring any form of alternate energy source to full maturity.

In the U.S. since the first oil well was discovered in 1859, our fossil fuel resources have been subjected to an ever-expanding rate of discovery and production. Therefore, it is possible and even probable that any resources found in the future will become harder to find and to produce, and finally, they will all be completely exhausted. A Dow Chemical official sees our oil and gas reserves exhausted by 1991; Universal Oil Products Co. states that our proven natural gas supply will be exhausted by the 1990s. In the near future, as these reserves become scarce, energy industries will be looking longer and digging deeper to meet their energy demands. This entails a huge increase in the cost of these precious fuels because more money will have to be spent on labor and better equipment (see Figure 1-3).

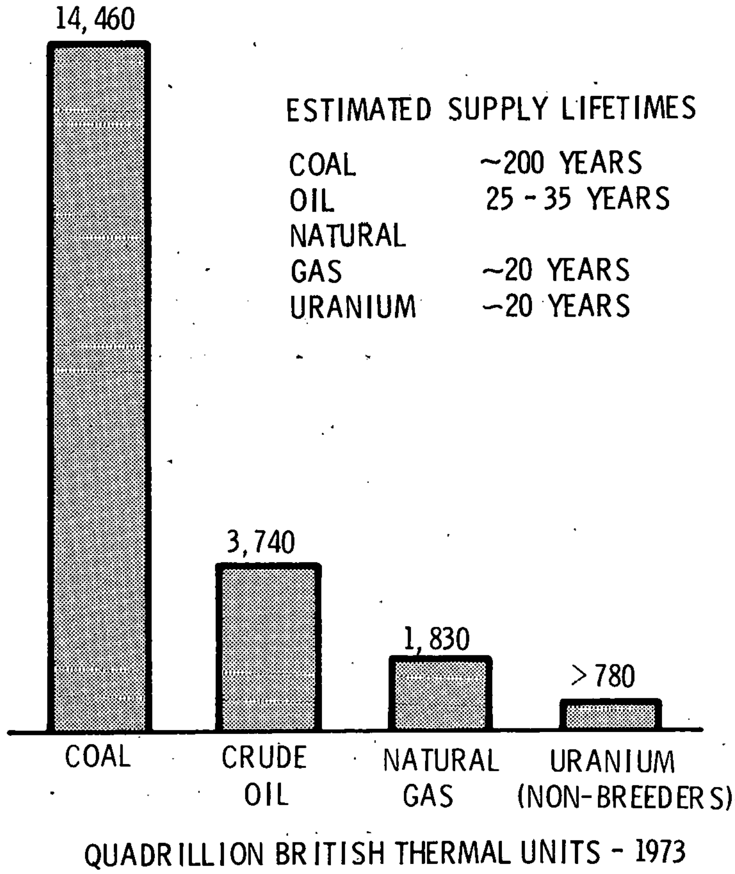

Figure 1-3. Measured World Nonrenewable Energy Reserves

Significant observations have been made concerning today's sources of energy and their availability:

1) Oil, which the world has made its dominant fuel over the past 30 years, is relatively scarce and poorly distributed (Figure 1-4) -- two factors that hold great potential for trouble in a world of exponentially increasing demand for energy.

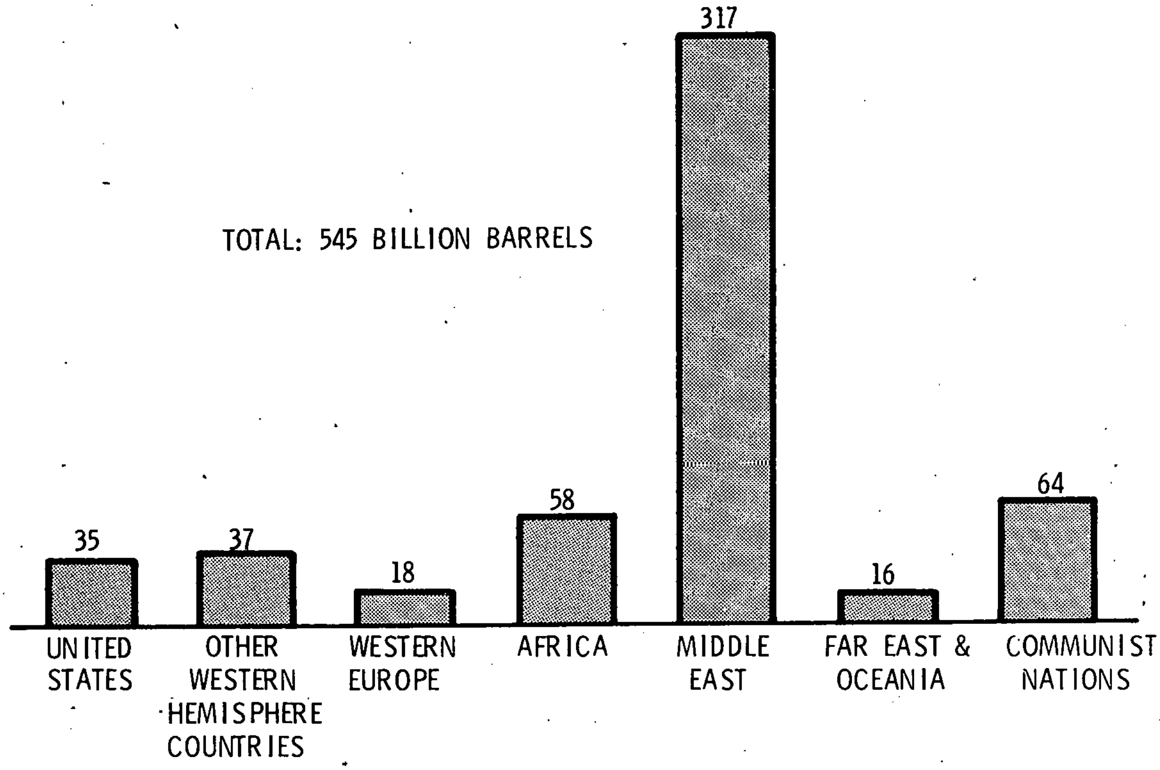

Figure 1-4. World Crude Oil Reserves, 1973

2) Natural gas in presently producible accumulation is even less abundant than petroleum, and its capacity to substitute for petroleum is accordingly limited.

3) Coal is by far the world's most abundant fossil fuel resource, yet serves less than 30 percent of its energy needs.

4) Hydrocarbons in gas accumulations presently not producible in oil shale and tar sands are abundant, yet presently contribute little or nothing to energy supply.

5) Uranium resources as presently assessed seem insufficient to support substantial burner reactor power production for more than a few decades. The problem is having to meet the world's

demand for electric power from burner reactors while developing safe, economically viable breeders without exhausting low-cost uranium resources before the latter can pick up the load from the former.

In the aggregate, potential resources of mineral fuels are large but their life against the buzz saw of exponential growth would be measured better in decades rather than centuries.

Fossil fuel shortages, resultant price rises, worry about nuclear reactor safety, all thrust solar energy into the limelight for a leading role in the nation's energy picture.

Everyday the earth is showered with several thousand times as much energy as we can use. In less than three days, the solar energy reaching the earth more than matches the estimated total of all the fossil fuels on earth. Figure 1-5 represents the growth of our energy demand and the amount of insolation -- the amount of solar radiation which falls on the earth's surface.

Translated into terms we can more readily visualize, a square yard of area exposed to direct sunlight continuously receives radiation equivalent to nearly 1.5 horsepower from the sun. Of course, clouds, haze, dust and smog decrease the amount of energy received considerably. The mean value of the solar constant is 428 Btus per square foot per hour.

Although the full impact of solar energy probably will not be visible for a decade or more, the economic viability of several important applications, such as heating and cooling of buildings, has already been proven in high energy cost areas. Some estimates indicate that solar energy may contribute as much as 25 percent of the nation's total energy requirements by the year 2020. Cost, legislation, fossil fuel depletion, and tax incentives are important factors as to whether or not these expectations will be met.

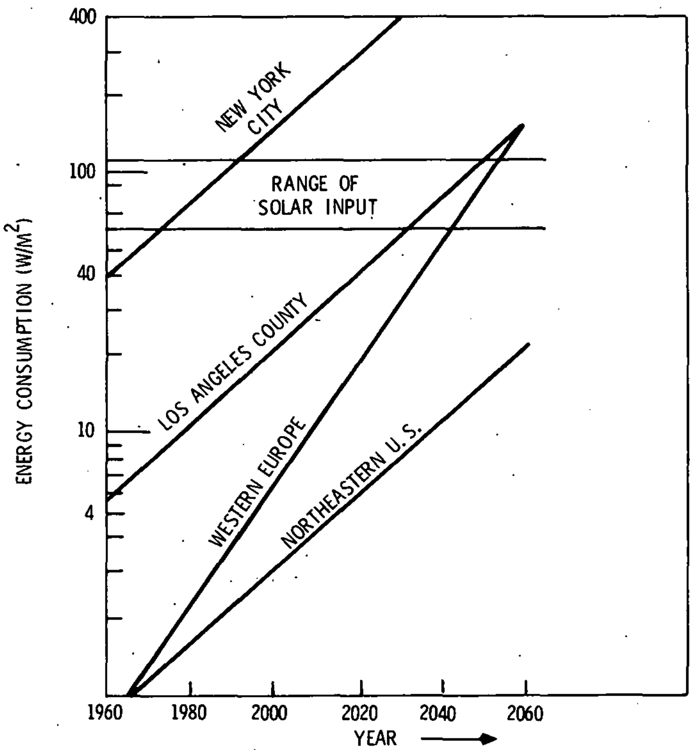

Figure 1-5. Energy Demand and Insolation

Figure 1-6 shows a breakdown of direct energy consumption nationwide. Notice that in every breakdown of a specific section, except for transportation, the possibilities for solar are immense. Presently, solar energy is the most feasible in space and water heating. For industrial, commercial and residential usage of energy, a considerable proportion of it is devoted to space and water heating. If we can put the sun to use in this area, we could greatly decrease the consumption of fuel. The shaded areas show the possibilities of solar energy usage.

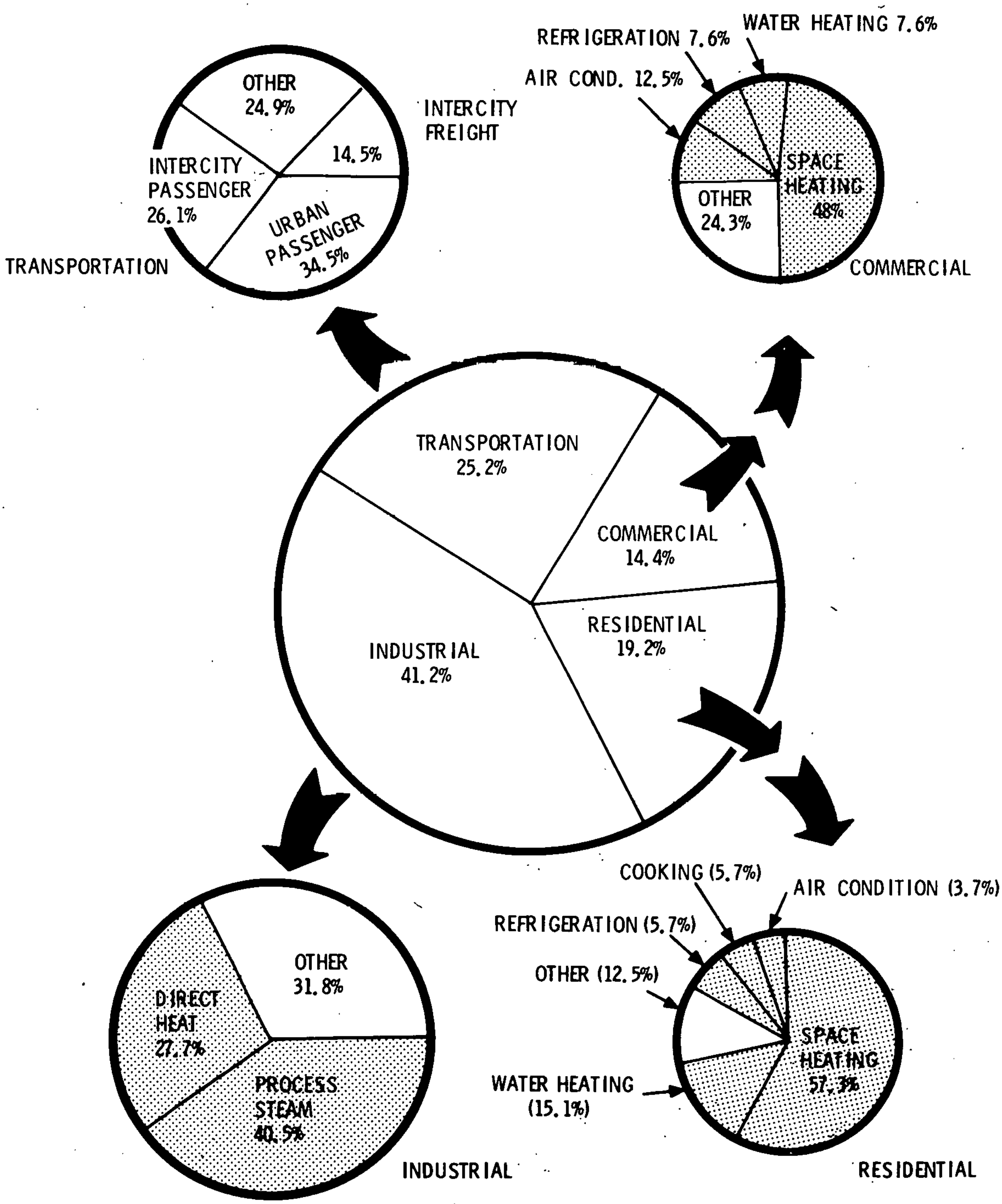

Figure 1-6. Breakdown of Direct Energy Consumption Nationwide

HISTORY

The use of the sun as a source of energy is not new. The sun has been both a blessing and a challenge as far back as 212 B.C., when the sun was used to ignite temple fires. In that same year, legend has it that Archimedes set fire to an attacking Roman fleet by concentrating the sun's rays with polished brass onto the sails of their ships (Figure 1-7).

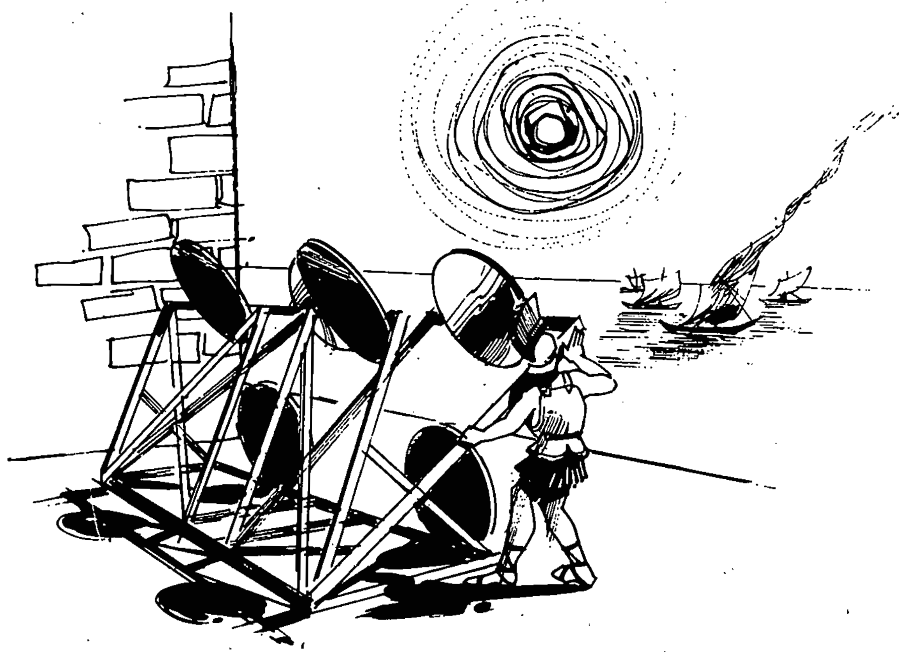

Figure 1-7. Archimedes Incinerates Roman Fleet with Solar Reflector

By the year 1600 A.D., science had begun to consider the sun as an energy source for purposes other than destruction. In France, Salomon de Caux put the sun to work heating air in his solar engine, used to pump water. De Caux was more than 200 years ahead of the next inventor of a solar engine, but the gap was filled with simpler devices.

In the late eighteenth century a great French chemist, Antoine Lavoisier, began to use the sun for research purposes. Lavoisier used curved glass discs fastened together at their rims, with wine filling the space between, to focus the sun's rays enough to attain temperatures of about 3000°F. He used these high temperatures to discover the nature of carbon and platinum. Lavoisier also carried the science of the solar furnace forward by heating samples in a vacuum and in controlled atmospheres, using quartz containers (Figure 1-8). Unfortunately, Lavoisier lived during the French revolution and was beheaded because "the Republic has no need for scientists." With the lopping off of this pioneer's head, work with solar furnaces halted, and it was more than a hundred years before men again achieved elevated temperatures using the sun's rays.

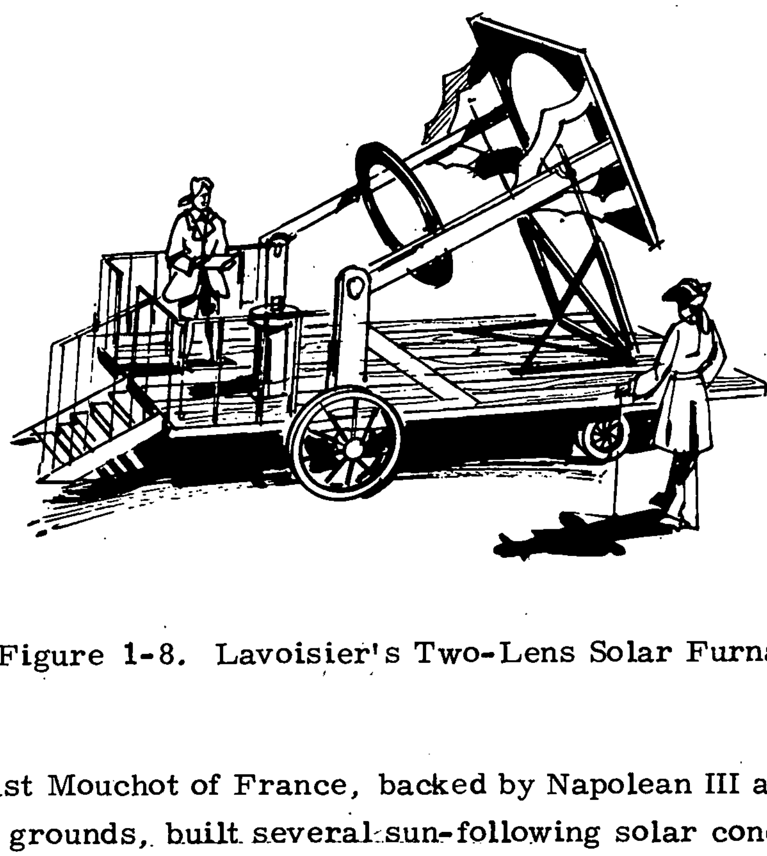

Figure 1-8. Lavoisier's Two-Lens Solar Furnace

In 1866, August Mouchot of France, backed by Napolean III and using Algeria as his testing grounds, built several sun-following solar concentrators which were large even by today's standards and used them to drive pumps and to distill water. But the government decided that Mouchot's machines could not be made with an economy "sufficient to the demands of commerce."

In the United States, a man named John Ericsson was famous during the civil war for his successful hot-air engines, and it was not surprising that he turned his inventive mind towards using the sun to run his engines. By 1875 Ericsson had built eight different models of his solar engines, but although he claimed high efficiency for the designs, none of them were practical. In 1883 he made one last try, building what was the second largest solar engine of that day. Measuring 11 by 16 feet, the rectangular parabolic collector drove a piston with a six-inch bore and eight-inch stroke (Figure 1-9). Ericsson claimed it delivered one horsepower for each hundred feet of collector. Incidently, some of Ericsson's solar engines may be seen today in the American-Swedish historical society in Philadelphia.

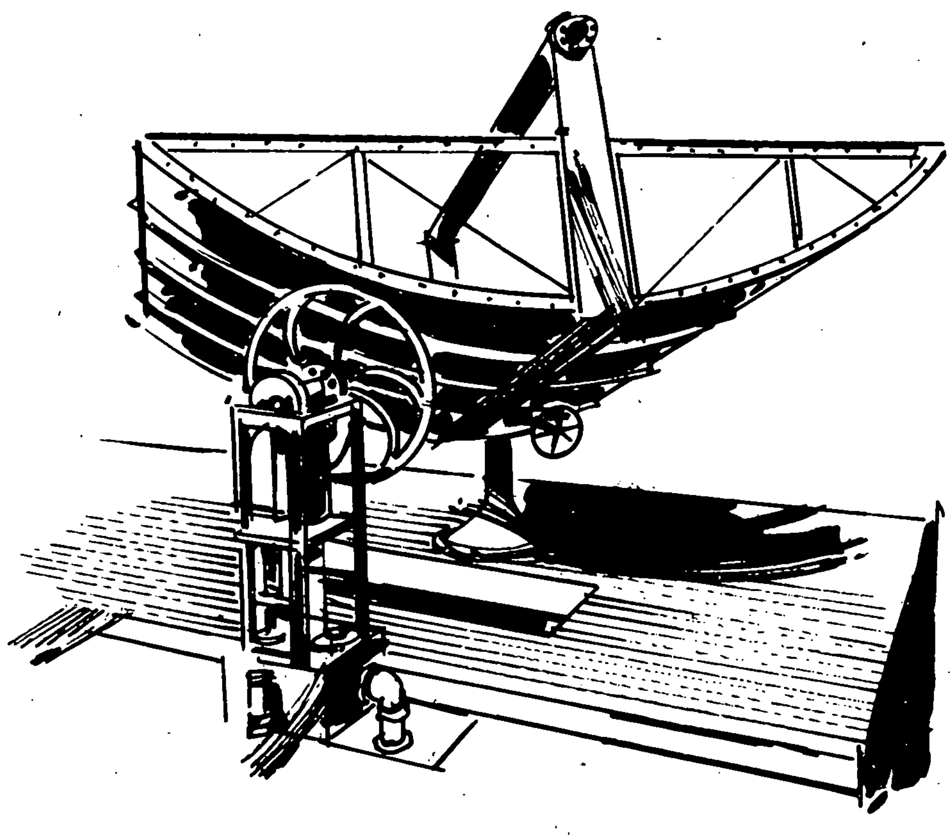

Figure 1-9. Ericsson's Solar Power Plant, 1883

In France, Abel Pifre built a steam engine, fired by a 100-square foot parabolic collector, which generated two-thirds horsepower. Pifre put it to work running a printing press to print understandably, "Le Journal Soleil," which means "The Sunshine Journal" (Figure 1-10).

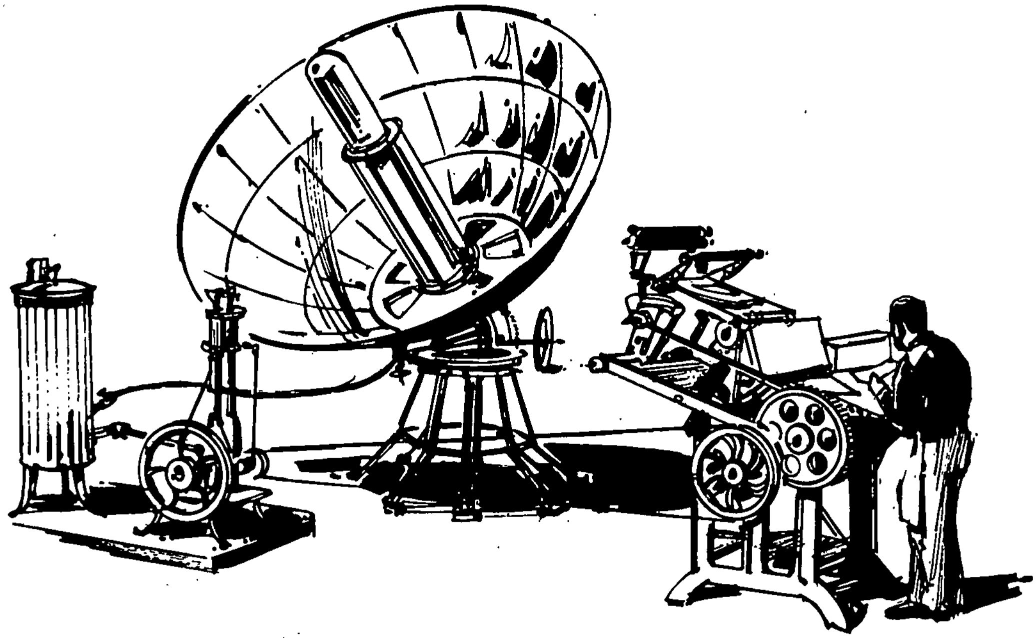

Figure 1-10. Abel Pifre Uses Sun to Print His "Sunshine Journal"

Shortly after this achievement the first flat-plate collector was built by Frenchman Charles Albert Tellier. Its 215 square feet of area drove an engine with ammonia as a working medium instead of steam, air or water. This was the first attempt to cut the costs of producing a solar collector. A little later an illustration in the Scientific American in 1885 proposed a system in which the flat-plate collector served also as a roof of a factory building. Certainly, inventors were beginning to realize the economics of their technologies (see Figure 1-11).

These solar pioneers did not use the sun only to run engines. In fact, one of the oldest uses of the sun is for food preparation. Food has been sun dried for ages. But the development of solar cookers dates back only about 150

Figure 1-11. Solar Water Pumping System, 1885

years. Mouchot demonstrated a solar cooker at the World Exhibition in Paris in 1878. The cookers were simple ovens with glass lids to let in sunlight and trap heat inside. His oven was able to cook a pound of beef in twenty minutes. In 1916, Dr. Charles Greely Abbot built a more sophisticated oven and tested it for several years on Mount Wilson (see Figure 1-12).

Another way to put the sun to use is in the distillation of water. In Chile, in 1871, need for drinking water arose at a copper mine high in the Andes at Las Salinas and a huge solar still was built by Charles Wilson, an American engineer, to convert locally available salt water into potable form. This still,

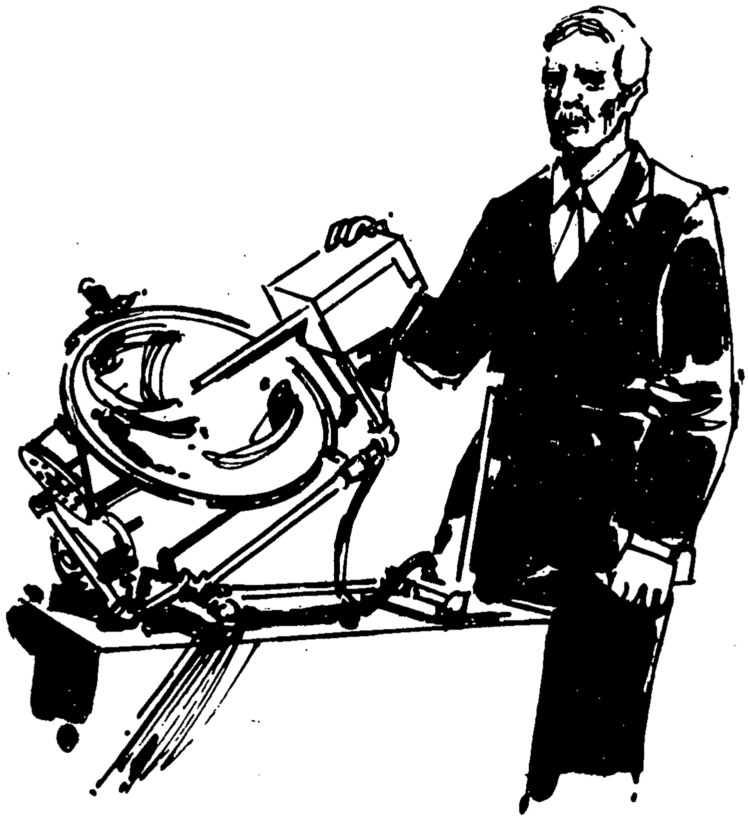

Figure 1-12. Dr. Charles Greely Abbot with His Solar Cooker, 1916

nearly an acre in size, could produce over 4000 gallons of water per day. It consisted, as do today's solar stills, of a shallow basin, painted with waterproof black compound and covered with a glass roof, shaped like an inverted and flattened V (see Figure 1-13).

When the sun's rays passed through the cover glasses, they were absorbed by the blackened interior of the still and thus the water, which was about 6 inches in depth, was warmed to the point where some of it was converted into vapor. In a solar still the cover glass remains relatively cool, hence the vapor condenses on the underside of the glass and trickles down into the container, as pure as any other kind of distilled water.

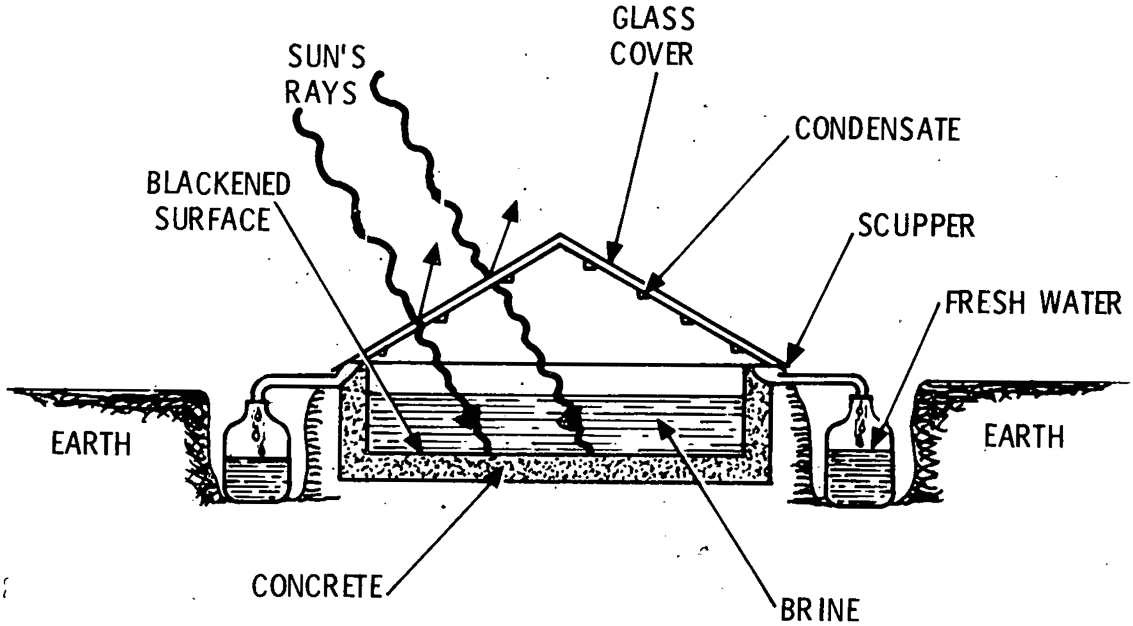

Figure 1-13. Operating Principles of Solar Still

Power for pumping water was the objective of the next group of solar experimenters who operated in the United States at the turn of the century. The most spectacular solar engines were those built in Arizona by an English inventor, A.G. Eneas, who talked a group of Boston financiers into backing his project to build giant solar concentrators to generate steam at pressures up to 150 psi to pump water at the rate of 1400 gallons per minute.

Eneas' concentrator was 33-1/2 feet in diameter at the top and 15 feet at the bottom and parabolic in shape. It received the full effect of the sun by using 1788 mirrors to concentrate its rays at a boiler located at the paraboloid's focal point. When the sun's rays had heated the water in the boiler so as to produce steam, the remainder of the process was the familiar operation of a compound engine and centrifugal pump. A modest price of $2500 to $3000 was quoted for the solar devices (see Figure 1-14).

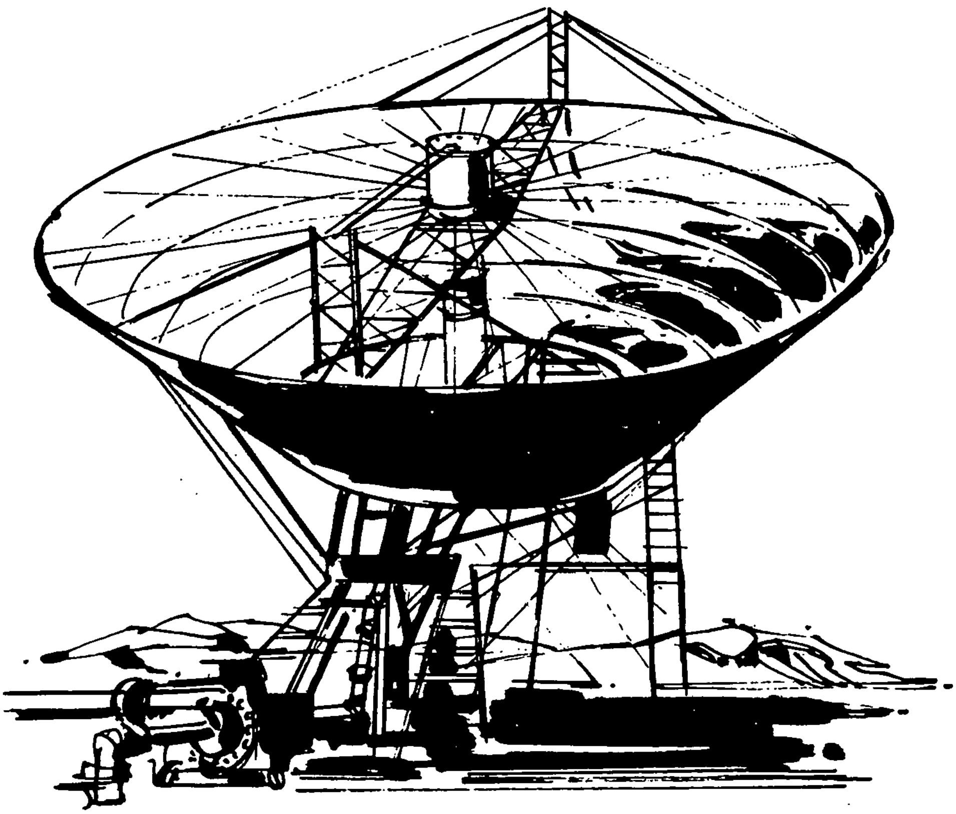

Figure 1-14. Eneas' Solar Concentrator

In 1907, in Lacony, Pennsylvania, an inventive engineer named Frank Shuman was beginning a career as the solar energy salesman who came the closest to making the grade. Instead of an engine he proposed a huge solar steam plant. Covering four acres, the heat collector would cover the entire tract of land itself (see Figure 1-15). Shuman estimated an output of 100 horsepower. He did not deliver anything like 100 horsepower in Lacony. There was air pollution even in those days, and smoke and clouds obscured the sky and severely hampered operation. Shuman formed the Sun Power Company in 1908. At that time he obtained British backing for what was to be the Eastern Sun Power Company, Ltd., of London. He also had the technical assistance of Professor C. V. Boys, a noted physicist, and a go-ahead to build his 100 horsepower plant in Egypt (see Figure 1-16). By 1912 his power plant was in operation in

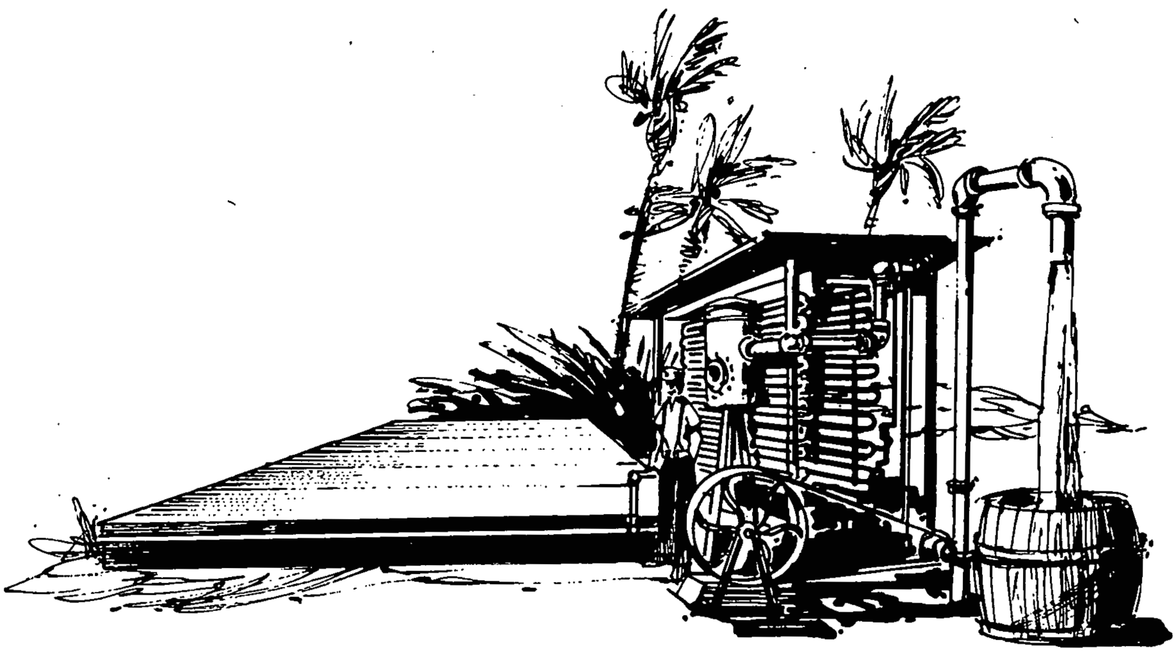

Figure 1-15. Shuman's Sun Power System, 1907

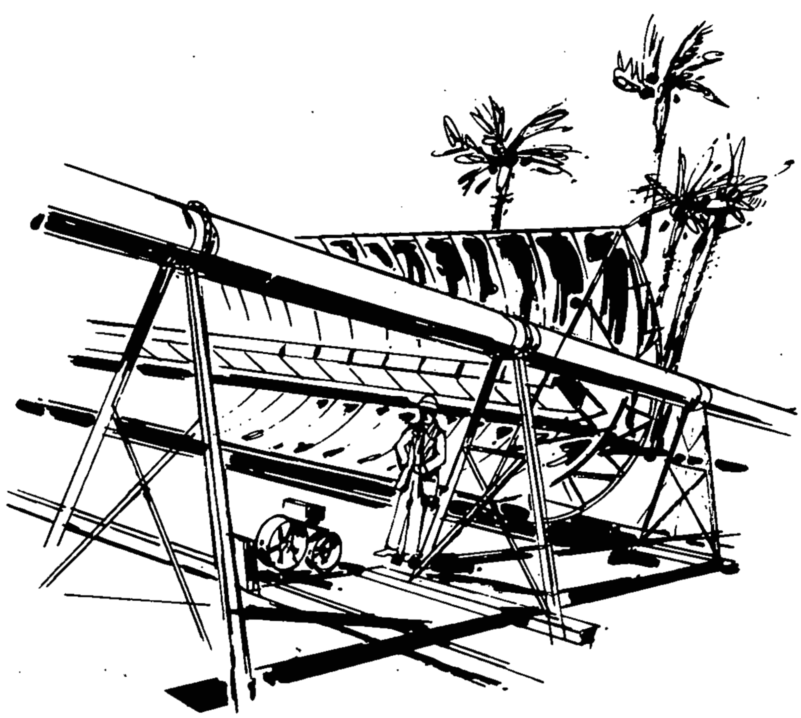

Figure 1-16. Shuman-Boys' Solar Power Plant, 1913

a suburb of Cairo. The plant's actual output was half of what was expected, but it did work. Unfortunately, caught in an advanced skirmish of the battle of automation versus manual labor, plus economics and the confusion of World War I, Shuman's marvelous power plant was eventually abandoned and fell into disrepair.

The solar battery also has a long history. In 1839 Antoine Becquerel found that sunlight caused a weak current in certain materials, in this case the electrodes of an electrolyte solution. Forty years later Adams and Day observed a similar effect in a solid material, selenium. But the electricity obtained was too feeble to do anything but move a needle on a scale.

In 1931 Dr. Bruno Land demonstrated photovoltaic solar power at Kaiser Wilhelm Institute. His invention was a "sandwich" of copper oxide, silver selenide and a third, secret ingredient. Exposed to sunlight, the battery powered a small electric motor indefinitely. Yet, this remained only a curiosity.

Solar water heaters also interested many inventors. These were developed mainly for hot baths of easterners and during World War I many large installations were made in Army cantonments. Most of them used the natural circulation "thermo-syphon" as shown in Figure 1-17. Thousands of these thermo-syphon water heaters are currently being used in Australia, Israel and Japan (there are a few in California and Florida). An auxiliary heater is generally inserted into the storage tank to provide hot water during periods of inclement weather.

We know that the sun itself has been around a long time, but it comes as a surprise to realize that men have been trying for so long to harness its energy. There have been many factors against early success, even when some pioneers must have felt they had it surely in their grasp. First was the lack of knowledge. And when men acquired knowledge, they were still short of the technology to apply it.

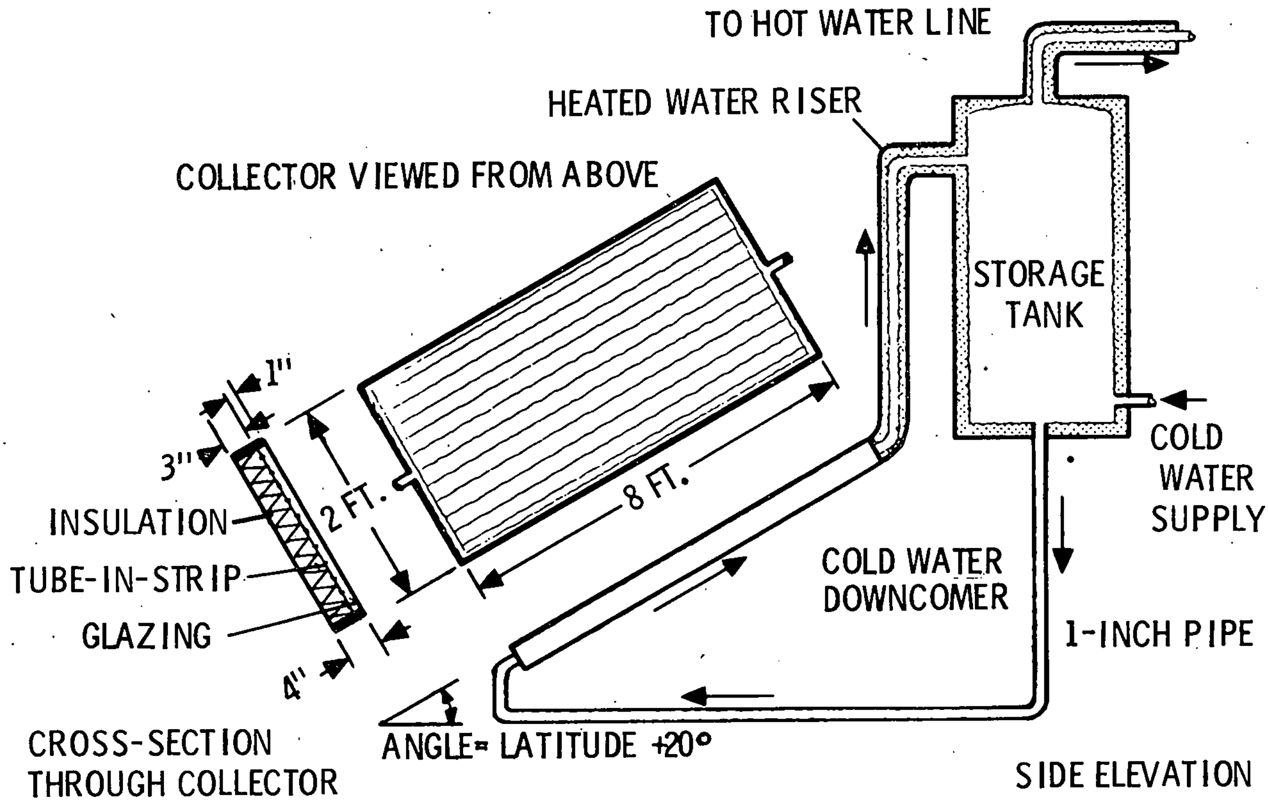

Figure 1-17. Thermo-Syphon Water Heater

Their main drawback, which overruled all other factors against the early success of solar energy, was the unavoidable fact that other forms of energy were very abundant and cheap to obtain. The initial cost of developing solar technology and equipment was far too great to compete with the cost of conventional forms of energy.

Therefore, since the cost of conventional forms of fuel has been on the rise in the last few years, renewed interest has developed in the promising field of solar energy. Current interest lies primarily in environmental control and water heating in buildings on which many institutions are presently doing experimental work.

EXAMPLES OF RECENT SOLAR ARCHITECTURE

The simplest solar heating technology relies mainly on architecture to achieve "passive" solar heating; buildings are simply designed to soak up lots of sun. More complex solar systems involve "active" systems based on solar collectors. Many of these systems not only heat a home, but also operate absorption-type air conditioners and heat water for use in the home. Since these collectors require a considerable amount of area and should be exposed to the sun as much as possible, they are generally structured on rooftops with a southward slope or on south-facing walls. They are usually tilted at an angle equal to the latitude plus or minus 15 degrees to receive the maximum solar radiation throughout the year.

In addition to heating homes, solar applications can be found on many commercial buildings and schools. A number of these are new construction, but many are retrofitted with solar systems. Figure 1-18 shows a ground installation designed and installed by Honeywell of 5000 ft^2 of collectors used to heat ventilation air, domestic water and swimming pool water of Northview Junior High School at Brooklyn Park, Minnesota.

Solar architecture need not look strange, indifferent or advertise the fact that it is a solar home. Such a home can fit very well into any neighborhood. Figure 1-19 is a photograph of the Marv Anderson home in Bloomington, Minnesota. From the front (the north side), it looks like many other homes. But from the back, the solar collectors fit very nicely into the south sloping roof (Figure 1-20). This home has a design heating load of 20,200 Btu/hour and the solar heating system is able to provide 55 percent of the annual load. Additionally, the solar system is able to provide 68 percent of the total annual hot water load.

*Experiments in cold climates have shown that large south-facing windows can lead to net losses unless they are covered at night by some kind of effective insulation.

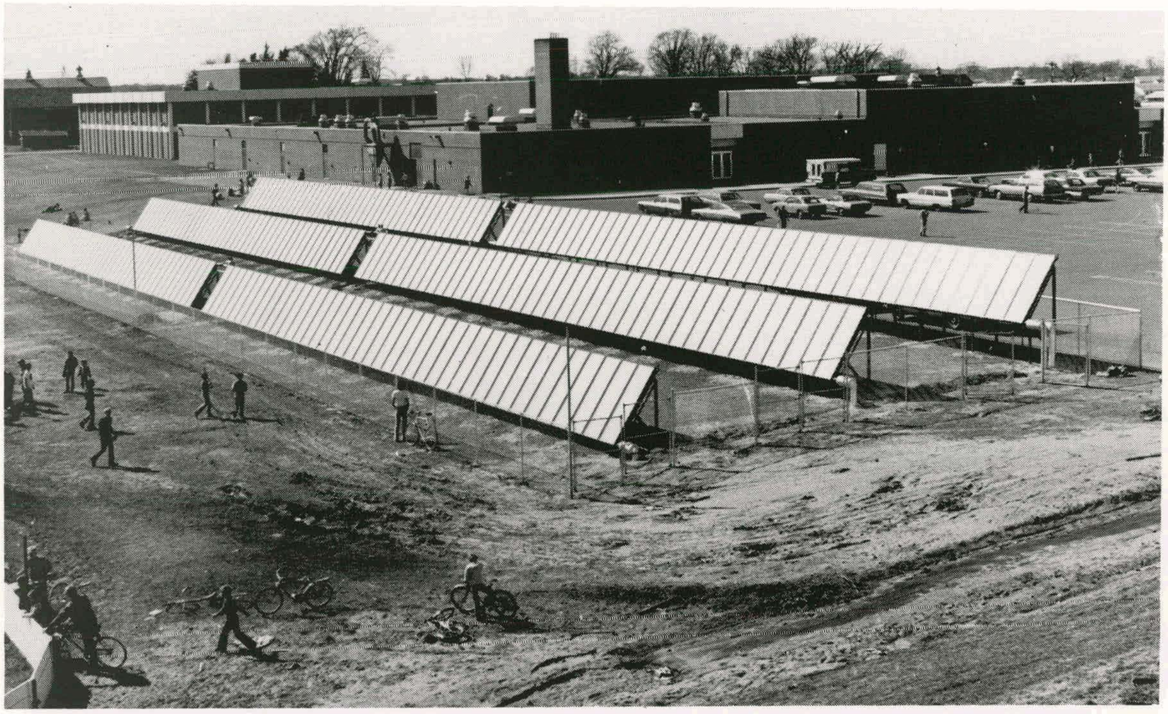

Figure 1-18. Northview Junior High School Ground Installation of 5000 ft^2 Collector to Heat Ventilation Air, Domestic Water and Swimming Pool Water

Figure 1-19. Marv Anderson Solar Home in Bloomington, Minn. - Front View

Figure 1-20. Rear View of Marv Anderson Solar Home

In the best known passive system, whose basic concept has been around for decades, huge south-facing windows allow sun to pour in during daytime in the cold months. With today's insulating materials, including special curtains that are drawn at sunset,* homes with passive systems are able to hold most of their heat at night. As with any solar space heating system, a conventional furnace provides warmth during cloudy spells. A few latter-day Jeffersonians, intent on self-sufficiency, fall back on wood-burning stoves supplied with fuel from their own acreage. The problems with passive systems concern matters of comfort. The sunshine that pours in can be blinding during the day and can drive interior temperatures to oppressive levels.

No matter what type of solar system you use the main idea behind its architecture is insulation. It would be very difficult to apply solar to houses designed to traditional Federal Housing Administration standards. A typical FHA home -- three bedrooms, 1400 square feet -- would take 500 to 700 square feet of collectors to save half the heating bill in Minneapolis. That same size home, designed to be energy conserving, would cut energy requirements by 50 percent and would need only 250 to 350 square feet of collectors to provide half its heating requirements.

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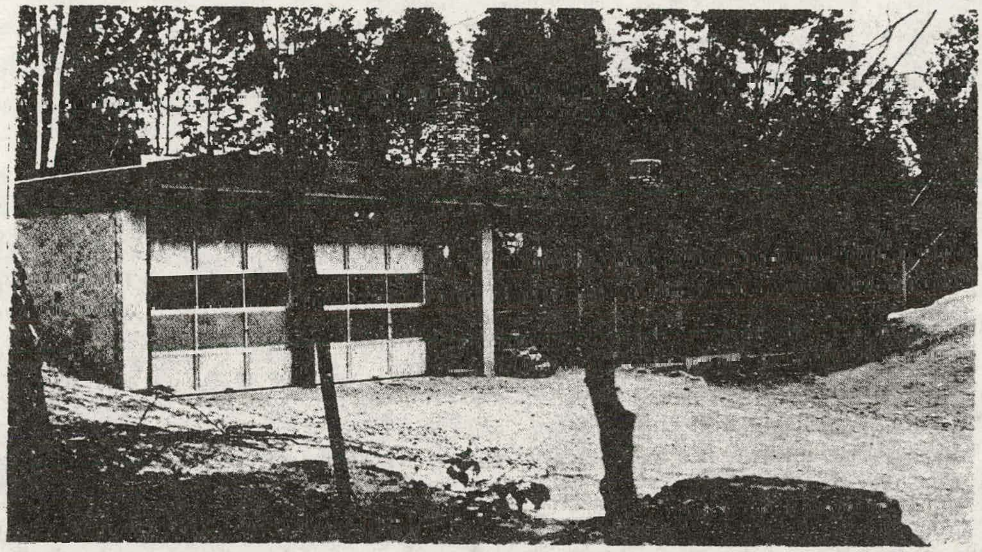
*Experiments in cold climates have shown that large south-facing windows can lead to net losses unless they are covered at night by some kind of effective insulation.

How is a home designed to be energy conserving?

- Solar homes are designed and oriented to serve as collectors themselves. They admit winter sun and are sheltered from prevailing winter winds. In summer months, they exclude the sun and have provisions for natural cooling.
- They have few or no windows on the north side. Most glass area is on the south-facing facade.
- They have extra insulation in walls and attic.
- Earth may be back-filled to partially or completely cover north, east and west walls.
- Heat lost through windows at night is cut by insulating shutters or drapes.
- The amount of cold (or warm) air entering the house when doors are opened is reduced by airlock entries.
- Air infiltration is minimized by careful construction and by caulking and sealing all measurable air leaks.
- Solar homes have close-in multistory floor plans rather than sprawling, single-story designs.

These energy-conserving features obviously place design constraints on solar homes. But architects are meeting the challenge in varied and exciting ways, as shown in Figures 1-21 through 1-27.



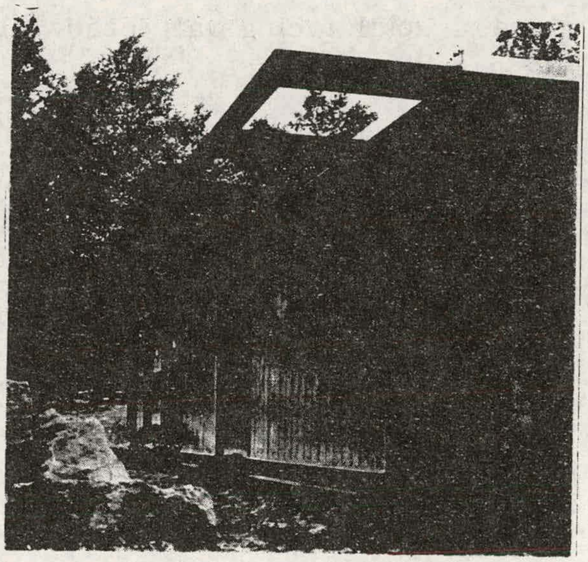


Figure 1-21. Passive Solar Installation in New Hampshire with Beadwall. Photo courtesy Popular Science Magazine

Designed By:

ARCHITECT - Doug Coonely
of Total Environment Action

Owners:

Tyrrells

The House:

Three bedrooms -- 2000 square feet

Energy Conserving Features:

North, East, West walls partially covered with earth; wall insulation on the outside has 2 in. of rigid styrofoam. Natural cooling by venting in north; insulating shutters for doors and windows. Air-lock entry through garage.

Solar Features:

Windows and collectors on south facing wall; beadwall panels.

Storage:

4 in. thick concrete floors; 1 ft thick concrete walls.

Back-up System:

Two Austrian wood stoves.

Cost:

Energy saving and solar components: $5000 to $7000

Design Fees -- $ 5,000
Total Cost -- $52,000

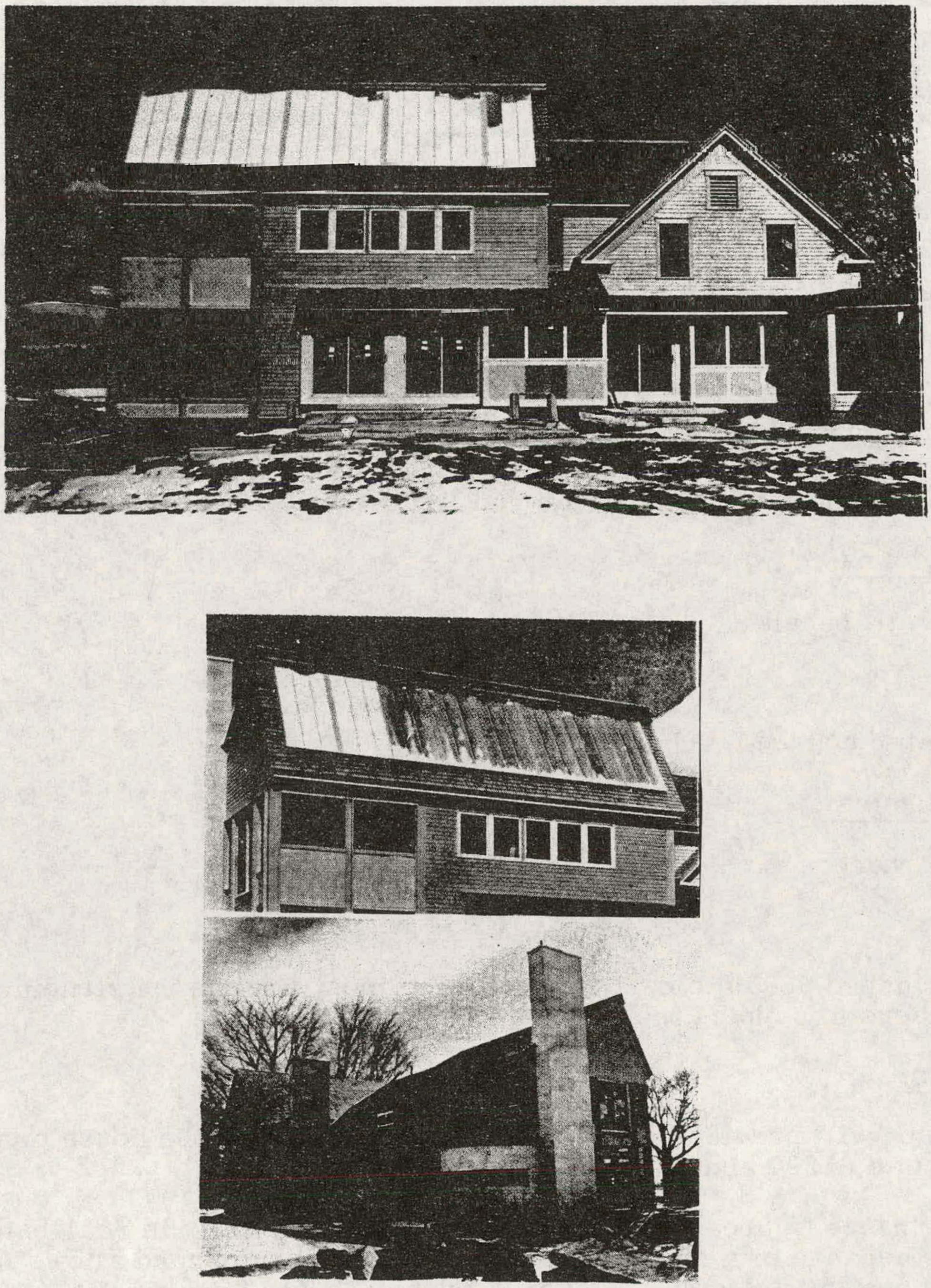


Figure 1-22. New Hampshire Farmhouse with Beadwall Addition.
Photo courtesy Popular Science Magazine

Designed By:

ARCHITECT - Bruce Ellis
with Total Environment Action (TEA) Advising

Owners:

Dr. Jackson Freeze

The House:

Renovated farmhouse

Energy Conserving Features:

10 in. insulation in roof;
12 in. insulation between attic and living space.

Solar Features:

Beadwall panels

Storage:

14 water beds (21,000 gallons) in attic

Back-up System:

Oil furnace

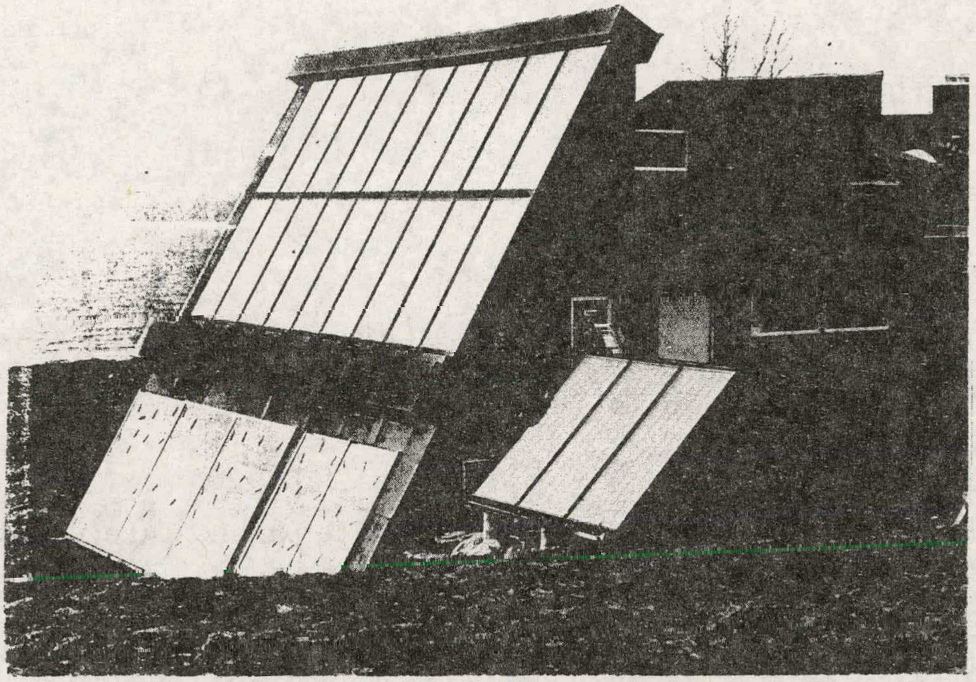
Cost:

Solar added $8000 to cost of renovation mostly for extra structural members to support the water and extra insulation.

Comments:

The sun will provide half the energy needed to heat the house or save $600 of a $1200 annual cost for fuel oil.

Dr. Freeze figures he'll save $450 and $500 annually in real-estate taxes because of a special deduction the City of Concord allows for solar heating systems. Pay back period -- 8 to 9 years.



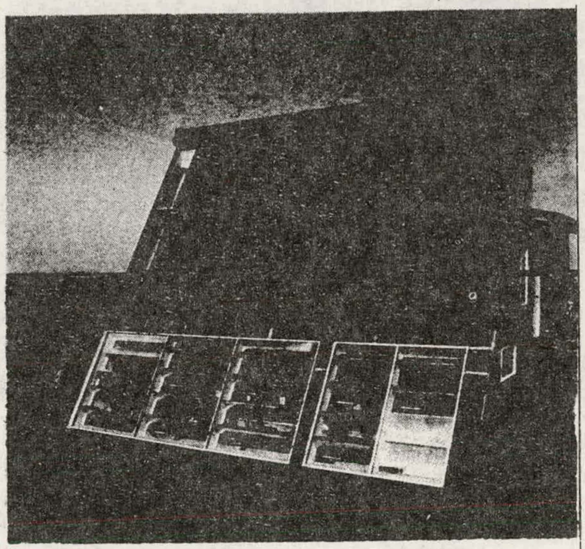


Figure 1-23. Rhode Island Contemporary with Liquid-Type Collectors. Photo courtesy Popular Science Magazine

Designed By:

Travis Price

Owners:

Eddys

The House:

Existing home poorly constructed electric bills were running from $300 to $400 a month. Built an addition that would be solar heated. Solar would heat 3 rooms in the existing home.

Energy Conserving Features:

Extremely well insulated. All windows double panel. Direct heating through south-facing windows.

Solar Features:

Eighteen 3 x 7 foot Sunworks air-type collectors; liquid type Sunworks collectors on free standing structure for hot water.

Storage:

1000 ft^3 rock bin

Back-up System:

Small woodburning stove

Comments:

The direct heating through the south facing windows makes up the missing 20 to 30 percent of heat needed and eliminates the need for fossil fuel back-up system.

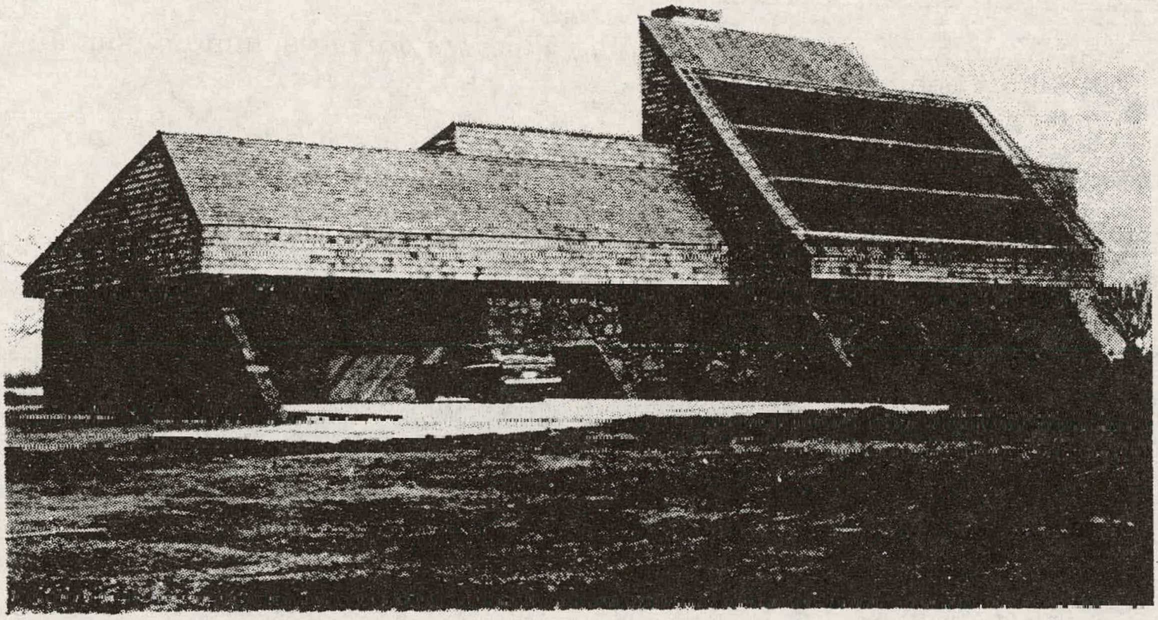


Figure 1-24. Oklahoma Contemporary with Liquid-Type Collectors. Photo courtesy Popular Science Magazine

Designed By:

ARCHITECT - Alan Lower

Owner:

Engles

The House:

Solar-heating components integrated with the structure rather than appear as an after thought.

Energy-Conserving Features:

Roof overhangs shade south facing windows during summer months but admit sun in winter.

All glass is double panel; walls above and below grade have 6 in. insulation; roof and ceiling have 12 in. of insulation.

Solar Features:

Heating and cooling by Energy Systems, Inc. liquid type copper collectors.

Storage:

Compartmentalized water tank -- 2000 gallons -- stores heat in winter when lower-temperature water is sufficient for space heating; 800 gallons -- stores heat in summer so that high temperatures can be reached to run the air conditioner.

Comments:

Major design element of the structure -- the steep 50 deg roof plane -- positions the collectors so that they're perpendicular to the sun's rays at low winter sun angles.

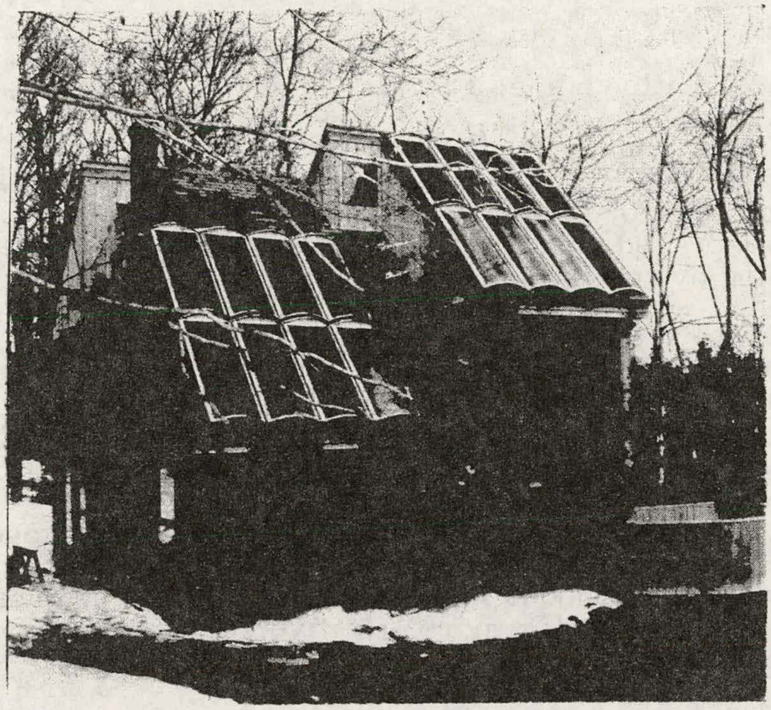


Figure 1-25. Vermont Vacation Home, with Grumman Collectors.
Photo courtesy Popular Science Magazine

Designed By:

Blue Minges of Blue/Sun Ltd.

Owner:

BUILDER - Bob Terrosi

The House:

3 Cedar-clad vacation home; 3 levels.

Energy-Conserving Features:

Post and beam construction; overhung exterior wall; 2-1/2 in. of polyurethane sprayed from the inside; 3 in. of polyurethane on roof; natural cooling by ventilation.

Solar Features:

Grumman solar collectors

Comments:

The house is oriented 20 deg west of south to take advantage of prevailing southwesterly summer winds. Also, the cool, hazy mornings and warmer, clearer afternoons in this part of the country make a slightly westerly-oriented collector more effective.

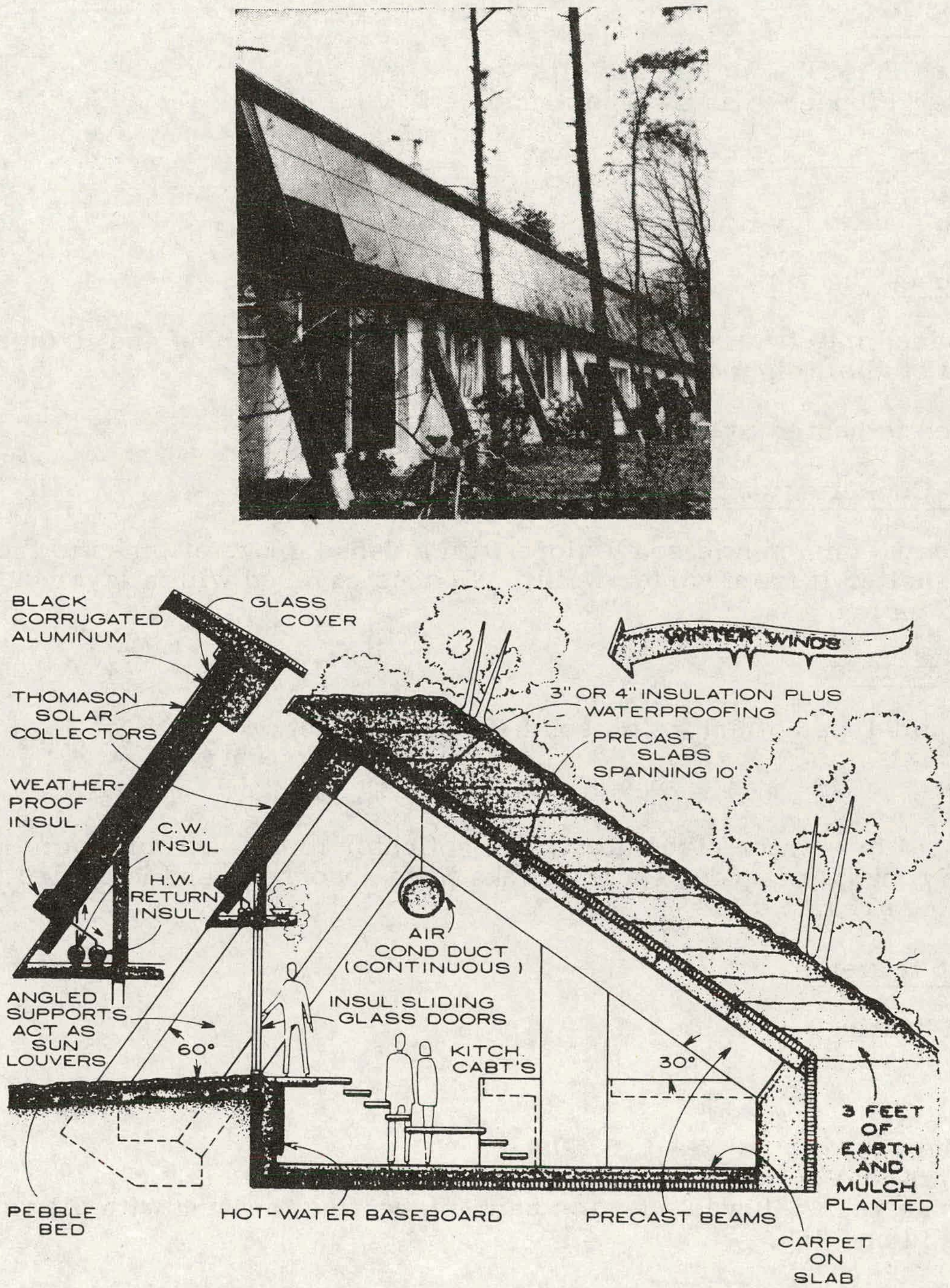


Figure 1-26. Thomason Solar Collector Installation. Photo courtesy Popular Science Magazine

Designed By:

ARCHITECT - Malcolm Wells
Solar Pioneer - Harry Thomason

Owners:

Bob and Nancy Homan

The House:

Divided into two areas -- day activity (kitchen, dining and living rooms, and studio); night activity (bedrooms).

Each is heated to different temperatures.

Energy-Conservation Features:

Located on a gentle south slope with a dense grove of pines to the north to shelter it from winter winds. Roof is covered with a layer of earth and mulch.

Solar Features:

Liquid-type collectors on south-facing facade.

Storage:

Rock bin - water circulates from collector to bin, air is blown through the rocks, picks up heat the rocks have absorbed, and is ducted to the living area.

Back-up System:

Oil heating

Cost:

Solar -- $ 5,500
Total cost of home -- $60,000
In one year $60 was spent on back-up heating; heating with oil alone would be $750.

Comments:

85 percent of heating is from the solar system. You may obtain a book with detailed drawings any architect can work from, for $24.95, from:

Edmund Scientific
700 Edscorp Bldg.
Barrington, New Jersey 08007

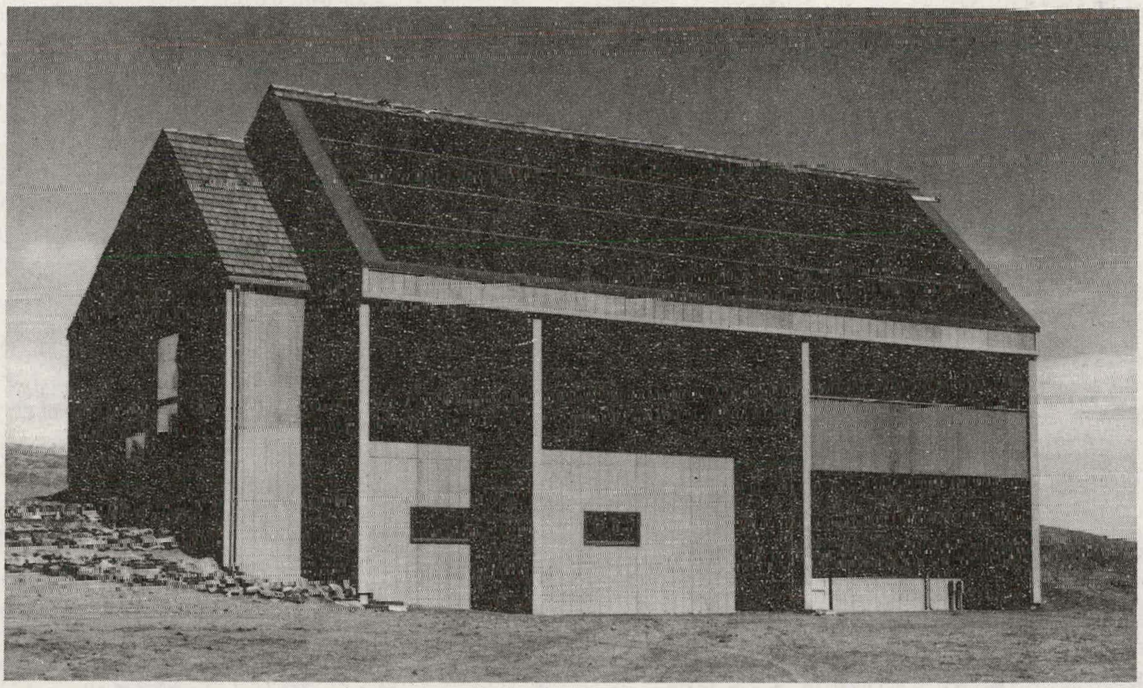


Figure 1-27. CSU Solar House with Air-Heating Collectors on South-Facing Roof

Designed By:

ARCHITECT - Richard Crowther, Crowther, Kruse and McWilliams
Manufacturer, Engineers - Solaron Corporation

Owners:

Colorado State University

The House:

Three bedrooms -- 3000 square feet

Energy-Conservation Features:

Six foot overhang on south side, vertical shading walls; double glazed windows, air lock entry between garage and living space.

Solar Features:

Air heating solar collectors on south facing roof

Storage:

Pebble-bed, 18 tons

Back-up System:

Natural gas furnace

Cost:

System installed cost -- $14,000
Total cost -- $51,500

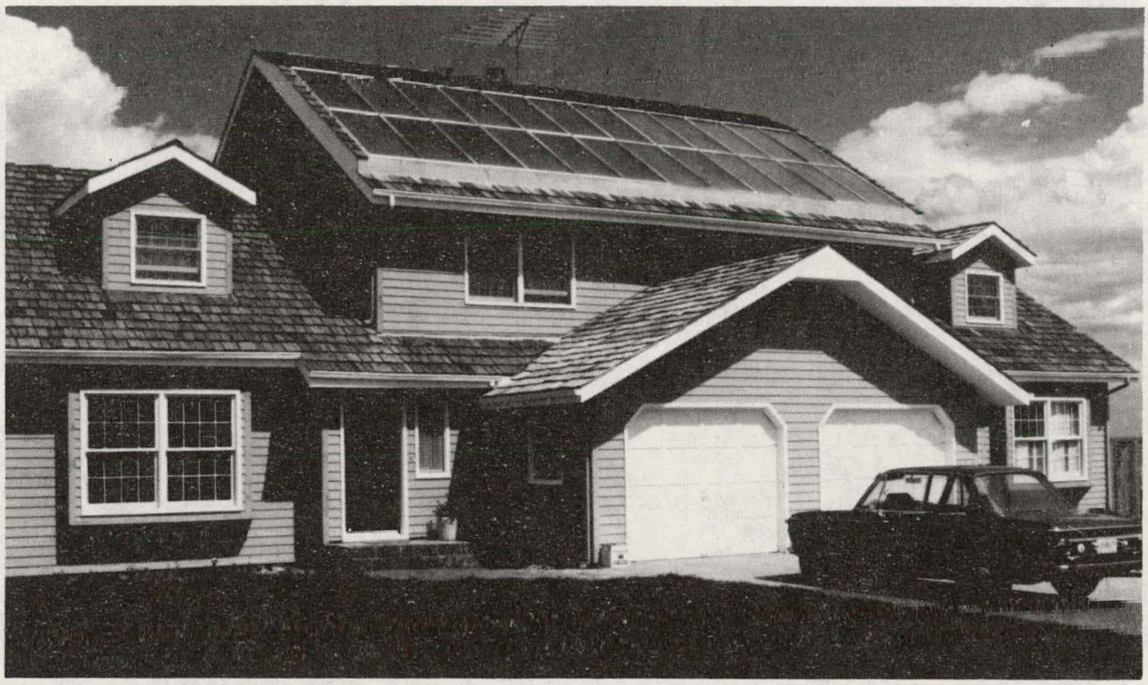


Figure 1-28. Splittgerber Solar House with Solaron Air-Type Collectors Mounted on a South-Facing, 48-degree Sloping Roof

Designed By:

ARCHITECT - Ron Splittgerber, with Solar Engineering assistance from Solaron Corporation

Owners:

Mr. Ron Splittgerber

The House:

A two-level duplex with a total of 3352 square feet of floor space

Energy Conserving Features:

Total of 14 inches of fiberglass insulation in ceiling

Solar Features:

Total of 429 square feet of Solaron air-type collectors mounted on a south-facing, 48 degree sloping roof. This home includes two separate systems with 2 air handlers, 2 controllers and 2 storage boxes.

Storage:

Two separate rock storage boxes with 107 cubic feet of washed river rock in each storage box.

Back-Up System:

2 Gas Furnaces

Comments:

This application demonstrates the feasibility of applying solar heating systems to multi-family units without making the application appear visibly disjointed.

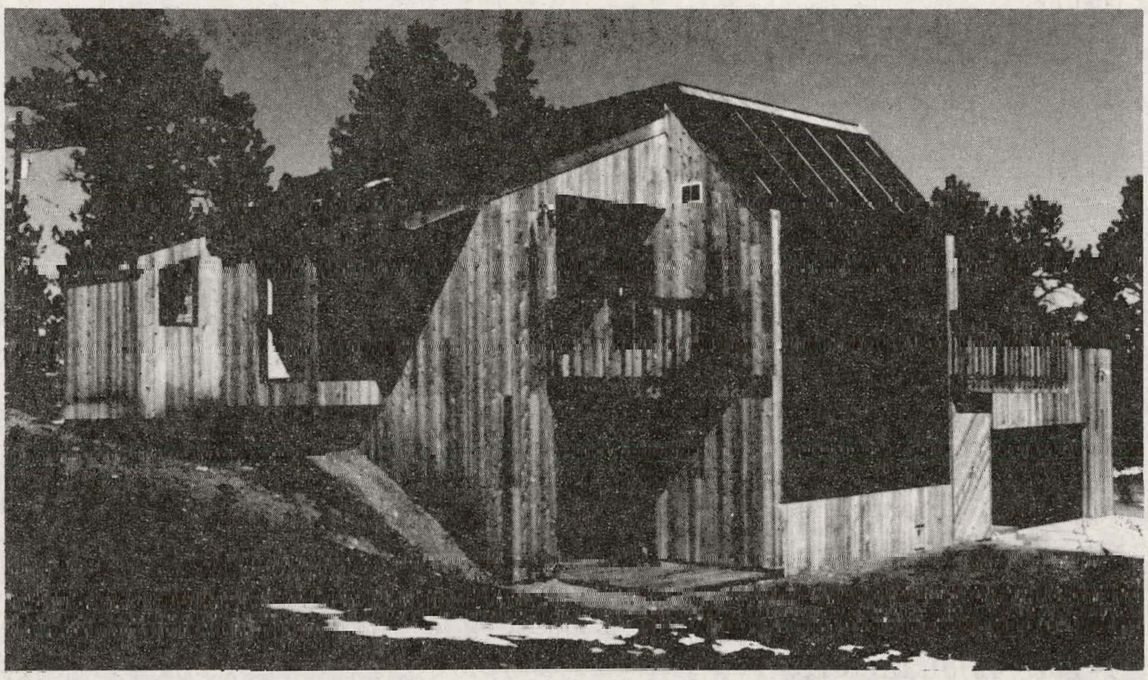


Figure 1-29. Crowther Solar House with Collector in Roof and South-Facing Wall

Designed By:

ARCHITECT - Richard Crowther, Crowther Solar Group, Denver, Co. with Solar Engineering assistance from Solaron Corporation

Owners:

Mr. Murray Watts

The House:

Home includes 1500 square feet of floor space with solar collector incorporated in the roof as well as the south-facing wall.

Energy Conserving Features:

Exterior walls: 6 inches thick fiberglass insulation. Ceiling: 12 inches of fiberglass insulation. Thermopane windows. Minimum windows on North and maximum windows on south.

Solar Features:

Entrance air-lock. Earth mound on north side of home decreases heat loss. Home includes 266 square feet of Solaron air-type collector, systems-engineered with rock box storage and domestic hot water heating. Collectors are incorporated in the roof as well as the south wall.

Storage:

Rock storage box containing 133 cubic feet of washed river rock, 3/4" - 1-1/2" in diameter.

Back-Up System:

Electric heat baseboard

Comments:

This application shows that solar collectors can be used in lieu of wall sections without loss of architectural aesthetics or without significant performance loss.

COLLECTORS/SYSTEMS

Obviously, the most important aspect of a solar building or any kind of solar heating system is the manner in which the sun's rays are collected. Solar-thermal collectors can be classified into three categories:

1) Low-temperature flat-plate collectors with no concentration, 150° to 300°F

2) Medium-temperature concentrating collectors typified by parabolic cylinders, 300° to 600°F

3) High-concentration, high-temperature collectors such as parabolic concentrators or concentrators composed of many flat mirrors focused at the same point, 600° to 4000°F

Flat-Plate Collectors

First of all, let us consider the low-temperature flat-plate collectors (Figure 1-30), which are primarily used for home solar systems as in the previous examples.

The optimum material used for these types of collectors is that which will absorb the maximum amount of solar radiation and emit a minimum amount (the "greenhouse" effect). Thus, the collector contains an absorber usually made of a conductive material covered with black coating.

This black material is covered with one or two pieces of glass or plastic, and the sides and bottom are insulated. Glass has the useful property of being nearly transparent (about 90 percent) to the sun's shortwave radiation but is

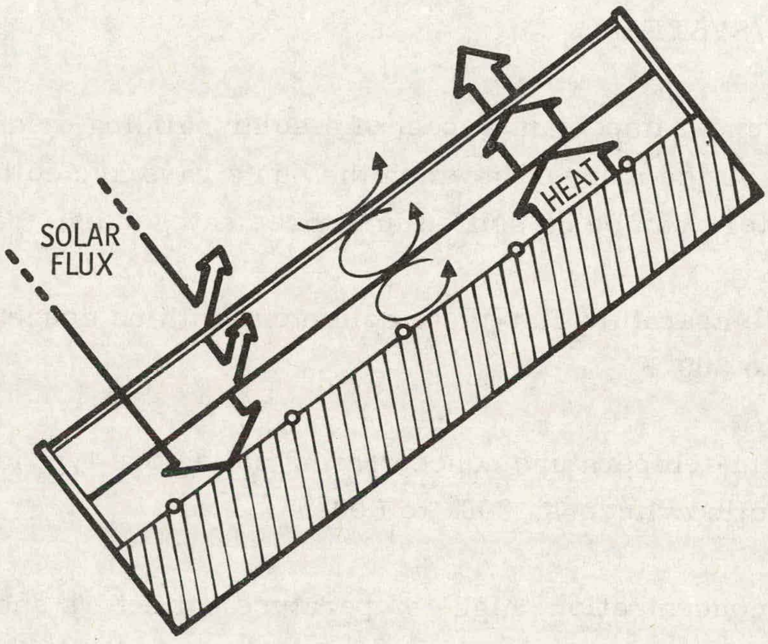


Figure 1-30. Solar Collector Greenhouse Effect

quite opaque to the longwave radiation emitted by the sun-warmed surfaces. Thus, with two glass covers separated by a small air space, about 80 percent of the incoming shortwave radiation will pass through to strike the black plate, where approximately 95 percent of it will be absorbed and 5 percent reflected back through the covers.

In this manner, the flat-plate collector traps the heat energy from the sun. You have probably encountered this effect in ordinary life. Even though it is cold outside, you can get into a car on a sunny day in winter time and the inside temperature will actually be hot. The shortwave radiation from the sun has gone through the windows, struck the seat covers, and been reradiated as longwave radiation that didn't escape from the car as readily.

After being trapped, this heat must be removed from the collector. This is done by means of a transfer medium. If water or some other liquid is used, it is called a hydronic system. If air is utilized, it is called a hot air system.

Systems

It is reasonable to ask, how is this heated water from flat-plate collectors integrated into a system to heat and cool a home?

Figure 1-31 shows the general idea of a solar heating and cooling hydronic system when the sun is shining. Here, sun heats the collector panel. The water circulates through the collector from the bottom to the top as it is being heated. This heated water is then pumped through copper heating coils in a forced-air chamber. Air is passed over the coils, heated and forced into the conditioned space and the house is heated.

Figure 1-32 shows one way of storing heat. In this case, a water storage tank is used. This takes place when the sun is shining and enough heat is emitted into the home at that specific time. The hot water from the collectors is diverted to a storage tank where it is kept for future use.

This stored hot water is then put to use when the sun is not shining. In Figure 1-33 the collector is bypassed and the stored hot water is pumped through the heating coils. This will heat the home efficiently until the stored hot water is used up.

When the stored water is used up, the auxiliary heater is used. In Figure 1-34 the collector system is shut off and a conventional burner is used to heat the water. This hot water is fed to auxiliary heating coils in a forced-air chamber.

During the summer months, when air conditioning is needed, the solar will perform equally as well (see Figure 1-35). Experiments have shown that hot water from solar collectors, or from the storage tank, can power an air conditioner similar to conventional gas burning or electric compressor-driver types.

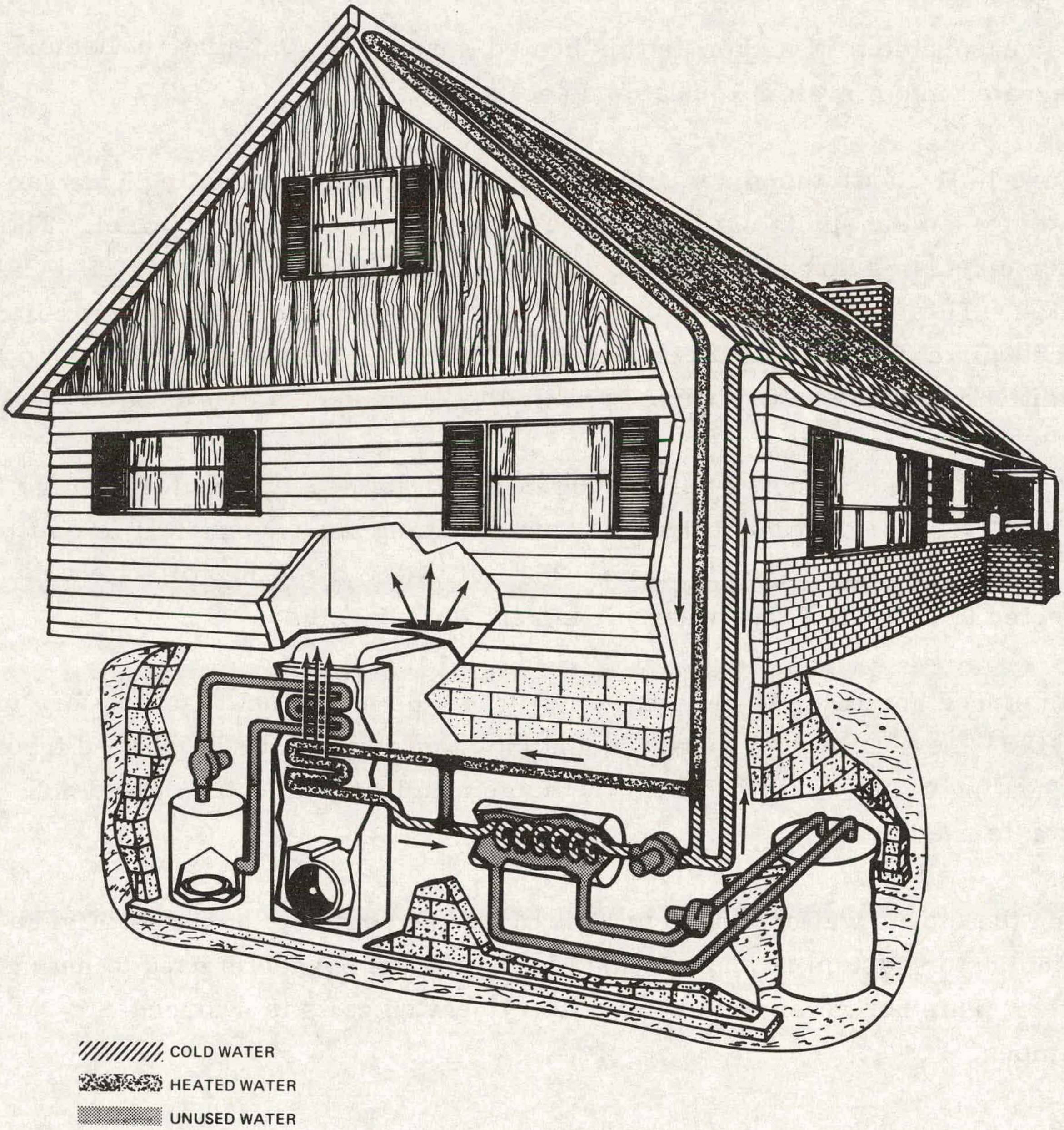


Figure 1-31. Sun Shining -- Heating with Solar Energy

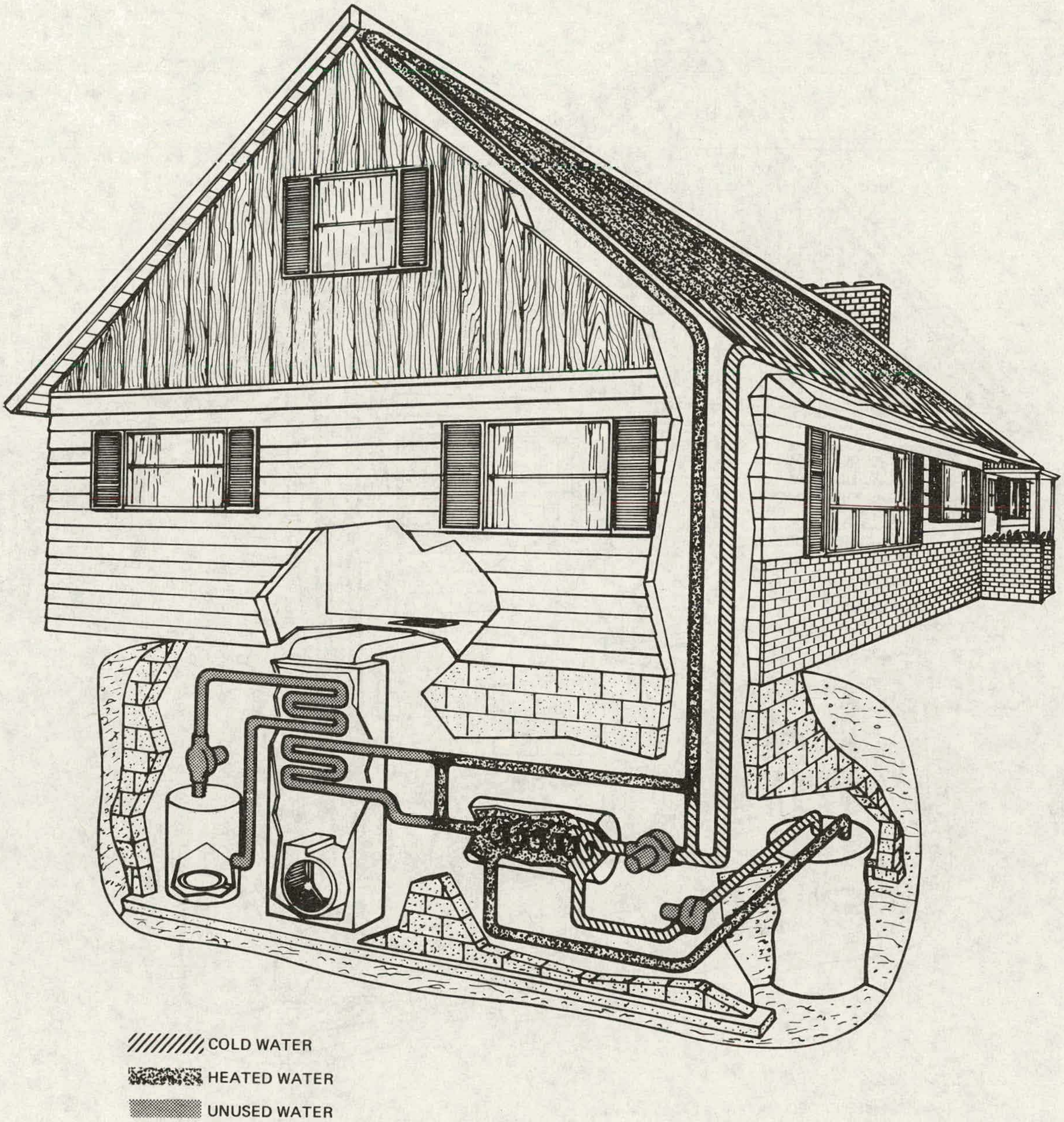


Figure 1-32. Sun Shining -- Storing Solar Energy

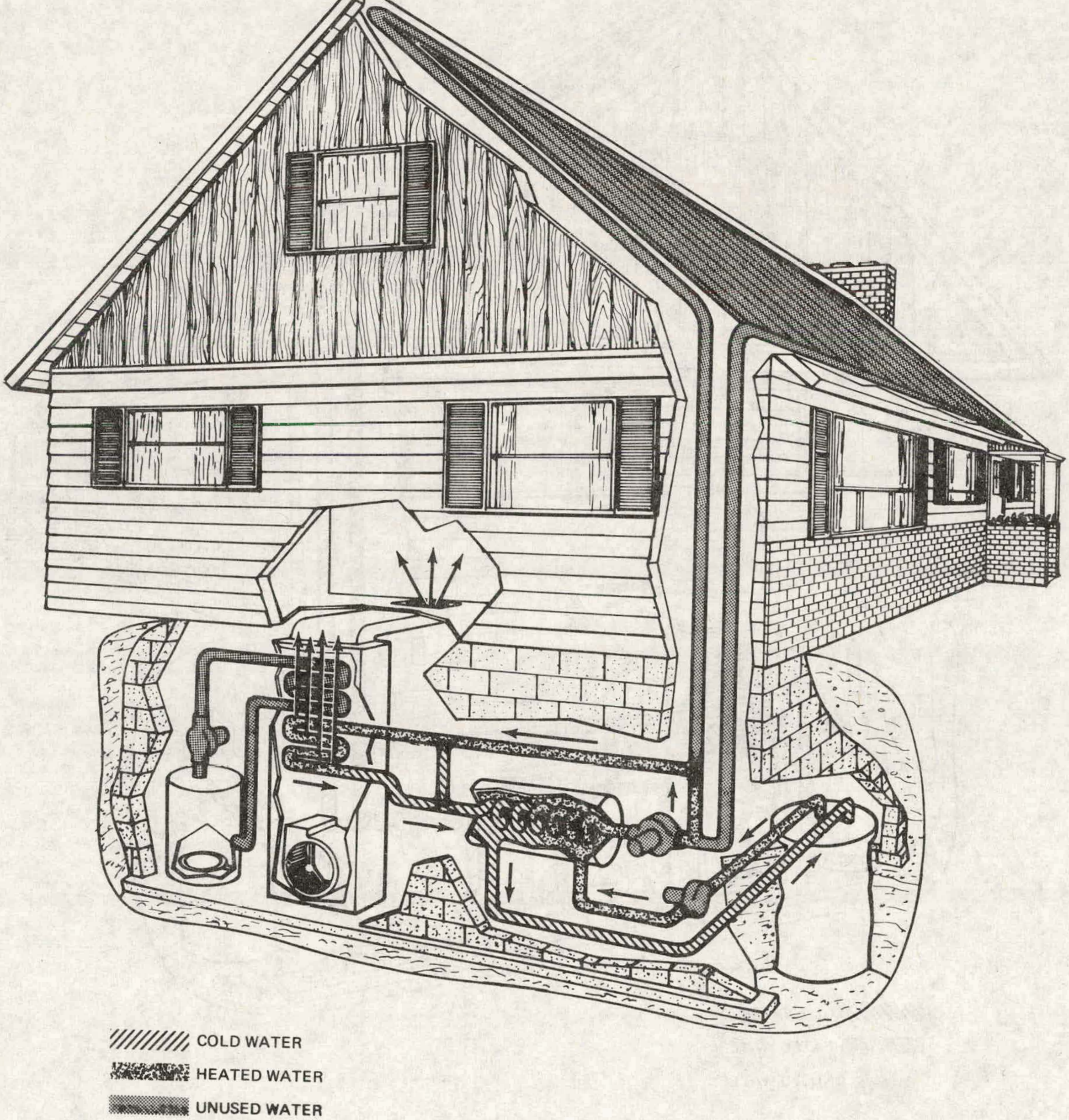


Figure 1-33. No Sunshine -- Heating with Stored Solar Energy

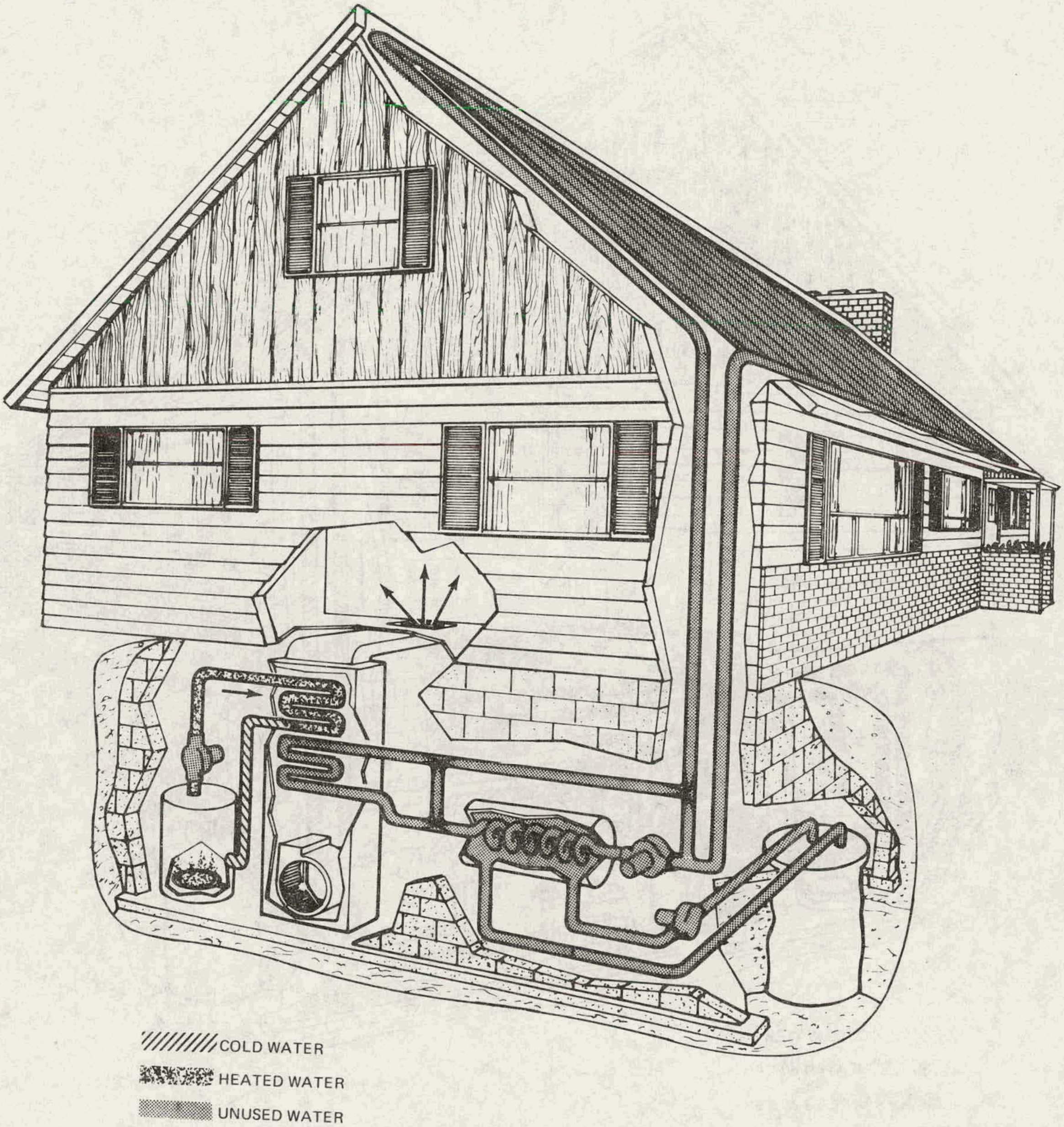


Figure 1-34. No Sunshine -- Auxiliary Heating

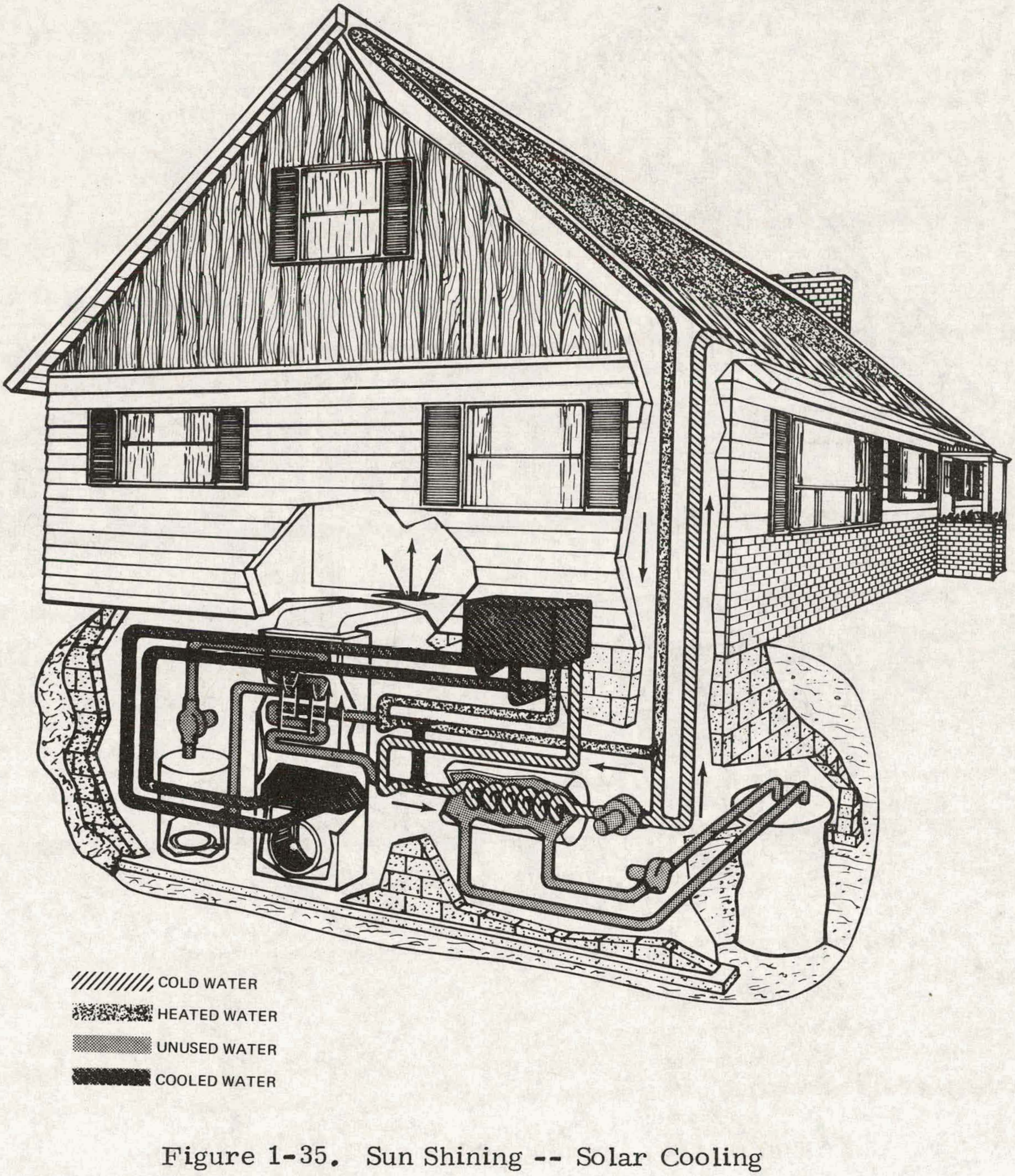


Figure 1-35. Sun Shining -- Solar Cooling

Concentrators

Another way to collect the sun's rays is by using concentrators to concentrate the radiation from the sun on a small area. By doing this, it is possible to produce temperatures that exceed 300°F for applications such as electric power generation or industrial use where high-temperature heat is needed.

The parabolic cylinder reflector concentrates sunlight onto a collecting pipe within a quartz or pyrex envelope. The pipe is coated with the selective coating and the transparent surrounding tube can be evacuated to reduce convective heat losses. This type of concentrator is known as a parabolic trough. The backing, that is the parabolic cylinder, is a mirror. Sunlight coming in perpendicularly is reflected onto the tube located at the parabola's focal point. A fluid is passed through the tube and heated.

For very high temperatures, a paraboloid, similar to the ones used to collect radio signals from outer space, is used. The orientation is the same as the parabolic cylinder, except that the sun's rays are concentrated at one spot at the focal point of the paraboloid. Both of these parabolic devices must be oriented with their axes toward the sun. One method of maintaining this orientation is to rotate the parabolic concentrator tracking the sun's motion across the sky, moving it about one or two axes to account for seasonal as well as daily motion.

An alternative to steering the concentrator is to use auxiliary mirrors. In this approach, a large flat-plane mirror is used to track the sun and reflect its rays into the parabolic concentrator. The surface of the plane mirror must be of greater area than the paraboloid because of the angles involved, but its structure is less complex than the paraboloid.

Even for power plants (currently in the conceptual stage), these parabolic concentrators are expensive to build, so many designs of solar power plants make use of many mirrors surrounding a tower with a boiler located at the top. The mirrors track the sun and direct the rays to the top of the tower. Here the boiler is operated and mechanical and electrical energy is produced.

Another way of concentrating the sun's rays is through a lens so that the light rays, upon passing through the curved glass, are directed at a point.

In any of these ways of collecting the sun's energy the actual temperature obtained will depend on the optical performance of the reflector, the accuracy of the tracking device, and the absorption efficiency of the receiver.

OTHER FORMS OF ENERGY

There are many other ways to utilize the sun's energy besides obtaining heat directly from its rays.

The French Physicist Jacques D'Arsonval suggested in 1881 that a heat engine operating between the warm upper layer and the cold deep water of tropical oceans could produce large amounts of power. Although the engine must be inherently inefficient, the amount of heat available is enormous, and since this heat comes from the sun, ocean thermal power is appropriately classified as a form of solar power.

In 1929, Georges Claude, a friend of D'Arsonval, demonstrated a 22-kilowatt ocean thermal power plant in Mantanza Bay, Cuba, but due to its low efficiency (less than one percent) the plant was not economically competitive with other power plants at that time. Claude used surface sea water admitted to a low-pressure evaporator to provide low-pressure steam to drive the turbine. This low-pressure steam was then recondensed by direct contact with cold seawater in a spray condenser. The plant itself was located on land and 2km-long tubes brought cold water from the depths, with resulting heating of the water as it flowed through the tubes. Despite the economic failure of the project, Claude's plant was the first to demonstrate power generation from ocean temperature gradients.

Two large experimental power plants, each using Claude's cycle, were built by the French off the Ivory Coast in 1956 to utilize a thermal difference of 36°F. An 8-foot diameter pipeline was built extending to a depth of 3 miles about 3 miles from shore, but difficulties in maintaining this pipeline prevented the plant from operating at full capacity. About 25 percent of the power generated was required for the pumps and other plant accessories. The plants were finally abandoned.

A floating power plant has been proposed that could use propane as a working fluid in an indirect vapor cycle. Sea water from the warm surface layer is passed through the boiler to vaporize propane at 150 psi. The propane exhausted from the turbine is condensed at about 110 psi by cold sea water.

Wind

Certainly most promising - and much better known - is the process of getting energy or power from the wind. For instance, the mechanical power derived from wind turbines, which might vary in size from several feet to several hundreds of feet in diameter, can be used to drive electrical generators, pump water or air, or perform other useful work. The largest anticipated wind powered units of current design are small by utility company standards. They are limited to an electrical generating capacity of a few megawatts and will require extensive electrical transmission facilities and proper phasing of the current generated to inter-tie with utility grids. The economic viabilities of all of these systems are strongly dependent not only on such factors as system reliabilities, lifetimes, costs and prices of energy derived from competing energy sources, but also on the time distribution of wind velocities at the specific geographical locations chosen for particular applications, since the wind system power output varies in proportion to the cube of the wind velocity.

Biomass

Biomass, in the form of organic waste or terrestrial and marine energy crops, is a direct result of solar energy and should be so treated here. It offers a vast renewable supply of material that may be converted into many types of liquid, solid and gaseous fuel. Experiments are being conducted that will allow the conversion of biomass to those fuels, especially in the area of expediting rapid commercialization and use of these technologies. Problems include possible conflicts in land use, some environmental difficulties, water resources for processing, and the aggregation of large economically attractive farming units for the production of low income biomass. Ocean-based biomass production raises several additional issues that will have to be addressed.

Geothermal

Geothermal energy consists of heat in rock and earth fluids at temperatures high enough to allow for extraction of heat for comfort or power. Probably the oldest use of geothermal energy was for space heating, a use that undoubtedly predates recorded history. Today, potential important uses of geothermal energy include generation of electrical power, chemical process steam, process heat for desalination of salt water, and chemical content recovery. Because the temperature of the earth at various depths is at least roughly known, it is possible to calculate the enormous amount of energy that could be available, assuming recovery is economically and environmentally feasible. Iceland and New Zealand are probably the best known areas where geothermal power is being used extensively. In the United States most of the potential for this power source lies in the west, particularly in California. While geothermal energy may never be a big factor in our energy supply, it can and will be of significant use in those areas where terrain and availability make it attractive and practical.

Oil Shale

Technically, oil shale is not an exotic potential future energy source. However, it is worthy of a special note in that it is a different kind of oil that must be treated as a somewhat different energy source from petroleum. Oil shale, found mostly in the western United States, is estimated by various experts as having five to nine times as much potential oil production as the entire middle east. However, economic and technological difficulties have hampered progress of oil shale production. Already there is a great deal of information available on oil shale, its production, environmental and economic problems, and its long range promise and the state of the art is rapidly developing. Oil shale could possibly be one of the major sources of this country's energy some time after the turn of the century. One thing is obvious; it will be at least as expensive as the highest priced imported oil.

SECTION II
SOLAR RADIATION AND WEATHER

THE NATURE OF SOLAR RADIATION

The energy from the sun is derived from thermonuclear reactions in its core and is radiated into space. The intensity of solar radiation varies inversely with distance from the sun, and because the distance to the earth from the sun varies during the course of the year, the amount of solar radiation reaching the upper limits of the earth's atmosphere varies. The average solar radiation at the upper limits of the earth's atmosphere is called the solar constant. Measurements have indicated the solar constant to be 428 Btu per hour per square foot (1353 watts per square meter, 4871 kilojoules per square meter per hour, 1.940 calories per square centimeter per minute or 1.940 langleys per minute).

While a solar constant is defined, what is finally of interest is the amount of solar radiation that reaches the surface of the earth. The radiation intensity will vary considerably with latitude, season of the year, and local weather conditions.

RADIATION ON THE EARTH'S SURFACE

The solar energy on the surface of earth varies over a wide range because the earth's axis is tilted with respect to the plane of earth's orbit around the sun, and because of local weather conditions. Some of the solar energy reaching the outer edges of the earth's atmosphere is reflected back into outer space at the top of the atmosphere. Still more is reflected from the tops of clouds. A portion of the radiation is absorbed by particles in the atmosphere. The ozone layer absorbs much of the ultraviolet radiation, and carbon dioxide, oxygen, and water vapor also absorb radiation. Some of the radiation is scattered by dust and clouds. The various processes that reduce the solar energy reaching the earth's surface are illustrated in Figure 2-1.

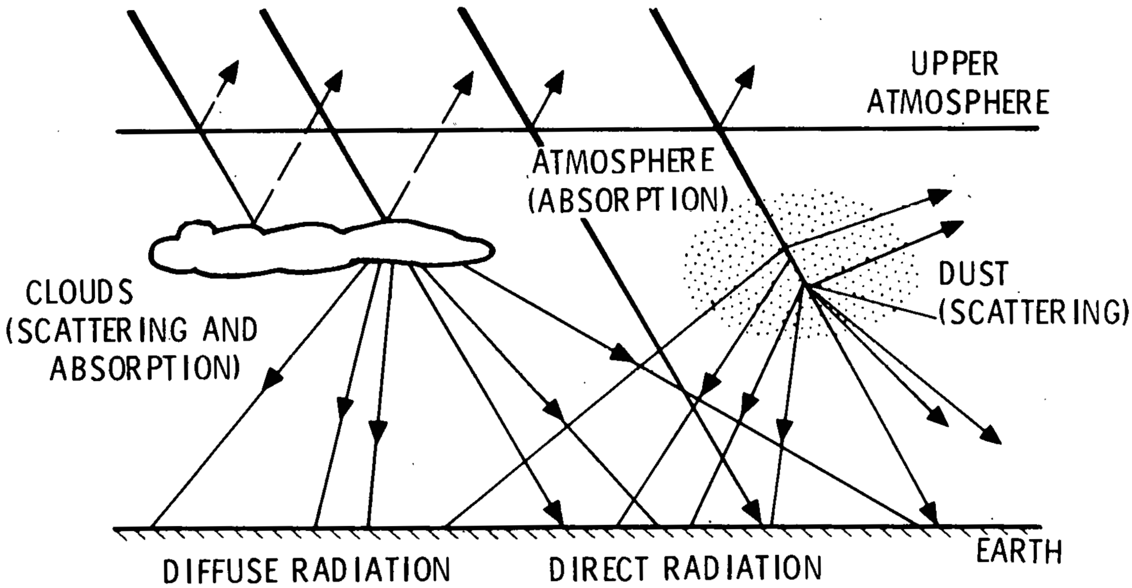


Figure 2-1. Atmospheric Effects on Solar Radiation Reaching the Earth's Surface

Radiation emanating within a cone that includes the sun's disc is called "direct" or "beam" radiation. Radiation that is scattered by reflection from clouds, particles in the air and the ground is called "diffuse" radiation. On a clear day most of the energy reaches earth as direct radiation, but on a cloudy overcast day, a large portion or all may be diffuse.

Long-Term Variations

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 from year-to-year.

Because of these variations, solar collector sizes to serve a particular house system cannot be determined by simply choosing solar radiation data for a particular hour, day, month or even one year. The sizing of collectors and design of the solar system must be based on long-term averages of solar radiation data and weather conditions, particularly of ambient air temperature.

The long-term average daily solar radiation on a horizontal surface for each month of the year at 122 different cities in the United States is listed in Table 2-1 at the end of this section. Also listed in the table are fractions of the maximum solar radiation possible at the site if there were no clouds to reduce the sunshine. The average daily air temperatures for each month and the average heating degree days are also listed in the table, as well as other values to be explained subsequently.

While designs of solar systems are based on long-term averages, it is useful to understand the nature of monthly, daily and hourly variations of solar radiation. The air temperatures also vary, the most notable being the day/night (diurnal) variations.

Monthly Variations

Solar energy on a horizontal surface at any location on earth, when averaged over a month, varies from month-to-month. This is due both to seasonal changes in weather, which affect the cloud cover, and the changing angular relationship between the sun and the horizontal surface. In winter the sun is lower in the sky than in summer, and the resultant angle between the sun and a horizontal surface reduces the portion of radiation intercepted by the surface, as shown in Figure 2-2.

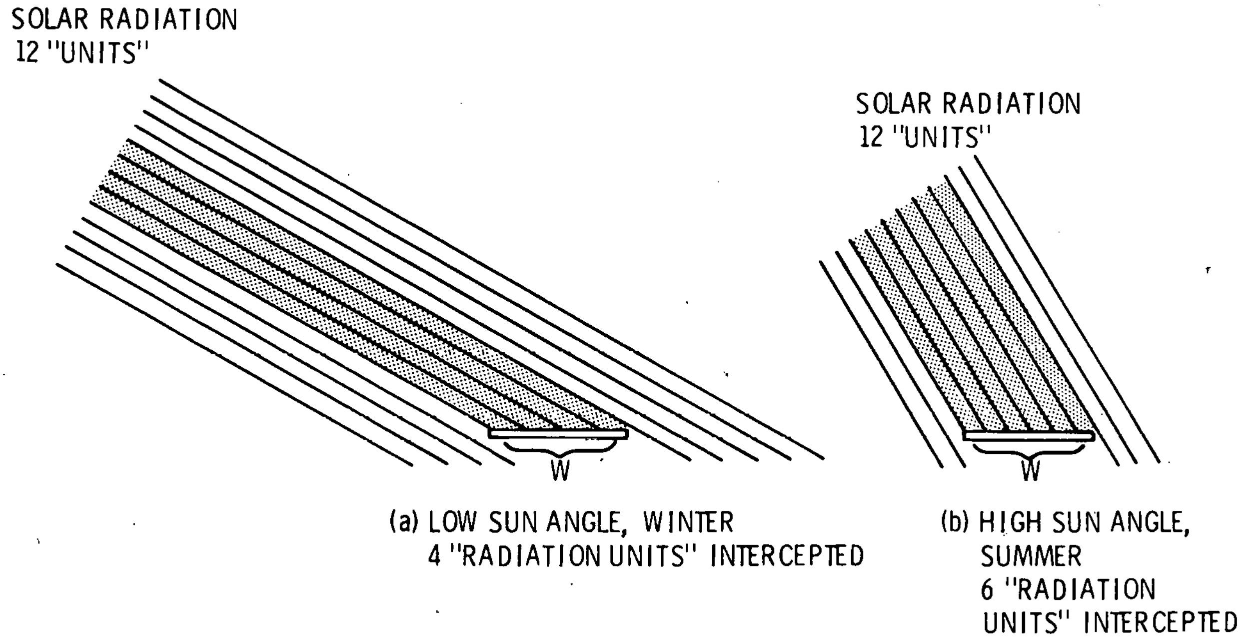


Figure 2-2. Energy Intercepted by Horizontal Collector

The energy intercepted by a collector that is w wide on the earth's surface in winter is shown in Figure 2-2(a), and in summer in Figure 2-2(b). The amount of energy intercepted by the same collector is clearly greater in summer than in winter.

A typical monthly variation in solar radiation incident on a horizontal surface is shown in Figure 2-3.

Daily Variations

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 house in a given day. There is little that a home owner can do to change it, however, because the size of a solar system on a house is fixed.

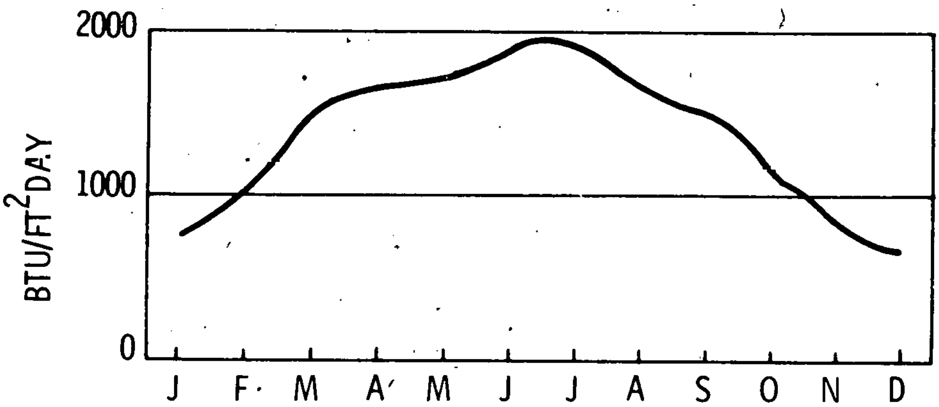


Figure 2-3. Typical Monthly Variation of Average Daily Radiation on a Horizontal Surface

Hourly Variations

Hourly variations in available solar energy at a given location are due to the earth's rotation 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. At midday, the distance of the earth's atmosphere through which the solar radiation must pass to reach the earth's surface is least, therefore the peak radiation intensity occurs at noon.

Characteristic variations of solar intensity on a horizontal surface during clear days in June, April, and January are shown in Figure 2-4. The smooth curves indicate that these data were obtained on clear days. The presence of clouds would result in breaks in the curves. Note that the intensity is higher and period of measurable radiation is longer during a summer day as compared to a winter day. The curves for clear days should be approximately symmetrical, with the peak intensity at solar noon. Clock time and solar time differ by varying intervals, depending on location in the time zone, season of the year, and, of course, the use of "daylight savings time."

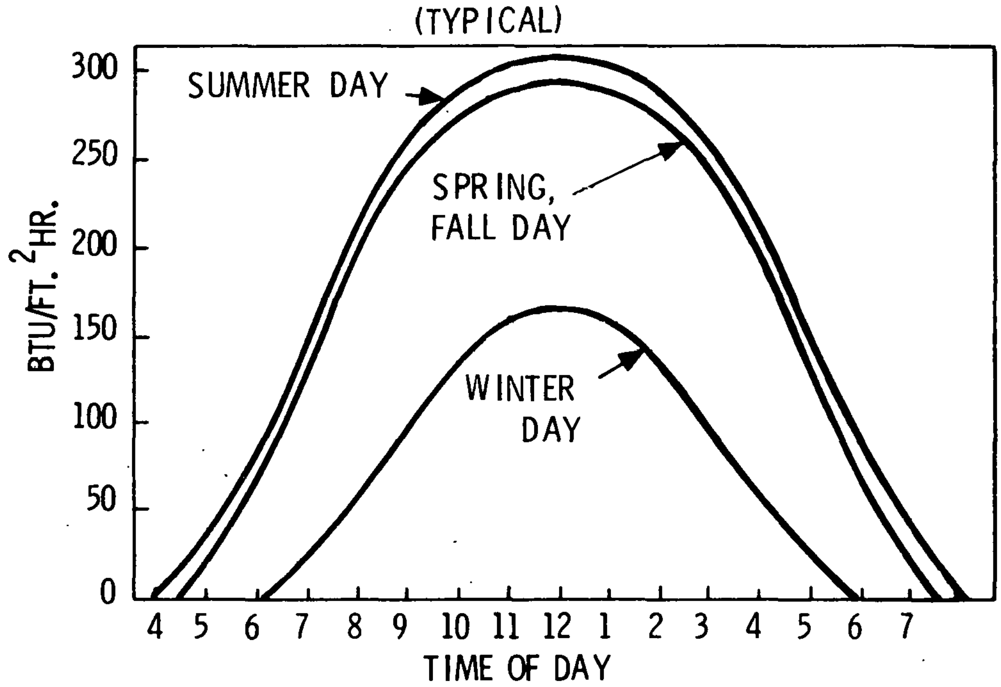


Figure 2-4. Hourly Variations of Clear Day Radiation on a Horizontal Surface for Different Seasons of the Year

Influence of Collector Tilt on Solar Radiation Collected

It is advantageous to tilt a solar collector from horizontal because more solar radiation can be intercepted by a given collector area. The increase in the solar radiation intercepted by a collector is shown in Figure 2-5. For the illustration shown, the amount of solar radiation intercepted by a collector is greatest at 45 degrees as shown in Figure 2-5(b), because at that tilt the collector is perpendicular to the direct beam. As the season changes, the most effective tilt angle changes.

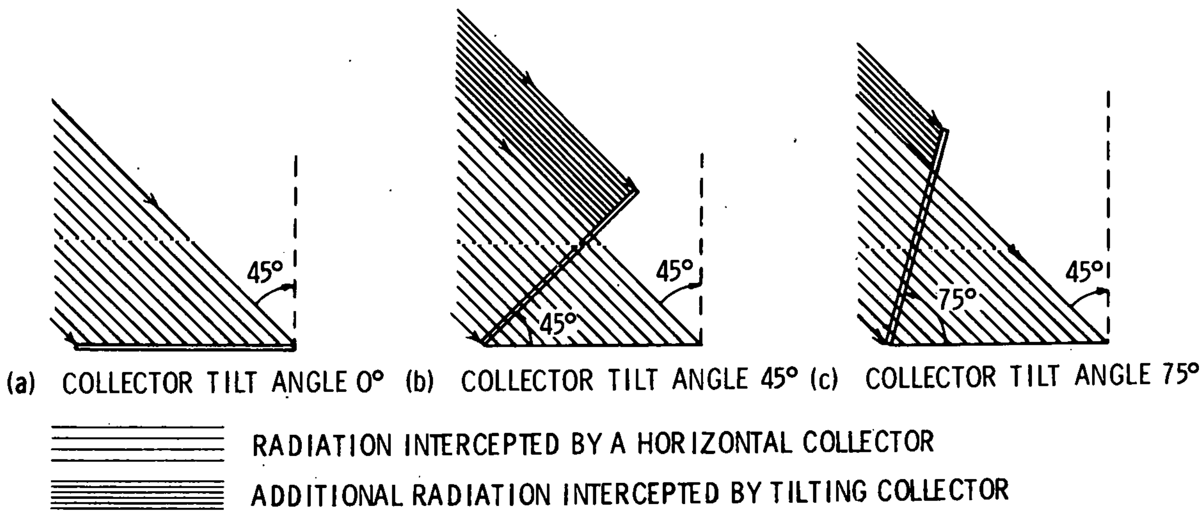


Figure 2-5. Effect of Tilting the Collector on Energy Intercepted

A maximum amount of solar energy could be intercepted if the collector could be made to be perpendicular to the solar rays all day long. This is called tracking the sun. Collectors could be made to track the sun, but many moving parts and flexible connections would be required as well as some means to sense the position of the sun at all times. Tracking collectors are not practical for installations on houses, and it is far more economical to add collector area at a fixed tilt to make up the reduced collection than it is to use a moving collector system with the added costs for the tracker, movable parts and maintenance.

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, and for a heating and cooling system a compromise must be made for winter and summer seasons. Figure 2-6 shows that tilting the collector causes a moderate decrease in solar energy received during the summer months and a substantial increase in the winter. A south-facing vertical collector is seen to intercept more winter radiation than a horizontal surface, but moderately less than received by a tilted surface.

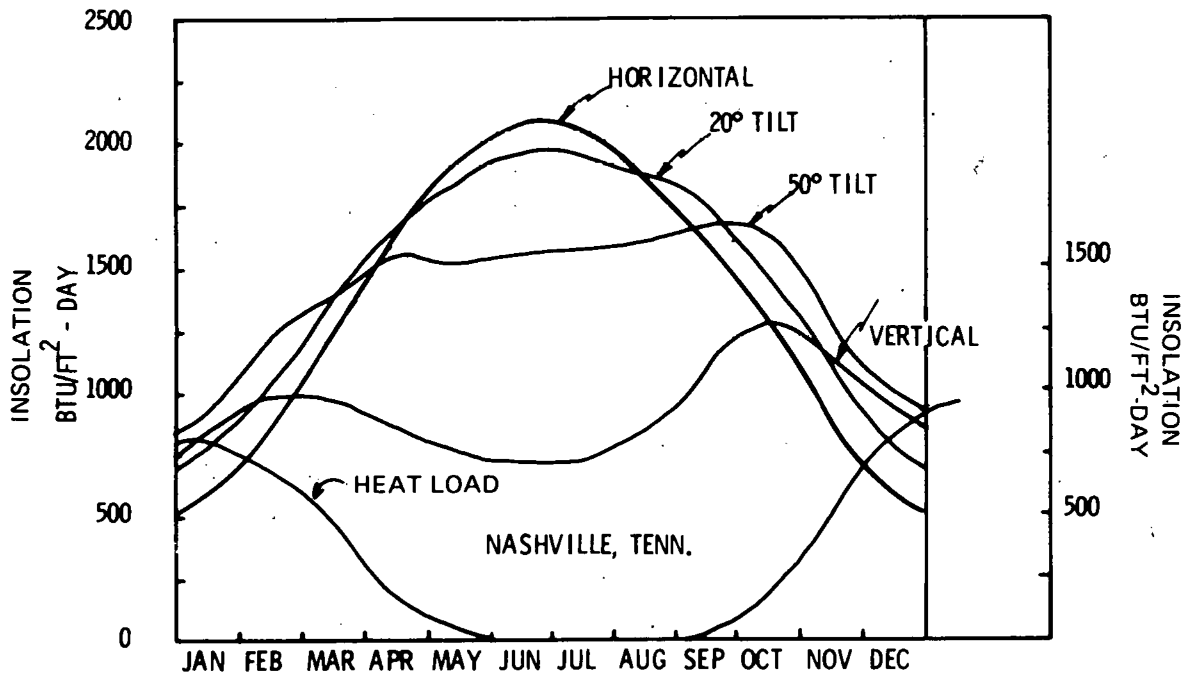


Figure 2-6. Effect of Collector Tilting Average Daily Intercepted Radiation

The Influence of Collector Orientation and Tilt on Solar Radiation Collected

The maximum intensity of direct radiation occurs at noon and because the distribution of radiation is symmetrical about noon, 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 serious reduction of the total solar energy collected during the day.

The solar radiation incident on a unit area of collector for various collector orientations (azimuths) and collector tilt angles (slopes) for 122 cities in the United States are listed in Table 2-1 at the end of this section. To illustrate the effect of collector orientation refer to the second page of Table 2-1 (p. 2-13) for Albuquerque, New Mexico. The average daily radiation in January on a collector that is tilted 40 degrees from horizontal with the plane of the collector oriented due south is 2020 Btu per square foot. If the collector at the same tilt is turned to face 15 degrees east or west from due south, the average daily radiation is 1980 Btu per square foot, or a reduction of only 2 percent incident solar energy on the collector. If the collector is faced 45 degrees east or west from due south, the average daily radiation is 1720 Btu per square foot, which is 15 percent reduction of incident solar radiation. At this orientation, it may be desirable to make up the reduction by additional collector area.

Accuracy of Solar Radiation Data

The solar radiation on tilted collectors was calculated from measured data on a horizontal surface. The method developed by Liu and Jordan (Ref. 1) and extended by Klein (Ref. 2) was used to convert from horizontal to tilted surfaces. The accuracy of the data is entirely dependent upon the accuracy of the measurements, and is probably about ±10 percent. It should be explained that solar radiation data were not a standard measurement required of weather stations, and the stations that measured radiation data are widely spaced across the United States. Furthermore, the instruments used to measure solar radiation were recalibrated only periodically, hence the accuracy of the data may vary from station to station.

ATMOSPHERIC TEMPERATURE

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 procured by the U. S. Weather Service in several thousand United States locations. As shown in Section IV, the practical maximum heating demand in a building is determined by use of a long-term minimum temperature measurement, usually chosen by excluding 1.0 to 2.5 percent of the coldest hourly values. This so-called "design temperature" for heating is that temperature which is used in a computation of the required furnace capacity. Table 2-22 contains a list of such temperatures for principal locations in the United States. A more complete list is published in the ASHRAE Handbook of Fundamentals (Ref. 3).

As "design temperatures," from Table 2-22, are used in sizing the furnace for maximum heat demand (Section IV), the average atmospheric temperatures or degree day values are representative of seasonal requirements and are used in sizing of solar heating systems.

The "degree days of heating" in a particular location is a quantity which 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 degrees. The degree days in a particular month, for example, are computed by subtracting from 65 degrees the daily mean temperature (one-half the sum of the maximum and minimum hourly temperature readings during a 24-hour period), and totaling these 30 or 31 numbers.

If the mean temperature on a January day is 25 degrees, 65 - 25 = 40 degree days of heating are computed. For the month, possibly 900 degree days may result, and for the year, perhaps 5000.

Table 2-1 shows values of monthly average atmospheric temperature and monthly degree day totals for each city in this collection. Table 2-22 gives additional heating degree days for many other locations in the United States. There are some differences in the degree days in Table 2-1 compared to those in Table 2-22. Although these numbers are based on long-term past records at each location, the length and period of record used were different, therefore slightly different results are obtained. Either set of values may be used with confidence.

Table 2-1. Values of Monthly Average Atmospheric Temperatures and Monthly Degree Day Totals for 122 Cities

ALBANY		NY	42.40											
		JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	
HORIZONTAL RAD.		456	673	1263	1340	1623	2220	1970	1642	1148	946	810	515	(BTU/DAY-FT2)
AVE. TEMP.		23.0	24.8	32.0	46.4	57.2	66.2	71.6	69.8	62.6	50.0	39.2	28.4	(F)
DEGREE-DAYS		1311.	1156.	992.	564.	239.	45.	0.	19.	138.	440.	777.	1194.	(F-DAYS)
AVERAGE DAILY RADIATION ON TILTED SURFACES (BTU/DAY-FT2)														
SLOPE	AZIMUTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	
20	0	644	862	1507	1420	1616	2147	1932	1700	1287	1211	1237	804	
30	0	717	929	1577	1415	1567	2052	1859	1677	1314	1303	1406	921	
40	0	773	974	1610	1381	1488	1919	1751	1618	1312	1363	1538	1014	
50	0	811	996	1604	1318	1382	1751	1610	1526	1281	1389	1629	1081	
60	0	828	995	1559	1229	1252	1553	1442	1403	1222	1382	1677	1120	
70	0	825	970	1477	1115	1102	1333	1251	1253	1136	1340	1680	1130	
80	0	802	923	1361	981	937	1099	1046	1082	1027	1266	1637	1109	
90	0	760	856	1216	834	769	868	840	900	900	1164	1553	1061	
20	15	637	855	1498	1418	1617	2151	1934	1700	1283	1201	1221	793	
30	15	707	918	1566	1416	1571	2060	1865	1679	1310	1288	1383	905	
40	15	760	960	1596	1384	1495	1932	1761	1624	1309	1343	1508	994	
50	15	795	980	1588	1325	1393	1770	1626	1536	1279	1366	1594	1058	
60	15	810	976	1543	1239	1267	1578	1463	1418	1222	1355	1637	1093	
70	15	806	950	1462	1130	1122	1365	1278	1275	1139	1312	1636	1101	
80	15	782	902	1347	1001	963	1138	1079	1110	1033	1236	1592	1079	
90	15	740	834	1205	861	799	913	879	935	910	1134	1507	1030	
20	30	617	834	1475	1412	1620	2161	1941	1698	1270	1173	1175	762	
30	30	677	889	1535	1411	1580	2082	1881	1681	1294	1249	1315	860	
40	30	722	923	1560	1384	1514	1968	1789	1634	1293	1295	1422	936	
50	30	749	936	1551	1330	1422	1823	1668	1556	1264	1311	1491	988	
60	30	758	928	1507	1252	1308	1650	1521	1451	1211	1296	1521	1015	
70	30	749	899	1429	1152	1176	1455	1354	1321	1133	1250	1511	1015	
80	30	723	850	1321	1034	1030	1247	1172	1172	1034	1176	1460	989	
90	30	679	783	1189	906	880	1039	988	1013	921	1077	1374	939	
20	45	586	804	1437	1400	1621	2173	1947	1689	1248	1132	1106	715	
30	45	633	847	1485	1398	1587	2108	1897	1675	1267	1192	1218	791	
40	45	666	872	1504	1372	1530	2013	1820	1634	1263	1227	1300	849	
50	45	684	878	1492	1324	1450	1889	1716	1566	1236	1235	1350	885	
60	45	686	866	1449	1253	1349	1739	1588	1472	1186	1216	1365	900	
70	45	672	836	1377	1163	1231	1569	1440	1357	1114	1171	1347	892	
80	45	644	788	1278	1056	1099	1383	1278	1223	1024	1100	1294	863	
90	45	602	725	1158	940	963	1195	1111	1080	921	1010	1212	813	

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	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	
HORIZONTAL RAD.	1134	1436	1885	2319	2533	2721	2540	2342	2084	1646	1244	1034	(BTU/DAY-FT2)
AVE. TEMP.	33.8	39.2	44.6	53.6	62.6	71.6	77.0	73.4	68.0	55.4	42.8	33.8	(F)
DEGREE-DAYS	930.	703.	595.	288.	81.	0.	0.	0.	12.	229.	642.	868.	(F-DAYS)

AVERAGE DAILY RADIATION ON TILTED SURFACES (BTU/DAY-FT2)

SLOPE	AZIMUTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
20	0	1667	1886	2213	2439	2461	2551	2422	2376	2345	2102	1789	1570
30	0	1872	2041	2295	2411	2346	2390	2289	2312	2387	2251	1994	1780
40	0	2027	2144	2319	2325	2181	2182	2109	2194	2369	2341	2146	1942
50	0	2127	2190	2283	2183	1972	1932	1889	2028	2291	2369	2240	2052
60	0	2169	2179	2189	1990	1724	1651	1635	1817	2155	2334	2274	2106
70	0	2153	2110	2039	1752	1448	1349	1358	1570	1965	2237	2245	2102
80	0	2078	1986	1839	1477	1155	1041	1070	1295	1727	2082	2156	2041
90	0	1950	1815	1599	1182	868	754	795	1011	1455	1878	2011	1927
20	15	1647	1668	2201	2439	2466	2559	2428	2378	2338	2083	1768	1550
30	15	1842	2015	2280	2416	2357	2405	2301	2319	2381	2224	1964	1751
40	15	1989	2110	2301	2336	2201	2206	2129	2209	2365	2307	2107	1905
50	15	2082	2150	2264	2204	2001	1967	1918	2051	2291	2329	2194	2007
60	15	2119	2134	2170	2022	1764	1696	1675	1852	2161	2289	2221	2055
70	15	2098	2061	2023	1797	1500	1406	1409	1617	1979	2189	2188	2047
80	15	2021	1935	1827	1539	1220	1109	1133	1357	1753	2032	2096	1983
90	15	1892	1763	1594	1263	946	831	868	1089	1495	1827	1951	1868
20	30	1588	1820	2169	2432	2479	2581	2445	2380	2314	2036	1708	1492
30	30	1757	1947	2239	2415	2387	2448	2335	2331	2354	2159	1877	1665
40	30	1880	2025	2256	2347	2251	2273	2186	2237	2340	2227	1997	1795
50	30	1952	2051	2219	2231	2077	2062	2001	2100	2273	2239	2063	1876
60	30	1972	2026	2131	2070	1869	1823	1786	1925	2155	2194	2074	1907
70	30	1940	1949	1994	1871	1636	1564	1550	1718	1991	2094	2030	1887
80	30	1855	1823	1813	1642	1388	1298	1303	1489	1786	1943	1931	1815
90	30	1725	1658	1602	1399	1145	1046	1065	1253	1556	1750	1786	1698
20	45	1502	1748	2118	2413	2490	2608	2463	2374	2273	1964	1620	1404
30	45	1634	1848	2173	2399	2415	2499	2374	2334	2305	2062	1754	1540
40	45	1726	1906	2183	2341	2302	2354	2249	2255	2291	2112	1844	1637
50	45	1775	1919	2147	2241	2154	2177	2092	2138	2231	2114	1887	1692
60	45	1778	1887	2065	2102	1976	1973	1908	1987	2126	2067	1884	1704
70	45	1737	1812	1942	1928	1774	1750	1704	1807	1980	1973	1833	1672
80	45	1652	1695	1781	1728	1557	1517	1487	1606	1800	1835	1737	1598
90	45	1530	1546	1595	1514	1340	1291	1274	1397	1598	1664	1603	1486

AMES IA 42.02

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	
HORIZONTAL RAD.	640	931	1204	1484	1767	1992	1973	1693	1351	1008	688	526	(BTU/DAY-FT2)
AVE. TEMP.	19.4	24.8	32.0	48.2	59.0	68.0	73.4	71.6	62.6	51.8	35.6	24.8	(F)
DEGREE-DAYS	1370.	1137.	915.	438.	180.	30.	0.	6.	96.	363.	826.	1225.	(F-DAYS)

AVERAGE DAILY RADIATION ON TILTED SURFACES (BTU/DAY-FT2)

SLOPE	AZIMUTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
20	0	972	1256	1424	1578	1759	1925	1933	1753	1532	1298	1005	816
30	0	1105	1375	1486	1575	1704	1841	1859	1728	1571	1398	1129	933
40	0	1208	1459	1513	1537	1617	1723	1749	1666	1573	1463	1224	1026
50	0	1281	1507	1504	1467	1499	1574	1608	1570	1539	1493	1288	1093
60	0	1320	1516	1459	1366	1354	1400	1438	1442	1469	1485	1318	1131
70	0	1324	1487	1381	1237	1187	1207	1246	1286	1366	1440	1314	1139
80	0	1293	1420	1270	1085	1004	1002	1041	1108	1232	1360	1276	1118
90	0	1230	1320	1134	918	818	800	834	918	1076	1250	1207	1068
20	15	960	1244	1416	1577	1760	1929	1936	1753	1527	1286	993	805
30	15	1087	1357	1475	1575	1709	1847	1865	1730	1565	1381	1111	917
40	15	1185	1436	1500	1541	1625	1734	1760	1672	1568	1442	1202	1006
50	15	1253	1479	1490	1475	1511	1590	1623	1581	1536	1467	1261	1069
60	15	1289	1485	1445	1378	1372	1422	1459	1458	1468	1456	1288	1104
70	15	1290	1453	1367	1255	1210	1234	1274	1309	1369	1409	1282	1110
80	15	1258	1384	1257	1109	1034	1035	1074	1138	1240	1328	1242	1087
90	15	1194	1283	1124	950	853	838	874	956	1090	1217	1173	1037
20	30	924	1209	1395	1570	1764	1937	1943	1751	1510	1256	959	774
30	30	1034	1307	1447	1570	1720	1866	1881	1733	1545	1339	1061	872
40	30	1118	1373	1468	1540	1646	1764	1789	1683	1548	1390	1137	947
50	30	1173	1406	1456	1481	1545	1635	1666	1603	1517	1408	1184	999
60	30	1198	1404	1412	1394	1419	1482	1519	1493	1455	1392	1202	1025
70	30	1192	1367	1337	1282	1273	1311	1350	1358	1362	1343	1188	1024
80	30	1155	1296	1235	1149	1112	1127	1168	1204	1243	1262	1144	997
90	30	1089	1197	1110	1004	947	944	984	1039	1105	1156	1073	946
20	45	870	1158	1361	1555	1765	1948	1949	1741	1482	1211	908	726
30	45	957	1236	1403	1555	1728	1888	1898	1727	1510	1277	989	803
40	45	1020	1287	1417	1528	1665	1803	1820	1684	1510	1316	1046	860
50	45	1059	1308	1403	1475	1578	1691	1715	1613	1481	1325	1079	896
60	45	1072	1298	1360	1397	1467	1558	1586	1516	1423	1305	1086	910
70	45	1058	1259	1291	1296	1337	1406	1437	1396	1338	1257	1066	901
80	45	1018	1192	1196	1176	1193	1242	1275	1258	1231	1181	1021	871
90	45	954	1100	1084	1045	1043	1076	1108	1110	1106	1084	953	820

AMHERST	MA	42.15											
	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	
HORIZONTAL RAD.	427	651	1104	1277	1587	1892	1900	1620	1215	920	563	456	(BTU/DAY-FT2)
AVE. TEMP.	24.8	26.6	33.8	46.4	57.2	66.2	69.8	68.0	60.8	51.8	39.2	28.4	(F)
DEGREE-DAYS	1339.	1196.	1063.	660.	326.	109.	26.	59.	217.	387.	831.	1256.	(F-DAYS)

AVERAGE DAILY RADIATION ON TILTED SURFACES (BTU/DAY-FT2)

SLOPE	AZIMUTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
20	0	588	825	1295	1348	1578	1831	1862	1675	1366	1170	789	685
30	0	650	886	1348	1342	1529	1751	1791	1651	1396	1255	876	776
40	0	697	927	1369	1309	1452	1641	1686	1592	1395	1310	941	848
50	0	727	946	1359	1248	1348	1501	1551	1501	1363	1333	984	899
60	0	740	943	1317	1163	1221	1338	1390	1379	1300	1324	1002	927
70	0	735	918	1245	1055	1075	1157	1207	1232	1208	1283	995	931
80	0	713	872	1145	928	915	964	1010	1063	1091	1210	963	912
90	0	674	808	1023	790	751	774	813	883	955	1112	909	870
20	15	582	819	1288	1347	1579	1833	1864	1675	1361	1160	780	676
30	15	641	876	1339	1343	1533	1757	1796	1653	1392	1240	863	764
40	15	685	914	1358	1311	1459	1651	1696	1598	1391	1291	926	832
50	15	714	930	1347	1254	1359	1516	1566	1510	1360	1311	965	880
60	15	725	926	1305	1172	1236	1358	1409	1394	1299	1299	981	906
70	15	719	899	1233	1069	1094	1182	1233	1252	1211	1256	972	908
80	15	695	852	1134	947	939	994	1042	1090	1098	1182	939	887
90	15	656	788	1014	815	781	809	851	918	966	1083	884	845
20	30	564	800	1270	1342	1582	1841	1870	1673	1348	1134	756	651
30	30	615	849	1314	1339	1542	1774	1812	1655	1375	1204	827	728
40	30	652	880	1330	1311	1477	1679	1723	1608	1374	1246	879	786
50	30	674	890	1317	1259	1387	1557	1606	1531	1345	1260	910	825
60	30	680	881	1276	1184	1276	1413	1465	1426	1288	1243	918	843
70	30	670	852	1207	1089	1146	1252	1304	1298	1205	1198	904	840
80	30	644	804	1114	978	1005	1079	1130	1151	1100	1126	868	816
90	30	605	740	1002	857	859	906	953	995	978	1030	813	773
20	45	537	772	1240	1330	1583	1851	1876	1664	1324	1094	719	614
30	45	577	810	1275	1326	1549	1795	1828	1649	1345	1150	775	673
40	45	604	832	1286	1301	1492	1714	1752	1608	1342	1182	814	717
50	45	618	837	1271	1254	1414	1609	1652	1540	1314	1188	834	743
60	45	618	824	1230	1186	1315	1483	1528	1448	1261	1168	835	752
70	45	604	793	1166	1100	1200	1340	1386	1334	1185	1123	817	743
80	45	577	747	1081	998	1072	1185	1230	1202	1089	1055	780	716
90	45	538	687	979	888	939	1027	1070	1061	979	967	726	673

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	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	
HORIZONTAL RAD.	645	895	1253	1544	1799	2053	1998	1729	1411	1083	696	571	(BTU/DAY-FT2)
AVE. TEMP.	33.8	35.6	42.8	53.6	62.6	71.6	75.2	73.4	68.0	57.2	46.4	35.6	(F)
DEGREE-DAYS	946.	818.	676.	330.	104.	0.	0.	0.	29.	246.	528.	871.	(F-DAYS)

AVERAGE DAILY RADIATION ON TILTED SURFACES (BTU/DAY-FT2)

SLOPE	AZIMUTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
20	0	904	1142	1448	1620	1770	1963	1935	1766	1571	1351	950	823
30	0	1004	1226	1497	1606	1705	1864	1848	1729	1598	1439	1045	922
40	0	1078	1282	1510	1558	1606	1731	1727	1656	1588	1491	1114	997
50	0	1126	1307	1489	1476	1478	1568	1574	1549	1541	1508	1156	1048
60	0	1146	1299	1433	1364	1324	1380	1395	1411	1460	1487	1169	1072
70	0	1137	1261	1344	1224	1149	1174	1196	1246	1346	1431	1154	1069
80	0	1099	1192	1225	1062	960	960	984	1061	1202	1339	1109	1039
90	0	1035	1096	1083	887	770	753	777	867	1038	1219	1039	984
20	15	895	1132	1441	1620	1772	1967	1938	1767	1567	1340	940	814
30	15	989	1212	1487	1608	1710	1872	1856	1733	1593	1423	1031	908
40	15	1060	1264	1499	1562	1616	1744	1739	1664	1584	1471	1096	980
50	15	1105	1285	1477	1485	1492	1587	1592	1561	1540	1484	1135	1027
60	15	1121	1275	1421	1378	1344	1405	1419	1429	1461	1461	1145	1049
70	15	1110	1234	1333	1245	1175	1206	1226	1272	1351	1402	1127	1044
80	15	1071	1164	1216	1090	993	998	1022	1095	1213	1309	1081	1012
90	15	1007	1068	1076	924	810	797	821	910	1056	1189	1011	957
20	30	866	1105	1421	1614	1778	1978	1947	1766	1552	1312	912	786
30	30	948	1174	1462	1605	1724	1894	1875	1738	1576	1384	990	867
40	30	1007	1216	1471	1565	1641	1781	1773	1678	1567	1423	1044	928
50	30	1041	1229	1448	1495	1531	1640	1641	1587	1525	1429	1073	965
60	30	1049	1214	1394	1398	1398	1476	1486	1469	1452	1402	1075	979
70	30	1032	1170	1311	1278	1245	1295	1312	1328	1350	1342	1052	968
80	30	989	1099	1201	1137	1081	1105	1127	1168	1223	1252	1003	933
90	30	924	1005	1071	987	915	919	943	1002	1080	1137	931	876
20	45	823	1066	1390	1601	1782	1992	1957	1759	1526	1270	871	744
30	45	887	1120	1422	1592	1736	1922	1896	1735	1545	1326	931	807
40	45	930	1150	1426	1557	1665	1825	1809	1683	1534	1354	971	852
50	45	952	1155	1402	1494	1569	1704	1696	1604	1495	1354	989	876
60	45	952	1135	1350	1408	1452	1561	1561	1499	1428	1324	983	880
70	45	929	1090	1273	1299	1317	1402	1407	1374	1335	1265	956	863
80	45	885	1023	1173	1173	1169	1233	1242	1231	1221	1181	907	825
90	45	822	937	1056	1038	1019	1064	1076	1081	1091	1076	839	770

ANNETTE AK 55.02

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	
HORIZONTAL RAD.	232	416	850	1325	1682	1716	1771	1296	979	449	217	147	(BTU/DAY-FT2)
AVE. TEMP.	32.0	35.6	37.4	41.0	48.2	51.8	59.0	57.2	53.6	46.4	39.2	35.6	(F)
DEGREE-DAYS	949.	837.	843.	686.	505.	336.	257.	223.	352.	567.	738.	899.	(F-DAYS)

AVERAGE DAILY RADIATION ON TILTED SURFACES (BTU/DAY-FT2)

SLOPE	AZIMUTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
20	0	463	636	1112	1500	1743	1712	1798	1397	1196	622	364	296
30	0	563	724	1206	1540	1727	1673	1768	1407	1264	688	426	360
40	0	648	795	1270	1545	1679	1604	1705	1389	1303	739	477	415
50	0	715	846	1303	1516	1597	1507	1611	1342	1311	771	516	459
60	0	763	875	1303	1453	1485	1385	1487	1268	1288	785	542	491
70	0	790	882	1272	1358	1346	1241	1338	1169	1235	780	554	509
80	0	795	866	1209	1234	1184	1079	1168	1048	1152	756	551	514
90	0	779	829	1119	1088	1009	911	987	912	1046	715	535	505
20	15	455	628	1103	1497	1742	1713	1798	1395	1190	615	359	290
30	15	551	713	1193	1538	1728	1675	1770	1407	1258	679	418	352
40	15	633	780	1254	1545	1682	1609	1710	1390	1297	726	467	405
50	15	697	828	1285	1519	1604	1515	1618	1346	1305	757	504	448
60	15	743	855	1284	1459	1495	1395	1498	1275	1283	769	528	478
70	15	768	860	1252	1368	1360	1254	1352	1179	1232	762	539	495
80	15	772	843	1190	1248	1202	1096	1186	1061	1152	738	536	499
90	15	755	805	1101	1107	1031	930	1009	928	1049	696	519	490
20	30	431	604	1079	1485	1740	1715	1798	1390	1172	597	343	275
30	30	516	679	1161	1527	1731	1682	1775	1404	1235	653	395	330
40	30	587	737	1216	1538	1692	1622	1722	1392	1271	694	438	376
50	30	643	777	1243	1517	1623	1536	1640	1354	1279	719	469	413
60	30	681	797	1240	1464	1524	1425	1529	1290	1259	727	489	439
70	30	701	797	1208	1382	1399	1293	1394	1202	1210	717	496	453
80	30	702	778	1147	1272	1252	1144	1238	1094	1135	691	491	454
90	30	684	739	1063	1141	1091	986	1072	971	1039	650	474	444
20	45	393.	570	1041	1462	1735	1717	1797	1377	1141	571	319	250
30	45	461	631	1110	1500	1731	1691	1781	1391	1195	617	360	294
40	45	516	677	1156	1511	1701	1641	1738	1382	1226	649	393	330
50	45	559	707	1177	1493	1643	1566	1669	1350	1232	668	417	358
60	45	586	721	1172	1447	1557	1469	1573	1294	1212	671	430	377
70	45	599	717	1140	1373	1447	1350	1453	1215	1167	659	433	385
80	45	595	695	1084	1274	1314	1214	1312	1117	1098	633	425	384
90	45	576	658	1006	1155	1168	1068	1159	1004	1010	594	407	373

APALACHICOLA FL 29.45

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	
HORIZONTAL RAD.	1078	1340	1623	2025	2242	2176	1992	1866	1693	1539	1226	972	(BTU/DAY-FT2)
AVE. TEMP.	53.6	55.4	59.0	66.2	73.4	78.8	80.6	80.6	78.8	69.8	60.8	55.4	(F)
DEGREE-DAYS	347.	260.	180.	33.	0.	0.	0.	0.	0.	16.	153.	319.	(F-DAYS)

AVERAGE DAILY RADIATION ON TILTED SURFACES (BTU/DAY-FT2)

SLOPE	AZIMUTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
20	0	1425	1633	1803	2060	2131	2010	1868	1842	1812	1834	1604	1309
30	0	1549	1722	1830	2007	2010	1870	1752	1771	1809	1916	1736	1432
40	0	1634	1769	1814	1910	1848	1696	1603	1663	1764	1951	1824	1519
50	0	1677	1773	1756	1769	1651	1494	1428	1522	1679	1937	1865	1568
60	0	1678	1733	1656	1592	1426	1272	1231	1351	1556	1876	1859	1577
70	0	1637	1651	1519	1382	1181	1038	1020	1158	1398	1769	1805	1546
80	0	1554	1529	1348	1148	929	807	808	949	1212	1618	1705	1476
90	0	1435	1374	1152	903	692	606	615	740	1007	1434	1566	1371
20	15	1412	1621	1796	2061	2137	2017	1873	1845	1809	1821	1589	1296
30	15	1529	1704	1821	2013	2021	1883	1762	1778	1806	1898	1714	1413
40	15	1608	1747	1804	1921	1867	1716	1620	1676	1764	1928	1796	1495
50	15	1647	1746	1746	1789	1679	1522	1451	1541	1682	1911	1832	1539
60	15	1644	1703	1647	1621	1464	1308	1262	1379	1564	1846	1821	1544
70	15	1600	1618	1513	1423	1231	1084	1061	1196	1413	1736	1764	1511
80	15	1515	1494	1346	1204	991	861	857	999	1236	1585	1662	1439
90	15	1396	1339	1157	978	765	663	669	803	1042	1401	1522	1334
20	30	1373	1588	1778	2060	2152	2036	1888	1849	1797	1790	1547	1258
30	30	1472	1659	1799	2018	2051	1918	1790	1791	1794	1855	1653	1358
40	30	1536	1690	1781	1937	1916	1770	1665	1701	1755	1876	1718	1424
50	30	1561	1682	1724	1819	1751	1599	1515	1582	1680	1853	1740	1455
60	30	1547	1634	1632	1670	1562	1409	1347	1438	1571	1787	1718	1449
70	30	1495	1547	1506	1494	1356	1209	1168	1275	1434	1680	1654	1407
80	30	1407	1426	1353	1299	1145	1009	986	1101	1273	1536	1549	1331
90	30	1287	1279	1183	1101	944	826	815	928	1101	1365	1410	1225
20	45	1315	1540	1748	2052	2167	2060	1906	1851	1777	1741	1484	1201
30	45	1391	1593	1761	2016	2083	1961	1823	1801	1772	1790	1565	1277
40	45	1435	1612	1741	1945	1969	1837	1716	1723	1734	1801	1610	1324
50	45	1446	1596	1688	1843	1828	1690	1588	1619	1666	1774	1618	1339
60	45	1423	1546	1603	1711	1664	1526	1441	1493	1568	1709	1588	1323
70	45	1367	1464	1489	1557	1485	1351	1284	1349	1445	1610	1522	1276
80	45	1282	1353	1352	1385	1298	1173	1121	1195	1303	1480	1423	1200
90	45	1171	1220	1201	1209	1117	1004	965	1039	1150	1328	1296	1101

ASTORIA	OR	46.12											
	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	
HORIZONTAL RAD.	338	574	983	1366	1804	1774	1970	1679	1321	777	419	287	(BTU/DAY-FT2)
AVE. TEMP.	41.0	42.8	42.8	46.4	51.8	55.4	59.0	59.0	57.2	51.8	46.4	41.0	(F)
DEGREE-DAYS	753.	622.	636.	480.	363.	231.	146.	130.	210.	375.	561.	679.	(F-DAYS)

AVERAGE DAILY RADIATION ON TILTED SURFACES (BTU/DAY-FT2)

SLOPE	AZIMUTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
20	0	489	758	1178	1474	1820	1736	1955	1767	1541	1015	604	429
30	0	549	825	1237	1482	1777	1673	1894	1756	1598	1100	676	486
40	0	596	873	1267	1458	1699	1580	1797	1708	1618	1159	733	532
50	0	629	901	1268	1403	1588	1459	1666	1624	1598	1190	771	565
60	0	646	907	1239	1318	1448	1315	1506	1505	1541	1192	791	584
70	0	648	891	1182	1206	1282	1152	1321	1357	1448	1164	791	588
80	0	634	855	1098	1070	1098	977	1118	1184	1321	1108	771	578
90	0	604	799	992	920	906	800	911	996	1169	1028	733	555
20	15	484	750	1171	1472	1821	1738	1956	1766	1535	1006	597	423
30	15	541	815	1228	1482	1781	1677	1898	1758	1592	1087	666	478
40	15	586	860	1256	1460	1706	1587	1805	1713	1611	1142	720	522
50	15	616	885	1255	1408	1599	1471	1679	1632	1594	1169	756	553
60	15	632	889	1226	1327	1463	1331	1524	1519	1539	1168	773	571
70	15	633	872	1169	1220	1303	1172	1345	1377	1449	1139	772	574
80	15	617	834	1085	1090	1124	1001	1148	1210	1327	1082	751	563
90	15	588	779	981	945	938	828	947	1029	1179	1001	713	539
20	30	467	731	1152	1465	1823	1743	1961	1762	1516	981	577	408
30	30	517	786	1203	1475	1790	1689	1911	1758	1568	1052	637	456
40	30	555	824	1227	1457	1725	1609	1829	1721	1586	1098	682	493
50	30	580	843	1224	1411	1630	1503	1717	1651	1569	1119	711	519
60	30	591	842	1195	1337	1507	1374	1576	1550	1518	1113	723	532
70	30	588	822	1140	1239	1362	1228	1412	1421	1435	1082	717	532
80	30	570	782	1060	1120	1198	1068	1231	1270	1321	1024	694	519
90	30	540	727	962	987	1026	906	1044	1105	1185	946	655	495
20	45	442	702	1123	1448	1822	1750	1965	1749	1483	944	547	385
30	45	481	746	1163	1457	1795	1705	1925	1747	1526	1001	594	422
40	45	510	774	1181	1441	1740	1636	1856	1716	1540	1037	628	450
50	45	526	786	1176	1399	1658	1545	1760	1655	1523	1050	648	467
60	45	531	780	1146	1333	1551	1432	1638	1566	1476	1040	653	474
70	45	524	758	1094	1245	1422	1301	1493	1452	1399	1007	643	470
80	45	505	719	1020	1137	1275	1157	1331	1316	1296	953	618	455
90	45	475	667	930	1016	1120	1009	1162	1167	1174	880	580	430

ATLANTA GA 33.39

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	
HORIZONTAL RAD.	839	1045	1388	1782	1970	2040	1981	1848	1517	1288	975	740	(BTU/DAY-FT2)
AVE. TEMP.	42.8	44.6	51.8	60.8	68.0	75.2	77.0	77.0	71.6	62.6	51.8	44.6	(F)
DEGREE-DAYS	636.	518.	428.	147.	25.	0.	0.	0.	18.	124.	417.	648.	(F-DAYS)

AVERAGE DAILY RADIATION ON TILTED SURFACES (BTU/DAY-FT2)

SLOPE	AZIMUTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
20	0	1127	1283	1561	1838	1904	1916	1884	1852	1646	1558	1298	1012
30	0	1232	1359	1594	1805	1814	1801	1782	1795	1656	1638	1415	1113
40	0	1308	1403	1591	1732	1689	1653	1647	1701	1627	1679	1496	1188
50	0	1351	1413	1551	1622	1532	1478	1482	1571	1562	1679	1540	1233
60	0	1360	1389	1476	1478	1349	1281	1294	1410	1461	1638	1545	1247
70	0	1335	1332	1367	1305	1146	1070	1090	1225	1329	1558	1510	1230
80	0	1276	1244	1229	1108	933	856	879	1020	1169	1440	1438	1183
90	0	1189	1130	1068	899	725	659	680	811	990	1292	1332	1107
20	15	1116	1274	1554	1838	1907	1921	1889	1854	1643	1547	1286	1001
30	15	1216	1345	1586	1808	1822	1810	1791	1801	1652	1622	1397	1098
40	15	1287	1384	1581	1740	1702	1669	1661	1711	1625	1659	1473	1169
50	15	1326	1391	1541	1636	1552	1500	1503	1588	1562	1655	1512	1210
60	15	1332	1364	1466	1499	1376	1310	1322	1435	1466	1611	1513	1221
70	15	1304	1306	1359	1335	1182	1107	1126	1258	1339	1528	1476	1202
80	15	1245	1216	1223	1149	977	900	923	1064	1185	1409	1402	1153
90	15	1156	1101	1066	953	778	707	730	867	1015	1261	1296	1077
20	30	1084	1247	1537	1834	1917	1936	1901	1856	1630	1518	1250	971
30	30	1169	1308	1564	1809	1842	1838	1815	1810	1638	1583	1344	1054
40	30	1227	1338	1557	1749	1737	1712	1700	1732	1613	1611	1406	1112
50	30	1255	1338	1518	1656	1604	1561	1560	1622	1555	1601	1433	1142
60	30	1251	1307	1446	1533	1448	1391	1398	1486	1465	1555	1424	1145
70	30	1217	1246	1346	1385	1274	1208	1222	1328	1348	1473	1381	1119
80	30	1154	1157	1219	1218	1091	1021	1039	1156	1208	1358	1304	1066
90	30	1065	1046	1076	1044	913	843	864	980	1055	1219	1197	989
20	45	1036	1208	1508	1824	1926	1954	1915	1854	1609	1474	1197	926
30	45	1102	1254	1528	1801	1863	1872	1842	1815	1613	1524	1270	989
40	45	1143	1274	1518	1748	1773	1765	1744	1747	1588	1542	1314	1031
50	45	1158	1267	1479	1666	1658	1635	1623	1651	1534	1527	1328	1048
60	45	1146	1233	1412	1557	1521	1487	1482	1531	1453	1479	1311	1041
70	45	1108	1173	1320	1426	1368	1326	1327	1392	1347	1402	1264	1010
80	45	1045	1090	1206	1277	1206	1159	1164	1238	1221	1297	1189	956
90	45	961	989	1078	1121	1044	996	1005	1081	1084	1171	1091	883

BETHEL AK 60.47

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	
HORIZONTAL RAD.	136	412	1038	1635	1690	1653	1362	935	732	430	165	84	(BTU/DAY-FT2)
AVE. TEMP.	6.8	8.6	12.2	24.8	39.2	50.0	53.6	51.8	44.6	30.2	17.6	5.0	(F)
DEGREE-DAYS	1903.	1590.	1655.	1173.	806.	402.	319.	394.	612.	1042.	1434.	1866.	(F-DAYS)

AVERAGE DAILY RADIATION ON TILTED SURFACES (BTU/DAY-FT2)

SLOPE	AZIMUTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
20	0	394	802	1574	1969	1777	1661	1386	1005	913	704	394	296
30	0	509	968	1784	2071	1779	1635	1370	1015	974	816	495	392
40	0	609	1108	1945	2123	1747	1581	1331	1005	1013	907	582	476
50	0	692	1217	2054	2123	1680	1500	1268	976	1028	975	653	546
60	0	756	1293	2106	2070	1580	1393	1184	929	1019	1017	706	601
70	0	797	1332	2101	1967	1450	1264	1081	865	987	1032	739	638
80	0	816	1334	2039	1816	1294	1116	961	785	932	1020	751	657
90	0	811	1300	1923	1626	1120	958	832	696	857	982	742	656
20	15	385	788	1556	1964	1776	1662	1386	1004	909	694	386	289
30	15	495	948	1759	2067	1779	1636	1371	1014	969	801	483	381
40	15	592	1082	1914	2121	1749	1584	1333	1005	1007	889	567	462
50	15	672	1186	2018	2125	1685	1505	1272	977	1023	953	635	530
60	15	733	1257	2067	2077	1588	1401	1190	931	1015	992	685	582
70	15	772	1294	2060	1978	1461	1274	1088	869	984	1005	717	618
80	15	790	1294	1996	1833	1308	1128	970	791	930	992	727	635
90	15	785	1260	1882	1649	1138	973	844	703	858	953	718	635
20	30	358	747	1509	1944	1772	1662	1385	1000	894	666	363	268
30	30	457	888	1695	2048	1779	1640	1372	1011	950	761	449	349
40	30	543	1005	1837	2107	1755	1593	1338	1005	987	837	523	422
50	30	613	1095	1931	2119	1698	1520	1282	980	1001	892	582	482
60	30	666	1155	1974	2081	1610	1423	1205	939	994	924	626	528
70	30	700	1183	1965	1995	1493	1303	1109	880	964	932	652	559
80	30	714	1178	1904	1864	1349	1164	997	808	913	915	659	573
90	30	708	1141	1795	1695	1189	1015	876	724	845	876	649	572
20	45	317	688	1435	1904	1765	1661	1383	992	869	625	325	233
30	45	396	803	1595	2001	1777	1645	1374	1003	918	704	394	299
40	45	464	898	1718	2060	1761	1605	1345	998	950	767	453	357
50	45	519	969	1800	2076	1716	1542	1297	977	962	811	499	405
60	45	560	1015	1835	2047	1641	1455	1228	940	954	834	532	441
70	45	585	1033	1825	1974	1537	1346	1141	887	926	837	550	464
80	45	593	1023	1768	1857	1408	1218	1037	820	879	819	552	475
90	45	585	987	1668	1705	1261	1079	924	742	815	781	541	471

BIG SPRING TX 32.15

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	
HORIZONTAL RAD.	986	1266	1716	2146	2106	2183	2032	1723	1925	1421	1071	957	(BTU/DAY-FT2)
AVE. TEMP.	42.8	48.2	53.6	64.4	71.6	78.8	82.4	82.4	75.2	64.4	53.6	44.6	(F)
DEGREE-DAYS	651.	468.	322.	90.	0.	0.	0.	0.	0.	87.	381.	592.	(F-DAYS)

AVERAGE DAILY RADIATION ON TILTED SURFACES (BTU/DAY-FT2)

SLOPE	AZIMUTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
20	0	1336	1574	1949	2216	2025	2038	1924	1717	2109	1718	1422	1344
30	0	1465	1673	1996	2173	1923	1907	1814	1660	2125	1807	1548	1490
40	0	1556	1731	1994	2080	1783	1742	1670	1569	2089	1850	1635	1598
50	0	1608	1745	1945	1940	1609	1547	1497	1447	2003	1848	1680	1665
60	0	1619	1717	1848	1756	1407	1330	1300	1297	1869	1800	1683	1689
70	0	1588	1646	1707	1535	1185	1099	1088	1125	1690	1708	1642	1668
80	0	1517	1535	1526	1285	952	866	871	938	1474	1574	1560	1604
90	0	1411	1390	1316	1020	729	655	667	746	1231	1407	1442	1501
20	15	1323	1562	1940	2216	2029	2044	1929	1719	2104	1706	1409	1330
30	15	1445	1655	1985	2178	1932	1919	1824	1665	2121	1789	1528	1469
40	15	1531	1707	1982	2091	1798	1760	1686	1579	2087	1828	1609	1571
50	15	1578	1718	1931	1959	1632	1573	1519	1462	2005	1821	1650	1632
60	15	1585	1685	1835	1786	1439	1364	1331	1320	1876	1770	1648	1651
70	15	1552	1612	1697	1577	1226	1141	1127	1156	1706	1675	1605	1628
80	15	1479	1499	1520	1342	1004	917	917	978	1499	1541	1521	1562
90	15	1371	1353	1316	1096	790	711	720	798	1270	1373	1402	1458
20	30	1284	1528	1917	2212	2041	2061	1942	1721	2087	1674	1370	1287
30	30	1388	1607	1955	2180	1956	1951	1850	1675	2102	1745	1471	1406
40	30	1458	1648	1950	2105	1839	1811	1728	1599	2072	1775	1537	1490
50	30	1491	1650	1901	1988	1692	1644	1581	1495	1996	1762	1564	1536
60	30	1488	1612	1811	1834	1521	1458	1412	1367	1879	1709	1552	1543
70	30	1446	1536	1682	1648	1332	1258	1230	1221	1724	1615	1502	1510
80	30	1369	1425	1519	1440	1135	1056	1042	1062	1538	1486	1415	1439
90	30	1261	1285	1334	1223	944	866	864	902	1333	1329	1296	1333
20	45	1226	1478	1879	2200	2052	2083	1958	1720	2057	1626	1312	1222
30	45	1306	1539	1908	2173	1981	1991	1880	1680	2067	1680	1390	1315
40	45	1356	1566	1899	2107	1881	1872	1777	1614	2038	1699	1437	1376
50	45	1375	1559	1852	2005	1755	1729	1650	1523	1970	1681	1450	1403
60	45	1360	1518	1768	1871	1606	1568	1503	1410	1865	1627	1430	1397
70	45	1314	1444	1651	1708	1441	1393	1343	1280	1727	1539	1376	1357
80	45	1239	1341	1506	1525	1266	1213	1176	1138	1562	1422	1292	1285
90	45	1138	1216	1343	1333	1093	1040	1013	994	1382	1282	1183	1186

BISMARCK ND 46.47

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	
HORIZONTAL RAD.	581	924	1292	1653	2029	2161	2253	1907	1406	1005	592	456	(BTU/DAY-FT2)
AVE. TEMP.	8.6	12.2	26.6	42.8	53.6	62.6	69.8	68.0	57.2	44.6	30.2	15.8	(F)
DEGREE-DAYS	1708.	1442.	1203.	645.	329.	117.	34.	28.	222.	577.	1083.	1463.	(F-DAYS)

AVERAGE DAILY RADIATION ON TILTED SURFACES (BTU/DAY-FT2)

SLOPE	AZIMUTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
20	0	991	1353	1611	1810	2055	2117	2242	2023	1655	1382	942	800
30	0	1160	1519	1714	1829	2008	2039	2173	2016	1722	1521	1083	943
40	0	1299	1645	1774	1806	1921	1924	2062	1965	1748	1622	1197	1062
50	0	1402	1728	1789	1742	1796	1773	1910	1870	1731	1681	1279	1152
60	0	1467	1765	1760	1639	1635	1591	1723	1734	1672	1696	1327	1210
70	0	1492	1755	1687	1500	1445	1385	1506	1562	1573	1667	1339	1236
80	0	1476	1698	1572	1330	1233	1162	1267	1360	1437	1594	1315	1228
90	0	1421	1599	1422	1138	1011	938	1023	1139	1272	1484	1258	1188
20	15	976	1337	1600	1808	2056	2120	2244	2022	1649	1368	929	787
30	15	1139	1496	1698	1828	2012	2045	2179	2018	1715	1500	1065	925
40	15	1271	1615	1755	1808	1929	1934	2072	1970	1741	1595	1173	1038
50	15	1369	1692	1769	1749	1809	1788	1926	1880	1725	1648	1250	1124
60	15	1429	1725	1738	1651	1654	1613	1745	1751	1669	1659	1294	1179
70	15	1451	1711	1665	1519	1471	1412	1535	1586	1574	1627	1304	1202
80	15	1433	1652	1552	1356	1265	1195	1304	1392	1443	1553	1279	1192
90	15	1378	1552	1404	1172	1050	976	1067	1179	1284	1442	1221	1151
20	30	933	1292	1570	1797	2058	2127	2250	2017	1627	1329	892	751
30	30	1075	1431	1659	1819	2023	2062	2195	2018	1688	1446	1010	872
40	30	1189	1533	1709	1804	1952	1964	2102	1980	1712	1527	1102	970
50	30	1271	1595	1719	1752	1845	1832	1972	1902	1698	1570	1166	1042
60	30	1319	1616	1689	1665	1707	1672	1809	1788	1646	1574	1199	1087
70	30	1331	1595	1618	1546	1541	1488	1618	1640	1557	1537	1201	1102
80	30	1308	1533	1511	1397	1353	1288	1406	1465	1436	1463	1171	1088
90	30	1250	1433	1373	1230	1156	1083	1187	1272	1289	1355	1112	1045
20	45	866	1225	1522	1774	2056	2135	2254	2001	1590	1271	836	695
30	45	979	1338	1596	1793	2029	2083	2211	2004	1641	1367	930	790
40	45	1068	1419	1636	1781	1970	2001	2135	1973	1660	1431	1002	866
50	45	1129	1465	1641	1736	1880	1890	2026	1907	1646	1462	1048	919
60	45	1160	1475	1610	1659	1760	1751	1886	1808	1598	1459	1069	949
70	45	1161	1449	1545	1552	1613	1589	1719	1677	1517	1421	1062	953
80	45	1132	1388	1447	1419	1446	1410	1531	1521	1407	1350	1029	933
90	45	1074	1295	1322	1269	1269	1225	1333	1349	1275	1251	971	889

BLUE HILL MA 42.13

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	
HORIZONTAL RAD.	574	791	1119	1395	1734	1903	1841	1598	1296	916	581	475	(BTU/DAY-FT2)
AVE. TEMP.	26.6	26.6	33.8	44.6	55.4	64.4	69.8	68.0	60.8	51.8	41.0	30.2	(F)
DEGREE-DAYS	1178.	1053.	936.	579.	267.	69.	0.	22.	107.	381.	690.	1065.	(F-DAYS)

AVERAGE DAILY RADIATION ON TILTED SURFACES (BTU/DAY-FT2)

SLOPE	AZIMUTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
20	0	852	1039	1314	1480	1726	1841	1803	1651	1465	1164	820	719
30	0	963	1129	1368	1475	1673	1761	1735	1627	1501	1248	913	817
40	0	1049	1191	1390	1440	1588	1650	1635	1569	1502	1303	982	895
50	0	1108	1224	1380	1374	1472	1509	1504	1479	1468	1326	1028	950
60	0	1139	1227	1338	1280	1331	1345	1349	1359	1401	1316	1048	981
70	0	1140	1200	1265	1160	1168	1162	1173	1214	1303	1275	1041	986
80	0	1112	1143	1164	1019	990	968	984	1048	1176	1203	1009	966
90	0	1057	1061	1040	864	807	777	794	872	1028	1105	952	923
20	15	842	1030	1307	1478	1728	1844	1806	1651	1460	1154	811	710
30	15	948	1115	1359	1476	1677	1767	1740	1629	1495	1234	899	804
40	15	1029	1173	1379	1443	1595	1660	1644	1574	1497	1285	966	878
50	15	1085	1202	1368	1380	1484	1524	1518	1488	1465	1304	1008	930
60	15	1113	1202	1325	1291	1348	1365	1368	1374	1401	1292	1025	958
70	15	1112	1173	1253	1176	1190	1187	1197	1234	1306	1249	1017	962
80	15	1082	1116	1152	1041	1018	999	1014	1075	1184	1175	983	940
90	15	1027	1033	1030	893	841	812	829	906	1041	1077	926	896
20	30	812	1003	1288	1472	1731	1852	1812	1649	1445	1128	785	684
30	30	903	1076	1334	1471	1688	1784	1755	1632	1477	1198	861	766
40	30	972	1124	1350	1442	1616	1688	1669	1584	1478	1240	917	829
50	30	1017	1146	1338	1386	1517	1566	1557	1508	1448	1253	950	871
60	30	1036	1140	1296	1305	1394	1421	1420	1405	1388	1236	959	891
70	30	1029	1107	1227	1200	1251	1258	1265	1279	1300	1191	945	889
80	30	995	1048	1132	1076	1094	1084	1097	1135	1186	1119	908	864
90	30	938	967	1018	942	932	911	927	981	1055	1024	851	819
20	45	766	964	1258	1459	1732	1862	1818	1640	1418	1089	746	643
30	45	838	1022	1294	1457	1696	1805	1770	1626	1444	1145	806	707
40	45	891	1058	1305	1431	1634	1724	1697	1585	1443	1176	848	755
50	45	921	1070	1290	1380	1548	1618	1600	1518	1414	1182	870	784
60	45	930	1059	1250	1307	1440	1491	1480	1426	1358	1162	871	794
70	45	916	1024	1185	1212	1313	1347	1343	1314	1277	1117	853	785
80	45	880	967	1098	1101	1172	1191	1192	1184	1174	1049	814	757
90	45	825	892	994	978	1025	1033	1038	1045	1056	962	759	712

BOISE ID 43.34

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	
HORIZONTAL RAD.	522	858	1248	1789	2161	2353	2463	2095	1679	1156	666	452	(BTU/DAY-FT2)
AVE. TEMP.	30.2	33.8	41.0	48.2	57.2	64.4	73.4	71.6	62.6	51.8	39.2	32.0	(F)
DEGREE-DAYS	1113.	854.	722.	438.	245.	81.	0.	0.	132.	415.	792.	1017.	(F-DAYS)

AVERAGE DAILY RADIATION ON TILTED SURFACES (BTU/DAY-FT2)

SLOPE	AZIMUTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
20	0	784	1165	1500	1936	2167	2282	2426	2200	1964	1549	997	704
30	0	888	1279	1575	1945	2106	2184	2336	2180	2036	1690	1128	805
40	0	970	1361	1611	1908	2001	2044	2199	2111	2057	1788	1230	887
50	0	1027	1409	1609	1829	1855	1867	2019	1995	2027	1840	1300	946
60	0	1058	1421	1568	1708	1674	1657	1800	1834	1947	1844	1336	980
70	0	1062	1397	1489	1550	1463	1422	1550	1635	1819	1800	1337	989
80	0	1038	1337	1375	1359	1231	1172	1280	1405	1646	1709	1303	972
90	0	989	1247	1233	1148	991	923	1008	1156	1440	1578	1237	931
20	15	774	1154	1491	1934	2169	2286	2429	2200	1956	1534	985	694
30	15	874	1262	1563	1945	2111	2192	2344	2183	2027	1668	1110	792
40	15	952	1339	1597	1913	2011	2058	2214	2119	2049	1760	1207	870
50	15	1006	1382	1593	1838	1872	1887	2040	2009	2022	1806	1272	925
60	15	1034	1391	1551	1724	1698	1684	1829	1856	1945	1806	1305	957
70	15	1035	1364	1473	1573	1494	1456	1588	1666	1822	1758	1304	964
80	15	1010	1303	1360	1391	1270	1213	1327	1445	1656	1666	1268	945
90	15	960	1212	1220	1190	1038	972	1063	1207	1458	1534	1201	904
20	30	746	1121	1467	1924	2174	2296	2439	2196	1931	1494	949	667
30	30	832	1215	1531	1937	2126	2215	2367	2186	1997	1611	1058	752
40	30	899	1279	1560	1911	2040	2096	2253	2133	2018	1690	1140	819
50	30	942	1313	1554	1846	1917	1943	2100	2038	1993	1725	1193	865
60	30	962	1314	1513	1743	1762	1760	1912	1904	1922	1718	1215	888
70	30	957	1282	1438	1607	1579	1553	1695	1734	1809	1668	1206	889
80	30	929	1219	1332	1443	1375	1330	1457	1536	1657	1576	1166	868
90	30	878	1129	1201	1260	1165	1106	1216	1322	1476	1449	1097	825
20	45	703	1072	1428	1902	2174	2309	2446	2181	1888	1433	896	626
30	45	771	1148	1480	1913	2136	2243	2389	2175	1943	1528	982	693
40	45	821	1197	1502	1891	2064	2144	2296	2131	1959	1589	1045	743
50	45	852	1219	1493	1834	1960	2015	2168	2050	1935	1614	1082	775
60	45	862	1213	1453	1744	1825	1857	2006	1934	1871	1600	1093	788
70	45	850	1179	1383	1623	1665	1676	1818	1785	1769	1550	1077	782
80	45	819	1118	1286	1476	1484	1478	1609	1610	1633	1464	1035	756
90	45	769	1035	1168	1313	1295	1276	1393	1419	1472	1348	969	714

BOSTON MA 42.22

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	
HORIZONTAL RAD.	511	729	1078	1340	1738	1837	1826	1565	1255	876	533	438	(BTU/DAY-FT2)
AVE. TEMP.	30.2	30.2	35.6	46.4	57.2	66.2	71.6	69.8	62.6	53.6	42.8	32.0	(F)
DEGREE-DAYS	1088.	972.	846.	513.	208.	36.	0.	9.	60.	316.	603.	983.	(F-DAYS)

AVERAGE DAILY RADIATION ON TILTED SURFACES (BTU/DAY-FT2)

SLOPE	AZIMUTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
20	0	740	944	1262	1418	1730	1778	1789	1616	1416	1106	740	651
30	0	830	1021	1313	1414	1677	1701	1722	1593	1449	1184	818	736
40	0	900	1074	1333	1379	1592	1595	1623	1536	1450	1234	878	803
50	0	947	1101	1322	1316	1477	1461	1494	1448	1417	1254	916	850
60	0	970	1101	1281	1226	1335	1303	1340	1331	1352	1244	931	875
70	0	969	1075	1211	1112	1172	1128	1166	1190	1258	1205	923	879
80	0	943	1024	1114	978	993	943	979	1028	1136	1136	893	860
90	0	895	950	996	831	810	759	791	857	993	1044	842	820
20	15	732	936	1256	1417	1732	1781	1792	1616	1412	1097	732	643
30	15	818	1009	1304	1414	1681	1707	1727	1595	1445	1171	807	724
40	15	884	1058	1322	1382	1600	1604	1632	1541	1445	1217	863	788
50	15	928	1082	1310	1322	1489	1475	1507	1457	1414	1234	898	832
60	15	949	1080	1269	1236	1352	1322	1358	1346	1352	1222	911	856
70	15	946	1052	1199	1127	1194	1152	1190	1210	1260	1180	902	857
80	15	919	1000	1103	998	1021	971	1008	1054	1142	1111	871	837
90	15	870	925	987	858	844	792	826	889	1005	1017	820	797
20	30	707	913	1238	1411	1735	1788	1798	1614	1397	1073	709	620
30	30	781	975	1280	1410	1692	1723	1742	1597	1427	1137	774	691
40	30	837	1016	1295	1382	1621	1631	1657	1551	1427	1175	821	745
50	30	872	1033	1282	1328	1522	1514	1545	1476	1398	1186	848	781
60	30	886	1026	1242	1249	1398	1375	1410	1376	1339	1170	854	797
70	30	877	994	1175	1149	1255	1219	1257	1253	1254	1127	841	794
80	30	847	941	1084	1031	1097	1052	1090	1112	1145	1058	807	771
90	30	798	867	975	903	935	885	922	962	1018	968	755	730
20	45	669	878	1209	1399	1736	1797	1803	1606	1372	1036	676	585
30	45	728	928	1242	1396	1700	1743	1756	1591	1395	1087	726	640
40	45	769	958	1252	1371	1639	1664	1684	1551	1393	1116	761	680
50	45	793	967	1237	1322	1553	1563	1588	1485	1365	1120	779	705
60	45	798	955	1198	1251	1444	1441	1470	1396	1311	1101	778	712
70	45	784	922	1135	1161	1317	1302	1333	1286	1233	1057	760	703
80	45	752	870	1051	1054	1175	1152	1184	1159	1133	992	725	677
90	45	704	802	952	937	1028	1000	1031	1024	1019	910	675	636

BOULDER	CO	40.00											
	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	
HORIZONTAL RAD.	740	988	1478	1695	1695	1935	1917	1618	1518	1142	818	670	(BTU/DAY-FT2)
AVE. TEMP.	32.0	33.8	37.4	48.2	57.2	66.2	73.4	71.6	62.6	53.6	41.0	35.6	(F)
DEGREE-DAYS	992.	826.	809.	482.	236.	88.	6.	0.	139.	367.	690.	905.	(F-DAYS)

AVERAGE DAILY RADIATION ON TILTED SURFACES (BTU/DAY-FT2)

SLOPE	AZIMUTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
20	0	1104	1304	1758	1799	1676	1860	1865	1659	1716	1460	1185	1040
30	0	1247	1418	1836	1791	1618	1772	1787	1628	1755	1567	1326	1188
40	0	1358	1496	1869	1743	1530	1652	1676	1564	1753	1636	1434	1305
50	0	1433	1536	1856	1657	1413	1504	1534	1467	1709	1664	1504	1388
60	0	1471	1538	1797	1535	1272	1332	1366	1342	1625	1650	1535	1434
70	0	1470	1501	1694	1381	1111	1143	1179	1192	1504	1594	1526	1442
80	0	1431	1426	1551	1201	936	944	979	1022	1349	1499	1477	1411
90	0	1355	1318	1375	1003	759	750	780	843	1168	1371	1392	1344
20	15	1091	1292	1748	1797	1677	1863	1868	1659	1710	1447	1171	1026
30	15	1227	1400	1822	1792	1623	1779	1794	1631	1749	1549	1306	1168
40	15	1332	1472	1853	1748	1538	1663	1686	1570	1748	1612	1408	1279
50	15	1403	1508	1838	1667	1426	1520	1550	1478	1706	1636	1473	1357
60	15	1437	1507	1779	1551	1289	1354	1388	1358	1626	1618	1500	1399
70	15	1433	1467	1678	1405	1134	1170	1206	1214	1509	1560	1488	1404
80	15	1392	1391	1537	1233	965	977	1013	1051	1360	1464	1437	1372
90	15	1316	1283	1365	1045	794	788	821	880	1187	1335	1351	1305
20	30	1051	1258	1721	1790	1682	1872	1876	1658	1692	1414	1131	986
30	30	1169	1351	1787	1787	1634	1798	1811	1635	1728	1503	1248	1110
40	30	1258	1411	1813	1750	1560	1695	1716	1581	1727	1556	1333	1204
50	30	1315	1437	1797	1677	1459	1566	1594	1500	1688	1571	1385	1268
60	30	1337	1428	1740	1573	1336	1415	1448	1392	1613	1549	1400	1298
70	30	1325	1384	1644	1441	1195	1248	1283	1262	1505	1489	1380	1295
80	30	1278	1307	1512	1285	1042	1070	1107	1115	1368	1394	1325	1257
90	30	1201	1201	1353	1116	886	895	931	960	1210	1271	1237	1188
20	45	992	1208	1677	1774	1684	1884	1883	1651	1662	1364	1072	926
30	45	1085	1281	1731	1771	1644	1821	1829	1631	1690	1435	1164	1022
40	45	1152	1327	1749	1737	1579	1734	1749	1584	1686	1475	1229	1094
50	45	1191	1342	1731	1674	1492	1623	1643	1513	1650	1481	1264	1138
60	45	1201	1327	1677	1581	1383	1491	1515	1417	1582	1455	1268	1154
70	45	1181	1281	1588	1463	1258	1343	1370	1301	1484	1397	1241	1141
80	45	1132	1207	1469	1323	1120	1184	1212	1169	1360	1309	1185	1099
90	45	1057	1110	1326	1172	978	1024	1052	1029	1218	1197	1103	1031

BROWNSVILLE TX 25.55

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	
HORIZONTAL RAD.	1056	1237	1480	1686	2047	2224	2279	2043	1712	1495	1045	931	(BTU/DAY-FT2)
AVE. TEMP.	59.0	62.6	68.0	73.4	78.8	82.4	82.4	82.4	80.6	75.2	66.2	60.8	(F)
DEGREE-DAYS	205.	106.	74.	0.	0.	0.	0.	0.	0.	0.	66.	149.	(F-DAYS)

AVERAGE DAILY RADIATION ON TILTED SURFACES (BTU/DAY-FT2)

SLOPE	AZIMUTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
20	0	1326	1444	1597	1682	1919	2020	2095	1986	1797	1721	1278	1181
30	0	1415	1499	1603	1625	1797	1859	1939	1892	1778	1775	1352	1266
40	0	1471	1519	1572	1534	1640	1666	1747	1758	1719	1786	1393	1321
50	0	1491	1503	1506	1413	1454	1446	1525	1589	1621	1755	1402	1345
60	0	1474	1453	1407	1263	1246	1209	1282	1389	1488	1681	1378	1336
70	0	1422	1369	1278	1091	1023	965	1028	1167	1322	1569	1320	1294
80	0	1336	1254	1122	903	798	731	778	931	1131	1420	1232	1222
90	0	1221	1115	949	711	597	547	569	700	923	1243	1119	1124
20	15	1315	1435	1592	1683	1925	2028	2102	1990	1795	1712	1269	1171
30	15	1399	1486	1597	1630	1809	1874	1954	1901	1777	1761	1338	1252
40	15	1451	1502	1566	1544	1659	1689	1771	1775	1721	1768	1376	1303
50	15	1467	1484	1500	1429	1481	1479	1559	1614	1627	1733	1381	1323
60	15	1447	1431	1403	1287	1282	1251	1326	1425	1498	1658	1354	1311
70	15	1393	1345	1276	1125	1070	1017	1083	1216	1341	1543	1294	1267
80	15	1305	1229	1125	949	857	792	845	995	1159	1394	1205	1194
90	15	1190	1089	958	773	663	603	638	783	966	1218	1091	1095
20	30	1284	1411	1580	1684	1940	2051	2124	1998	1786	1686	1242	1142
30	30	1354	1453	1581	1637	1838	1916	1994	1921	1770	1727	1299	1210
40	30	1393	1462	1551	1560	1707	1753	1834	1809	1717	1728	1326	1249
50	30	1399	1438	1488	1456	1551	1567	1648	1668	1631	1690	1323	1259
60	30	1371	1382	1397	1329	1375	1366	1443	1501	1514	1615	1289	1239
70	30	1311	1297	1279	1185	1189	1160	1230	1317	1371	1504	1226	1190
80	30	1221	1185	1141	1029	1002	958	1021	1124	1208	1363	1135	1113
90	30	1106	1053	992	874	829	781	832	939	1038	1202	1023	1013
20	45	1238	1376	1559	1683	1958	2081	2151	2005	1770	1648	1202	1099
30	45	1290	1405	1557	1641	1872	1969	2043	1939	1753	1676	1244	1149
40	45	1314	1406	1526	1573	1760	1831	1908	1843	1705	1671	1259	1174
50	45	1309	1378	1467	1481	1626	1673	1749	1721	1627	1631	1248	1173
60	45	1275	1322	1383	1369	1475	1501	1574	1576	1522	1558	1210	1146
70	45	1214	1242	1277	1241	1312	1320	1389	1415	1395	1456	1147	1094
80	45	1128	1139	1153	1102	1145	1141	1203	1245	1251	1330	1061	1020
90	45	1023	1021	1021	962	986	974	1029	1078	1100	1186	959	927

CAPE HATTERAS	NC	35.16											
	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	
HORIZONTAL RAD.	898	1167	1590	2102	2338	2375	2316	2051	1738	1329	1045	795	(BTU/DAY-FT2)
AVE. TEMP.	46.4	46.4	50.0	57.2	66.2	73.4	77.0	77.0	73.4	64.4	55.4	48.2	(F)
DEGREE-DAYS	580.	518.	440.	177.	25.	0.	0.	0.	0.	78.	273.	521	(F-DAYS)

AVERAGE DAILY RADIATION ON TILTED SURFACES (BTU/DAY-FT2)

SLOPE	AZIMUTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
20	0	1259	1484	1833	2201	2273	2237	2212	2075	1924	1642	1449	1141
30	0	1395	1590	1890	2173	2170	2104	2095	2018	1949	1740	1599	1274
40	0	1496	1657	1901	2095	2022	1931	1936	1918	1928	1795	1708	1375
50	0	1558	1683	1865	1969	1833	1724	1741	1777	1860	1806	1773	1440
60	0	1580	1667	1785	1798	1611	1490	1517	1599	1749	1771	1791	1468
70	0	1561	1609	1662	1589	1363	1237	1272	1391	1597	1693	1763	1458
80	0	1502	1512	1500	1348	1099	979	1016	1159	1409	1573	1688	1411
90	0	1407	1380	1309	1089	840	738	772	920	1196	1418	1573	1328
20	15	1245	1471	1824	2200	2278	2243	2218	2076	1919	1629	1434	1128
30	15	1375	1572	1878	2177	2180	2116	2105	2024	1944	1722	1577	1255
40	15	1470	1634	1887	2105	2039	1950	1954	1930	1924	1772	1679	1350
50	15	1528	1655	1851	1986	1858	1751	1767	1796	1860	1778	1738	1411
60	15	1546	1635	1771	1825	1646	1525	1551	1626	1753	1740	1752	1435
70	15	1524	1575	1650	1627	1408	1282	1315	1428	1608	1659	1720	1423
80	15	1463	1475	1491	1399	1155	1033	1070	1208	1428	1538	1644	1373
90	15	1367	1344	1304	1157	907	798	834	982	1225	1383	1528	1290
20	30	1205	1437	1800	2194	2289	2260	2232	2078	1901	1596	1389	1090
30	30	1317	1523	1847	2176	2205	2149	2135	2034	1925	1676	1512	1199
40	30	1396	1573	1853	2113	2082	2002	2001	1952	1906	1716	1597	1279
50	30	1439	1585	1818	2009	1924	1826	1836	1834	1847	1715	1640	1326
60	30	1446	1558	1741	1865	1736	1624	1645	1684	1749	1674	1642	1339
70	30	1416	1495	1628	1688	1525	1406	1434	1508	1615	1593	1602	1318
80	30	1350	1396	1481	1486	1301	1181	1214	1313	1452	1476	1521	1264
90	30	1253	1268	1310	1271	1080	967	1001	1112	1269	1330	1405	1180
20	45	1146	1385	1761	2178	2298	2281	2247	2073	1872	1546	1323	1032
30	45	1233	1453	1798	2162	2229	2189	2167	2036	1889	1608	1419	1117
40	45	1291	1488	1799	2108	2126	2066	2055	1966	1870	1636	1482	1176
50	45	1318	1491	1763	2017	1991	1916	1914	1864	1816	1629	1509	1206
60	45	1313	1460	1692	1891	1829	1742	1749	1733	1727	1586	1500	1207
70	45	1277	1397	1588	1736	1645	1552	1565	1578	1607	1509	1455	1179
80	45	1211	1304	1456	1557	1447	1353	1371	1405	1462	1401	1376	1122
90	45	1120	1189	1304	1367	1249	1158	1178	1227	1299	1269	1268	1041

CARIBOU ME 46.52

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	
HORIZONTAL RAD.	504	846	1351	1473	1745	1767	1874	1657	1226	773	405	390	(BTU/DAY-FT2)
AVE. TEMP.	10.4	14.0	24.8	35.6	48.2	59.0	64.4	60.8	53.6	42.8	32.0	17.6	(F)
DEGREE-DAYS	1690.	1470.	1308.	858.	468.	183.	78.	115.	336.	682.	1044.	1535.	(F-DAYS)

AVERAGE DAILY RADIATION ON TILTED SURFACES (BTU/DAY-FT2)

SLOPE	AZIMUTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
20	0	829	1219	1696	1600	1762	1730	1861	1746	1423	1016	584	655
30	0	963	1362	1808	1613	1721	1668	1804	1736	1474	1103	654	765
40	0	1071	1470	1875	1590	1647	1577	1713	1690	1490	1164	709	855
50	0	1151	1540	1894	1532	1541	1458	1591	1608	1472	1196	747	923
60	0	1201	1570	1865	1441	1406	1315	1441	1492	1419	1199	766	966
70	0	1218	1558	1789	1320	1248	1154	1267	1347	1334	1173	766	984
80	0	1203	1506	1668	1172	1071	979	1077	1176	1218	1118	748	975
90	0	1156	1417	1510	1006	887	803	882	991	1080	1038	711	942
20	15	817	1205	1684	1599	1763	1732	1862	1745	1418	1006	577	645
30	15	945	1341	1792	1613	1724	1673	1808	1738	1468	1089	644	751
40	15	1049	1443	1855	1592	1653	1584	1721	1694	1485	1146	697	837
50	15	1125	1508	1872	1538	1551	1469	1603	1616	1468	1175	732	901
60	15	1171	1534	1842	1452	1421	1331	1458	1505	1417	1176	749	942
70	15	1186	1520	1766	1335	1268	1173	1289	1365	1334	1147	748	958
80	15	1169	1466	1646	1193	1096	1003	1104	1201	1223	1091	729	948
90	15	1122	1376	1490	1034	917	831	914	1023	1089	1011	692	913
20	30	783	1165	1652	1589	1765	1738	1867	1741	1400	981	557	617
30	30	895	1285	1749	1605	1733	1685	1820	1738	1446	1054	616	710
40	30	984	1372	1805	1589	1671	1605	1743	1702	1462	1102	660	784
50	30	1047	1424	1818	1541	1580	1501	1637	1634	1445	1124	688	838
60	30	1083	1440	1788	1463	1462	1373	1505	1535	1398	1120	700	871
70	30	1090	1419	1715	1357	1323	1228	1350	1409	1321	1089	695	880
80	30	1069	1362	1602	1228	1165	1069	1180	1260	1217	1032	673	867
90	30	1020	1272	1457	1082	1000	908	1003	1097	1093	954	635	831
20	45	730	1108	1600	1570	1763	1744	1870	1728	1371	944	528	574
30	45	819	1204	1681	1584	1737	1700	1832	1727	1409	1002	574	646
40	45	887	1273	1727	1570	1685	1633	1768	1696	1420	1039	608	704
50	45	934	1311	1734	1527	1606	1542	1677	1637	1404	1054	627	743
60	45	956	1317	1704	1458	1504	1430	1561	1550	1360	1045	632	764
70	45	955	1292	1636	1363	1379	1300	1425	1438	1289	1013	623	765
80	45	929	1236	1533	1246	1238	1157	1272	1304	1194	959	599	747
90	45	880	1153	1401	1114	1088	1009	1112	1158	1081	886	562	711

CHARLESTON SC 32.54

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	
HORIZONTAL RAD.	931	1115	1443	1896	2025	2062	1925	1826	1502	1263	1049	795	(BTU/DAY-FT2)
AVE. TEMP.	50.0	50.0	57.2	64.4	71.6	77.0	80.6	78.8	75.2	66.2	57.2	50.0	(F)
DEGREE-DAYS	487.	389.	291.	54.	0.	0.	0.	0.	0.	59.	282.	471.	(F-DAYS)

AVERAGE DAILY RADIATION ON TILTED SURFACES (BTU/DAY-FT2)

SLOPE	AZIMUTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
20	0	1257	1369	1619	1952	1951	1930	1827	1824	1622	1511	1396	1086
30	0	1376	1449	1652	1915	1855	1811	1726	1765	1628	1583	1520	1194
40	0	1461	1495	1647	1834	1722	1658	1593	1669	1596	1618	1607	1273
50	0	1509	1504	1603	1714	1558	1478	1432	1539	1529	1613	1653	1321
60	0	1519	1477	1522	1557	1366	1277	1249	1379	1428	1570	1656	1335
70	0	1490	1415	1407	1368	1156	1062	1051	1195	1296	1489	1618	1315
80	0	1424	1319	1261	1155	934	845	847	993	1137	1373	1538	1263
90	0	1325	1196	1093	929	721	647	656	787	960	1229	1423	1181
20	15	1244	1359	1612	1952	1955	1936	1832	1826	1619	1501	1383	1075
30	15	1358	1434	1643	1918	1863	1821	1735	1770	1624	1569	1501	1178
40	15	1437	1475	1637	1843	1737	1675	1607	1679	1595	1599	1582	1253
50	15	1481	1481	1593	1729	1579	1501	1452	1555	1530	1591	1623	1296
60	15	1487	1451	1513	1581	1396	1307	1276	1403	1433	1544	1622	1307
70	15	1456	1387	1399	1402	1194	1101	1086	1228	1306	1462	1581	1285
80	15	1388	1290	1256	1201	982	891	890	1037	1154	1345	1500	1231
90	15	1288	1166	1092	990	777	697	704	843	986	1200	1384	1148
20	30	1208	1331	1594	1949	1965	1951	1844	1828	1607	1474	1344	1042
30	30	1305	1394	1621	1920	1886	1850	1758	1780	1612	1532	1445	1131
40	30	1370	1426	1612	1854	1775	1720	1645	1700	1584	1554	1510	1192
50	30	1401	1425	1569	1752	1635	1566	1508	1591	1524	1541	1538	1223
60	30	1397	1390	1493	1619	1472	1392	1350	1455	1434	1493	1527	1225
70	30	1358	1324	1387	1459	1293	1206	1180	1299	1317	1411	1479	1196
80	30	1286	1228	1255	1280	1104	1017	1003	1128	1178	1298	1394	1138
90	30	1185	1108	1105	1093	921	838	835	956	1027	1163	1278	1054
20	45	1154	1289	1565	1939	1975	1970	1857	1827	1587	1434	1287	994
30	45	1228	1338	1584	1913	1908	1885	1785	1786	1588	1477	1365	1062
40	45	1275	1358	1573	1855	1813	1775	1689	1716	1561	1490	1411	1105
50	45	1291	1349	1531	1766	1693	1642	1570	1620	1505	1472	1425	1123
60	45	1278	1312	1460	1648	1551	1491	1433	1501	1423	1424	1406	1114
70	45	1235	1247	1363	1507	1393	1328	1282	1363	1318	1346	1355	1080
80	45	1164	1158	1243	1348	1226	1159	1124	1211	1194	1243	1273	1021
90	45	1070	1050	1110	1181	1060	996	970	1057	1058	1121	1166	941

CHICAGO	IL	41.59											
	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	
HORIZONTAL RAD.	353	541	836	1220	1563	1688	1743	1485	1153	763	442	280	(BTU/DAY-FT2)
AVE. TEMP.	24.8	28.4	35.6	48.2	59.0	69.8	73.4	73.4	64.4	53.6	39.2	30.2	(F)
DEGREE-DAYS	1265.	1086.	939.	534.	260.	72.	0.	12.	117.	381.	807.	1166.	(F-DAYS)

AVERAGE DAILY RADIATION ON TILTED SURFACES (BTU/DAY-FT2)

SLOPE	AZIMUTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
20	0	455	656	945	1281	1551	1632	1705	1528	1286	935	576	356
30	0	492	693	970	1273	1502	1561	1639	1503	1311	990	626	384
40	0	519	716	975	1239	1425	1463	1544	1447	1307	1024	662	403
50	0	535	723	959	1180	1322	1341	1421	1363	1274	1034	682	415
60	0	538	715	924	1098	1196	1198	1274	1252	1212	1020	687	417
70	0	530	691	869	996	1052	1040	1109	1119	1125	983	676	411
80	0	510	653	797	876	895	872	931	967	1015	924	650	396
90	0	479	602	712	746	734	707	754	806	887	846	610	373
20	15	451	651	941	1280	1552	1634	1707	1528	1282	928	571	353
30	15	487	687	965	1273	1506	1566	1644	1505	1307	980	618	379
40	15	512	707	969	1242	1431	1472	1552	1452	1303	1011	652	398
50	15	526	713	952	1186	1332	1353	1433	1372	1271	1019	671	408
60	15	528	704	916	1107	1211	1215	1291	1265	1212	1003	674	410
70	15	519	679	862	1009	1071	1061	1131	1137	1128	965	662	403
80	15	498	640	791	894	919	897	959	991	1021	904	635	387
90	15	468	589	706	769	764	736	787	836	898	826	594	364
20	30	440	638	930	1275	1556	1641	1713	1526	1270	909	556	344
30	30	470	668	950	1270	1515	1581	1658	1507	1292	955	597	367
40	30	490	685	952	1242	1449	1496	1576	1461	1288	980	624	382
50	30	500	686	935	1191	1360	1388	1469	1390	1258	983	637	389
60	30	499	674	900	1119	1250	1261	1341	1294	1202	964	636	388
70	30	488	647	847	1028	1123	1120	1194	1177	1123	924	621	380
80	30	466	608	779	922	983	968	1037	1044	1024	865	592	363
90	30	435	558	700	808	841	818	877	904	910	789	551	339
20	45	423	620	912	1265	1557	1649	1719	1519	1249	882	534	331
30	45	446	642	927	1259	1522	1598	1672	1503	1266	917	565	348
40	45	460	653	926	1233	1465	1525	1602	1462	1260	935	584	358
50	45	464	651	908	1186	1387	1431	1509	1399	1231	933	591	361
60	45	460	636	873	1121	1289	1320	1396	1313	1179	912	586	357
70	45	446	608	823	1039	1175	1193	1266	1208	1106	872	568	346
80	45	422	570	760	942	1049	1057	1124	1089	1015	816	539	328
90	45	392	523	687	838	919	919	979	961	912	746	499	305

CLEVELAND	OH 41.24	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	
HORIZONTAL RAD.		456	662	1148	1388	1925	2058	2029	1815	1384	968	519	423	(BTU/DAY-FT2)
AVE. TEMP.		28.4	28.4	35.6	46.4	57.2	66.2	71.6	69.8	64.4	53.6	41.0	32.0	(F)
DEGREE-DAYS		1159.	1047.	918.	552.	260.	66.	9.	25.	105.	384.	738.	1088.	(F-DAYS)

AVERAGE DAILY RADIATION ON TILTED SURFACES (BTU/DAY-FT2)

SLOPE	AZIMUTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
20	0	626	831	1343	1466	1913	1984	1982	1877	1565	1226	699	605
30	0	690	889	1395	1459	1851	1894	1903	1849	1602	1313	767	677
40	0	739	927	1415	1421	1753	1768	1787	1781	1602	1368	817	732
50	0	770	943	1402	1353	1620	1612	1639	1674	1564	1391	847	770
60	0	783	938	1357	1258	1458	1429	1462	1534	1491	1379	857	789
70	0	777	911	1281	1138	1271	1227	1263	1363	1384	1334	847	788
80	0	752	863	1175	998	1068	1013	1049	1169	1246	1256	816	768
90	0	710	798	1047	844	861	803	836	962	1085	1151	767	729
20	15	619	824	1336	1465	1915	1988	1985	1877	1560	1215	692	598
30	15	681	879	1386	1459	1856	1901	1909	1852	1596	1298	757	667
40	15	727	914	1404	1424	1762	1780	1799	1788	1597	1349	804	720
50	15	756	928	1390	1360	1635	1629	1655	1687	1561	1368	832	755
60	15	767	921	1344	1269	1479	1452	1485	1553	1491	1353	840	771
70	15	759	893	1268	1154	1299	1256	1292	1389	1387	1306	828	769
80	15	733	844	1164	1020	1102	1049	1085	1203	1254	1227	796	748
90	15	691	778	1039	873	902	844	878	1005	1100	1122	747	710
20	30	601	806	1317	1459	1920	1997	1993	1875	1543	1188	672	579
30	30	654	853	1361	1455	1870	1921	1927	1855	1577	1260	728	638
40	30	692	881	1376	1424	1788	1814	1830	1801	1577	1303	767	682
50	30	714	890	1360	1367	1675	1678	1702	1712	1544	1315	787	710
60	30	720	878	1316	1284	1535	1518	1546	1592	1478	1296	790	721
70	30	708	847	1243	1179	1373	1339	1373	1446	1382	1247	774	715
80	30	680	798	1145	1056	1194	1148	1185	1278	1259	1169	740	691
90	30	637	733	1028	922	1012	959	995	1099	1117	1068	690	651
20	45	573	779	1286	1446	1922	2009	2000	1866	1515	1148	643	548
30	45	614	815	1321	1442	1880	1946	1946	1849	1542	1205	686	594
40	45	642	835	1330	1414	1810	1855	1864	1802	1539	1236	714	627
50	45	655	838	1313	1362	1713	1739	1754	1725	1508	1241	727	645
60	45	654	823	1270	1287	1591	1599	1620	1620	1447	1219	723	649
70	45	639	791	1202	1193	1447	1441	1466	1490	1360	1171	704	637
80	45	609	743	1112	1081	1288	1271	1298	1340	1248	1098	669	611
90	45	568	683	1006	960	1124	1099	1127	1180	1121	1005	621	572

COLUMBIA MO 38.58

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	
HORIZONTAL RAD.	682	920	1266	1594	1955	2102	2113	1936	1649	1193	817	622	(BTU/DAY-FT2)
AVE. TEMP.	30.2	32.0	42.8	53.6	64.4	73.4	77.0	75.2	68.0	57.2	42.8	32.0	(F)
DEGREE-DAYS	1076.	874.	716.	324.	121.	12.	0.	0.	54.	251.	651.	967.	(F-DAYS)

AVERAGE DAILY RADIATION ON TILTED SURFACES (BTU/DAY-FT2)

SLOPE	AZIMUTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
20	0	934	1178	1465	1675	1925	2009	2046	1985	1859	1507	1150	914
30	0	1039	1267	1514	1661	1853	1907	1954	1945	1898	1612	1276	1029
40	0	1117	1326	1529	1611	1744	1770	1824	1863	1892	1676	1370	1118
50	0	1168	1353	1508	1527	1602	1602	1660	1740	1841	1699	1429	1178
60	0	1189	1346	1451	1410	1432	1409	1468	1582	1745	1679	1452	1208
70	0	1180	1307	1361	1265	1238	1197	1254	1394	1609	1618	1436	1207
80	0	1142	1235	1241	1097	1029	976	1028	1181	1436	1516	1384	1175
90	0	1076	1137	1097	915	819	763	806	957	1236	1380	1299	1114
20	15	924	1168	1457	1674	1927	2013	2050	1986	1853	1495	1137	903
30	15	1024	1253	1505	1663	1859	1915	1961	1949	1892	1593	1257	1013
40	15	1098	1307	1517	1616	1755	1784	1837	1871	1887	1653	1346	1097
50	15	1146	1330	1495	1536	1619	1622	1679	1756	1838	1671	1401	1154
60	15	1163	1320	1439	1425	1455	1435	1494	1605	1747	1648	1420	1181
70	15	1152	1279	1350	1287	1268	1230	1288	1425	1616	1584	1402	1177
80	15	1112	1206	1231	1127	1067	1016	1069	1221	1450	1481	1348	1144
90	15	1046	1107	1090	954	865	809	854	1008	1258	1345	1262	1082
20	30	894	1140	1438	1668	1934	2025	2060	1985	1834	1462	1101	871
30	30	980	1213	1479	1659	1875	1939	1983	1955	1870	1548	1204	966
40	30	1042	1257	1489	1619	1784	1822	1873	1888	1865	1597	1278	1037
50	30	1078	1272	1466	1547	1663	1677	1733	1787	1820	1607	1320	1083
60	30	1088	1256	1411	1447	1517	1508	1567	1653	1736	1580	1329	1100
70	30	1071	1211	1327	1322	1349	1322	1382	1491	1615	1514	1304	1090
80	30	1027	1138	1216	1176	1167	1127	1184	1309	1463	1413	1246	1052
90	30	959	1042	1085	1020	984	936	988	1119	1289	1284	1159	989
20	45	850	1099	1406	1655	1938	2039	2070	1977	1801	1412	1047	823
30	45	916	1156	1439	1646	1889	1968	2006	1952	1830	1480	1128	897
40	45	962	1188	1443	1610	1811	1869	1914	1895	1823	1516	1183	950
50	45	986	1194	1419	1546	1707	1744	1793	1807	1781	1519	1211	980
60	45	986	1174	1367	1457	1579	1598	1649	1689	1704	1488	1209	986
70	45	963	1128	1289	1345	1431	1434	1486	1547	1596	1425	1179	969
80	45	918	1059	1187	1214	1269	1260	1310	1385	1459	1331	1121	928
90	45	853	970	1069	1074	1104	1086	1133	1215	1304	1214	1039	867

COLUMBUS OH 40.00

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	
HORIZONTAL RAD.	475	729	1089	1447	1797	2069	1995	1756	1554	1053	655	486	(BTU/DAY-FT2)
AVE. TEMP.	30.2	32.0	39.2	50.0	60.8	69.8	73.4	71.6	66.2	53.6	41.0	32.0	(F)
DEGREE-DAYS	1088.	949.	809.	426.	171.	27.	0.	6.	84.	347.	714.	1039.	(F-DAYS)

AVERAGE DAILY RADIATION ON TILTED SURFACES (BTU/DAY-FT2)

SLOPE	AZIMUTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
20	0	639	915	1254	1523	1777	1987	1942	1805	1759	1329	907	697
30	0	701	978	1295	1513	1715	1892	1860	1773	1800	1422	1002	780
40	0	747	1019	1308	1470	1621	1762	1743	1703	1799	1480	1073	844
50	0	775	1036	1290	1397	1496	1601	1594	1597	1755	1501	1117	887
60	0	785	1029	1243	1295	1344	1414	1418	1459	1669	1486	1134	908
70	0	776	998	1169	1168	1171	1209	1221	1294	1544	1434	1122	907
80	0	749	945	1069	1019	984	993	1011	1106	1385	1348	1082	882
90	0	705	871	949	858	794	783	803	908	1199	1231	1017	837
20	15	633	907	1248	1522	1779	1991	1945	1805	1753	1318	897	689
30	15	692	967	1287	1514	1720	1899	1867	1776	1794	1406	988	768
40	15	735	1005	1298	1474	1630	1774	1754	1710	1794	1459	1055	829
50	15	761	1020	1280	1405	1509	1619	1611	1609	1752	1477	1096	869
60	15	769	1011	1233	1308	1363	1439	1441	1478	1670	1459	1110	888
70	15	759	978	1159	1186	1197	1240	1251	1319	1550	1405	1096	885
80	15	731	923	1060	1044	1015	1030	1047	1139	1396	1317	1055	859
90	15	686	849	943	890	832	826	845	950	1218	1200	989	814
20	30	614	887	1232	1516	1783	2001	1953	1804	1734	1289	870	666
30	30	665	938	1266	1510	1733	1921	1885	1780	1772	1365	948	735
40	30	701	969	1274	1475	1654	1810	1786	1723	1772	1409	1004	786
50	30	720	977	1254	1413	1547	1670	1658	1634	1733	1420	1035	818
60	30	723	964	1209	1325	1415	1507	1505	1517	1657	1398	1041	830
70	30	709	929	1138	1214	1264	1326	1333	1374	1546	1342	1021	821
80	30	678	873	1045	1084	1100	1134	1148	1212	1405	1256	977	793
90	30	633	801	936	944	933	945	963	1042	1242	1144	910	746
20	45	587	857	1205	1504	1786	2014	1961	1796	1703	1246	829	631
30	45	626	897	1232	1497	1744	1947	1905	1776	1733	1306	890	684
40	45	652	918	1235	1466	1675	1853	1821	1726	1730	1338	931	722
50	45	663	920	1214	1410	1582	1733	1711	1649	1693	1342	951	743
60	45	660	903	1170	1330	1467	1591	1577	1545	1623	1316	949	746
70	45	642	867	1105	1230	1333	1432	1425	1418	1523	1262	925	732
80	45	611	814	1019	1114	1186	1260	1260	1274	1396	1181	880	701
90	45	567	746	920	987	1035	1089	1093	1120	1251	1079	817	656

CORPUS CHRISTI TX 27.46

		JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	
HORIZONTAL RAD.		965	1216	1522	1747	2068	2226	2318	2057	1732	2610	1050	884	(BTU/DAY-FT2)
AVE. TEMP.		55.4	59.0	64.4	71.6	77.0	80.6	84.2	84.2	80.6	73.4	64.4	59.0	(F)
DEGREE-DAYS		304.	199.	120.	0.	0.	0.	0.	0.	0.	7.	81.	219.	(F-DAYS)

AVERAGE DAILY RADIATION ON TILTED SURFACES (BTU/DAY-FT2)

SLOPE	AZIMUTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
20	0	1222	1439	1663	1757	1953	2038	2147	2015	1837	3488	1311	1140
30	0	1309	1502	1677	1704	1836	1886	1996	1928	1826	3766	1397	1229
40	0	1365	1529	1653	1615	1684	1699	1808	1799	1773	3926	1449	1289
50	0	1388	1521	1591	1492	1501	1485	1587	1634	1679	3962	1467	1318
60	0	1378	1476	1493	1340	1293	1252	1343	1437	1548	3872	1449	1314
70	0	1334	1398	1362	1163	1070	1009	1085	1216	1384	3661	1395	1279
80	0	1258	1287	1203	967	842	773	829	979	1190	3333	1309	1213
90	0	1154	1150	1023	765	632	576	606	744	979	2909	1194	1120
20	15	1212	1430	1657	1758	1959	2046	2155	2018	1834	3453	1300	1130
30	15	1294	1488	1670	1709	1847	1900	2011	1936	1824	3716	1382	1214
40	15	1346	1512	1645	1625	1702	1721	1830	1815	1773	3862	1430	1270
50	15	1365	1500	1583	1509	1527	1516	1619	1658	1684	3886	1443	1295
60	15	1362	1453	1487	1364	1329	1292	1386	1472	1558	3788	1422	1289
70	15	1306	1372	1359	1197	1116	1059	1140	1263	1400	3570	1367	1252
80	15	1228	1260	1203	1013	899	831	895	1040	1217	3240	1279	1184
90	15	1125	1122	1030	827	698	634	677	823	1019	2817	1164	1091
20	30	1183	1404	1642	1758	1973	2068	2175	2025	1823	3362	1271	1100
30	30	1252	1453	1652	1715	1875	1939	2050	1954	1814	3593	1338	1172
40	30	1292	1468	1627	1640	1748	1781	1891	1847	1767	3716	1375	1216
50	30	1301	1451	1568	1536	1593	1600	1706	1709	1685	3727	1379	1231
60	30	1279	1400	1477	1406	1419	1401	1501	1544	1570	3627	1350	1216
70	30	1228	1319	1358	1256	1231	1195	1284	1360	1427	3420	1290	1173
80	30	1147	1210	1215	1093	1040	991	1068	1165	1262	3116	1200	1102
90	30	1044	1080	1059	929	861	808	871	975	1087	2736	1086	1008
20	45	1139	1367	1618	1754	1989	2095	2200	2030	1805	3225	1227	1057
30	45	1191	1402	1622	1716	1907	1988	2096	1969	1794	3412	1277	1110
40	45	1216	1408	1596	1650	1798	1855	1963	1877	1750	3507	1300	1139
50	45	1215	1386	1540	1558	1665	1700	1805	1758	1676	3508	1294	1143
60	45	1187	1334	1457	1443	1514	1529	1628	1615	1573	3415	1261	1121
70	45	1134	1257	1349	1311	1350	1349	1440	1454	1445	3234	1200	1074
80	45	1066	1157	1221	1166	1180	1168	1249	1282	1299	2974	1115	1004
90	45	961	1040	1083	1019	1017	998	1068	1111	1144	2655	1011	917

CORVALLIS OR 44.33

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	
HORIZONTAL RAD.	371	511	1034	1487	1870	2139	2467	2014	1469	865	515	298	(BTU/DAY-FT2)
AVE. TEMP.	37.4	42.8	44.6	50.0	55.4	60.8	64.4	64.4	60.8	51.8	44.6	41.0	(F)
DEGREE-DAYS	803.	627.	589.	426.	279.	135.	34.	34.	129.	366.	585.	719.	(F-DAYS)

AVERAGE DAILY RADIATION ON TILTED SURFACES (BTU/DAY-FT2)

SLOPE	AZIMUTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
20	0	522	637	1227	1600	1877	2082	2439	2121	1707	1121	745	421
30	0	581	681	1283	1605	1827	1998	2353	2105	1767	1211	835	470
40	0	627	710	1309	1574	1741	1876	2220	2042	1784	1272	905	508
50	0	657	723	1305	1510	1620	1721	2043	1934	1758	1302	952	534
60	0	672	720	1271	1413	1470	1537	1827	1784	1690	1300	976	547
70	0	671	701	1207	1287	1294	1330	1579	1596	1581	1266	974	548
80	0	653	667	1116	1136	1100	1108	1310	1378	1436	1201	948	535
90	0	620	619	1003	968	900	886	1036	1141	1262	1109	900	510
20	15	517	632	1220	1598	1879	2085	2442	2120	1701	1111	737	417
30	15	573	674	1274	1605	1831	2004	2361	2108	1760	1197	823	463
40	15	616	700	1298	1577	1748	1888	2234	2049	1778	1254	889	499
50	15	645	712	1293	1517	1633	1738	2064	1947	1753	1280	933	524
60	15	658	707	1258	1425	1488	1559	1855	1804	1688	1275	954	536
70	15	655	687	1194	1304	1318	1358	1616	1624	1584	1239	951	535
80	15	637	652	1104	1159	1130	1142	1355	1415	1443	1173	924	522
90	15	604	604	993	999	936	926	1090	1188	1276	1080	874	496
20	30	500	619	1201	1590	1882	2093	2450	2116	1680	1085	712	403
30	30	549	654	1249	1598	1842	2023	2382	2109	1734	1159	786	444
40	30	585	675	1269	1575	1770	1919	2272	2062	1750	1207	842	474
50	30	608	682	1262	1521	1667	1784	2122	1974	1728	1226	877	494
60	30	616	675	1228	1438	1537	1622	1935	1847	1668	1217	891	502
70	30	610	652	1167	1328	1383	1438	1719	1686	1571	1178	882	498
80	30	589	617	1081	1196	1212	1239	1482	1498	1441	1112	852	483
90	30	556	569	977	1050	1034	1038	1239	1294	1287	1023	802	457
20	45	475	598	1172	1573	1881	2103	2457	2101	1644	1045	674	383
30	45	513	626	1210	1579	1849	2046	2404	2097	1689	1105	733	414
40	45	540	641	1224	1559	1788	1959	2314	2058	1701	1141	776	436
50	45	555	643	1215	1511	1700	1844	2188	1983	1679	1153	800	449
60	45	557	632	1181	1437	1586	1703	2029	1873	1624	1139	805	451
70	45	547	609	1123	1338	1450	1541	1841	1732	1536	1100	792	444
80	45	524	573	1044	1219	1296	1364	1632	1565	1419	1037	760	427
90	45	491	529	949	1086	1136	1182	1415	1382	1281	955	711	401

DALLAS	TX	32.51											
	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	
HORIZONTAL RAD.	851	1131	1452	1673	1920	2193	2167	1983	1688	1338	962	814	(BTU/DAY-FT2)
AVE. TEMP.	44.6	48.2	55.4	66.2	73.4	80.6	84.2	84.2	77.0	66.2	55.4	46.4	(F)
DEGREE-DAYS	608.	437.	314.	71.	0.	0.	0.	0.	0.	55.	284.	521.	(F-DAYS)

AVERAGE DAILY RADIATION ON TILTED SURFACES (BTU/DAY-FT2)

SLOPE	AZIMUTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
20	0	1130	1391	1630	1716	1851	2050	2052	1983	1836	1612	1261	1117
30	0	1231	1473	1663	1681	1761	1920	1934	1918	1846	1692	1368	1230
40	0	1303	1520	1658	1611	1637	1755	1779	1812	1813	1732	1440	1312
50	0	1342	1530	1614	1506	1482	1560	1592	1669	1738	1729	1477	1362
60	0	1347	1503	1533	1371	1303	1342	1380	1492	1623	1684	1478	1377
70	0	1320	1440	1417	1209	1106	1110	1150	1288	1472	1598	1441	1357
80	0	1259	1343	1270	1026	899	876	915	1064	1288	1474	1368	1304
90	0	1170	1217	1099	834	698	663	694	836	1083	1319	1265	1219
20	15	1120	1380	1623	1716	1854	2056	2057	1985	1832	1600	1250	1105
30	15	1216	1458	1654	1684	1768	1931	1945	1924	1843	1676	1351	1213
40	15	1282	1500	1648	1618	1650	1773	1796	1824	1812	1711	1418	1291
50	15	1318	1506	1603	1519	1502	1585	1617	1688	1740	1704	1451	1336
60	15	1320	1476	1523	1390	1330	1376	1413	1520	1629	1656	1448	1348
70	15	1290	1411	1409	1237	1141	1152	1192	1326	1484	1568	1409	1326
80	15	1228	1312	1265	1064	943	927	966	1114	1309	1443	1335	1270
90	15	1139	1186	1099	884	750	718	753	900	1115	1288	1231	1185
20	30	1088	1352	1605	1713	1864	2073	2072	1988	1818	1571	1216	1072
30	30	1170	1417	1631	1686	1789	1963	1973	1936	1827	1635	1302	1164
40	30	1224	1450	1623	1627	1684	1823	1843	1849	1798	1662	1356	1227
50	30	1248	1449	1580	1538	1553	1656	1684	1728	1732	1650	1378	1261
60	30	1242	1414	1503	1422	1400	1469	1503	1579	1630	1600	1366	1263
70	30	1206	1346	1396	1283	1231	1269	1306	1407	1497	1513	1320	1234
80	30	1140	1249	1263	1128	1054	1066	1104	1219	1338	1392	1243	1174
90	30	1050	1127	1112	967	882	874	911	1030	1164	1247	1139	1088
20	45	1042	1309	1576	1705	1873	2094	2089	1986	1793	1526	1167	1021
30	45	1104	1359	1595	1680	1810	2002	2006	1942	1799	1576	1233	1092
40	45	1142	1380	1583	1628	1720	1884	1896	1867	1771	1592	1271	1137
50	45	1154	1372	1541	1549	1607	1741	1760	1762	1710	1575	1280	1156
60	45	1140	1334	1470	1445	1473	1579	1603	1632	1618	1524	1261	1148
70	45	1100	1269	1372	1322	1324	1404	1431	1480	1499	1442	1213	1113
80	45	1035	1178	1252	1184	1166	1223	1251	1314	1357	1332	1138	1053
90	45	951	1068	1117	1039	1010	1048	1076	1145	1202	1201	1042	971

DAVIS CA 38.33

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	
HORIZONTAL RAD.	581	942	1480	1944	2342	2585	2540	2249	1833	1281	795	544	(BTU/DAY-FT2)
AVE. TEMP.	44.6	48.2	51.8	57.2	62.6	69.8	73.4	71.6	69.8	62.6	51.8	44.6	(F)
DEGREE-DAYS	583.	414.	332.	178.	72.	0.	0.	0.	0.	56.	321.	546.	(F-DAYS)

AVERAGE DAILY RADIATION ON TILTED SURFACES (BTU/DAY-FT2)

SLOPE	AZIMUTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
20	0	793	1207	1736	2059	2306	2460	2455	2315	2083	1631	1107	772
30	0	873	1299	1803	2047	2216	2326	2337	2269	2133	1748	1225	859
40	0	932	1359	1826	1987	2081	2147	2172	2172	2130	1821	1313	926
50	0	968	1386	1805	1882	1903	1927	1965	2026	2074	1848	1367	971
60	0	981	1379	1740	1735	1689	1675	1721	1835	1967	1828	1386	991
70	0	970	1338	1633	1551	1446	1400	1461	1607	1812	1762	1370	986
80	0	935	1264	1488	1335	1184	1113	1165	1350	1614	1651	1319	957
90	0	879	1163	1313	1101	921	839	885	1078	1384	1503	1236	905
20	15	785	1197	1727	2058	2309	2466	2460	2316	2077	1617	1096	763
30	15	861	1283	1790	2049	2225	2338	2348	2275	2126	1728	1208	847
40	15	917	1339	1812	1994	2096	2166	2191	2184	2124	1795	1290	911
50	15	950	1362	1789	1896	1926	1955	1992	2045	2071	1817	1340	952
60	15	961	1362	1724	1756	1720	1712	1758	1865	1969	1794	1356	969
70	15	948	1369	1619	1581	1487	1447	1498	1647	1820	1724	1337	963
80	15	912	1234	1476	1377	1236	1170	1222	1402	1631	1612	1285	932
90	15	855	1133	1304	1156	983	904	953	1145	1412	1463	1202	880
20	30	781	1168	1701	2050	2318	2483	2474	2315	2054	1581	1061	738
30	30	827	1242	1758	2045	2247	2372	2378	2283	2100	1677	1158	811
40	30	873	1288	1775	1998	2135	2221	2241	2206	2098	1733	1226	864
50	30	898	1303	1752	1911	1986	2034	2066	2086	2050	1747	1264	896
60	30	902	1287	1690	1787	1804	1817	1859	1927	1956	1718	1271	906
70	30	884	1240	1590	1630	1596	1578	1626	1734	1820	1647	1245	894
80	30	845	1165	1457	1446	1372	1328	1380	1516	1647	1538	1188	860
90	30	787	1066	1298	1248	1145	1085	1136	1288	1449	1396	1105	807
20	45	726	1125	1661	2032	2324	2503	2488	2305	2015	1526	1010	700
30	45	777	1184	1706	2027	2265	2412	2410	2279	2052	1602	1086	756
40	45	810	1217	1717	1987	2172	2287	2298	2215	2049	1644	1137	795
50	45	825	1223	1692	1910	2045	2129	2149	2112	2004	1649	1161	816
60	45	822	1202	1633	1801	1889	1944	1971	1974	1920	1616	1158	817
70	45	800	1155	1542	1662	1707	1737	1770	1806	1798	1548	1128	800
80	45	760	1084	1421	1499	1509	1517	1553	1614	1644	1447	1071	764
90	45	705	992	1280	1323	1307	1298	1335	1412	1469	1319	992	712

DODGE CITY KA 37.46

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	
HORIZONTAL RAD.	953	1204	1590	1988	2073	2426	2393	2146	1815	1399	1031	854	(BTU/DAY-FT2)
AVE. TEMP.	30.2	33.8	41.0	53.6	62.6	73.4	78.8	77.0	68.0	55.4	41.0	32.0	(F)
DEGREE-DAYS	1051.	840.	719.	354.	124.	9.	0.	0.	33.	251.	666.	939.	(F-DAYS)

AVERAGE DAILY RADIATION ON TILTED SURFACES (BTU/DAY-FT2)

SLOPE	AZIMUTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
20	0	1417	1584	1867	2099	2033	2304	2306	2196	2048	1787	1487	1311
30	0	1598	1718	1938	2083	1952	2177	2193	2148	2090	1917	1661	1492
40	0	1737	1808	1962	2019	1832	2009	2037	2052	2082	1997	1792	1634
50	0	1829	1851	1938	1908	1677	1804	1842	1910	2022	2026	1875	1732
60	0	1872	1848	1866	1755	1491	1569	1614	1728	1913	2003	1908	1783
70	0	1865	1796	1748	1564	1281	1314	1362	1512	1758	1928	1891	1787
80	0	1808	1699	1589	1341	1056	1050	1097	1269	1562	1804	1822	1742
90	0	1706	1562	1396	1100	831	798	839	1014	1335	1639	1709	1652
20	15	1400	1569	1857	2099	2036	2310	2310	2197	2041	1772	1470	1294
30	15	1573	1696	1925	2085	1959	2188	2203	2153	2084	1894	1636	1467
40	15	1704	1780	1947	2026	1845	2027	2054	2063	2077	1968	1759	1602
50	15	1790	1818	1921	1922	1696	1830	1866	1929	2020	1992	1836	1694
60	15	1829	1810	1849	1777	1517	1604	1648	1756	1916	1965	1865	1741
70	15	1818	1755	1733	1596	1315	1357	1405	1550	1767	1887	1843	1740
80	15	1759	1656	1576	1385	1099	1102	1150	1318	1579	1761	1773	1693
90	15	1655	1518	1389	1158	883	857	901	1077	1364	1595	1659	1603
20	30	1349	1528	1830	2091	2044	2326	2324	2197	2020	1731	1420	1244
30	30	1499	1638	1890	2082	1978	2220	2231	2162	2059	1838	1563	1395
40	30	1609	1707	1908	2031	1878	2077	2101	2084	2053	1900	1666	1509
50	30	1677	1734	1882	1940	1746	1902	1935	1967	2001	1914	1726	1583
60	30	1701	1717	1813	1810	1587	1700	1741	1815	1905	1882	1741	1615
70	30	1680	1658	1703	1648	1406	1478	1524	1631	1769	1803	1710	1604
80	30	1614	1558	1558	1458	1212	1247	1295	1425	1598	1681	1634	1550
90	30	1509	1424	1385	1256	1017	1022	1069	1211	1403	1523	1518	1458
20	45	1274	1468	1786	2073	2050	2345	2337	2189	1984	1670	1346	1169
30	45	1391	1554	1834	2066	1995	2258	2261	2160	2015	1755	1459	1287
40	45	1475	1606	1845	2021	1910	2138	2152	2094	2007	1801	1537	1373
50	45	1521	1621	1818	1941	1796	1990	2012	1994	1959	1806	1577	1424
60	45	1530	1598	1753	1827	1658	1816	1844	1861	1873	1770	1579	1439
70	45	1500	1538	1653	1684	1499	1622	1655	1700	1751	1695	1541	1418
80	45	1432	1444	1522	1516	1326	1418	1453	1519	1599	1582	1465	1360
90	45	1332	1323	1369	1336	1151	1216	1251	1328	1426	1441	1358	1271

EAST LANSING MI 42.44

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	
HORIZONTAL RAD.	423	736	1082	1248	1730	1911	1881	1623	1299	891	475	379	(BTU/DAY-FT2)
AVE. TEMP.	23.0	24.8	32.0	46.4	55.4	66.2	69.8	68.0	60.8	50.0	37.4	28.4	(F)
DEGREE-DAYS	1262.	1142.	1011.	579.	273.	69.	6.	22.	138.	431.	813.	1163.	(F-DAYS)

AVERAGE DAILY RADIATION ON TILTED SURFACES (BTU/DAY-FT2)

SLOPE	AZIMUTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
20	0	586	959	1270	1317	1724	1850	1845	1681	1473	1131	642	544
30	0	649	1039	1321	1311	1672	1770	1776	1658	1510	1213	706	609
40	0	696	1094	1343	1279	1588	1659	1674	1600	1512	1266	753	660
50	0	727	1123	1333	1220	1473	1519	1541	1509	1480	1288	782	695
60	0	741	1124	1292	1137	1333	1355	1382	1387	1414	1279	793	713
70	0	737	1099	1222	1033	1171	1171	1201	1240	1315	1240	785	713
80	0	715	1047	1125	910	993	977	1007	1071	1188	1170	757	696
90	0	677	972	1006	776	811	784	812	891	1040	1076	713	662
20	15	580	950	1263	1316	1726	1853	1847	1681	1468	1121	636	538
30	15	640	1026	1312	1312	1676	1777	1781	1660	1505	1199	697	600
40	15	685	1078	1332	1281	1595	1669	1683	1605	1508	1248	741	648
50	15	714	1103	1321	1226	1485	1534	1555	1518	1477	1267	768	681
60	15	726	1102	1280	1146	1350	1374	1401	1402	1413	1256	777	697
70	15	720	1075	1210	1046	1193	1196	1226	1260	1318	1214	767	696
80	15	697	1022	1114	928	1021	1007	1038	1098	1196	1143	739	678
90	15	659	947	997	800	845	819	849	925	1052	1048	695	644
20	30	562	926	1244	1311	1729	1861	1854	1678	1452	1096	618	520
30	30	614	992	1288	1308	1687	1793	1796	1662	1486	1164	670	574
40	30	651	1034	1304	1281	1616	1698	1709	1615	1488	1204	706	615
50	30	674	1052	1292	1230	1518	1575	1594	1538	1459	1217	727	641
60	30	680	1046	1252	1158	1395	1430	1455	1434	1399	1202	730	652
70	30	671	1015	1185	1066	1253	1267	1296	1306	1311	1158	717	647
80	30	646	961	1094	957	1096	1092	1124	1159	1197	1088	686	626
90	30	607	887	984	839	935	918	949	1002	1066	997	641	592
20	45	535	891	1215	1299	1730	1870	1859	1669	1425	1058	590	492
30	45	575	942	1250	1296	1694	1814	1812	1655	1452	1112	630	534
40	45	603	974	1260	1271	1634	1733	1738	1615	1452	1143	657	564
50	45	617	984	1246	1225	1548	1627	1639	1548	1424	1148	670	581
60	45	617	973	1207	1159	1441	1500	1517	1455	1368	1129	668	585
70	45	604	941	1144	1075	1314	1356	1376	1341	1288	1086	651	576
80	45	577	888	1061	977	1173	1199	1222	1209	1185	1020	620	553
90	45	539	819	961	869	1026	1040	1063	1068	1066	936	576	519

EL PASO TX 31.48

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	
HORIZONTAL RAD.	1218	1590	2021	2411	2632	2688	2467	2353	2117	1701	1351	1152	(BTU/DAY-FT2)
AVE. TEMP.	44.6	48.2	55.4	62.6	71.6	80.6	80.6	78.8	73.4	64.4	51.8	44.6	(F)
DEGREE-DAYS	685.	445.	319.	105.	0.	0.	0.	0.	0.	84.	414.	648.	(F-DAYS)

AVERAGE DAILY RADIATION ON TILTED SURFACES (BTU/DAY-FT2)

SLOPE	AZIMUTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
20	0	1700	2033	2326	2494	2517	2483	2319	2348	2328	2096	1856	1662
30	0	1878	2179	2391	2444	2377	2305	2174	2265	2347	2216	2040	1856
40	0	2008	2268	2395	2335	2186	2083	1986	2131	2307	2279	2170	2001
50	0	2084	2298	2338	2171	1950	1823	1761	1950	2210	2283	2242	2092
60	0	2105	2267	2221	1955	1678	1535	1507	1728	2058	2227	2254	2127
70	0	2070	2177	2048	1696	1379	1230	1234	1472	1855	2114	2206	2105
80	0	1979	2031	1824	1403	1068	927	956	1193	1609	1947	2099	2026
90	0	1840	1837	1562	1093	772	657	700	909	1333	1736	1940	1896
20	15	1682	2015	2315	2495	2524	2492	2326	2351	2322	2080	1837	1643
30	15	1852	2153	2377	2450	2391	2322	2188	2274	2342	2193	2012	1828
40	15	1973	2235	2379	2349	2209	2109	2008	2148	2305	2250	2133	1965
50	15	2043	2258	2321	2195	1985	1860	1793	1977	2213	2248	2198	2049
60	15	2058	2222	2206	1993	1725	1584	1549	1766	2067	2188	2205	2079
70	15	2019	2129	2036	1749	1441	1292	1288	1525	1874	2072	2152	2052
80	15	1927	1980	1818	1475	1145	1000	1022	1261	1640	1903	2043	1971
90	15	1787	1785	1564	1189	864	737	775	997	1381	1692	1883	1840
20	30	1628	1967	2285	2490	2541	2517	2345	2356	2303	2038	1781	1587
30	30	1774	2085	2339	2454	2428	2369	2225	2291	2321	2136	1931	1746
40	30	1874	2151	2339	2367	2271	2183	2068	2182	2288	2180	2030	1859
50	30	1925	2162	2283	2232	2075	1964	1879	2033	2204	2171	2076	1923
60	30	1925	2118	2175	2054	1848	1721	1665	1848	2072	2108	2068	1937
70	30	1876	2022	2019	1839	1599	1462	1434	1635	1898	1994	2006	1898
80	30	1777	1876	1820	1598	1341	1203	1198	1405	1688	1833	1891	1810
90	30	1636	1690	1592	1348	1093	963	976	1174	1458	1637	1732	1677
20	45	1549	1896	2236	2477	2559	2549	2367	2356	2269	1975	1698	1502
30	45	1662	1988	2278	2446	2465	2427	2268	2302	2282	2051	1815	1626
40	45	1735	2034	2273	2372	2335	2273	2136	2209	2251	2081	1888	1709
50	45	1765	2034	2220	2256	2170	2088	1976	2081	2176	2064	1914	1749
60	45	1752	1986	2122	2102	1976	1881	1792	1922	2059	2002	1894	1746
70	45	1697	1893	1982	1916	1762	1658	1592	1737	1905	1896	1828	1699
80	45	1600	1760	1806	1705	1536	1431	1384	1536	1721	1751	1718	1610
90	45	1470	1594	1607	1486	1315	1214	1184	1331	1519	1577	1574	1485

ELY NV 39.17

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	
HORIZONTAL RAD.	876	1226	1708	2076	2297	2607	2386	2238	1911	1447	1056	810	(BTU/DAY-FT2)
AVE. TEMP.	24.8	28.4	32.0	41.0	50.0	57.2	66.2	64.4	55.4	44.6	33.8	26.6	(F)
DEGREE-DAYS	1308.	1075.	977.	672.	456.	225.	28.	43.	234.	592.	939.	1184.	(F-DAYS)

AVERAGE DAILY RADIATION ON TILTED SURFACES (BTU/DAY-FT2)

SLOPE	AZIMUTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
20	0	1329	1660	2054	2218	2270	2489	2314	2312	2195	1903	1593	1284
30	0	1508	1817	2152	2211	2186	2357	2209	2271	2257	2061	1802	1475
40	0	1647	1927	2195	2153	2057	2180	2060	2178	2261	2165	1963	1626
50	0	1742	1987	2182	2043	1886	1961	1872	2036	2208	2211	2070	1734
60	0	1790	1994	2113	1887	1679	1709	1650	1849	2100	2200	2121	1794
70	0	1790	1949	1991	1689	1443	1432	1402	1624	1939	2130	2114	1806
80	0	1742	1853	1819	1455	1188	1143	1139	1369	1732	2004	2050	1768
90	0	1649	1712	1607	1199	931	865	880	1099	1488	1829	1932	1684
20	15	1312	1644	2042	2216	2273	2494	2318	2313	2188	1885	1573	1267
30	15	1483	1793	2135	2213	2193	2369	2218	2276	2249	2035	1773	1449
40	15	1615	1896	2175	2160	2070	2199	2076	2189	2255	2131	1925	1593
50	15	1704	1949	2161	2058	1907	1989	1895	2055	2205	2172	2025	1695
60	15	1747	1952	2092	1910	1709	1746	1681	1877	2102	2155	2071	1750
70	15	1744	1903	1971	1722	1482	1479	1443	1663	1948	2081	2059	1758
80	15	1693	1805	1802	1500	1237	1199	1189	1420	1749	1953	1992	1718
90	15	1600	1663	1595	1259	990	929	939	1164	1517	1779	1874	1633
20	30	1263	1597	2009	2207	2281	2511	2330	2311	2162	1838	1515	1216
30	30	1411	1727	2092	2208	2214	2402	2244	2283	2219	1969	1688	1375
40	30	1523	1813	2127	2163	2107	2253	2120	2210	2225	2051	1816	1497
50	30	1594	1853	2111	2074	1964	2066	1960	2094	2180	2080	1896	1580
60	30	1623	1845	2045	1942	1788	1849	1770	1937	2085	2056	1925	1620
70	30	1609	1791	1931	1774	1586	1609	1556	1747	1945	1981	1902	1617
80	30	1552	1692	1774	1575	1366	1356	1327	1531	1764	1856	1828	1570
90	30	1457	1554	1583	1360	1144	1109	1100	1303	1554	1690	1708	1484
20	45	1190	1529	1955	2185	2285	2530	2341	2301	2119	1767	1429	1138
30	45	1306	1632	2023	2186	2231	2442	2272	2278	2165	1873	1566	1263
40	45	1391	1698	2049	2148	2142	2318	2168	2217	2168	1935	1665	1356
50	45	1441	1723	2030	2070	2020	2161	2032	2117	2127	1953	1721	1415
60	45	1454	1708	1968	1956	1868	1976	1868	1982	2042	1924	1734	1437
70	45	1431	1652	1865	1808	1691	1767	1682	1816	1917	1851	1702	1421
80	45	1372	1568	1724	1632	1497	1545	1480	1626	1756	1736	1627	1370
90	45	1281	1433	1555	1441	1298	1323	1276	1424	1571	1587	1515	1285

FAIRBANKS AK 64.49

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	
HORIZONTAL RAD.	70	279	858	1417	1756	1940	1635	1336	877	316	99	22	(BTU/DAY-FT2)
AVE. TEMP.	-11.2	-2.2	8.6	30.2	46.4	57.2	59.0	53.6	42.8	26.6	3.2	-7.6	(F)
DEGREE-DAYS	2359.	1901.	1739.	1068.	555.	222.	171.	332.	842.	1203.	1833.	2254.	(F-DAYS)

AVERAGE DAILY RADIATION ON TILTED SURFACES (BTU/DAY-FT2)

SLOPE	AZIMUTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
20	0	369	636	1387	1736	1866	1957	1679	1509	884	571	354	180
30	0	504	791	1600	1840	1883	1939	1674	1555	958	679	469	252
40	0	625	924	1771	1901	1864	1890	1640	1569	1011	770	570	317
50	0	728	1032	1892	1916	1808	1807	1576	1549	1038	839	655	372
60	0	809	1110	1962	1884	1715	1692	1483	1495	1041	887	721	416
70	0	866	1167	1978	1806	1589	1547	1363	1409	1019	910	765	448
80	0	896	1171	1939	1685	1432	1376	1221	1293	973	909	788	467
90	0	901	1152	1849	1527	1255	1190	1064	1154	905	883	787	471
20	15	358	623	1369	1731	1864	1956	1679	1506	879	562	345	174
30	15	489	772	1576	1836	1882	1940	1674	1553	953	666	456	244
40	15	606	901	1739	1899	1865	1893	1641	1569	1005	752	554	307
50	15	705	1004	1856	1916	1812	1813	1579	1550	1033	819	635	360
60	15	783	1078	1922	1888	1722	1700	1489	1499	1037	864	698	403
70	15	837	1123	1935	1813	1599	1557	1372	1415	1016	885	741	433
80	15	867	1135	1895	1696	1445	1390	1232	1302	971	882	762	451
90	15	871	1116	1805	1543	1271	1207	1077	1166	904	857	761	455
20	30	328	586	1324	1714	1859	1956	1676	1498	863	536	320	158
30	30	445	719	1513	1820	1880	1943	1675	1547	933	628	418	221
40	30	549	831	1663	1887	1869	1901	1647	1566	982	704	505	277
50	30	637	921	1770	1911	1822	1828	1590	1554	1009	761	577	324
60	30	706	985	1829	1891	1741	1723	1506	1509	1012	798	633	362
70	30	754	1021	1839	1827	1626	1588	1396	1434	993	814	670	390
80	30	780	1029	1799	1721	1482	1428	1262	1329	950	808	688	405
90	30	782	1008	1713	1579	1316	1252	1114	1201	887	782	685	409
20	45	280	531	1252	1678	1850	1954	1672	1481	836	498	278	133
30	45	375	639	1417	1778	1875	1946	1674	1531	898	574	358	184
40	45	459	730	1548	1845	1872	1913	1653	1555	941	637	427	229
50	45	530	801	1640	1873	1837	1850	1605	1549	965	683	485	268
60	45	584	850	1690	1861	1768	1756	1531	1514	968	712	528	298
70	45	622	876	1697	1807	1667	1634	1431	1448	949	722	556	320
80	45	641	878	1659	1713	1536	1486	1308	1355	909	714	569	332
90	45	642	856	1580	1585	1383	1321	1170	1238	851	688	565	335

FORT WORTH TX 32.50

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	
HORIZONTAL RAD.	927	1182	1565	1078	2065	2364	2253	2165	1841	1450	1097	898	(BTU/DAY-FT2)
AVE. TEMP.	44.6	48.2	55.4	64.4	71.6	80.6	84.2	84.2	77.0	66.2	55.4	46.4	(F)
DEGREE-DAYS	614.	448.	319.	99.	0.	0.	0.	0.	0.	65.	324.	536.	(F-DAYS)

AVERAGE DAILY RADIATION ON TILTED SURFACES (BTU/DAY-FT2)

SLOPE	AZIMUTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
20	0	1250	1461	1767	1090	1989	2204	2132	2168	2014	1765	1470	1254
30	0	1368	1550	1807	1065	1891	2060	2007	2097	2029	1859	1604	1388
40	0	1452	1601	1803	1020	1755	1878	1845	1979	1995	1907	1698	1488
50	0	1500	1614	1758	957	1586	1663	1648	1820	1914	1908	1749	1549
60	0	1509	1587	1670	877	1390	1424	1425	1622	1787	1861	1754	1570
70	0	1480	1521	1544	784	1174	1169	1184	1395	1619	1767	1715	1550
80	0	1414	1419	1383	679	947	912	936	1145	1415	1631	1631	1491
90	0	1315	1286	1196	569	728	679	705	890	1185	1459	1509	1396
20	15	1238	1449	1759	1090	1993	2211	2137	2170	2009	1752	1456	1241
30	15	1350	1533	1797	1067	1899	2073	2019	2104	2025	1840	1583	1369
40	15	1429	1580	1792	1024	1770	1899	1863	1993	1993	1883	1671	1462
50	15	1472	1589	1746	963	1608	1692	1674	1842	1915	1879	1716	1518
60	15	1478	1558	1659	886	1420	1462	1460	1655	1794	1829	1718	1535
70	15	1446	1490	1535	796	1213	1217	1229	1439	1633	1733	1675	1513
80	15	1379	1386	1377	696	996	969	991	1203	1438	1596	1590	1452
90	15	1279	1253	1196	592	787	741	768	963	1221	1424	1467	1356
20	30	1202	1419	1739	1089	2004	2230	2153	2174	1993	1718	1414	1201
30	30	1297	1490	1771	1067	1923	2110	2049	2117	2007	1794	1523	1311
40	30	1362	1526	1764	1028	1809	1956	1913	2022	1978	1828	1594	1388
50	30	1392	1527	1719	972	1666	1773	1746	1889	1906	1817	1626	1430
60	30	1388	1491	1637	901	1499	1568	1556	1723	1795	1764	1616	1436
70	30	1349	1421	1521	817	1315	1349	1350	1532	1649	1670	1566	1405
80	30	1277	1318	1376	725	1122	1126	1138	1324	1472	1538	1476	1339
90	30	1177	1190	1210	631	935	918	936	1114	1279	1377	1354	1241
20	45	1148	1373	1706	1085	2014	2254	2171	2172	1965	1668	1353	1142
30	45	1222	1428	1729	1065	1946	2154	2085	2125	1974	1726	1437	1227
40	45	1268	1452	1719	1028	1849	2024	1969	2043	1946	1748	1488	1282
50	45	1284	1444	1675	977	1726	1869	1827	1928	1881	1731	1505	1307
60	45	1270	1406	1599	911	1581	1692	1663	1784	1781	1678	1486	1301
70	45	1227	1337	1494	835	1419	1502	1483	1617	1650	1589	1432	1264
80	45	1156	1242	1363	751	1248	1305	1295	1434	1494	1469	1346	1196
90	45	1063	1126	1216	663	1078	1115	1112	1246	1323	1325	1234	1104

FRESNO CA 36.46

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	
HORIZONTAL RAD.	684	1089	1612	2006	2345	2566	2459	2231	1852	1380	887	589	(BTU/DAY-FT2)
AVE. TEMP.	44.6	50.0	53.6	60.8	66.2	73.4	80.6	78.8	73.4	64.4	53.6	44.6	(F)
DEGREE-DAYS	605.	426.	335.	162.	62.	6.	0.	0.	0.	84.	354.	577.	(F-DAYS)

AVERAGE DAILY RADIATION ON TILTED SURFACES (BTU/DAY-FT2)

SLOPE	AZIMUTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
20	0	932	1393	1880	2109	2292	2425	2360	2275	2079	1739	1220	815
30	0	1025	1497	1947	2088	2194	2283	2238	2221	2117	1856	1343	901
40	0	1093	1563	1966	2019	2051	2097	2072	2116	2104	1926	1433	965
50	0	1134	1591	1937	1904	1866	1873	1867	1964	2039	1947	1487	1006
60	0	1147	1580	1860	1746	1647	1618	1628	1771	1924	1918	1503	1022
70	0	1131	1529	1738	1551	1400	1341	1365	1541	1763	1841	1480	1012
80	0	1088	1440	1575	1325	1136	1056	1090	1285	1561	1718	1420	978
90	0	1019	1319	1380	1081	874	788	824	1017	1328	1555	1325	921
20	15	923	1381	1870	2109	2296	2431	2365	2277	2073	1725	1207	806
30	15	1011	1479	1934	2091	2204	2296	2250	2227	2111	1835	1325	888
40	15	1075	1541	1951	2027	2067	2118	2091	2129	2099	1899	1410	949
50	15	1113	1565	1921	1919	1890	1902	1893	1985	2038	1915	1459	987
60	15	1123	1549	1844	1769	1680	1657	1664	1801	1928	1883	1471	1000
70	15	1106	1496	1724	1584	1443	1390	1412	1583	1773	1803	1445	989
80	15	1061	1406	1564	1371	1190	1116	1147	1339	1580	1678	1383	953
90	15	992	1284	1373	1141	940	855	891	1086	1359	1515	1288	896
20	30	895	1348	1844	2102	2307	2450	2380	2277	2052	1687	1170	781
30	30	971	1432	1900	2089	2228	2332	2280	2237	2087	1783	1271	852
40	30	1024	1482	1914	2033	2109	2176	2142	2153	2077	1836	1341	902
50	30	1052	1497	1883	1938	1954	1985	1968	2028	2020	1844	1378	931
60	30	1054	1475	1810	1805	1768	1766	1764	1865	1919	1807	1380	937
70	30	1031	1418	1697	1639	1558	1527	1539	1672	1778	1726	1347	920
80	30	983	1328	1549	1447	1332	1280	1302	1456	1602	1605	1281	882
90	30	913	1210	1374	1243	1108	1042	1071	1232	1403	1451	1186	823
20	45	854	1299	1802	2085	2315	2472	2395	2270	2016	1630	1116	743
30	45	913	1365	1846	2074	2250	2376	2314	2237	2044	1706	1195	798
40	45	951	1401	1853	2026	2150	2245	2198	2166	2033	1745	1247	834
50	45	967	1406	1822	1942	2018	2084	2050	2058	1981	1744	1269	852
60	45	962	1380	1754	1825	1858	1896	1876	1918	1890	1704	1261	849
70	45	934	1323	1651	1679	1674	1689	1680	1749	1764	1627	1224	827
80	45	885	1238	1517	1509	1476	1472	1471	1559	1608	1516	1159	787
90	45	819	1131	1362	1328	1275	1257	1264	1360	1432	1377	1070	730

GAINESVILLE	FL 29.39												
	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	
HORIZONTAL RAD.	1023	1351	1638	1984	2157	2003	1914	1870	1635	1355	1170	935	(BTU/DAY-FT2)
AVE. TEMP.	55.4	57.2	62.6	69.8	75.2	78.8	80.6	80.6	78.8	71.6	62.6	57.2	(F)
DEGREE-DAYS	332.	246.	174.	21.	0.	0.	0.	0.	0.	12.	144.	310.	(F-DAYS)

AVERAGE DAILY RADIATION ON TILTED SURFACES (BTU/DAY-FT2)

SLOPE	AZIMUTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
20	0	1340	1647	1820	2017	2052	1855	1797	1846	1745	1591	1519	1250
30	0	1452	1737	1847	1965	1936	1729	1686	1774	1741	1654	1640	1364
40	0	1528	1785	1831	1869	1782	1573	1545	1666	1697	1678	1719	1445
50	0	1566	1789	1772	1732	1594	1392	1378	1524	1614	1662	1756	1489
60	0	1565	1749	1672	1559	1379	1192	1190	1353	1496	1606	1748	1496
70	0	1524	1665	1533	1354	1147	981	990	1159	1345	1511	1695	1465
80	0	1446	1542	1359	1126	906	772	788	950	1167	1382	1600	1398
90	0	1335	1386	1162	888	681	590	604	739	970	1225	1469	1298
20	15	1327	1635	1813	2018	2057	1861	1802	1848	1742	1581	1505	1238
30	15	1434	1719	1839	1970	1947	1740	1696	1781	1738	1640	1620	1346
40	15	1505	1762	1822	1880	1799	1590	1561	1678	1696	1660	1694	1422
50	15	1538	1762	1762	1751	1620	1416	1400	1543	1617	1640	1725	1462
60	15	1534	1718	1663	1587	1415	1223	1220	1381	1503	1581	1713	1465
70	15	1490	1632	1526	1394	1193	1021	1028	1197	1359	1485	1658	1432
80	15	1410	1507	1357	1180	964	820	834	999	1189	1356	1561	1363
90	15	1299	1350	1166	960	749	639	655	803	1004	1199	1429	1263
20	30	1292	1602	1794	2017	2071	1878	1816	1853	1731	1555	1466	1202
30	30	1382	1673	1816	1975	1975	1771	1722	1794	1727	1604	1563	1295
40	30	1438	1705	1798	1896	1846	1638	1603	1704	1688	1617	1621	1355
50	30	1459	1697	1741	1781	1688	1483	1460	1584	1615	1593	1640	1383
60	30	1445	1648	1647	1634	1507	1311	1300	1440	1511	1534	1618	1376
70	30	1395	1561	1520	1463	1311	1130	1128	1276	1379	1440	1556	1336
80	30	1311	1439	1365	1273	1109	949	955	1102	1225	1316	1456	1262
90	30	1199	1290	1193	1080	917	782	792	929	1060	1170	1325	1161
20	45	1239	1553	1764	2010	2086	1899	1832	1855	1712	1516	1408	1149
30	45	1307	1607	1778	1974	2005	1810	1753	1804	1706	1552	1482	1220
40	45	1346	1626	1758	1904	1895	1696	1651	1726	1669	1557	1522	1262
50	45	1354	1610	1704	1803	1760	1563	1528	1622	1602	1529	1528	1275
60	45	1331	1560	1618	1675	1604	1414	1388	1495	1508	1471	1498	1258
70	45	1278	1477	1503	1524	1432	1254	1238	1351	1390	1383	1434	1213
80	45	1197	1365	1365	1356	1253	1092	1082	1196	1253	1270	1340	1140
90	45	1093	1231	1212	1184	1079	938	933	1040	1106	1140	1220	1045

GLASGOW MT 48.13

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	
HORIZONTAL RAD.	567	931	1388	1675	2069	2257	2356	1966	1509	986	570	434	(BTU/DAY-FT2)
AVE. TEMP.	10.4	15.8	26.6	42.8	53.6	62.6	69.8	69.8	57.2	46.4	30.2	17.6	(F)
DEGREE-DAYS	1711.	1439.	1187.	648.	335.	150.	31.	47.	270.	608.	1104.	1466.	(F-DAYS)

AVERAGE DAILY RADIATION ON TILTED SURFACES (BTU/DAY-FT2)

SLOPE	AZIMUTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
20	0	1026	1422	1785	1853	2109	2222	2359	2106	1818	1393	949	810
30	0	1218	1615	1919	1881	2068	2147	2295	2108	1908	1547	1104	968
40	0	1377	1765	2003	1865	1985	2031	2184	2062	1950	1661	1231	1101
50	0	1498	1868	2036	1806	1862	1878	2030	1970	1943	1731	1324	1204
60	0	1578	1920	2016	1707	1702	1691	1837	1835	1887	1755	1382	1273
70	0	1614	1920	1944	1569	1511	1477	1612	1660	1785	1734	1402	1307
80	0	1604	1868	1822	1397	1295	1244	1362	1452	1639	1667	1384	1305
90	0	1552	1768	1657	1202	1068	1006	1103	1223	1458	1558	1330	1268
20	15	1009	1404	1772	1850	2110	2225	2361	2104	1810	1378	935	796
30	15	1194	1589	1900	1880	2072	2153	2300	2109	1898	1524	1084	949
40	15	1346	1731	1981	1867	1993	2041	2195	2067	1941	1632	1205	1076
50	15	1461	1827	2011	1813	1875	1893	2047	1981	1936	1696	1293	1173
60	15	1536	1874	1989	1719	1721	1712	1860	1852	1883	1716	1347	1239
70	15	1568	1870	1917	1587	1536	1504	1642	1684	1785	1691	1364	1270
80	15	1557	1816	1796	1423	1326	1277	1399	1484	1644	1622	1344	1266
90	15	1504	1714	1634	1235	1106	1046	1148	1263	1470	1513	1290	1229
20	30	961	1352	1735	1838	2111	2231	2366	2098	1783	1337	895	757
30	30	1123	1514	1851	1869	2082	2169	2316	2108	1865	1466	1025	891
40	30	1255	1637	1923	1861	2015	2071	2224	2076	1905	1558	1129	1001
50	30	1352	1716	1949	1815	1911	1938	2093	2002	1901	1611	1203	1085
60	30	1413	1750	1926	1731	1773	1773	1925	1889	1853	1623	1245	1139
70	30	1435	1737	1857	1612	1605	1582	1727	1739	1762	1593	1253	1162
80	30	1417	1678	1742	1463	1413	1371	1504	1558	1632	1523	1228	1153
90	30	1362	1577	1591	1292	1210	1155	1271	1358	1471	1417	1172	1113
20	45	886	1277	1676	1813	2108	2239	2369	2079	1738	1275	834	695
30	45	1016	1409	1774	1840	2086	2190	2331	2091	1808	1381	938	802
40	45	1118	1507	1833	1835	2032	2109	2258	2066	1842	1455	1019	887
50	45	1192	1567	1852	1795	1944	1997	2149	2004	1836	1494	1074	950
60	45	1233	1588	1828	1721	1825	1854	2005	1906	1792	1498	1102	987
70	45	1242	1569	1763	1615	1678	1687	1832	1775	1710	1466	1101	998
80	45	1217	1510	1659	1482	1508	1499	1635	1614	1593	1399	1072	982
90	45	1161	1416	1523	1328	1325	1303	1426	1435	1448	1301	1016	940

GRAND JUNCTION CO 39.07

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	
HORIZONTAL RAD.	854	1196	1583	1962	2227	2607	2470	2139	1844	1392	968	795	(BTU/DAY-FT2)
AVE. TEMP.	26.6	32.0	41.0	51.8	60.8	71.6	77.0	75.2	66.2	53.6	39.2	30.2	(F)
DEGREE-DAYS	1209.	907.	729.	387.	146.	21.	0.	0.	30.	313.	786.	1111.	(F-DAYS)

AVERAGE DAILY RADIATION ON TILTED SURFACES (BTU/DAY-FT2)

SLOPE	AZIMUTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
20	0	1285	1610	1883	2088	2199	2488	2395	2205	2109	1814	1424	1252
30	0	1454	1759	1965	2079	2118	2356	2285	2164	2164	1959	1601	1435
40	0	1586	1863	1999	2022	1993	2178	2129	2075	2166	2053	1735	1580
50	0	1675	1918	1983	1919	1828	1959	1931	1940	2113	2094	1824	1682
60	0	1720	1924	1917	1772	1629	1706	1699	1763	2008	2080	1864	1739
70	0	1718	1879	1804	1587	1402	1429	1440	1550	1854	2011	1853	1749
80	0	1671	1785	1648	1370	1157	1140	1165	1309	1655	1891	1793	1712
90	0	1581	1649	1456	1132	910	862	894	1055	1423	1726	1688	1630
20	15	1269	1594	1872	2087	2202	2493	2399	2205	2102	1797	1407	1235
30	15	1431	1736	1951	2081	2125	2367	2295	2168	2157	1935	1576	1410
40	15	1555	1833	1982	2029	2006	2197	2146	2085	2160	2022	1703	1548
50	15	1639	1882	1964	1932	1848	1987	1956	1957	2110	2057	1786	1645
60	15	1679	1883	1899	1793	1657	1743	1733	1789	2010	2038	1820	1697
70	15	1674	1835	1787	1618	1439	1476	1483	1586	1862	1967	1806	1703
80	15	1625	1739	1633	1411	1203	1197	1218	1357	1672	1844	1744	1663
90	15	1534	1602	1445	1187	966	926	957	1115	1450	1678	1638	1581
20	30	1222	1550	1843	2078	2209	2510	2412	2204	2078	1754	1358	1185
30	30	1362	1673	1913	2076	2144	2401	2322	2175	2129	1874	1504	1338
40	30	1467	1754	1939	2032	2041	2251	2192	2104	2132	1947	1611	1455
50	30	1534	1790	1921	1947	1902	2065	2026	1993	2087	1972	1676	1534
60	30	1561	1782	1857	1823	1733	1847	1827	1844	1995	1947	1696	1572
70	30	1546	1728	1752	1665	1538	1607	1603	1664	1860	1874	1672	1568
80	30	1490	1631	1609	1479	1326	1354	1365	1459	1686	1754	1604	1521
90	30	1398	1497	1436	1278	1112	1107	1128	1244	1486	1596	1497	1437
20	45	1152	1485	1797	2059	2214	2530	2424	2194	2037	1688	1284	1111
30	45	1263	1583	1853	2057	2161	2441	2351	2171	2079	1784	1400	1230
40	45	1342	1644	1872	2019	2074	2317	2244	2111	2079	1840	1481	1319
50	45	1389	1667	1851	1944	1955	2160	2102	2015	2038	1854	1526	1375
60	45	1400	1651	1791	1835	1808	1974	1932	1886	1955	1825	1533	1395
70	45	1376	1596	1695	1696	1638	1765	1738	1728	1834	1753	1501	1379
80	45	1318	1504	1565	1531	1451	1543	1528	1547	1680	1643	1433	1328
90	45	1230	1382	1411	1352	1259	1321	1316	1356	1502	1501	1332	1246

GRAND LAKE CO 40.16

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	
HORIZONTAL RAD.	781	1153	1559	1887	2035	2330	2212	1861	1754	1330	862	678	(BTU/DAY-FT2)
AVE. TEMP.	15.8	19.4	24.8	32.0	42.8	50.0	55.4	53.6	46.4	37.4	26.6	17.6	(F)
DEGREE-DAYS	1556.	1322.	1296.	945.	685.	450.	276.	313.	504.	803.	1176.	1476.	(F-DAYS)

AVERAGE DAILY RADIATION ON TILTED SURFACES (BTU/DAY-FT2)

SLOPE	AZIMUTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
20	0	1183	1569	1869	2015	2015	2236	2153	1918	2012	1746	1267	1059
30	0	1342	1720	1957	2010	1946	2126	2061	1885	2068	1890	1424	1212
40	0	1465	1827	1996	1960	1837	1976	1929	1812	2073	1986	1544	1333
50	0	1551	1887	1986	1864	1692	1790	1761	1699	2027	2030	1623	1419
60	0	1595	1897	1925	1727	1517	1575	1562	1552	1931	2021	1660	1467
70	0	1596	1857	1817	1552	1316	1337	1338	1375	1788	1959	1653	1476
80	0	1555	1769	1665	1346	1097	1087	1100	1173	1602	1847	1602	1446
90	0	1475	1639	1477	1120	876	844	864	960	1385	1690	1511	1379
20	15	1168	1553	1858	2013	2018	2240	2157	1918	2005	1730	1252	1045
30	15	1320	1697	1942	2012	1952	2135	2069	1889	2060	1867	1402	1191
40	15	1437	1797	1979	1965	1848	1991	1943	1819	2067	1956	1515	1307
50	15	1517	1851	1967	1876	1709	1812	1781	1713	2023	1994	1590	1388
60	15	1557	1856	1906	1746	1540	1604	1589	1572	1931	1980	1622	1432
70	15	1555	1813	1799	1580	1347	1374	1373	1402	1794	1915	1611	1438
80	15	1512	1723	1649	1384	1136	1132	1143	1210	1616	1801	1558	1406
90	15	1431	1592	1464	1170	923	896	914	1006	1409	1644	1466	1338
20	30	1124	1509	1828	2004	2023	2253	2166	1917	1982	1687	1208	1004
30	30	1256	1634	1904	2006	1967	2161	2091	1893	2033	1807	1337	1131
40	30	1356	1718	1935	1967	1877	2034	1980	1834	2039	1882	1433	1229
50	30	1420	1758	1921	1888	1754	1874	1836	1740	1999	1910	1492	1296
60	30	1447	1754	1862	1772	1603	1687	1664	1615	1915	1890	1512	1328
70	30	1436	1705	1761	1623	1429	1478	1470	1463	1789	1822	1492	1325
80	30	1387	1614	1621	1446	1239	1258	1261	1289	1626	1710	1434	1287
90	30	1304	1485	1451	1253	1046	1040	1052	1107	1437	1561	1341	1218
20	45	1059	1443	1780	1985	2026	2268	2176	1908	1942	1622	1142	941
30	45	1163	1543	1841	1986	1980	2193	2114	1888	1984	1719	1245	1041
40	45	1239	1607	1864	1952	1904	2086	2021	1837	1987	1776	1318	1116
50	45	1283	1634	1848	1883	1798	1950	1898	1756	1950	1793	1359	1162
60	45	1296	1622	1792	1781	1667	1789	1749	1646	1874	1768	1366	1179
70	45	1276	1571	1700	1648	1513	1606	1579	1511	1761	1702	1339	1166
80	45	1225	1484	1573	1491	1344	1411	1394	1357	1616	1599	1280	1124
90	45	1145	1367	1421	1320	1170	1215	1206	1193	1448	1464	1192	1056

GREAT FALLS MT 47.29

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	
HORIZONTAL RAD.	508	843	1333	1579	1929	2176	2338	1947	1487	964	567	412	(BTU/DAY-FT2)
AVE. TEMP.	21.2	26.6	32.0	42.8	51.8	60.8	68.0	68.0	57.2	48.2	33.8	28.4	(F)
DEGREE-DAYS	1349.	1154.	1063.	642.	384.	186.	28.	53.	258.	543.	921.	1169.	(F-DAYS)

AVERAGE DAILY RADIATION ON TILTED SURFACES (BTU/DAY-FT2)

SLOPE	AZIMUTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
20	0	861	1233	1685	1732	1957	2137	2334	2076	1775	1335	915	727
30	0	1007	1384	1801	1751	1916	2061	2266	2074	1855	1473	1056	859
40	0	1127	1499	1871	1731	1835	1947	2153	2025	1890	1574	1171	969
50	0	1217	1575	1894	1672	1719	1798	1998	1931	1878	1634	1254	1052
60	0	1273	1610	1869	1576	1570	1617	1804	1794	1820	1652	1304	1107
70	0	1296	1602	1797	1446	1392	1411	1579	1620	1717	1626	1319	1132
80	0	1282	1552	1679	1286	1193	1187	1330	1413	1573	1559	1298	1126
90	0	1236	1463	1523	1104	985	960	1074	1187	1395	1453	1244	1091
20	15	848	1218	1673	1729	1958	2139	2336	2075	1767	1321	902	716
30	15	989	1363	1784	1751	1919	2067	2272	2075	1847	1453	1038	843
40	15	1103	1472	1851	1734	1843	1958	2164	2030	1882	1547	1147	947
50	15	1188	1543	1872	1679	1731	1813	2014	1942	1872	1602	1225	1027
60	15	1241	1573	1845	1588	1587	1638	1828	1811	1816	1616	1272	1079
70	15	1260	1562	1773	1463	1415	1437	1609	1644	1718	1587	1284	1101
80	15	1246	1510	1656	1309	1222	1219	1368	1445	1578	1518	1261	1094
90	15	1198	1421	1503	1135	1019	998	1119	1227	1407	1412	1207	1058
20	30	811	1177	1640	1719	1960	2146	2341	2069	1742	1283	865	683
30	30	934	1303	1740	1741	1928	2083	2288	2075	1816	1399	983	794
40	30	1032	1397	1800	1729	1863	1986	2194	2040	1849	1481	1077	885
50	30	1104	1454	1817	1681	1764	1856	2062	1964	1840	1525	1142	952
60	30	1146	1474	1790	1600	1634	1696	1894	1849	1789	1531	1177	994
70	30	1157	1456	1720	1487	1478	1512	1695	1699	1697	1498	1182	1010
80	30	1138	1401	1610	1347	1302	1310	1474	1520	1569	1428	1154	998
90	30	1089	1312	1466	1188	1115	1104	1244	1322	1411	1326	1098	960
20	45	753	1117	1587	1697	1957	2154	2345	2052	1700	1227	809	631
30	45	851	1219	1671	1717	1933	2104	2304	2059	1762	1321	904	719
40	45	927	1293	1720	1706	1879	2023	2229	2031	1790	1386	976	789
50	45	980	1335	1731	1665	1794	1913	2118	1967	1780	1419	1024	839
60	45	1008	1346	1703	1592	1682	1775	1974	1868	1733	1418	1047	867
70	45	1009	1323	1638	1491	1544	1613	1801	1736	1650	1383	1042	872
80	45	984	1268	1537	1365	1386	1432	1605	1576	1534	1316	1012	855
90	45	935	1185	1408	1222	1218	1245	1399	1399	1392	1222	957	816

GREENSBORO NC 36.05

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	
HORIZONTAL RAD.	754	1001	1303	1727	1962	2069	1992	1749	1517	1211	894	684	(BTU/DAY-FT2)
AVE. TEMP.	37.4	39.2	46.4	57.2	66.2	73.4	77.0	75.2	69.8	57.2	46.4	39.2	(F)
DEGREE-DAYS	784.	672.	552.	234.	47.	0.	0.	0.	33.	192.	513.	778.	(F-DAYS)

AVERAGE DAILY RADIATION ON TILTED SURFACES (BTU/DAY-FT2)

SLOPE	AZIMUTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
20	0	1040	1258	1484	1800	1915	1961	1913	1769	1671	1491	1223	970
30	0	1147	1344	1524	1777	1834	1853	1818	1724	1692	1580	1345	1080
40	0	1226	1398	1529	1715	1718	1711	1690	1642	1673	1630	1433	1163
50	0	1274	1417	1499	1616	1568	1539	1531	1527	1616	1640	1485	1217
60	0	1291	1403	1435	1483	1391	1344	1347	1382	1522	1610	1499	1240
70	0	1274	1354	1337	1320	1193	1133	1145	1212	1393	1540	1475	1231
80	0	1226	1273	1211	1132	982	916	933	1023	1235	1434	1413	1191
90	0	1149	1164	1062	931	773	710	729	827	1056	1296	1318	1122
20	15	1029	1248	1477	1799	1918	1966	1916	1770	1667	1480	1210	960
30	15	1131	1329	1515	1779	1841	1862	1826	1728	1688	1564	1326	1064
40	15	1206	1378	1519	1722	1730	1725	1703	1651	1670	1609	1409	1143
50	15	1250	1395	1488	1628	1587	1560	1550	1541	1615	1615	1457	1193
60	15	1263	1377	1424	1502	1417	1372	1373	1403	1524	1582	1467	1213
70	15	1244	1326	1328	1347	1226	1168	1178	1240	1401	1510	1440	1202
80	15	1195	1243	1203	1169	1023	957	974	1060	1249	1402	1377	1160
90	15	1117	1134	1058	979	822	757	776	874	1078	1264	1281	1091
20	30	997	1220	1459	1794	1926	1979	1927	1771	1652	1450	1174	928
30	30	1085	1289	1492	1778	1859	1887	1848	1735	1671	1522	1274	1018
40	30	1146	1329	1493	1727	1761	1766	1739	1667	1654	1559	1342	1084
50	30	1180	1337	1462	1644	1635	1618	1603	1570	1603	1559	1377	1122
60	30	1184	1314	1401	1530	1483	1449	1444	1446	1519	1522	1377	1133
70	30	1158	1260	1310	1390	1312	1264	1269	1301	1406	1450	1343	1115
80	30	1105	1178	1194	1229	1130	1073	1085	1139	1267	1345	1276	1069
90	30	1026	1071	1059	1059	949	889	904	972	1111	1214	1180	999
20	45	950	1178	1430	1782	1932	1995	1938	1767	1627	1406	1120	881
30	45	1018	1232	1455	1767	1876	1918	1872	1736	1641	1462	1198	951
40	45	1063	1260	1452	1722	1793	1815	1779	1677	1623	1487	1248	998
50	45	1083	1260	1421	1648	1683	1688	1662	1592	1576	1480	1269	1023
60	45	1078	1233	1362	1547	1550	1541	1524	1482	1499	1441	1260	1023
70	45	1048	1179	1278	1422	1400	1379	1369	1353	1397	1372	1222	998
80	45	993	1102	1173	1279	1238	1208	1205	1208	1272	1276	1155	951
90	45	919	1005	1052	1127	1074	1040	1041	1058	1133	1158	1066	883

GRIFFIN GA 33.15

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	
HORIZONTAL RAD.	876	1112	1428	1911	2124	2135	2058	1925	1609	1369	1060	773	(BTU/DAY-FT2)
AVE. TEMP.	42.8	46.4	51.8	60.8	69.8	75.2	77.0	77.0	71.6	62.6	51.8	44.6	(F)
DEGREE-DAYS	505.	403.	295.	63.	0.	0.	0.	0.	0.	71.	297.	502.	(F-DAYS)

AVERAGE DAILY RADIATION ON TILTED SURFACES (BTU/DAY-FT2)

SLOPE	AZIMUTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
20	0	1181	1372	1608	1973	2050	2002	1955	1929	1751	1664	1426	1061
30	0	1293	1456	1643	1938	1951	1879	1847	1869	1762	1753	1559	1170
40	0	1373	1505	1639	1859	1813	1721	1704	1769	1732	1799	1652	1249
50	0	1418	1517	1598	1740	1640	1535	1531	1632	1662	1800	1703	1297
60	0	1428	1492	1520	1583	1438	1326	1333	1463	1554	1757	1711	1313
70	0	1402	1432	1407	1393	1215	1102	1119	1267	1412	1671	1674	1295
80	0	1341	1337	1263	1178	980	876	898	1052	1240	1544	1595	1245
90	0	1249	1214	1097	950	753	668	689	832	1047	1384	1478	1165
20	15	1169	1362	1601	1973	2055	2007	1960	1931	1747	1652	1412	1050
30	15	1276	1441	1634	1942	1960	1889	1856	1875	1758	1736	1538	1154
40	15	1351	1485	1629	1868	1828	1738	1719	1780	1730	1777	1626	1228
50	15	1392	1493	1587	1755	1662	1559	1553	1650	1663	1774	1672	1272
60	15	1399	1466	1510	1606	1469	1357	1363	1489	1559	1728	1675	1285
70	15	1370	1403	1399	1427	1255	1142	1157	1303	1423	1639	1635	1265
80	15	1307	1306	1258	1224	1031	923	944	1099	1258	1511	1554	1213
90	15	1215	1183	1096	1011	813	720	742	892	1075	1351	1436	1133
20	30	1135	1333	1583	1969	2065	2023	1973	1934	1733	1621	1371	1018
30	30	1226	1400	1611	1943	1983	1919	1882	1885	1743	1692	1479	1107
40	30	1287	1434	1604	1878	1868	1785	1761	1803	1717	1724	1550	1168
50	30	1317	1435	1563	1777	1722	1626	1614	1688	1655	1715	1582	1201
60	30	1314	1402	1489	1644	1550	1445	1444	1544	1559	1666	1575	1204
70	30	1278	1337	1385	1484	1361	1252	1260	1379	1434	1579	1528	1177
80	30	1212	1242	1255	1302	1161	1054	1069	1197	1284	1455	1443	1121
90	30	1118	1123	1106	1113	966	868	886	1014	1119	1305	1325	1040
20	45	1085	1290	1553	1958	2076	2043	1988	1932	1710	1573	1311	970
30	45	1155	1342	1574	1935	2007	1956	1912	1890	1715	1628	1395	1038
40	45	1198	1364	1564	1878	1909	1842	1809	1819	1690	1649	1446	1082
50	45	1214	1358	1524	1789	1783	1705	1682	1719	1632	1634	1464	1101
60	45	1202	1322	1455	1672	1634	1549	1534	1593	1546	1584	1447	1094
70	45	1162	1258	1359	1530	1468	1379	1372	1447	1433	1502	1396	1061
80	45	1096	1169	1241	1369	1291	1203	1203	1286	1299	1389	1314	1005
90	45	1008	1061	1109	1201	1115	1033	1036	1122	1152	1254	1205	927

INDIANAPOLIS IN 39.44

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	
HORIZONTAL RAD.	641	788	1148	1447	1808	2014	1995	1789	1491	1078	648	478	(BTU/DAY-FT2)
AVE. TEMP.	28.4	32.0	39.2	51.8	60.8	71.6	75.2	73.4	66.2	55.4	41.0	32.0	(F)
DEGREE-DAYS	1113.	949.	809.	432.	177.	39.	0.	0.	90.	316.	723.	1051.	(F-DAYS)

AVERAGE DAILY RADIATION ON TILTED SURFACES (BTU/DAY-FT2)

SLOPE	AZIMUTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
20	0	743	994	1324	1519	1784	1931	1938	1836	1676	1357	885	674
30	0	819	1065	1368	1507	1721	1837	1855	1801	1711	1450	974	750
40	0	877	1111	1380	1463	1624	1710	1736	1728	1705	1507	1039	808
50	0	913	1131	1361	1389	1497	1553	1585	1619	1660	1528	1079	846
60	0	927	1124	1311	1286	1343	1371	1408	1477	1576	1511	1092	864
70	0	918	1090	1232	1158	1168	1171	1210	1307	1456	1456	1079	860
80	0	886	1031	1125	1009	979	962	1000	1114	1304	1366	1038	835
90	0	835	950	998	848	788	759	792	911	1128	1247	974	791
20	15	735	986	1317	1518	1786	1935	1941	1836	1671	1346	876	667
30	15	808	1053	1359	1508	1726	1845	1861	1805	1705	1434	960	739
40	15	862	1096	1370	1467	1633	1722	1748	1736	1701	1487	1022	794
50	15	896	1113	1350	1397	1511	1571	1603	1632	1658	1503	1059	830
60	15	907	1103	1300	1299	1363	1395	1432	1496	1577	1483	1070	846
70	15	897	1068	1221	1176	1194	1201	1240	1333	1462	1426	1054	840
80	15	865	1008	1116	1034	1012	999	1037	1149	1315	1335	1012	814
90	15	813	926	991	880	827	801	836	955	1146	1215	948	770
20	30	713	964	1300	1513	1791	1945	1950	1835	1654	1317	849	645
30	30	776	1021	1337	1505	1739	1866	1880	1809	1685	1393	922	708
40	30	820	1056	1345	1469	1658	1757	1780	1750	1681	1437	973	754
50	30	846	1066	1324	1405	1549	1621	1651	1658	1641	1446	1001	782
60	30	851	1052	1275	1316	1416	1461	1497	1537	1566	1422	1004	791
70	30	836	1013	1200	1205	1264	1285	1324	1391	1459	1364	983	781
80	30	801	952	1101	1075	1098	1100	1139	1225	1324	1275	939	753
90	30	748	872	985	935	931	917	955	1051	1170	1160	873	707
20	45	679	930	1272	1501	1794	1958	1958	1828	1625	1273	811	613
30	45	728	975	1300	1493	1751	1891	1901	1806	1650	1333	868	661
40	45	761	1000	1304	1460	1681	1799	1815	1754	1643	1365	905	695
50	45	776	1003	1282	1403	1586	1682	1704	1674	1605	1367	922	712
60	45	774	985	1235	1323	1469	1543	1570	1567	1537	1340	918	714
70	45	755	946	1165	1223	1334	1388	1417	1438	1440	1283	893	699
80	45	718	887	1074	1106	1186	1222	1252	1290	1319	1200	848	668
90	45	668	813	969	979	1034	1055	1085	1133	1180	1095	786	623

INYOKERN CA 35.39

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	
HORIZONTAL RAD.	1148	1542	2128	2581	2905	3078	2887	2717	2386	1782	1347	1086	(BTU/DAY-FT2)
AVE. TEMP.	44.6	50.0	55.4	64.4	71.6	80.6	87.8	86.0	78.8	68.0	53.6	44.6	(F)
DEGREE-DAYS	546.	364.	267.	105.	19.	0.	0.	0.	0.	37.	282.	502.	(F-DAYS)

AVERAGE DAILY RADIATION ON TILTED SURFACES (BTU/DAY-FT2)

SLOPE	AZIMUTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
20	0	1708	2070	2560	2742	2826	2876	2749	2779	2748	2331	2002	1688
30	0	1925	2255	2677	2719	2690	2683	2591	2707	2819	2516	2252	1926
40	0	2089	2380	2720	2626	2493	2434	2378	2569	2813	2631	2440	2111
50	0	2197	2442	2691	2467	2240	2136	2115	2369	2731	2675	2560	2239
60	0	2245	2437	2589	2246	1941	1800	1813	2112	2574	2646	2609	2304
70	0	2231	2366	2417	1971	1606	1439	1483	1809	2347	2544	2585	2305
80	0	2157	2232	2181	1650	1251	1071	1139	1469	2058	2372	2489	2243
90	0	2026	2043	1894	1304	901	731	812	1116	1723	2142	2327	2121
20	15	1687	2049	2545	2742	2832	2885	2756	2781	2739	2310	1977	1666
30	15	1894	2225	2656	2724	2704	2702	2607	2717	2810	2484	2216	1893
40	15	2050	2342	2697	2640	2517	2464	2404	2588	2807	2591	2394	2069
50	15	2150	2396	2666	2491	2278	2180	2153	2400	2730	2627	2505	2189
60	15	2192	2385	2564	2284	1993	1858	1864	2158	2581	2592	2547	2247
70	15	2174	2310	2395	2026	1674	1512	1548	1871	2366	2486	2517	2244
80	15	2096	2173	2165	1726	1335	1158	1219	1551	2091	2312	2418	2178
90	15	1965	1983	1886	1404	1003	829	904	1221	1775	2081	2255	2056
20	30	1626	1993	2504	2732	2849	2913	2777	2783	2707	2253	1906	1601
30	30	1805	2145	2604	2722	2742	2756	2650	2733	2774	2406	2112	1798
40	30	1935	2242	2639	2652	2583	2550	2475	2626	2773	2495	2261	1946
50	30	2014	2280	2608	2524	2376	2302	2257	2465	2705	2520	2348	2042
60	30	2038	2259	2513	2343	2129	2019	2004	2255	2572	2478	2370	2082
70	30	2007	2178	2357	2116	1850	1713	1725	2005	2379	2372	2327	2064
80	30	1922	2042	2145	1852	1554	1400	1435	1726	2134	2205	2221	1990
90	30	1789	1859	1894	1570	1262	1103	1154	1438	1854	1989	2057	1865
20	45	1535	1909	2437	2708	2863	2947	2800	2775	2652	2167	1801	1502
30	45	1676	2031	2518	2701	2778	2821	2698	2736	2708	2290	1964	1657
40	45	1774	2104	2544	2644	2648	2653	2554	2649	2707	2358	2078	1769
50	45	1827	2126	2514	2536	2476	2448	2373	2514	2647	2370	2138	1835
60	45	1834	2097	2427	2381	2267	2211	2159	2336	2531	2325	2142	1853
70	45	1794	2018	2288	2185	2030	1951	1921	2122	2363	2225	2091	1823
80	45	1708	1892	2102	1956	1773	1679	1668	1881	2150	2075	1987	1745
90	45	1584	1728	1882	1711	1516	1416	1420	1630	1907	1884	1837	1626

ITHACA	NY	42.27											
		JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
HORIZONTAL RAD.		449	747	1038	1281	1727	1984	1970	1693	1310	913	460	364	(BTU/DAY-FT2)
AVE. TEMP.		23.0	24.8	32.0	44.6	53.6	64.4	68.0	66.2	59.0	50.0	39.2	28.4	(F)
DEGREE-DAYS		1271.	1140.	1004.	570.	248.	45.	6.	28.	132.	415.	744.	1153.	(F-DAYS)

AVERAGE DAILY RADIATION ON TILTED SURFACES (BTU/DAY-FT2)

SLOPE	AZIMUTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
20	0	629	973	1210	1353	1719	1920	1931	1755	1485	1161	615	514
30	0	699	1054	1257	1347	1667	1836	1858	1731	1522	1245	673	573
40	0	752	1110	1275	1314	1582	1719	1749	1670	1524	1300	716	618
50	0	787	1139	1263	1254	1468	1572	1608	1574	1491	1323	742	649
60	0	803	1141	1224	1168	1327	1400	1440	1447	1424	1315	751	664
70	0	800	1115	1156	1060	1166	1207	1249	1291	1324	1274	742	663
80	0	776	1062	1064	933	988	1003	1044	1113	1196	1202	715	646
90	0	735	985	951	794	807	802	838	923	1046	1105	673	614
20	15	622	965	1204	1352	1721	1923	1933	1755	1480	1151	609	508
30	15	689	1041	1248	1348	1671	1843	1864	1733	1517	1231	665	564
40	15	739	1094	1265	1317	1590	1730	1759	1676	1519	1282	705	607
50	15	772	1120	1252	1259	1480	1588	1624	1585	1488	1302	729	636
60	15	786	1119	1212	1177	1344	1421	1461	1463	1423	1290	736	650
70	15	781	1091	1145	1074	1188	1234	1276	1313	1327	1247	726	647
80	15	757	1036	1054	952	1016	1036	1077	1143	1203	1175	698	630
90	15	716	960	943	819	840	840	877	961	1059	1076	656	597
20	30	602	940	1187	1346	1724	1931	1940	1752	1464	1125	592	492
30	30	660	1006	1226	1344	1682	1861	1880	1736	1497	1195	640	540
40	30	702	1050	1239	1316	1610	1761	1788	1687	1499	1237	673	577
50	30	728	1068	1226	1264	1512	1632	1667	1606	1470	1250	691	599
60	30	736	1061	1186	1189	1390	1480	1519	1497	1409	1234	693	608
70	30	727	1030	1122	1094	1248	1310	1352	1363	1320	1190	679	602
80	30	700	975	1035	983	1091	1127	1170	1208	1205	1118	649	582
90	30	658	899	931	861	930	945	986	1043	1072	1023	606	550
20	45	573	904	1160	1335	1725	1942	1947	1743	1437	1086	566	467
30	45	617	956	1191	1331	1689	1883	1897	1729	1464	1142	603	504
40	45	649	988	1199	1306	1628	1798	1819	1687	1463	1173	628	531
50	45	665	999	1183	1259	1543	1688	1715	1616	1435	1179	638	546
60	45	667	987	1145	1191	1435	1555	1586	1520	1379	1160	635	548
70	45	653	954	1085	1105	1309	1404	1438	1400	1297	1115	618	538
80	45	626	901	1004	1003	1168	1241	1276	1262	1193	1048	587	516
90	45	583	830	910	893	1022	1075	1109	1113	1073	961	546	483

JACKSONVILLE FL 30.25

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	
HORIZONTAL RAD.	984	1275	1559	1894	2049	1935	1924	1754	1411	1220	1010	847	(BTU/DAY-FT2)
AVE. TEMP.	53.6	55.4	60.8	68.0	73.4	78.8	80.6	80.6	77.0	69.8	60.8	53.6	(F)
DEGREE-DAYS	348.	282.	176.	24.	0.	0.	0.	0.	0.	19.	161.	317.	(F-DAYS)

AVERAGE DAILY RADIATION ON TILTED SURFACES (BTU/DAY-FT2)

SLOPE	AZIMUTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
20	0	1295	1556	1735	1931	1957	1800	1811	1736	1501	1426	1295	1128
30	0	1406	1643	1763	1884	1852	1683	1703	1672	1497	1482	1393	1230
40	0	1483	1689	1750	1796	1710	1536	1563	1574	1460	1502	1458	1302
50	0	1522	1695	1696	1669	1536	1364	1397	1445	1391	1488	1486	1342
60	0	1524	1659	1602	1507	1337	1174	1210	1288	1292	1438	1478	1349
70	0	1467	1582	1472	1315	1120	973	1009	1110	1167	1356	1434	1322
80	0	1413	1468	1310	1100	895	773	806	917	1018	1242	1354	1262
90	0	1307	1322	1124	876	682	595	619	723	855	1105	1244	1174
20	15	1263	1545	1728	1932	1962	1805	1816	1738	1499	1418	1284	1117
30	15	1389	1626	1754	1889	1861	1693	1712	1678	1495	1469	1377	1215
40	15	1460	1668	1740	1806	1726	1552	1578	1585	1459	1486	1436	1282
50	15	1495	1669	1686	1686	1560	1386	1419	1462	1393	1469	1461	1318
60	15	1493	1629	1593	1532	1369	1203	1239	1313	1297	1417	1450	1322
70	15	1454	1550	1466	1351	1162	1010	1046	1144	1177	1333	1403	1292
80	15	1378	1434	1307	1149	947	817	851	961	1035	1219	1322	1231
90	15	1271	1288	1128	941	743	641	669	779	881	1081	1211	1142
20	30	1248	1513	1710	1930	1974	1821	1829	1742	1490	1395	1251	1086
30	30	1338	1582	1732	1893	1886	1721	1738	1690	1485	1438	1330	1168
40	30	1395	1613	1716	1819	1767	1596	1620	1607	1452	1449	1377	1223
50	30	1418	1607	1664	1712	1621	1448	1478	1498	1390	1428	1391	1248
60	30	1406	1563	1577	1575	1452	1285	1318	1365	1302	1375	1371	1242
70	30	1359	1482	1458	1413	1268	1111	1146	1214	1191	1292	1319	1206
80	30	1280	1369	1312	1233	1078	936	970	1052	1062	1183	1235	1141
90	30	1173	1229	1149	1049	895	774	805	890	923	1054	1125	1051
20	45	1196	1467	1681	1922	1987	1840	1845	1743	1474	1361	1204	1039
30	45	1264	1519	1695	1890	1913	1756	1768	1698	1467	1392	1264	1101
40	45	1304	1538	1677	1825	1811	1649	1667	1626	1435	1396	1295	1139
50	45	1314	1525	1627	1731	1685	1522	1544	1530	1378	1371	1298	1151
60	45	1293	1478	1547	1610	1538	1380	1405	1413	1298	1319	1272	1136
70	45	1243	1401	1439	1467	1377	1227	1254	1279	1198	1241	1218	1096
80	45	1166	1296	1306	1308	1208	1070	1097	1135	1081	1141	1138	1031
90	45	1067	1171	1164	1144	1042	920	945	989	957	1025	1037	946

KEY WEST FL 24.33

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	
HORIZONTAL RAD.	1205	1511	1806	2108	2134	2001	1968	1846	1640	1452	1223	1076	(BTU/DAY-FT2)
AVE. TEMP.	69.8	69.8	73.4	77.0	80.6	82.4	84.2	84.2	82.4	78.8	73.4	69.8	(F)
DEGREE-DAYS	16.	25.	5.	0.	0.	0.	0.	0.	0.	0.	0.	18.	(F-DAYS)

AVERAGE DAILY RADIATION ON TILTED SURFACES (BTU/DAY-FT2)

SLOPE	AZIMUTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
20	0	1520	1784	1960	2098	1989	1817	1810	1786	1709	1653	1509	1375
30	0	1624	1859	1969	2021	1855	1674	1679	1700	1686	1698	1599	1477
40	0	1689	1887	1931	1899	1685	1503	1517	1578	1625	1702	1651	1543
50	0	1712	1870	1847	1735	1485	1308	1331	1426	1528	1666	1663	1571
60	0	1693	1808	1720	1535	1262	1098	1127	1248	1399	1591	1634	1560
70	0	1631	1701	1555	1305	1026	884	915	1050	1240	1479	1565	1511
80	0	1530	1554	1355	1055	790	679	708	842	1057	1334	1458	1425
90	0	1394	1376	1132	800	582	525	538	641	861	1164	1320	1307
20	15	1507	1773	1954	2101	1995	1825	1817	1790	1707	1645	1497	1363
30	15	1606	1842	1961	2029	1868	1688	1691	1708	1685	1685	1582	1459
40	15	1665	1866	1923	1913	1706	1523	1536	1593	1627	1685	1629	1521
50	15	1684	1844	1840	1759	1515	1336	1358	1448	1534	1647	1637	1545
60	15	1661	1778	1715	1570	1303	1135	1163	1279	1410	1570	1604	1531
70	15	1597	1669	1553	1355	1079	929	960	1093	1258	1457	1533	1479
80	15	1493	1521	1360	1124	855	732	762	899	1085	1312	1425	1391
90	15	1358	1342	1147	893	655	569	591	713	903	1142	1286	1273
20	30	1471	1742	1938	2103	2013	1845	1835	1798	1700	1622	1464	1328
30	30	1553	1798	1942	2040	1901	1724	1724	1725	1679	1654	1535	1409
40	30	1598	1813	1905	1938	1759	1579	1588	1624	1625	1650	1569	1457
50	30	1605	1785	1826	1801	1592	1414	1430	1495	1540	1608	1566	1469
60	30	1572	1716	1711	1634	1406	1236	1258	1346	1426	1532	1526	1445
70	30	1501	1608	1562	1445	1209	1053	1079	1182	1289	1423	1450	1386
80	30	1395	1465	1387	1242	1014	876	903	1012	1134	1287	1340	1295
90	30	1261	1298	1198	1043	835	721	746	849	974	1131	1204	1176
20	45	1418	1696	1911	2103	2033	1872	1857	1805	1686	1588	1416	1278
30	45	1479	1736	1910	2048	1940	1770	1764	1743	1666	1609	1468	1338
40	45	1507	1740	1873	1960	1819	1647	1648	1655	1616	1599	1488	1368
50	45	1501	1708	1801	1841	1676	1506	1513	1543	1539	1556	1475	1367
60	45	1461	1639	1696	1696	1516	1352	1364	1413	1437	1483	1430	1335
70	45	1390	1538	1563	1530	1345	1192	1207	1269	1315	1383	1355	1274
80	45	1290	1409	1408	1362	1171	1033	1050	1117	1178	1260	1253	1186
90	45	1168	1261	1243	1175	1006	886	903	969	1035	1123	1130	1077

LAKE CHARLES LA 30.13

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	
HORIZONTAL RAD.	880	1119	1458	1778	2040	2143	1918	1855	1649	1480	1089	854	(BTU/DAY-FT2)
AVE. TEMP.	51.8	53.6	59.0	68.0	73.4	80.6	82.4	80.6	77.0	69.8	59.0	53.6	(F)
DEGREE-DAYS	381.	274.	195.	39.	0.	0.	0.	0.	0.	19.	210.	341.	(F-DAYS)

AVERAGE DAILY RADIATION ON TILTED SURFACES (BTU/DAY-FT2)

SLOPE	AZIMUTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
20	0	1135	1342	1613	1808	1947	1986	1805	1836	1768	1766	1411	1136
30	0	1225	1409	1635	1764	1842	1851	1697	1768	1767	1846	1523	1239
40	0	1285	1442	1621	1681	1700	1683	1557	1663	1726	1882	1598	1311
50	0	1314	1442	1569	1563	1528	1487	1391	1524	1645	1871	1632	1351
60	0	1311	1407	1482	1412	1330	1270	1205	1356	1527	1814	1625	1358
70	0	1276	1340	1361	1235	1114	1042	1005	1165	1376	1712	1578	1330
80	0	1211	1241	1212	1036	890	815	802	958	1196	1569	1491	1270
90	0	1118	1117	1041	829	678	615	616	750	997	1394	1371	1181
20	15	1125	1333	1607	1809	1952	1992	1810	1839	1765	1754	1399	1125
30	15	1210	1395	1628	1768	1851	1863	1706	1774	1765	1829	1505	1223
40	15	1266	1425	1612	1690	1716	1702	1572	1675	1725	1860	1574	1291
50	15	1292	1421	1560	1578	1551	1513	1413	1543	1647	1845	1604	1327
60	15	1286	1384	1474	1435	1362	1305	1234	1383	1534	1784	1593	1330
70	15	1249	1314	1356	1267	1155	1086	1042	1202	1389	1681	1543	1300
80	15	1182	1214	1209	1081	942	867	847	1006	1218	1537	1455	1239
90	15	1089	1090	1044	888	739	670	666	811	1030	1362	1334	1149
20	30	1096	1308	1590	1808	1964	2010	1823	1843	1753	1723	1363	1094
30	30	1168	1360	1608	1772	1876	1897	1732	1787	1753	1787	1452	1177
40	30	1212	1381	1591	1702	1758	1754	1614	1699	1716	1809	1507	1231
50	30	1228	1371	1541	1602	1612	1587	1472	1582	1644	1789	1525	1256
60	30	1214	1330	1459	1474	1444	1401	1312	1440	1540	1727	1505	1250
70	30	1171	1259	1349	1323	1261	1205	1141	1279	1407	1626	1449	1214
80	30	1101	1162	1214	1157	1071	1009	966	1106	1252	1489	1357	1148
90	30	1008	1043	1064	986	890	827	802	933	1085	1325	1237	1057
20	45	1053	1271	1564	1801	1977	2033	1839	1844	1733	1676	1309	1046
30	45	1108	1310	1575	1769	1903	1938	1762	1796	1729	1725	1378	1109
40	45	1138	1321	1557	1708	1801	1817	1661	1720	1695	1736	1415	1147
50	45	1142	1305	1509	1619	1676	1674	1539	1618	1629	1711	1421	1159
60	45	1121	1263	1433	1506	1530	1514	1399	1493	1535	1650	1393	1144
70	45	1076	1194	1332	1372	1369	1342	1249	1351	1416	1556	1335	1103
80	45	1007	1104	1211	1224	1201	1167	1092	1197	1278	1432	1248	1037
90	45	921	996	1077	1072	1037	1000	942	1042	1129	1286	1138	952

LANDER WY 42.48

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	
HORIZONTAL RAD.	846	1182	1660	2036	2154	2485	2386	2135	1708	1310	872	725	(BTU/DAY-FT2)
AVE. TEMP.	19.4	24.8	32.0	41.0	51.8	60.8	68.0	66.2	55.4	44.6	32.0	21.2	(F)
DEGREE-DAYS	1417.	1145.	1017.	654.	381.	153.	6.	19.	204.	555.	1020.	1299.	(F-DAYS)

AVERAGE DAILY RADIATION ON TILTED SURFACES (BTU/DAY-FT2)

SLOPE	AZIMUTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
20	0	1398	1684	2057	2212	2153	2403	2342	2236	1988	1776	1360	1240
30	0	1622	1874	2179	2223	2088	2294	2252	2212	2057	1944	1554	1453
40	0	1802	2013	2245	2181	1980	2141	2116	2137	2074	2060	1707	1625
50	0	1933	2099	2253	2088	1833	1948	1940	2015	2040	2122	1813	1753
60	0	2010	2128	2202	1945	1650	1721	1727	1848	1955	2128	1871	1833
70	0	2031	2100	2094	1759	1439	1467	1486	1643	1822	2077	1877	1861
80	0	1995	2015	1932	1534	1206	1198	1226	1406	1645	1971	1832	1838
90	0	1907	1880	1727	1284	968	933	964	1151	1434	1817	1740	1766
20	15	1378	1665	2043	2210	2155	2407	2346	2236	1981	1759	1342	1222
30	15	1593	1846	2161	2224	2094	2303	2260	2215	2049	1918	1528	1425
40	15	1764	1977	2223	2187	1991	2157	2130	2146	2067	2027	1673	1590
50	15	1888	2056	2228	2100	1850	1971	1961	2030	2035	2082	1773	1711
60	15	1959	2080	2176	1965	1674	1751	1756	1872	1954	2083	1825	1785
70	15	1975	2048	2069	1788	1470	1506	1523	1676	1826	2028	1827	1810
80	15	1937	1960	1910	1574	1246	1245	1271	1449	1656	1920	1780	1784
90	15	1848	1824	1708	1337	1016	987	1018	1205	1454	1765	1687	1711
20	30	1319	1612	2006	2198	2160	2419	2355	2232	1956	1711	1289	1167
30	30	1506	1770	2111	2215	2109	2330	2282	2219	2019	1851	1451	1345
40	30	1653	1881	2166	2185	2020	2200	2169	2162	2036	1944	1574	1487
50	30	1755	1944	2169	2110	1896	2035	2019	2062	2007	1987	1656	1588
60	30	1809	1955	2118	1991	1740	1837	1836	1922	1932	1980	1693	1646
70	30	1813	1915	2017	1833	1556	1615	1626	1747	1815	1922	1684	1659
80	30	1767	1825	1868	1640	1353	1376	1397	1544	1659	1815	1631	1626
90	30	1676	1692	1682	1427	1144	1138	1166	1326	1474	1666	1536	1550
20	45	1230	1534	1946	2172	2161	2434	2363	2218	1914	1639	1211	1083
30	45	1379	1661	2033	2187	2120	2361	2305	2208	1966	1753	1340	1223
40	45	1493	1749	2077	2163	2046	2255	2211	2161	1979	1826	1436	1333
50	45	1567	1793	2075	2098	1940	2115	2085	2076	1951	1856	1495	1407
60	45	1600	1794	2027	1994	1804	1945	1927	1955	1884	1842	1516	1443
70	45	1591	1751	1934	1854	1643	1752	1744	1802	1778	1784	1497	1442
80	45	1540	1664	1800	1684	1464	1541	1542	1623	1639	1684	1441	1402
90	45	1451	1542	1634	1495	1276	1327	1335	1428	1474	1550	1351	1326

LARAMIE WY 41.18

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	
HORIZONTAL RAD.	824	1097	1561	1833	2018	2308	2183	1936	1546	1174	835	673	(BTU/DAY-FT2)
AVE. TEMP.	21.2	24.8	28.4	37.4	46.4	55.4	62.6	60.8	53.6	42.8	32.0	24.8	(F)
DEGREE-DAYS	1212.	1042.	1026.	702.	428.	150.	28.	37.	219.	543.	909.	1085.	(F-DAYS)

AVERAGE DAILY RADIATION ON TILTED SURFACES (BTU/DAY-FT2)

SLOPE	AZIMUTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
20	0	1299	1503	1890	1965	2006	2223	2133	2007	1764	1530	1248	1082
30	0	1489	1652	1986	1964	1940	2119	2047	1978	1812	1653	1409	1247
40	0	1639	1759	2033	1918	1836	1974	1920	1905	1816	1735	1534	1380
50	0	1746	1820	2028	1829	1696	1794	1758	1791	1776	1773	1618	1475
60	0	1805	1833	1972	1699	1524	1583	1564	1639	1694	1765	1659	1531
70	0	1814	1799	1867	1532	1327	1350	1346	1454	1573	1712	1656	1546
80	0	1775	1717	1715	1334	1111	1104	1112	1244	1415	1616	1609	1519
90	0	1689	1595	1526	1116	892	863	879	1019	1230	1483	1522	1452
20	15	1281	1487	1878	1963	2008	2227	2136	2007	1758	1516	1232	1067
30	15	1463	1629	1971	1965	1946	2128	2054	1981	1805	1633	1386	1225
40	15	1606	1729	2014	1923	1846	1989	1933	1913	1810	1709	1505	1351
50	15	1706	1785	2008	1840	1712	1815	1776	1804	1773	1742	1584	1442
60	15	1760	1794	1951	1717	1546	1612	1590	1660	1694	1730	1620	1493
70	15	1766	1756	1847	1558	1356	1386	1379	1483	1577	1675	1614	1505
80	15	1724	1673	1697	1369	1148	1147	1153	1281	1426	1577	1565	1476
90	15	1638	1549	1512	1162	936	912	927	1067	1248	1443	1477	1408
20	30	1230	1444	1847	1954	2013	2239	2145	2005	1738	1479	1187	1023
30	30	1389	1567	1929	1958	1960	2152	2074	1985	1782	1581	1321	1161
40	30	1510	1652	1967	1924	1874	2029	1968	1927	1786	1645	1421	1269
50	30	1592	1694	1959	1850	1755	1874	1829	1832	1752	1669	1484	1344
60	30	1631	1693	1904	1740	1607	1690	1661	1704	1679	1652	1508	1382
70	30	1626	1650	1805	1597	1436	1485	1471	1546	1571	1594	1493	1384
80	30	1577	1564	1666	1426	1248	1267	1265	1365	1431	1498	1438	1349
90	30	1488	1443	1495	1240	1055	1051	1059	1172	1269	1370	1349	1280
20	45	1153	1380	1796	1934	2015	2253	2153	1994	1705	1424	1121	956
30	45	1279	1479	1864	1938	1972	2182	2095	1978	1740	1506	1227	1065
40	45	1372	1544	1893	1908	1898	2079	2006	1929	1742	1555	1304	1147
50	45	1431	1572	1881	1843	1796	1947	1888	1847	1709	1569	1348	1200
60	45	1452	1563	1829	1746	1667	1789	1742	1735	1642	1547	1359	1222
70	45	1437	1517	1738	1619	1517	1609	1575	1595	1544	1490	1336	1213
80	45	1384	1436	1612	1467	1349	1416	1393	1434	1419	1400	1280	1173
90	45	1299	1325	1459	1300	1176	1220	1207	1262	1274	1283	1195	1105

LAS VEGAS NV 36.05

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	
HORIZONTAL RAD.	1027	1421	1859	2290	2585	2747	2489	2308	2051	1579	1170	957	(BTU/DAY-FT2)
AVE. TEMP.	42.8	48.2	53.6	62.6	73.4	82.4	87.8	86.0	78.8	66.2	51.8	44.6	(F)
DEGREE-DAYS	688.	487.	335.	111.	6.	0.	0.	0.	0.	78.	387.	617.	(F-DAYS)

AVERAGE DAILY RADIATION ON TILTED SURFACES (BTU/DAY-FT2)

SLOPE	AZIMUTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
20	0	1506	1890	2199	2420	2522	2586	2384	2353	2320	2027	1691	1459
30	0	1691	2055	2287	2398	2410	2428	2259	2294	2369	2175	1889	1657
40	0	1831	2166	2316	2318	2245	2222	2088	2184	2356	2266	2036	1810
50	0	1923	2220	2286	2183	2034	1974	1878	2024	2285	2297	2129	1915
60	0	1962	2214	2198	1996	1783	1692	1634	1820	2155	2268	2164	1968
70	0	1950	2151	2054	1764	1502	1388	1366	1580	1971	2179	2141	1968
80	0	1884	2030	1858	1495	1201	1076	1086	1311	1740	2033	2059	1914
90	0	1772	1861	1622	1205	904	784	817	1031	1473	1839	1926	1811
20	15	1488	1872	2186	2419	2527	2594	2389	2354	2313	2009	1671	1441
30	15	1665	2028	2271	2402	2421	2443	2270	2301	2361	2149	1860	1630
40	15	1797	2131	2298	2328	2265	2245	2107	2197	2351	2233	1999	1775
50	15	1882	2178	2266	2202	2063	2007	1905	2046	2283	2258	2085	1874
60	15	1917	2168	2178	2026	1823	1737	1671	1853	2160	2224	2114	1921
70	15	1900	2100	2036	1807	1554	1445	1414	1624	1984	2132	2087	1917
80	15	1833	1978	1844	1554	1267	1144	1145	1370	1763	1984	2003	1860
90	15	1719	1807	1615	1281	983	861	886	1106	1510	1790	1868	1756
20	30	1436	1822	2153	2411	2540	2615	2405	2355	2289	1962	1615	1386
30	30	1588	1957	2228	2399	2450	2484	2302	2312	2334	2084	1777	1550
40	30	1699	2042	2251	2337	2315	2312	2160	2223	2325	2154	1893	1673
50	30	1765	2075	2220	2227	2140	2102	1982	2092	2264	2169	1959	1751
60	30	1785	2055	2136	2071	1929	1862	1775	1922	2151	2130	1973	1783
70	30	1758	1982	2004	1877	1691	1601	1546	1720	1992	2037	1935	1767
80	30	1683	1860	1827	1651	1437	1332	1306	1495	1792	1895	1845	1703
90	30	1568	1695	1618	1411	1186	1074	1072	1262	1565	1711	1710	1596
20	45	1358	1747	2101	2391	2550	2641	2421	2348	2247	1892	1530	1303
30	45	1477	1854	2161	2381	2477	2534	2337	2313	2283	1989	1659	1432
40	45	1561	1918	2175	2329	2365	2392	2218	2238	2274	2041	1747	1524
50	45	1605	1937	2144	2233	2217	2216	2068	2126	2218	2046	1791	1578
60	45	1609	1910	2067	2099	2037	2012	1890	1979	2118	2004	1790	1591
70	45	1573	1838	1947	1929	1831	1787	1691	1803	1977	1916	1745	1564
80	45	1498	1724	1789	1731	1609	1551	1480	1605	1800	1786	1656	1497
90	45	1390	1576	1605	1519	1385	1320	1270	1399	1601	1623	1531	1395

LEMONT IL 41.40

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	
HORIZONTAL RAD.	629	854	1200	1436	1830	2036	1940	1789	1414	975	578	482	(BTU/DAY-FT2)
AVE. TEMP.	24.8	28.4	35.6	50.0	59.0	69.8	73.4	71.6	64.4	53.6	39.2	28.4	(F)
DEGREE-DAYS	1265.	1086.	939.	534.	260.	72.	0.	12.	117.	381.	807.	1166.	(F-DAYS)

AVERAGE DAILY RADIATION ON TILTED SURFACES (BTU/DAY-FT2)

SLOPE	AZIMUTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
20	0	937	1124	1412	1520	1818	1964	1897	1851	1602	1239	801	718
30	0	1058	1221	1470	1514	1760	1875	1822	1823	1642	1328	886	811
40	0	1153	1288	1494	1476	1667	1752	1713	1756	1644	1386	950	885
50	0	1218	1323	1482	1406	1543	1598	1572	1652	1606	1409	991	937
60	0	1251	1326	1436	1308	1390	1418	1405	1515	1532	1399	1007	964
70	0	1252	1296	1356	1183	1215	1218	1217	1347	1422	1353	998	968
80	0	1220	1234	1245	1037	1025	1008	1014	1156	1281	1275	964	946
90	0	1159	1144	1110	876	830	800	812	953	1116	1169	908	901
20	15	925	1113	1404	1519	1820	1968	1899	1851	1597	1228	793	709
30	15	1041	1205	1460	1515	1765	1882	1828	1826	1637	1313	874	799
40	15	1131	1268	1481	1479	1676	1764	1723	1763	1639	1366	934	869
50	15	1192	1300	1469	1413	1556	1615	1588	1664	1603	1386	972	917
60	15	1222	1300	1422	1319	1409	1441	1426	1533	1532	1372	985	942
70	15	1221	1267	1343	1200	1241	1247	1244	1372	1426	1325	975	944
80	15	1188	1204	1234	1060	1056	1042	1048	1189	1290	1246	940	921
90	15	1125	1113	1101	907	868	841	852	995	1131	1140	884	876
20	30	892	1084	1383	1513	1824	1977	1906	1849	1580	1201	768	683
30	30	993	1164	1433	1510	1777	1902	1845	1829	1616	1275	838	761
40	30	1069	1216	1451	1479	1699	1796	1752	1776	1618	1319	888	821
50	30	1117	1239	1437	1420	1593	1663	1631	1689	1585	1332	917	860
60	30	1138	1232	1391	1335	1461	1505	1485	1571	1518	1314	924	878
70	30	1129	1196	1315	1226	1308	1328	1319	1427	1420	1265	908	873
80	30	1092	1131	1212	1098	1140	1140	1140	1262	1294	1187	870	847
90	30	1028	1042	1089	959	969	953	960	1087	1149	1084	813	801
20	45	842	1042	1350	1499	1826	1988	1913	1839	1551	1159	732	644
30	45	921	1105	1390	1496	1786	1926	1862	1823	1580	1218	787	705
40	45	978	1144	1402	1468	1720	1837	1783	1777	1579	1251	824	750
50	45	1012	1157	1385	1415	1628	1722	1679	1701	1547	1257	843	776
60	45	1021	1145	1341	1338	1512	1584	1552	1598	1486	1235	842	784
70	45	1005	1107	1271	1240	1377	1428	1405	1470	1397	1187	822	774
80	45	965	1044	1177	1125	1227	1260	1245	1323	1283	1113	783	744
90	45	904	962	1065	999	1071	1090	1082	1165	1152	1019	728	699

LEXINGTON KY 38.02

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	
HORIZONTAL RAD.	629	950	1340	1752	2121	2286	2268	2054	1808	1329	865	629	(BTU/DAY-FT2)
AVE. TEMP.	32.0	33.8	42.8	53.6	62.6	71.6	75.2	73.4	68.0	57.2	44.6	35.6	(F)
DEGREE-DAYS	946.	818.	685.	325.	105.	0.	0.	0.	54.	239.	609.	902.	(F-DAYS)

AVERAGE DAILY RADIATION ON TILTED SURFACES (BTU/DAY-FT2)

SLOPE	AZIMUTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
20	0	868	1213	1552	1844	2085	2178	2191	2104	2047	1695	1217	915
30	0	958	1304	1605	1829	2004	2063	2088	2060	2092	1818	1351	1027
40	0	1026	1363	1620	1774	1882	1909	1944	1971	2087	1894	1450	1113
50	0	1068	1389	1597	1679	1724	1720	1763	1838	2030	1922	1512	1170
60	0	1083	1381	1536	1547	1534	1504	1552	1667	1923	1901	1535	1198
70	0	1072	1339	1440	1384	1319	1268	1318	1463	1770	1832	1518	1195
80	0	1034	1264	1310	1195	1088	1023	1070	1233	1575	1716	1462	1162
90	0	972	1162	1156	989	856	788	828	992	1350	1561	1371	1100
20	15	859	1203	1544	1844	2088	2183	2195	2105	2040	1681	1204	904
30	15	945	1288	1595	1831	2011	2073	2097	2065	2086	1797	1331	1011
40	15	1009	1343	1608	1779	1895	1925	1959	1981	2082	1867	1425	1093
50	15	1047	1365	1584	1690	1743	1743	1785	1855	2028	1890	1482	1147
60	15	1060	1354	1523	1565	1561	1535	1582	1692	1925	1865	1501	1171
70	15	1047	1310	1428	1410	1354	1307	1356	1498	1779	1793	1482	1166
80	15	1008	1235	1300	1230	1132	1070	1118	1279	1592	1675	1424	1131
90	15	946	1132	1149	1036	909	841	884	1050	1377	1519	1332	1069
20	30	832	1174	1523	1837	2095	2197	2207	2105	2018	1643	1165	873
30	30	907	1248	1568	1828	2030	2100	2122	2072	2060	1744	1275	965
40	30	959	1292	1578	1783	1929	1969	2001	2000	2057	1802	1353	1034
50	30	989	1306	1553	1703	1795	1808	1847	1890	2007	1816	1397	1077
60	30	994	1289	1494	1591	1632	1620	1666	1746	1914	1786	1405	1092
70	30	975	1242	1404	1451	1448	1415	1463	1572	1779	1713	1378	1080
80	30	933	1166	1285	1288	1248	1199	1248	1377	1609	1598	1315	1041
90	30	869	1065	1145	1114	1047	989	1036	1173	1415	1450	1222	977
20	45	793	1132	1490	1822	2101	2214	2218	2097	1981	1585	1108	826
30	45	851	1189	1524	1814	2046	2134	2148	2070	2015	1665	1194	898
40	45	889	1221	1529	1774	1961	2024	2047	2008	2010	1709	1253	948
50	45	907	1227	1503	1703	1846	1886	1916	1913	1964	1714	1281	976
60	45	904	1205	1448	1604	1705	1724	1759	1787	1879	1680	1279	981
70	45	881	1157	1364	1479	1542	1544	1582	1635	1759	1609	1246	962
80	45	837	1085	1256	1334	1365	1353	1391	1462	1608	1504	1184	920
90	45	777	993	1130	1178	1184	1163	1200	1280	1435	1370	1097	858

LINCOLN NE 40.51

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	
HORIZONTAL RAD.	699	939	1277	1561	1826	2006	1977	1870	1517	1196	762	633	(BTU/DAY-FT2)
AVE. TEMP.	24.8	28.4	37.4	51.8	60.8	71.6	77.0	75.2	66.2	53.6	39.2	30.2	(F)
DEGREE-DAYS	1237.	1016.	834.	402.	171.	30.	0.	6.	75.	301.	729.	1066.	(F-DAYS)

AVERAGE DAILY RADIATION ON TILTED SURFACES (BTU/DAY-FT2)

SLOPE	AZIMUTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
20	0	1042	1239	1502	1653	1809	1931	1927	1931	1719	1549	1099	982
30	0	1177	1346	1563	1646	1748	1840	1848	1899	1761	1671	1229	1122
40	0	1282	1420	1586	1602	1653	1717	1734	1826	1761	1750	1329	1234
50	0	1354	1459	1573	1525	1527	1563	1588	1714	1720	1785	1394	1313
60	0	1391	1461	1521	1415	1373	1384	1415	1567	1637	1775	1423	1357
70	0	1390	1427	1435	1276	1198	1187	1220	1389	1517	1719	1414	1365
80	0	1354	1357	1315	1113	1007	980	1013	1187	1362	1620	1369	1337
90	0	1283	1256	1168	935	813	777	807	972	1182	1483	1291	1275
20	15	1030	1227	1494	1652	1811	1934	1930	1931	1714	1536	1087	969
30	15	1159	1329	1552	1646	1753	1847	1854	1902	1755	1651	1211	1104
40	15	1258	1398	1574	1607	1662	1728	1745	1834	1756	1724	1305	1209
50	15	1326	1433	1559	1533	1541	1580	1604	1728	1717	1754	1365	1284
60	15	1358	1432	1507	1428	1393	1407	1437	1587	1638	1740	1390	1324
70	15	1355	1395	1421	1296	1223	1210	1249	1417	1522	1681	1380	1330
80	15	1317	1323	1303	1140	1039	1014	1048	1223	1373	1581	1333	1300
90	15	1246	1222	1159	971	852	817	849	1018	1200	1444	1254	1237
20	30	992	1195	1472	1645	1816	1944	1938	1929	1695	1499	1050	932
30	30	1104	1283	1523	1642	1766	1868	1872	1906	1733	1599	1157	1049
40	30	1188	1340	1541	1607	1686	1762	1775	1848	1734	1661	1236	1139
50	30	1242	1365	1525	1542	1578	1628	1650	1755	1697	1683	1284	1199
60	30	1264	1357	1475	1447	1445	1471	1499	1630	1624	1663	1298	1229
70	30	1253	1316	1393	1327	1292	1297	1329	1477	1517	1602	1280	1226
80	30	1210	1243	1282	1185	1125	1112	1146	1303	1380	1503	1229	1191
90	30	1138	1144	1148	1032	954	929	963	1119	1222	1372	1149	1127
20	45	936	1147	1437	1630	1818	1955	1945	1919	1664	1444	995	874
30	45	1024	1217	1478	1627	1776	1892	1891	1901	1694	1524	1080	966
40	45	1088	1260	1489	1596	1708	1802	1809	1851	1693	1571	1140	1034
50	45	1125	1275	1471	1537	1614	1687	1701	1770	1658	1583	1172	1076
60	45	1135	1261	1423	1453	1498	1551	1569	1660	1591	1559	1176	1092
70	45	1116	1218	1347	1345	1362	1397	1419	1525	1494	1499	1152	1080
80	45	1071	1148	1246	1218	1212	1231	1256	1370	1370	1407	1100	1041
90	45	1001	1057	1125	1080	1058	1065	1090	1205	1229	1288	1024	978

LITTLE ROCK AR 34.44

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	
HORIZONTAL RAD.	729	964	1318	1675	1944	2069	2054	1900	1627	1274	898	688	(BTU/DAY-FT2)
AVE. TEMP.	41.0	44.6	51.8	60.8	69.8	77.0	80.6	78.8	73.4	62.6	51.8	42.8	(F)
DEGREE-DAYS	756.	577.	434.	126.	9.	0.	0.	0.	9.	127.	465.	716.	(F-DAYS)

AVERAGE DAILY RADIATION ON TILTED SURFACES (BTU/DAY-FT2)

SLOPE	AZIMUTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
20	0	970	1184	1486	1732	1886	1950	1961	1913	1785	1553	1198	946
30	0	1068	1254	1520	1704	1801	1836	1857	1858	1802	1639	1306	1043
40	0	1121	1295	1519	1639	1681	1689	1719	1764	1778	1685	1383	1115
50	0	1157	1306	1484	1539	1529	1514	1549	1633	1711	1689	1425	1159
60	0	1164	1285	1414	1407	1351	1315	1355	1469	1606	1653	1431	1174
70	0	1143	1234	1313	1247	1153	1102	1143	1278	1464	1575	1401	1160
80	0	1094	1155	1184	1066	944	884	922	1068	1290	1460	1337	1117
90	0	1020	1051	1033	872	738	681	712	851	1094	1314	1241	1048
20	15	961	1175	1479	1732	1889	1955	1965	1915	1781	1542	1186	936
30	15	1045	1241	1511	1706	1808	1846	1866	1863	1798	1623	1289	1029
40	15	1104	1278	1509	1645	1693	1705	1733	1774	1775	1664	1361	1096
50	15	1136	1286	1473	1551	1548	1535	1570	1650	1712	1664	1399	1137
60	15	1141	1263	1405	1425	1377	1344	1383	1494	1610	1625	1402	1149
70	15	1117	1210	1305	1274	1187	1138	1179	1312	1474	1545	1370	1133
80	15	1067	1129	1178	1102	986	928	967	1112	1307	1429	1303	1089
90	15	993	1025	1031	920	789	730	764	907	1121	1282	1207	1019
20	30	934	1151	1462	1728	1898	1969	1977	1916	1766	1512	1153	907
30	30	1005	1207	1490	1706	1828	1873	1891	1873	1782	1581	1241	987
40	30	1053	1236	1486	1652	1727	1748	1774	1795	1760	1614	1299	1042
50	30	1076	1236	1450	1567	1598	1597	1629	1685	1701	1608	1326	1073
60	30	1073	1209	1384	1454	1445	1425	1462	1546	1607	1565	1320	1077
70	30	1044	1154	1290	1317	1275	1239	1279	1384	1482	1486	1281	1055
80	30	991	1074	1172	1162	1095	1048	1088	1205	1331	1374	1211	1007
90	30	916	973	1037	1000	918	866	903	1023	1162	1236	1115	936
20	45	893	1115	1435	1718	1906	1987	1991	1913	1740	1467	1104	864
30	45	948	1158	1455	1698	1846	1906	1918	1876	1751	1521	1172	925
40	45	982	1176	1447	1650	1760	1799	1818	1808	1729	1542	1214	965
50	45	994	1170	1412	1574	1648	1670	1694	1712	1675	1531	1228	983
60	45	984	1140	1350	1474	1515	1520	1549	1591	1590	1487	1213	978
70	45	951	1086	1264	1352	1365	1357	1388	1448	1478	1411	1172	950
80	45	898	1010	1156	1213	1205	1187	1218	1289	1342	1308	1104	901
90	45	827	919	1035	1067	1044	1021	1050	1126	1192	1184	1014	833

LOS ANGELES	CA	33.56											
	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	
HORIZONTAL RAD.	946	1266	1690	1907	2121	2272	2389	2168	1855	1355	1078	905	(BTU/DAY-FT2)
AVE. TEMP.	53.6	55.4	55.4	59.0	60.8	64.4	68.0	68.0	68.0	64.4	59.0	55.4	(F)
DEGREE-DAYS	372.	302.	288.	219.	158.	81.	28.	28.	42.	78.	180.	291.	(F-DAYS)

AVERAGE DAILY RADIATION ON TILTED SURFACES (BTU/DAY-FT2)

SLOPE	AZIMUTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
20	0	1302	1599	1936	1973	2050	2129	2267	2181	2044	1651	1465	1292
30	0	1434	1709	1990	1940	1952	1997	2138	2115	2066	1741	1605	1439
40	0	1530	1776	1996	1862	1816	1828	1966	2002	2037	1788	1706	1550
50	0	1587	1799	1953	1744	1644	1628	1758	1845	1959	1791	1762	1620
60	0	1603	1777	1862	1589	1444	1403	1520	1650	1835	1750	1772	1648
70	0	1578	1710	1727	1400	1222	1162	1262	1424	1667	1665	1737	1633
80	0	1512	1600	1551	1186	988	917	995	1174	1462	1540	1657	1576
90	0	1411	1455	1344	958	760	692	744	918	1230	1383	1537	1479
20	15	1288	1586	1927	1973	2054	2135	2273	2184	2039	1639	1450	1277
30	15	1414	1689	1978	1943	1961	2009	2150	2122	2061	1723	1584	1418
40	15	1504	1751	1982	1871	1831	1847	1986	2015	2034	1765	1678	1522
50	15	1556	1769	1939	1759	1667	1654	1786	1867	1960	1764	1729	1588
60	15	1569	1743	1849	1612	1475	1437	1558	1682	1841	1720	1735	1611
70	15	1541	1673	1715	1434	1262	1205	1310	1467	1680	1633	1696	1593
80	15	1473	1562	1543	1231	1038	969	1054	1231	1484	1507	1614	1534
90	15	1371	1416	1342	1019	820	750	812	990	1265	1349	1494	1437
20	30	1248	1549	1902	1969	2065	2153	2290	2186	2022	1607	1407	1234
30	30	1356	1638	1947	1944	1984	2042	2182	2134	2042	1680	1522	1356
40	30	1431	1687	1949	1880	1870	1898	2039	2042	2017	1713	1598	1442
50	30	1469	1696	1906	1781	1725	1727	1863	1912	1949	1705	1635	1492
60	30	1470	1663	1821	1649	1555	1533	1661	1749	1840	1658	1630	1504
70	30	1434	1590	1696	1489	1366	1325	1440	1558	1693	1572	1583	1477
80	30	1362	1480	1537	1308	1166	1113	1213	1349	1516	1451	1497	1411
90	30	1259	1340	1354	1119	972	912	994	1137	1319	1302	1377	1313
20	45	1190	1495	1863	1957	2075	2174	2308	2183	1991	1559	1344	1170
30	45	1273	1564	1897	1935	2007	2081	2219	2140	2006	1615	1433	1264
40	45	1327	1599	1894	1879	1910	1961	2098	2061	1982	1637	1489	1328
50	45	1350	1598	1852	1792	1785	1814	1949	1949	1920	1624	1509	1359
60	45	1340	1561	1773	1676	1638	1647	1775	1807	1822	1575	1494	1357
70	45	1299	1490	1660	1534	1472	1465	1583	1640	1691	1494	1444	1322
80	45	1227	1388	1518	1374	1295	1277	1382	1456	1533	1383	1360	1256
90	45	1131	1261	1356	1206	1119	1094	1185	1267	1360	1250	1249	1162

LOUISVILLE KY 38.11

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	
HORIZONTAL RAD.	604	851	1198	1548	1898	2064	2027	1835	1504	1117	700	552	(BTU/DAY-FT2)
AVE. TEMP.	32.0	35.6	42.8	55.4	64.4	71.6	75.2	75.2	68.0	57.2	44.6	33.8	(F)
DEGREE-DAYS	983.	818.	661.	286.	105.	0.	0.	0.	35.	241.	600.	911.	(F-DAYS)

AVERAGE DAILY RADIATION ON TILTED SURFACES (BTU/DAY-FT2)

SLOPE	AZIMUTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
20	0	827	1070	1373	1621	1866	1970	1960	1875	1677	1391	947	782
30	0	912	1144	1415	1605	1795	1869	1871	1835	1706	1480	1039	870
40	0	974	1191	1424	1555	1688	1734	1745	1755	1696	1533	1106	938
50	0	1013	1210	1401	1472	1550	1568	1589	1639	1645	1549	1146	982
60	0	1027	1200	1346	1359	1384	1378	1405	1490	1557	1527	1157	1002
70	0	1016	1162	1261	1218	1197	1170	1201	1312	1434	1467	1140	997
80	0	979	1096	1148	1055	995	954	986	1113	1279	1372	1095	966
90	0	920	1007	1013	880	793	747	775	904	1101	1248	1024	914
20	15	819	1061	1366	1620	1868	1974	1964	1875	1672	1380	938	773
30	15	899	1131	1406	1607	1801	1877	1878	1838	1701	1464	1026	858
40	15	958	1175	1414	1560	1699	1747	1758	1764	1692	1513	1089	921
50	15	994	1191	1390	1481	1566	1587	1607	1653	1644	1525	1125	963
60	15	1005	1178	1335	1373	1407	1404	1430	1511	1559	1500	1134	980
70	15	992	1138	1251	1239	1226	1203	1233	1341	1440	1438	1114	973
80	15	955	1071	1139	1084	1032	993	1026	1150	1291	1342	1067	942
90	15	895	981	1008	918	837	791	821	951	1121	1217	996	889
20	30	794	1037	1349	1615	1874	1986	1973	1875	1656	1351	911	748
30	30	863	1097	1384	1604	1816	1900	1899	1844	1682	1424	986	821
40	30	912	1132	1389	1563	1727	1785	1793	1780	1673	1464	1038	874
50	30	939	1141	1364	1492	1609	1642	1658	1682	1629	1469	1064	906
60	30	943	1124	1311	1394	1466	1476	1500	1555	1550	1440	1065	916
70	30	925	1081	1231	1273	1304	1294	1322	1403	1440	1377	1041	904
80	30	884	1013	1126	1132	1129	1103	1134	1232	1303	1283	991	869
90	30	824	926	1004	981	952	916	948	1054	1148	1164	919	815
20	45	757	1002	1321	1603	1879	2000	1983	1868	1629	1307	870	710
30	45	811	1049	1347	1592	1830	1929	1921	1842	1649	1365	929	766
40	45	846	1073	1348	1555	1754	1831	1831	1786	1638	1393	966	805
50	45	863	1075	1323	1492	1651	1708	1715	1701	1596	1392	982	826
60	45	859	1054	1272	1405	1526	1564	1577	1589	1524	1360	976	827
70	45	836	1010	1197	1295	1383	1403	1421	1455	1425	1299	947	809
80	45	794	946	1102	1169	1226	1232	1253	1302	1302	1212	897	772
90	45	737	865	992	1033	1067	1063	1084	1142	1163	1104	830	719

LYNN MA 42.28

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	
HORIZONTAL RAD.	434	769	1104	1450	1671	1981	1984	1554	1251	850	489	368	(BTU/DAY-FT2)
AVE. TEMP.	30.2	32.0	37.4	48.2	57.2	68.0	71.6	69.8	64.4	53.6	44.6	32.0	(F)
DEGREE-DAYS	1088.	972.	846.	513.	208.	36.	0.	9.	60.	316.	603.	983.	(F-DAYS)

AVERAGE DAILY RADIATION ON TILTED SURFACES (BTU/DAY-FT2)

SLOPE	AZIMUTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
20	0	603	1008	1297	1543	1664	1916	1945	1605	1412	1069	665	521
30	0	668	1093	1350	1540	1613	1833	1872	1581	1445	1143	732	581
40	0	718	1153	1372	1504	1531	1716	1762	1525	1446	1190	781	627
50	0	750	1184	1362	1436	1421	1570	1620	1438	1413	1209	812	659
60	0	764	1187	1321	1338	1286	1397	1450	1323	1349	1199	823	675
70	0	760	1160	1249	1213	1131	1206	1258	1182	1255	1160	815	674
80	0	738	1106	1149	1065	960	1002	1050	1022	1133	1094	787	657
90	0	698	1027	1027	902	786	801	842	852	991	1005	741	624
20	15	597	998	1290	1541	1665	1919	1948	1605	1408	1060	658	515
30	15	659	1080	1341	1540	1617	1839	1878	1583	1441	1130	722	573
40	15	706	1135	1361	1507	1539	1727	1772	1530	1442	1174	769	617
50	15	736	1163	1350	1443	1433	1585	1636	1447	1411	1190	797	646
60	15	748	1163	1308	1349	1302	1419	1471	1337	1349	1177	807	660
70	15	743	1135	1237	1230	1152	1232	1285	1202	1257	1137	797	658
80	15	719	1079	1138	1088	987	1035	1084	1048	1140	1069	768	640
90	15	680	1000	1018	933	818	839	882	884	1003	980	722	608
20	30	578	973	1271	1535	1668	1928	1955	1603	1393	1037	639	498
30	30	632	1043	1316	1535	1627	1858	1894	1586	1423	1098	694	548
40	30	671	1089	1332	1506	1558	1757	1801	1540	1423	1134	732	585
50	30	694	1109	1320	1449	1463	1630	1679	1466	1394	1144	754	609
60	30	702	1103	1279	1364	1345	1478	1531	1366	1336	1128	758	618
70	30	692	1071	1211	1255	1209	1308	1361	1245	1251	1086	744	612
80	30	666	1014	1117	1126	1058	1125	1178	1105	1142	1019	713	592
90	30	626	936	1005	984	903	944	992	956	1016	932	666	559
20	45	550	935	1241	1520	1669	1938	1961	1594	1368	1003	610	473
30	45	592	990	1277	1520	1634	1880	1911	1580	1392	1051	653	511
40	45	621	1025	1288	1494	1575	1795	1833	1540	1390	1077	681	539
50	45	636	1037	1273	1442	1493	1685	1728	1475	1361	1081	695	554
60	45	636	1025	1233	1366	1388	1553	1598	1386	1307	1062	693	556
70	45	623	992	1169	1268	1266	1402	1449	1277	1229	1020	675	546
80	45	595	936	1083	1151	1131	1239	1285	1151	1130	957	643	524
90	45	556	864	982	1023	990	1074	1117	1017	1017	877	598	491

MADISON	WI	43.08											
	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	
HORIZONTAL RAD.	564	812	1232	1455	1745	2031	2046	1740	1443	993	555	495	(BTU/DAY-FT2)
AVE. TEMP.	17.6	21.2	32.0	44.6	55.4	66.2	69.8	68.0	59.0	50.0	33.8	23.0	(F)
DEGREE-DAYS	1473.	1274.	1113.	618.	310.	102.	25.	40.	174.	474.	930.	1330.	(F-DAYS)

AVERAGE DAILY RADIATION ON TILTED SURFACES (BTU/DAY-FT2)

SLOPE	AZIMUTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
20	0	856	1088	1475	1553	1742	1970	2011	1811	1659	1292	793	783
30	0	973	1189	1546	1553	1692	1886	1938	1789	1710	1398	885	899
40	0	1065	1260	1580	1520	1608	1769	1827	1729	1719	1468	956	993
50	0	1129	1301	1576	1453	1494	1619	1682	1633	1688	1503	1002	1061
60	0	1165	1309	1534	1356	1353	1444	1507	1503	1617	1499	1024	1101
70	0	1169	1285	1456	1232	1190	1247	1308	1344	1508	1458	1020	1112
80	0	1144	1228	1343	1084	1011	1038	1094	1161	1365	1381	990	1094
90	0	1090	1143	1203	921	827	830	878	964	1195	1273	937	1048
20	15	845	1077	1466	1552	1744	1973	2014	1810	1653	1281	784	772
30	15	957	1173	1534	1554	1696	1893	1944	1791	1703	1381	872	884
40	15	1044	1241	1566	1523	1616	1780	1837	1735	1714	1446	939	973
50	15	1105	1277	1561	1460	1506	1635	1698	1644	1684	1477	983	1037
60	15	1137	1282	1518	1368	1370	1465	1529	1520	1616	1470	1002	1074
70	15	1140	1256	1440	1249	1212	1274	1337	1367	1511	1426	996	1083
80	15	1113	1198	1329	1107	1039	1071	1129	1191	1373	1348	965	1063
90	15	1058	1112	1191	951	861	869	919	1002	1209	1239	911	1017
20	30	814	1048	1443	1545	1747	1981	2021	1807	1634	1250	758	741
30	30	911	1131	1503	1548	1706	1911	1960	1794	1680	1337	834	839
40	30	985	1187	1531	1521	1636	1810	1867	1746	1689	1392	890	915
50	30	1034	1215	1523	1466	1538	1680	1742	1666	1662	1415	925	968
60	30	1057	1213	1482	1382	1416	1525	1590	1555	1599	1403	936	996
70	30	1053	1182	1407	1273	1272	1351	1415	1417	1501	1357	925	998
80	30	1022	1122	1302	1144	1114	1163	1225	1258	1374	1279	891	975
90	30	966	1038	1174	1002	951	975	1032	1087	1223	1174	836	927
20	45	766	1004	1405	1529	1747	1991	2027	1797	1601	1203	719	694
30	45	843	1070	1455	1532	1713	1933	1977	1786	1639	1273	779	771
40	45	899	1113	1475	1508	1653	1848	1899	1745	1645	1316	822	828
50	45	934	1131	1464	1458	1569	1737	1792	1675	1618	1329	845	866
60	45	946	1123	1424	1383	1461	1602	1660	1577	1560	1312	849	882
70	45	934	1089	1354	1285	1333	1448	1506	1455	1472	1267	832	876
80	45	900	1032	1258	1168	1191	1280	1336	1313	1356	1193	797	848
90	45	845	954	1142	1039	1043	1109	1162	1159	1221	1097	744	800

MANHATTAN	KA	39.12											
		JAN	FEB	MAR	APR	.MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
HORIZONTAL RAD.		117	339	892	1312	1607	1703	1507	1157	729	368	140	55 (BTU/DAY-FT2)
AVE. TEMP.		30.2	33.8	41.0	55.4	64.4	73.4	78.8	77.0	68.0	57.2	42.8	32.0 (F)
DEGREE-DAYS		1122.	893.	722.	330.	124.	12.	0.	0.	57.	270.	672.	980. (F-DAYS)

AVERAGE DAILY RADIATION ON TILTED SURFACES (BTU/DAY-FT2)

SLOPE	AZIMUTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
20	0	107	362	997	1369	1583	1634	1464	1170	769	387	131	43
30	0	101	365	1020	1356	1527	1557	1404	1144	768	388	125	37
40	0	93	362	1021	1315	1442	1453	1318	1097	753	382	117	31
50	0	86	353	1000	1247	1331	1324	1211	1029	724	371	109	26
60	0	77	339	958	1154	1197	1176	1085	944	682	354	100	20
70	0	69	320	897	1040	1045	1013	944	844	629	332	90	16
80	0	61	296	818	908	881	843	795	732	566	305	81	12
90	0	53	269	726	765	716	677	648	615	497	276	72	8
20	15	108	361	993	1369	1585	1637	1466	1171	768	386	131	44
30	15	101	363	1014	1357	1531	1563	1408	1146	767	386	125	38
40	15	94	360	1014	1318	1449	1462	1326	1100	752	380	118	32
50	15	86	351	993	1253	1342	1338	1222	1035	723	369	109	27
60	15	78	336	951	1165	1213	1194	1100	953	683	351	100	21
70	15	70	317	891	1055	1067	1036	963	857	631	329	91	17
80	15	62	293	813	929	908	871	819	749	569	302	81	13
90	15	54	266	722	793	749	709	675	636	502	273	72	9
20	30	108	357	982	1364	1589	1645	1472	1170	763	383	132	45
30	30	102	359	1000	1354	1542	1579	1420	1148	761	382	126	39
40	30	95	354	998	1319	1470	1489	1346	1107	746	376	119	34
50	30	88	344	977	1261	1374	1376	1252	1048	719	363	110	29
60	30	80	329	936	1180	1257	1245	1141	973	680	346	102	24
70	30	72	309	878	1080	1124	1101	1016	884	630	323	92	19
80	30	64	285	804	964	980	948	883	785	572	297	83	16
90	30	56	258	719	840	834	798	750	681	508	268	74	12
20	45	110	353	965	1354	1592	1655	1477	1167	756	379	133	46
30	45	104	352	978	1344	1552	1599	1433	1147	752	377	127	42
40	45	97	346	973	1313	1489	1521	1369	1109	737	369	120	37
50	45	90	335	950	1259	1405	1423	1286	1056	710	356	112	32
60	45	82	320	911	1186	1301	1308	1187	987	672	338	103	28
70	45	75	300	856	1095	1183	1179	1075	906	625	316	94	23
80	45	67	276	787	990	1052	1041	954	815	571	290	85	20
90	45	59	250	709	878	920	903	832	720	511	262	76	17

MATANUSKA AK 61.34

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	
HORIZONTAL RAD.	747	916	1233	1594	1841	2010	1955	1885	1443	1078	791	567	(BTU/DAY-FT2)
AVE. TEMP.	12.2	19.4	26.6	35.6	46.4	53.6	57.2	53.6	46.4	33.8	21.2	14.0	(F)
DEGREE-DAYS	1646.	1285.	1240.	858.	558.	303.	233.	304.	519.	946.	1329.	1628.	(F-DAYS)

AVERAGE DAILY RADIATION ON TILTED SURFACES (BTU/DAY-FT2)

SLOPE	AZIMUTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
20	0	7684	4613	2062	1929	1948	2030	2015	2162	2089	3512	2187	1177
30	0	0015	6247	2395	2032	1956	2004	2005	2236	2331	4567	0939	8618
40	0	5681	7670	2658	2087	1926	1943	1957	2259	2508	5471	7617	1812
50	0	2991	8840	2845	2091	1857	1848	1873	2229	2616	6196	1716	7017
60	0	0508	9719	2949	2043	1751	1718	1752	2146	2650	6721	2808	1036
70	0	7090	0283	2968	1945	1610	1559	1598	2012	2610	7028	0554	1315
80	0	1931	0513	2900	1800	1439	1374	1417	1833	2497	7109	4721	6024
90	0	4648	0409	2751	1616	1247	1176	1218	1617	2318	6967	5207	4210
20	15	2976	4484	2035	1923	1946	2030	2015	2158	2074	3426	0760	0871
30	15	3133	6058	2357	2028	1956	2005	2006	2234	2314	4441	8852	3551
40	15	6834	7427	2611	2085	1928	1947	1961	2259	2491	5310	4935	2443
50	15	2448	8550	2790	2092	1863	1855	1879	2233	2599	6004	8520	3933
60	15	8588	9392	2888	2048	1760	1728	1762	2154	2636	6503	9194	4939
70	15	4157	9928	2903	1955	1622	1572	1612	2026	2600	6792	6633	2999
80	15	8377	0141	2834	1815	1455	1391	1434	1852	2491	6862	0611	6348
90	15	0885	0031	2687	1637	1267	1195	1239	1642	2319	6716	1035	4076
20	30	9175	4106	1963	1904	1942	2030	2013	2145	2024	3183	6576	0654
30	30	2958	5505	2259	2009	1955	2010	2008	2224	2250	4090	2736	9377
40	30	0897	6717	2492	2071	1935	1959	1970	2258	2419	4862	7072	5654
50	30	1537	7704	2656	2086	1877	1874	1897	2243	2524	5474	9149	6255
60	30	3643	8436	2746	2053	1784	1757	1789	2178	2562	5908	8600	8427
70	30	6239	8891	2757	1971	1657	1611	1649	2064	2531	6150	5138	9979
80	30	8639	9054	2691	1845	1500	1439	1482	1905	2432	6194	8564	9342
90	30	0534	8928	2552	1681	1323	1252	1296	1711	2273	6043	8801	5729
20	45	7221	3548	1850	1864	1933	2029	2009	2116	1940	2831	9934	2586
30	45	0863	4708	2107	1963	1952	2016	2010	2196	2141	3596	3030	9106
40	45	9637	5710	2311	2025	1941	1975	1983	2236	2293	4247	4599	5316
50	45	2365	6521	2455	2044	1897	1903	1922	2232	2390	4762	4289	8594
60	45	8053	7117	2532	2019	1819	1800	1829	2182	2426	5125	1805	6715
70	45	5920	7479	2540	1949	1707	1668	1705	2086	2400	5323	6919	7913
80	45	5424	7695	2480	1838	1566	1510	1553	1947	2312	5350	9476	0936
90	45	6344	7467	2355	1690	1404	1336	1382	1773	2170	5211	9424	5188

MEDFORD OR 42.23

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	
HORIZONTAL RAD.	434	780	1222	1782	2168	2404	2573	2216	1653	1023	559	338	(BTU/DAY-FT2)
AVE. TEMP.	37.4	41.0	44.6	50.0	57.2	64.4	71.6	69.8	64.4	53.6	42.8	37.4	(F)
DEGREE-DAYS	918.	697.	642.	432.	242.	78.	0.	0.	78.	372.	678.	871.	(F-DAYS)

AVERAGE DAILY RADIATION ON TILTED SURFACES (BTU/DAY-FT2)

SLOPE	AZIMUTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
20	0	602	1024	1451	1916	2166	2323	2525	2322	1913	1323	784	466
30	0	667	1112	1516	1920	2099	2218	2425	2297	1975	1428	870	516
40	0	716	1172	1545	1879	1990	2070	2275	2219	1989	1497	936	553
50	0	748	1205	1537	1796	1841	1884	2080	2091	1953	1528	978	578
60	0	763	1208	1493	1672	1656	1665	1845	1916	1870	1522	996	590
70	0	758	1181	1414	1513	1442	1421	1578	1700	1741	1478	989	587
80	0	736	1126	1301	1323	1207	1163	1291	1451	1571	1397	958	571
90	0	696	1045	1162	1112	967	909	1003	1183	1369	1284	904	542
20	15	596	1015	1443	1915	2168	2327	2529	2322	1906	1312	776	461
30	15	658	1098	1505	1920	2105	2227	2434	2301	1968	1410	858	509
40	15	704	1155	1532	1883	2001	2085	2291	2228	1982	1475	920	544
50	15	734	1184	1523	1805	1858	1905	2104	2107	1949	1502	959	568
60	15	747	1184	1478	1689	1680	1694	1878	1941	1869	1492	975	578
70	15	741	1155	1399	1537	1474	1458	1621	1735	1745	1446	966	574
80	15	717	1099	1288	1355	1248	1208	1343	1497	1582	1363	934	557
90	15	678	1017	1152	1155	1016	960	1065	1241	1388	1250	879	528
20	30	577	988	1421	1905	2173	2339	2540	2318	1883	1280	751	447
30	30	631	1060	1476	1913	2121	2252	2460	2305	1940	1367	822	488
40	30	670	1107	1499	1883	2031	2126	2336	2245	1953	1421	874	518
50	30	693	1128	1488	1814	1905	1966	2171	2141	1923	1440	904	536
60	30	700	1123	1444	1710	1747	1776	1970	1995	1849	1426	913	542
70	30	690	1090	1368	1573	1562	1562	1739	1812	1735	1377	899	536
80	30	664	1032	1264	1408	1357	1333	1488	1599	1585	1295	864	517
90	30	624	952	1137	1227	1147	1105	1235	1371	1408	1186	808	487
20	45	550	950	1385	1885	2174	2353	2549	2303	1844	1234	714	426
30	45	591	1007	1430	1892	2132	2282	2486	2294	1890	1303	770	457
40	45	620	1042	1446	1865	2057	2178	2385	2245	1900	1344	809	479
50	45	634	1054	1432	1805	1950	2042	2247	2157	1871	1355	829	490
60	45	635	1043	1390	1713	1813	1879	2075	2031	1804	1336	830	491
70	45	621	1009	1320	1591	1650	1692	1875	1871	1702	1287	812	480
80	45	594	953	1224	1444	1469	1489	1655	1683	1567	1210	775	460
90	45	554	879	1109	1282	1280	1284	1429	1481	1409	1111	722	430

MIAMI	FL	25.47											
	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	
HORIZONTAL RAD.	1263	1531	1808	2003	2032	1955	1977	1870	1646	1432	1303	1174	(BTU/DAY-FT2)
AVE. TEMP.	66.2	66.2	69.8	73.4	77.0	80.6	80.6	82.4	80.6	77.0	71.6	68.0	(F)
DEGREE-DAYS	74.	56.	19.	0.	0.	0.	0.	0.	0.	0.	0.	65.	(F-DAYS)

AVERAGE DAILY RADIATION ON TILTED SURFACES (BTU/DAY-FT2)

SLOPE	AZIMUTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
20	0	1625	1829	1975	2002	1905	1785	1826	1817	1724	1642	1640	1542
30	0	1748	1913	1990	1933	1784	1651	1698	1733	1705	1690	1751	1672
40	0	1828	1950	1956	1822	1628	1488	1539	1613	1648	1699	1818	1760
50	0	1862	1938	1877	1672	1444	1302	1354	1461	1553	1667	1840	1803
60	0	1848	1879	1753	1487	1237	1101	1152	1282	1426	1596	1816	1800
70	0	1788	1774	1589	1274	1016	893	939	1083	1268	1489	1746	1751
80	0	1683	1626	1390	1040	793	693	730	872	1085	1347	1633	1658
90	0	1539	1444	1167	801	594	534	553	666	888	1180	1483	1527
20	15	1610	1816	1969	2004	1911	1792	1833	1821	1722	1633	1627	1528
30	15	1727	1895	1981	1940	1795	1663	1710	1741	1704	1677	1731	1651
40	15	1801	1926	1948	1835	1647	1506	1557	1627	1649	1682	1793	1733
50	15	1830	1910	1869	1693	1471	1328	1381	1483	1558	1647	1810	1771
60	15	1812	1848	1747	1519	1273	1135	1187	1313	1436	1574	1782	1764
70	15	1749	1740	1587	1319	1063	935	984	1126	1285	1465	1709	1712
80	15	1641	1590	1394	1101	852	743	783	928	1112	1323	1594	1617
90	15	1497	1408	1180	884	660	579	608	737	928	1157	1444	1485
20	30	1569	1783	1951	2005	1926	1811	1850	1828	1714	1609	1588	1486
30	30	1667	1848	1960	1949	1825	1697	1742	1758	1697	1645	1676	1590
40	30	1725	1869	1927	1857	1694	1558	1607	1657	1646	1645	1722	1655
50	30	1739	1846	1853	1730	1539	1400	1451	1530	1563	1607	1727	1678
60	30	1710	1780	1739	1575	1365	1229	1280	1379	1451	1534	1689	1659
70	30	1640	1672	1592	1398	1181	1051	1100	1214	1314	1429	1611	1599
80	30	1529	1528	1417	1207	995	878	922	1040	1158	1295	1494	1499
90	30	1385	1356	1227	1017	823	724	762	873	996	1142	1346	1366
20	45	1508	1733	1922	2003	1944	1835	1871	1834	1699	1574	1532	1424
30	45	1582	1781	1926	1955	1859	1739	1780	1774	1682	1599	1597	1502
40	45	1620	1790	1893	1874	1747	1622	1666	1687	1635	1591	1627	1545
50	45	1620	1761	1823	1764	1614	1486	1532	1576	1559	1552	1619	1553
60	45	1583	1695	1721	1628	1464	1337	1383	1445	1459	1482	1576	1524
70	45	1511	1594	1589	1472	1302	1182	1226	1299	1337	1385	1490	1460
80	45	1406	1464	1434	1304	1137	1026	1067	1145	1199	1264	1389	1363
90	45	1275	1312	1266	1135	979	881	917	994	1054	1128	1256	1241

MIDLAND	TX	31.56											
	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	
HORIZONTAL RAD.	1034	1325	1756	2029	2272	2264	2261	2161	1881	1469	1185	1001	(BTU/DAY-FT2)
AVE. TEMP.	42.8	46.4	53.6	62.6	71.6	78.8	80.6	80.6	73.4	64.4	51.8	44.6	(F)
DEGREE-DAYS	651.	468.	322.	90.	0.	0.	0.	0.	0.	87.	381.	592.	(F-DAYS)

AVERAGE DAILY RADIATION ON TILTED SURFACES (BTU/DAY-FT2)

SLOPE	AZIMUTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
20	0	1400	1647	1991	2084	2178	2106	2131	2155	2050	1774	1588	1404
30	0	1534	1750	2037	2040	2063	1967	2002	2080	2061	1863	1732	1555
40	0	1628	1810	2033	1950	1906	1791	1835	1959	2023	1907	1833	1667
50	0	1682	1824	1980	1817	1713	1585	1635	1797	1936	1903	1885	1735
60	0	1692	1793	1879	1644	1489	1356	1408	1598	1803	1852	1889	1758
70	0	1659	1717	1733	1437	1244	1114	1165	1369	1629	1755	1845	1735
80	0	1583	1599	1546	1204	988	870	916	1119	1418	1615	1752	1667
90	0	1470	1446	1330	958	743	652	686	865	1182	1441	1618	1558
20	15	1386	1634	1982	2085	2183	2113	2137	2158	2045	1761	1572	1388
30	15	1513	1731	2026	2045	2073	1979	2014	2088	2057	1845	1710	1533
40	15	1602	1785	2021	1961	1924	1811	1854	1974	2021	1884	1803	1638
50	15	1650	1795	1967	1835	1739	1613	1662	1820	1938	1875	1851	1701
60	15	1656	1760	1867	1671	1526	1393	1445	1631	1811	1821	1850	1719
70	15	1620	1681	1723	1476	1291	1159	1211	1414	1644	1722	1802	1693
80	15	1543	1562	1541	1257	1047	925	973	1178	1443	1581	1707	1623
90	15	1429	1408	1331	1029	813	711	750	940	1221	1406	1572	1513
20	30	1345	1599	1958	2081	2196	2132	2153	2162	2030	1729	1528	1344
30	30	1454	1681	1996	2048	2102	2014	2046	2102	2040	1800	1645	1467
40	30	1526	1723	1989	1974	1971	1866	1906	2003	2007	1830	1720	1554
50	30	1560	1724	1937	1862	1809	1690	1736	1868	1931	1815	1753	1601
60	30	1555	1683	1843	1716	1620	1494	1544	1701	1815	1759	1740	1607
70	30	1510	1603	1710	1542	1413	1286	1336	1509	1663	1661	1684	1571
80	30	1428	1485	1542	1347	1197	1075	1124	1302	1482	1526	1585	1495
90	30	1314	1338	1352	1146	990	878	923	1093	1284	1363	1451	1384
20	45	1285	1546	1920	2071	2209	2155	2172	2162	2002	1679	1461	1277
30	45	1368	1610	1948	2042	2131	2057	2083	2111	2008	1734	1552	1372
40	45	1420	1638	1938	1977	2020	1932	1964	2026	1977	1752	1606	1435
50	45	1438	1630	1888	1880	1881	1782	1820	1910	1908	1732	1623	1463
60	45	1422	1586	1801	1752	1719	1613	1654	1765	1804	1676	1601	1455
70	45	1373	1508	1681	1599	1538	1431	1473	1597	1669	1584	1541	1412
80	45	1293	1399	1532	1427	1348	1244	1284	1414	1508	1461	1447	1336
90	45	1187	1267	1364	1248	1160	1064	1102	1228	1333	1316	1324	1232

MT WEATHER VA 39.04

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	
HORIZONTAL RAD.	634	1010	1246	1526	1872	1935	1880	1585	1382	1035	744	619	(BTU/DAY-FT2)
AVE. TEMP.	30.2	32.0	37.4	50.0	59.0	68.0	71.6	69.8	64.4	53.6	41.0	32.0	(F)
DEGREE-DAYS	1107.	963.	815.	452.	183.	23.	0.	6.	80.	341.	666.	1032.	(F-DAYS)

AVERAGE DAILY RADIATION ON TILTED SURFACES (BTU/DAY-FT2)

SLOPE	AZIMUTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
20	0	894	1320	1443	1603	1846	1854	1824	1618	1540	1290	1037	919
30	0	994	1430	1494	1591	1779	1763	1745	1585	1567	1373	1148	1038
40	0	1070	1504	1509	1544	1677	1641	1633	1519	1558	1424	1231	1130
50	0	1119	1540	1489	1464	1543	1491	1492	1423	1514	1439	1283	1193
60	0	1140	1538	1435	1354	1382	1317	1327	1299	1435	1420	1302	1226
70	0	1132	1498	1348	1217	1199	1126	1142	1151	1325	1367	1288	1227
80	0	1095	1420	1230	1058	1001	927	947	985	1185	1281	1241	1195
90	0	1033	1309	1088	885	802	734	754	811	1025	1167	1165	1135
20	15	884	1308	1436	1602	1848	1858	1827	1618	1536	1280	1026	908
30	15	980	1412	1484	1592	1785	1771	1751	1588	1563	1358	1132	1021
40	15	1052	1481	1498	1548	1687	1653	1644	1525	1555	1405	1210	1109
50	15	1097	1513	1477	1473	1559	1507	1508	1433	1512	1417	1258	1168
60	15	1115	1508	1423	1368	1403	1339	1348	1315	1436	1395	1274	1198
70	15	1105	1465	1336	1237	1227	1155	1170	1173	1329	1339	1257	1196
80	15	1067	1385	1220	1085	1036	961	981	1014	1195	1252	1209	1163
90	15	1004	1274	1081	921	844	773	793	848	1042	1138	1132	1102
20	30	856	1275	1417	1597	1854	1868	1835	1617	1521	1253	994	875
30	30	938	1364	1459	1589	1799	1791	1769	1592	1545	1321	1085	974
40	30	998	1421	1469	1550	1714	1686	1674	1537	1538	1359	1150	1048
50	30	1033	1444	1448	1483	1599	1555	1552	1455	1498	1365	1186	1095
60	30	1043	1431	1395	1388	1460	1403	1408	1349	1427	1339	1193	1115
70	30	1027	1384	1313	1269	1301	1234	1247	1221	1328	1282	1170	1106
80	30	985	1303	1204	1131	1129	1057	1074	1077	1204	1197	1118	1069
90	30	921	1195	1075	982	954	883	903	927	1064	1088	1041	1007
20	45	813	1225	1385	1584	1858	1880	1843	1611	1496	1212	946	826
30	45	877	1296	1418	1576	1811	1815	1787	1589	1514	1266	1018	902
40	45	921	1338	1423	1542	1738	1726	1706	1541	1505	1293	1066	958
50	45	944	1350	1401	1481	1639	1613	1601	1469	1467	1292	1090	990
60	45	945	1332	1350	1396	1517	1480	1475	1374	1402	1264	1087	998
70	45	923	1284	1274	1289	1377	1331	1332	1260	1312	1209	1059	982
80	45	880	1207	1174	1165	1222	1172	1178	1131	1200	1129	1007	941
90	45	819	1108	1059	1031	1065	1013	1022	995	1074	1030	934	880

NASHVILLE	TN	36.07											
	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	
HORIZONTAL RAD.	600	883	1211	1657	1903	2087	2036	1819	1576	1204	799	592	(BTU/DAY-FT2)
AVE. TEMP.	37.4	41.0	48.2	59.0	68.0	75.2	78.8	77.0	71.6	60.8	48.2	41.0	(F)
DEGREE-DAYS	828.	672.	524.	176.	45.	0.	0.	0.	10.	180.	498.	763.	(F-DAYS)

AVERAGE DAILY RADIATION ON TILTED SURFACES (BTU/DAY-FT2)

SLOPE	AZIMUTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
20	0	789	1090	1370	1724	1858	1978	1955	1842	1741	1482	1070	814
30	0	858	1157	1404	1702	1780	1869	1858	1795	1764	1569	1170	898
40	0	907	1198	1406	1643	1667	1725	1726	1710	1746	1619	1241	961
50	0	935	1211	1377	1548	1524	1552	1563	1590	1687	1629	1281	1000
60	0	941	1195	1316	1421	1353	1355	1374	1438	1589	1599	1290	1015
70	0	924	1151	1227	1266	1162	1141	1166	1259	1455	1529	1266	1004
80	0	885	1080	1111	1087	959	922	949	1061	1289	1423	1211	969
90	0	827	987	975	896	757	714	739	854	1101	1287	1128	912
20	15	782	1082	1364	1724	1860	1983	1959	1843	1737	1470	1060	806
30	15	847	1145	1396	1704	1786	1878	1866	1799	1760	1553	1155	886
40	15	894	1182	1397	1648	1679	1740	1739	1719	1743	1598	1221	945
50	15	919	1192	1367	1559	1541	1573	1582	1604	1686	1604	1258	981
60	15	922	1174	1307	1438	1377	1383	1401	1459	1592	1571	1264	994
70	15	904	1128	1218	1291	1194	1177	1200	1289	1463	1499	1238	981
80	15	864	1056	1104	1121	998	964	991	1100	1304	1392	1181	945
90	15	806	963	971	941	804	761	788	904	1125	1255	1098	887
20	30	760	1059	1348	1719	1868	1996	1970	1844	1721	1441	1030	781
30	30	817	1113	1375	1703	1804	1904	1889	1807	1742	1512	1111	850
40	30	854	1142	1374	1654	1709	1781	1777	1737	1726	1548	1165	899
50	30	872	1145	1344	1573	1587	1632	1637	1635	1674	1548	1192	926
60	30	869	1122	1286	1464	1440	1461	1475	1506	1587	1511	1189	931
70	30	846	1074	1202	1331	1276	1274	1295	1353	1468	1440	1157	914
80	30	804	1003	1095	1178	1100	1081	1105	1184	1323	1336	1097	874
90	30	745	912	973	1016	925	895	921	1009	1160	1206	1014	815
20	45	729	1025	1322	1707	1874	2012	1981	1839	1695	1396	985	744
3C	45	772	1067	1342	1692	1820	1935	1914	1807	1710	1452	1048	797
40	45	796	1086	1337	1649	1739	1831	1819	1747	1693	1477	1087	832
50	45	807	1083	1307	1577	1633	1703	1698	1658	1645	1470	1102	848
60	45	798	1057	1252	1480	1504	1554	1557	1544	1565	1431	1092	845
70	45	772	1009	1174	1361	1359	1390	1398	1409	1458	1363	1056	823
80	45	729	941	1077	1224	1202	1218	1230	1258	1328	1267	997	782
90	45	673	858	966	1079	1044	1048	1062	1101	1183	1150	919	725

NATICK MA 42.17

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	
HORIZONTAL RAD.	559	854	1200	1439	1841	1506	1889	1682	1321	961	541	493	(BTU/DAY-FT2)
AVE. TEMP.	26.6	28.4	35.6	46.4	57.2	66.2	71.6	69.8	62.6	51.8	41.0	30.2	(F)
DEGREE-DAYS	1271.	1123.	998.	612.	304.	78.	6.	34.	147.	450.	774.	1172.	(F-DAYS)

AVERAGE DAILY RADIATION ON TILTED SURFACES (BTU/DAY-FT2)

SLOPE	AZIMUTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
20	0	826	1137	1421	1529	1834	1458	1851	1742	1497	1229	751	756
30	0	932	1240	1483	1526	1778	1398	1781	1718	1535	1322	832	861
40	0	1014	1313	1511	1490	1686	1314	1677	1657	1537	1382	892	945
50	0	1071	1353	1502	1422	1563	1209	1543	1562	1503	1409	931	1005
60	0	1100	1359	1458	1325	1411	1086	1382	1435	1435	1401	947	1039
70	0	1101	1331	1380	1200	1236	949	1201	1281	1335	1358	940	1046
80	0	1073	1270	1270	1054	1044	803	1006	1104	1205	1282	909	1025
90	0	1020	1180	1135	893	848	659	810	916	1053	1178	857	979
20	15	816	1126	1413	1528	1836	1460	1853	1742	1492	1219	743	746
30	15	917	1224	1473	1526	1782	1402	1786	1720	1529	1306	820	847
40	15	995	1292	1498	1493	1695	1321	1687	1663	1532	1362	878	927
50	15	1048	1328	1488	1429	1576	1219	1557	1572	1500	1385	914	983
60	15	1076	1331	1444	1336	1430	1099	1402	1451	1435	1374	927	1014
70	15	1073	1301	1366	1217	1261	966	1226	1303	1338	1329	918	1019
80	15	1045	1239	1257	1077	1075	824	1037	1133	1212	1252	886	997
90	15	991	1148	1124	923	885	683	847	953	1066	1148	834	951
20	30	787	1096	1392	1522	1840	1466	1860	1740	1476	1191	720	718
30	30	875	1181	1445	1522	1794	1414	1801	1723	1510	1267	787	806
40	30	941	1237	1466	1493	1718	1340	1713	1674	1512	1314	834	874
50	30	983	1264	1455	1435	1612	1247	1597	1594	1482	1330	862	920
60	30	1001	1260	1411	1351	1481	1136	1457	1485	1421	1314	869	943
70	30	994	1226	1337	1243	1328	1013	1297	1352	1331	1267	855	941
80	30	961	1162	1234	1114	1159	881	1124	1198	1215	1191	821	916
90	30	906	1073	1110	974	986	749	949	1035	1080	1090	768	868
20	45	744	1051	1357	1507	1841	1472	1865	1730	1449	1149	686	674
30	45	812	1119	1400	1507	1803	1428	1817	1716	1476	1210	738	743
40	45	862	1161	1415	1480	1738	1364	1742	1674	1475	1245	773	795
50	45	891	1178	1401	1429	1647	1282	1642	1604	1447	1253	791	827
60	45	899	1168	1359	1353	1531	1184	1520	1508	1390	1233	791	838
70	45	885	1132	1289	1256	1396	1072	1378	1389	1308	1187	773	830
80	45	850	1070	1196	1140	1245	952	1223	1252	1202	1115	738	801
90	45	797	987	1083	1013	1088	831	1064	1104	1081	1023	687	754

NEW ORLEANS LA 29.59

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	
HORIZONTAL RAD.	788	984	1235	1518	1655	1633	1537	1533	1411	1316	1024	729	(BTU/DAY-FT2)
AVE. TEMP.	51.8	55.4	59.0	68.0	73.4	78.8	80.6	80.6	77.0	68.0	59.0	53.6	(F)
DEGREE-DAYS	363.	258.	192.	39.	0.	0.	0.	0.	0.	19.	192.	322.	(F-DAYS)

AVERAGE DAILY RADIATION ON TILTED SURFACES (BTU/DAY-FT2)

SLOPE	AZIMUTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
20	0	992	1117	1345	1535	1581	1524	1451	1512	1497	1543	1306	936
30	0	1061	1162	1356	1495	1499	1428	1369	1456	1490	1604	1402	1009
40	0	1106	1182	1339	1424	1389	1309	1263	1371	1451	1626	1464	1058
50	0	1125	1174	1292	1324	1256	1170	1137	1259	1381	1610	1490	1082
60	0	1117	1141	1217	1199	1102	1016	996	1126	1281	1556	1480	1081
70	0	1084	1082	1117	1052	936	853	844	975	1154	1465	1433	1054
80	0	1025	1000	995	889	763	691	690	811	1006	1341	1352	1002
90	0	944	899	857	719	599	546	548	647	843	1189	1240	929
20	15	984	1110	1340	1536	1585	1528	1455	1514	1494	1533	1295	928
30	15	1049	1152	1351	1498	1506	1436	1376	1460	1488	1590	1386	997
40	15	1091	1169	1332	1431	1401	1321	1274	1379	1451	1609	1443	1043
50	15	1107	1159	1285	1336	1272	1187	1153	1273	1383	1589	1466	1064
60	15	1097	1124	1212	1217	1125	1039	1016	1146	1286	1533	1452	1061
70	15	1061	1063	1113	1078	965	881	870	1002	1165	1440	1403	1032
80	15	1001	980	993	924	800	724	721	847	1023	1315	1320	979
90	15	920	879	859	766	643	581	583	693	869	1164	1207	905
20	30	960	1091	1328	1535	1594	1540	1464	1517	1485	1508	1263	904
30	30	1016	1126	1336	1501	1524	1458	1394	1470	1479	1556	1340	963
40	30	1048	1137	1317	1441	1431	1355	1303	1398	1444	1568	1385	999
50	30	1056	1122	1272	1355	1316	1235	1194	1303	1381	1545	1396	1012
60	30	1039	1084	1201	1248	1185	1101	1071	1188	1292	1487	1374	1001
70	30	999	1023	1109	1122	1041	959	939	1059	1180	1396	1320	968
80	30	937	942	998	983	893	816	804	920	1051	1277	1234	912
90	30	856	844	876	842	751	682	677	783	912	1136	1123	837
20	45	926	1064	1309	1530	1603	1555	1476	1518	1470	1471	1216	869
30	45	967	1089	1312	1500	1543	1485	1415	1477	1462	1506	1274	913
40	45	987	1092	1292	1446	1463	1397	1336	1413	1429	1510	1304	937
50	45	987	1074	1248	1370	1362	1292	1241	1329	1370	1483	1305	940
60	45	965	1034	1183	1273	1247	1174	1132	1228	1289	1426	1277	923
70	45	923	976	1098	1161	1119	1047	1014	1112	1188	1341	1221	886
80	45	862	899	997	1037	986	917	892	988	1072	1232	1139	831
90	45	786	811	887	909	856	793	774	863	948	1106	1037	760

NEWPORT	RI	41.29											
	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	
HORIZONTAL RAD.	570	850	1215	1454	1800	1981	1903	1653	1399	1005	644	519	(BTU/DAY-FT2)
AVE. TEMP.	28.4	30.2	35.6	44.6	53.6	62.6	69.8	68.0	60.8	51.8	41.0	32.0	(F)
DEGREE-DAYS	1020.	955.	877.	612.	344.	99.	0.	16.	78.	307.	594.	902.	(F-DAYS)

AVERAGE DAILY RADIATION ON TILTED SURFACES (BTU/DAY-FT2)

SLOPE	AZIMUTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
20	0	828	1116	1430	1540	1788	1911	1860	1705	1583	1280	912	785
30	0	929	1212	1489	1534	1730	1824	1787	1677	1621	1374	1016	891
40	0	1007	1278	1513	1495	1639	1705	1680	1615	1622	1434	1094	975
50	0	1059	1312	1501	1424	1517	1556	1542	1520	1585	1460	1145	1034
60	0	1085	1314	1454	1324	1367	1381	1378	1394	1511	1449	1166	1066
70	0	1083	1284	1373	1197	1195	1188	1194	1241	1402	1402	1159	1071
80	0	1053	1222	1261	1048	1008	984	996	1068	1262	1322	1121	1048
90	0	998	1132	1123	886	817	784	799	884	1099	1212	1057	999
20	15	818	1106	1422	1539	1790	1914	1863	1705	1578	1269	902	775
30	15	915	1197	1478	1534	1735	1831	1792	1680	1616	1358	1001	876
40	15	988	1258	1500	1498	1647	1716	1690	1621	1617	1414	1075	956
50	15	1038	1289	1488	1432	1530	1572	1557	1530	1582	1435	1122	1012
60	15	1060	1288	1440	1336	1386	1403	1399	1409	1510	1422	1141	1041
70	15	1056	1255	1360	1215	1220	1216	1220	1263	1406	1373	1131	1044
80	15	1026	1192	1249	1072	1039	1018	1029	1097	1271	1291	1092	1020
90	15	970	1102	1114	917	854	822	838	921	1115	1180	1028	971
20	30	790	1077	1401	1532	1794	1923	1870	1703	1561	1241	873	746
30	30	874	1156	1451	1530	1747	1850	1808	1683	1596	1318	958	834
40	30	936	1207	1469	1499	1670	1747	1718	1632	1597	1365	1020	902
50	30	975	1229	1455	1439	1566	1618	1599	1552	1563	1379	1057	948
60	30	989	1221	1409	1352	1436	1464	1456	1444	1497	1360	1067	969
70	30	979	1185	1332	1242	1286	1293	1294	1312	1400	1310	1051	965
80	30	945	1120	1227	1112	1121	1111	1119	1161	1276	1229	1009	937
90	30	888	1032	1102	970	953	930	943	1002	1132	1123	944	887
20	45	748	1035	1367	1519	1795	1934	1876	1694	1533	1197	829	702
30	45	813	1097	1407	1516	1756	1873	1825	1678	1560	1259	896	771
40	45	860	1135	1419	1487	1691	1786	1748	1634	1559	1294	943	822
50	45	886	1148	1403	1434	1600	1674	1646	1563	1527	1300	967	853
60	45	891	1135	1358	1356	1486	1541	1521	1467	1466	1278	969	864
70	45	875	1097	1287	1256	1353	1389	1377	1350	1377	1228	948	853
80	45	839	1035	1191	1139	1205	1226	1221	1215	1265	1152	905	821
90	45	784	953	1078	1011	1053	1062	1061	1071	1136	1056	843	772

NEW YORK	NY	40.46										
	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	
HORIZONTAL RAD.	637	773	1148	1392	1675	1936	1907	1811	1329	964	589	471	(BTU/DAY-FT2)
AVE. TEMP.	32.0	32.0	39.2	50.0	60.8	69.8	75.2	73.4	68.0	57.2	46.4	33.8	(F)
DEGREE-DAYS	973.	879.	750.	414.	124.	6.	0.	0.	27.	223.	528.	887.	(F-DAYS)

AVERAGE DAILY RADIATION ON TILTED SURFACES (BTU/DAY-FT2)

SLOPE	AZIMUTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
20	0	754	986	1334	1465	1658	1864	1859	1867	1489	1209	804	679
30	0	837	1061	1383	1456	1602	1777	1783	1836	1520	1290	885	761
40	0	900	1110	1400	1416	1516	1659	1673	1765	1515	1341	945	824
50	0	941	1133	1384	1346	1402	1511	1533	1657	1476	1359	982	867
60	0	959	1129	1337	1249	1263	1340	1367	1515	1404	1345	995	888
70	0	953	1098	1259	1128	1105	1151	1181	1344	1300	1297	984	887
80	0	924	1041	1153	987	933	952	983	1149	1168	1219	948	864
90	0	873	962	1025	833	759	758	786	943	1016	1115	891	821
20	15	746	978	1328	1464	1660	1867	1861	1868	1485	1199	796	671
30	15	825	1048	1374	1456	1607	1784	1789	1839	1515	1276	873	749
40	15	885	1094	1389	1419	1524	1670	1683	1773	1511	1323	930	809
50	15	923	1114	1372	1353	1414	1527	1549	1670	1474	1338	964	850
60	15	939	1108	1325	1261	1280	1362	1388	1534	1404	1320	974	869
70	15	931	1075	1247	1145	1128	1179	1209	1370	1304	1271	961	866
80	15	900	1017	1143	1009	961	985	1016	1184	1177	1192	924	842
90	15	849	937	1017	863	793	796	825	987	1030	1087	867	798
20	30	722	955	1309	1458	1664	1876	1869	1866	1470	1173	772	648
30	30	790	1015	1350	1453	1618	1803	1805	1843	1497	1240	838	716
40	30	840	1053	1362	1420	1545	1701	1712	1786	1493	1279	885	767
50	30	870	1066	1344	1360	1447	1573	1592	1696	1468	1287	911	799
60	30	879	1054	1298	1276	1326	1422	1447	1575	1393	1266	915	811
70	30	866	1018	1224	1170	1187	1255	1284	1428	1300	1215	897	804
80	30	832	959	1126	1047	1036	1077	1109	1260	1182	1137	857	777
90	30	780	881	1009	913	882	902	933	1083	1048	1037	799	732
20	45	686	921	1280	1446	1666	1887	1876	1857	1445	1135	737	614
30	45	740	968	1312	1440	1627	1826	1823	1838	1466	1188	789	666
40	45	776	995	1319	1410	1564	1739	1744	1789	1460	1215	823	704
50	45	796	1001	1299	1357	1478	1629	1640	1710	1427	1217	839	725
60	45	796	985	1255	1281	1372	1497	1513	1604	1366	1193	836	729
70	45	779	948	1186	1185	1248	1349	1369	1473	1281	1143	814	716
80	45	743	891	1095	1074	1112	1190	1212	1324	1175	1070	774	686
90	45	693	819	989	953	972	1030	1053	1164	1054	978	718	642

NORFOLK VA 36.54

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	
HORIZONTAL RAD.	766	995	1371	1758	1990	2108	2027	1773	1467	1142	822	678	(BTU/DAY-FT2)
AVE. TEMP.	39.2	41.0	46.4	57.2	66.2	73.4	77.0	75.2	71.6	60.8	50.0	41.0	(F)
DEGREE-DAYS	760.	661.	532.	226.	53.	0.	0.	0.	9.	141.	402.	704.	(F-DAYS)

AVERAGE DAILY RADIATION ON TILTED SURFACES (BTU/DAY-FT2)

SLOPE	AZIMUTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
20	0	1069	1257	1574	1838	1946	2001	1950	1798	1617	1403	1116	969
30	0	1184	1345	1622	1817	1865	1892	1855	1753	1638	1486	1224	1081
40	0	1269	1400	1631	1756	1748	1748	1725	1672	1621	1533	1303	1167
50	0	1322	1422	1602	1657	1598	1574	1564	1556	1566	1542	1349	1223
60	0	1342	1409	1536	1522	1419	1375	1377	1410	1477	1514	1361	1248
70	0	1327	1362	1434	1355	1218	1160	1171	1238	1354	1449	1339	1241
80	0	1279	1282	1300	1164	1003	937	955	1046	1202	1350	1283	1202
90	0	1200	1174	1141	958	790	726	746	846	1030	1222	1197	1134
20	15	1058	1246	1566	1838	1949	2006	1953	1799	1613	1393	1104	958
30	15	1167	1329	1612	1819	1872	1901	1863	1757	1634	1471	1208	1065
40	15	1247	1381	1620	1763	1760	1762	1738	1681	1618	1513	1282	1146
50	15	1297	1399	1590	1668	1616	1595	1583	1570	1565	1519	1324	1198
60	15	1313	1383	1524	1540	1444	1403	1403	1431	1479	1488	1332	1220
70	15	1296	1334	1423	1383	1251	1195	1205	1266	1361	1421	1308	1211
80	15	1246	1252	1291	1201	1044	980	996	1083	1215	1320	1250	1170
90	15	1167	1144	1136	1007	839	774	794	893	1051	1192	1164	1102
20	30	1024	1218	1546	1832	1956	2019	1964	1799	1599	1365	1072	926
30	30	1118	1289	1586	1817	1890	1927	1885	1764	1617	1432	1161	1019
40	30	1185	1330	1591	1768	1792	1804	1775	1697	1602	1466	1221	1086
50	30	1222	1340	1561	1684	1664	1654	1637	1599	1553	1466	1252	1127
60	30	1229	1319	1498	1568	1511	1481	1476	1475	1473	1431	1252	1139
70	30	1205	1266	1403	1426	1338	1293	1297	1327	1364	1364	1221	1123
80	30	1151	1185	1280	1262	1153	1097	1109	1163	1231	1267	1160	1078
90	30	1070	1079	1137	1088	968	908	924	993	1081	1145	1073	1009
20	45	974	1175	1514	1819	1962	2035	1975	1794	1574	1323	1024	878
30	45	1048	1231	1544	1805	1907	1958	1909	1764	1588	1376	1093	950
40	45	1096	1260	1544	1761	1823	1854	1815	1706	1572	1399	1137	999
50	45	1120	1262	1514	1687	1713	1725	1697	1620	1526	1392	1155	1025
60	45	1116	1236	1454	1585	1579	1575	1556	1510	1453	1356	1147	1027
70	45	1087	1184	1367	1458	1427	1410	1399	1379	1354	1291	1112	1004
80	45	1032	1107	1255	1312	1262	1235	1231	1233	1234	1201	1051	957
90	45	956	1010	1127	1156	1095	1063	1064	1080	1100	1091	970	890

NORTH OMAHA	NE	41.22											
	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	
HORIZONTAL RAD.	752	1021	1312	1706	1891	2075	2094	1920	1459	1083	729	611	(BTU/DAY-FT2)
AVE. TEMP.	23.0	26.6	37.4	50.0	62.6	71.6	77.0	73.4	66.2	53.6	39.2	28.4	(F)
DEGREE-DAYS	1355.	1126.	939.	465.	208.	42.	0.	12.	105.	357.	828.	1175.	(F-DAYS)

AVERAGE DAILY RADIATION ON TILTED SURFACES (BTU/DAY-FT2)

SLOPE	AZIMUTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
20	0	1160	1381	1556	1822	1879	2001	2046	1990	1657	1395	1059	961
30	0	1323	1513	1625	1819	1818	1909	1963	1961	1699	1502	1187	1101
40	0	1451	1606	1654	1776	1721	1782	1843	1889	1701	1572	1285	1214
50	0	1540	1658	1644	1693	1591	1624	1689	1776	1663	1602	1350	1294
60	0	1589	1668	1594	1573	1432	1440	1505	1626	1585	1593	1380	1340
70	0	1594	1635	1506	1420	1250	1235	1298	1443	1471	1543	1374	1351
80	0	1558	1560	1383	1238	1051	1019	1076	1235	1324	1456	1333	1325
90	0	1481	1447	1232	1039	848	807	854	1013	1152	1335	1258	1266
20	15	1146	1368	1548	1820	1880	2004	2049	1990	1652	1383	1047	948
30	15	1301	1493	1613	1820	1823	1916	1970	1964	1693	1484	1169	1083
40	15	1422	1580	1640	1780	1730	1794	1855	1897	1696	1549	1262	1190
50	15	1506	1627	1629	1702	1605	1642	1707	1789	1659	1575	1323	1266
60	15	1550	1633	1579	1588	1452	1463	1529	1646	1585	1562	1349	1308
70	15	1553	1597	1491	1442	1277	1265	1329	1471	1475	1510	1341	1316
80	15	1514	1520	1370	1269	1084	1055	1114	1272	1334	1421	1297	1288
90	15	1437	1407	1221	1080	889	849	899	1060	1169	1300	1222	1228
20	30	1101	1329	1524	1812	1885	2014	2057	1988	1634	1350	1011	910
30	30	1236	1438	1582	1814	1836	1937	1989	1968	1672	1439	1117	1028
40	30	1339	1511	1605	1780	1755	1829	1888	1911	1674	1493	1195	1119
50	30	1408	1546	1592	1711	1644	1691	1756	1817	1640	1511	1243	1181
60	30	1439	1543	1543	1609	1507	1529	1596	1690	1571	1493	1259	1213
70	30	1432	1502	1460	1477	1348	1349	1415	1533	1469	1439	1243	1212
80	30	1387	1423	1346	1320	1174	1156	1219	1354	1339	1351	1195	1180
90	30	1308	1312	1208	1149	996	965	1022	1163	1187	1235	1119	1119
20	45	1035	1272	1486	1794	1887	2026	2065	1977	1603	1301	958	853
30	45	1141	1359	1533	1796	1846	1962	2009	1961	1634	1372	1042	945
40	45	1220	1415	1549	1766	1777	1870	1924	1913	1633	1413	1101	1014
50	45	1269	1438	1533	1705	1681	1753	1810	1832	1601	1423	1134	1058
60	45	1285	1428	1486	1614	1561	1612	1672	1720	1538	1401	1139	1076
70	45	1269	1384	1409	1496	1421	1453	1512	1582	1445	1348	1117	1066
80	45	1221	1309	1305	1356	1265	1281	1338	1422	1327	1265	1068	1029
90	45	1145	1207	1181	1203	1104	1107	1161	1252	1192	1159	996	968

OAK RIDGE	TE	36.01											
	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	
HORIZONTAL RAD.	611	876	1200	1646	1896	2006	1918	1752	1535	1174	777	592	(BTU/DAY-FT2)
AVE. TEMP.	37.4	39.2	46.4	57.2	66.2	73.4	75.2	75.2	69.8	59.0	46.4	37.4	(F)
DEGREE-DAYS	778.	669.	552.	228.	56.	0.	0.	0.	39.	192.	531.	772.	(F-DAYS)

AVERAGE DAILY RADIATION ON TILTED SURFACES (BTU/DAY-FT2)

SLOPE	AZIMUTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
20	0	806	1079	1355	1712	1850	1903	1842	1773	1693	1440	1034	813
30	0	877	1145	1389	1689	1772	1798	1752	1727	1714	1523	1129	897
40	0	928	1184	1391	1630	1660	1661	1629	1645	1695	1570	1195	959
50	0	957	1196	1361	1536	1517	1496	1478	1530	1637	1578	1233	998
60	0	963	1180	1301	1410	1347	1309	1302	1384	1542	1548	1240	1012
70	0	946	1136	1212	1256	1157	1105	1109	1214	1412	1480	1216	1002
80	0	907	1066	1097	1079	955	896	907	1024	1251	1377	1163	966
90	0	847	974	963	890	754	698	712	827	1069	1244	1083	909
20	15	798	1071	1350	1711	1853	1907	1846	1774	1688	1429	1026	805
30	15	866	1133	1381	1691	1779	1807	1760	1731	1709	1507	1114	885
40	15	914	1169	1382	1636	1672	1675	1642	1654	1692	1550	1177	943
50	15	940	1178	1351	1547	1534	1516	1496	1544	1636	1554	1211	979
60	15	944	1159	1291	1427	1371	1335	1326	1405	1546	1521	1215	991
70	15	926	1114	1204	1280	1189	1138	1140	1242	1419	1461	1189	979
80	15	885	1042	1091	1113	994	936	945	1061	1265	1347	1134	942
90	15	825	950	960	934	801	743	756	875	1092	1214	1054	865
20	30	776	1048	1334	1707	1860	1919	1856	1774	1674	1401	996	780
30	30	834	1101	1361	1690	1796	1831	1780	1738	1693	1468	1072	849
40	30	873	1129	1359	1641	1702	1714	1676	1671	1676	1502	1123	897
50	30	892	1132	1329	1561	1580	1572	1546	1573	1624	1500	1147	924
60	30	889	1109	1271	1453	1434	1408	1394	1449	1539	1464	1144	929
70	30	866	1061	1188	1320	1270	1230	1226	1303	1424	1394	1112	912
80	30	823	990	1082	1169	1095	1046	1049	1140	1283	1293	1054	872
90	30	763	900	961	1008	921	868	877	973	1125	1167	974	813
20	45	744	1015	1308	1695	1866	1935	1867	1770	1648	1358	953	744
30	45	786	1056	1328	1680	1812	1860	1803	1739	1662	1411	1013	796
40	45	816	1074	1323	1636	1731	1761	1714	1680	1645	1434	1049	831
50	45	825	1071	1293	1565	1626	1638	1601	1595	1597	1426	1062	847
60	45	816	1044	1238	1469	1498	1496	1468	1485	1519	1388	1051	843
70	45	790	997	1161	1350	1353	1339	1320	1355	1415	1321	1017	821
80	45	746	930	1065	1215	1197	1174	1162	1210	1288	1227	959	780
90	45	688	847	955	1071	1039	1012	1006	1060	1147	1113	884	723

OKLAHOMA CITY OK 35.24

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	
HORIZONTAL RAD.	939	1167	1498	1833	1988	2319	2246	2165	1782	1395	1045	872	(BTU/DAY-FT2)
AVE. TEMP.	35.6	39.2	48.2	59.0	68.0	77.0	80.6	80.6	73.4	60.8	48.2	39.2	(F)
DEGREE-DAYS	868.	664.	527.	189.	34.	0.	0.	0.	15.	164.	498.	766.	(F-DAYS)

AVERAGE DAILY RADIATION ON TILTED SURFACES (BTU/DAY-FT2)

SLOPE	AZIMUTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
20	0	1329	1485	1718	1909	1934	2187	2147	2194	1978	1736	1451	1278
30	0	1477	1592	1768	1883	1850	2058	2034	2135	2005	1845	1602	1435
40	0	1587	1660	1776	1814	1729	1891	1882	2029	1985	1907	1712	1555
50	0	1656	1686	1742	1706	1575	1690	1695	1878	1916	1922	1777	1635
60	0	1682	1670	1666	1561	1393	1463	1480	1688	1802	1887	1796	1671
70	0	1663	1613	1551	1385	1191	1218	1244	1465	1646	1805	1768	1663
80	0	1602	1515	1401	1182	976	968	998	1218	1452	1678	1694	1611
90	0	1501	1384	1223	965	764	733	762	961	1232	1514	1578	1519
20	15	1314	1472	1710	1908	1938	2193	2152	2196	1972	1723	1436	1263
30	15	1455	1574	1758	1885	1857	2069	2044	2141	2000	1825	1579	1413
40	15	1559	1636	1764	1822	1741	1909	1899	2041	1981	1882	1683	1527
50	15	1623	1658	1729	1720	1594	1716	1719	1899	1916	1891	1742	1601
60	15	1644	1638	1653	1582	1420	1497	1512	1718	1806	1853	1757	1633
70	15	1623	1578	1540	1415	1225	1261	1285	1506	1657	1769	1726	1622
80	15	1559	1479	1392	1223	1019	1019	1049	1271	1471	1640	1649	1568
90	15	1458	1347	1219	1019	815	791	821	1029	1262	1476	1533	1475
20	30	1271	1438	1688	1903	1946	2209	2166	2197	1954	1687	1391	1218
30	30	1392	1525	1730	1884	1876	2101	2072	2152	1980	1775	1514	1348
40	30	1479	1575	1733	1829	1775	1959	1944	2066	1962	1821	1600	1443
50	30	1527	1587	1698	1738	1644	1788	1785	1941	1902	1823	1644	1501
60	30	1536	1561	1626	1614	1489	1592	1601	1782	1802	1781	1646	1520
70	30	1506	1498	1520	1464	1315	1380	1398	1594	1664	1697	1606	1500
80	30	1437	1399	1383	1291	1130	1161	1186	1385	1496	1573	1526	1440
90	30	1335	1271	1224	1109	947	952	980	1171	1307	1417	1409	1345
20	45	1207	1387	1653	1891	1953	2229	2180	2192	1923	1632	1325	1151
30	45	1302	1454	1685	1873	1895	2140	2102	2154	1942	1702	1422	1252
40	45	1365	1490	1683	1824	1808	2020	1995	2081	1924	1734	1485	1323
50	45	1396	1493	1648	1744	1695	1874	1859	1973	1869	1729	1512	1361
60	45	1393	1462	1581	1635	1560	1705	1699	1835	1779	1685	1503	1366
70	45	1356	1400	1484	1501	1407	1520	1522	1670	1656	1604	1458	1336
80	45	1287	1307	1360	1348	1242	1326	1334	1487	1506	1491	1379	1274
90	45	1191	1191	1218	1186	1076	1137	1148	1296	1339	1351	1271	1184

PAGE	AZ	36.38											
	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	
HORIZONTAL RAD.	1105	1408	1939	2278	2562	2606	2506	2197	1902	1482	1142	895	(BTU/DAY-FT2)
AVE. TEMP.	32.0	35.6	41.0	50.0	59.0	68.0	75.2	71.6	64.4	53.6	41.0	32.0	(F)
DEGREE-DAYS	1063.	804.	713.	432.	193.	37.	0.	11.	73.	341.	702.	1011.	(F-DAYS)

AVERAGE DAILY RADIATION ON TILTED SURFACES (BTU/DAY-FT2)

SLOPE	AZIMUTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
20	0	1665	1878	2315	2411	2504	2461	2403	2239	2139	1886	1652	1354
30	0	1883	2044	2416	2391	2394	2316	2279	2184	2180	2020	1845	1534
40	0	2050	2157	2453	2313	2233	2126	2108	2081	2167	2101	1990	1674
50	0	2162	2212	2427	2180	2026	1896	1897	1932	2101	2128	2081	1769
60	0	2214	2209	2337	1996	1779	1635	1652	1742	1982	2100	2117	1817
70	0	2205	2147	2187	1766	1501	1353	1382	1517	1816	2017	2095	1816
80	0	2137	2029	1980	1499	1205	1062	1100	1265	1606	1883	2016	1766
90	0	2012	1861	1730	1210	911	789	828	1003	1366	1704	1887	1671
20	15	1644	1860	2302	2410	2508	2468	2409	2240	2133	1870	1632	1337
30	15	1852	2017	2398	2394	2405	2329	2290	2190	2174	1996	1817	1509
40	15	2011	2122	2433	2323	2252	2147	2127	2093	2163	2071	1954	1642
50	15	2115	2171	2405	2198	2054	1926	1925	1952	2099	2093	2038	1731
60	15	2161	2162	2315	2025	1818	1675	1690	1771	1986	2060	2068	1774
70	15	2148	2097	2167	1808	1552	1403	1431	1557	1827	1974	2042	1769
80	15	2076	1976	1965	1556	1269	1123	1159	1318	1626	1838	1961	1717
90	15	1951	1807	1721	1286	988	858	897	1070	1398	1659	1831	1621
20	30	1583	1810	2265	2401	2520	2487	2424	2241	2111	1828	1577	1287
30	30	1763	1946	2351	2391	2433	2366	2322	2200	2149	1938	1736	1436
40	30	1897	2033	2381	2331	2301	2206	2180	2117	2139	2000	1850	1548
50	30	1979	2067	2353	2222	2129	2011	2002	1994	2081	2012	1916	1619
60	30	2008	2049	2268	2069	1921	1788	1793	1834	1978	1974	1930	1648
70	30	1982	1978	2130	1876	1687	1544	1563	1644	1832	1888	1893	1632
80	30	1903	1857	1944	1652	1435	1292	1320	1432	1650	1756	1806	1573
90	30	1776	1694	1722	1413	1186	1050	1084	1213	1445	1587	1675	1475
20	45	1492	1735	2207	2381	2530	2510	2441	2234	2074	1764	1495	1212
30	45	1634	1843	2277	2373	2459	2411	2357	2200	2104	1851	1620	1328
40	45	1735	1909	2298	2322	2349	2278	2238	2130	2093	1897	1707	1412
50	45	1792	1929	2269	2228	2204	2114	2088	2024	2040	1900	1750	1461
60	45	1803	1903	2191	2095	2026	1923	1909	1885	1947	1859	1750	1472
70	45	1767	1832	2067	1926	1823	1712	1709	1719	1818	1777	1707	1446
80	45	1687	1720	1901	1730	1603	1490	1495	1533	1656	1656	1621	1384
90	45	1567	1573	1706	1519	1381	1272	1283	1338	1474	1505	1500	1290

PASADENA CA 34.09

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	
HORIZONTAL RAD.	925	1227	1618	1876	2097	2138	2337	2208	1776	1349	999	870	(BTU/DAY-FT2)
AVE. TEMP.	53.6	55.4	55.4	59.0	62.6	66.2	73.4	73.4	71.6	66.2	59.0	55.4	(F)
DEGREE-DAYS	343.	272.	254.	169.	85.	46.	0.	0.	10.	53.	163.	299.	(F-DAYS)

AVERAGE DAILY RADIATION ON TILTED SURFACES (BTU/DAY-FT2)

SLOPE	AZIMUTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
20	0	1279	1552	1853	1944	2032	2011	2223	2227	1957	1651	1349	1243
30	0	1411	1660	1905	1913	1937	1891	2099	2162	1978	1744	1477	1387
40	0	1508	1726	1912	1840	1804	1736	1935	2048	1952	1794	1567	1494
50	0	1566	1750	1872	1725	1637	1552	1734	1890	1879	1800	1618	1563
60	0	1584	1730	1786	1574	1440	1345	1504	1692	1762	1761	1628	1592
70	0	1561	1666	1659	1390	1222	1123	1254	1462	1604	1678	1596	1579
80	0	1498	1562	1492	1181	992	896	996	1207	1410	1555	1523	1524
90	0	1399	1422	1297	957	766	685	750	944	1191	1398	1414	1433
20	15	1265	1539	1845	1944	2036	2016	2229	2229	1952	1639	1335	1229
30	15	1391	1641	1894	1917	1946	1901	2111	2169	1974	1726	1457	1366
40	15	1482	1702	1899	1848	1819	1753	1953	2062	1949	1772	1542	1468
50	15	1536	1721	1858	1740	1658	1576	1761	1912	1880	1773	1588	1532
60	15	1550	1697	1773	1596	1470	1376	1540	1724	1767	1731	1594	1556
70	15	1524	1631	1647	1422	1261	1161	1300	1505	1616	1646	1559	1540
80	15	1459	1524	1484	1224	1040	942	1052	1264	1430	1521	1484	1484
90	15	1359	1384	1294	1015	824	737	815	1017	1223	1364	1375	1391
20	30	1226	1504	1821	1940	2045	2031	2244	2231	1935	1607	1297	1188
30	30	1334	1591	1864	1917	1968	1930	2142	2181	1955	1682	1401	1306
40	30	1409	1640	1866	1856	1856	1799	2004	2089	1932	1718	1470	1390
50	30	1448	1649	1826	1760	1715	1641	1834	1958	1868	1713	1503	1440
60	30	1451	1619	1746	1631	1548	1462	1638	1792	1765	1667	1498	1452
70	30	1417	1549	1628	1475	1361	1269	1424	1598	1627	1583	1456	1427
80	30	1348	1444	1477	1298	1165	1070	1202	1385	1458	1463	1377	1365
90	30	1247	1308	1304	1112	971	882	989	1167	1271	1314	1267	1271
20	45	1168	1451	1783	1928	2055	2050	2261	2228	1906	1558	1239	1126
30	45	1252	1519	1816	1907	1989	1965	2176	2185	1920	1617	1320	1217
40	45	1306	1553	1813	1854	1895	1854	2060	2107	1898	1641	1370	1280
50	45	1330	1553	1774	1769	1773	1719	1915	1994	1839	1629	1389	1311
60	45	1322	1518	1699	1656	1628	1563	1747	1850	1746	1582	1375	1310
70	45	1282	1451	1592	1518	1464	1394	1560	1681	1622	1502	1328	1277
80	45	1213	1352	1457	1360	1289	1217	1364	1493	1473	1392	1252	1214
90	45	1119	1230	1303	1194	1115	1046	1171	1300	1307	1259	1150	1124

PENSACOLA	FL	30.28											
	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	
HORIZONTAL RAD.	921	1183	1493	1876	2071	2094	1979	1876	1585	1452	1024	825	(BTU/DAY-FT2)
AVE. TEMP.	51.8	53.6	59.0	68.0	73.4	78.8	80.6	80.6	77.0	69.8	59.0	53.6	(F)
DEGREE-DAYS	427.	323.	211.	37.	0.	0.	0.	0.	0.	32.	189.	359.	(F-DAYS)

AVERAGE DAILY RADIATION ON TILTED SURFACES (BTU/DAY-FT2)

SLOPE	AZIMUTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
20	0	1200	1431	1656	1912	1978	1943	1862	1858	1697	1731	1317	1094
30	0	1299	1506	1681	1866	1871	1813	1750	1789	1695	1810	1418	1192
40	0	1366	1545	1667	1779	1728	1650	1605	1683	1655	1844	1485	1260
50	0	1400	1547	1615	1653	1552	1460	1433	1543	1578	1833	1515	1298
60	0	1399	1512	1526	1493	1350	1250	1239	1373	1465	1777	1507	1304
70	0	1364	1441	1402	1303	1130	1029	1031	1180	1321	1678	1462	1277
80	0	1295	1336	1248	1091	902	808	821	970	1150	1539	1382	1219
90	0	1197	1204	1073	869	686	613	627	758	961	1368	1270	1133
20	15	1189	1420	1649	1913	1983	1949	1867	1860	1694	1720	1306	1084
30	15	1283	1491	1673	1870	1881	1824	1760	1796	1693	1793	1402	1177
40	15	1346	1526	1658	1788	1744	1668	1621	1695	1654	1823	1463	1241
50	15	1376	1524	1606	1670	1576	1486	1456	1562	1580	1808	1489	1275
60	15	1372	1486	1517	1518	1383	1284	1269	1400	1472	1749	1478	1277
70	15	1334	1413	1396	1339	1173	1071	1070	1217	1334	1648	1431	1249
80	15	1264	1307	1246	1139	955	858	868	1019	1171	1508	1348	1189
90	15	1165	1174	1075	933	748	666	680	821	992	1336	1236	1103
20	30	1158	1393	1632	1911	1995	1966	1881	1864	1683	1689	1273	1054
30	30	1237	1452	1652	1874	1906	1856	1787	1808	1681	1752	1354	1132
40	30	1287	1478	1636	1801	1786	1718	1664	1720	1646	1773	1402	1184
50	30	1306	1469	1585	1695	1638	1556	1517	1602	1577	1753	1417	1207
60	30	1293	1427	1502	1560	1467	1376	1352	1458	1477	1693	1398	1201
70	30	1249	1353	1389	1399	1281	1185	1174	1295	1351	1594	1344	1166
80	30	1176	1248	1250	1222	1088	994	993	1119	1203	1460	1259	1103
90	30	1077	1121	1096	1040	903	817	822	945	1043	1300	1148	1016
20	45	1111	1352	1605	1903	2008	1988	1898	1865	1663	1644	1224	1008
30	45	1171	1396	1618	1871	1933	1896	1818	1817	1659	1691	1286	1068
40	45	1206	1411	1600	1807	1831	1779	1714	1741	1625	1702	1319	1104
50	45	1212	1396	1551	1714	1703	1640	1587	1638	1562	1678	1322	1114
60	45	1192	1352	1474	1594	1555	1484	1443	1512	1472	1618	1296	1100
70	45	1145	1281	1371	1453	1391	1317	1287	1368	1359	1525	1241	1060
80	45	1073	1184	1246	1298	1220	1146	1126	1212	1226	1404	1160	997
90	45	981	1069	1109	1133	1053	983	969	1055	1084	1261	1057	915

PHOENIX	AZ	33.26											
	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	
HORIZONTAL RAD.	1093	1502	1918	2367	2666	2725	2400	2253	2091	1664	1248	1031	(BTU/DAY-FT2)
AVE. TEMP.	50.0	55.4	59.0	66.2	75.2	84.2	89.6	87.8	82.4	71.6	59.0	51.8	(F)
DEGREE-DAYS	474.	328.	217.	75.	0.	0.	0.	0.	0.	22.	234.	415.	(F-DAYS)

AVERAGE DAILY RADIATION ON TILTED SURFACES (BTU/DAY-FT2)

SLOPE	AZIMUTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
20	0	1538	1943	2224	2469	2569	2535	2275	2265	2324	2084	1736	1502
30	0	1706	2092	2295	2430	2436	2364	2143	2195	2355	2217	1916	1683
40	0	1828	2186	2307	2333	2251	2146	1969	2075	2325	2291	2046	1820
50	0	1903	2223	2261	2180	2018	1889	1759	1910	2238	2306	2121	1909
60	0	1928	2203	2157	1976	1747	1601	1518	1705	2094	2251	2140	1946
70	0	1901	2124	2000	1727	1447	1294	1258	1466	1899	2157	2102	1932
80	0	1825	1990	1793	1443	1132	985	990	1204	1659	1996	2008	1866
90	0	1703	1809	1548	1140	827	704	738	934	1386	1790	1864	1753
20	15	1522	1925	2213	2469	2575	2544	2281	2268	2318	2067	1717	1484
30	15	1681	2066	2280	2436	2450	2380	2155	2202	2349	2192	1889	1657
40	15	1797	2153	2290	2346	2273	2172	1989	2090	2322	2260	2011	1787
50	15	1865	2184	2243	2202	2052	1925	1787	1933	2239	2269	2080	1869
60	15	1885	2158	2141	2010	1793	1649	1557	1739	2102	2219	2093	1902
70	15	1855	2076	1986	1776	1507	1355	1307	1513	1916	2112	2051	1883
80	15	1776	1940	1783	1509	1207	1057	1050	1264	1687	1950	1954	1815
90	15	1654	1758	1546	1228	916	784	807	1012	1430	1743	1809	1701
20	30	1472	1878	2183	2463	2591	2568	2298	2271	2297	2023	1664	1432
30	30	1609	1999	2242	2437	2484	2426	2189	2216	2325	2131	1811	1581
40	30	1705	2069	2249	2360	2333	2243	2043	2119	2302	2186	1911	1689
50	30	1756	2088	2203	2234	2140	2026	1865	1982	2226	2187	1962	1753
60	30	1762	2053	2107	2065	1914	1782	1662	1810	2102	2133	1961	1771
70	30	1722	1967	1963	1857	1663	1521	1440	1611	1933	2027	1909	1741
80	30	1637	1833	1777	1622	1399	1256	1211	1392	1727	1872	1807	1666
90	30	1514	1659	1563	1375	1143	1008	992	1170	1498	1678	1662	1550
20	45	1399	1807	2134	2447	2606	2597	2317	2268	2260	1956	1584	1355
30	45	1506	1902	2181	2425	2519	2481	2226	2222	2282	2041	1699	1471
40	45	1576	1953	2182	2359	2393	2330	2104	2140	2259	2081	1774	1550
50	45	1608	1959	2138	2251	2231	2147	1953	2022	2191	2073	1804	1592
60	45	1600	1920	2049	2104	2038	1940	1778	1874	2080	2018	1791	1593
70	45	1554	1836	1920	1924	1822	1715	1585	1699	1931	1918	1734	1554
80	45	1470	1712	1755	1718	1592	1482	1383	1507	1750	1778	1636	1478
90	45	1355	1556	1567	1502	1364	1259	1185	1310	1549	1607	1503	1368

PHILADELPHIA PA 39.53

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	
HORIZONTAL RAD.	645	892	1279	1566	1817	2042	1983	1714	1430	1080	704	560	(BTU/DAY-FT2)
AVE. TEMP.	32.0	33.8	41.0	51.8	62.6	71.6	75.2	73.4	68.0	57.2	46.4	35.6	(F)
DEGREE-DAYS	1014.	871.	716.	367.	122.	0.	0.	0.	38.	249.	564.	924.	(F-DAYS)

AVERAGE DAILY RADIATION ON TILTED SURFACES (BTU/DAY-FT2)

SLOPE	AZIMUTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
20	0	923	1151	1492	1652	1794	1958	1927	1757	1603	1361	979	822
30	0	1031	1241	1547	1641	1731	1863	1844	1724	1635	1454	1084	926
40	0	1113	1302	1567	1595	1634	1734	1726	1654	1629	1512	1162	1006
50	0	1167	1331	1549	1514	1506	1574	1577	1550	1585	1533	1210	1061
60	0	1191	1327	1495	1402	1351	1390	1402	1415	1504	1516	1229	1089
70	0	1185	1291	1406	1261	1175	1187	1205	1253	1390	1462	1216	1089
80	0	1149	1224	1285	1097	985	974	997	1071	1245	1372	1172	1061
90	0	1085	1129	1139	918	793	768	790	879	1078	1252	1101	1008
20	15	913	1141	1484	1651	1796	1962	1930	1757	1598	1349	969	813
30	15	1015	1227	1537	1642	1736	1871	1851	1727	1630	1438	1069	912
40	15	1093	1283	1554	1599	1643	1746	1738	1661	1624	1491	1142	988
50	15	1144	1308	1536	1523	1520	1592	1594	1562	1583	1508	1187	1040
60	15	1165	1302	1481	1416	1371	1414	1425	1433	1505	1488	1202	1065
70	15	1157	1263	1393	1282	1202	1217	1235	1278	1395	1432	1187	1063
80	15	1119	1194	1274	1125	1018	1011	1033	1103	1256	1341	1142	1033
90	15	1055	1099	1131	955	832	810	833	920	1095	1221	1071	979
20	30	882	1113	1463	1644	1801	1973	1938	1756	1582	1320	939	784
30	30	971	1187	1510	1638	1749	1892	1869	1731	1611	1397	1024	870
40	30	1036	1233	1524	1601	1668	1782	1770	1674	1606	1441	1085	934
50	30	1076	1250	1504	1532	1558	1643	1642	1586	1566	1451	1120	976
60	30	1088	1237	1451	1436	1425	1482	1489	1471	1495	1427	1127	992
70	30	1073	1195	1368	1314	1271	1303	1318	1332	1393	1369	1105	984
80	30	1032	1126	1256	1172	1105	1114	1134	1174	1264	1280	1057	951
90	30	966	1032	1123	1018	936	928	951	1009	1118	1165	984	896
20	45	836	1071	1429	1630	1804	1985	1947	1749	1555	1276	894	741
30	45	906	1129	1466	1624	1761	1918	1889	1727	1577	1336	961	807
40	45	954	1163	1475	1591	1691	1825	1805	1678	1570	1369	1006	855
50	45	980	1172	1453	1530	1596	1706	1694	1601	1533	1371	1029	883
60	45	983	1154	1403	1443	1478	1565	1561	1499	1467	1344	1027	889
70	45	963	1111	1325	1334	1342	1407	1410	1375	1375	1288	1001	874
80	45	919	1045	1223	1206	1193	1239	1246	1234	1259	1204	952	838
90	45	856	959	1103	1068	1040	1070	1080	1086	1127	1100	883	784

PITTSBURGH PA 40.30

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	
HORIZONTAL RAD.	582	785	1187	1474	1795	2060	2016	1776	1496	1083	678	523	(BTU/DAY-FT^2)
AVE. TEMP.	32.0	32.0	41.0	51.8	62.6	71.6	75.2	73.4	66.2	55.4	44.6	33.8	(F)
DEGREE-DAYS	1066.	924.	763.	382.	161.	10.	0.	6.	58.	298.	627.	983.	(F-DAYS)

AVERAGE DAILY RADIATION ON TILTED SURFACES (BTU/DAY-FT^2)

SLOPE	AZIMUTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
20	0	829	1002	1382	1555	1777	1981	1964	1829	1692	1379	951	771
30	0	925	1078	1433	1546	1716	1887	1882	1797	1731	1478	1055	869
40	0	998	1128	1451	1504	1623	1759	1765	1728	1730	1542	1133	946
50	0	1046	1151	1435	1430	1498	1599	1615	1621	1688	1567	1183	999
60	0	1068	1147	1386	1327	1348	1414	1437	1482	1606	1554	1203	1026
70	0	1063	1115	1306	1197	1175	1210	1238	1315	1487	1502	1192	1027
80	0	1031	1057	1195	1045	988	996	1025	1125	1335	1412	1151	1002
90	0	974	976	1062	879	798	786	814	923	1158	1292	1083	953
20	15	820	993	1375	1554	1779	1984	1967	1829	1687	1367	940	762
30	15	911	1065	1424	1547	1721	1894	1889	1800	1726	1461	1040	856
40	15	980	1112	1440	1508	1632	1771	1776	1735	1725	1520	1114	929
50	15	1025	1132	1423	1438	1512	1617	1632	1634	1685	1541	1160	978
60	15	1044	1125	1374	1339	1367	1438	1460	1501	1606	1524	1177	1003
70	15	1037	1092	1294	1215	1200	1241	1268	1340	1492	1470	1164	1002
80	15	1004	1033	1185	1070	1020	1032	1062	1158	1345	1379	1122	976
90	15	947	951	1054	912	836	828	857	966	1176	1258	1053	926
20	30	793	970	1355	1548	1783	1995	1975	1828	1669	1336	911	735
30	30	872	1031	1399	1543	1734	1916	1907	1805	1705	1418	996	816
40	30	929	1069	1411	1509	1655	1806	1808	1748	1704	1467	1058	878
50	30	965	1083	1394	1446	1549	1668	1679	1659	1667	1481	1093	918
60	30	976	1071	1346	1357	1418	1506	1525	1540	1594	1459	1102	935
70	30	963	1034	1269	1243	1268	1326	1350	1396	1488	1403	1083	928
80	30	926	974	1167	1111	1103	1135	1163	1232	1353	1314	1037	898
90	30	869	894	1045	968	937	946	976	1059	1197	1198	968	847
20	45	752	935	1325	1535	1786	2007	1983	1819	1638	1290	866	694
30	45	814	983	1359	1530	1744	1941	1927	1800	1667	1355	933	757
40	45	857	1011	1366	1499	1677	1848	1843	1751	1664	1391	980	803
50	45	880	1016	1347	1443	1584	1730	1732	1673	1628	1397	1003	830
60	45	882	1000	1301	1362	1469	1589	1597	1569	1562	1372	1002	837
70	45	864	963	1229	1260	1336	1430	1444	1441	1466	1317	979	824
80	45	826	905	1136	1141	1189	1260	1277	1294	1344	1234	932	791
90	45	770	831	1026	1012	1037	1088	1107	1139	1205	1129	866	741

POCATELLO ID 42.55

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	
HORIZONTAL RAD.	608	921	1345	1917	2138	2414	2488	2175	1751	1216	755	571	(BTU/DAY-FT2)
AVE. TEMP.	24.8	30.2	33.8	44.6	53.6	60.8	69.8	68.0	59.0	48.2	35.6	28.4	(F)
DEGREE-DAYS	1296.	997.	918.	591.	336.	138.	0.	20.	192.	515.	879.	1181.	(F-DAYS)

AVERAGE DAILY RADIATION ON TILTED SURFACES (BTU/DAY-FT2)

SLOPE	AZIMUTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
20	0	925	1251	1620	2074	2137	2335	2444	2280	2045	1626	1140	919
30	0	1052	1373	1700	2082	2073	2231	2349	2256	2118	1772	1292	1060
40	0	1151	1460	1740	2042	1967	2084	2207	2181	2138	1872	1410	1175
50	0	1221	1510	1736	1954	1821	1897	2021	2057	2104	1924	1491	1258
60	0	1259	1521	1690	1821	1640	1678	1797	1886	2017	1926	1533	1307
70	0	1264	1494	1603	1648	1430	1434	1542	1676	1881	1877	1534	1322
80	0	1236	1429	1478	1439	1200	1175	1268	1434	1698	1780	1495	1301
90	0	1177	1330	1321	1208	964	919	992	1173	1480	1640	1417	1246
20	15	913	1239	1610	2072	2139	2340	2447	2280	2037	1610	1126	906
30	15	1035	1354	1687	2083	2079	2240	2358	2260	2109	1749	1271	1042
40	15	1129	1436	1724	2047	1977	2098	2222	2190	2130	1842	1383	1151
50	15	1195	1481	1719	1964	1837	1919	2043	2072	2099	1889	1459	1229
60	15	1230	1489	1672	1839	1664	1707	1828	1911	2016	1886	1497	1275
70	15	1232	1459	1586	1674	1462	1471	1582	1710	1885	1834	1495	1287
80	15	1202	1392	1462	1476	1239	1220	1317	1478	1710	1734	1454	1264
90	15	1143	1293	1309	1256	1011	971	1050	1229	1501	1594	1376	1209
20	30	879	1203	1584	2061	2144	2351	2457	2276	2011	1568	1084	869
30	30	984	1304	1653	2075	2094	2264	2381	2263	2078	1689	1210	987
40	30	1065	1372	1684	2045	2006	2140	2264	2206	2098	1769	1305	1081
50	30	1118	1407	1677	1974	1883	1980	2106	2105	2069	1805	1367	1146
60	30	1143	1407	1632	1862	1728	1789	1914	1962	1994	1795	1393	1181
70	30	1138	1372	1549	1714	1546	1574	1693	1784	1873	1740	1382	1184
80	30	1104	1303	1433	1535	1345	1344	1452	1576	1713	1642	1335	1157
90	30	1042	1205	1290	1337	1138	1114	1209	1353	1522	1507	1256	1100
20	45	827	1151	1541	2038	2145	2365	2466	2261	1967	1504	1022	812
30	45	910	1232	1598	2050	2104	2295	2406	2253	2023	1603	1122	905
40	45	972	1284	1621	2025	2031	2191	2309	2205	2038	1665	1195	976
50	45	1009	1307	1611	1963	1926	2056	2176	2119	2011	1689	1239	1022
60	45	1022	1300	1567	1865	1792	1892	2012	1996	1943	1673	1252	1043
70	45	1009	1262	1491	1734	1632	1704	1820	1840	1835	1618	1234	1037
80	45	972	1196	1385	1575	1454	1501	1608	1657	1691	1527	1185	1004
90	45	912	1105	1256	1398	1268	1294	1391	1458	1522	1404	1109	948

PORTLAND ME 43.39

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	
HORIZONTAL RAD.	578	872	1321	1495	1889	1992	2065	1774	1410	1005	578	508	(BTU/DAY-FT2)
AVE. TEMP.	23.0	24.8	32.0	41.0	51.8	60.8	68.0	66.2	59.0	48.2	37.4	28.4	(F)
DEGREE-DAYS	1339.	1182.	1042.	675.	372.	111.	12.	53.	195.	508.	807.	1015.	(F-DAYS)

AVERAGE DAILY RADIATION ON TILTED SURFACES (BTU/DAY-FT2)

SLOPE	AZIMUTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
20	0	889	1190	1600	1601	1890	1933	2033	1851	1621	1317	839	815
30	0	1015	1308	1684	1602	1836	1853	1959	1830	1670	1427	941	941
40	0	1114	1393	1727	1569	1746	1739	1848	1771	1680	1502	1020	1042
50	0	1184	1442	1727	1502	1622	1594	1702	1673	1651	1539	1073	1116
60	0	1223	1456	1684	1403	1468	1423	1526	1541	1582	1537	1099	1160
70	0	1230	1432	1601	1275	1289	1231	1326	1378	1476	1497	1096	1174
80	0	1205	1371	1479	1122	1092	1027	1109	1191	1337	1419	1066	1156
90	0	1149	1279	1326	953	889	824	890	989	1172	1309	1010	1109
20	15	878	1178	1591	1599	1892	1936	2035	1850	1615	1305	829	804
30	15	998	1290	1671	1603	1841	1859	1965	1832	1664	1409	927	924
40	15	1092	1370	1711	1572	1754	1749	1858	1777	1675	1479	1001	1021
50	15	1158	1415	1709	1509	1635	1609	1718	1684	1647	1512	1051	1091
60	15	1194	1425	1666	1416	1487	1443	1548	1558	1581	1507	1074	1132
70	15	1199	1398	1583	1292	1314	1257	1354	1402	1479	1464	1070	1143
80	15	1172	1337	1463	1146	1123	1059	1144	1221	1345	1385	1038	1124
90	15	1116	1243	1312	985	927	861	931	1028	1186	1274	982	1076
20	30	844	1144	1564	1592	1895	1944	2042	1847	1596	1272	801	771
30	30	949	1241	1636	1597	1852	1876	1982	1835	1641	1364	885	876
40	30	1029	1308	1670	1571	1777	1778	1888	1787	1651	1423	948	959
50	30	1083	1343	1666	1515	1671	1652	1763	1706	1625	1447	988	1017
60	30	1109	1345	1624	1429	1538	1501	1609	1594	1563	1437	1003	1049
70	30	1106	1314	1545	1318	1382	1331	1433	1453	1469	1391	992	1053
80	30	1075	1250	1432	1184	1208	1148	1241	1290	1345	1313	957	1029
90	30	1018	1158	1291	1037	1028	964	1045	1116	1199	1206	900	980
20	45	794	1094	1521	1575	1895	1954	2048	1836	1564	1224	758	721
30	45	876	1172	1580	1579	1860	1898	1999	1826	1601	1298	825	803
40	45	937	1224	1606	1556	1797	1815	1920	1786	1607	1343	873	866
50	45	975	1247	1599	1506	1706	1706	1813	1715	1582	1358	900	908
60	45	990	1242	1558	1429	1589	1575	1680	1616	1525	1343	906	926
70	45	979	1207	1484	1329	1451	1424	1525	1492	1439	1297	890	921
80	45	946	1146	1381	1209	1295	1260	1353	1346	1327	1223	853	893
90	45	888	1060	1254	1076	1133	1093	1177	1189	1196	1125	798	844

PROSSER WA 46.15

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	
HORIZONTAL RAD.	431	818	1294	1920	2271	2506	2606	2226	1688	1010	501	368	(BTU/DAY-FT2)
AVE. TEMP.	30.2	39.2	42.8	50.0	57.2	64.4	69.8	68.0	60.8	50.0	39.2	32.0	(F)
DEGREE-DAYS	1123.	770.	676.	432.	228.	85.	12.	28.	118.	415.	744.	977.	(F-DAYS)

AVERAGE DAILY RADIATION ON TILTED SURFACES (BTU/DAY-FT2)

SLOPE	AZIMUTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
20	0	671	1161	1608	2122	2304	2454	2596	2380	2026	1382	757	599
30	0	768	1292	1708	2150	2251	2360	2514	2377	2121	1519	859	694
40	0	846	1390	1766	2127	2152	2221	2381	2318	2162	1618	940	771
50	0	903	1452	1780	2054	2008	2040	2199	2206	2148	1675	997	829
60	0	936	1477	1749	1932	1824	1821	1973	2043	2080	1688	1028	865
70	0	945	1464	1675	1766	1605	1573	1711	1835	1958	1658	1033	878
80	0	929	1412	1559	1561	1360	1305	1424	1588	1788	1584	1011	868
90	0	891	1326	1410	1328	1105	1035	1129	1318	1579	1473	964	836
20	15	662	1148	1597	2119	2305	2457	2598	2379	2017	1368	747	590
30	15	755	1273	1693	2150	2256	2368	2522	2379	2111	1499	845	681
40	15	830	1365	1748	2131	2162	2235	2395	2326	2153	1591	922	755
50	15	883	1423	1759	2063	2024	2060	2220	2220	2141	1643	976	810
60	15	914	1444	1728	1948	1847	1849	2003	2065	2076	1652	1004	843
70	15	921	1428	1654	1790	1636	1608	1750	1866	1960	1619	1007	855
80	15	904	1375	1539	1594	1399	1348	1472	1630	1796	1544	984	844
90	15	865	1289	1392	1372	1152	1084	1186	1371	1595	1432	936	812
20	30	636	1112	1567	2105	2308	2467	2606	2372	1988	1330	720	566
30	30	718	1221	1654	2138	2269	2390	2543	2379	2075	1445	805	645
40	30	781	1299	1702	2125	2189	2273	2434	2338	2115	1524	870	709
50	30	826	1345	1711	2068	2069	2117	2280	2249	2105	1565	914	755
60	30	849	1358	1679	1966	1911	1926	2086	2114	2045	1567	935	781
70	30	850	1335	1608	1825	1721	1707	1858	1937	1938	1530	931	787
80	30	830	1279	1500	1648	1507	1467	1605	1726	1788	1455	904	773
90	30	790	1194	1362	1447	1281	1223	1343	1493	1603	1346	856	740
20	45	597	1058	1520	2077	2306	2478	2612	2352	1938	1273	679	528
30	45	661	1146	1592	2106	2277	2418	2564	2362	2013	1366	746	590
40	45	710	1208	1630	2097	2212	2322	2477	2330	2046	1429	796	639
50	45	741	1241	1634	2047	2111	2191	2350	2256	2035	1459	827	672
60	45	755	1245	1602	1959	1975	2028	2185	2140	1981	1454	839	688
70	45	750	1218	1536	1834	1810	1837	1988	1986	1885	1415	829	687
80	45	726	1164	1437	1677	1620	1625	1766	1800	1750	1344	800	669
90	45	686	1084	1313	1498	1417	1405	1532	1593	1586	1245	753	635

PULLMAN	WA	46.44											
	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	
HORIZONTAL RAD.	452	670	1093	1679	1995	2526	2599	2032	1576	942	541	353	(BTU/DAY-FT2)
AVE. TEMP.	28.4	33.8	37.4	44.6	51.8	59.0	66.2	64.4	59.0	48.2	37.4	32.0	(F)
DEGREE-DAYS	986.	745.	589.	342.	177.	45.	0.	0.	87.	310.	681.	843.	(F-DAYS)

AVERAGE DAILY RADIATION ON TILTED SURFACES (BTU/DAY-FT2)

SLOPE	AZIMUTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
20	0	721	919	1333	1840	2020	2475	2592	2163	1879	1280	840	573
30	0	831	1013	1408	1859	1974	2382	2512	2158	1963	1404	961	664
40	0	920	1082	1449	1836	1889	2243	2380	2104	1998	1493	1057	738
50	0	984	1124	1455	1771	1765	2061	2200	2002	1984	1544	1126	794
60	0	1023	1139	1427	1667	1608	1841	1976	1857	1920	1555	1165	828
70	0	1035	1125	1364	1525	1422	1591	1716	1671	1808	1527	1173	841
80	0	1020	1083	1269	1352	1213	1321	1430	1452	1652	1459	1151	832
90	0	979	1015	1148	1156	996	1048	1136	1213	1461	1357	1100	802
20	15	711	909	1325	1837	2021	2478	2594	2162	1871	1267	829	565
30	15	817	999	1396	1859	1978	2390	2519	2160	1954	1385	945	653
40	15	901	1064	1435	1839	1897	2257	2394	2110	1990	1469	1036	723
50	15	962	1103	1440	1779	1778	2081	2221	2014	1977	1515	1101	776
60	15	999	1115	1410	1680	1626	1869	2005	1876	1916	1523	1137	808
70	15	1009	1099	1348	1545	1446	1626	1754	1698	1809	1491	1143	819
80	15	992	1055	1254	1379	1244	1364	1477	1488	1659	1422	1119	809
90	15	951	988	1134	1191	1034	1098	1192	1258	1475	1319	1068	778
20	30	683	883	1302	1826	2024	2488	2602	2156	1845	1233	797	542
30	30	775	961	1366	1849	1989	2412	2540	2160	1922	1336	898	618
40	30	847	1015	1400	1835	1918	2295	2432	2121	1955	1408	976	679
50	30	898	1046	1402	1782	1814	2138	2280	2039	1944	1445	1029	723
60	30	926	1051	1372	1694	1678	1946	2087	1917	1888	1445	1056	749
70	30	929	1031	1312	1572	1515	1725	1861	1758	1789	1411	1055	755
80	30	909	985	1223	1421	1330	1484	1608	1569	1650	1341	1027	741
90	30	866	918	1110	1250	1137	1237	1347	1361	1481	1241	974	710
20	45	639	844	1265	1803	2021	2499	2607	2138	1800	1181	749	506
30	45	712	906	1318	1823	1994	2439	2561	2144	1865	1265	829	566
40	45	767	948	1344	1811	1936	2344	2475	2113	1893	1322	889	612
50	45	804	969	1343	1766	1847	2213	2349	2044	1881	1348	928	644
60	45	821	968	1313	1687	1729	2049	2185	1939	1830	1342	944	659
70	45	817	945	1256	1579	1585	1856	1989	1799	1741	1306	936	658
80	45	793	900	1174	1444	1421	1643	1768	1632	1616	1240	905	641
90	45	750	837	1072	1290	1247	1421	1535	1446	1465	1148	853	609

PUT IN BAY OH 41.39

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	
HORIZONTAL RAD.	441	732	1075	1358	1819	1995	2087	1900	1469	1086	578	408	(BTU/DAY-FT2)
AVE. TEMP.	26.6	28.4	35.6	46.4	59.0	69.8	73.4	73.4	66.2	55.4	42.8	32.0	(F)
DEGREE-DAYS	1159.	1047.	918.	552.	260.	66.	9.	25.	105.	384.	738.	1088.	(F-DAYS)

AVERAGE DAILY RADIATION ON TILTED SURFACES (BTU/DAY-FT2)

SLOPE	AZIMUTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
20	0	602	938	1249	1434	1807	1925	2041	1970	1671	1401	801	581
30	0	664	1010	1295	1427	1749	1838	1959	1941	1714	1510	886	648
40	0	710	1059	1312	1390	1657	1718	1840	1870	1717	1582	950	701
50	0	739	1083	1298	1324	1533	1568	1687	1759	1679	1614	990	736
60	0	751	1080	1255	1231	1382	1392	1504	1611	1602	1605	1006	754
70	0	744	1052	1184	1115	1209	1197	1298	1431	1487	1556	997	753
80	0	720	1000	1087	978	1019	992	1077	1226	1339	1468	964	733
90	0	680	925	969	829	826	789	856	1007	1166	1347	908	696
20	15	596	930	1243	1433	1809	1929	2044	1970	1665	1389	793	574
30	15	655	999	1287	1427	1754	1845	1966	1944	1708	1492	874	639
40	15	698	1044	1302	1393	1666	1729	1852	1878	1712	1559	934	689
50	15	725	1065	1287	1331	1547	1584	1704	1772	1676	1586	972	722
60	15	735	1060	1244	1242	1401	1414	1528	1631	1602	1574	985	737
70	15	728	1030	1173	1130	1233	1225	1328	1459	1491	1522	974	735
80	15	703	976	1077	999	1050	1025	1114	1262	1349	1433	940	714
90	15	662	902	961	857	863	828	900	1053	1182	1311	883	678
20	30	578	908	1225	1427	1813	1938	2052	1967	1647	1356	768	556
30	30	629	967	1264	1423	1766	1864	1985	1948	1686	1446	838	612
40	30	665	1004	1276	1393	1689	1761	1884	1892	1689	1502	888	653
50	30	686	1018	1260	1337	1583	1630	1753	1799	1656	1521	917	680
60	30	690	1008	1218	1256	1452	1476	1594	1674	1587	1504	924	690
70	30	679	975	1150	1154	1300	1303	1414	1520	1485	1450	908	683
80	30	652	920	1059	1034	1134	1120	1219	1342	1353	1362	870	660
90	30	611	847	951	904	963	937	1023	1154	1201	1246	813	623
20	45	552	875	1198	1415	1815	1949	2059	1957	1616	1307	732	527
30	45	591	921	1228	1411	1775	1888	2004	1941	1647	1379	786	570
40	45	617	948	1235	1383	1709	1800	1920	1893	1648	1421	824	601
50	45	630	955	1218	1332	1618	1688	1807	1813	1616	1432	842	618
60	45	628	941	1177	1259	1503	1553	1669	1703	1553	1410	841	621
70	45	613	907	1113	1167	1368	1401	1510	1567	1460	1357	821	609
80	45	585	854	1030	1058	1219	1236	1337	1409	1341	1275	783	584
90	45	545	785	931	940	1065	1070	1160	1241	1205	1168	728	547

RALEIGH	NC	35.47											
	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	
HORIZONTAL RAD.	876	1123	1480	1741	1837	2099	1999	1778	1421	1148	880	743	(BTU/DAY-FT2)
AVE. TEMP.	41.0	42.8	50.0	59.0	68.0	75.2	77.0	77.0	71.6	60.8	50.0	41.0	(F)
DEGREE-DAYS	725.	616.	487.	180.	34.	0.	0.	0.	21.	164.	450.	716.	(F-DAYS)

AVERAGE DAILY RADIATION ON TILTED SURFACES (BTU/DAY-FT2)

SLOPE	AZIMUTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
20	0	1229	1425	1698	1811	1789	1984	1916	1796	1554	1397	1188	1059
30	0	1362	1526	1748	1786	1713	1872	1819	1748	1568	1473	1301	1180
40	0	1461	1590	1756	1722	1603	1726	1688	1663	1547	1514	1382	1272
50	0	1523	1615	1723	1620	1464	1550	1527	1544	1491	1519	1428	1331
60	0	1545	1600	1649	1485	1300	1350	1341	1395	1402	1487	1439	1357
70	0	1528	1545	1536	1319	1117	1134	1137	1221	1282	1420	1412	1347
80	0	1470	1452	1388	1129	922	913	925	1027	1135	1319	1351	1303
90	0	1378	1326	1213	926	729	705	720	827	970	1190	1257	1227
20	15	1216	1413	1690	1811	1792	1989	1920	1797	1550	1387	1176	1047
30	15	1343	1509	1737	1789	1719	1882	1827	1752	1564	1459	1284	1163
40	15	1436	1568	1744	1729	1614	1741	1702	1672	1544	1496	1360	1250
50	15	1493	1588	1710	1633	1481	1571	1547	1559	1490	1497	1402	1305
60	15	1511	1569	1636	1504	1323	1379	1368	1417	1404	1462	1409	1327
70	15	1491	1512	1525	1346	1147	1170	1171	1250	1289	1393	1380	1314
80	15	1432	1417	1379	1166	959	956	966	1066	1149	1291	1317	1268
90	15	1339	1291	1209	975	774	753	768	876	991	1162	1223	1192
20	30	1177	1380	1668	1806	1799	2003	1931	1798	1537	1360	1142	1012
30	30	1286	1462	1710	1788	1736	1908	1850	1760	1550	1422	1234	1112
40	30	1363	1510	1714	1735	1644	1783	1739	1689	1531	1451	1296	1184
50	30	1406	1521	1680	1649	1525	1632	1601	1589	1481	1447	1327	1227
60	30	1414	1496	1609	1533	1384	1459	1441	1462	1401	1409	1324	1239
70	30	1385	1435	1504	1391	1225	1271	1264	1313	1294	1340	1289	1219
80	30	1321	1341	1369	1229	1057	1076	1079	1148	1165	1241	1222	1169
90	30	1227	1219	1213	1058	889	890	899	978	1022	1118	1128	1091
20	45	1119	1331	1633	1794	1806	2020	1943	1794	1515	1320	1091	960
30	45	1204	1395	1665	1777	1752	1941	1875	1761	1524	1368	1163	1037
40	45	1261	1429	1664	1731	1672	1835	1780	1700	1504	1387	1208	1090
50	45	1288	1431	1630	1655	1569	1705	1661	1612	1457	1377	1226	1117
60	45	1284	1401	1564	1552	1445	1554	1522	1500	1384	1338	1214	1118
70	45	1249	1341	1468	1425	1305	1389	1366	1368	1288	1271	1175	1091
80	45	1185	1253	1346	1281	1154	1216	1201	1221	1171	1180	1110	1038
90	45	1096	1142	1206	1127	1003	1046	1038	1068	1043	1069	1022	964

RAPID CTY SD 44.09

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	
HORIZONTAL RAD.	684	1023	1469	1785	1973	2180	2191	1992	1583	1156	754	581	(BTU/DAY-FT2)
AVE. TEMP.	23.0	26.6	32.0	44.6	53.6	64.4	71.6	69.8	59.0	48.2	35.6	28.4	(F)
DEGREE-DAYS	1333.	1145.	1051.	615.	326.	126.	22.	12.	165.	481.	897.	1172.	(F-DAYS)

AVERAGE DAILY RADIATION ON TILTED SURFACES (BTU/DAY-FT2)

SLOPE	AZIMUTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
20	0	1122	1458	1817	1940	1981	2120	2162	2094	1851	1568	1185	991
30	0	1300	1622	1925	1952	1927	2033	2086	2077	1919	1717	1358	1160
40	0	1444	1745	1985	1919	1835	1908	1969	2014	1940	1822	1495	1298
50	0	1548	1821	1995	1842	1706	1748	1815	1906	1914	1880	1592	1401
60	0	1611	1850	1954	1723	1546	1559	1628	1757	1840	1889	1646	1466
70	0	1630	1829	1864	1567	1358	1347	1414	1572	1722	1848	1656	1491
80	0	1604	1760	1727	1378	1151	1120	1181	1356	1562	1759	1621	1475
90	0	1536	1647	1551	1166	936	893	946	1123	1371	1627	1544	1420
20	15	1106	1441	1805	1938	1983	2123	2164	2094	1844	1552	1170	976
30	15	1277	1598	1909	1952	1932	2040	2092	2080	1911	1694	1335	1138
40	15	1414	1714	1966	1923	1844	1920	1981	2021	1933	1793	1465	1270
50	15	1513	1785	1973	1851	1720	1766	1832	1919	1908	1845	1557	1368
60	15	1571	1808	1931	1739	1565	1583	1651	1777	1838	1849	1606	1429
70	15	1586	1784	1841	1590	1384	1376	1444	1599	1724	1805	1612	1451
80	15	1558	1712	1706	1409	1183	1156	1219	1392	1571	1713	1575	1433
90	15	1489	1599	1533	1207	976	935	990	1169	1387	1581	1497	1377
20	30	1059	1395	1772	1927	1986	2132	2171	2089	1820	1510	1123	932
30	30	1208	1532	1866	1943	1944	2059	2110	2082	1882	1635	1267	1075
40	30	1326	1631	1916	1920	1867	1953	2012	2033	1903	1719	1378	1188
50	30	1408	1687	1920	1857	1758	1814	1880	1945	1880	1760	1453	1271
60	30	1452	1699	1879	1757	1619	1648	1717	1820	1815	1757	1489	1319
70	30	1457	1668	1793	1623	1455	1460	1529	1661	1710	1709	1486	1331
80	30	1423	1594	1666	1459	1273	1256	1323	1474	1569	1618	1443	1307
90	30	1353	1482	1506	1277	1083	1051	1113	1273	1400	1491	1363	1250
20	45	988	1328	1719	1904	1986	2142	2177	2075	1780	1446	1054	865
30	45	1107	1438	1797	1918	1952	2083	2128	2070	1832	1548	1169	978
40	45	1197	1515	1836	1899	1887	1994	2046	2030	1848	1614	1255	1065
50	45	1257	1556	1836	1844	1794	1876	1934	1955	1826	1643	1310	1125
60	45	1285	1558	1796	1756	1673	1732	1794	1845	1767	1633	1331	1156
70	45	1279	1523	1717	1636	1528	1566	1629	1706	1672	1585	1318	1156
80	45	1240	1451	1601	1490	1366	1385	1446	1540	1545	1500	1272	1128
90	45	1171	1348	1457	1327	1195	1200	1257	1360	1394	1384	1196	1068

RENO NV 39.30

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	
HORIZONTAL RAD.	862	1194	1655	2182	2447	2632	2606	2381	1961	1456	1021	770	(BTU/DAY-FT2)
AVE. TEMP.	32.0	35.6	39.2	46.4	53.6	60.8	68.0	66.2	59.0	50.0	39.2	32.0	(F)
DEGREE-DAYS	1026.	781.	766.	546.	328.	145.	17.	50.	168.	456.	747.	992.	(F-DAYS:

AVERAGE DAILY RADIATION ON TILTED SURFACES (BTU/DAY-FT2)

SLOPE	AZIMUTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
20	0	1308	1612	1984	2340	2421	2513	2527	2468	2263	1921	1530	1210
30	0	1483	1763	2076	2336	2331	2381	2411	2426	2329	2083	1728	1387
40	0	1620	1869	2116	2276	2192	2202	2245	2328	2337	2189	1880	1527
50	0	1713	1926	2102	2162	2008	1981	2034	2176	2284	2238	1981	1626
60	0	1761	1933	2036	1996	1784	1726	1786	1974	2173	2227	2029	1682
70	0	1761	1889	1918	1786	1529	1446	1508	1731	2008	2158	2022	1691
80	0	1714	1796	1753	1536	1252	1153	1213	1454	1793	2031	1959	1655
90	0	1623	1660	1550	1263	973	871	923	1160	1541	1855	1847	1577
20	15	1291	1596	1972	2339	2424	2519	2532	2469	2255	1903	1511	1194
30	15	1459	1740	2060	2338	2340	2393	2422	2432	2321	2056	1700	1363
40	15	1589	1839	2097	2284	2208	2221	2264	2340	2330	2155	1844	1497
50	15	1676	1890	2082	2177	2031	2009	2062	2197	2280	2198	1939	1590
60	15	1719	1892	2015	2021	1817	1763	1823	2006	2175	2182	1981	1640
70	15	1716	1844	1899	1822	1572	1493	1555	1774	2017	2108	1969	1647
80	15	1666	1749	1736	1586	1306	1210	1271	1510	1811	1980	1905	1609
90	15	1575	1612	1538	1328	1039	936	991	1232	1571	1803	1791	1529
20	30	1243	1552	1940	2328	2433	2536	2546	2467	2228	1855	1455	1147
30	30	1388	1676	2019	2332	2362	2426	2452	2440	2289	1989	1619	1294
40	30	1498	1759	2051	2287	2249	2276	2315	2363	2298	2073	1741	1407
50	30	1568	1797	2035	2194	2095	2088	2137	2240	2254	2104	1816	1483
60	30	1597	1789	1970	2056	1905	1868	1925	2073	2158	2081	1843	1520
70	30	1583	1736	1861	1878	1687	1625	1687	1868	2013	2006	1820	1516
80	30	1528	1640	1709	1667	1450	1369	1432	1634	1826	1880	1749	1472
90	30	1434	1506	1527	1437	1210	1119	1179	1388	1609	1713	1634	1390
20	45	1170	1486	1890	2304	2438	2555	2560	2455	2182	1783	1374	1074
30	45	1285	1585	1954	2308	2381	2467	2484	2434	2233	1891	1504	1190
40	45	1368	1648	1977	2271	2287	2342	2370	2371	2238	1955	1597	1276
50	45	1418	1672	1958	2191	2156	2184	2221	2266	2198	1974	1650	1330
60	45	1431	1657	1897	2070	1994	1996	2040	2122	2112	1947	1661	1349
70	45	1408	1602	1797	1914	1804	1786	1834	1945	1984	1874	1630	1334
80	45	1350	1511	1661	1729	1596	1561	1611	1740	1818	1758	1558	1285
90	45	1260	1389	1499	1525	1381	1336	1385	1522	1626	1607	1450	1205

RICHLAND WA 46.17

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	
HORIZONTAL RAD.	316	740	1226	1719	1900	2382	2121	2213	1428	843	456	364	(BTU/DAY-FT2)
AVE. TEMP.	32.0	39.2	44.6	53.6	60.8	68.0	73.4	71.6	64.4	51.8	41.0	35.6	(F)
DEGREE-DAYS	1163.	868.	713.	435.	220.	69.	0.	12.	144.	450.	828.	1039.	(F-DAYS)

AVERAGE DAILY RADIATION ON TILTED SURFACES (BTU/DAY-FT2)

SLOPE	AZIMUTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
20	0	448	1030	1513	1884	1920	2332	2106	2365	1680	1118	673	590
30	0	500	1140	1603	1904	1874	2244	2041	2361	1747	1218	759	683
40	0	540	1221	1655	1880	1792	2113	1936	2303	1772	1288	827	759
50	0	568	1272	1666	1813	1675	1943	1793	2191	1754	1326	874	816
60	0	582	1290	1635	1705	1525	1738	1618	2030	1694	1331	899	851
70	0	583	1276	1565	1559	1350	1505	1416	1823	1592	1302	901	864
80	0	569	1229	1457	1380	1153	1253	1195	1579	1454	1242	880	854
90	0	542	1154	1317	1179	949	1000	968	1311	1285	1153	838	823
20	15	443	1019	1503	1882	1921	2335	2108	2363	1673	1108	665	582
30	15	493	1123	1590	1904	1878	2251	2046	2363	1740	1202	748	671
40	15	531	1200	1638	1883	1800	2126	1945	2310	1765	1268	812	744
50	15	557	1247	1647	1821	1687	1961	1808	2205	1749	1302	856	797
60	15	570	1263	1616	1718	1543	1763	1639	2052	1691	1304	878	830
70	15	569	1246	1546	1579	1373	1537	1443	1854	1593	1273	879	841
80	15	555	1198	1438	1408	1182	1292	1228	1620	1460	1211	857	831
90	15	528	1122	1300	1215	984	1045	1008	1363	1297	1122	815	799
20	30	429	988	1476	1870	1923	2344	2114	2357	1651	1079	642	558
30	30	472	1079	1554	1894	1888	2271	2061	2364	1713	1162	713	636
40	30	504	1144	1597	1879	1820	2161	1973	2323	1736	1218	768	699
50	30	525	1181	1603	1825	1720	2013	1850	2234	1721	1244	803	744
60	30	534	1189	1571	1734	1591	1834	1698	2100	1667	1241	819	769
70	30	530	1167	1503	1608	1436	1627	1519	1925	1577	1207	814	775
80	30	513	1117	1402	1453	1262	1402	1322	1714	1453	1145	789	761
90	30	486	1041	1273	1277	1080	1172	1118	1483	1303	1058	746	728
20	45	407	943	1432	1847	1921	2354	2118	2337	1614	1037	607	521
30	45	440	1016	1497	1867	1893	2296	2076	2346	1665	1104	663	582
40	45	465	1066	1531	1855	1837	2205	2003	2315	1684	1147	705	630
50	45	478	1092	1532	1808	1751	2081	1899	2241	1669	1165	730	662
60	45	481	1093	1501	1727	1638	1927	1767	2126	1619	1156	737	678
70	45	474	1068	1437	1616	1502	1746	1610	1973	1537	1122	728	677
80	45	455	1018	1344	1477	1346	1546	1435	1788	1425	1062	701	659
90	45	428	948	1228	1319	1181	1339	1251	1583	1290	982	658	625

RIVERSIDE	CA.	33.57												
		JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	
HORIZONTAL RAD.		1013	1353	1762	1994	2296	2506	2481	2278	1972	1500	1176	995	(BTU/DAY-FT2)
AVE. TEMP.		51.8	53.6	55.4	59.0	64.4	68.0	75.2	75.2	71.6	64.4	57.2	51.8	(F)
DEGREE-DAYS		406.	312.	283.	168.	74.	22.	0.	0.	5.	62.	212.	375.	(F-DAYS)

AVERAGE DAILY RADIATION ON TILTED SURFACES (BTU/DAY-FT2)

SLOPE	AZIMUTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
20	0	1413	1725	2027	2067	2219	2343	2352	2294	2184	1853	1623	1448
30	0	1562	1849	2087	2032	2111	2192	2216	2224	2211	1963	1788	1622
40	0	1671	1927	2095	1952	1960	2000	2036	2104	2182	2023	1906	1754
50	0	1738	1955	2052	1827	1771	1771	1817	1938	2100	2032	1975	1839
60	0	1758	1934	1957	1663	1549	1516	1567	1731	1967	1989	1991	1876
70	0	1733	1863	1815	1464	1304	1242	1296	1489	1787	1896	1955	1862
80	0	1663	1745	1630	1238	1045	965	1016	1223	1564	1755	1867	1799
90	0	1552	1587	1412	997	794	712	753	950	1313	1575	1734	1691
20	15	1398	1710	2018	2067	2224	2350	2358	2296	2178	1839	1606	1431
30	15	1540	1828	2074	2036	2121	2206	2229	2232	2205	1942	1763	1597
40	15	1643	1899	2081	1961	1977	2021	2056	2119	2179	1997	1874	1722
50	15	1704	1922	2036	1844	1796	1802	1847	1962	2101	2001	1936	1801
60	15	1720	1896	1943	1688	1584	1556	1607	1765	1974	1954	1948	1833
70	15	1692	1822	1803	1500	1349	1293	1347	1536	1801	1858	1908	1815
80	15	1619	1702	1622	1287	1102	1027	1079	1285	1589	1716	1818	1750
90	15	1508	1544	1410	1061	862	780	825	1028	1352	1536	1684	1641
20	30	1353	1670	1991	2062	2236	2370	2376	2299	2159	1802	1557	1381
30	30	1475	1770	2041	2037	2147	2244	2264	2245	2184	1891	1691	1524
40	30	1560	1828	2044	1971	2022	2082	2113	2148	2160	1934	1783	1628
50	30	1605	1840	2001	1867	1863	1889	1929	2011	2089	1931	1828	1690
60	30	1609	1807	1913	1728	1676	1670	1717	1838	1973	1881	1826	1707
70	30	1572	1730	1782	1560	1468	1436	1486	1636	1816	1785	1777	1679
80	30	1494	1611	1615	1369	1249	1196	1248	1414	1624	1649	1682	1607
90	30	1382	1459	1423	1170	1035	971	1020	1188	1412	1480	1548	1496
20	45	1288	1610	1949	2050	2247	2395	2396	2296	2125	1745	1484	1306
30	45	1383	1688	1987	2027	2173	2291	2303	2251	2144	1815	1589	1418
40	45	1445	1729	1986	1970	2068	2156	2177	2169	2121	1845	1656	1495
50	45	1472	1731	1943	1879	1932	1992	2021	2051	2056	1834	1683	1534
60	45	1464	1693	1862	1757	1770	1804	1839	1901	1952	1783	1670	1536
70	45	1421	1618	1744	1609	1589	1601	1639	1725	1813	1693	1616	1499
80	45	1344	1508	1595	1440	1395	1390	1429	1530	1644	1569	1524	1425
90	45	1239	1371	1424	1263	1203	1186	1224	1330	1457	1418	1401	1320

ST. CLOUD MN 45.34

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	
HORIZONTAL RAD.	625	924	1347	1557	1837	1992	2043	1808	1325	887	537	452	(BTU/DAY-FT2)
AVE. TEMP.	10.4	14.0	28.4	42.8	55.4	64.4	69.8	68.0	59.0	46.4	32.0	17.6	(F)
DEGREE-DAYS	1702.	1445.	1221.	666.	326.	105.	29.	47.	233.	537.	1065.	1500.	(F-DAYS)

AVERAGE DAILY RADIATION ON TILTED SURFACES (BTU/DAY-FT2)

SLOPE	AZIMUTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
20	0	1044	1321	1669	1688	1850	1944	2023	1903	1537	1172	807	756
30	0	1216	1473	1770	1699	1803	1870	1957	1890	1590	1274	914	881
40	0	1355	1586	1828	1672	1722	1761	1854	1836	1606	1345	999	984
50	0	1458	1659	1839	1607	1606	1622	1715	1743	1583	1383	1058	1060
60	0	1522	1687	1805	1508	1461	1454	1546	1612	1524	1386	1089	1109
70	0	1543	1672	1726	1377	1291	1266	1351	1449	1429	1354	1093	1127
80	0	1523	1612	1604	1218	1102	1063	1139	1259	1301	1289	1068	1115
90	0	1462	1513	1446	1040	905	860	923	1053	1148	1194	1017	1075
20	15	1029	1306	1658	1686	1851	1947	2025	1902	1531	1161	797	745
30	15	1194	1451	1755	1699	1807	1876	1963	1892	1583	1258	900	865
40	15	1327	1558	1809	1674	1729	1771	1863	1842	1600	1325	980	963
50	15	1424	1625	1819	1614	1618	1636	1730	1753	1579	1358	1035	1036
60	15	1483	1649	1784	1520	1478	1474	1566	1628	1522	1358	1064	1081
70	15	1501	1630	1704	1394	1313	1291	1378	1472	1430	1324	1065	1097
80	15	1479	1569	1583	1242	1130	1093	1171	1289	1307	1258	1039	1084
90	15	1418	1469	1429	1072	939	895	961	1091	1159	1162	988	1043
20	30	984	1264	1627	1677	1853	1954	2031	1898	1512	1132	768	713
30	30	1128	1391	1715	1691	1817	1891	1977	1893	1560	1217	857	818
40	30	1243	1482	1763	1671	1749	1798	1890	1851	1575	1273	925	902
50	30	1324	1535	1769	1618	1650	1676	1771	1774	1556	1299	970	963
60	30	1370	1550	1734	1534	1524	1528	1623	1664	1502	1293	991	999
70	30	1379	1524	1658	1420	1375	1360	1451	1523	1417	1257	986	1008
80	30	1350	1459	1544	1281	1207	1177	1261	1357	1303	1190	956	991
90	30	1287	1360	1400	1125	1032	992	1067	1177	1166	1098	903	948
20	45	916	1202	1579	1657	1852	1962	2035	1884	1480	1087	724	663
30	45	1031	1304	1651	1669	1823	1911	1992	1881	1520	1156	795	746
40	45	1119	1376	1690	1652	1766	1832	1919	1847	1531	1200	847	811
50	45	1179	1415	1691	1606	1681	1728	1818	1780	1512	1217	879	855
60	45	1208	1419	1656	1530	1571	1599	1689	1683	1462	1206	890	877
70	45	1206	1390	1586	1428	1438	1450	1538	1559	1384	1169	879	877
80	45	1173	1327	1482	1303	1288	1286	1369	1411	1280	1105	847	855
90	45	1110	1235	1351	1163	1130	1118	1193	1249	1158	1021	796	812

SALT LAKE CITY UT 40.46

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	
HORIZONTAL RAD.	648	964	1347	1826	2191	2540	2342	2084	1671	1233	780	567	(BTU/DAY-FT2)
AVE. TEMP.	28.4	32.0	39.2	48.2	57.2	68.0	77.0	75.2	64.4	51.8	39.2	32.0	(F)
DEGREE-DAYS	1172.	910.	763.	459.	233.	84.	0.	0.	81.	419.	849.	1082.	(F-DAYS)

AVERAGE DAILY RADIATION ON TILTED SURFACES (BTU/DAY-FT2)

SLOPE	AZIMUTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
20	0	948	1277	1592	1949	2174	2438	2282	2159	1911	1604	1130	856
30	0	1066	1390	1660	1945	2099	2317	2185	2125	1963	1732	1265	971
40	0	1157	1467	1688	1897	1982	2151	2045	2044	1967	1816	1368	1061
50	0	1218	1508	1675	1805	1825	1945	1865	1918	1923	1853	1436	1125
60	0	1248	1512	1621	1674	1634	1705	1652	1750	1833	1843	1466	1159
70	0	1246	1476	1529	1507	1414	1440	1412	1547	1698	1786	1459	1163
80	0	1211	1404	1401	1309	1175	1161	1156	1316	1524	1684	1413	1137
90	0	1147	1300	1245	1092	932	890	902	1069	1320	1542	1332	1083
20	15	937	1265	1584	1948	2176	2443	2286	2159	1905	1589	1117	845
30	15	1050	1372	1648	1946	2106	2328	2193	2129	1956	1711	1246	955
40	15	1136	1445	1674	1902	1994	2168	2059	2053	1961	1789	1344	1041
50	15	1193	1481	1659	1816	1844	1970	1887	1934	1920	1821	1407	1101
60	15	1220	1481	1606	1692	1660	1738	1681	1774	1833	1807	1433	1132
70	15	1215	1443	1514	1533	1449	1482	1450	1580	1704	1747	1423	1134
80	15	1179	1369	1388	1344	1218	1213	1203	1359	1537	1642	1375	1106
90	15	1115	1264	1235	1139	984	950	957	1124	1341	1500	1294	1051
20	30	904	1232	1560	1939	2183	2458	2296	2157	1883	1551	1079	814
30	30	1002	1324	1617	1940	2124	2357	2217	2135	1930	1657	1191	909
40	30	1074	1384	1638	1903	2027	2217	2100	2071	1935	1723	1273	982
50	30	1120	1411	1623	1827	1895	2041	1947	1966	1897	1746	1322	1031
60	30	1137	1403	1570	1716	1731	1833	1764	1825	1818	1726	1338	1053
70	30	1125	1361	1484	1572	1541	1602	1556	1653	1699	1664	1319	1048
80	30	1085	1286	1366	1403	1334	1357	1332	1455	1545	1561	1267	1016
90	30	1019	1183	1223	1217	1123	1116	1109	1245	1367	1425	1185	960
20	45	855	1182	1522	1920	2186	2475	2306	2146	1846	1493	1022	766
30	45	932	1255	1568	1921	2137	2393	2242	2128	1885	1578	1111	841
40	45	986	1301	1582	1888	2056	2277	2144	2074	1887	1628	1173	896
50	45	1017	1317	1564	1822	1943	2129	2014	1985	1851	1641	1206	929
60	45	1023	1303	1514	1723	1801	1951	1856	1862	1779	1617	1211	939
70	45	1005	1259	1434	1596	1635	1750	1675	1710	1671	1556	1186	927
80	45	963	1187	1326	1445	1452	1534	1477	1535	1534	1461	1133	891
90	45	899	1093	1199	1279	1262	1317	1276	1348	1375	1337	1055	836

SAN ANTONIO TX 29.32

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	
HORIZONTAL RAD.	1020	1277	1542	1657	1984	2224	2301	2143	1804	1454	1071	927	(BTU/DAY-FT2)
AVE. TEMP.	51.8	53.6	60.8	68.0	75.2	80.6	82.4	82.4	78.8	69.8	59.0	53.6	(F)
DEGREE-DAYS	428.	286.	195.	39.	0.	0.	0.	0.	0.	31.	204.	363.	(F-DAYS)

AVERAGE DAILY RADIATION ON TILTED SURFACES (BTU/DAY-FT2)

SLOPE	AZIMUTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
20	0	1333	1545	1705	1676	1889	2052	2148	2116	1936	1720	1370	1237
30	0	1444	1626	1728	1632	1785	1907	2007	2032	1934	1792	1472	1349
40	0	1519	1667	1711	1553	1646	1727	1828	1904	1887	1821	1539	1428
50	0	1556	1668	1654	1442	1477	1519	1615	1736	1795	1806	1567	1471
60	0	1554	1629	1560	1303	1284	1290	1378	1533	1663	1747	1556	1477
70	0	1514	1550	1430	1139	1074	1050	1126	1303	1493	1645	1507	1447
80	0	1436	1434	1269	957	858	813	871	1055	1291	1504	1421	1380
90	0	1325	1289	1086	767	654	607	643	805	1068	1333	1303	1281
20	15	1321	1534	1699	1677	1894	2059	2155	2119	1932	1709	1358	1225
30	15	1426	1610	1720	1636	1794	1920	2020	2041	1931	1776	1455	1331
40	15	1496	1647	1702	1562	1661	1748	1848	1920	1886	1801	1516	1405
50	15	1529	1644	1645	1456	1500	1548	1645	1761	1799	1782	1540	1444
60	15	1523	1601	1552	1324	1315	1328	1418	1568	1671	1719	1526	1447
70	15	1480	1520	1424	1169	1115	1098	1177	1351	1509	1616	1475	1414
80	15	1400	1403	1267	997	908	869	933	1117	1317	1474	1387	1345
90	15	1289	1256	1090	821	713	666	711	885	1108	1303	1269	1246
20	30	1285	1504	1682	1676	1906	2079	2174	2125	1919	1680	1324	1190
30	30	1374	1568	1699	1640	1819	1957	2056	2057	1918	1737	1406	1281
40	30	1430	1595	1680	1573	1702	1805	1906	1952	1877	1754	1454	1340
50	30	1451	1585	1626	1479	1559	1628	1727	1812	1796	1730	1467	1367
60	30	1436	1538	1538	1359	1396	1433	1526	1642	1680	1666	1444	1360
70	30	1386	1455	1419	1220	1218	1227	1313	1450	1532	1565	1387	1319
80	30	1302	1341	1275	1067	1035	1022	1097	1245	1359	1431	1297	1246
90	30	1190	1201	1115	911	861	835	897	1042	1174	1271	1179	1146
20	45	1233	1460	1654	1671	1919	2104	2196	2128	1897	1636	1275	1138
30	45	1300	1508	1665	1639	1845	2002	2098	2070	1893	1679	1337	1207
40	45	1339	1523	1645	1580	1745	1874	1971	1980	1854	1686	1369	1248
50	45	1346	1506	1593	1496	1622	1723	1819	1859	1781	1658	1370	1260
60	45	1323	1458	1511	1390	1480	1554	1646	1712	1677	1596	1341	1244
70	45	1270	1379	1404	1266	1324	1375	1461	1544	1546	1502	1282	1198
80	45	1189	1273	1274	1129	1161	1193	1270	1363	1392	1380	1196	1126
90	45	1086	1148	1132	989	1002	1020	1087	1182	1228	1238	1089	1032

SAN DIEGO	CA 32.44	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	
HORIZONTAL RAD.		976	1264	1577	1710	1817	1880	2016	1839	1644	1330	1046	903	(BTU/DAY-FT2)
AVE. TEMP.		53.6	55.4	57.2	59.0	62.6	64.4	68.0	69.8	69.8	64.4	59.0	55.4	(F)
DEGREE-DAYS		314.	237.	219.	144.	79.	52.	6.	0.	16.	43.	140.	257.	(F-DAYS)

AVERAGE DAILY RADIATION ON TILTED SURFACES (BTU/DAY-FT2)

SLOPE	AZIMUTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
20	0	1327	1576	1782	1754	1751	1763	1911	1836	1784	1601	1390	1261
30	0	1455	1676	1822	1719	1667	1657	1803	1777	1793	1680	1513	1395
40	0	1548	1736	1819	1647	1551	1522	1662	1679	1760	1719	1598	1495
50	0	1600	1752	1773	1539	1407	1361	1491	1548	1687	1715	1643	1556
60	0	1612	1725	1684	1400	1240	1182	1297	1386	1575	1670	1646	1577
70	0	1583	1655	1557	1234	1055	990	1087	1201	1428	1585	1608	1558
80	0	1513	1544	1394	1046	862	797	872	997	1250	1461	1528	1498
90	0	1408	1399	1205	848	674	619	669	789	1052	1307	1413	1402
20	15	1313	1563	1774	1755	1755	1768	1916	1838	1780	1589	1377	1247
30	15	1436	1658	1812	1722	1674	1666	1813	1782	1789	1664	1494	1376
40	15	1522	1712	1808	1654	1563	1536	1677	1690	1758	1698	1573	1469
50	15	1570	1724	1761	1552	1425	1381	1513	1565	1688	1691	1614	1526
60	15	1578	1693	1673	1420	1264	1208	1326	1411	1580	1643	1613	1543
70	15	1546	1620	1548	1263	1087	1023	1125	1234	1439	1555	1571	1520
80	15	1475	1508	1389	1085	902	836	917	1041	1270	1431	1490	1459
90	15	1368	1363	1205	900	722	662	722	846	1082	1277	1374	1362
20	30	1274	1529	1754	1752	1763	1781	1929	1841	1767	1560	1339	1207
30	30	1379	1610	1786	1724	1693	1691	1838	1793	1775	1624	1438	1318
40	30	1450	1652	1780	1663	1595	1575	1719	1712	1746	1650	1503	1395
50	30	1484	1655	1734	1572	1472	1437	1573	1601	1681	1637	1530	1437
60	30	1481	1618	1651	1453	1329	1281	1407	1464	1582	1587	1519	1443
70	30	1441	1543	1534	1311	1170	1114	1226	1306	1452	1500	1470	1412
80	30	1365	1432	1387	1152	1004	944	1040	1134	1298	1381	1385	1345
90	30	1258	1293	1220	987	842	784	863	961	1130	1236	1270	1247
20	45	1216	1478	1720	1743	1772	1798	1944	1840	1743	1517	1282	1148
30	45	1297	1540	1744	1718	1712	1722	1868	1798	1748	1565	1359	1233
40	45	1348	1569	1734	1664	1628	1622	1766	1728	1719	1581	1405	1289
50	45	1367	1563	1690	1583	1521	1503	1640	1631	1660	1563	1418	1314
60	45	1354	1523	1613	1478	1395	1367	1496	1511	1570	1512	1399	1307
70	45	1309	1450	1506	1351	1255	1219	1337	1371	1454	1430	1347	1270
80	45	1234	1347	1374	1210	1106	1067	1171	1219	1316	1321	1265	1202
90	45	1134	1222	1226	1062	959	919	1009	1063	1167	1191	1159	1109

SANTA MARIA CA 34.54

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	
HORIZONTAL RAD.	975	1288	1789	2062	2345	2562	2507	2253	1929	1539	1145	931	(BTU/DAY-FT2)
AVE. TEMP.	50.0	51.8	51.8	53.6	55.4	59.0	60.8	60.8	62.6	59.0	55.4	50.0	(F)
DEGREE-DAYS	459.	370.	363.	282.	233.	165.	99.	93.	96.	146.	270.	391.	(F-DAYS)

AVERAGE DAILY RADIATION ON TILTED SURFACES (BTU/DAY-FT2)

SLOPE	AZIMUTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
20	0	1373	1650	2078	2150	2275	2403	2386	2279	2146	1929	1599	1363
30	0	1523	1772	2147	2119	2168	2252	2253	2214	2177	2054	1767	1530
40	0	1634	1849	2162	2040	2017	2058	2074	2100	2153	2126	1890	1657
50	0	1703	1880	2124	1914	1826	1827	1856	1939	2077	2143	1963	1741
60	0	1727	1862	2032	1746	1601	1566	1605	1738	1951	2105	1984	1778
70	0	1706	1798	1890	1541	1350	1287	1332	1502	1777	2013	1953	1768
80	0	1641	1688	1702	1305	1085	1002	1049	1240	1562	1869	1869	1711
90	0	1535	1539	1479	1053	826	738	780	970	1317	1683	1740	1611
20	15	1358	1636	2068	2149	2279	2410	2392	2281	2140	1914	1581	1347
30	15	1501	1751	2133	2123	2178	2266	2265	2221	2171	2031	1742	1506
40	15	1606	1822	2147	2049	2034	2080	2094	2114	2150	2097	1858	1627
50	15	1669	1848	2107	1931	1851	1858	1885	1962	2077	2109	1924	1704
60	15	1689	1826	2015	1772	1636	1607	1645	1770	1956	2066	1940	1737
70	15	1665	1758	1876	1578	1396	1338	1383	1546	1790	1971	1905	1724
80	15	1597	1646	1692	1355	1143	1064	1111	1299	1585	1826	1820	1665
90	15	1491	1497	1475	1120	895	808	852	1044	1353	1639	1690	1564
20	30	1314	1597	2039	2144	2291	2430	2409	2283	2120	1873	1531	1299
30	30	1437	1696	2097	2123	2204	2305	2299	2233	2149	1974	1669	1437
40	30	1524	1753	2107	2059	2079	2142	2151	2141	2129	2028	1765	1538
50	30	1572	1768	2068	1954	1919	1945	1967	2008	2063	2031	1815	1598
60	30	1579	1739	1981	1812	1729	1723	1754	1840	1953	1985	1817	1617
70	30	1546	1668	1851	1639	1516	1482	1521	1642	1801	1890	1772	1594
80	30	1473	1557	1681	1440	1291	1236	1279	1423	1615	1750	1682	1528
90	30	1365	1413	1484	1231	1070	1002	1046	1199	1408	1574	1552	1426
20	45	1249	1538	1994	2129	2301	2455	2428	2278	2086	1810	1458	1228
30	45	1345	1616	2039	2111	2230	2352	2338	2237	2108	1891	1566	1335
40	45	1409	1657	2043	2055	2124	2215	2213	2159	2088	1929	1637	1410
50	45	1439	1661	2004	1964	1987	2050	2057	2045	2028	1924	1668	1450
60	45	1434	1627	1924	1840	1824	1859	1875	1899	1929	1876	1658	1453
70	45	1394	1557	1806	1687	1639	1651	1674	1726	1794	1786	1608	1421
80	45	1321	1454	1655	1512	1440	1434	1461	1534	1630	1659	1520	1353
90	45	1220	1324	1480	1326	1242	1223	1251	1335	1447	1502	1400	1256

SAULT ST. MARIE MI 46.28

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	
HORIZONTAL RAD.	489	832	1310	1542	1936	2025	2110	1756	1185	795	386	349	(BTU/DAY-FT2)
AVE. TEMP.	15.8	14.0	24.8	37.4	48.2	57.2	62.6	62.6	55.4	44.6	32.0	21.2	(F)
DEGREE-DAYS	1525.	1380.	1277.	810.	477.	201.	96.	105.	279.	580.	951.	1367.	(F-DAYS)

AVERAGE DAILY RADIATION ON TILTED SURFACES (BTU/DAY-FT2)

SLOPE	AZIMUTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
20	0	792	1187	1634	1679	1958	1982	2096	1854	1369	1046	546	562
30	0	916	1323	1738	1693	1913	1909	2031	1844	1415	1136	608	649
40	0	1016	1426	1798	1670	1829	1801	1927	1795	1429	1199	656	720
50	0	1090	1491	1814	1609	1709	1661	1786	1707	1409	1233	688	773
60	0	1135	1518	1784	1513	1557	1493	1612	1583	1357	1236	704	806
70	0	1149	1506	1709	1384	1377	1302	1412	1427	1274	1208	703	818
80	0	1133	1454	1592	1227	1176	1096	1192	1244	1163	1152	684	808
90	0	1088	1366	1440	1052	967	888	967	1045	1030	1069	650	778
20	15	781	1174	1623	1677	1959	1985	2098	1853	1364	1036	540	554
30	15	900	1304	1722	1693	1917	1915	2036	1846	1409	1122	599	638
40	15	995	1401	1780	1672	1837	1811	1937	1800	1423	1181	645	706
50	15	1065	1461	1793	1615	1722	1675	1801	1716	1405	1211	675	756
60	15	1107	1484	1762	1524	1575	1512	1633	1598	1355	1211	689	786
70	15	1119	1469	1687	1401	1401	1327	1438	1448	1275	1182	686	796
80	15	1101	1415	1571	1251	1206	1126	1225	1272	1167	1124	667	786
90	15	1056	1327	1421	1082	1003	923	1006	1080	1039	1040	633	756
20	30	749	1136	1592	1668	1962	1991	2103	1848	1347	1010	522	531
30	30	852	1250	1682	1685	1927	1930	2051	1846	1389	1085	574	605
40	30	935	1332	1733	1668	1858	1838	1963	1808	1402	1135	612	663
50	30	993	1381	1743	1618	1756	1715	1842	1736	1384	1158	636	705
60	30	1025	1394	1711	1536	1624	1566	1691	1630	1338	1154	645	729
70	30	1030	1373	1640	1425	1466	1395	1513	1495	1263	1122	639	734
80	30	1008	1316	1530	1288	1288	1209	1317	1336	1163	1063	617	721
90	30	961	1229	1390	1134	1102	1020	1115	1162	1043	982	582	689
20	45	699	1081	1544	1647	1960	1999	2107	1835	1320	971	496	496
30	45	782	1173	1618	1662	1932	1949	2066	1834	1354	1032	537	554
40	45	845	1237	1659	1648	1875	1872	1993	1803	1363	1071	565	598
50	45	887	1272	1664	1604	1788	1767	1891	1740	1346	1086	582	628
60	45	907	1277	1632	1531	1673	1637	1759	1648	1302	1076	585	643
70	45	904	1251	1565	1431	1534	1486	1604	1528	1233	1043	574	641
80	45	878	1196	1465	1308	1375	1320	1429	1386	1141	987	551	624
90	45	831	1114	1339	1169	1207	1148	1246	1229	1033	913	517	592

SCHENECTADY NY 42.50

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	
HORIZONTAL RAD.	478	740	1008	1251	1524	1653	1635	1469	1104	806	475	382	(BTU/DAY-FT2)
AVE. TEMP.	23.0	24.8	32.0	46.4	57.2	68.0	71.6	69.8	60.8	50.0	39.2	28.4	(F)
DEGREE-DAYS	1283.	1131.	970.	543.	211.	30.	0.	22.	123.	422.	756.	1159.	(F-DAYS)

AVERAGE DAILY RADIATION ON TILTED SURFACES (BTU/DAY-FT2)

SLOPE	AZIMUTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
20	0	686	966	1174	1321	1516	1602	1603	1515	1233	1008	643	552
30	0	767	1046	1219	1316	1471	1535	1544	1493	1259	1075	707	619
40	0	829	1103	1236	1284	1397	1442	1457	1440	1256	1118	755	671
50	0	872	1132	1225	1225	1299	1324	1345	1359	1226	1135	784	707
60	0	892	1134	1186	1142	1178	1186	1211	1251	1169	1125	795	726
70	0	891	1109	1121	1037	1040	1033	1059	1120	1087	1088	787	727
80	0	867	1057	1032	914	888	870	896	971	982	1026	760	709
90	0	822	981	923	779	732	708	731	812	861	942	716	676
20	15	678	957	1168	1320	1517	1604	1604	1515	1230	1000	637	546
30	15	755	1034	1210	1316	1474	1540	1548	1495	1255	1064	698	610
40	15	815	1086	1226	1286	1404	1450	1465	1445	1252	1103	743	659
50	15	854	1112	1214	1230	1309	1336	1356	1367	1223	1117	770	693
60	15	873	1112	1175	1151	1192	1202	1226	1263	1168	1104	779	710
70	15	869	1085	1111	1050	1057	1053	1079	1138	1089	1066	769	709
80	15	844	1031	1022	932	910	894	920	994	988	1003	741	691
90	15	800	956	915	803	759	736	760	841	871	919	697	657
20	30	655	932	1152	1315	1520	1610	1609	1513	1218	978	618	527
30	30	722	999	1189	1312	1482	1553	1560	1497	1240	1034	671	583
40	30	772	1042	1201	1285	1420	1472	1485	1453	1237	1067	708	625
50	30	804	1061	1188	1235	1335	1368	1387	1384	1210	1075	728	652
60	30	815	1055	1150	1162	1229	1246	1269	1291	1158	1059	732	663
70	30	807	1024	1088	1070	1106	1108	1134	1176	1083	1019	719	659
80	30	779	970	1004	961	971	960	987	1045	989	956	688	638
90	30	734	895	904	843	832	813	839	906	881	875	643	603
20	45	621	897	1126	1303	1521	1618	1614	1506	1197	947	591	499
30	45	674	949	1155	1300	1488	1569	1572	1491	1214	990	631	542
40	45	711	981	1163	1275	1434	1499	1508	1453	1210	1014	659	573
50	45	732	992	1148	1229	1359	1409	1422	1392	1183	1017	671	591
60	45	736	981	1110	1163	1265	1301	1318	1308	1134	997	669	595
70	45	722	948	1052	1079	1155	1178	1197	1206	1066	958	652	586
80	45	693	896	974	980	1033	1044	1065	1088	979	898	621	563
90	45	648	826	883	873	906	909	930	961	881	823	578	528

SEATTLE WA 47.27

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	
HORIZONTAL RAD.	287	500	972	1458	1844	1918	2087	1749	1207	696	390	235	(BTU/DAY-FT2)
AVE. TEMP.	41.0	44.6	44.6	50.0	55.4	60.8	64.4	64.4	60.8	53.6	46.4	42.8	(F)
DEGREE-DAYS	738.	599.	577.	396.	242.	117.	50.	47.	129.	329.	543.	657.	(F-DAYS)

AVERAGE DAILY RADIATION ON TILTED SURFACES (BTU/DAY-FT2)

SLOPE	AZIMUTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
20	0	409	654	1177	1590	1869	1883	2080	1854	1408	907	569	343
30	0	457	711	1240	1605	1829	1817	2020	1848	1461	983	641	386
40	0	495	751	1275	1584	1752	1718	1920	1802	1480	1036	697	421
50	0	521	774	1280	1529	1642	1589	1784	1718	1464	1064	735	445
60	0	535	779	1254	1440	1500	1433	1615	1597	1414	1067	756	459
70	0	536	765	1200	1321	1332	1256	1418	1443	1331	1043	758	462
80	0	524	734	1118	1176	1143	1064	1202	1262	1218	995	741	454
90	0	500	688	1013	1012	946	869	980	1064	1082	925	706	435
20	15	404	648	1169	1588	1870	1885	2082	1853	1403	899	563	339
30	15	450.	702	1230	1604	1832	1822	2025	1849	1455	971	631	380
40	15	486	740	1263	1586	1759	1726	1929	1807	1474	1021	684	413
50	15	511	761	1266	1534	1653	1602	1798	1727	1459	1046	721	436
60	15	524	764	1240	1450	1516	1450	1634	1611	1411	1046	739	449
70	15	524	749	1186	1336	1353	1278	1444	1463	1331	1021	740	451
80	15	511	717	1104	1197	1170	1090	1234	1289	1222	971	722	443
90	15	487	670	1001	1039	978	900	1017	1098	1090	901	687	424
20	30	391	632	1150	1578	1872	1890	2087	1848	1385	877	543	327
30	30	431	678	1204	1596	1841	1835	2038	1849	1433	940	602	363
40	30	462	709	1233	1582	1778	1750	1954	1815	1450	982	648	391
50	30	481	725	1234	1537	1683	1637	1837	1745	1436	1001	677	410
60	30	490	724	1207	1461	1560	1498	1689	1642	1392	997	690	420
70	30	487	706	1154	1357	1411	1339	1515	1510	1317	969	686	419
80	30	473	673	1077	1229	1244	1165	1322	1351	1215	919	666	409
90	30	448	626	979	1086	1067	986	1121	1177	1093	851	630	390
20	45	371	607	1119	1559	1869	1897	2090	1833	1355	844	514	309
30	45	402	644	1163	1574	1845	1852	2051	1836	1395	895	561	337
40	45	425	667	1185	1562	1792	1780	1983	1808	1408	927	595	358
50	45	438	677	1182	1522	1712	1683	1883	1748	1394	939	616	371
60	45	441	672	1156	1454	1604	1562	1755	1658	1352	931	622	375
70	45	435	652	1106	1361	1473	1421	1602	1540	1283	902	614	371
80	45	419	619	1034	1246	1323	1264	1430	1399	1191	854	591	359
90	45	394	575	944	1115	1163	1102	1249	1242	1080	790	556	339

SHREVEPORT LA 32.25

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	
HORIZONTAL RAD.	832	1027	1392	1719	2018	2003	2069	1914	1528	1274	894	729	(BTU/DAY-FT2)
AVE. TEMP.	46.4	50.0	57.2	64.4	71.6	78.8	82.4	82.4	77.0	66.2	55.4	48.2	(F)
DEGREE-DAYS	552.	426.	304.	81.	0.	0.	0.	0.	0.	47.	297.	477.	(F-DAYS)

AVERAGE DAILY RADIATION ON TILTED SURFACES (BTU/DAY-FT2)

SLOPE	AZIMUTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
20	0	1096	1243	1554	1762	1942	1875	1959	1911	1649	1522	1155	974
30	0	1191	1310	1583	1726	1845	1758	1847	1848	1654	1594	1246	1064
40	0	1257	1346	1575	1653	1712	1611	1700	1746	1622	1627	1308	1129
50	0	1293	1351	1532	1544	1548	1437	1523	1607	1552	1622	1337	1166
60	0	1296	1323	1453	1404	1357	1242	1322	1437	1449	1577	1334	1175
70	0	1268	1265	1342	1237	1146	1035	1105	1242	1314	1495	1298	1154
80	0	1209	1178	1202	1047	926	825	883	1028	1151	1377	1230	1106
90	0	1122	1066	1041	848	714	634	674	809	971	1231	1136	1032
20	15	1086	1234	1548	1763	1946	1880	1964	1913	1646	1512	1145	965
30	15	1176	1297	1575	1730	1854	1768	1857	1854	1651	1579	1231	1051
40	15	1238	1329	1566	1661	1727	1626	1716	1757	1620	1608	1288	1111
50	15	1270	1331	1522	1558	1569	1459	1546	1626	1554	1599	1314	1145
60	15	1270	1301	1444	1425	1386	1271	1353	1464	1454	1552	1308	1151
70	15	1240	1241	1335	1266	1185	1071	1145	1278	1324	1468	1270	1129
80	15	1179	1152	1198	1087	974	869	931	1075	1169	1349	1201	1079
90	15	1092	1040	1041	901	771	682	729	870	998	1203	1106	1005
20	30	1056	1210	1531	1760	1956	1895	1978	1916	1634	1485	1115	937
30	30	1133	1263	1554	1731	1876	1796	1884	1865	1638	1542	1189	1010
40	30	1183	1287	1543	1670	1765	1670	1760	1780	1609	1564	1234	1060
50	30	1204	1282	1501	1578	1625	1521	1609	1664	1547	1550	1250	1084
60	30	1196	1248	1427	1458	1463	1352	1437	1520	1455	1500	1236	1082
70	30	1160	1187	1324	1315	1284	1173	1251	1355	1336	1417	1193	1053
80	30	1096	1099	1197	1155	1096	990	1059	1175	1195	1303	1121	1000
90	30	1008	991	1054	989	914	818	877	993	1040	1166	1026	925
20	45	1012	1175	1504	1752	1966	1913	1993	1915	1613	1444	1072	896
30	45	1070	1214	1520	1726	1899	1830	1915	1872	1614	1488	1128	952
40	45	1105	1229	1507	1671	1804	1723	1809	1798	1586	1500	1159	986
50	45	1115	1218	1465	1590	1684	1594	1680	1697	1529	1481	1165	998
60	45	1100	1182	1396	1483	1542	1448	1530	1571	1446	1431	1144	988
70	45	1060	1121	1302	1356	1384	1290	1367	1425	1338	1353	1099	955
80	45	997	1040	1187	1213	1218	1126	1196	1265	1211	1249	1030	901
90	45	915	942	1059	1065	1053	968	1030	1102	1074	1126	942	830

SILVER HILL MD 38.50

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	
HORIZONTAL RAD.	670	898	1251	1612	1889	2043	1900	1690	1461	1086	743	600	(BTU/DAY-FT2)
AVE. TEMP.	35.6	37.4	44.6	55.4	64.4	73.4	77.0	75.2	69.8	59.0	48.2	37.4	(F)
DEGREE-DAYS	871.	762.	626.	288.	74.	0.	0.	0.	33.	217.	519.	834.	(F-DAYS)

AVERAGE DAILY RADIATION ON TILTED SURFACES (BTU/DAY-FT2)

SLOPE	AZIMUTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
20	0	945	1144	1445	1695	1859	1953	1840	1725	1630	1353	1025	873
30	0	1051	1229	1493	1681	1789	1854	1758	1688	1659	1441	1132	979
40	0	1131	1284	1507	1630	1685	1722	1644	1617	1649	1493	1210	1062
50	0	1182	1309	1485	1544	1548	1560	1500	1512	1602	1509	1258	1118
60	0	1204	1301	1429	1426	1384	1373	1331	1377	1517	1488	1274	1145
70	0	1195	1262	1340	1279	1199	1168	1143	1217	1398	1431	1258	1142
80	0	1155	1193	1221	1108	998	955	945	1037	1249	1340	1210	1111
90	0	1089	1097	1079	923	797	749	750	848	1077	1219	1134	1053
20	15	935	1135	1438	1694	1861	1957	1843	1725	1625	1343	1015	862
30	15	1036	1215	1484	1682	1795	1862	1765	1691	1654	1425	1116	965
40	15	1111	1266	1495	1635	1695	1735	1655	1624	1646	1473	1190	1043
50	15	1159	1287	1473	1554	1564	1578	1516	1524	1600	1485	1234	1095
60	15	1178	1277	1417	1441	1406	1398	1353	1395	1518	1462	1247	1119
70	15	1166	1236	1329	1301	1227	1200	1172	1242	1404	1402	1229	1114
80	15	1126	1165	1212	1139	1034	993	980	1070	1260	1310	1180	1082
90	15	1058	1069	1072	963	841	793	791	890	1096	1189	1103	1023
20	30	905	1108	1419	1688	1867	1968	1851	1725	1610	1314	984	833
30	30	992	1177	1459	1679	1810	1885	1783	1696	1636	1386	1071	921
40	30	1055	1218	1467	1638	1723	1772	1686	1637	1627	1425	1132	987
50	30	1091	1231	1444	1565	1606	1631	1562	1549	1585	1431	1165	1028
60	30	1101	1215	1390	1464	1465	1468	1415	1433	1509	1403	1169	1043
70	30	1083	1171	1306	1337	1304	1288	1251	1295	1403	1343	1145	1033
80	30	1039	1100	1197	1189	1129	1099	1076	1140	1271	1252	1092	996
90	30	970	1006	1068	1031	954	914	903	978	1121	1137	1015	936
20	45	859	1068	1388	1674	1871	1982	1860	1718	1583	1272	938	787
30	45	927	1122	1419	1666	1823	1912	1803	1694	1603	1328	1006	856
40	45	974	1152	1423	1629	1748	1816	1720	1643	1593	1356	1051	905
50	45	998	1157	1398	1564	1648	1695	1612	1565	1553	1355	1072	932
60	45	998	1137	1347	1474	1524	1553	1484	1463	1484	1325	1068	937
70	45	974	1092	1269	1360	1381	1395	1339	1340	1388	1266	1039	919
80	45	929	1024	1169	1228	1225	1226	1183	1201	1268	1182	986	880
90	45	863	938	1053	1085	1067	1058	1026	1055	1134	1077	913	821

SPOKANE WA 47.40

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	
HORIZONTAL RAD.	434	784	1167	1719	2047	2227	2441	2040	1498	758	482	279	(BTU/DAY-FT2)
AVE. TEMP.	28.4	32.0	39.2	46.4	55.4	60.8	69.8	68.0	59.0	48.2	35.6	32.0	(F)
DEGREE-DAYS	1231.	980.	834.	531.	188.	135.	9.	25.	168.	493.	879.	1082.	(F-DAYS)

AVERAGE DAILY RADIATION ON TILTED SURFACES (BTU/DAY-FT2)

SLOPE	AZIMUTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
20	0	709	1132	1450	1898	2081	2188	2439	2182	1791	1007	749	437
30	0	821	1267	1541	1923	2037	2111	2369	2182	1874	1098	857	502
40	0	913	1369	1595	1905	1953	1995	2251	2132	1910	1162	944	555
50	0	981	1436	1609	1842	1829	1841	2088	2034	1899	1198	1006	594
60	0	1023	1465	1584	1738	1669	1655	1884	1890	1841	1204	1042	618
70	0	1038	1457	1520	1594	1479	1443	1646	1706	1738	1180	1051	626
80	0	1026	1410	1419	1416	1265	1213	1384	1487	1592	1127	1032	618
90	0	987	1329	1287	1215	1040	980	1114	1247	1413	1049	987	595
20	15	699	1119	1440	1895	2082	2191	2442	2180	1783	998	740	432
30	15	807	1248	1528	1923	2041	2117	2376	2183	1865	1084	843	494
40	15	895	1344	1579	1907	1961	2005	2263	2138	1902	1144	925	544
50	15	959	1407	1591	1850	1842	1857	2106	2045	1892	1176	984	581
60	15	998	1432	1565	1751	1688	1677	1909	1909	1837	1179	1017	603
70	15	1011	1421	1500	1614	1504	1471	1679	1732	1738	1154	1024	610
80	15	997	1372	1400	1444	1296	1247	1425	1522	1598	1100	1004	602
90	15	958	1291	1270	1250	1079	1019	1162	1290	1425	1021	959	579
20	30	669	1082	1413	1883	2083	2198	2447	2174	1758	972	711	415
30	30	764	1195	1492	1912	2051	2134	2393	2182	1834	1047	801	469
40	30	840	1277	1537	1902	1982	2035	2295	2147	1868	1099	872	512
50	30	893	1327	1546	1852	1878	1902	2157	2069	1860	1124	920	543
60	30	924	1344	1520	1764	1740	1738	1980	1949	1809	1122	945	560
70	30	931	1326	1458	1641	1573	1549	1772	1792	1717	1093	945	564
80	30	913	1275	1363	1486	1384	1341	1539	1602	1587	1039	921	553
90	30	872	1193	1241	1311	1184	1129	1296	1393	1428	962	875	529
20	45	625	1028	1371	1857	2081	2206	2452	2155	1715	933	668	389
30	45	700	1119	1436	1883	2056	2155	2410	2165	1779	995	740	431
40	45	758	1184	1472	1876	2000	2073	2332	2138	1808	1034	794	464
50	45	797	1221	1477	1833	1911	1960	2217	2073	1799	1051	829	486
60	45	816	1228	1450	1755	1792	1819	2066	1969	1752	1045	844	496
70	45	815	1206	1391	1646	1645	1653	1885	1831	1669	1015	838	494
80	45	793	1155	1304	1508	1477	1468	1679	1663	1552	963	811	480
90	45	753	1079	1193	1350	1297	1275	1462	1476	1409	892	766	456

STATE COLLEGE PA 40.48

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	
HORIZONTAL RAD.	511	743	1093	1373	1719	2003	1944	1671	1329	1012	570	441	(BTU/DAY-FT2)
AVE. TEMP.	28.4	28.4	35.6	48.2	59.0	68.0	71.6	69.8	62.6	51.8	41.0	30.2	(F)
DEGREE-DAYS	1122.	1002.	856.	468.	177.	24.	0.	9.	111.	375.	717.	1073.	(F-DAYS)

AVERAGE DAILY RADIATION ON TILTED SURFACES (BTU/DAY-FT2)

SLOPE	AZIMUTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
20	0	709	942	1264	1444	1702	1927	1895	1719	1490	1278	774	626
30	0	785	1011	1307	1435	1645	1837	1817	1689	1520	1367	850	698
40	0	842	1057	1321	1396	1556	1713	1705	1623	1516	1424	906	753
50	0	879	1077	1305	1327	1439	1560	1562	1525	1477	1445	941	790
60	0	894	1072	1260	1232	1296	1382	1392	1396	1404	1431	952	808
70	0	888	1042	1186	1113	1132	1185	1202	1240	1300	1382	940	806
80	0	859	988	1086	973	955	978	999	1064	1169	1300	906	784
90	0	811	912	966	822	775	775	797	877	1016	1189	851	744
20	15	702	935	1257	1444	1704	1930	1897	1719	1485	1268	766	619
30	15	774	1000	1299	1436	1649	1844	1823	1691	1515	1352	839	688
40	15	828	1042	1311	1399	1564	1725	1716	1630	1512	1404	892	740
50	15	862	1060	1294	1334	1451	1577	1578	1536	1474	1422	923	775
60	15	876	1063	1249	1243	1313	1405	1414	1412	1405	1405	933	791
70	15	867	1021	1175	1129	1156	1214	1230	1263	1304	1354	919	787
80	15	838	965	1077	996	984	1013	1033	1094	1177	1270	884	764
90	15	789	889	959	851	810	815	837	916	1031	1159	828	723
20	30	680	913	1240	1438	1708	1940	1905	1717	1470	1240	743	599
30	30	742	969	1277	1432	1661	1864	1840	1695	1498	1313	806	658
40	30	787	1003	1286	1400	1586	1758	1745	1642	1494	1356	850	702
50	30	814	1014	1268	1341	1485	1625	1622	1558	1459	1367	873	730
60	30	820	1002	1224	1258	1361	1469	1475	1448	1394	1346	876	739
70	30	808	968	1154	1154	1218	1294	1308	1313	1301	1293	858	731
80	30	775	911	1060	1032	1062	1110	1128	1161	1183	1211	820	706
90	30	726	836	950	900	903	927	949	1000	1048	1104	764	664
20	45	647	881	1213	1426	1710	1952	1912	1709	1445	1198	710	568
30	45	696	925	1242	1420	1670	1888	1859	1691	1466	1256	759	614
40	45	729	949	1247	1390	1606	1799	1778	1644	1460	1288	791	646
50	45	745	953	1227	1338	1518	1684	1672	1571	1427	1291	805	664
60	45	745	937	1184	1263	1409	1548	1543	1473	1367	1267	802	666
70	45	728	902	1118	1169	1281	1394	1395	1353	1282	1215	780	653
80	45	694	847	1033	1058	1141	1229	1235	1217	1175	1138	741	626
90	45	646	778	933	939	997	1063	1072	1071	1054	1041	688	585

STILLWATER OK 36.09

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	
HORIZONTAL RAD.	762	1053	1428	1679	1848	2183	2183	1995	1675	1296	946	751	(BTU/DAY-FT2)
AVE. TEMP.	35.6	41.0	48.2	60.8	68.0	77.0	80.6	80.6	71.6	62.6	48.2	39.2	(F)
DEGREE-DAYS	893.	683.	539.	213.	47.	0.	0.	0.	18.	158.	522.	787.	(F-DAYS)

AVERAGE DAILY RADIATION ON TILTED SURFACES (BTU/DAY-FT2)

SLOPE	AZIMUTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
20	0	1053	1333	1641	1748	1804	2067	2095	2025	1860	1611	1308	1086
30	0	1162	1428	1690	1726	1729	1951	1989	1974	1887	1712	1442	1215
40	0	1243	1488	1700	1666	1620	1800	1845	1880	1870	1770	1541	1314
50	0	1293	1511	1669	1570	1482	1616	1667	1746	1808	1784	1599	1380
60	0	1310	1497	1599	1441	1317	1408	1461	1577	1704	1754	1617	1409
70	0	1293	1447	1492	1283	1133	1182	1235	1377	1560	1680	1593	1402
80	0	1245	1361	1351	1102	937	950	998	1154	1381	1565	1527	1359
90	0	1166	1245	1183	908	743	731	769	922	1177	1415	1425	1282
20	15	1042	1322	1633	1748	1807	2073	2099	2027	1855	1598	1294	1073
30	15	1146	1412	1680	1728	1735	1961	1998	1980	1882	1693	1422	1197
40	15	1222	1467	1688	1672	1631	1815	1860	1891	1866	1747	1515	1291
50	15	1268	1486	1657	1581	1498	1639	1689	1764	1807	1756	1569	1352
60	15	1282	1469	1587	1459	1340	1438	1491	1602	1707	1723	1582	1377
70	15	1263	1416	1481	1309	1163	1220	1273	1411	1569	1646	1555	1368
80	15	1213	1329	1342	1137	974	996	1045	1199	1398	1529	1488	1323
90	15	1134	1213	1179	954	787	782	824	980	1204	1379	1385	1245
20	30	1009	1292	1612	1743	1814	2087	2111	2027	1838	1565	1254	1036
30	30	1099	1368	1653	1727	1751	1989	2024	1988	1863	1647	1364	1143
40	30	1162	1413	1658	1677	1660	1860	1902	1911	1848	1690	1441	1222
50	30	1196	1423	1627	1596	1542	1702	1751	1800	1793	1693	1481	1269
60	30	1201	1400	1560	1485	1400	1522	1574	1656	1701	1655	1483	1284
70	30	1176	1344	1460	1350	1241	1325	1379	1486	1574	1579	1448	1267
80	30	1121	1257	1330	1195	1071	1122	1173	1297	1418	1465	1377	1217
90	30	1042	1144	1180	1030	902	925	973	1102	1242	1323	1274	1138
20	45	962	1246	1578	1731	1819	2104	2125	2022	1808	1515	1195	981
30	45	1031	1306	1609	1716	1767	2023	2052	1989	1827	1579	1281	1064
40	45	1077	1337	1610	1672	1688	1913	1949	1923	1811	1610	1338	1122
50	45	1098	1339	1578	1600	1585	1779	1819	1826	1761	1605	1362	1153
60	45	1093	1312	1515	1501	1461	1622	1666	1700	1677	1565	1355	1156
70	45	1062	1256	1423	1381	1321	1450	1495	1551	1563	1492	1315	1131
80	45	1008	1174	1306	1242	1169	1269	1313	1383	1424	1388	1245	1078
90	45	932	1071	1172	1094	1016	1090	1132	1209	1268	1260	1149	1002

SUMMIT	MT	48.19											
	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	
HORIZONTAL RAD.	449	597	988	1526	1703	1817	2064	1880	1305	796	376	230	(BTU/DAY-FT2)
AVE. TEMP.	15.8	21.2	24.8	33.8	42.8	48.2	55.4	53.6	46.4	37.4	26.6	21.2	(F)
DEGREE-DAYS	1538.	1243.	1287.	933.	679.	456.	258.	307.	543.	822.	1164.	1398.	(F-DAYS)

AVERAGE DAILY RADIATION ON TILTED SURFACES (BTU/DAY-FT2)

SLOPE	AZIMUTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
20	0	764	828	1210	1677	1728	1787	2063	2009	1546	1081	559	455
30	0	894	917	1281	1699	1692	1728	2006	2009	1613	1187	633	528
40	0	1001	983	1322	1682	1624	1637	1910	1965	1642	1263	691	587
50	0	1082	1025	1331	1627	1525	1518	1779	1877	1631	1308	732	632
60	0	1134	1041	1309	1537	1397	1374	1614	1749	1581	1320	755	660
70	0	1155	1032	1255	1413	1246	1209	1422	1583	1493	1298	759	672
80	0	1144	996	1173	1260	1075	1030	1210	1386	1371	1244	744	666
90	0	1104	938	1065	1086	896	848	991	1169	1220	1161	711	643
20	15	752	820	1203	1675	1728	1789	2064	2007	1539	1070	552	449
30	15	878	904	1271	1698	1695	1732	2010	2010	1606	1171	623	518
40	15	980	966	1309	1684	1630	1645	1919	1970	1635	1243	678	575
50	15	1057	1005	1317	1633	1534	1529	1792	1887	1625	1284	717	618
60	15	1105	1019	1293	1547	1411	1389	1633	1764	1577	1292	738	644
70	15	1123	1008	1240	1429	1264	1228	1446	1605	1493	1268	740	654
80	15	1112	971	1158	1282	1098	1053	1240	1416	1374	1213	724	647
90	15	1071	913	1052	1115	924	875	1026	1207	1229	1129	691	624
20	30	719	795	1181	1664	1729	1794	2068	2001	1518	1041	533	430
30	30	829	868	1243	1688	1702	1743	2023	2009	1580	1129	594	491
40	30	917	921	1276	1679	1645	1665	1943	1978	1607	1191	641	540
50	30	982	952	1281	1635	1560	1560	1829	1907	1598	1223	673	576
60	30	1020	959	1257	1558	1448	1431	1685	1799	1553	1226	688	597
70	30	1032	944	1205	1451	1314	1283	1514	1656	1475	1199	686	603
80	30	1016	905	1127	1316	1161	1119	1324	1485	1365	1143	667	594
90	30	973	847	1027	1164	1000	952	1125	1295	1230	1061	633	570
20	45	668	759	1148	1643	1727	1799	2071	1984	1483	997	503	401
30	45	755	818	1198	1664	1705	1758	2035	1993	1535	1069	551	449
40	45	824	859	1225	1656	1658	1692	1970	1969	1556	1118	587	486
50	45	871	880	1226	1617	1584	1602	1873	1909	1547	1141	610	512
60	45	897	882	1201	1549	1486	1489	1749	1815	1505	1138	618	525
70	45	899	863	1152	1453	1367	1356	1599	1689	1433	1109	611	526
80	45	878	825	1079	1332	1230	1209	1429	1536	1333	1055	590	513
90	45	835	769	988	1194	1083	1056	1250	1366	1212	979	557	489

TALLAHASSEE FL 30.26

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	
HORIZONTAL RAD.	909	1145	1557	1778	2018	1752	2003	1977	1561	1299	1340	1145	(BTU/DAY-FT2)
AVE. TEMP.	51.8	53.6	60.8	66.2	73.4	78.8	80.6	80.6	77.0	68.0	59.0	53.6	(F)
DEGREE-DAYS	375.	286.	202.	36.	0.	0.	0.	0.	0.	28.	198.	360.	(F-DAYS)

AVERAGE DAILY RADIATION ON TILTED SURFACES (BTU/DAY-FT2)

SLOPE	AZIMUTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
20	0	1182	1379	1732	1809	1927	1635	1884	1959	1669	1530	1802	1611
30	0	1278	1449	1761	1765	1824	1532	1769	1886	1668	1593	1967	1786
40	0	1343	1485	1747	1683	1685	1403	1622	1773	1628	1618	2081	1914
50	0	1376	1486	1693	1565	1515	1252	1448	1623	1552	1604	2140	1992
60	0	1374	1451	1600	1415	1320	1084	1251	1442	1441	1553	2143	2017
70	0	1339	1383	1471	1238	1107	907	1040	1236	1300	1465	2089	1988
80	0	1271	1282	1309	1039	886	730	826	1012	1132	1342	1980	1907
90	0	1175	1154	1123	832	676	571	630	786	946	1193	1824	1778
20	15	1171	1369	1726	1810	1932	1640	1889	1961	1666	1520	1784	1594
30	15	1262	1435	1752	1769	1833	1541	1780	1893	1665	1579	1941	1760
40	15	1323	1467	1738	1692	1700	1417	1639	1786	1627	1600	2047	1881
50	15	1352	1464	1684	1580	1538	1271	1471	1644	1554	1583	2100	1952
60	15	1347	1427	1592	1438	1351	1109	1282	1472	1447	1529	2098	1972
70	15	1310	1356	1464	1270	1147	938	1080	1276	1312	1439	2040	1940
80	15	1241	1254	1306	1083	937	767	874	1065	1151	1316	1929	1856
90	15	1144	1126	1126	890	736	610	684	854	977	1167	1771	1727
20	30	1140	1343	1708	1808	1943	1653	1903	1966	1656	1495	1733	1542
30	30	1217	1398	1730	1773	1857	1565	1807	1907	1654	1544	1866	1685
40	30	1266	1422	1714	1704	1741	1454	1683	1813	1618	1559	1952	1784
50	30	1284	1412	1662	1604	1597	1324	1534	1687	1551	1538	1988	1837
60	30	1271	1371	1575	1476	1432	1178	1366	1535	1453	1482	1972	1842
70	30	1227	1299	1456	1326	1251	1024	1186	1361	1328	1394	1906	1798
80	30	1155	1198	1311	1159	1064	868	1002	1174	1183	1276	1790	1708
90	30	1057	1076	1148	988	885	723	829	989	1026	1137	1634	1577
20	45	1095	1304	1678	1802	1956	1669	1920	1967	1637	1457	1657	1464
30	45	1153	1345	1693	1770	1883	1595	1839	1916	1633	1494	1760	1575
40	45	1186	1369	1675	1709	1784	1499	1733	1835	1599	1500	1822	1646
50	45	1192	1343	1625	1621	1660	1386	1605	1727	1537	1475	1840	1678
60	45	1172	1300	1545	1508	1516	1259	1459	1593	1448	1420	1814	1668
70	45	1125	1231	1437	1374	1357	1122	1301	1441	1336	1337	1744	1617
80	45	1055	1138	1307	1226	1191	982	1137	1275	1206	1230	1635	1527
90	45	964	1027	1162	1074	1028	847	979	1109	1066	1105	1493	1405

TAMPA FL 27.58

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	
HORIZONTAL RAD.	1204	1439	1756	2006	2191	2110	1962	1822.	1671	1491	1314	1112	(BTU/DAY-FT2)
AVE. TEMP.	60.8	60.8	66.2	69.8	75.2	78.8	80.6	80.6	78.8	73.4	66.2	60.8	(F)
DEGREE-DAYS	202.	148.	102.	0.	0.	0.	0.	0.	0.	0.	60.	171.	(F-DAYS)

AVERAGE DAILY RADIATION ON TILTED SURFACES (BTU/DAY-FT2)

SLOPE	AZIMUTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
20	0	1579	1739	1939	2024	2068	1937	1828	1785	1770	1743	1698	1490
30	0	1711	1827	1963	1964	1942	1795	1708	1710	1759	1808	1829	1626
40	0	1799	1870	1939	1860	1778	1622	1557	1600	1708	1830	1913	1722
50	0	1842	1868	1870	1716	1581	1423	1380	1458	1618	1807	1949	1773
60	0	1838	1819	1756	1536	1358	1205	1183	1289	1493	1740	1935	1779
70	0	1786	1726	1602	1325	1118	979	974	1099	1335	1632	1872	1740
80	0	1690	1591	1411	1092	873	758	766	895	1151	1485	1761	1655
90	0	1554	1422	1196	852	648	572	582	693	949	1309	1609	1532
20	15	1564	1726	1932	2025	2073	1944	1834	1788	1767	1733	1682	1475
30	15	1689	1809	1954	1970	1954	1808	1719	1717	1757	1793	1806	1605
40	15	1772	1847	1929	1872	1798	1642	1574	1613	1708	1810	1885	1694
50	15	1809	1840	1860	1736	1610	1451	1404	1478	1622	1784	1915	1741
60	15	1800	1788	1748	1568	1397	1242	1215	1317	1502	1714	1897	1742
70	15	1746	1692	1597	1368	1168	1024	1016	1137	1351	1604	1830	1699
80	15	1648	1555	1412	1150	936	811	816	946	1176	1457	1717	1613
90	15	1511	1385	1204	929	720	625	636	758	987	1281	1565	1489
20	30	1522	1693	1913	2026	2089	1963	1849	1794	1758	1705	1639	1433
30	30	1627	1762	1931	1977	1985	1844	1748	1732	1748	1755	1744	1543
40	30	1693	1790	1906	1891	1848	1697	1620	1639	1703	1765	1805	1615
50	30	1716	1775	1840	1769	1683	1528	1470	1519	1623	1735	1822	1646
60	30	1696	1718	1735	1618	1496	1342	1302	1377	1513	1665	1792	1635
70	30	1633	1621	1595	1442	1295	1149	1125	1217	1376	1558	1719	1584
80	30	1531	1489	1427	1250	1090	957	947	1048	1217	1419	1603	1492
90	30	1394	1328	1241	1057	899	785	784	883	1050	1256	1452	1367
20	45	1459	1643	1882	2021	2106	1989	1868	1797	1740	1663	1575	1369
30	45	1539	1695	1893	1978	2019	1888	1783	1744	1729	1700	1655	1453
40	45	1584	1710	1867	1903	1903	1764	1674	1664	1687	1701	1697	1503
50	45	1592	1688	1805	1797	1762	1619	1545	1559	1615	1668	1699	1517
60	45	1562	1631	1709	1664	1600	1459	1399	1434	1515	1600	1662	1495
70	45	1497	1539	1584	1510	1425	1289	1244	1293	1393	1501	1588	1439
80	45	1399	1418	1434	1341	1244	1119	1085	1143	1252	1375	1478	1349
90	45	1274	1275	1270	1168	1070	958	933	994	1103	1230	1342	1233

TRENTON NJ 40.13

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	
HORIZONTAL RAD.	637	899	1264	1563	1810	2012	1990	1729	1434	1083	718	571	(BTU/DAY-FT2)
AVE. TEMP.	32.0	32.0	41.0	51.8	60.8	69.8	75.2	73.4	66.2	55.4	44.6	33.8	(F)
DEGREE-DAYS	1020.	885.	738.	384.	135.	0.	0.	0.	39.	252.	561.	933.	(F-DAYS)

AVERAGE DAILY RADIATION ON TILTED SURFACES (BTU/DAY-FT2)

SLOPE	AZIMUTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
20	0	923	1172	1480	1652	1790	1934	1938	1777	1613	1376	1016	856
30	0	1034	1268	1537	1643	1729	1842	1857	1745	1648	1474	1130	969
40	0	1119	1334	1559	1599	1634	1717	1740	1677	1645	1537	1216	1058
50	0	1176	1366	1543	1520	1508	1562	1592	1573	1603	1561	1271	1120
60	0	1203	1365	1491	1409	1356	1382	1417	1438	1524	1547	1294	1153
70	0	1199	1331	1405	1270	1181	1183	1221	1276	1410	1494	1283	1156
80	0	1165	1263	1286	1106	992	975	1011	1092	1266	1405	1240	1129
90	0	1102	1168	1141	928	800	771	804	898	1098	1284	1167	1074
20	15	912	1161	1472	1651	1792	1937	1941	1777	1608	1364	1005	845
30	15	1018	1252	1527	1644	1734	1850	1863	1748	1643	1457	1114	954
40	15	1099	1314	1546	1603	1643	1729	1752	1684	1640	1515	1195	1038
50	15	1152	1343	1530	1529	1522	1579	1609	1585	1600	1535	1246	1096
60	15	1176	1339	1477	1423	1375	1405	1440	1456	1525	1518	1265	1126
70	15	1170	1302	1391	1290	1207	1213	1250	1300	1415	1463	1252	1127
80	15	1134	1233	1274	1134	1024	1010	1047	1124	1276	1372	1208	1098
90	15	1071	1137	1133	965	839	812	846	938	1115	1251	1134	1043
20	30	881	1132	1451	1645	1797	1947	1949	1776	1592	1334	972	815
30	30	973	1210	1499	1640	1747	1870	1882	1752	1623	1415	1066	909
40	30	1041	1261	1515	1604	1667	1763	1783	1696	1621	1463	1134	980
50	30	1083	1281	1497	1538	1559	1628	1656	1609	1583	1476	1174	1027
60	30	1097	1271	1447	1442	1427	1470	1503	1494	1513	1453	1184	1048
70	30	1085	1230	1365	1321	1275	1295	1332	1354	1411	1397	1164	1042
80	30	1044	1160	1255	1180	1110	1109	1147	1195	1283	1308	1116	1009
90	30	980	1066	1123	1026	941	926	963	1028	1135	1192	1041	952
20	45	834	1088	1417	1630	1800	1959	1957	1768	1564	1288	924	767
30	45	906	1150	1455	1626	1757	1895	1901	1748	1589	1352	998	841
40	45	957	1188	1465	1594	1689	1804	1817	1700	1584	1388	1049	894
50	45	985	1199	1446	1534	1596	1688	1708	1623	1548	1393	1075	926
60	45	990	1183	1397	1449	1480	1551	1575	1521	1484	1367	1076	936
70	45	971	1141	1321	1340	1345	1396	1423	1397	1391	1312	1051	922
80	45	928	1074	1221	1213	1196	1230	1259	1255	1275	1228	1001	886
90	45	866	987	1102	1075	1044	1063	1092	1104	1143	1123	931	831

TUCSON AZ 32.07

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	
HORIZONTAL RAD.	1152	1480	2010	2452	2725	2610	2312	2172	2139	1646	1307	1093	(BTU/DAY-FT2)
AVE. TEMP.	50.0	51.8	57.2	64.4	71.6	80.6	86.0	82.4	78.8	68.0	57.2	50.0	(F)
DEGREE-DAYS	471.	344.	242.	75.	6.	0.	0.	0.	0.	25.	231.	406.	(F-DAYS)

AVERAGE DAILY RADIATION ON TILTED SURFACES (BTU/DAY-FT2)

SLOPE	AZIMUTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
20	0	1605	1881	2322	2546	2611	2421	2182	2171	2364	2030	1800	1576
30	0	1773	2013	2392	2500	2467	2254	2052	2098	2388	2147	1980	1760
40	0	1895	2093	2399	2392	2269	2043	1882	1978	2352	2210	2108	1898
50	0	1968	2120	2346	2226	2024	1796	1677	1817	2256	2215	2180	1985
60	0	1988	2092	2232	2008	1740	1521	1446	1617	2105	2163	2193	2020
70	0	1956	2010	2062	1745	1428	1230	1196	1388	1901	2056	2149	2000
80	0	1872	1876	1841	1445	1102	938	940	1137	1652	1896	2047	1927
90	0	1743	1699	1580	1127	790	676	702	881	1371	1694	1894	1805
20	15	1588	1865	2311	2547	2618	2429	2188	2174	2358	2014	1781	1558
30	15	1748	1989	2377	2506	2481	2269	2064	2105	2383	2125	1952	1734
40	15	1863	2063	2383	2406	2294	2068	1901	1993	2349	2181	2072	1864
50	15	1929	2084	2328	2251	2061	1831	1705	1839	2259	2181	2137	1945
60	15	1944	2051	2216	2046	1790	1567	1483	1650	2114	2125	2145	1974
70	15	1908	1966	2049	1799	1493	1287	1243	1433	1919	2015	2097	1950
80	15	1822	1830	1833	1518	1183	1007	998	1196	1683	1854	1992	1874
90	15	1692	1653	1581	1224	887	751	768	956	1419	1651	1839	1752
20	30	1537	1821	2280	2542	2635	2453	2205	2177	2337	1974	1726	1505
30	30	1675	1928	2338	2509	2520	2313	2097	2119	2361	2069	1873	1656
40	30	1769	1987	2341	2424	2358	2137	1954	2022	2331	2113	1971	1764
50	30	1818	1996	2289	2288	2156	1928	1781	1887	2249	2106	2018	1826
60	30	1819	1956	2184	2108	1920	1695	1584	1720	2117	2047	2012	1839
70	30	1773	1868	2029	1889	1660	1446	1372	1528	1942	1938	1953	1804
80	30	1681	1734	1832	1643	1389	1196	1153	1319	1729	1784	1844	1722
90	30	1550	1565	1605	1387	1129	963	946	1108	1495	1595	1691	1597
20	45	1463	1756	2231	2527	2653	2482	2224	2176	2301	1912	1646	1425
30	45	1569	1839	2276	2499	2559	2367	2134	2127	2319	1986	1760	1542
40	45	1638	1881	2274	2427	2425	2220	2014	2044	2291	2017	1832	1621
50	45	1667	1879	2224	2311	2255	2043	1866	1928	2217	2002	1860	1660
60	45	1656	1835	2128	2155	2054	1844	1697	1783	2101	1943	1842	1658
70	45	1604	1750	1990	1966	1831	1630	1511	1615	1946	1841	1779	1614
80	45	1514	1627	1815	1751	1596	1409	1318	1431	1760	1702	1674	1531
90	45	1392	1475	1617	1527	1364	1198	1131	1243	1555	1535	1534	1414

TWIN FALLS ID 40.35

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	
HORIZONTAL RAD.	600	884	1308	1703	2035	2182	2219	1990	1592	1054	648	482	(BTU/DAY-FT2)
AVE. TEMP.	28.4	32.0	37.4	46.4	55.4	62.6	71.6	68.0	59.0	48.2	37.4	32.0	(F)
DEGREE-DAYS	1159.	882.	818.	522.	289.	131.	0.	22.	178.	468.	795.	1060.	(F-DAYS)

AVERAGE DAILY RADIATION ON TILTED SURFACES (BTU/DAY-FT2)

SLOPE	AZIMUTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
20	0	862	1153	1540	1810	2017	2097	2162	2058	1811	1336	902	698
30	0	964	1248	1603	1804	1948	1996	2070	2024	1857	1432	998	783
40	0	1042	1313	1628	1757	1840	1859	1939	1946	1858	1492	1071	848
50	0	1094	1346	1614	1672	1696	1688	1770	1826	1815	1516	1116	893
60	0	1118	1345	1561	1550	1520	1490	1570	1667	1728	1502	1134	916
70	0	1114	1311	1472	1398	1320	1271	1346	1475	1601	1451	1123	915
80	0	1081	1245	1348	1214	1101	1041	1107	1256	1436	1365	1084	891
90	0	1022	1151	1197	1016	880	816	870	1024	1244	1248	1019	846
20	15	852	1142	1532	1809	2019	2101	2165	2058	1805	1325	892	690
30	15	950	1233	1592	1805	1954	2005	2078	2028	1850	1415	984	771
40	15	1024	1293	1615	1762	1850	1872	1952	1955	1853	1471	1053	833
50	15	1072	1322	1599	1681	1712	1708	1790	1841	1812	1491	1095	875
60	15	1093	1319	1546	1566	1544	1516	1597	1689	1728	1474	1109	895
70	15	1087	1283	1458	1419	1350	1304	1381	1506	1606	1421	1096	893
80	15	1053	1215	1336	1246	1140	1081	1150	1298	1448	1333	1056	868
90	15	994	1121	1188	1058	926	862	920	1075	1264	1216	991	823
20	30	824	1114	1509	1801	2025	2112	2175	2056	1785	1296	865	667
30	30	908	1191	1562	1800	1969	2028	2100	2033	1827	1374	944	737
40	30	970	1241	1581	1763	1879	1911	1989	1971	1829	1420	1001	789
50	30	1008	1262	1565	1692	1757	1763	1845	1871	1791	1433	1033	823
60	30	1021	1252	1513	1588	1607	1590	1673	1737	1714	1411	1040	836
70	30	1008	1212	1429	1455	1433	1397	1478	1573	1601	1357	1021	828
80	30	971	1143	1315	1298	1243	1193	1268	1385	1456	1271	977	801
90	30	910	1061	1177	1128	1049	991	1059	1187	1288	1159	912	754
20	45	781	1071	1473	1784	2027	2126	2184	2046	1751	1251	823	631
30	45	847	1132	1515	1783	1982	2056	2123	2027	1785	1314	885	685
40	45	893	1169	1528	1750	1906	1957	2030	1974	1784	1348	928	724
50	45	918	1180	1509	1687	1801	1831	1907	1888	1749	1353	948	746
60	45	922	1165	1460	1595	1669	1681	1758	1771	1678	1328	947	751
70	45	903	1124	1382	1476	1516	1512	1587	1626	1576	1274	924	737
80	45	864	1068	1278	1336	1347	1330	1401	1460	1446	1193	880	707
90	45	806	973	1154	1184	1173	1148	1212	1283	1296	1091	817	662

WASHINGTON	DC 38.51												
	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	
HORIZONTAL RAD.	585	846	1178	1484	1646	2054	1947	1701	1351	1034	777	541	(BTU/DAY-FT2)
AVE. TEMP.	35.6	37.4	44.6	55.4	64.4	73.4	77.0	75.2	69.8	59.0	48.2	37.4	(F)
DEGREE-DAYS	871.	762.	626.	288.	74.	0.	0.	0.	33.	217.	519.	834.	(F-DAYS)

AVERAGE DAILY RADIATION ON TILTED SURFACES (BTU/DAY-FT2)

SLOPE	AZIMUTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
20	0	802	1069	1352	1553	1618	1963	1886	1736	1498	1281	1081	768
30	0	884	1144	1394	1539	1559	1864	1802	1700	1521	1360	1195	857
40	0	945	1193	1404	1492	1470	1731	1684	1628	1510	1407	1280	924
50	0	983	1213	1382	1413	1354	1567	1536	1522	1465	1421	1333	969
60	0	997	1205	1329	1306	1216	1379	1362	1386	1387	1400	1352	989
70	0	987	1167	1246	1172	1059	1173	1166	1225	1278	1345	1336	985
80	0	952	1102	1135	1018	890	959	964	1044	1142	1258	1287	956
90	0	895	1014	1004	852	720	752	762	853	987	1145	1206	904
20	15	794	1060	1345	1553	1620	1967	1889	1737	1494	1271	1069	760
30	15	872	1131	1385	1540	1564	1872	1809	1703	1517	1346	1178	844
40	15	930	1177	1394	1496	1478	1744	1696	1635	1507	1389	1259	908
50	15	965	1194	1372	1421	1367	1586	1553	1534	1463	1399	1307	950
60	15	976	1182	1318	1319	1233	1405	1385	1404	1388	1375	1323	968
70	15	964	1143	1236	1192	1082	1205	1198	1250	1283	1318	1305	961
80	15	928	1077	1127	1045	919	997	1000	1077	1152	1231	1254	931
90	15	871	988	998	887	755	796	805	895	1003	1117	1173	880
20	30	770	1036	1328	1547	1625	1979	1898	1736	1480	1245	1036	735
30	30	837	1097	1363	1537	1576	1895	1828	1708	1501	1310	1130	808
40	30	885	1133	1369	1498	1500	1781	1728	1649	1491	1345	1196	861
50	30	911	1143	1346	1431	1401	1640	1600	1559	1460	1349	1233	894
60	30	916	1127	1294	1338	1280	1475	1449	1443	1380	1321	1240	904
70	30	898	1085	1216	1223	1143	1294	1280	1304	1283	1264	1215	893
80	30	859	1018	1113	1089	994	1104	1100	1148	1162	1178	1160	860
90	30	801	931	993	946	845	918	922	985	1025	1069	1078	807
20	45	734	1000	1300	1536	1628	1992	1907	1730	1456	1205	986	697
30	45	786	1047	1327	1526	1586	1923	1848	1706	1472	1256	1060	753
40	45	821	1073	1329	1491	1521	1826	1763	1654	1461	1281	1110	793
50	45	837	1076	1304	1431	1433	1704	1653	1576	1422	1279	1133	813
60	45	834	1056	1255	1347	1327	1561	1521	1473	1357	1249	1130	815
70	45	812	1013	1182	1243	1204	1402	1372	1349	1269	1193	1100	798
80	45	772	949	1088	1123	1071	1232	1211	1209	1160	1113	1045	763
90	45	716	869	980	993	935	1063	1050	1062	1037	1014	968	711

YUMA AZ 32.40

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	
HORIZONTAL RAD.	1124	1478	1905	2333	2591	2599	2403	2164	1953	1629	1216	999	(BTU/DAY-FT2)
AVE. TEMP.	53.6	59.0	62.6	69.8	77.0	84.2	93.2	91.4	86.0	75.2	62.6	55.4	(F)
DEGREE-DAYS	308.	192.	98.	24.	0.	0.	0.	0.	0.	0.	108.	276.	(F-DAYS)

AVERAGE DAILY RADIATION ON TILTED SURFACES (BTU/DAY-FT2)

SLOPE	AZIMUTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
20	0	1567	1885	2192	2420	2489	2414	2269	2165	2146	2013	1658	1421
30	0	1731	2020	2255	2377	2356	2249	2134	2094	2164	2131	1819	1582
40	0	1851	2104	2261	2277	2174	2042	1956	1977	2130	2195	1933	1701
50	0	1923	2132	2210	2123	1947	1798	1742	1816	2043	2202	1996	1776
60	0	1944	2106	2104	1919	1683	1525	1499	1619	1908	2152	2007	1805
70	0	1913	2025	1945	1674	1393	1236	1237	1391	1727	2047	1965	1785
80	0	1832	1893	1739	1394	1089	946	968	1142	1506	1890	1872	1719
90	0	1706	1716	1497	1098	797	684	718	887	1258	1690	1733	1611
20	15	1550	1869	2182	2421	2495	2422	2276	2168	2141	1998	1641	1405
30	15	1707	1997	2242	2382	2369	2265	2146	2101	2160	2109	1794	1558
40	15	1820	2073	2246	2289	2196	2066	1976	1991	2127	2166	1901	1671
50	15	1885	2096	2194	2145	1980	1832	1771	1839	2045	2168	1958	1740
60	15	1901	2065	2089	1953	1728	1570	1539	1652	1915	2114	1964	1764
70	15	1867	1981	1933	1722	1452	1293	1287	1436	1742	2006	1918	1741
80	15	1784	1846	1731	1460	1162	1014	1030	1200	1532	1847	1823	1673
90	15	1657	1668	1497	1185	884	759	788	961	1298	1647	1683	1564
20	30	1501	1825	2153	2416	2511	2445	2293	2171	2123	1957	1592	1359
30	30	1635	1934	2206	2385	2404	2308	2181	2115	2140	2053	1723	1490
40	30	1728	1995	2207	2305	2254	2133	2032	2019	2111	2098	1811	1583
50	30	1776	2007	2157	2178	2065	1927	1852	1886	2036	2092	1851	1636
60	30	1778	1968	2058	2009	1845	1696	1646	1720	1917	2035	1844	1646
70	30	1734	1881	1914	1804	1602	1449	1423	1529	1760	1929	1789	1614
80	30	1646	1748	1729	1573	1348	1200	1194	1321	1570	1777	1689	1539
90	30	1518	1578	1518	1332	1103	967	977	1111	1362	1590	1550	1428
20	45	1428	1759	2108	2402	2526	2473	2313	2170	2092	1896	1520	1288
30	45	1532	1844	2148	2375	2438	2360	2220	2122	2104	1970	1622	1390
40	45	1600	1888	2145	2307	2313	2215	2095	2040	2076	2002	1686	1459
50	45	1629	1888	2097	2197	2154	2041	1942	1925	2008	1988	1709	1491
60	45	1618	1845	2006	2051	1966	1843	1765	1782	1902	1931	1690	1487
70	45	1568	1761	1876	1872	1756	1630	1571	1615	1762	1831	1632	1447
80	45	1481	1638	1712	1670	1534	1410	1369	1431	1595	1693	1536	1371
90	45	1363	1486	1526	1458	1315	1200	1173	1244	1411	1528	1408	1267

CHURCHILL	MA	58.45											
	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	
HORIZONTAL RAD.	239	552	1123	1638	1878	1951	1859	1399	828	423	220	128	(BTU/DAY-FT2)
AVE. TEMP.	-16.6	-14.8	-2.2	14.0	28.4	41.0	51.8	51.8	41.0	30.2	12.2	-5.8	(F)
DEGREE-DAYS	2558.	2277.	2130.	1569.	1153.	675.	360.	375.	681.	1082.	1620.	2248.	(F-DAYS)

AVERAGE DAILY RADIATION ON TILTED SURFACES (BTU/DAY-FT2)

SLOPE	AZIMUTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
20	0	669	1056	1654	1941	1973	1963	1904	1540	1026	639	482	376
30	0	859	1269	1858	2028	1972	1929	1884	1567	1092	725	596	487
40	0	1025	1447	2012	2066	1931	1861	1829	1560	1132	794	693	583
50	0	1161	1585	2112	2054	1851	1760	1739	1520	1146	843	772	663
60	0	1264	1679	2154	1992	1734	1627	1617	1448	1133	870	829	724
70	0	1330	1725	2137	1882	1583	1466	1466	1345	1093	875	863	764
80	0	1357	1722	2063	1727	1403	1283	1290	1216	1028	858	872	782
90	0	1345	1672	1935	1536	1205	1088	1101	1067	942	820	858	778
20	15	654	1038	1636	1936	1972	1964	1904	1538	1022	631	473	368
30	15	837	1243	1833	2024	1972	1931	1885	1565	1086	713	582	474
40	15	997	1413	1981	2064	1934	1866	1833	1561	1127	779	676	567
50	15	1127	1545	2076	2056	1858	1768	1746	1523	1141	825	751	644
60	15	1226	1633	2115	1999	1745	1638	1627	1454	1129	850	805	702
70	15	1288	1675	2097	1894	1598	1481	1480	1355	1090	853	837	741
80	15	1313	1670	2022	1745	1422	1301	1308	1229	1027	835	846	757
90	15	1301	1620	1895	1561	1228	1110	1122	1083	943	796	831	753
20	30	610	985	1589	1918	1969	1965	1903	1531	1005	608	446	342
30	30	773	1166	1769	2006	1973	1937	1889	1561	1066	682	543	437
40	30	914	1315	1905	2051	1943	1879	1844	1561	1103	738	625	519
50	30	1029	1428	1991	2051	1876	1790	1766	1531	1117	777	690	587
60	30	1114	1501	2025	2004	1774	1669	1657	1470	1105	797	737	638
70	30	1167	1532	2005	1911	1639	1522	1519	1380	1069	796	763	671
80	30	1187	1521	1933	1776	1475	1352	1357	1264	1009	776	768	685
90	30	1172	1468	1813	1607	1292	1170	1181	1129	930	737	752	679
20	45	540	909	1515	1880	1961	1965	1901	1514	978	576	403	302
30	45	670	1057	1670	1962	1972	1945	1893	1544	1030	637	481	378
40	45	782	1178	1787	2007	1952	1898	1858	1548	1063	683	546	444
50	45	872	1268	1860	2012	1898	1822	1794	1525	1074	713	596	497
60	45	937	1323	1888	1973	1812	1716	1699	1472	1062	726	630	536
70	45	975	1343	1867	1893	1693	1584	1577	1393	1028	722	648	560
80	45	985	1327	1801	1773	1547	1429	1431	1289	973	701	647	569
90	45	968	1275	1692	1621	1381	1261	1269	1166	900	664	630	561

EDMONTON	AT	53.34											
	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	
HORIZONTAL RAD.	327	648	1148	1520	1874	1889	1936	1506	1097	692	408	243	(BTU/DAY-FT2)
AVE. TEMP.	6.8	12.2	23.0	39.2	51.8	57.2	60.8	59.0	50.0	41.0	24.8	14.0	(F)
DEGREE-DAYS	1810.	1520.	1330.	765.	400.	222.	74.	180.	411.	738.	1215.	1603.	(F-DAYS)

AVERAGE DAILY RADIATION ON TILTED SURFACES (BTU/DAY-FT2)

SLOPE	AZIMUTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
20	0	657	1050	1540	1723	1939	1881	1962	1627	1336	1017	775	518
30	0	799	1213	1680	1768	1918	1834	1925	1639	1410	1144	931	638
40	0	919	1345	1778	1773	1860	1753	1852	1616	1451	1242	1062	740
50	0	1014	1440	1829	1736	1764	1642	1743	1559	1457	1309	1163	822
60	0	1081	1497	1834	1660	1634	1501	1602	1469	1428	1341	1233	881
70	0	1117	1513	1790	1546	1473	1337	1433	1349	1365	1338	1268	915
80	0	1123	1488	1700	1398	1287	1154	1242	1202	1269	1300	1268	924
90	0	1097	1425	1570	1225	1086	964	1041	1038	1147	1230	1234	908
20	15	646	1035	1527	1720	1938	1882	1962	1625	1330	1005	762	509
30	15	782	1192	1662	1766	1920	1837	1928	1638	1403	1127	912	624
40	15	897	1317	1755	1773	1865	1759	1857	1618	1444	1220	1037	722
50	15	988	1407	1804	1740	1773	1651	1753	1564	1451	1281	1134	800
60	15	1051	1460	1806	1668	1647	1515	1616	1478	1423	1310	1199	856
70	15	1085	1473	1761	1559	1491	1354	1452	1362	1362	1304	1232	889
80	15	1089	1446	1672	1417	1309	1175	1265	1220	1270	1265	1230	896
90	15	1063	1382	1543	1250	1114	989	1068	1060	1151	1195	1195	879
20	30	611	993	1491	1706	1937	1885	1963	1619	1310	972	724	480
30	30	732	1131	1614	1753	1925	1846	1935	1635	1378	1079	855	582
40	30	832	1239	1699	1764	1878	1776	1874	1621	1416	1160	965	668
50	30	911	1315	1741	1738	1797	1678	1780	1575	1422	1212	1048	736
60	30	964	1356	1741	1675	1683	1552	1655	1498	1397	1233	1102	784
70	30	990	1361	1697	1577	1540	1402	1503	1393	1340	1222	1126	810
80	30	990	1329	1611	1447	1372	1234	1329	1263	1253	1181	1119	814
90	30	962	1264	1490	1294	1190	1058	1144	1116	1143	1111	1083	796
20	45	558	931	1435	1679	1931	1888	1963	1603	1276	923	665	435
30	45	653	1044	1539	1722	1925	1857	1943	1620	1334	1011	770	516
40	45	732	1131	1610	1733	1889	1800	1894	1610	1366	1077	856	583
50	45	792	1190	1645	1712	1822	1716	1815	1571	1371	1117	919	635
60	45	830	1219	1641	1657	1724	1606	1707	1504	1346	1130	958	670
70	45	846	1216	1599	1570	1598	1473	1573	1411	1293	1116	971	686
80	45	839	1183	1520	1453	1448	1321	1417	1294	1214	1075	959	684
90	45	810	1121	1410	1315	1283	1159	1248	1161	1114	1010	921	664

KAPUSKASING ONT 49.25

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	
HORIZONTAL RAD.	405	699	1141	1362	1509	1767	1767	1473	994	589	294	294	(BTU/DAY-FT2)
AVE. TEMP.	-0.4	3.2	15.8	32.0	44.6	57.2	60.8	59.0	50.0	39.2	24.8	6.8	(F)
DEGREE-DAYS	2037.	1735.	1562.	978.	580.	222.	74.	171.	405.	756.	1245.	1807.	(F-DAYS)

AVERAGE DAILY RADIATION ON TILTED SURFACES (BTU/DAY-FT2)

SLOPE	AZIMUTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
20	0	698	1029	1444	1494	1531	1742	1767	1561	1152	768	420	514
30	0	821	1158	1545	1512	1502	1687	1721	1558	1194	833	470	607
40	0	922	1257	1609	1498	1443	1602	1643	1523	1210	879	509	684
50	0	998	1324	1632	1451	1359	1489	1535	1456	1198	904	536	743
60	0	1048	1357	1614	1373	1249	1352	1400	1360	1159	908	550	783
70	0	1070	1354	1557	1265	1119	1194	1242	1237	1094	890	551	801
80	0	1063	1316	1461	1133	973	1021	1067	1091	1006	851	539	798
90	0	1028	1245	1332	982	819	845	886	931	899	794	515	775
20	15	688	1017	1434	1492	1532	1744	1768	1560	1148	761	415	506
30	15	805	1140	1531	1512	1504	1691	1724	1559	1190	823	463	595
40	15	902	1234	1591	1499	1448	1609	1650	1526	1205	866	500	669
50	15	975	1297	1612	1455	1366	1499	1545	1462	1194	889	526	725
60	15	1022	1326	1593	1381	1260	1365	1414	1370	1156	891	539	763
70	15	1041	1320	1535	1278	1133	1211	1260	1251	1094	871	539	779
80	15	1032	1281	1440	1150	991	1043	1090	1110	1008	831	526	775
90	15	997	1210	1313	1005	840	870	913	956	904	774	501	751
20	30	657	982	1406	1482	1532	1748	1771	1555	1134	743	402	483
30	30	760	1090	1493	1503	1509	1701	1733	1557	1172	797	443	561
40	30	844	1170	1547	1494	1460	1628	1667	1531	1186	833	475	625
50	30	905	1221	1564	1456	1386	1528	1573	1475	1175	850	495	673
60	30	943	1242	1544	1389	1290	1404	1453	1392	1140	848	504	704
70	30	956	1230	1488	1295	1173	1261	1311	1285	1081	827	501	716
80	30	943	1187	1397	1178	1041	1104	1153	1156	1000	786	486	709
90	30	906	1116	1278	1044	901	941	987	1014	903	730	461	684
20	45	609	931	1361	1463	1530	1753	1772	1543	1110	715	381	447
30	45	691	1018	1434	1482	1511	1715	1742	1546	1142	758	414	509
40	45	756	1082	1478	1474	1469	1652	1687	1524	1152	786	437	558
50	45	801	1120	1489	1440	1405	1566	1606	1475	1141	798	451	593
60	45	826	1131	1468	1380	1320	1458	1501	1402	1107	792	455	614
70	45	830	1115	1415	1296	1216	1330	1376	1305	1052	769	449	618
80	45	813	1072	1331	1189	1096	1188	1233	1189	978	729	433	607
90	45	775	1005	1223	1068	968	1039	1082	1060	889	676	407	581

LETHBRIDGE	AT 49.38												
	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	
HORIZONTAL RAD.	441	773	1251	1546	1914	2135	2246	1914	1362	883	515	331	(BTU/DAY-FT2)
AVE. TEMP.	17.6	19.4	28.4	41.0	51.8	57.2	62.6	60.8	53.6	44.6	32.0	24.8	(F)
DEGREE-DAYS	1497.	1291.	1159.	696.	403.	213.	56.	112.	318.	611.	1011.	1277.	(F-DAYS)

AVERAGE DAILY RADIATION ON TILTED SURFACES (BTU/DAY-FT2)

SLOPE	AZIMUTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
20	0	786	1166	1609	1713	1956	2109	2256	2060	1639	1251	874	606
30	0	930	1321	1730	1740	1922	2042	2199	2067	1720	1391	1022	722
40	0	1049	1441	1807	1728	1849	1938	2099	2027	1760	1495	1143	820
50	0	1141	1524	1839	1677	1739	1798	1958	1942	1755	1561	1234	895
60	0	1201	1566	1823	1589	1596	1626	1779	1814	1708	1585	1292	947
70	0	1228	1567	1762	1465	1424	1428	1569	1648	1620	1569	1314	972
80	0	1222	1526	1655	1310	1229	1212	1335	1448	1492	1511	1300	971
90	0	1184	1446	1511	1134	1022	990	1092	1226	1333	1417	1253	944
20	15	773	1151	1596	1710	1956	2111	2257	2058	1632	1237	861	596
30	15	912	1299	1713	1739	1924	2047	2204	2067	1712	1371	1003	708
40	15	1026	1414	1787	1730	1855	1947	2108	2032	1751	1469	1119	801
50	15	1113	1491	1816	1683	1750	1811	1972	1952	1749	1529	1205	873
60	15	1170	1529	1799	1599	1612	1645	1800	1830	1704	1550	1259	922
70	15	1194	1527	1737	1480	1445	1452	1596	1670	1619	1531	1278	945
80	15	1187	1484	1631	1332	1255	1241	1368	1477	1495	1471	1263	943
90	15	1147	1403	1489	1162	1054	1024	1131	1263	1341	1376	1215	915
20	30	737	1110	1563	1699	1957	2117	2261	2051	1608	1200	823	567
30	30	859	1240	1669	1729	1932	2061	2217	2065	1682	1317	947	666
40	30	958	1338	1735	1724	1873	1972	2134	2039	1719	1402	1047	747
50	30	1032	1402	1759	1683	1780	1850	2013	1971	1717	1452	1120	809
60	30	1078	1429	1741	1609	1655	1698	1857	1864	1676	1465	1162	848
70	30	1095	1419	1681	1502	1503	1520	1671	1721	1596	1441	1173	866
80	30	1082	1372	1581	1366	1329	1324	1461	1546	1482	1380	1153	859
90	30	1041	1292	1447	1211	1144	1121	1241	1352	1339	1287	1104	831
20	45	681	1049	1511	1675	1953	2123	2263	2032	1568	1144	765	522
30	45	778	1155	1599	1702	1935	2079	2230	2048	1631	1240	865	600
40	45	855	1233	1654	1698	1887	2006	2164	2028	1662	1309	943	663
50	45	910	1281	1672	1663	1808	1902	2063	1971	1658	1346	997	709
60	45	941	1298	1652	1597	1700	1770	1929	1879	1620	1351	1026	736
70	45	948	1282	1595	1502	1566	1614	1766	1753	1547	1324	1028	744
80	45	930	1235	1504	1380	1411	1438	1580	1598	1444	1266	1003	733
90	45	888	1159	1383	1240	1243	1253	1382	1423	1315	1180	954	703

MONCTON	NB	46.07											
	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	
HORIZONTAL RAD.	368	662	1067	1399	1620	1657	1730	1509	1141	773	405	331	(BTU/DAY-FT2)
AVE. TEMP.	17.6	17.6	26.6	37.4	48.2	59.0	62.6	60.8	55.4	44.6	33.8	23.0	(F)
DEGREE-DAYS	1482.	1336.	1194.	789.	468.	171.	62.	105.	276.	611.	891.	1342.	(F-DAYS)

AVERAGE DAILY RADIATION ON TILTED SURFACES (BTU/DAY-FT2)

SLOPE	AZIMUTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
20	0	545	900	1293	1512	1631	1620	1714	1581	1311	1009	576	518
30	0	616	989	1362	1520	1591	1561	1661	1569	1352	1093	643	595
40	0	672	1054	1399	1496	1521	1475	1577	1524	1363	1151	695	657
50	0	712	1093	1403	1440	1423	1364	1464	1448	1343	1181	730	703
60	0	734	1105	1373	1352	1299	1232	1327	1343	1292	1182	747	730
70	0	737	1090	1311	1237	1153	1082	1169	1212	1212	1155	746	739
80	0	723	1048	1218	1098	992	920	996	1060	1105	1099	727	729
90	0	690	982	1101	942	823	757	819	895	979	1019	690	701
20	15	539	891	1285	1510	1631	1622	1716	1580	1306	999	569	512
30	15	607	976	1351	1520	1594	1565	1665	1570	1347	1079	634	585
40	15	660	1037	1386	1498	1527	1482	1584	1528	1358	1134	683	644
50	15	697	1073	1388	1445	1432	1375	1475	1456	1339	1160	716	687
60	15	717	1083	1358	1362	1312	1246	1342	1355	1290	1159	731	713
70	15	720	1065	1296	1252	1171	1099	1188	1229	1212	1130	729	720
80	15	704	1022	1204	1118	1014	942	1020	1082	1110	1073	708	709
90	15	671	956	1088	969	850	782	847	923	987	993	672	681
20	30	519	866	1263	1502	1633	1627	1720	1577	1291	975	551	492
30	30	579	939	1323	1513	1602	1577	1675	1570	1328	1045	606	556
40	30	624	991	1353	1495	1543	1502	1604	1535	1338	1091	648	607
50	30	654	1019	1353	1448	1458	1403	1505	1471	1320	1111	674	642
60	30	669	1022	1322	1373	1349	1285	1384	1380	1274	1105	684	662
70	30	667	1001	1262	1272	1220	1149	1242	1266	1201	1073	677	665
80	30	649	955	1175	1150	1076	1002	1087	1132	1105	1016	655	652
90	30	615	889	1066	1013	924	852	926	987	991	938	617	622
20	45	490	828	1229	1485	1632	1632	1723	1566	1265	938	523	461
30	45	537	887	1278	1494	1606	1590	1686	1561	1296	995	567	511
40	45	571	927	1301	1478	1556	1526	1625	1531	1302	1030	598	549
50	45	592	945	1297	1436	1482	1441	1541	1475	1284	1043	615	575
60	45	599	943	1266	1369	1386	1336	1434	1394	1241	1032	619	586
70	45	592	919	1210	1278	1271	1215	1308	1292	1174	1000	609	583
80	45	572	874	1130	1167	1140	1081	1168	1171	1086	945	584	567
90	45	538	812	1030	1043	1003	944	1022	1039	983	873	548	537

MONTREAL QU 45.30

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	
HORIZONTAL RAD.	405	736	1178	1473	1730	1804	1878	1620	1141	736	368	294	(BTU/DAY-FT2)
AVE. TEMP.	15.8	19.4	28.4	41.0	53.6	62.6	64.4	62.6	59.0	46.4	33.8	21.2	(F)
DEGREE-DAYS	1566.	1381.	1175.	684.	316.	69.	9.	43.	165.	521.	882.	1392.	(F-DAYS)

AVERAGE DAILY RADIATION ON TILTED SURFACES (BTU/DAY-FT2)

SLOPE	AZIMUTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
20	0	601	1007	1433	1591	1740	1761	1858	1697	1303	941	498	429
30	0	680	1108	1512	1599	1696	1694	1797	1683	1341	1013	548	484
40	0	742	1182	1554	1572	1619	1597	1703	1633	1349	1061	585	526
50	0	786	1227	1558	1510	1511	1473	1577	1549	1327	1084	609	557
60	0	810	1241	1525	1417	1376	1325	1424	1434	1274	1081	619	573
70	0	814	1223	1455	1293	1217	1157	1248	1291	1193	1052	614	576
80	0	797	1175	1350	1145	1041	977	1057	1124	1086	999	595	565
90	0	760	1100	1217	979	859	797	862	945	959	923	563	540
20	15	594	996	1424	1589	1741	1763	1859	1696	1299	933	493	424
30	15	669	1093	1499	1598	1699	1699	1802	1684	1337	1001	541	476
40	15	729	1163	1539	1574	1626	1606	1711	1638	1345	1046	576	517
50	15	770	1204	1542	1517	1522	1485	1590	1558	1323	1066	598	545
60	15	792	1214	1508	1427	1391	1341	1442	1448	1272	1061	607	561
70	15	794	1195	1438	1310	1238	1178	1271	1310	1194	1030	601	562
80	15	776	1146	1334	1167	1067	1003	1085	1149	1090	976	581	550
90	15	739	1070	1204	1008	890	827	895	976	968	900	548	526
20	30	573	968	1400	1580	1743	1769	1864	1692	1284	912	479	410
30	30	638	1051	1467	1591	1708	1712	1815	1685	1319	971	520	455
40	30	689	1110	1502	1571	1644	1629	1735	1646	1326	1009	549	490
50	30	722	1142	1502	1520	1551	1519	1626	1576	1305	1023	566	513
60	30	738	1146	1468	1440	1433	1387	1491	1477	1257	1014	570	524
70	30	735	1122	1401	1333	1293	1237	1335	1352	1184	981	561	522
80	30	714	1070	1303	1202	1137	1074	1164	1207	1087	926	540	508
90	30	677	995	1180	1057	974	909	988	1049	974	853	507	483
20	45	541	925	1361	1563	1742	1776	1868	1681	1259	880	457	387
30	45	592	992	1416	1572	1714	1729	1827	1675	1287	927	489	422
40	45	630	1037	1443	1554	1659	1658	1760	1642	1291	955	511	448
50	45	653	1059	1440	1509	1579	1563	1667	1581	1271	963	521	464
60	45	661	1056	1406	1437	1475	1447	1549	1494	1226	950	521	469
70	45	653	1030	1343	1340	1351	1314	1411	1383	1158	917	509	463
80	45	630	979	1253	1223	1210	1167	1257	1252	1070	865	486	447
90	45	593	909	1142	1091	1063	1016	1098	1109	967	797	454	421

OTTAWA	OT	45.27											
	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	
HORIZONTAL RAD.	530	839	1233	1484	1830	2054	2014	1727	1307	813	452	401	(BTU/DAY-FT2)
AVE. TEMP.	14.0	14.0	26.6	41.0	53.6	60.8	62.6	60.8	57.2	46.4	32.0	17.6	(F)
DEGREE-DAYS	1624.	1441.	1231.	708.	341.	90.	25.	81.	222.	567.	936.	1469.	(F-DAYS)

AVERAGE DAILY RADIATION ON TILTED SURFACES (BTU/DAY-FT2)

SLOPE	AZIMUTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
20	0	846	1176	1509	1603	1842	2005	1994	1813	1512	1058	649	645
30	0	974	1304	1594	1611	1795	1928	1928	1800	1564	1145	727	746
40	0	1078	1398	1641	1584	1714	1815	1826	1748	1578	1204	786	827
50	0	1153	1457	1647	1522	1599	1670	1690	1658	1556	1234	827	888
60	0	1198	1478	1613	1428	1454	1496	1523	1534	1497	1234	847	925
70	0	1211	1461	1540	1303	1285	1300	1332	1380	1403	1203	846	937
80	0	1191	1407	1430	1153	1096	1090	1123	1200	1277	1144	823	925
90	0	1142	1319	1289	986	901	879	911	1005	1127	1059	782	890
20	15	834	1163	1499	1601	1843	2008	1996	1813	1507	1048	642	637
30	15	958	1285	1581	1611	1799	1934	1933	1801	1557	1131	716	733
40	15	1056	1374	1625	1587	1721	1825	1836	1753	1572	1186	772	811
50	15	1127	1428	1629	1529	1610	1685	1704	1668	1551	1213	810	868
60	15	1169	1446	1595	1439	1471	1517	1543	1549	1495	1210	828	902
70	15	1179	1426	1522	1320	1307	1326	1358	1401	1404	1177	825	913
80	15	1158	1370	1412	1176	1124	1121	1155	1227	1283	1117	802	900
90	15	1108	1281	1274	1015	935	915	948	1040	1138	1031	760	864
20	30	800	1128	1473	1593	1845	2015	2001	1809	1488	1023	621	610
30	30	908	1234	1546	1604	1809	1950	1948	1802	1535	1095	685	695
40	30	993	1309	1585	1584	1741	1854	1862	1762	1549	1142	732	762
50	30	1051	1352	1587	1533	1643	1727	1744	1687	1529	1162	762	809
60	30	1083	1361	1552	1451	1517	1574	1598	1582	1476	1154	774	836
70	30	1086	1336	1482	1343	1368	1399	1429	1448	1392	1119	767	841
80	30	1061	1277	1379	1212	1201	1210	1243	1291	1279	1058	741	825
90	30	1009	1189	1249	1065	1027	1018	1052	1121	1145	975	698	788
20	45	749	1075	1431	1575	1844	2024	2005	1796	1457	985	589	570
30	45	834	1160	1491	1584	1815	1971	1962	1792	1496	1043	639	636
40	45	899	1219	1521	1566	1757	1890	1890	1757	1506	1079	675	687
50	45	942	1250	1519	1521	1673	1781	1790	1693	1486	1091	696	721
60	45	961	1250	1485	1448	1563	1648	1663	1600	1437	1079	700	737
70	45	955	1222	1419	1351	1431	1494	1514	1482	1360	1043	688	735
80	45	928	1164	1325	1232	1282	1325	1348	1341	1258	985	661	715
90	45	875	1082	1208	1100	1124	1150	1175	1188	1137	909	619	677

ST. JOHNS	NF	47.31										
	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	
HORIZONTAL RAD.	294	552	883	1178	1473	1583	1620	1251	1031	625	294	257	(BTU/DAY-FT2)
AVE. TEMP.	24.8	24.8	28.4	33.8	41.0	50.0	59.0	59.0	51.8	42.8	35.6	30.2	(F)
DEGREE-DAYS	1262.	1170.	1187.	927.	710.	432.	186.	180.	342.	651.	831.	1113.	(F-DAYS)

AVERAGE DAILY RADIATION ON TILTED SURFACES (BTU/DAY-FT2)

SLOPE	AZIMUTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
20	0	424	739	1056	1266	1485	1553	1609	1305	1182	800	393	389
30	0	475	809	1108	1272	1451	1499	1562	1295	1219	861	431	443
40	0	516	859	1136	1251	1390	1420	1487	1259	1230	903	460	486
50	0	544	890	1137	1204	1304	1317	1385	1198	1212	924	478	517
60	0	559	899	1112	1134	1195	1194	1260	1114	1168	923	486	536
70	0	561	886	1062	1040	1067	1053	1115	1011	1098	901	482	541
80	0	549	852	989	928	923	901	956	890	1005	858	467	533
90	0	525	799	896	803	774	747	793	760	893	796	443	512
20	15	419	732	1050	1264	1485	1554	1610	1305	1178	793	390	384
30	15	468	798	1100	1271	1453	1503	1565	1295	1215	852	426	436
40	15	507	846	1126	1252	1395	1426	1493	1261	1225	891	453	477
50	15	533	874	1126	1208	1312	1326	1394	1203	1209	909	470	506
60	15	547	881	1100	1140	1206	1206	1273	1122	1166	906	476	524
70	15	548	866	1050	1051	1081	1069	1132	1022	1098	882	472	528
80	15	535	832	977	943	942	920	977	906	1008	838	456	519
90	15	511	778	885	822	796	769	818	779	899	776	432	498
20	30	405	712	1033	1258	1486	1558	1613	1302	1164	775	379	370
30	30	448	769	1078	1265	1459	1512	1574	1295	1198	826	410	415
40	30	480	809	1100	1249	1408	1443	1509	1265	1207	858	432	450
50	30	502	831	1098	1210	1333	1352	1420	1213	1191	872	445	475
60	30	512	832	1072	1148	1236	1240	1309	1140	1151	865	448	488
70	30	509	815	1024	1065	1121	1113	1179	1048	1087	840	442	489
80	30	495	778	954	965	992	974	1035	941	1002	795	425	479
90	30	470	725	867	854	857	831	886	825	901	735	400	457
20	45	383	682	1007	1244	1485	1563	1616	1294	1141	748	362	348
30	45	417	728	1043	1250	1462	1525	1583	1288	1169	788	386	383
40	45	441	759	1059	1235	1418	1465	1528	1261	1175	813	403	410
50	45	456	773	1054	1200	1352	1385	1451	1215	1159	821	411	427
60	45	460	769	1028	1143	1266	1287	1352	1149	1121	811	410	434
70	45	454	749	982	1068	1163	1172	1236	1066	1061	784	401	431
80	45	438	713	917	977	1046	1045	1106	968	983	741	383	418
90	45	412	663	837	875	923	915	970	862	891	685	358	396

TORONTO OT 43.40

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	
HORIZONTAL RAD.	445	681	1075	1369	1760	1914	1940	1598	1266	824	452	349	(BTU/DAY-FT2)
AVE. TEMP.	26.6	26.6	32.0	42.8	53.6	62.6	64.4	62.6	59.0	50.0	39.2	30.2	(F)
DEGREE-DAYS	1233.	1119.	1013.	616.	298.	62.	7.	18.	151.	439.	760.	1111.	(F-DAYS)

AVERAGE DAILY RADIATION ON TILTED SURFACES (BTU/DAY-FT2)

SLOPE	AZIMUTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
20	0	642	887	1270	1459	1759	1859	1909	1659	1441	1047	619	505
30	0	719	962	1326	1458	1709	1782	1840	1639	1480	1123	682	566
40	0	779	1014	1351	1427	1626	1673	1737	1585	1486	1173	730	614
50	0	820	1041	1345	1365	1511	1535	1602	1498	1457	1195	760	648
60	0	841	1044	1307	1275	1370	1372	1438	1380	1394	1188	772	665
70	0	840	1021	1239	1159	1205	1189	1253	1237	1300	1153	765	667
80	0	819	974	1143	1022	1025	995	1052	1072	1178	1090	741	652
90	0	778	906	1025	871	839	801	849	895	1034	1004	699	622
20	15	634	879	1263	1458	1761	1861	1911	1659	1436	1038	612	499
30	15	708	950	1317	1459	1713	1788	1846	1641	1475	1110	673	558
40	15	765	998	1340	1429	1633	1683	1746	1590	1481	1157	718	604
50	15	804	1023	1332	1371	1523	1549	1616	1507	1453	1175	746	635
60	15	822	1023	1294	1285	1386	1391	1458	1395	1393	1166	756	651
70	15	820	999	1226	1174	1227	1214	1278	1257	1303	1129	748	651
80	15	798	951	1132	1042	1052	1024	1083	1098	1184	1065	723	635
90	15	757	883	1015	898	872	836	886	928	1045	978	681	605
20	30	613	857	1244	1451	1764	1869	1917	1656	1421	1015	594	482
30	30	677	918	1292	1453	1723	1804	1861	1643	1456	1078	646	533
40	30	725	958	1311	1428	1653	1710	1773	1599	1461	1116	684	572
50	30	756	976	1302	1376	1555	1589	1656	1526	1435	1129	705	597
60	30	768	971	1264	1297	1432	1445	1513	1425	1379	1116	710	608
70	30	761	943	1199	1196	1288	1282	1350	1300	1294	1077	698	605
80	30	736	894	1109	1076	1128	1108	1171	1156	1184	1013	670	587
90	30	694	826	1000	943	963	932	989	1002	1056	929	628	555
20	45	581	824	1214	1437	1764	1878	1922	1647	1393	980	567	456
30	45	631	872	1252	1438	1730	1824	1876	1636	1422	1030	608	496
40	45	667	902	1265	1415	1671	1744	1802	1598	1424	1059	635	524
50	45	687	912	1253	1368	1586	1640	1702	1533	1399	1065	649	541
60	45	692	903	1217	1297	1477	1514	1577	1444	1347	1048	648	546
70	45	680	873	1156	1206	1349	1370	1432	1333	1269	1009	633	538
80	45	653	826	1073	1097	1206	1213	1273	1203	1169	949	604	517
90	45	612	762	974	977	1056	1053	1108	1064	1053	871	563	486

VANCOUVER	BC	48.59											
	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	
HORIZONTAL RAD.	279	382	688	1263	1723	1774	2006	1465	927	589	349	206	(BTU/DAY-FT2)
AVE. TEMP.	35.6	37.4	42.8	48.2	53.6	59.0	60.8	60.8	57.2	50.0	42.8	39.2	(F)
DEGREE-DAYS	862.	723.	676.	501.	310.	156.	81.	87.	219.	456.	657.	787.	(F-DAYS)

AVERAGE DAILY RADIATION ON TILTED SURFACES (BTU/DAY-FT2)

SLOPE	AZIMUTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
20	0	416	479	803	1372	1751	1747	2007	1548	1061	759	516	303
30	0	471	514	835	1385	1716	1690	1953	1543	1095	821	582	342
40	0	514	538	851	1368	1648	1603	1861	1507	1104	863	635	373
50	0	546	550	848	1321	1549	1488	1735	1439	1089	885	672	396
60	0	564	550	827	1248	1420	1348	1577	1341	1051	887	693	409
70	0	568	538	789	1148	1267	1189	1392	1218	990	867	696	413
80	0	559	515	734	1027	1095	1015	1187	1073	908	828	682	406
90	0	536	481	666	890	913	838	975	914	810	771	651	390
20	15	411	476	798	1371	1751	1749	2008	1547	1058	753	510	299
30	15	463	508	830	1384	1719	1694	1957	1544	1090	811	573	337
40	15	505	531	844	1369	1654	1610	1869	1510	1100	850	623	367
50	15	535	541	840	1326	1558	1498	1747	1445	1086	870	658	388
60	15	551	540	819	1255	1434	1363	1594	1352	1049	870	677	400
70	15	555	528	780	1160	1285	1207	1415	1233	989	849	679	403
80	15	544	504	726	1043	1118	1037	1215	1092	910	809	664	396
90	15	521	470	659	911	941	864	1009	939	815	751	633	380
20	30	396	465	787	1363	1752	1753	2012	1543	1045	735	492	289
30	30	442	493	815	1377	1726	1705	1968	1543	1075	786	547	321
40	30	478	511	826	1365	1669	1629	1892	1515	1084	819	590	347
50	30	502	518	821	1327	1584	1528	1782	1458	1070	834	618	365
60	30	514	514	799	1263	1472	1403	1643	1374	1035	830	632	374
70	30	514	500	762	1175	1336	1258	1479	1266	979	807	630	374
80	30	502	475	709	1067	1181	1100	1295	1138	904	766	612	366
90	30	478	441	646	946	1018	936	1103	997	815	710	581	349
20	45	373	449	769	1346	1749	1758	2014	1531	1025	708	465	272
30	45	409	471	791	1359	1729	1718	1980	1532	1050	749	508	298
40	45	436	484	799	1348	1682	1655	1917	1508	1055	774	541	317
50	45	453	487	792	1313	1608	1567	1824	1459	1041	784	561	329
60	45	460	481	769	1256	1510	1457	1704	1385	1007	776	568	334
70	45	456	465	733	1176	1390	1328	1559	1288	955	752	561	331
80	45	441	440	684	1078	1251	1185	1394	1172	886	712	542	320
90	45	417	408	624	968	1102	1036	1221	1044	804	659	511	304

WINNIPEG MA 49.54

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	
HORIZONTAL RAD.	482	828	1336	1616	1878	1933	2091	1738	1174	764	438	338	(BTU/DAY-FT2)
AVE. TEMP,	1.4	5.0	19.4	37.4	51.8	59.0	62.6	62.6	53.6	42.8	24.8	8.6	(F)
DEGREE-DAYS	2008.	1719.	1465.	813.	405.	147.	38.	71.	322.	683.	1251.	1757.	(F-DAYS)

AVERAGE DAILY RADIATION ON TILTED SURFACES (BTU/DAY-FT2)

SLOPE	AZIMUTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
20	0	886	1274	1740	1798	1918	1908	2099	1861	1391	1040	715	629
30	0	1066	1451	1879	1830	1885	1849	2046	1864	1453	1147	829	753
40	0	1198	1590	1969	1819	1814	1756	1954	1827	1480	1226	922	856
50	0	1307	1686	2009	1767	1707	1631	1824	1750	1472	1274	990	936
60	0	1380	1737	1996	1675	1568	1479	1660	1635	1430	1290	1033	991
70	0	1416	1741	1932	1545	1400	1303	1468	1486	1354	1273	1048	1019
80	0	1410	1698	1817	1382	1209	1111	1254	1309	1247	1224	1035	1019
90	0	1367	1612	1660	1196	1007	915	1031	1112	1114	1147	996	992
20	15	872	1258	1726	1795	1919	1910	2100	1859	1386	1029	705	619
30	15	1035	1427	1860	1828	1888	1853	2050	1864	1446	1132	814	737
40	15	1171	1559	1946	1821	1820	1763	1962	1830	1474	1206	903	836
50	15	1274	1649	1983	1773	1718	1643	1837	1758	1467	1250	968	913
60	15	1343	1696	1968	1686	1583	1495	1679	1648	1426	1263	1007	965
70	15	1375	1696	1903	1562	1420	1324	1492	1505	1353	1244	1020	991
80	15	1368	1651	1790	1406	1235	1136	1283	1334	1249	1193	1006	989
90	15	1325	1563	1635	1226	1038	944	1066	1144	1121	1115	966	961
20	30	829	1211	1689	1783	1919	1915	2103	1853	1367	1000	675	588
30	30	973	1360	1810	1817	1895	1865	2062	1863	1423	1090	771	693
40	30	1091	1473	1888	1814	1837	1785	1985	1837	1448	1154	847	779
50	30	1179	1548	1919	1774	1746	1675	1873	1774	1442	1190	901	845
60	30	1235	1582	1903	1696	1625	1539	1729	1677	1404	1196	932	888
70	30	1258	1574	1841	1585	1476	1381	1558	1549	1335	1173	939	907
80	30	1245	1524	1733	1442	1306	1206	1365	1393	1238	1122	921	901
90	30	1200	1436	1588	1278	1124	1026	1163	1219	1119	1045	880	872
20	45	764	1142	1630	1757	1915	1920	2105	1837	1335	956	631	540
30	45	878	1263	1732	1788	1898	1880	2074	1847	1382	1030	707	623
40	45	970	1354	1796	1787	1850	1813	2011	1827	1403	1081	766	690
50	45	1036	1411	1820	1752	1774	1719	1917	1774	1395	1107	806	739
60	45	1075	1433	1803	1684	1668	1601	1793	1689	1359	1107	826	769
70	45	1086	1419	1744	1584	1537	1460	1643	1576	1296	1082	826	778
80	45	1067	1368	1646	1457	1385	1303	1471	1436	1208	1032	804	767
90	45	1021	1286	1515	1309	1221	1138	1288	1280	1100	961	763	736

Table 2-21

NORMAL TOTAL HEATING DEGREE DAYS (Base 65°)

STATE AND STATION	JULY	AUG.	SEP.	OCT.	NOV.	DEC.	JAN.	FEB.	MAR.	APR.	MAY	JUNE	ANNUAL	Design T_o °F Win.	Summ.
ALA. BIRMINGHAM	0	0	6	93	363	555	592	462	363	108	9	0	2551	19	97
HUNTSVILLE	0	0	12	127	426	663	694	557	434	138	19	0	3070	13	97
MOBILE	0	0	0	22	213	357	415	300	211	42	0	0	1560	26	95
MONTGOMERY	0	0	0	68	330	527	543	417	316	90	0	0	2291	22	98
ALASKA ANCHORAGE	245	291	516	930	1284	1572	1631	1316	1293	879	592	315	10864	-25	73
ANNETTE	242	208	327	567	738	899	949	837	843	648	490	321	7069		
BARROW	803	840	1035	1500	1971	2362	2517	2332	2468	1944	1445	957	20174	-45	58
BARTER IS.	735	775	987	1482	1944	2337	2536	2369	2477	1923	1373	924	19862		
BETHEL	319	394	612	1042	1434	1866	1903	1590	1655	1173	806	402	13196		
COLD BAY	474	425	525	772	918	1122	1153	1036	1122	951	791	591	9880		
CORDOVA	366	391	522	781	1017	1221	1299	1086	1113	864	660	444	9764		
FAIRBANKS	171	332	642	1203	1833	2254	2359	1901	1739	1068	555	222	14279	-53	82
JUNEAU	301	338	483	725	921	1135	1237	1070	1073	810	601	381	9075	- 7	75
KING SALMON	313	322	513	908	1290	1606	1600	1333	1411	966	673	408	11343		
KOTZEBUE	381	446	723	1249	1728	2127	2192	1932	2080	1554	1057	636	16105		
MCGRATH	208	338	633	1184	1791	2232	2294	1817	1758	1122	648	258	14283		
NOME	481	496	693	1094	1455	1820	1879	1666	1770	1314	930	573	14171	-32	66
SAINT PAUL	605	539	612	862	963	1197	1228	1168	1265	1098	936	726	11199		
SHEMYA	577	475	501	784	876	1042	1045	958	1011	885	837	696	9687		
YAKUTAT	338	347	474	716	936	1144	1169	1019	1042	840	632	435	9092		
ARIZ. FLAGSTAFF	46	68	201	558	867	1073	1169	991	911	651	437	180	7152	0	84
PHOENIX	0	0	0	22	234	415	474	328	217	75	0	0	1765	31	108
PRESCOTT	0	0	27	245	579	797	865	711	605	360	158	15	4362	15	96
TUCSON	0	0	0	25	231	406	471	344	242	75	6	0	1800	29	105
WINSLOW	0	0	6	245	711	1008	1054	770	601	291	96	0	4782	9	97
YUMA	0	0	0	0	148	319	363	228	130	29	0	0	1217	37	111
ARK. FORT SMITH	0	0	12	127	450	704	781	596	456	144	22	0	3292	15	101
LITTLE ROCK	0	0	9	127	465	716	756	577	434	126	9	0	3219	19	99
TEXARKANA	0	0	0	78	345	561	626	468	350	105	0	0	2533	22	99
CALIF. BAKERSFIELD	0	0	0	37	282	502	546	364	267	105	19	0	2122	31	103
BISHOP	0	0	42	248	576	797	874	666	539	306	143	36	4227		
BLUE CANYON	34	50	120	347	579	766	865	781	791	582	397	195	5507		
BURBANK	0	0	6	43	177	301	366	277	239	138	81	18	1646	36	97
EUREKA	270	257	258	329	414	499	546	470	505	438	372	285	4643	32	67
FRESNO	0	0	0	78	339	558	586	406	319	150	56	0	2492	28	101
LONG BEACH	0	0	12	40	156	288	375	297	267	168	90	18	1711	36	87
LOS ANGELES	28	22	42	78	180	291	372	302	288	219	158	81	2061	42	94
MT. SHASTA	25	34	123	406	696	902	983	784	738	525	347	159	5722		
OAKLAND	53	50	45	127	309	481	527	400	353	255	180	90	2870	35	85
POINT ARGUELLO	202	186	162	205	291	400	474	392	403	339	298	243	3595		
RED BLUFF	0	0	0	53	318	555	605	428	341	168	47	0	2515		
SACRAMENTO	0	0	12	81	363	577	614	442	360	216	102	6	2773	30	100
SANDBERG	0	0	30	202	480	691	778	661	620	426	264	57	4209		
SAN DIEGO	6	0	15	37	123	251	313	249	202	123	84	36	1439	42	86
SAN FRANCISCO	81	78	60	143	306	462	508	395	363	279	214	126	3015	42	80
SANTA CATALINA	16	0	9	50	165	279	353	308	326	249	192	105	2052		
SANTA MARIA	99	93	96	146	270	391	459	370	363	282	233	165	2967	32	85
COLO. ALAMOSA	65	99	279	639	1065	1420	1476	1162	1020	696	440	168	8529	-17	84
COLORADO SPRINGS	9	25	132	456	825	1032	1128	938	893	582	319	84	6423	- 1	90
DENVER	6	9	117	428	819	1035	1132	938	887	558	288	66	6283	- 2	92
GRAND JUNCTION	0	0	30	313	786	1113	1209	907	729	387	146	21	5641	8	96
PUEBLO	0	0	54	326	750	986	1085	871	772	429	174	15	5462	- 5	96
CONN. BRIDGEPORT	0	0	66	307	615	986	1079	966	853	510	208	27	5617	4	90
HARDFORT	0	6	99	372	711	1119	1209	1061	899	495	177	24	6172	1	90
NEW HAVEN	0	12	87	347	648	1011	1097	991	871	543	245	45	5897	5	88
DEL. WILMINGTON	0	0	51	270	588	927	980	874	735	387	112	6	4930	12	93
FLA. APALACHICOLA	0	0	0	16	153	319	347	260	180	33	0	0	1308		
DAYTONA BEACH	0	0	0	0	75	211	248	190	140	15	0	0	879	32	94
FORT MYERS	0	0	0	0	24	109	146	101	62	0	0	0	442	38	94
JACKSONVILLE	0	0	0	12	144	310	332	246	174	21	0	0	1239	29	96
KEY WEST	0	0	0	0	0	28	40	31	9	0	0	0	108	55	90
LAKELAND	0	0	0	0	57	164	195	146	99	0	0	0	661	35	95
MIAMI BEACH	0	0	0	0	0	40	56	36	9	0	0	0	141	45	91
ORLANDO	0	0	0	0	72	198	220	165	105	6	0	0	766	33	96
PENSACOLA	0	0	0	19	195	353	400	277	183	36	0	0	1463	29	92
TALLAHASSEE	0	0	0	28	198	360	375	286	202	36	0	0	1485	25	96
TAMPA	0	0	0	0	60	171	202	148	102	0	0	0	683	36	92
WEST PALM BEACH	0	0	0	0	6	65	87	64	31	0	0	0	253	40	92

Table 2-21 (Continued)

NORMAL TOTAL HEATING DEGREE DAYS (Base 65°)

STATE AND STATION	JULY	AUG.	SEP.	OCT.	NOV.	DEC.	JAN.	FEB.	MAR.	APR.	MAY	JUNE	ANNUAL	Des. Temp. °F Win	Des. Temp. °F Sum
GA. ATHENS	0	0	12	115	405	632	642	529	431	141	22	0	2929	17	[illegible]
ATLANTA	0	0	18	127	414	626	639	529	437	168	25	0	2983	18	95
AUGUSTA	0	0	0	78	333	552	549	445	350	90	0	0	2397	20	98
COLUMBUS	0	0	0	87	333	543	552	434	338	96	0	0	2383	23	98
MACON	0	0	0	71	297	502	505	403	295	63	0	0	2136	23	98
ROME	0	0	24	161	474	701	710	577	468	177	34	0	3326	16	97
SAVANNAH	0	0	0	47	246	437	437	353	254	45	0	0	1819	24	96
THOMASVILLE	0	0	0	25	198	366	394	305	208	33	0	0	1529		
IDAHO BOISE	0	0	132	415	792	1017	1113	854	722	438	245	81	5809	4	96
IDAHO FALLS 46W	16	34	270	623	1056	1370	1538	1249	1085	651	391	192	8475		
IDAHO FALLS 42NW	16	40	282	648	1107	1432	1600	1291	1107	657	388	192	8760		
LEWISTON	0	0	123	403	756	933	1063	815	694	426	239	90	5542	6	98
POCATELLO	0	0	172	493	900	1166	1324	1058	905	555	319	141	7033	-8	94
ILL. CAIRO	0	0	36	164	513	791	856	680	539	195	47	0	3821		
CHICAGO	0	0	81	326	753	1113	1209	1044	890	480	211	48	6155	-3	94
MOLINE	0	9	99	335	774	1181	1314	1100	918	450	189	39	6408	-7	94
PEORIA	0	6	87	326	759	1113	1218	1025	849	426	183	33	6025	-2	94
ROCKFORD	6	9	114	400	837	1221	1333	1137	961	516	236	60	6830	-7	92
SPRINGFIELD	0	0	72	291	696	1023	1135	935	769	354	136	18	5429	-1	95
IND. EVANSVILLE	0	0	66	220	606	896	955	767	620	237	68	0	4435	6	96
FORT WAYNE	0	9	105	378	783	1135	1178	1028	890	471	189	39	6205	0	93
INDIANAPOLIS	0	0	90	316	723	1051	1113	949	809	432	177	39	5699	0	93
SOUTH BEND	0	6	111	372	777	1125	1221	1070	933	525	239	60	6439	-2	92
IOWA Burlington	0	0	93	322	768	1135	1259	1042	859	426	177	33	6114	-4	95
DES MOINES	0	9	99	363	837	1231	1398	1165	967	489	211	39	6808	-7	95
DUBUQUE	12	31	156	450	906	1287	1420	1204	1026	546	260	78	7376	-11	92
SIOUX CITY	0	9	108	369	867	1240	1435	1198	989	483	214	39	6951	-10	96
WATERLOO	12	19	138	428	909	1296	1460	1221	1023	531	229	54	7320	-12	91
KANS. CONCORDIA	0	0	57	276	705	1023	1163	935	781	372	149	18	5479		
DODGE CITY	0	0	33	251	666	939	1051	840	719	354	124	9	4986	3	99
GOODLAND	0	6	81	381	810	1073	1166	955	884	507	236	42	6141	-2	99
TOPEKA	0	0	57	270	672	980	1122	893	722	330	124	12	5182	3	99
WICHITA	0	0	33	229	618	905	1023	804	645	270	87	6	4620	5	102
. COVINGTON	0	0	75	291	669	983	1035	893	756	390	149	24	5265	3	93
LEXINGTON	0	0	54	239	609	902	946	818	685	325	105	0	4683	6	94
LOUISVILLE	0	0	54	248	609	890	930	818	682	315	105	9	4660	8	96
LA. ALEXANDRIA	0	0	0	56	273	431	471	361	260	69	0	0	1921	25	97
BATON ROUGE	0	0	0	31	216	369	409	294	208	33	0	0	1560	25	96
BURRWOOD	0	0	0	0	96	214	298	218	171	27	0	0	1024		
LAKE CHARLES	0	0	0	19	210	341	381	274	195	39	0	0	1459	29	[illegible]
NEW ORLEANS	0	0	0	19	192	322	363	258	192	39	0	0	1385	32	93
SHREVEPORT	0	0	0	47	297	477	552	426	304	81	0	0	2184	22	99
MAINE CARIBOU	78	115	336	682	1044	1535	1690	1470	1308	858	468	183	9767	-18	85
PORTLAND	12	53	195	508	807	1215	1339	1182	1042	675	372	111	7511	-5	88
MD. BALTIMORE	0	0	48	264	585	905	936	820	679	327	90	0	4654	16	94
FREDERICK	0	0	66	307	624	955	995	876	741	384	127	12	5087	7	94
MASS. BLUE HILL OBSY	0	22	108	381	690	1085	1178	1053	936	579	267	69	6368		
BOSTON	0	9	60	316	603	983	1088	972	846	513	208	36	5634	6	91
NANTUCKET	12	22	93	332	573	896	992	941	896	621	384	129	5891		
PITTSFIELD	25	59	219	524	831	1231	1339	1196	1063	660	326	105	7578	-1	86
WORCESTER	6	34	147	450	774	1172	1271	1123	998	612	304	78	6969	1	89
MICH. ALPENA	68	105	273	580	912	1268	1404	1299	1218	777	446	156	8506	-5	87
DETROIT (CITY)	0	0	87	360	738	1088	1181	1058	936	522	220	42	6232	4	92
ESCANABA	59	87	243	539	924	1293	1445	1296	1203	777	456	159	8481	-7	82
FLINT	16	40	159	465	843	1212	1330	1198	1066	639	319	90	7377	-1	89
GRAND RAPIDS	9	28	135	434	804	1147	1259	1134	1011	579	279	75	6894	2	91
LANSING	6	22	138	431	813	1163	1262	1142	1011	579	273	69	6909	2	89
MARQUETTE	59	81	240	527	936	1268	1411	1268	1187	771	468	177	8393	-8	88
MUSKEGON	12	28	120	400	762	1088	1209	1100	995	594	310	78	6696	4	87
SAULT STE. MARIE	96	105	279	580	951	1367	1525	1380	1277	810	477	201	9048	-12	83
MINN. DULUTH	71	109	330	632	1131	1581	1745	1518	1355	840	490	198	10000	-19	85
INTERNATIONAL FALLS	71	112	363	701	1236	1724	1919	1621	1414	828	443	174	10606	-29	86
MINNEAPOLIS	22	31	189	505	1014	1454	1631	1380	1166	621	288	81	8382	-14	92
ROCHESTER	25	34	186	474	1005	1438	1593	1366	1150	630	301	93	8295	-17	90
SAINT CLOUD	28	47	225	549	1065	1500	1702	1445	1221	666	326	105	8879	-20	90

Table 2-21 (Continued)

NORMAL TOTAL HEATING DEGREE DAYS (Base 65°)

STATE AND STATION	JULY	AUG.	SEP.	OCT.	NOV.	DEC.	JAN.	FEB.	MAR.	APR.	MAY	JUNE	ANNUAL	Design Temp. °F Win.	Design Temp. °F Summ.
MISS. JACKSON	0	0	0	65	315	502	546	414	310	87	0	0	2239	21	98
MERIDIAN	0	0	0	81	339	518	543	417	310	81	0	0	2289	20	97
VICKSBURG	0	0	0	53	279	462	512	384	282	69	0	0	2041	23	97
MO. COLUMBIA	0	0	54	251	651	967	1076	874	716	324	121	12	5046	2	97
KANSAS	0	0	39	220	612	905	1032	818	682	294	109	0	4711	4	100
ST. JOSEPH	0	6	60	285	708	1039	1172	949	769	348	133	15	5484	- 1	97
ST. LOUIS	0	0	60	251	627	936	1026	848	704	312	121	15	4900	7	96
SPRINGFIELD	0	0	45	223	600	877	973	781	660	291	105	6	4561	5	97
MONT. BILLINGS	6	15	186	487	897	1135	1296	1100	970	570	285	102	7049	-10	94
GLASGOW	31	47	270	608	1104	1466	1711	1439	1187	648	335	150	8996	-25	96
GREAT FALLS	28	53	258	543	921	1169	1349	1154	1063	642	384	186	7750	-20	91
HAVRE	28	53	306	595	1065	1367	1584	1364	1181	657	338	162	8700	-22	91
HELENA	31	59	294	601	1002	1265	1438	1170	1042	651	381	195	8129	-17	90
KALISPELL	50	99	321	654	1020	1240	1401	1134	1029	639	397	207	8191	- 7	88
MILES CITY	6	6	174	502	972	1296	1504	1252	1057	579	276	99	7723	-19	97
MISSOULA	34	74	303	651	1035	1287	1420	1120	970	621	391	219	8125	- 7	92
NEBR. GRAND ISLAND	0	6	108	381	834	1172	1314	1089	908	462	211	45	6530	- 6	98
LINCOLN	0	6	75	301	726	1066	1237	1016	834	402	171	30	5864	- 4	100
NORFOLK	9	0	111	397	873	1234	1414	1179	983	498	233	48	6979	-11	97
NORTH PLATTE	0	6	123	440	885	1166	1271	1039	930	519	248	57	6684	- 6	97
OMAHA	0	12	105	357	828	1175	1355	1126	939	465	208	42	6612	- 5	97
SCOTTSBLUFF	0	0	138	459	876	1128	1231	1008	921	552	285	75	6673	- 8	96
VALENTINE	9	12	165	493	942	1237	1395	1176	1045	579	288	84	7425		
NEV. ELKO	9	34	225	561	924	1197	1314	1036	911	621	409	192	7433	-13	94
ELY	28	43	234	592	939	1184	1308	1075	977	672	456	225	7733	- 6	90
LAS VEGAS	0	0	0	78	387	617	688	487	335	111	6	0	2709	23	108
RENO	43	87	204	490	801	1026	1073	823	729	510	357	189	6332	12	94
WINNEMUCCA	0	34	210	536	876	1091	1172	916	837	573	363	153	6761	1	97
N. H. CONCORD	6	50	177	505	822	1240	1358	1184	1032	636	298	75	7383	-11	91
MT. WASH. OBSY.	493	536	720	1057	1341	1742	1820	1663	1652	1260	930	603	13817		
N. J. ATLANTIC CITY	0	0	39	251	549	880	936	848	741	420	133	15	4812	14	91
NEWARK	0	0	30	248	573	921	983	876	729	381	118	0	4859	11	94
TRENTON	0	0	57	264	576	924	989	885	753	399	121	12	4980	12	92
N. MEX. ALBUQUERQUE	0	0	12	229	642	868	930	703	595	288	81	0	4348	14	96
CLAYTON	0	6	66	310	699	899	986	812	747	429	183	21	5158		
RATON	9	28	126	431	825	1048	1116	904	834	543	301	63	6228	- 2	92
ROSWELL	0	0	18	202	573	806	840	641	481	201	31	0	3793	16	101
SILVER CITY	0	0	6	183	525	729	791	605	518	261	87	0	3705	14	95
N. Y. ALBANY	0	19	138	440	777	1194	1311	1156	992	564	239	45	6875	1	91
BINGHAMTON (AP)	22	65	201	471	810	1184	1277	1154	1045	645	313	99	7286	- 2	91
BINGHAMTON (PO)	0	28	141	406	732	1107	1190	1081	949	543	229	45	6451		
BUFFALO	19	37	141	440	777	1156	1256	1145	1039	645	329	78	7062	- 5	90
CENTRAL PARK	0	0	30	233	540	902	986	885	760	408	118	9	4871	11	94
J. F. KENNEDY INTL	0	0	36	248	564	933	1029	935	815	480	167	12	5219	17	91
LAGUARDIA	0	0	27	223	528	887	973	879	750	414	124	6	4811	12	93
ROCHESTER	9	31	126	415	747	1125	1234	1123	1014	597	279	48	6748	2	91
SCHENECTADY	0	22	123	422	756	1159	1283	1131	970	543	211	30	6650	- 5	90
SYRACUSE	6	28	132	415	744	1153	1271	1140	1004	570	248	45	6756	- 2	90
N.C. ASHEVILLE	0	0	48	245	555	775	784	683	592	273	87	0	4042	13	91
CAPE HATTERAS	0	0	0	78	273	521	580	518	440	177	25	0	2612		
CHARLOTTE	0	0	6	124	438	691	691	582	481	156	22	0	3191	18	96
GREENSBORO	0	0	33	192	513	778	784	672	552	234	47	0	3805	14	94
RALEIGH	0	0	21	164	450	716	725	616	487	180	34	0	3393	16	95
WILMINGTON	0	0	0	74	291	521	546	462	357	96	0	0	2347	23	94
WINSTON SALEM	0	0	21	171	483	747	753	652	524	207	37	0	3595	14	94
N. DAK. BISMARCK	34	28	222	577	1083	1463	1708	1442	1203	645	329	117	8851	-24	95
DEVILS LAKE	40	53	273	642	1191	1634	1872	1579	1345	753	381	138	9901	-23	93
FARGO	28	37	219	574	1107	1569	1789	1520	1262	690	332	99	9226	-22	92
WILLISTON	31	43	261	601	1122	1513	1758	1473	1262	681	357	141	9243	-21	94
OHIO AKRON	0	9	96	381	726	1070	1138	1016	871	489	202	39	6037	1	89
CINCINNATI	0	0	54	248	612	921	970	837	701	336	118	9	4806	8	94
CLEVELAND	9	25	105	384	738	1088	1159	1047	918	552	260	66	6351	2	91
COLUMBUS	0	6	84	347	714	1039	1088	949	809	426	171	27	5660	2	92
DAYTON	0	6	78	310	696	1045	1097	955	809	429	167	30	5622	0	92
MANSFIELD	9	22	114	397	768	1110	1169	1042	924	543	245	60	6403	1	91
SANDUSKY	0	6	66	313	684	1032	1107	991	868	495	198	36	5796	4	92
TOLEDO	0	16	117	406	792	1138	1200	1056	924	543	242	60	6494	1	92
YOUNGSTOWN	6	19	120	412	771	1104	1169	1047	921	540	248	60	6417	1	89

Table 2-21 (Continued)

NORMAL TOTAL HEATING DEGREE DAYS (Base 65°)

STATE AND STATION	JULY	AUG.	SEP.	OCT.	NOV.	DEC.	JAN.	FEB.	MAR.	APR.	MAY	JUNE	ANNUAL	Design Temp °F W	Design Temp °F S
OKLA. OKLAHOMA CITY	0	0	15	164	498	766	868	664	527	189	34	0	3725	11	100
TULSA	0	0	18	158	522	787	893	683	539	213	47	0	3860	12	102
OREG. ASTORIA	146	130	210	375	561	679	753	622	636	480	363	231	5.85	27	79
BURNS	12	37	210	515	867	1113	1246	988	856	570	366	177	6957		
EUGENE	34	34	129	366	585	719	803	627	589	426	279	135	4726	22	91
MEACHAM	84	124	288	580	918	1091	1209	1005	983	726	527	339	7874		
MEDFORD	0	0	78	372	678	871	918	697	642	432	242	78	5008	21	98
PENDLETON	0	0	111	350	711	884	1017	773	617	396	205	63	5127	3	97
PORTLAND	25	28	114	335	597	735	825	644	586	396	245	105	4635	26	91
ROSEBURG	22	16	105	329	567	713	766	608	570	405	267	123	4491	25	93
SALEM	37	31	111	338	594	729	822	647	611	417	273	144	4754	21	92
SEXTON SUMMIT	81	81	171	443	666	874	958	809	818	609	465	279	6254		
PA. ALLENTOWN	0	0	90	353	693	1045	1116	1002	849	471	167	24	5810	3	92
ERIE	0	25	102	391	714	1063	1169	1081	973	585	288	60	6451	7	88
HARRISBURG	0	0	63	298	648	992	1045	907	766	396	124	12	5251	9	92
PHILADELPHIA	0	0	60	291	621	964	1014	890	744	390	115	12	5101	11	93
PITTSBURGH	0	9	105	375	726	1063	1119	1002	874	480	195	39	5987	7	90
READING	0	0	54	257	597	939	1001	885	735	372	105	0	4945	6	92
SCRANTON	0	19	132	434	762	1104	1156	1028	893	498	195	33	6254	2	89
WILLIAMSPORT	0	9	111	375	717	1073	1122	1002	856	468	177	24	5934	1	91
R. I. BLOCK IS.	0	16	78	307	594	902	1020	955	877	612	344	99	5804		
PROVIDENCE	0	16	96	372	660	1023	1110	988	868	534	236	51	5954	6	89
S. C. CHARLESTON	0	0	0	59	282	471	487	389	291	54	0	0	2033	26	95
COLUMBIA	0	0	0	84	345	577	570	470	357	81	0	0	2484	20	98
FLORENCE	0	0	0	78	315	552	552	459	347	84	0	0	2387	21	96
GREENVILLE	0	0	0	112	387	636	648	535	434	120	12	0	2884	19	95
SPARTANBURG	0	0	15	130	417	667	663	560	453	144	25	0	3074	18	95
S. DAK. HURON	9	12	165	508	1014	1432	1628	1355	1125	600	288	87	8223	-16	97
RAPID CITY	22	12	165	481	897	1172	1333	1145	1051	615	326	126	7345	- 9	96
SIOUX FALLS	19	25	168	462	972	1361	1544	1285	1082	573	270	78	7839	-14	95
TENN. BRISTOL	0	0	51	236	573	828	828	700	598	261	68	0	4143	11	92
CHATTANOOGA	0	0	18	143	468	698	722	577	453	150	25	0	3254	15	97
KNOXVILLE	0	0	30	171	489	725	732	613	493	198	43	0	3494	13	95
MEMPHIS	0	0	18	130	447	698	729	585	456	147	22	0	3232	17	98
NASHVILLE	0	0	30	158	495	732	778	644	512	189	40	0	3578	12	97
OAK RIDGE (CO)	0	0	39	192	531	772	778	669	552	228	56	0	3817		
TEX. ABILENE	0	0	0	99	366	586	642	470	347	114	0	0	2624	17	101
AMARILLO	0	0	18	205	570	797	877	664	546	252	56	0	3985	8	98
AUSTIN	0	0	0	31	225	388	468	325	223	51	0	0	1711	25	101
BROWNSVILLE	0	0	0	0	66	149	205	106	74	0	0	0	600	36	94
CORPUS CHRISTI	0	0	0	0	120	220	291	174	109	0	0	0	914	32	95
DALLAS	0	0	0	62	321	524	601	440	319	90	6	0	2363	19	101
EL PASO	0	0	0	84	414	648	685	445	319	105	0	0	2700	21	100
FORT WORTH	0	0	0	65	324	536	614	448	319	99	0	0	2405	20	102
GALVESTON	0	0	0	0	138	270	350	258	189	30	0	0	1235	32	91
HOUSTON	0	0	0	6	183	307	384	288	192	36	0	0	1396	29	96
LAREDO	0	0	0	0	105	217	267	134	74	0	0	0	797	32	103
LUBBOCK	0	0	18	174	513	744	800	613	484	201	31	0	3578	11	99
MIDLAND	0	0	0	87	381	592	651	468	322	90	0	0	2591	19	100
PORT ARTHUR	0	0	0	22	207	329	384	274	192	39	0	0	1447	29	94
SAN ANGELO	0	0	0	68	318	536	567	412	288	66	0	0	2255	20	101
SAN ANTONIO	0	0	0	31	207	363	428	286	195	39	0	0	1549	25	99
VICTORIA	0	0	0	6	150	270	344	230	152	21	0	0	1173	28	98
WACO	0	0	0	43	270	456	536	389	270	66	0	0	2030	21	101
WICHITA FALLS	0	0	0	99	381	632	698	518	378	120	6	0	2832	15	103
UTAH MILFORD	0	0	99	443	867	1141	1252	988	822	519	279	87	6497		
SALT LAKE CITY	0	0	81	419	849	1082	1172	910	763	459	233	84	6052	5	97
WENDOVER	0	0	48	372	822	1091	1178	902	729	408	177	51	5778		
VT. BURLINGTON	28	65	207	539	891	1349	1513	1333	1187	714	353	90	8269	-12	88
VA. CAPE HENRY	0	0	0	112	360	645	694	633	536	246	53	0	3279		
LYNCHBURG	0	0	51	223	540	822	849	731	605	267	78	0	4166	15	94
NORFOLK	0	0	0	136	408	698	738	655	533	216	37	0	3421	20	94
RICHMOND	0	0	36	214	495	784	815	703	546	219	53	0	3865	14	96
ROANOKE	0	0	51	229	549	825	834	722	614	261	65	0	4150	15	94
WASH. NAT'L. AP.	0	0	33	217	519	834	871	762	626	288	74	0	4224		

Table 2-21 (Concluded)

NORMAL TOTAL HEATING DEGREE DAYS (Base 65°)

STATE AND STATION	JULY	AUG.	SEP.	OCT.	NOV.	DEC.	JAN.	FEB.	MAR.	APR.	MAY	JUNE	ANNUAL	Design Temp °F W	Design Temp °F Sum.
WASH. OLYMPIA	68	71	198	422	636	753	834	675	645	450	307	177	5236	21	85
SEATTLE	50	47	129	329	543	657	738	599	577	396	242	117	4424	23	82
SEATTLE BOEING	34	40	147	384	624	763	831	655	608	411	242	99	4838		
SEATTLE TACOMA	56	62	162	391	633	750	828	678	657	474	295	159	5145	20	85
SPOKANE	9	25	168	493	879	1082	1231	980	834	531	288	135	6655	- 2	93
STAMPEDE PASS	273	291	393	701	1008	1178	1287	1075	1085	855	654	483	9283		
TATOOSH IS.	295	279	306	406	534	639	713	613	645	525	431	333	5719		
WALLA WALLA	0	0	87	310	681	843	986	745	589	342	177	45	4805	12	98
YAKIMA	0	12	144	450	828	1039	1163	868	713	435	220	69	5941	6	94
W. VA. CHARLESTON	0	0	63	254	591	865	880	770	648	300	96	9	4476	9	92
ELKINS	9	25	135	400	729	992	1008	896	791	444	198	48	5675	1	87
HUNTINGTON	0	0	63	257	585	856	880	764	636	294	99	12	4446	10	95
PARKERSBURG	0	0	60	264	606	905	942	826	691	339	115	6	4754	8	93
WIS. GREEN BAY	28	50	174	484	924	1333	1494	1313	1141	654	335	99	8029	-12	88
LA CROSSE	12	19	153	437	924	1339	1504	1277	1070	540	245	69	7589	-12	90
MADISON	25	40	174	474	930	1330	1473	1274	1113	618	310	102	7863	- 9	92
MILWAUKEE	43	47	174	471	876	1252	1376	1193	1054	642	372	135	7635	- 6	90
WYO. CASPER	6	16	192	524	942	1169	1290	1084	1020	657	381	129	7410	-11	92
CHEYENNE	19	31	210	543	924	1101	1228	1056	1011	672	381	102	7278	- 6	89
LANDER	6	19	204	555	1020	1299	1417	1145	1017	654	381	153	7870	-16	92
SHERIAN	25	31	219	539	948	1200	1355	1154	1054	642	366	150	7683	-12	95

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1. Liu, B. Y. H., and Jordan, R. C., (1960) "The Interrelationship and Characteristic Distribution of Direct, Diffuse and Total Solar Radiation, Solar Energy, 4(3).

2. Klein, S. A., (1976) "Calculation of Monthly Average Insolation on Tilted Surfaces," Volume I, Proc. ISES and SESC Joint Conference, Winnipeg.

3. ASHRAE (1972) Handbook of Fundamentals, New York.

4. Solaron (1976) Application Engineering Manual, Solaron Corporation, Denver, Colorado.

SECTION III
PASSIVE SOLAR DESIGN

Solar heating and cooling is usually restricted to system designs that use manufactured hardware and components that are off the shelf (e. g. : pumps, fans, heat exchangers) or can quickly become mass-produced, marketed and serviced (e. g. : collectors, fluids, controls). Solar systems usually require collectors, thermal storage, a thermal energy transport system between the collector array and storage, and another between storage and the heated or cooled building; both transport systems use pumps or fans. The components are usually attached to, or installed in, a building without having much effect on the building's architectural fabric (roof, walls, floor, etc.). Such systems are referred to as "active."

Energy conservation in buildings is the reduction of energy consumption, whether the conserved energy is renewable (e. g. : solar) or nonrenewable (e. g. : fossil fuel). Although solar energy can be used to reduce consumption of fossil fuels, it is not generally regarded as an energy conservation feature. Many simple architectural features, such as the combination of south-facing glass and thermal mass, are not considered energy conservation techniques.

Solar heating and cooling systems and energy conservation exclude many simple methods for using solar and other natural forms of energy. "Passive" solar energy does not use mechanical power (e. g. : pumps, fans) but instead uses natural energy flows for transfer of thermal energy into, out of, and through a building.

Thermal energy transfer in and out of buildings, in and out of thermal energy storage, and around and through a conditioned space is by natural means. Control elements and other comfort-regulating devices can be incorporated into passive solar designs. Thermal energy storage and control elements are not considered necessary components of passive designs.

Techniques that combine natural thermal energy flow with mechanically powered energy flow are called hybrid. For example, a fan may be added to a passive system to improve energy transfer and/or to provide an additional level of control.

The term passive may conflict with some energy conservation definitions, and may exclude other natural energy uses not considered energy conservation measures. For example, wood heating, natural ventilation, and roofpond evaporative cooling would not fit into definitions of energy conservation or passive design.

Techniques for reducing a building's consumption of nonrenewable energy might, therefore, be as follows:

- Energy Conservation Techniques
- Natural Energy Features
- Passive Solar Design
- Hybrid Solar Systems
- Active Solar Systems

PASSIVE APPLICATIONS

Combination of Collection/Storage/Space

Passive solar systems are designed by linkage between solar collection, thermal energy storage, and space.

1. Solar energy enters directly through windows to the space. In many cases, 10 to 30 percent of the building's heating requirements can be met without providing special thermal storage.

2. Solar heat enters through a window and directly strikes thermal mass, such as concrete or brick floors, or solar heat enters through windows, overheats the living space, and in turn, heats the thermal mass of which the building is constructed. The thermal mass stores the energy as heat, and as the space loses heat to the outdoors, the mass in turn releases the stored heat to the space.

3. Sunlight enters through a glazing system and strikes a thermal storage wall without first coming in contact with the conditioned space. Heat can be stored at somewhat higher temperatures, resulting in a somewhat smaller heat storage volume.

4. Solar heat enters directly through the windows. If there is no thermal mass, the space overheats and a fan circulates the overheated air through a separate gravel bed. The heat is retrieved when needed by the space, again with the fan circulating room air through the thermal storage bed. Such a system uses mechanical energy (i. e., a fan) to move thermal energy; as noted earlier, this is often regarded as a hybrid system.

Medium of Collection/Storage

Direct Gain (Figure 3-1) -- Direct gain systems use sunlight entering directly through glass or plastic into the space to be heated. Virtually all of the sunlight entering the room turns directly into heat. Thermal mass for storing excess heat may be located with exposure to the sunlight for direct gain (as in a concrete floor) or indirectly, in some other part of the building. To reduce heat loss at night and, therefore, to increase overall thermal performance, insulation may be applied to the glass, either inside or outside.

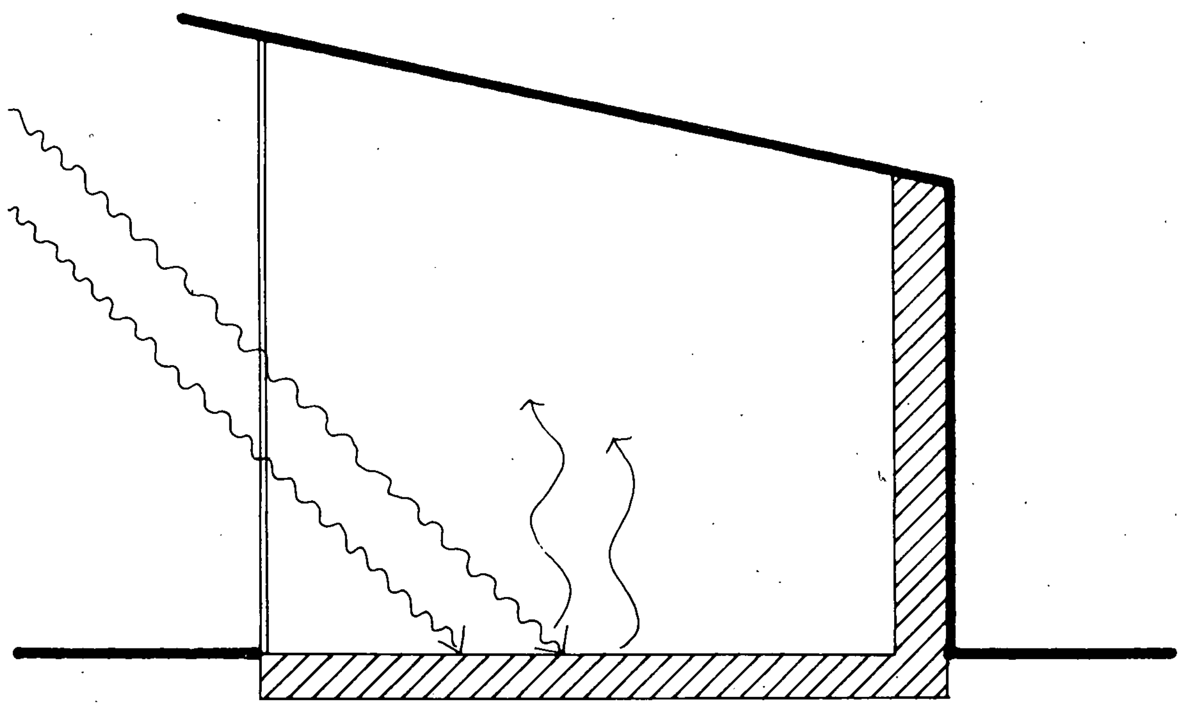


Figure 3-1. Direct Gain

During the heating season, south-facing glass takes advantage of the sun's low position in the sky; in the summer when the sun is high in the sky, the glass is easily shaded by overhangs or trees.

Thermal Storage Walls (Figure 3-2) -- Thermal energy storage can be located between a wall of glass (or plastic) and the space to be heated. There are two types of thermal storage walls. One wall uses heavy masonry materials approximately one foot thick. The wall, painted a dark color, heats up as the sun passes through the glass and strikes it. There are usually portals at the top and bottom, allowing room air to become warm and rise between the storage wall and the glass. Such systems are usually referred to as "Trombe Walls" after Felix Trombe of Odeillo, France.

Fans can be used to increase and/or control air flow. Much of the heat, however, is absorbed by and conducted through masonry material, finally radiating directly to the space. Manual or automatic dampers can be installed to prevent the nighttime reverse flow of air which can cool the space. As with direct gain systems, insulating shutters may be moved into place to cover glass at night to reduce heat loss and thereby increase overall thermal performance.

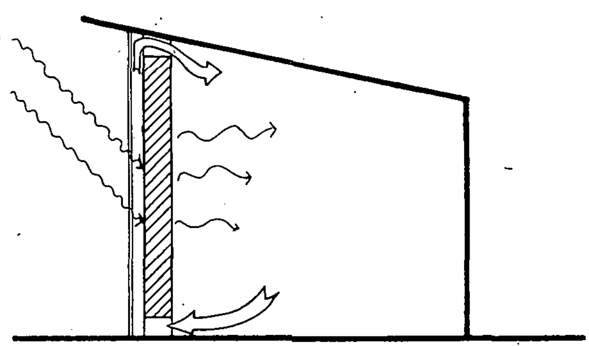


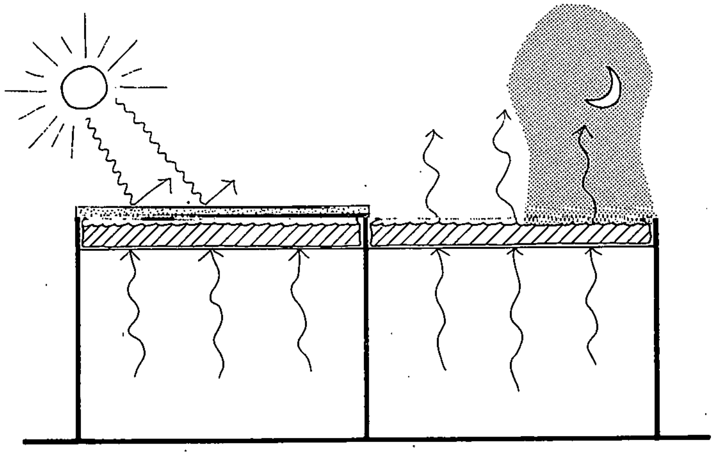
Figure 3-2. Thermal Storage Wall

Containers of water are often used as a substitute for masonry materials. Tubes of water, 55-gallon barrels, and specially fabricated water walls are commonly used. The natural flow of air from the room to the space between the wall of glass and the containers of water, then back to the room, is usually not a serious design consideration. Instead, solar heat is transferred quickly through the water containers which radiate their heat directly to the living space.

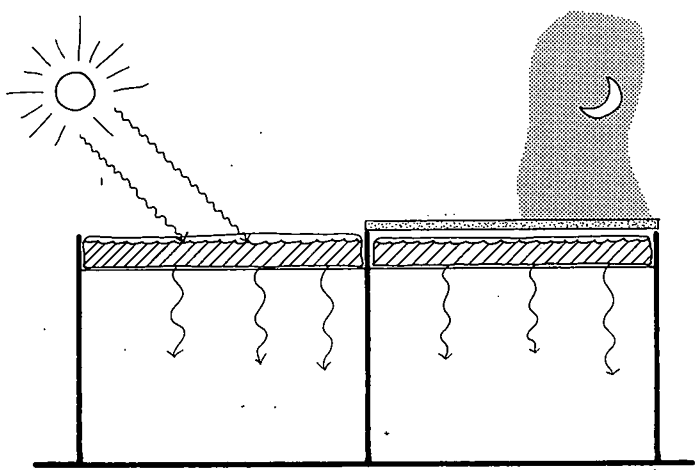
To control this radiational heating (or to hide the containers), a partition can be placed between the water wall and the living space. A fan may be used to thermostatically supply warm air from the resulting water wall heat storage "closet" directly to the space.

Thermal Storage Roofs (Figure 3-3) -- Some passive designs call for the thermal storage to be located on the roof. The most widely known system, developed by Harold Hay, is called "Skytherm." It uses roof ponds that contain water stored in large plastic bags. These dark colored bags absorb the heat during the day and radiate it through the ceiling to the space below. Insulating panels cover the roof ponds at night to reduce heat loss.

Depending on the climate, this system can be used for cooling during the summer. The water absorbs heat from the space below and radiates the heat to the outside through a process called nocturnal radiation cooling. The insulating panels cover and shade the roof ponds during the day and are removed at night to permit radiational cooling.



SUMMER COOLING



WINTER HEATING

Figure 3-3. Thermal Storage Roofs: Summer & Winter Operation

Attached Greenhouses (Figure 3-4) -- Greenhouses and other solar rooms can be attached to new or existing buildings. Overheated greenhouse air can be delivered directly to the building to be heated, or the building and the greenhouse can have a common thermal storage wall. The heat stored in the thermal storage wall will be shared by both the greenhouse and the building. For a properly designed greenhouse, solar energy can provide all, or nearly all, of the heat required depending on climate. Excess solar energy can be used to heat the building while simultaneously acting as a buffer zone, reducing heat loss from the building to the outdoors.

Convective Loops (Figure 3-5) -- As fluids increase in temperature, their buoyancy increases compared with cooler fluids. The result is that warm fluid tends to rise, and cool fluid drops to take its place. A natural convective loop uses this principle by permitting a fluid, either liquid or air, to flow into contact with a solar absorbing surface. The warm fluid rises, either directly to the space to be heated or to a thermal storage container, which is usually at an elevation above that of the absorber. Cooler fluid is drawn from the room (or from thermal storage) to the collector, replacing the warm rising fluid.

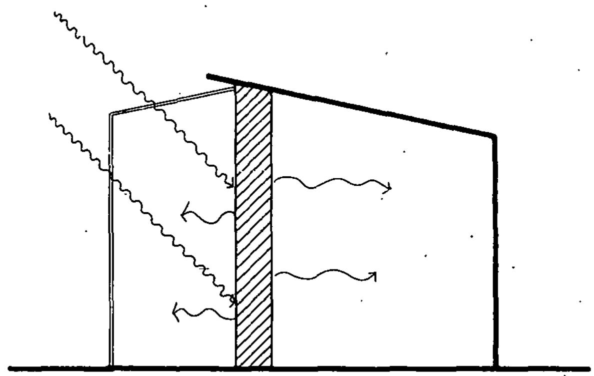


Figure 3-4. Solar Greenhouse[1]

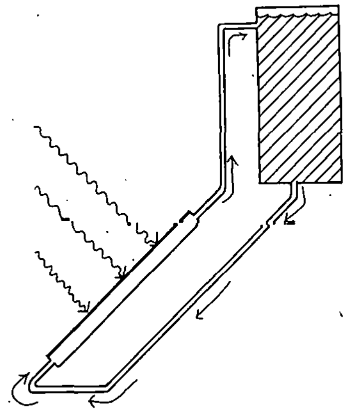


Figure 3-5. Convective Loop: Water Heating

Categories of Use

Domestic Hot Water Heating -- In a domestic hot water system, the solar collector is at an elevation below that of a hot water tank. Warmed liquid rises through the collector and up to the water tank where it is stored. In some systems, an electric heating element is located at the top third of the tank to boost the temperature of the water prior to use. In other systems, the solar tank serves to preheat the water prior to final heating in a conventional water heater.

Passive solar water heating can also be accomplished through the use of black uninsulated water tanks directly exposed to sunlight. Efficiency is usually enhanced through the use of one or two layers of glass or plastic between the black storage container and the outdoors. In cold climates, insulation covers the tank at night.

Plastic water bags on a level platform can be used in mild climates where heat loss is not a severe problem. Reflecting surfaces can increase the amount of heat the water absorbs, resulting in higher temperatures.

Heating Only -- Probably the simplest "heating only" passive systems are thermosiphoning air collectors. The simplest form of a thermosiphoning air collector is illustrated in Figure 3-6. As the air in the space between the glass and the blackened absorber surface is heated, it expands and becomes lighter, rises through the collector, and flows into the room from the vent at the top. Cooled room air is drawn into the collector through another vent at the base of the wall, replacing the warm air leaving the collector. It is heated and subsequently expelled from the top of the collector into the room. This process continues as long as there is enough sunlight to raise the temperature of the collector above the temperature of the room.

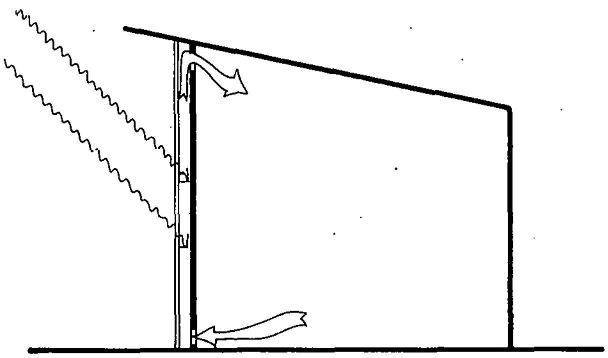


Figure 3-6. A Thermosiphoning Air Collector

The simplicity of direct gain systems is apparent, and they are already used to some extent on nearly all of our 70 million buildings. Thermal mass on the order of 30 Btu/$^{\circ}$F per square foot of south-facing window is considered the requirement if the mass is directly exposed to the sun. If the mass is not struck by direct sunlight, approximately four times as much thermal mass, or 120 Btu/$^{\circ}$F per square foot, is required for best performance.

Direct gain can be increased by reflective surfaces used outside of the building. Nighttime insulation for reducing heat loss in combination with reflectors can double ~~and even triple~~ the net effective energy output of direct gain systems. Beadwall®, designed by Zomeworks Corporation, uses polystyrene beads that are blown between two panes of glass or plastic at night to reduce heat loss. Three inches of beads provide an R-value of about 10. The beads are drawn out during sunny winter weather by small vacuum cleaner blowers that operate only a few minutes per day.

Figure 3-7 shows movable insulation combined with a concrete thermal storage wall. The economic value of movable insulation in passive systems increases with an increasing number of degree days. However, most concrete storage wall systems to date have not used movable insulation because of its relative inconvenience and increased first cost.

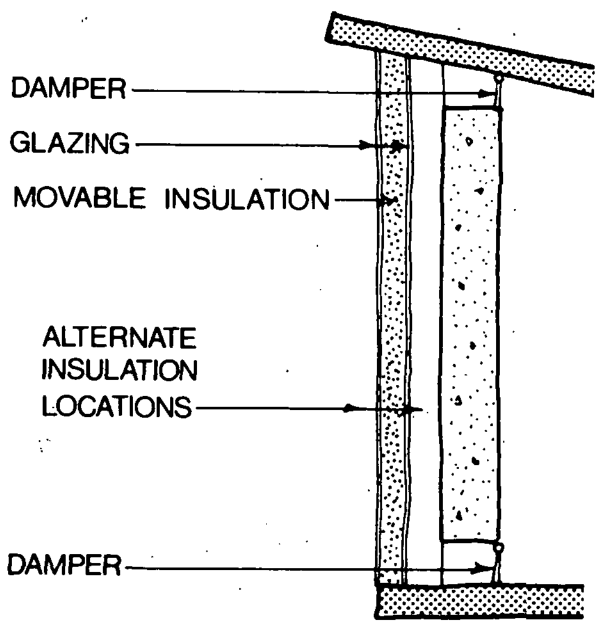


Figure 3-7. Movable Insulation with a Concrete Thermal Storage Wall (Night Time Operation)

Figure 3-8 shows an example of water as a thermal storage wall. This system, first developed by Steve Baer of Zomeworks Corporation, uses 55-gallon drums filled with water. Insulating panels hinged at the base of each wall can cover the single layer of glass at night to reduce heat loss. With the shutters open and laying flat on the ground, the aluminum surface reflects additional sunlight onto the drums. During the summer, the shutters, in closed position, shade the glass.

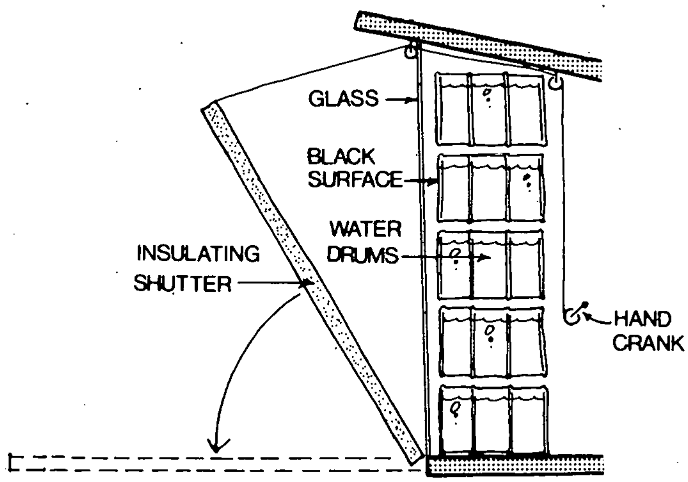


Figure 3-8. Hand-Operated Insulating Shutter with Water Drum Thermal Storage

Another example of a water wall (Figure 3-9) uses vertical tubes of water produced by Kalwall Corporation. In this example, the tubes are separated from the living space by a wall through which air from the room can pass and contact the warm tubes. A fan controls the movement of heat from the collector to the living space. A thermal curtain closes between the tubes and the glass at night to reduce heat loss.

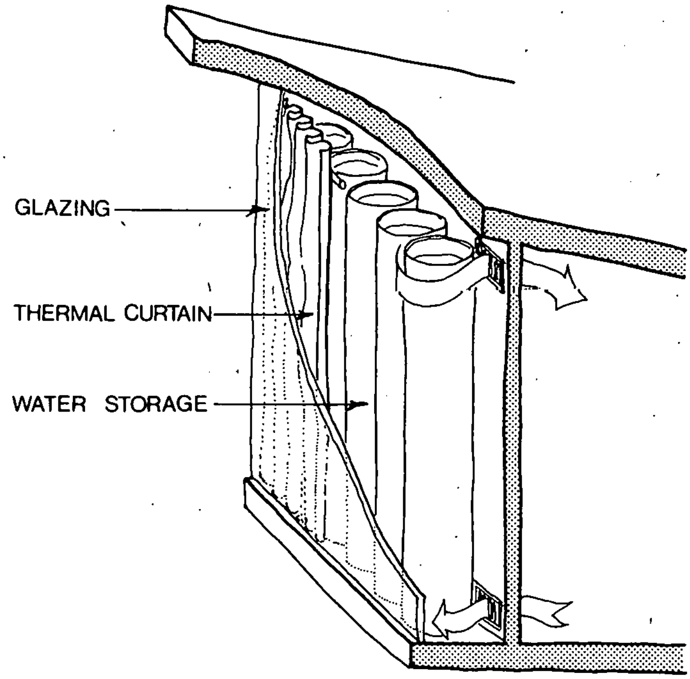


Figure 3-9. Thermal Curtain with Water Tube Storage

Attics can be used to advantage for passive heating. One method, for example, is to glaze south-facing attic roofs, circulating the overheated attic air to the building below.

A variation of this scheme includes heat storage, in some cases in black plastic waterbed-like containers laying on the floor of the attic. The warm attic air is then circulated through the use of fans to spaces below, or the heat radiates from the bags of water directly through a heat-conducting ceiling in a manner similar to Harold Hay's Skytherm system.

Solar heat from a convective loop collector can be stored in rock bins located inside the house. Little or no mechanical power may be needed. The accompanying design by Jonathon Hammond (Figure 3-10) shows the heated air rising through the collector, and then through a vertical rock storage bin in the house. Air flow passes through the living space between the storage bin and the collector. In this particular design, the wood stove flue is imbedded in the storage bin to provide supplementary heat during periods of cold, cloudy weather.

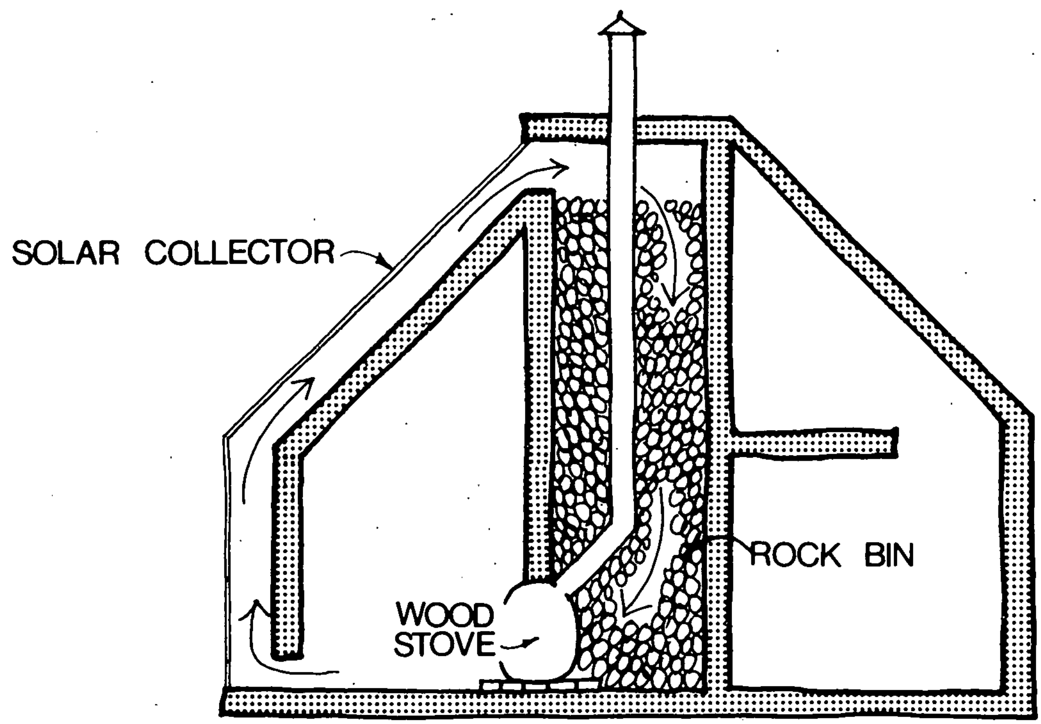


Figure 3-10. Convective Loop Including Rock Bin Thermal Storage

A greenhouse can be located in front of a thermal storage wall, as shown in Figure 3-11. Hot air from the concrete wall can heat the house directly, while some of the heat lost from the wall warms the greenhouse before passing to the outdoors, thereby extending the growing season. At the same time, the concrete wall keeps the greenhouse from becoming overheated on clear, sunny days. Excess heat is absorbed by the concrete and held there until needed by the house.

Figure 3-11. The Hofman House: A Concrete South Wall Combined with a Greenhouse

Heating/Cooling -- Figure 3-12 shows a thermal storage wall for heating also being used for natural ventilation. Dampers are positioned as shown so the solar heated air between the glass and the warm concrete creates a "chimney effect", drawing warm room air to the base of the collector and cool outdoor air into the house through vents in other exterior walls.

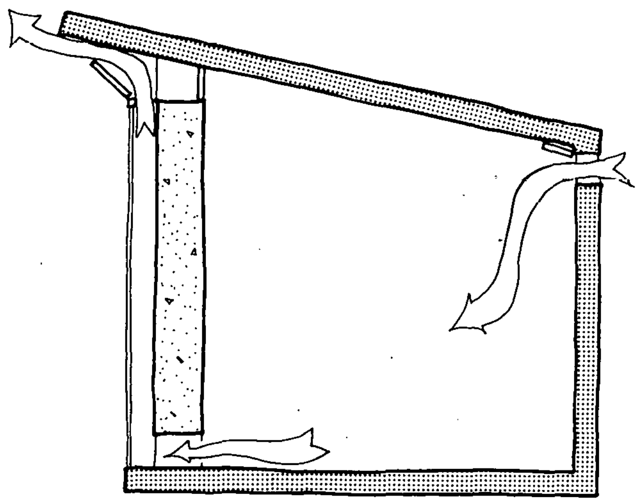


Figure 3-12. Thermal Storage Wall: Cooling

In addition to the basic Skytherm system described earlier for both heating and cooling, variations include flooding the bags of water to use evaporative cooling during the day in addition to nocturnal radiational cooling at night. This is particularly valuable in excessively hot climates.

To increase performance during the winter, a thin layer of transparent plastic can be inflated slightly above the roof ponds; the result is higher collection efficiency.

In direct gain systems, the thermal mass used for storing heat during the winter can be used to reduce cooling loads in the summer. The building can be opened up during cool nights. The resulting cool thermal mass will help keep the building cool during the day.

Cooling Only -- Although often considered an energy conservation measure, the best means of "solar cooling" is to keep the sun from hitting and/or penetrating the building during the cooling season.

So also, cross-ventilation and the use of the chimney effect to increase natural ventilation can in many cases be used in lieu of other forms of air-conditioning.

In many cooling-only climates, the Skytherm-based system of roof ponds can provide nocturnal radiational cooling without necessarily being used for heating.

Specifics of Some Passive Schemes:

David Wright's House -- Santa Fe, New Mexico: Direct Gain

There is direct gain through the south side of this semi-cylindrical house that has 384 square feet of insulating glass. There are few windows elsewhere. Seventeen-inch-thick adobe walls and a two-foot-thick adobe floor are insulated on the outside by two inches of polyurethane foam. The house loses about 13,000 Btu per degree day. On a clear January day, as much as

500, 000 Btu enter the house through the south windows. The temperature of the house is permitted to fluctuate between the range of 60-80^{O}F. This fluctuation, in combination with the large expanse of glass and considerable volume of thermal mass, permits 90% of the heating needs to be satisfied by solar in the 6200-degree-day climate of Santa Fe, New Mexico.

At night, heat loss through the south glass is reduced by folding, insulating shutters made of two-inch-thick foam insulation covered with canvas (Figure 3-13).

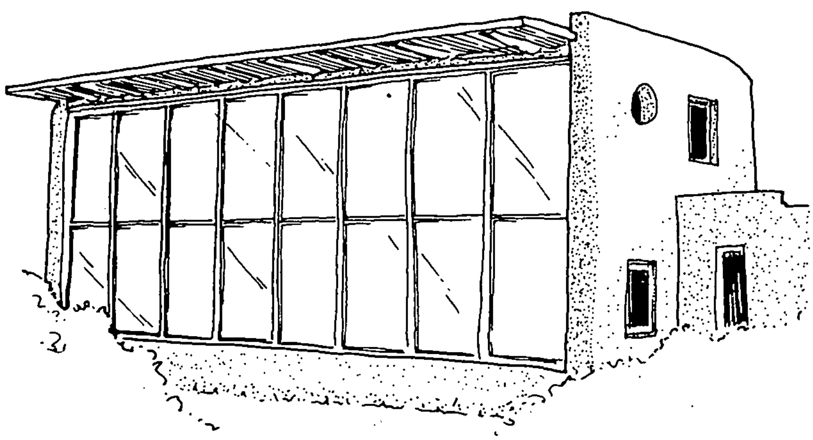


Figure 3-13. David Wright's House: Direct Gain

Doug Kelbaugh's House-Princeton, New Jersey: Trombe Wall

Doug Kelbaugh used a forty-foot-long, two-story concrete Trombe wall, incorporating a large greenhouse and several windows. By permitting a three-to six-degree temperature swing on a daily basis, the wall provides about 70 percent of the heating requirements in a 4500-degree-day climate. The per-degree-day heat loss of the house is between 15, 000 and 20, 000 Btu, not including the greenhouse (Figures 3-14 and 3-15).

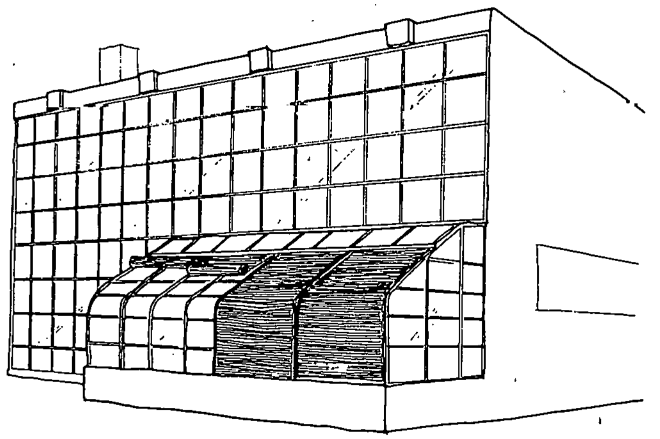


Figure 3-14. Doug Kelbaugh's House: Trombe Wall and Greenhouse

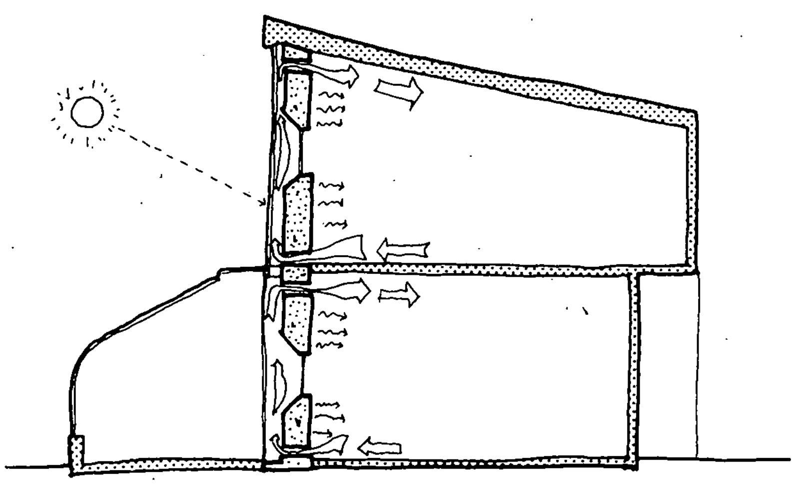


Figure 3-15. Doug Kelbaugh's House: Winter Operation

Harold Hay's Skytherm -- Atascadero, California: Roof Pond

One of the best known solar homes in the country is Harold Hay's "solarchitecture" house (Figure 3-16) built in 1973. The 1100 square feet of floor area is covered by an equal square footage of roof pond. Nine flat, insulating panels slide horizontally in tracks above the roof ponds.

The water is contained in four eight by thirty-eight foot transparent plastic bags, similar to waterbeds. The eight inches of water has a total volume of 7,000 gallons. A plastic liner between the bags of water and the metal pan roof (which is also the ceiling) protects against leaks and rainwater seepage. Just above the bags, an inflatable transparent cover serves to reduce heat loss from the bags, increasing the greenhouse effect and, therefore, the overall solar heat collection efficiency. It also protects the bags from ultraviolet radiation.

During the summer, heat from the house rises through the metal ceiling and is absorbed by the roof pond. The warm bags reradiate their heat into outside air. The transparent plastic is deflated to allow higher levels of radiational cooling.

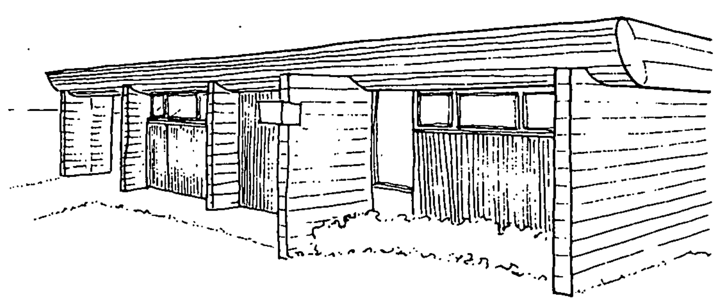


Figure 3-16. Harold Hay's Solarchitecture House: Roof Pond

Concrete block exterior walls and interior partitions are filled with sand to increase the thermal mass of the house. This house is 100 percent solar heated and cooled; it has no backup system. In research and monitoring studies financed by HUD, the tenants declared they were extremely pleased with the cooling system; they rated it far superior to conventional cooling. There are only small variations in indoor temperature. During the winter, temperatures typically fluctuate between 66-73°F.

Davis House-Albuquerque, New Mexico: Thermosiphoning Rockbed

The Paul Davis house has used a thermosiphoning collector in combination with a thermosiphoning rockbed since 1972. The air flow is shown in Figure 3-17.

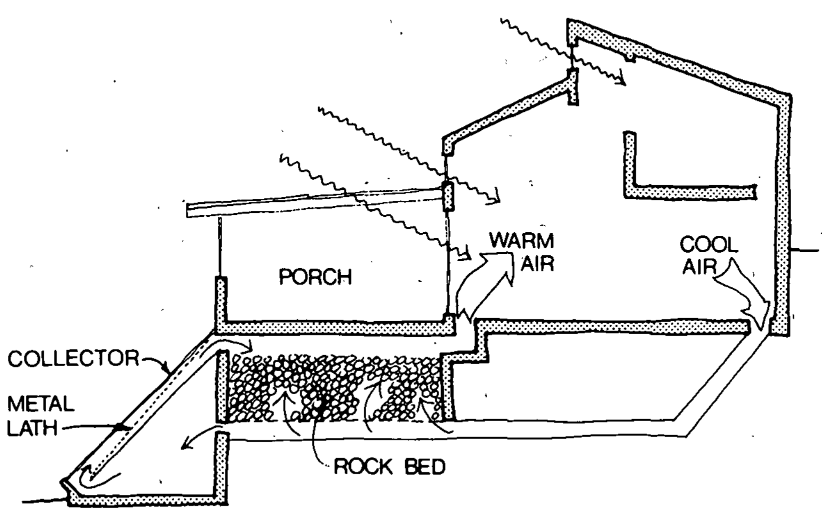


Figure 3-17. The Davis House: Thermosiphoning Rock Bed

Three-hundred-twenty square feet of collector is incorporated into the support structure of the porch at an elevation below that of the house. Warm air rises through the collector, becoming heated in the process. From there it travels through the rockbed located below the porch. Heat rises through floor registers, and cool house air returns to the collector. Approximately 75 percent of the heat for this 1,000 square foot house is provided by the passive movement of air. Reverse thermosiphoning on winter nights is prevented by manual dampers which also control the amount of heat rising into the house.

Jackson House-Western Tennessee: Attached Greenhouse

Perhaps more appropriately termed a "sunroom" than a greenhouse, the 360 square feet of south glazing on the Jackson house can collect 500,000 Btu on a clear winter day.

The heat is stored primarily in the four-inch-thick slab floor of the house, and in the eighteen inches of dirt beneath it. Insulated from the ground below by two inches of foam insulation, the slab and 18 inches of earth can store 500,000 Btu in a 10°F temperature rise.

During the summer, deciduous trees in combination with roof overhangs prevent direct penetration of sunlight into the house. Excess hot air is vented at the peak of the greenhouse. To replace this vented air, earth-cooled outdoor air flows through buried pipes that feed into the subfloor duct work (Figure 3-18).

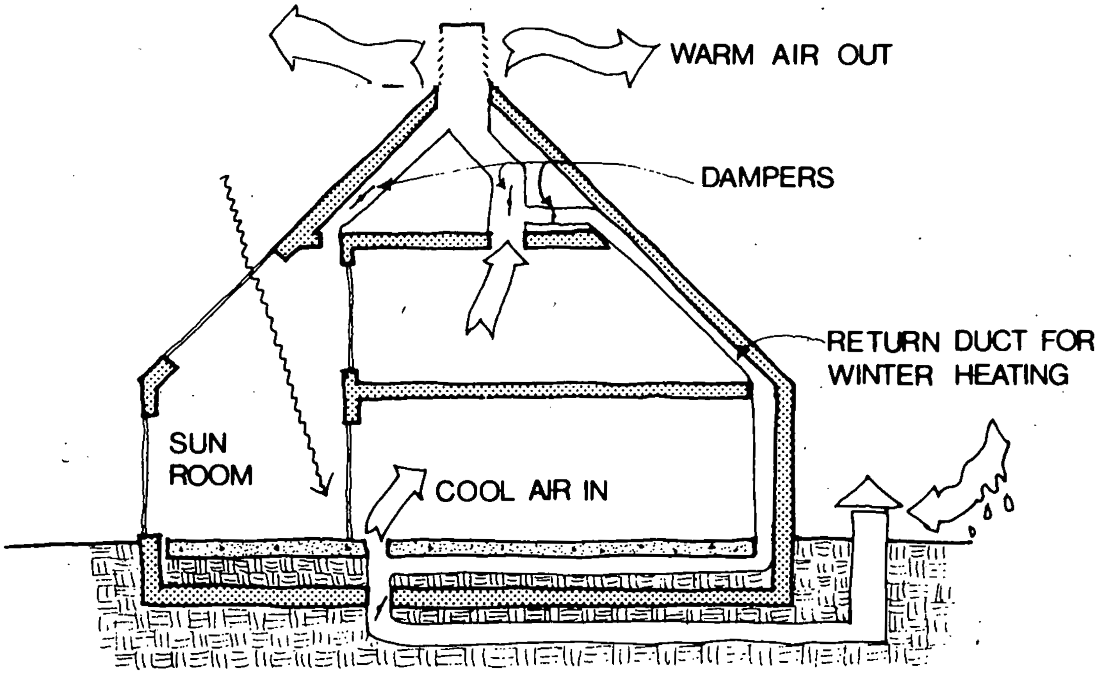


Figure 3-18. The Jackson House: Summer Operation

National Scientific Research Center-Odeillo, France: Thermosiphoning Wall Panel

The main office building of the National Scientific Research Center uses thermosiphoning wall panels in combination with windows. Together, the windows and wall panels supply about 50 percent of the building's heat (Figure 3-19).

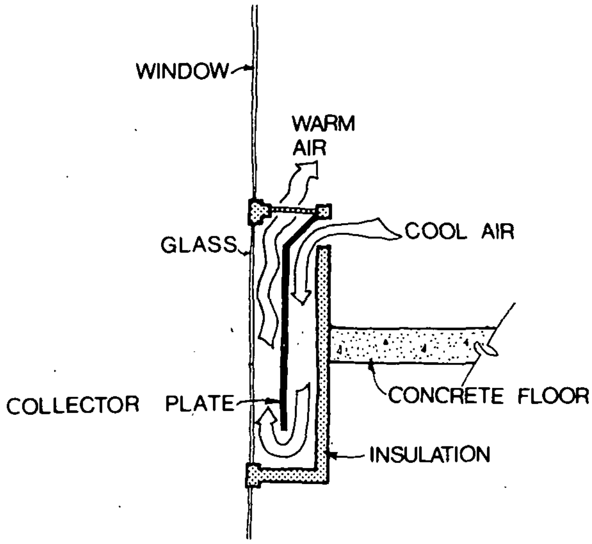


Figure 3-19. Odeillo Office Building: Thermosiphoning Wall Panel

No provision has been made to store the heat other than the thermal mass of the building, which in this case is reinforced poured concrete. The panels are designed to be easily closed and "turned off" during warm weather. Their design allows cool air to settle to the bottom of the air passages, and prevents cold air in the panels from entering the building at night because it inhibits thermosiphoning.

Breadbox: Solar Water Heater

A breadbox solar water heater usually consists of a tank (or tanks) of water covered by glass or plastic and enclosed in an insulated box. The tank is painted flat black and lays horizontally inside the insulated box, which is oriented south with its long axis in the east-west direction. Zomeworks Corporation, the developer of this system, recommends double glazing over the tank. In fact, triple glazing should be used in frigid climates.

The insulating box minimizes heat loss by completely enclosing the tank and glazing during cloudy or sunless weather. Multiple (four or five) layers of very clear plastic film can be used in lieu of movable insulation.

The tanks can be filled with water from either a pressurized or non-pressurized source. Once in the tank, the water is heated slowly but uniformly. In unpressurized systems, the water is used up before the tank is refilled. In pressurized systems, cold water is brought into the tank as warm water is drawn off, and some mixing occurs. If dual tanks are used (Figures 3-20 and 3-21), the effect of mixing is reduced; hot water is drawn from one tank while cold water flows into the other.

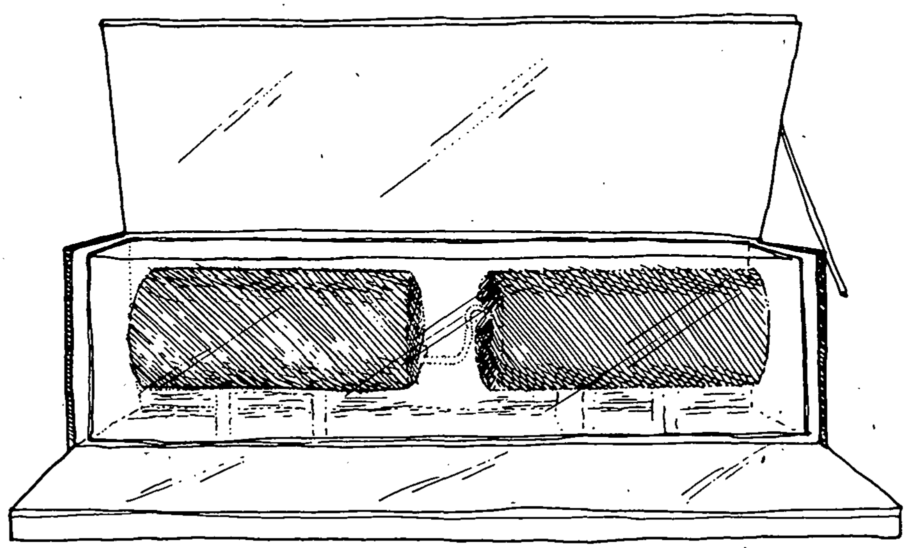


Figure 3-20. Dual-Tank Breadbox Hot Water Heater

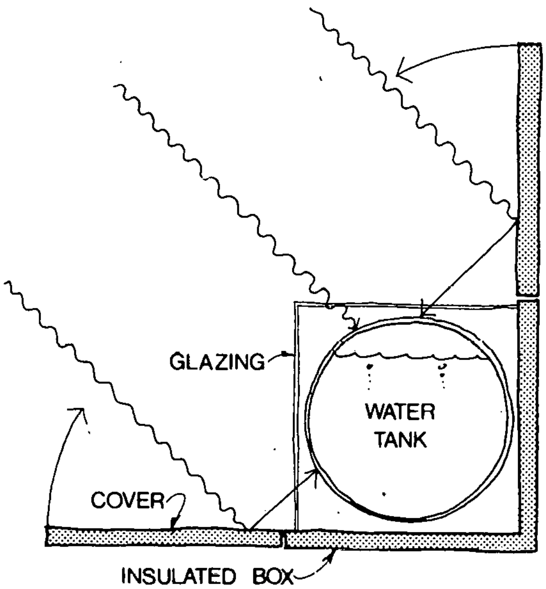


Figure 3-21. Breadbox Hot Water Heater: Cross-Section

PASSIVE SYSTEM DESIGN

Direct Gain

During the winter, total heating demand can be lessened by direct entry of sunlight through windows. Customarily, however, such passive solar gains have not been included in the computation of seasonal heating supply and demand. Building designers should be concerned with reducing total seasonal energy consumption. Unfortunately, most research on solar gain has focused on reducing energy required for cooling and refrigeration in hot weather rather than on reducing heating energy needs in cold weather. The development of useful design tools for direct solar gain has begun based on air conditioning practices.

Probably the best way of using the sun's energy for heating is to let it penetrate through the roof, walls, and windows of a building. Insulated roofs and walls do not allow this to occur nearly as readily as do windows. The color of roofs and walls affects the amount of heat that passes through them since dark colors usually absorb more sunlight than light colors. Color is particularly important when walls and roofs have little or no insulation. It has a decreasing effect as insulation levels increase. In warm and hot climates, exterior surfaces that face the sun should be light in color; in cool and cold climates, such surfaces should be dark.

Since solar radiation strikes differently oriented surfaces with varying intensity, most buildings benefit if walls and roof are oriented to receive this heat in the winter and to shed it in the summer.

Victor Olgyay in his book, Design With Climate, cautions against conclusions about the orientation of walls and roofs that generalize for all locations. Due south may not be optimal for all locations, but will almost always be better than 30° east or west of it. The type of building, its method of construction, and especially the climate, greatly affect the design.

A building's energy demands can be reduced by optimizing the ratios of its length to its width to its height. The optimum shape loses the minimum amount of outward moving heat and gains the maximum amount of solar heat in the winter, and absorbs the minimum amount of solar heat in the summer. Olgyay has shown that:

- In the upper latitudes (40°N+), south sides of buildings receive nearly twice as much radiation in winter as in summer. East and west receive 2 1/2 times more in summer than in winter.

- Lower latitudes (35^{o}N-) gain even more on south sides in the winter than in summer. East and west walls can gain two or three times more heat than those on the south in the summer.

- Well-insulated buildings and those with shading devices on the south side show even greater variances, but those with windows that are small or fully shaded show less.

- The square house is not the 'optimum' form in any location.

- All shapes elongated on the north-south axis work with less efficiency than the square one in both winter and summer.

- The optimum form for most locations is elongated along the east-west direction.

Besides saving energy, there are other considerations in building shape, some of which also affect total energy and resource savings and environmental well being. For instance, the orientation or size of the site may not accommodate the optimum shape; the needs and purposes of the building may require other shapes; or, if natural lighting is desired, more perimeter exterior surface areas may be needed for the placement of windows.

Besides reducing the electrical energy required for lighting, glass exposed to sunlight admits heat. Houses with major areas of south-facing glass are designed to benefit from this fact. Such "solar houses" have reportedly saved up to 30 percent in fuel bills. The greenhouse effect is primarily responsible for this phenomenon.

Glass readily transmits short-wave light radiation but does not readily transmit in the other direction the long-wave thermal radiation resulting when the light energy changes to heat energy as it hits an interior surface.

Extensive work on this "solar house" concept was done by F. W. Hutchinson at Purdue University. In 1945, under a grant from Libbey-Owens-Ford Glass Company, two nearly identical houses were built side by side. The only difference was that one of the houses had considerably more south-facing glass. Based on the performance of these two houses, Hutchinson reported in May 1947 that the available solar gain for double windows in south walls in most cities in the U. S. A. is more than sufficient to offset the excess transmission loss through the glass.

The use of large areas of south-facing glass requires that the thermal capacity of the inside of the building be great enough to absorb and store the excess heat so that the interior space does not require venting. The better the insulating value of the walls and windows, the less heat will be lost through heat transmission and the greater the heat capacity will have to be.

Large glass areas require a larger sized heating system because of the extra heat loss through the additional glass during cold cloudy weather. Most heating plants in current residential construction are oversized. For a given latitude, solar intensity is uniform while heat loss varies with outside temperature. It follows then that south-facing glass in mild climates has greater potential for reducing seasonal heating demand than it does in cold climates at the same latitude.

This is illustrated in Table 3-1 prepared by Hutchinson. It can be used as a design tool to approximate solar heat gain through south-facing windows for the seven-month season. The effects of window type and latitude are relatively small compared with the effects of normal outside air temperature and with the fraction of possible sunshine.

Table 3-1. Solar Heat Gain Through Use of Glass

City	Fraction, F, of maximum possible sunshine.	Normal temperature during seven-month heating season.	Design outside winter temperature.	Net energy gain, Btu/hr/sqft due to use of glass.	
				Single glass	Double glass
1. Albany, N.Y.	.463	35.2	−24	−12.8	5.6
2. Albuquerque, N.M.	.770	47.0	−10	18.05	30.2
3. Atlanta, Ga.	.522	51.5	−8	9.0	18.8
4. Baltimore, Md.	.553	43.8	−7	2.0	15.9
5. Birmingham, Ala.	.510	53.8	−10	10.9	19.5
6. Bismarck, N.D.	.546	24.6	−45	−20.1	4.0
7. Boise, Id.	.540	45.2	−28	22.9	16.0
8. Boston, Mass.	.540	38.1	−18	5.2	11.7
9. Burlington, Va.	.419	31.5	−29	−19.5	.9
10. Chattanooga, Tenn.	.503	49.8	−10	5.9	16.7
11. Cheyenne, Wyo.	.666	41.3	−38	5.7	20.3
12. Cleveland, Ohio	.408	37.2	−17	−13.7	3.7
13. Columbia, S.C.	.511	54.0	− 2	11.2	19.6
14. Concord, N.H.	.515	33.3	−35	−12.0	7.4
15. Dallas, Texas	.470	52.5	−3	7.1	16.4
16. Davenport, Iowa	.539	40.0	−27	−3.1	12.8
17. Denver, Colo.	.705	38.9	−29	5.2	21.7
18. Detroit, Mich.	.429	35.8	−24	14.1	44.0
19. Eugene, Ore.	.439	50.2	−4	2.7	13.2
20. Harrisburg, Pa.	.495	43.6	−14	−1.5	12.5
21. Hartford, Conn.	.532	42.8	−18	−.3	14.1
22. Helena, Mont.	.521	40.7	−42	−3.3	12.2
23. Huron, S.D.	.579	28.2	−43	−14.1	8.0
24. Indianapolis, Ind.	.507	40.3	−25	−4.6	11.2
25. Jacksonville, Fla.	.400	62.0	−10	13.9	18.1
26. Joliet, Ill.	.530	40.8	−25	2.9	12.8
27. Lincoln, Neb.	.614	37.0	−29	−2.2	15.3
28. Little Rock, Ark.	.513	51.6	−12	8.5	18.3
29. Louisville, Ky.	.514	45.3	−20	1.5	14.6
30. Madison, Wis.	.504	37.8	−29	−7.6	9.5
31. Minneapolis, Minn.	.527	29.4	−34	−15.74	5.8
32. Newark, N.J.	.550	43.4	−13	1.4	15.5
33. New Orleans, La.	.370	61.6	7	11.7	16.1
34. Phoenix, Ariz.	.590	59.5	16	21.9	27.5
35. Portland, Me.	.525	33.8	21	−7.2	12.0
36. Providence, R.I.	.542	37.2	−17	−6.1	11.3
37. Raleigh, N.C.	.570	50.0	−2	−10.0	20.6
38. Reno, Nev.	.637	45.4	−19	8.6	21.7
39. Richmond, Va.	.594	47.0	−3	8.0	20.2
40. St. Louis, Mo.	.567	43.6	−22	2.6	16.6
41. Salt Lake City, Utah	.592	40.0	−20	0.0	15.9
42. San Francisco, Cal.	.615	54.2	27	17.3	25.7
43. Seattle, Wash.	.340	46.3	3	−7.3	5.2
44. Topeka, Kan.	.613	42.3	−25	3.8	18.4
45. Tulsa, Okla.	.560	48.2	−16	7.4	19.0
46. Vicksburg, Miss.	.447	56.8	−1	−10.7	17.7
47. Wheeling, W.Va.	.408	46.1	−18	3.7	9.0
48. Wilmington, Del.	.558	45.0	−15	3.7	16.9

From <u>Progressive Architecture</u>

May, 1974, pp. 90-94

The fourth and fifth columns show the net gain of energy (a negative number represents a loss) resulting from the use of one square foot of single or double glass. All 48 cities show net energy gains through the double glass. (The losses for single glass in some cities should be compared with corresponding heat loss through walls.) The approximate seasonal heat gain is the product of the value in column four or five (single or double glass) times the window area, times the number of hours in the heating season. Of course, there will be many days when there will be too much heat to use comfortably. Often, too, other factors such as pulled shades or closed curtains will reduce solar heat gain. Thermal barriers (e.g., insulating shutters) to cover windows at night can greatly reduce heat loss and increase the overall net heat gain. In St. Louis, for example, the net energy gain through south-facing double glass is 16.6 Btu/hr./sq. ft. (Column five). Assuming a 200-day heating season, the total seasonal net gain is 200 days/season x 24 hrs/day x 16.6 Btu/hr/sq. ft., or about 80,000 Btu/season/sq. ft., comparable to the useful energy output of a good solar heating system.

If heat gain is to be maximized and heat loss minimized during the winter, two layers of clear glass must be used. Although this configuration may transmit considerable heat during the summer, shading devices such as trees, awnings, and venetian blinds can reduce the need for reflecting or heat-absorbing glass. These expensive glasses might be considered for east- or west-facing windows because they are usually more difficult to shade than south-facing ones. (North-facing glass does not require shading except in the southern part of the country where the sun may strike north-facing glass to a significant extent at sunrise and sunset during the summer.)

Large buildings with small exterior surface areas compared to relatively large amounts of useful floor area often generate tremendous amounts of internal heat from the activities of people, the burning of lights, and the operation of equipment. It is not uncommon for such buildings to require air-conditioning year round, even in the dead of winter and particularly in the summer. The use of glass that is shaded twelve months a year instead of only during the summer will be most successful in these situations. Of course, every effort should be made to reduce the amount of heat produced by people, lights, and machines. The dependence on artificial lighting should be reduced by using more natural lighting (through windows), by using lower lighting levels, or by placing lighting fixtures directly where the light is needed (task lighting).

Designers should also consider the shading effects of buildings on the surrounding environment, i. e., whether the shading occurs on buildings that directly or indirectly use the sun's heat or light or on wild vegetation or gardens that need sun to grow.

When a building is a solar collector, it needs a method of soaking up or storing heat to prevent overheating when the sun shines and to retain (store) some of the heat for use when the sun does not shine.

Probably the most efficient storage container is the material of which the building is built - the walls, floors, roof, and partitions. All materials absorb and store heat as they are warmed. When temperatures around them become cooler, the stored heat is released to the cooler surroundings and the materials themselves cool.

For a building, this phenomenon is very significant. Solar energy penetrates through the walls, roof, and windows of the building during the day. The short-wave light is stopped by the partitions, floors, and furniture of the building after it penetrates through the glass. As it is stopped, it turns into heat, much of which is absorbed. If the objects and materials inside of the building are already warm--filled to capacity with heat--they release their heat to cooler objects and materials in the building. The air in the building is one of the "materials" likely to heat up the soonest, and it helps to distribute the excess solar heat gain to the rest of the materials.

However, if the building materials have already heated up to the temperature of the air or cannot absorb the heat fast enough, the air continues to warm and overheat, causing possible discomfort to the occupants. The materials in the building in turn continue to rise in temperature, storing more heat. The greater the heat storage capacity of the objects and materials in the building, the longer it will take for the air to reach temperatures of discomfort.

When the sun goes down, and if it is cold outside, the building begins losing heat. For buildings which have not stored any solar heat during the day, the heat will have to be provided by other means. However, if a building has a sufficient amount of materials inside of it, and if the sun is able to penetrate during the day to warm these materials, it will be heated by the sun even after the sun has set. The warmed materials will lose their stored heat to the inside air as it cools off. Depending on the quantity of heat storage material, the amount of sun that penetrates the building and is stored by the materials, and the heat loss of the building (which depends on a number of parameters such as the amount of insulation, the inside temperature, and the outside temperature), a building can remain comfortable for many hours and possibly even days without requiring extra heat from other sources. Direct gain passive systems use this combination of windows and interior building heat storage to accomplish solar heating.

These south-facing glass areas, in combination with the mass of the building, reduce the energy need; the building's mass also aids in leveling off demands on heating and cooling equipment. If the building does not respond quickly when the outside temperature fluctuates, the mechanical equipment will not have to be as large to satisfy the needs and will be able to operate at more constant conditions. One extreme is a lightweight, uninsulated wood-framed building. On a cold but sunny day, the furnace might not be used at all. However, at night its full capacity might be needed to maintain comfortable temperatures. A massive, earth-embedded building, on the other hand, would "see" an outdoor temperature that would be averaged over several days, and possibly as much as ten days or two weeks. A relatively small heating system would operate fairly constantly, and the comfort within the building would be fairly even throughout.

Although total overall energy consumption is reduced for some heavy buildings, a higher initial load than for lightweight buildings may be placed on the heating and cooling equipment in the morning if temperatures are allowed to drop during the night. This is because the mass must be heated to room temperature before the room will be comfortable. (Temperatures do not drop nearly as much in heavy buildings as in light ones.) Setting the thermostat lower at night, however, saves considerable amounts of energy. Current studies at Brookhaven National Laboratories as well as previous work by the National Bureau of Standards indicate the potential energy savings "heavy" construction offers.

Unfortunately, designing heavy buildings is contrary to current thinking and design practice. Technology and design focus on trying to "do more with less," and the structural genius is the person who can use the least amount of material in the process of enclosing a space. Such thinking is usually limited to evaluating only the materials used without including the energy consumed or the longevity of the product. The visual weight of buildings is an important esthetic consideration for some people, and the trend now is to design and build a structure so that it appears to be light in weight.

Adding mass can add to the cost of a building. Poured concrete rises and falls in favor among construction professionals. Cost, availability, ease of handling, and weight influence these attitudes.

More materials are required for heavy buildings than for light ones. The extra energy required for the manufacture of the added materials is difficult to compare with the heating and cooling energy that could be saved, but heavy buildings are likely to have long lives and in most cases are more durable than light ones. (Noteworthy exceptions are wood homes lasting several hundred years. Examples of massive buildings with long lives are Greek and Roman temples and Western European cathedrals.)

Adding thermal mass need not be difficult. Placing containers of water within the confines of a building (or, better yet, in front of a sunlit window) is one solution, though unlikely to be accepted by very many people. Sand, gravel, concrete or even water (in plastic vinyl containers) can be used to fill the voids in concrete masonry block. Massive fireplaces, interior partitions of concrete or brick, or two inches of concrete or brick on the floor can greatly add to the thermal inertia of buildings. Even additional layers of gypsum board on interior wall surfaces may help. And there is increasing use of gravel or sand beds in crawl spaces through which overheated room air is circulated through the use of fans. The heat is stored for later use when the room temperature drops below the storage temperature. The cooler room area is then heated as it is circulated through the warm sand or gravel. Several homes using this system in combination with good energy conservation construction are experiencing fuel bills of about 10 percent of conventional construction.

Trombe Walls

Basic System Configuration -- The Trombe wall is a south-facing concrete or masonry wall covered on the exterior by light-transmitting glazing. Its uninsulated interior face is exposed to the heated face. The recommended design has vents at the top and bottom to permit air flow by natural convection from the outer surface of the wall into the building. A variety of system designs have been built, and optimization of the design for specific climates is possible. The design illustrated in Figure 3-22 is considered cost effective for heating applications in the majority of U.S. climates. The modular dimensions and the particular construction details used here should help to simplify the contractor's tasks of estimation and installation. From a performance standpoint, however, the Trombe wall concept need not be so rigidly defined. (See regional and climatic considerations under Economics.)

Materials -- The design consists of an outer glazing system, an inner thermal energy storage wall, backdraft dampers for air flow control, and various optional trim and structural integration details.

The outer curtain wall/window wall system is aluminum framing in combination with two layers of translucent or semi-transparent low-cost plastic (such as Filon or Kalwall) rather than glass. Unlike a direct gain passive system, views out are not possible; views in, showing the rough concrete wall surface, may be undesirable. Maximum system temperatures, even under stagnation conditions, are in the range of 150-180°F, far below the stagnation temperatures of metal flat plate collectors. Heat resistant plastics easily withstand the lower temperatures experienced by the glazing.

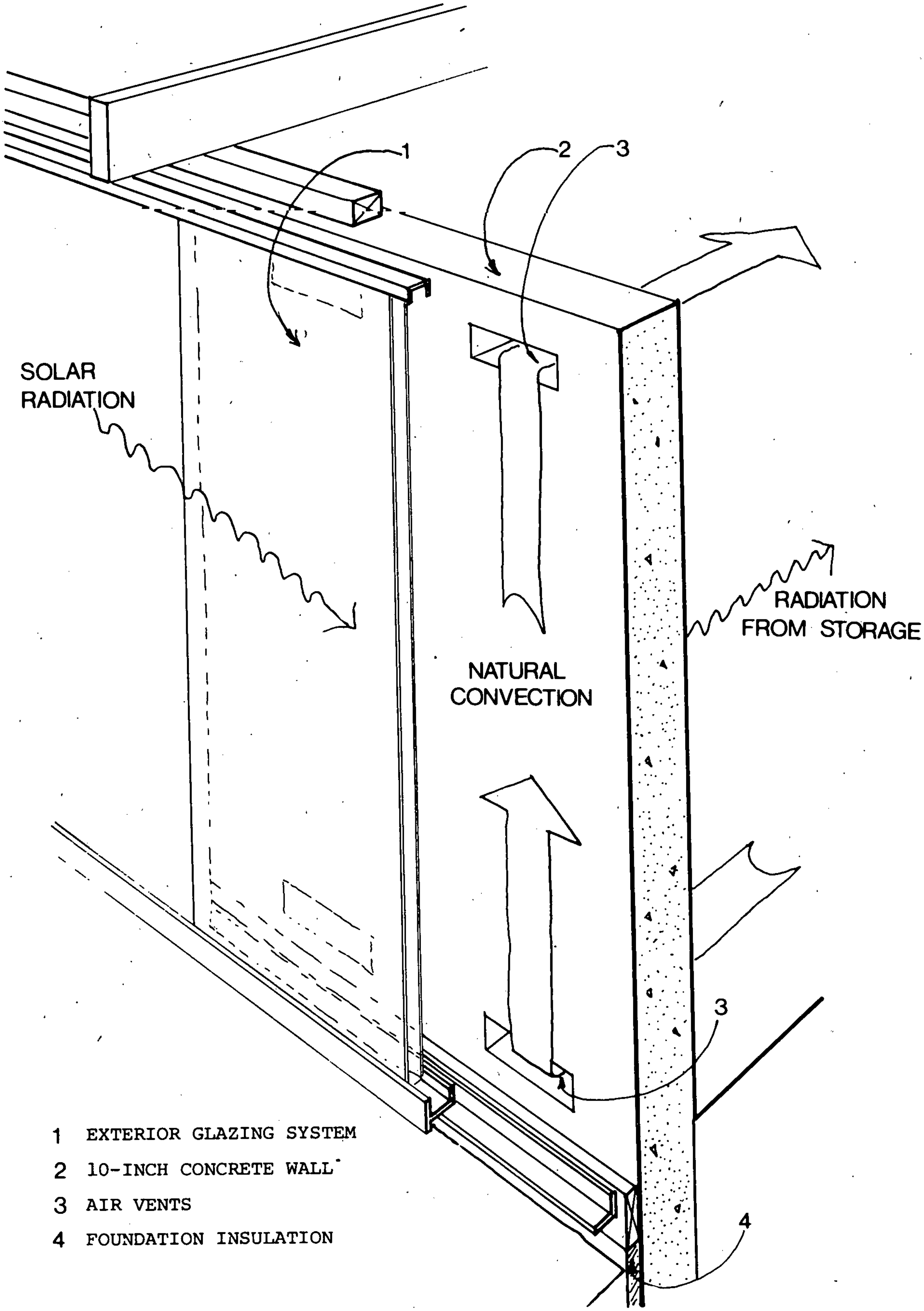


Figure 3-22. Trombe Wall Design

The thermal storage wall is concrete, either cast in place or laid with solid concrete masonry units and concrete mortar. The concrete should be regular stone concrete (about 140 lbs/cf); lightweight aggregates should not be used. When, as in most cases, the Trombe wall serves also as a structural wall, the necessary reinforcing wire or bar and any structural anchors can be added without altering the wall's solar performance characteristics. In general the juncture between the inner storage wall and the foundation, floors, adjacent side walls, and roof should be treated as normal construction. A primary exception is to eliminate or change details that permit direct conduction of heat to masonry or metal exposed to the weather. For this reason, the concrete wall is thermally isolated from the metal frame of the glazing system by wooden blocking and from adjacent conventional concrete construction by preformed vinyl or rubber control joints. Foundations directly below Trombe walls should be protected with rigid insulation in the same way as are perimeter heating systems in slab-on-grade construction.

The backdraft dampers serve the same function as backdraft dampers in HVAC systems, that of preventing air circulation in the "wrong" direction. However, in Trombe walls, slowly rising solar heated air in the cavity between the concrete wall and the glazing exerts a slight pressure to open them while cool air falling exerts a slight reverse pressure, forcing them to close. There are no commercial suppliers of these dampers, and present installations use either custom-fabricated dampers or do without. Without the dampers, the performance of a Trombe wall can be reduced by as much as 20 percent. Furthermore, drafts are created by the cool reverse flowing air.

Any interior finish on the Trombe wall must not prevent its heat from reaching the room. Conventional architectural concrete finish such as exposed aggregate and sandblasted or brushed surfaces can be used. The surface can be sealed and painted any color. Sheet materials, such as wood or hardwood paneling or gypsum board, should not be used.

The exterior surface should be cleaned with a masonry cleaner prior to painting with virtually any dull finish. Although dark brown and dark green have been used, flat black paint is preferred.

Design -- The concrete storage wall in this basic design is 10 inches thick and nominally 8 feet high. A 7-foot 10-inch height is suitable for cast-in-place construction. Walls can be any length, but vent holes must be provided on 2-foot centers across the entire length. Vent holes in concrete masonry walls are nominally 3-5/8 inches by 15-5/8 inches; single blocks are left out of lower and upper courses. In poured concrete walls, 4 inches by 15 inches is preferred. The upper and lower vents are placed as close to the ceiling and floor as is practical, and in no case should the vertical distance between vents be less than 6 feet. Decorative grills are installed over these openings on the interior face. The lower grill includes the backdraft damper.

The exterior glazing system is mounted 3 to 4 inches away from the outer blackened concrete surface. Where glazing supports are attached to the wall, wood or other insulating material should be used as a separator. The glazing should extend above and below the face of the storage wall, fully exposing it to the sun. Since glazing is the weather skin of the building, it must be airtight and water resistant.

Construction and Installation -- Building the Trombe wall described here normally requires only general contracting skills. Depending on contractor preference, the installation of the glazing system can usually be handled by the manufacturer's representative. This enables the building owner to obtain a better warranty on its weather tightness. The storage wall should be constructed at the lowest cost possible given the thermal, structural and interior finish requirements outlined above. If the contractor or his subcontractors normally use poured concrete only in foundation work, or if multi-story installations are planned, the solid masonry unit wall is usually preferred.

Work scheduling presents no problem if the contractor carefully reviews construction requirements in advance. The glazing system is usually fabricated to site dimensions; therefore, to avoid delays in closing the building, these dimensions should be established early in construction and orders should be placed early for the glazing. Concrete finishing work may require the appropriate trades on the job site at other than the normal times.

System Selection Criteria --

Building Integration -- Trombe walls have temperature stability and are appropriate for a variety of building types. The thermosiphoning air vents provide a significant level of control over heat delivery to the space. The opaque wall eliminates the excessive glare associated with direct sun. Sun damage to goods and furnishings is avoided, an advantage if used in retail stores and commercial buildings. The structural wall is fire resistant and provides security for warehouses and manufacturing plants as well as structural stability in high rise construction. Finish details can be very rough to suit manufacturing and industrial applications, yet the Trombe wall can be detailed and constructed to fit residential designs.

Costs -- First costs for Trombe walls vary with differences in construction and detailing of the mass storage wall and the exterior glazing. In areas where concrete and concrete masonry construction above grade is common, the storage wall is generally inexpensive. If an experienced subcontractor is available, or if materials can be obtained cheaply through local suppliers, the exterior glazing will be low cost.

Cost estimates prepared for the design described here (with plaster interior finish) vary from a low of $11/square foot to a high of $13/square foot in 1977 dollars. To obtain a true net cost differential for passive solar heating, the cost of conventional construction replaced by the Trombe wall should be subtracted. Since the most expensive conventional exterior wall construction, including insulation and interior finish, usually runs between $2-$3/square foot, the true first cost of the Trombe wall is estimated at $9/square foot.

Operating costs for the Trombe wall are zero, and little or no maintenance is required. Maintenance in many climates is comparable to that for vinyl siding: occasional (every 2 to 4 years) washing of the exterior glazing is advised. Harsh industrial environments may degrade the plastic glazing; "refinishing" coatings are available from leading manufacturers and may be be applied on a 3- to 5-year basis.

Thermal Performance -- Thermally, the Trombe wall performs reliably. Heat losses, even under worst conditions, are not very different from conventional commercial construction. The overall U-factor of 0.23 (back thermosiphoning prevented) enables the wall to meet ASHRAE 90-75 standards for single-family residences located in climates not exceeding 5200 degree days. If solar gains are considered, it is a net heat producer. In a sense, then, this results in a negative U-factor over the course of the heating season.

Solar energy collection takes place at low to moderate temperatures at the surface of a Trombe wall, generally not exceeding 150^{o} F. This provides good instantaneous efficiencies (generally comparable to active system flat plate collectors), while the vertical south wall orientation enables good winter heating performance and minimizes summer overheating concerns except in the deep south. Air is delivered to the room through the vents at low temperature, generally not exceeding 90^{o}F (or temperatures 30^{o}F higher than entering room air). Normal air flow is approximately 1 cfm/square foot.

The interior surface of the wall also delivers heat to the space by radiant means, fluctuating in temperature on a daily basis. Temperature swings on the interior wall face are most often recorded between 8-15^{o}F. The maximum delivered air temperature and the maximum interior wall surface temperature occur approximately eight hours apart, with the latter generally in the late evening. Peak heat transfer rates are normally lower than 30 Btu/square foot/hour for combined radiant and convective heat transfer from the interior surface. Total convective and radiant heat transfer from the interior wall is usually not more than 35 Btu/square foot/hour.

Over the heating season, the Trombe wall absorbs enough solar energy to cancel all thermal losses from the building interior through the wall itself and delivers excess heat to the remaining building load. Simulations at Los Alamos Scientific Laboratories support estimates that each square foot of Trombe wall provides 35 to 70,000 Btu units to the building heating load each season. If predictable seasonal losses that would have occurred through a conventional wall are considered, each square foot of Trombe wall replacing conventional construction will effectively reduce building oil consumption by 0.9 gallons, or electrical consumption by 19 Kwh.

Economics -- Estimates for delivered energy and the cost per million of Btu units delivery are shown for representative cities in Table 3-2. For comparison with current conventional energy costs, consider the following: electricity at 4.4¢/Kwh is equivalent to an energy cost of $12.90/MBtu; number 2 fuel oil burned at a seasonal efficiency of 0.50 at 50¢/gallon results in an energy cost of $7.14/MBtu. Actual performance will vary with the ratio of system size to building load. Future conventional energy costs will be much higher. The 10 percent inflation factors listed in Table 2, page 6-55, of this text indicate that costs will double in eight years and be 6.12 times greater in twenty. The average multiplier of 2.86 yields a time-averaged fuel cost of $36.93/MBtu (electrical). Like all solar systems, oversized Trombe wall passive systems will be less cost effective. Within the constraints of normal building designs, however, it is difficult to oversize south-facing Trombe

TABLE 3-2

DELIVERED ENERGY[1)] & ASSOCIATED COSTS[2)] FOR TROMBE WALLS

City	Btu/sf-yr	Cost/MBtu
Fort Worth, Texas	38,200	$23.60
Madison, Wisconsin	44,900	$20.00
Boston, Massachusetts	47,100	$19.10
Medford, Oregon	47,400	$19.00
Los Angeles, California	53,700	$16.80
Boulder, Colorado	62,500	$14.40

1) These estimates were prepared by J. Douglas Blacomb at Los Alamos Scientific Laboratories for a particular double-glazed Trombe wall, and a fixed area-to-building load ratio: 2 square feet (system)/Btu-^{o}F-hr (loss).

2) These figures are the effective energy cost obtained by applying a capital recovery factor of 10% (corresponding to a 7-1/2% interest rate and a 20-year term) to estimated first costs.

wall systems, and the performance estimates provided here can be taken as representative for initial project development.

Alternate System Configurations --

Variations in Trombe wall design reflect the nature of local materials, builder skills, and architectural approaches. Walls have been constructed from almost every masonry material, from architectural grade brick to adobe. Thicknesses vary, reflecting each designer's attempts to work with the time-lag and thermal storage characteristics of the wall material. (Recent work on this subject suggests that dense concrete between 8 to 20 inches thick is proper.)

Glazing systems can be of one, two or even three layers; selections of one- or three-layer options should reflect a careful analysis of the cost-effectiveness of a particular design.

As previously mentioned, the height and width of a Trombe wall can be changed to suit architectural requirements without any loss in performance.

New Materials -- One of the most important characteristics of the Trombe wall as it is currently built is its use of existing, available construction materials for solar heating. These materials do not behave as well, thermally, as some would wish. A close relative of the Trombe wall, the waterwall (epitomized by Zomeworks' Drumwall), is adopted by some to obtain faster heat transfer into storage and cooler surface temperatures. New techniques and materials could be developed along these lines. Heat pipes could link a storage space and an absorbing surface, separated by a thin but effective insulating barrier. The resulting heat transfer would be one way, reducing to a minimum the losses from the system, especially those that occur at night. (Insulating shades and movable insulations systems, including Beadwall®, have been tried to reduce these heat losses, but the cost effectiveness of such approaches has to be carefully examined in each case.) Such one way flow of energy through a thermal mass wall is accomplished by the "Thermic Diode" as demonstrated at the Massachusetts Institute of Technology by Dr. Shaun Buckley; it is currently under further development. A "diode" is a one way valve. A thermic diode, then, permits heat to move in one direction only. In this case, it permits warm water to move from the warm collector surface to the storage wall by thermosiphoning but prevents reverse thermosiphoning at night from the storage wall to the cooled-down collector surface.

The encapsulation of eutectic salts and their incorporation into a variety of Trombe wall system designs, resulting in lightweight mass walls, is under study. Improvements along these material and product development lines will increase system efficiencies, but the in-place cost of improved systems will rise accordingly. From a cost-per-Btu basis, Trombe walls (and most passive solar heating techniques) are not likely to undergo much change.

Improved Engineering -- Trombe walls are very close to being established, accepted heating systems. Their reliability has been demonstrated in many installations. Their costs are becoming better known, and work such as that carried out by Los Alamos Laboratories is establishing a simple engineering base from which designers and installers can work. This Los Alamos work is reported in the Sandia Laboratories publication referenced at the end of this chapter.

Improvements in engineering require that such work continue by including alternate designs outlined above, as well as keeping pace with new materials developments.

Solar Roof Ponds

Basic System Configuration --

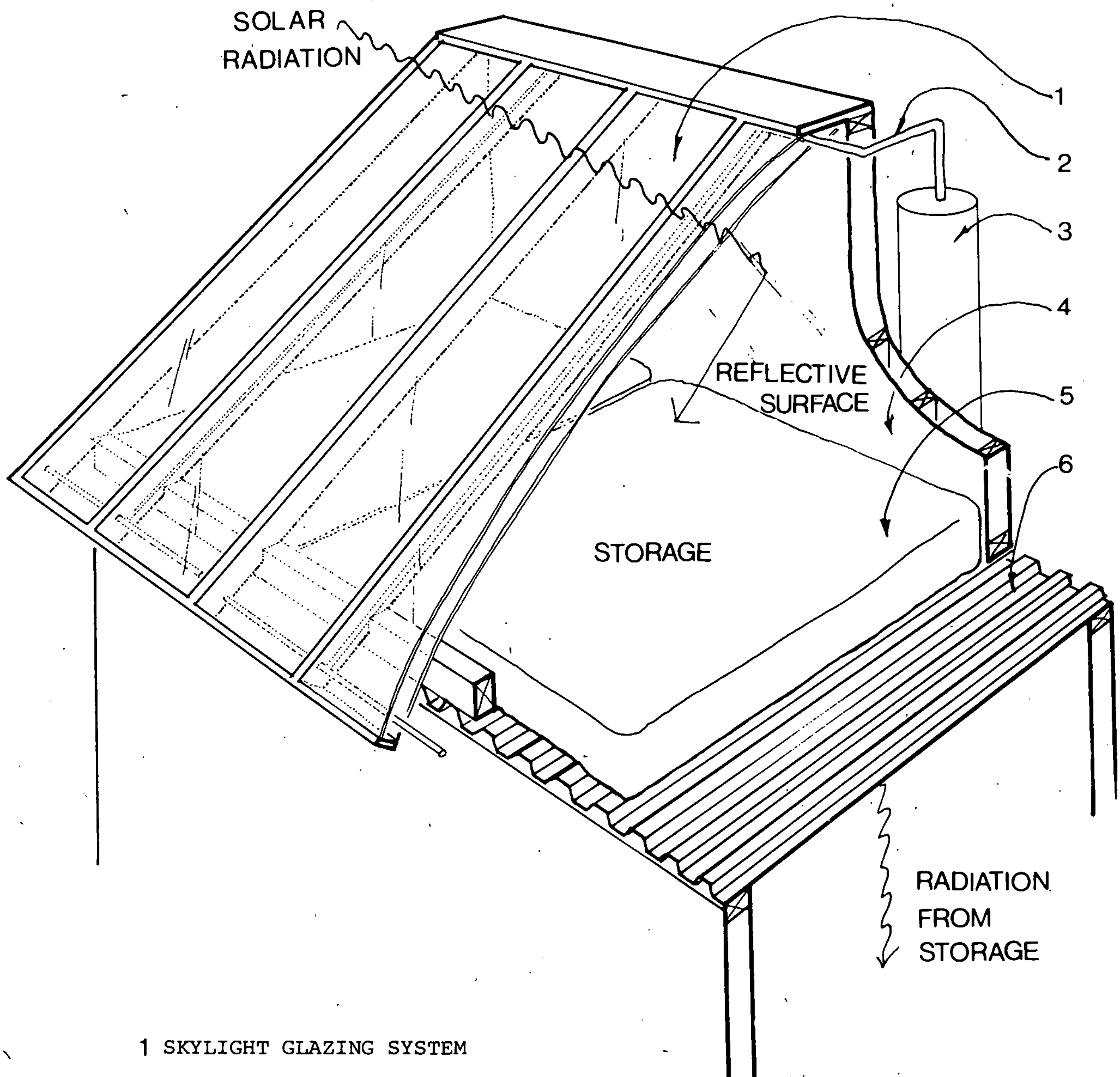
The roof pond is unique in that it is the only passive solar heating system that provides substantial cooling effects. The most widely accepted version of this system employs a shallow pond of water in thermal contact with a strong but highly conductive flat roof and ceiling structure. Water bags, which serve as thermal storage, are exposed to solar heat gain and protected against heat loss at appropriate times by controlled movable insulating panels. Cooling is accomplished with combinations of night-sky radiation, night air convection, and in some cases, evaporative cooling of water flooding the outer surface of the bags.

The design of solar roof ponds varies substantially from region to region as efforts are made to improve winter heating performance in climates harsher than those where original installations are located. All are adaptations of the original "Skytherm" concept, now a proprietary, patented design marketed by Skytherm Processes and Engineering, Los Angeles, California. Costs and thermal performance of the original Atascadero House are covered in sections that follow.

Figure 3-23 shows the approach taken on a retrofit roof pond application in Concord, New Hampshire -- the Freese House (1976). It uses Beadwall® to replace the horizontal movable panel insulation used by Harold Hay. Using other forms of tilted movable insulation can increase the weatherability of the system in climates where snow and ice are common winter conditions, but can decrease the system's natural cooling potential and its cost effectiveness. For installations in climatic regions characterized by significant cooling loads and mild (usually above freezing) winters, the original system, known as "Skytherm Southwest," is recommended. (See also Alternative System Configurations.)

Materials -- The solar roof pond attic replaces the ceiling and roof in conventional construction. It is a modular design based on a 12-foot span. Major subcomponents are:

- Steel floor deck and ceiling
- Vinyl plastic water bag thermal storage
- Wood framed glazing rafters and north reflective wall
- Plastic and aluminum double-glazed skylight system
- Beadwall brand movable insulation subsystem, including controls and bead storage



1 SKYLIGHT GLAZING SYSTEM
2 MOVABLE INSULATION PLUMBING
3 MOVABLE INSULATION STORAGE TANK
4 REFLECTOR WALL
5 10-INCH WATER BAGS
6 STEEL DECK

Figure 3-23. Roof Pond Design

Design -- The Beadwall® system is a form of movable insulation in which expanded polystyrene beads one-eighth to three-sixteenths of an inch in diameter are blown from a central storage container into the cavity between two glazings. When the sun shines, the beads are drawn from the cavity under vacuum and returned to the storage container. Two-stage through-flow blowers developing about 3.5 psi of either pressure or vacuum are used. These pressures must be withstood by the bead storage container. Several types of storage containers have been used, including 55-gallon steel drums. The design shown here incorporates 18-inch diameter, 18-gauge galvanized steel containers as described in the manufacturer's literature. A standard control package incorporates a sun sensor and timer to automatically power the Beadwall® system.

Zomeworks, Inc. does not usually supply the glazing system with the Beadwall®. The County Airport in Aspen, Colorado (1975), for example, integrates Beadwall® into a glazing system manufactured by Kalwall Corporation of Manchester, New Hampshire. This same combination is selected for the solar roof pond design.

The Kalwall system is based on modular aluminum framed panels faced with translucent fiberglass reinforced polyester sheet. A full range of battens, sills, skylight curbs and other mounting systems for roof applications are available. In the illustrated design, the panels are supported by conventional dimension lumber rafters. The rafters are doubled up on four-foot centers. (Rafter spacing should, of course, conform to local codes.) Rafter size should conform to local codes with respect to snow loads and other live loads; the dead load of the Kalwall glazing panels is less than 2 lbs/square foot.

The rafters bear on the back reflector wall. This is an insulated stud wall of conventional construction, with any desired exterior finish. The interior (attic) side of the wall is faced with an inexpensive reflective sheet material. Foil-backed gypsum board, applied backside out, or "Thermo-ply", a foil-faced paper-board insulating sheathing, may be used. Gable end walls are of similar construction. Gable vents should not be used unless they can be completely sealed during winter months.

The water bags, serving as solar collecting surface and thermal storage material, rest on the steel deck within the enclosure built of the materials described above. These bags should be fabricated of UV-stablized plastic. Twenty-mil PVC was used in the 1973 Atascadero House. Clear plastic may have the advantage of admitting solar energy to the full depth of the pond, but the effects of heat, light, and moisture may cloud the material in time. Appropriate materials may have been identified by Hay and others developing these systems. If not, the use of opaque, black vinyl bags, fabricated by a waterbed manufacturer, is suggested.

The steel deck must carry the dead load of the water (52 lb./square foot) over the 12-foot span, provide structural bracing equal to the conventional ceiling framing it replaces, and serve as a finished ceiling. Steel deck with ribs three inches deep, of 18-guage material, normally satisfies these requirements. Conventional paint finishes can be applied to the ceiling side of the deck; preparing the steel for painting should not be overlooked.

Construction and Installation -- The solar roof pond design requires careful scheduling by both contractor and owner. Two key items are the installation of the metal deck and the Kalwall panels. The deck must be detailed to drain leakage from the waterbags; it, therefore, provides a reasonable weather skin during construction. It should be tested with a water-spray for leaks before finish work is started on the floor below. Since the Kalwall glazing incorporating Beadwall® is a special order item requiring close coordination between two manufacturers, the architect or builder must arrange for this well in advance of installation time.

Installing and filling the water bags is the last step in construction. To service the Beadwall® system and allow periodic inspection of the water bags, a hatch door into attic space must be provided.

System Selection Criteria --

Building Integration -- The solar roof pond is the largest passive system type (in architectural volume). The 12-foot module is based on the span capability of both the steel deck and the wood rafters used. Larger spans are possible, but since an 8:12 or greater pitch must be used for the Beadwall/Kalwall roof, the system would become excessively large in volume with little increase in floor area coverage. The 12-foot dimension is characteristic of residential room sizes and commercial structural grid sizes.

Since the system distributes heat by direct radiation to the occupied space, it can only serve the floor directly beneath it: The system cannot be ranked in sawtooth fashion across a large flat-roofed structure without causing self-shading of adjacent units. On larger structures, it is logical to place the solar roof pond above zones along the north side since the south zones can usually benefit by direct passive heating system described elsewhere in this chapter. Multilevel construction is possible when the building takes a terraced form.

Costs -- The solar roof pond used for the prototype Skytherm House in Atascadero, California, had an in-place cost (1973) of approximately $6.80/square foot of bag area. Cost reductions would result from experience with this prototype, but given the rise in material and labor prices in the interim, the first cost of a similar system (1977) might be the same. For the modified design described above, first costs will be considerably higher. Estimates of the component costs include the deck at $3.50/square foot, the north wall at $2.50/square foot, the Beadwall® system at $8.50/square foot, and the Kalwall roof glazing at $6.50/square foot (all per unit surface area). Translated to cost per square foot of roof pond area, this is about $22.50/square foot plus $1.50/square foot for structural integration. This first cost estimate of $24/square foot of pond area is for an assembly that replaces the entire ceiling and roof in that portion of the building where it is used. A 1976 study at Princeton University estimated the system cost of a solar roof pond (of very different design) at $14.18/square foot. This wide range of cost is created in part by the scarcity and current high price of acceptable automatic movable insulation systems. If the Beadwall® estimate used above were cut in half, and the Kalwall price reduced by one-third, the estimated system cost would drop to just under $18/square foot.

Running costs for this solar roof pond design are essentially those for the Beadwall® system. Beads become charged with static electricity, and the anti-static agent used to keep the beads flowing freely through the system must be replaced. This is in reality a simple maintenance task but occurs perhaps every three months of use. Physical abrasion of the beads can occur in poorly designed systems, and UV breakdown of the polystyrene requires the replacement of the bead stock. The life of the beads is not known at this time. Electrical power consumption is small because blowers that draw 7 amps at 120 volts are used less than one hour a day.

Thermal Performance -- Simulations of roof pond performance by Philip Niles of the Atascadero House, and work by Harrison Fraker at Princeton University on roof ponds in a temperate climate are the basis for the following observations.

Solar roof ponds are characterized by very low temperature operation. The seasonal variation in storage temperature may never exceed 80° F; the daily swing in winter may average 5° F. The average mid-winter temperature of the pond is seldom greater than 10° F over room temperature.

Under these conditions, the average daily heating contribution of a 10-inch deep pond is in the range of 100 to 250 Btu/square foot, delivered primarily as radiation at rates usually between 10-20 Btu/square foot/hour, depending on both the surface temperature of the pond-heated ceiling and the average unheated room surface temperature. The seasonal contribution to the heating load from the roof pond is difficult to assess; in instrumented buildings the contribution has been 100 percent of the demand. The Atascadero House has a demand equal to 8.6 Btu/degree day/square foot of roof pond; to provide 100 percent heating in a 4,000 degree day climate, the pond supplied 34,400 Btu/square foot over five months.

Given the average daily contribution estimated above, a pond would supply 47,250 Btu units to a space heating load over a nine-month period. The performance of the pond is characterized by almost constant heating at low rates. That portion of a building's external skin that is a roof pond will generally never contribute to the auxiliary system load. This means space conditioning equipment can be sized smaller than in conventional buildings. For a building load of 7.5 Btu/degree day/square foot of pond area, the pond should provide all heating needs down to about 35° F outside temperatures and about half the load at 0° F.

Economics -- The performance and cost estimates for the particular solar roof pond presented above can be translated into an energy cost of between $36 to $49/MBtu. This compares with $12.90/MBtu for 44¢/Kwh electricity and $7.14/MBtu for 50¢ per gallon of oil burned at about 50 percent efficiency. Future conventional energy costs will be much higher. The 10 percent inflation factors listed in Table 2, page 6-55, of this text, indicate that costs will double in eight years and will be 6.12 times greater in twenty years. The average multiplier of 2.86 yields a time-averaged fuel cost of $36.93/MBtu (electrical). The roof pond presented above can be four times more expensive than the solar energy obtained from the thermosiphoning air heater. However, the pond, unlike the thermosiphoning heater, can provide significant reductions in peak demand. Where significant savings in operating or first costs can be obtained by lowering peak space heating demand, this extra cost may be justified.

Alternative System Configurations -- The solar roof pond can be modified to emphasize either its space heating or cooling aspects. The design discussed above stressed heating and a snow-shedding roof design. Built versions of the solar roof pond, other than the Skytherm installations mentioned, include a house in Winters, California, by John Hammond in which reflective lids operated with hydraulic rams serve as movable insulation and non-concentrating reflectors. Versions have been proposed by Dr. Harry Thomason and others in which heated pond water would be drained below fixed insulation at night. Since the basic concept as developed by Harold Hay (Skytherm) includes cooling, and natural cooling strategies rely heavily on climatic variables such as relative humidity as well as night time air temperatures, a great deal of regional variation can be expected as additional work is completed on these systems.

New Materials -- Developments that could radically alter design characteristics of solar roof ponds include materials with reverse thermosiphoning characteristics, such as the "reverse juices" proposed by William Mingenbach of the Architects Taos, Taos, New Mexico, at the First Annual Passive Conference (Proceedings referred to at the end of this chapter). Solar salt gradient ponds are examples of large scale systems where the cooler liquid rises to the top. This effect creates a naturally insulating layer at the top of the pond; this could replace the most troublesome part of the solar roof pond concept in all its current versions: the movable insulation.

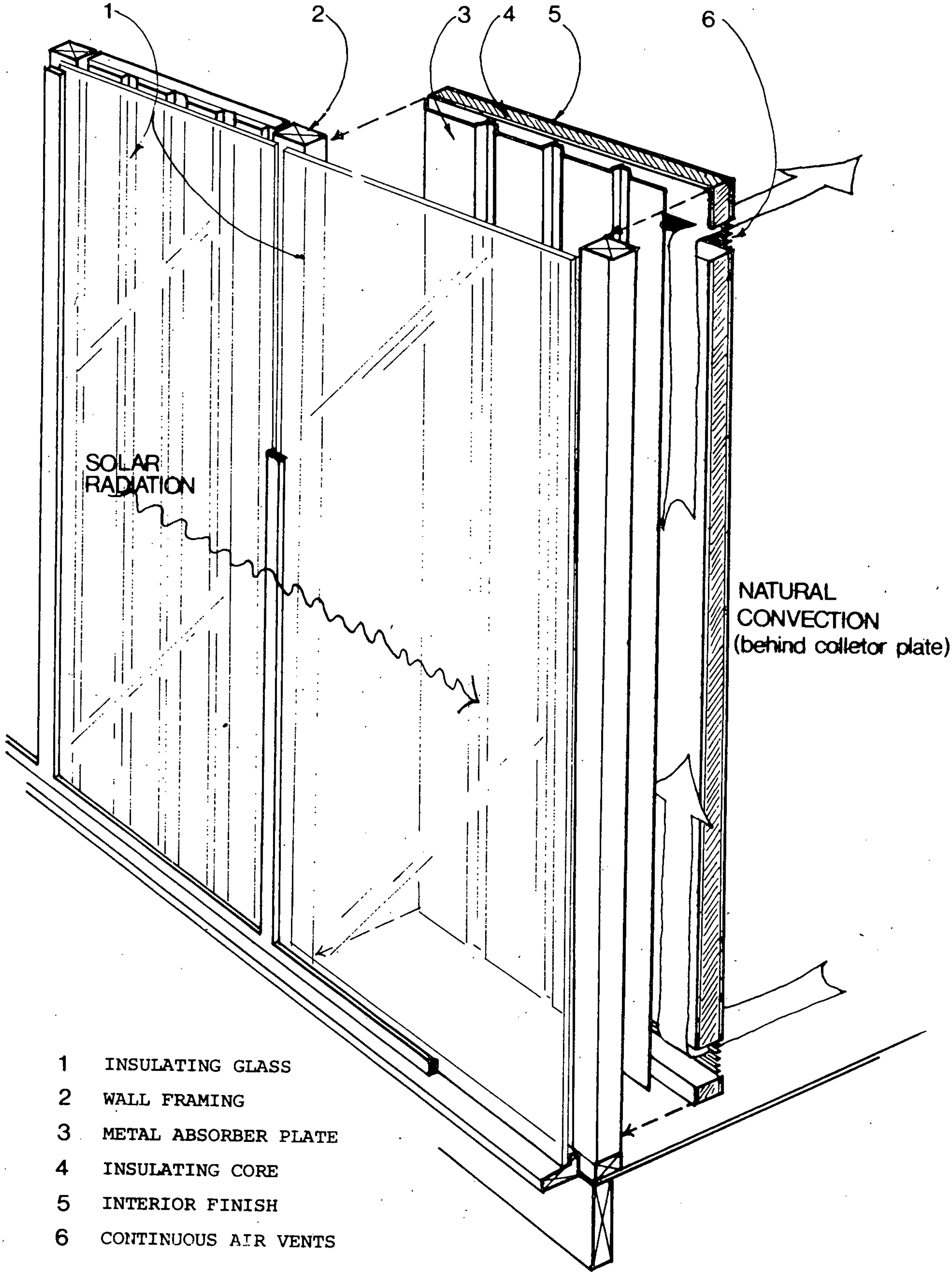
Improved Engineering -- Failing developments along these material lines, improved engineering of movable insulation subsystems emphasizing lower first cost and trouble-free operation in all weather conditions is needed to broaden the applicability of the solar roof pond concept in the space heating mode. Engineering approaches that take full advantage of the system's peak-reducing characteristics must be clarified for builders and designers.

Thermosiphoning Air Collectors

Basic System Configuration -- Thermosiphoning panels are air heating solar collectors through which the fluid flow is powered by the pressure differentials created between the solar heated air and the lower temperature room air. A few flat plate air collectors now manufactured could, with simple modification, serve as thermosiphoning air heaters. An optimized design requires a minimum restriction to air flow and a maximum heat transfer ratio between absorber and moving air. In practice, these requirements tend toward mutually exclusive solutions. Current thermosiphoning designs are characterized more by their adaptation of existing materials and manufacturing techniques than by an optimization of thermal efficiency (Figure 3-24). Nevertheless, good cost effective performance is achievably by such a thermosiphoning air heater in most U.S. climates, and the illustrated design has certain characteristics which make it very well suited for integration into commercial and industrial building types.

Materials -- The air heater consists of exterior glazing, a composite wall element consisting of the thermosiphoning absorber plate, rigid insulation and interior finish, and the required trim, including air grills and backdraft dampers. The low mass, insulated construction of the heater will cause it to undergo greater temperature extremes during a given weather sequence than a Trombe wall. Consequently sealants, glazings, and other materials must be selected to withstand greater thermal stresses.

Tempered double-pane insulating glass is the glazing material chosen for this design. Economy of installation and availability for replacement purposes is assured by the use of stock lites manufactured for the sliding glass door market.



1 INSULATING GLASS
2 WALL FRAMING
3 METAL ABSORBER PLATE
4 INSULATING CORE
5 INTERIOR FINISH
6 CONTINUOUS AIR VENTS

Figure 3-24. Thermosiphon Air Panel

In construction, the glazing supports should minimize the thermal connection to the thermosiphoning panel that is built behind the glazing. The design recommended there double as a structural wall in lightweight wood-frame construction, and the glazing details are carried out in wood, a natural insulating material. The core panel consists of a urethane and mineral board roof insulation sandwiched between the black painted absorber and an interior finish panel of half-inch fire-code gypsum board. The interior gypsum surface can be used as the base for a variety of conventional interior finishes or can be supplied prefinished with fabric or vinyl coverings.

The insulating core in the design described here is fabricated from a roof insulation supplied by a variety of manufacturers. These boards are usually 3 by 4 feet, 1-1/2 inches thick, providing a nominal R-value of 6.7. The mineral board side of the urethane/mineral composite faces the absorber panel; the flammable urethane foam is protected by the gypsum board.

The absorber panel is corrugated metal siding, a building material readily available complete with compatible fasteners and preformed EDPM or neoprene closure strips, simplifying construction of an airtight, durable thermosiphoning heater. The ribs give such an absorber self-spacing characteristics and structural stability. Alcoa ribbed 8-inch siding of 0.032-inch aluminum selected for this design has a cross-sectional free area for thermocirculation of 9 square inches per foot of width.

The absorber is obtained as mill-finished aluminum and must be prepared for painting with an etching-cleaner. The recommended finish is a thin coat of flat black enamel. "Nextal" brand 'Black Velvet' by 3M Company over a suitable primer is commonly used.

The panel is vented to the heated space through a full-width register that provides manual control of the air flow. Continuous linear diffusers normally available for commercial HVAC systems should be used.

Backdrafts at night or during very poor weather are prevented by the use of very lightweight (1 mil) plastic film one-way dampers. These dampers must be specially fabricated. In the suggested design (Figure 3-25), the plastic film is attached to a punched or die cut 24-gauge galvanized sheet with double-sided adhesive tape.

Design -- The dimensions of the thermosiphoning air heater are based on its use as an infill panel in a wood-framed bearing wall. Doubled 2- by 4-inch studs, 3-feet on center replace conventional framing. The panel should not be relied upon to provide overall wind bracing of the building frame. Good building practice requires the use of methods such as plywood shear panels or diagonal bracing.

This 3-foot module permits the use of 34- by 90-inch insulating glass lights. The 90-inch size permits the design to be used as a full-height infill panel between floor construction. The addition of a spandrel glass element (not described here) would allow the design to be incorporated into curtain wall construction. The core panel is dimensioned to fit the 3-foot module created by the 34-inch glazing. Overall depth of the panel from black absorber to interior finish is a nominal 3 inches, providing, when installed, a 1/2-inch clearance to the exterior stud surface to which the glazing system is attached.

Construction and Installation -- The modular, lightweight (3-4 lbs/square foot) panels are best shop-fabricated, with glazing and interior trim (vent grills and dampers) applied after installation in the field. If the seal made between panel sides and bottom and abutting construction is adequately caulked, the panel provides a temporary weatherskin, and installation of the exterior glazing can be scheduled independently. Care must be taken, however, not to let the foam core or interior gypsum finish be damaged by weather.

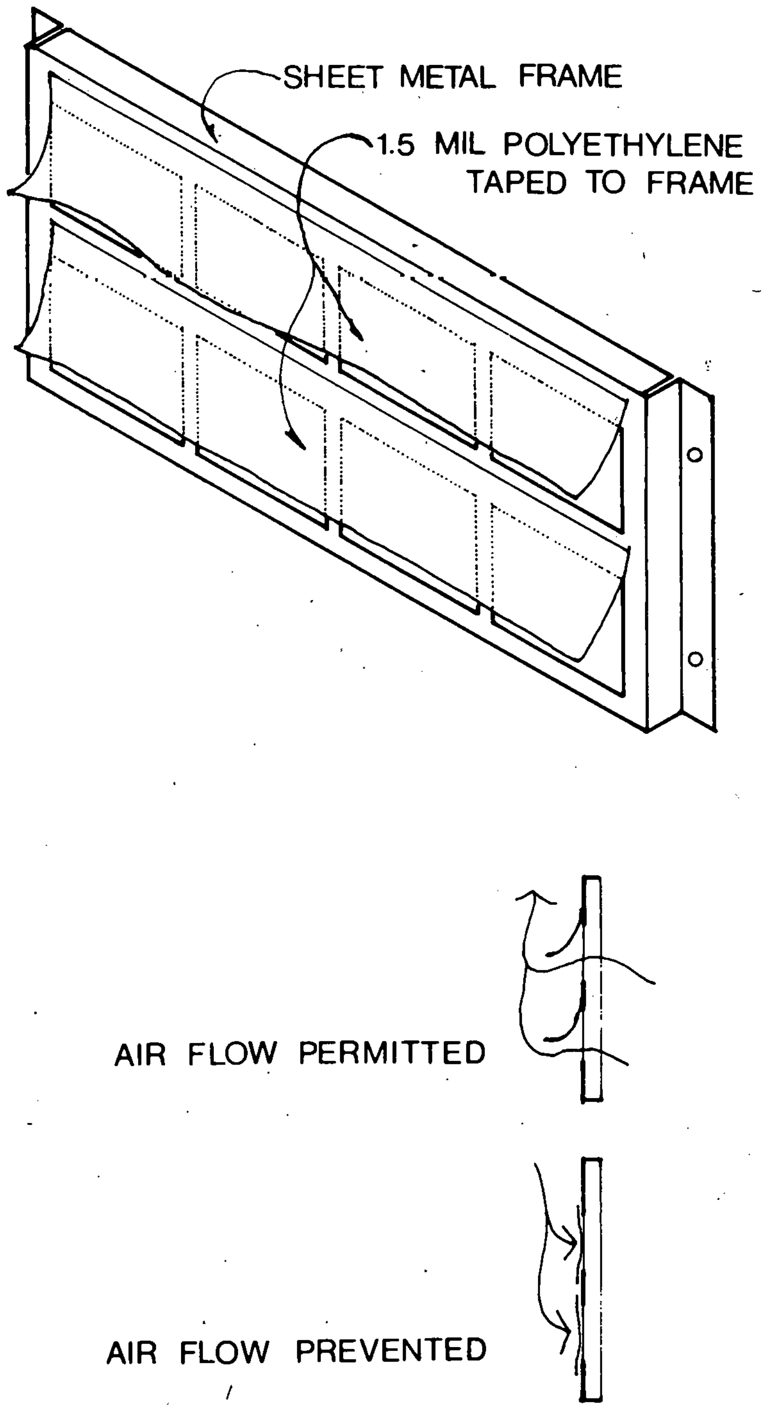


Figure 3-25. Thermosiphon Air Panel: Damper

Unlike most active systems, there are no startup procedures to follow and no precautions to take against freezing or overheating during installation. Electrical wiring should be handled with surface-mounted systems.

System Selection Criteria --

Building Integration -- Thermosiphoning air heaters (natural collectors) are suited to structures where the heating load is large compared to the proposed panel area. (This is because all of the panel output can be absorbed immediately by the building load, so the lack of thermal storage does not decrease system performance). Schools and low-rise office buildings are such structures. The intermittent use of these buildings matches well with the thermosiphoning air heater's daily cycle. The air heaters can be used in both single-family and multifamily houses, but unless separate thermal storage designs are incorporated, the low loads (especially in well insulated housing) and 24-hour use mean that a smaller fraction of the heater's potential output can be usefully employed, decreasing its applicability.

Architecturally, the modular air heater with its curtain wall characteristics and glass-surfaced appearance is well suited for integration into most new commercial construction. With minor design modifications, the heater can be a cost-effective retrofit application over existing exterior walls.

Costs -- First costs for thermosiphoning air heaters are dependent primarily on labor costs. The major materials used are supplied by a number of competitive manufacturers and are widely available. Setup charges for shop fabrication may be high given the unconventionality of the product, but the contractor will save a portion of the normal markup sequence for manufactured products.

Materials costs for designs similar to the one shown here have been in the $3.50 to $4/square foot range (1976). Estimates of installed cost for the modular air heater panel in eight cities were consistently near $10.30/ square foot. Since the panel replaces the conventional wall in light-frame construction, usually $2.60/square foot, or the infill in steel-framed construction, usually $5.50/square foot, the net cost applicable to the solar aspects of the panel are $7.70 and $4.80/square foot, respectively. Operating costs are non-existent.

Thermal Performance -- Performance in the thermosiphoning air heater depends entirely on the delicate natural convection currents set up in the system. Air flow is low to non-existent (reverse flow being prevented by one-way dampers) at times of little or no sun, but establishes itself rapidly under sunny conditions. Flow rates are generally higher than in Trombe walls; flows of 3 cfm/square foot of collector have been noted. The design shown here has a probable maximum flow rate of 2 cfm/square foot with an average temperature rise from an inlet to outlet of 95° F. The resulting 90 Btu/square foot/hour represents an average collection efficiency similar to that of low temperature flat-plate collectors used in standard active system designs.

The chief determinant of overall performance is the ratio of load to collector area. Effective performance deteriorates rapidly with increasing system size. Estimates of useful delivered energy using simplified analyses range from 30 to 120,000 Btu/square foot/heating season. The high numbers in this range are typically associated with poorly insulated buildings in cold climates (Madison, Wisconsin); the low numbers with low-load buildings in warm climates (Atlanta, Georgia, Ft. Worth, Texas); 50 to 80,000 Btu/square foot each heating season in moderate climates (Boston, Massachusetts) (for total solar contributions between 60 and 40 percent of total load, respectively) are reasonable estimates for preliminary design.

This wide fluctuation in estimated performance is due primarily to the lack of stabilizing thermal mass that can effectively store excess heat as it is produced. To maximize system performance, especially in well insulated (low-load) buildings, modifications to increase the building heat storage, such as doubling the thickness of gypsum board, should be considered. Potential overheating with resulting lack of performance and comfort must be assessed whenever systems are estimated to provide over 30 percent of the seasonal load.

Economics -- Combined performance and first-cost estimates establish a probable energy cost between a high of $15.20/MBtu and a low of $6/MBtu based on a capital recovery factor of 10 percent. This is an extremely economical range when compared to current $12.90/MBtu for 4.4¢/Kwh electricity. Future conventional energy costs will be much higher. The 10 percent inflation factors listed in Table 2, page 6-55, of this text indicate that costs will double in eight years, and be 6.12 times greater in twenty. The average multiplier of 2.86 yields a time-averaged fuel cost of $36.93/MBtu (electrical). Energy cost estimates prepared for specific cities (based on other work by TEA, 1977) are shown in Table 3-3.

TABLE 3-3

DELIVERED ENERGY[1] & ASSOCIATED COSTS[2] FOR THERMOSIPHONING AIR PANELS

City	Btu/sf-yr	Cost/MBtu
Ft. Worth, Texas	51,000	$12.25
Medford, Oregon	61,000	$10.25
Boston, Massachusetts	63,000	$ 9.90
Madison, Wisconsin	80,000	$ 7.80
Boulder, Colorado	96,000	$ 6.50

1) Delivered energy figures are averages of estimates prepared for four different building types and multiple building load/system size ratio.
(Source: "Passive Systems", a TEA report prepared for Booz-Allen-Hamilton, 1977)

2) These figures are the effective energy costs obtained by applying a capital recovery factor of 10% to the average ($8.25) of the high and low net first cost estimated.

Alternative System Configurations -- The thermosiphoning air heater could easily be incorporated into the existing building products manufacturing industry. A large number of system types providing a choice of construction and installation techniques, a range of prefabrication, and a variety of sizes, could be developed.

New Materials -- Differences in materials used and design details in alternative configurations center around the absorber plate and the type and number of glazings. The use of mesh or multiple-screen absorbers is favored by some researchers. Site-fabricated projects, where labor is substituted for materials costs, usually emphasize multiple lite untempered glass (often recycled) or plastic glazing, and absorbers fabricated from cheap materials such as discarded aluminum printing plates.

Improved Engineering -- Further development of the air heating thermosiphoning panel should identify dimensional characteristics such as height, air gap, and outlet and inlet free areas, that affect collector efficiency. Confirmation of the average operating conditions discussed above and identification of the probable operating extremes (in a variety of climates) are necessary tasks. For this particular passive system, engineering methods that will provide good matches to particular building load and thermal storage characteristics are yet to be developed.

SUMMARY

This Section is a brief outline of passive solar systems -- their definition, applications, performance and costs. In preparing this Section we have drawn heavily from the work of others. This work is described in the literature, and anyone working with passive solar systems will profit from exposure to the experiences of others that may be gained by reading this material.

Very good information can be found in the following:

1. Conference and Workshop Proceedings
   First Passive Solar Heating & Cooling Conference, May 18-19, 1976, Albuquerque, N.M. (Available from NTIS)

2. Proceeding of the 1977 Annual Meeting, American Section of ISES, June 6-10, 1977, Orlando, Fla. (Available from ISES)

3. Bulletin of the New Mexico Solar Energy Association
   (Available from NMSEA, PO Box 2004, Santa Fe, N.M. 87501)

4. Decision Making in Solar Technology; First Annual Conference Proceedings of the New England Solar Energy Association, June 24-27, 1976, Amherst, Mass. (Available from NESEA, Box 541, Brattleboro, Vt. 05301)

5. Passive Solar Buildings: A compilation of Data and Results, Report by the Sandia Laboratories, August, 1977 (Available from NTIS)

Since a good background in basic solar principles and heat transfer phenomena is useful when evaluating alternative system designs, the following books are also recommended:

1. Solar Energy Thermal Processes, John A. Duffie, William A. Beckman; (1974) John Wiley & Sons; New York, N.Y.

2. Solar Energy: Fundamentals in Building Design, Bruce Anderson; (1977) McGraw-Hill; New York, N.Y.

3. The Solar Home Book, Bruce Anderson with Michael Riordan; (1976), Cheshire Books, Harrisville, N.H.

4. Solar Heating and Cooling; Jan F. Kreider, Frank Kreith; (1975) McGraw-Hill; New York, N.Y.

5. Solar Heating Design by the F-Chart Method; William A. Beckman, Sanford A. Klein, John A. Duffie; (1977) John Wiley & Sons; New York, N.Y.

SECTION IV
SYSTEM CHARACTERISTICS AND SELECTION

SERVICE HOT WATER SYSTEMS

Introduction

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 declined during the past 40 years, use in Australia, Israel, and Japan has risen rapidly, particularly in the last 15 years.

In its simplest form, a solar water heater comprises a flat-plate water heating collector and an insulated storage tank positioned at a higher level than the collector. These components, connected to the cold-water main and the hot-water service piping in the dwelling, provide most of the hot-water requirements in a sunny climate. Nearly all of the solar hot-water systems used in the United States have been of this type.

Most of the solar water heaters that have been experimentally and commercially used can be placed in two main groups:

1. Circulating types, involving the supply of solar heat to a fluid circulating through a collector and storage of hot water in a separate tank

2. Non-circulating types, involving the use of water containers that serve both as solar collector and storage.

The circulating group may be divided into the following types and sub-types:

1. Direct heating, single-fluid types in which the water is heated directly in the collector, by
   a. Thermosiphon circulation between collector and storage
   b. Pumped circulation between collector, load or storage
2. Indirect heating, dual-fluid types in which a non-freezing medium is circulated through the collector for subsequent heat exchange with water, when
   a. Heat transfer medium is a non-freezing liquid
   b. Heat transfer medium is air.

Characteristics of Solar Water Heaters

Direct Heating, Thermosiphon Circulating Type -- The most common type of solar water heater, used almost exclusively in non-freezing climates, is shown in Figure 4-1. The collector, usually single glazed, may vary in size from about 30 square feet to 80 square feet, whereas the insulated storage tank is commonly in the range of 40 to 80 gallons capacity. The hot-water requirements of a family of four persons can usually be met by a system in the middle of this size range, in a sunny climate. Operation at supply line pressure can be provided if the system is so designed. With a float valve in the storage tank or in an elevated head tank, unpressurized operation can be utilized if the system is not designed for pressure. In the latter case, gravity flow from the hot-water tank to hot-water faucets would have to be accepted, or an automatic pump would have to be provided in the hot-water line to supply pressure service. Plumbing systems and fixtures in the United States normally require the pressurized system.

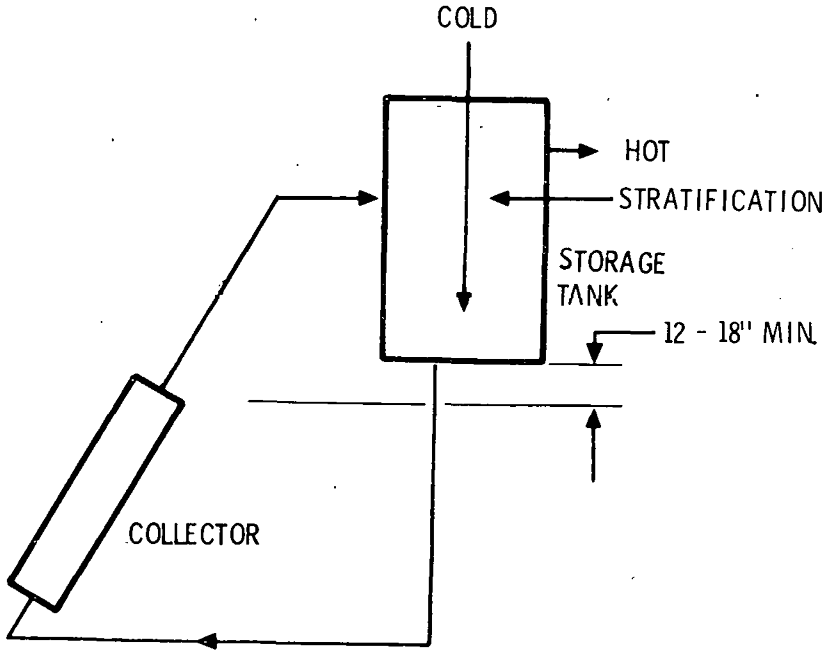


Figure 4-1. Circulation Type of Solar Water Heater Direct Heating Thermosiphon

Location of the tank higher than the top of the collector permits circulation of water from the bottom of the tank through the collector and back to the top of the tank. The density difference between cold and hot water produces the circulating flow. Temperature stratification in the storage tank permits operation of the collector under most favorable conditions, water at the lowest available temperature being supplied to the collector and 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 radiation level, the greater the heating and the more rapid the circulating rate will be. In a typical collector under a full sun, a temperature rise of 15°F 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 located above the top header of the collector. If the collector is on a house roof, the tank may also be on the roof or in the attic space beneath a sloping roof.

Although seldom used in cold climates, the thermosiphon type of solar water heater (storage tank above collector), can be protected from freezing by draining the collector. To avoid draining the storage tank also, thermostatically actuated valves in the lines between collector and storage tank must close when freezing threatens, a collector drain valve must open, and a collector vent valve must also open. The collector will then drain and air will enter the collector tubes. Water in the storage tank, either inside the heated space or sufficiently well insulated to avoid freezing, does not enter the collector during the period when sub-freezing temperatures threaten. 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.

Direct Heating, Pump Circulation Types -- If placement of the storage tank above the collector is inconvenient or impossible, the tank may be located below the collector and a small pump used for circulating water between collector and storage tank. This arrangement is usually more practical than the thermosiphon type in the United States, because the collector would often be located on the roof with a storage tank in the basement. Instead of thermosiphon circulation when the sun shines, a temperature sensor actuates a small pump which circulates water through the collector-storage loop. A schematic arrangement is shown in Figure 4-2. To obtain maximum utilization of solar energy, control is based on the difference in water temperature at collector outlet and bottom of storage tank. Whenever this difference exceeds a preset number of degrees, say 10°F, the pump motor is actuated. The sensor at the collector outlet must be located close enough to the collector so that it is affected by collector temperature even when the pump is not running. Similarly, the sensor in the storage tank should be located in or near the bottom outlet from which the collector is supplied. When the temperature difference falls below the preset value, the pump is shut off and circulation ceases. 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.

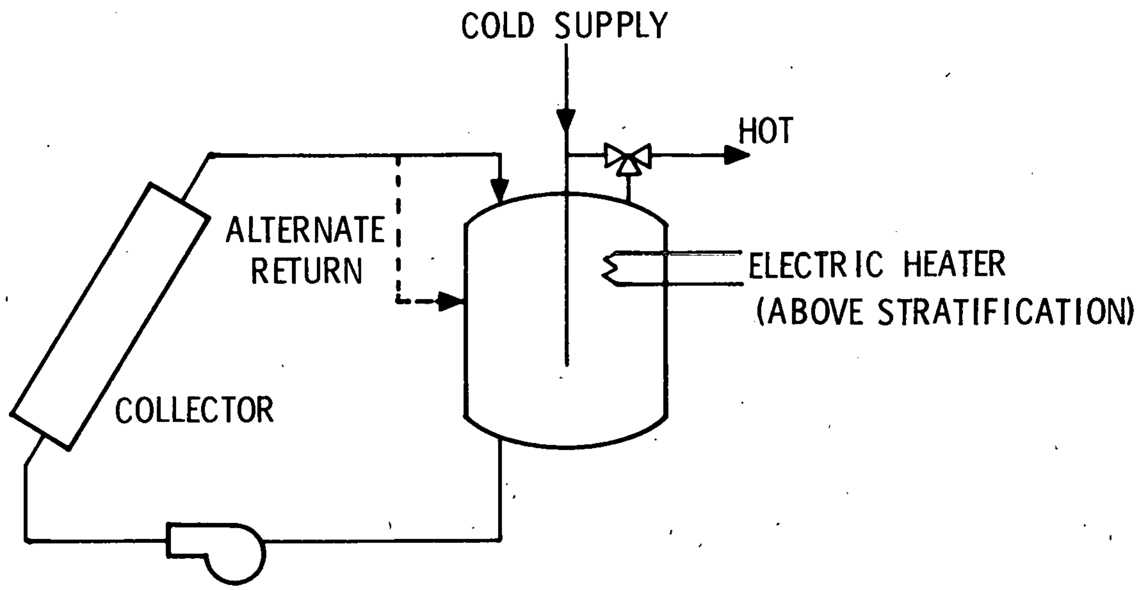


Figure 4-2. Direct Heating, Pump Circulation Type of Solar Water Heater

If hot water use is not sufficient to maintain storage tank temperature at normal levels (as during several days of non-use), boiling may occur in the collector. If a check valve or pressure-reducing valve prohibits back flow from the storage tank into the main, a relief valve must be provided in the collector-storage loop. The relief valve will permit the escape of steam and prevent damage to the system.

Direct Heating, Pump Circulation, Drainable Types -- If the solar water heater described above is used in a cold climate, it may be protected from freeze damage by draining the collector when sub-freezing temperatures are encountered. Several methods can be used. Their common requirement, however, is reliability, even when electric power may not be available. One method is shown in Figure 4-3.

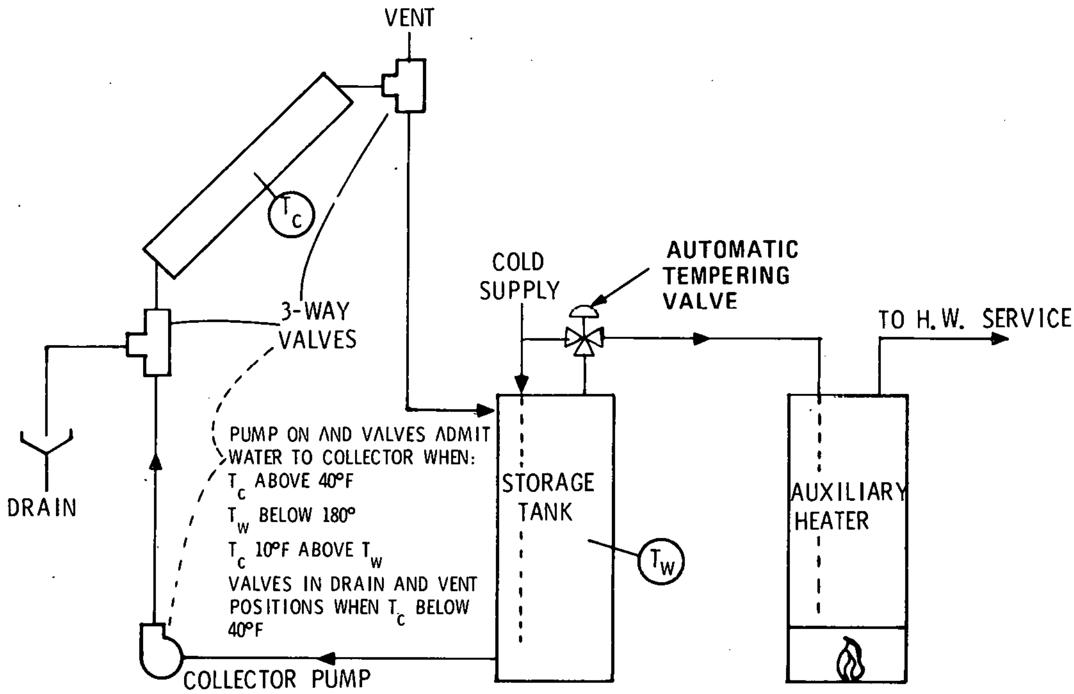


Figure 4-3. Solar Water Heater with Freeze Protection by Automatic Collector Drainage

Drainage of the collector in freezing weather can be accomplished by automatic valves which provide water outflow to a drain (sewer) and the inflow of air to the collector. The control system can be arranged so that whenever the circulating pump is not in operation, these two valves are open. To assure maximum reliability, the valves should be mechanically driven to the drain position (by springs or other means), rather than electrically, so that in the event of a power failure, the collector can automatically drain.

The drainage system shown in Figure 4-3 is actuated by a temperature sensor either in the collector itself or in the atmosphere. When the sensor indicates a possibility of freezing, it can open the drainage and vent valves, 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 where the valves are held open by electrical means, automatically closing either when electrical failure occurs, or at low temperatures.

Another possibility for drainage of the collector is based on use of a non-pressurized collector and storage assembly as shown in Figure 4-4. 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. With this design, the solar collector drains into the storage tank whenever the pump is not operating, as air enters the collector through a vent.

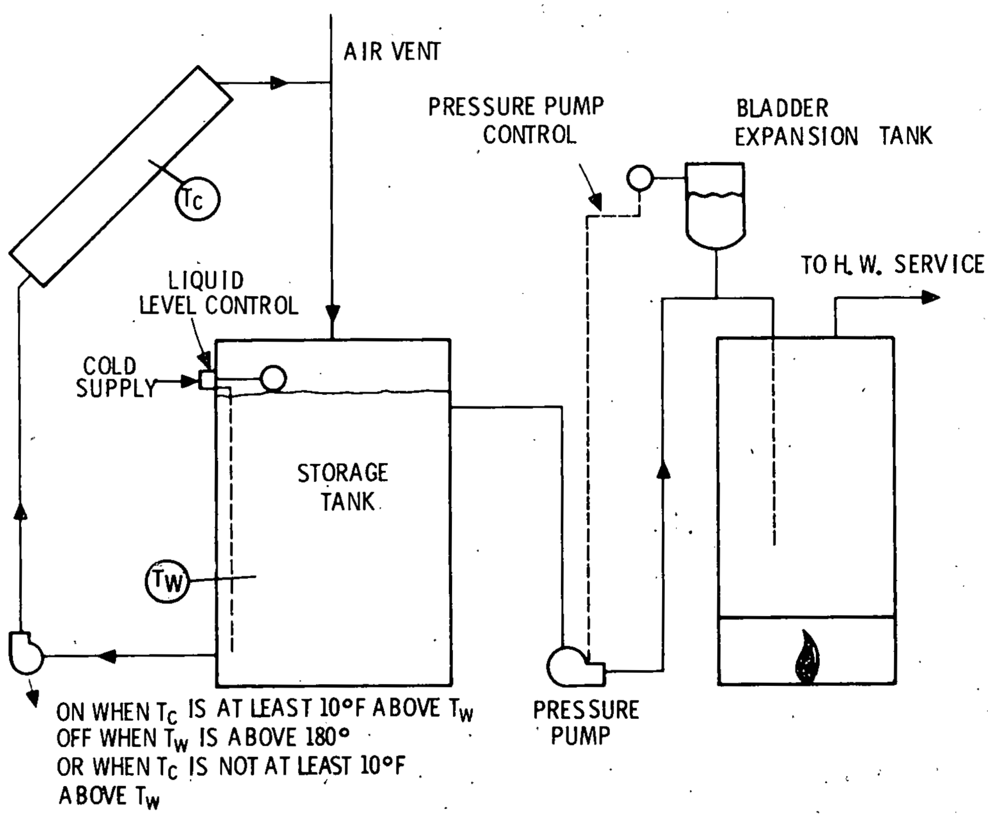


Figure 4-4. Unpressurized Vented Solar Water Heater System

Start-up of any of the vented collector systems must permit the displacement of air from the collector. In either the line-pressure system or the unpressurized system, the entry of water into the collector (from the shut-off valve or pump) forces air from the collector tubes as long as the vent remains open. The vent valve design can be of a type which automatically passes air but shuts off when water reaches it.

Circulating Type, Indirect Heating -- As can be inferred from the above discussions of needs and means for collector drainage in freezing climates, costs and hazards are involved with those systems. The drainage requirement can be eliminated by the use of a non-freezing heat transfer medium in the solar collector, and a heat exchanger (inside the building) for transfer of heat from the solar heat collecting medium to the service water. The collector need never be drained, and there is no risk of freezing and damage. Corrosion rate in the wet collector tubes is also decreased when intermittent admission of oxygen is not required.

Liquid Transfer Media -- Figure 4-5 illustrates a method for solar water heating with a liquid heat transfer medium in the solar collector. The most commonly used liquid is a solution of ethylene glycol (common automobile radiator antifreeze) in water. A pump circulates this unpressurized solution, as in the direct water heating system, and delivers the liquid to and through a liquid-to-liquid heat exchanger. Simultaneously, another pump circulates domestic water from the storage tank through the exchanger, back to storage. The control system is essentially the same as that in the design employing water in the collector directly. 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.

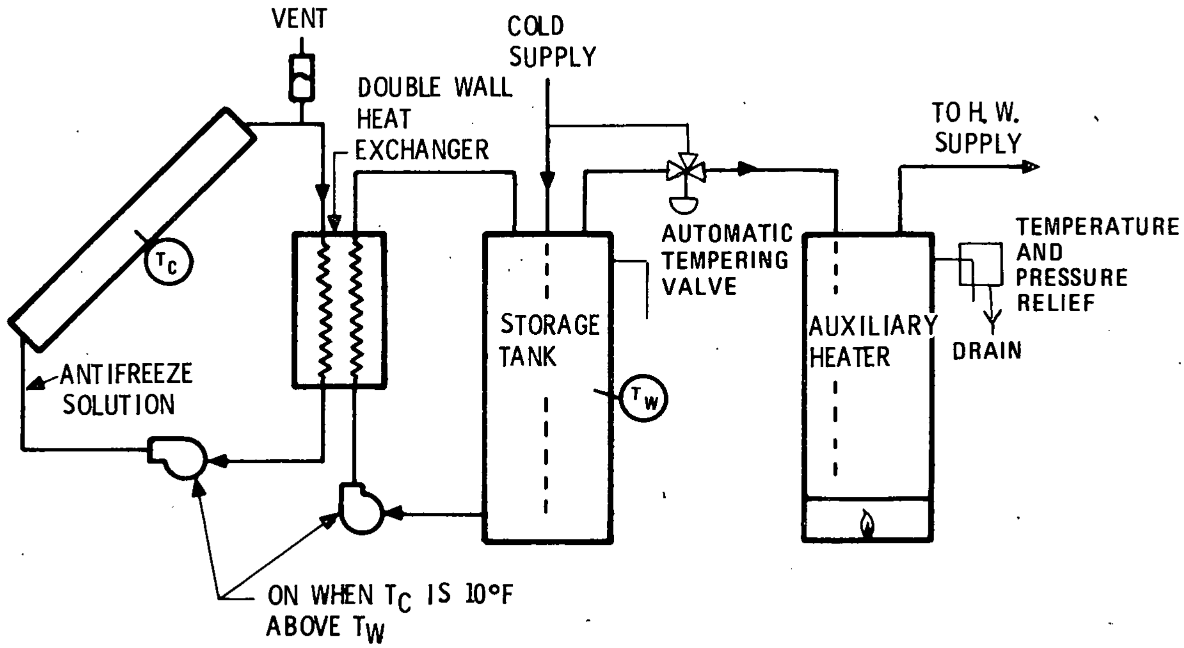


Figure 4-5. Dual Liquid Solar Hot Water Heater

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. A conventional tube-and-shell exchanger would therefore not usually be acceptable. Similarly, a coil inside the storage tank, through which the collector fluid is circulated, would not be satisfactory. 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.

Although aqueous solutions of ethylene glycol and propylene glycol appear to be most practical for solar energy collection, organic liquids such as Dowtherm J and Therminol may be employed. Price and viscosity are drawbacks, but chemical stability and assurance against boiling are advantages over the antifreeze mixtures.

Solar Collection in Heated Air -- In a manner similar to that described immediately above, solar energy can be employed in an air-heating collector with subsequent transfer to domestic water in an air-to-water heat exchanger. Figure 4-6 illustrates a method for employing 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. Differential temperature control (between collector and storage) is employed as in the other systems described. 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.

Non-Circulating Type -- Although probably of little potential interest in the United States, a type of solar water heater extensively used in Japan involves heat collection and water storage in the same unit. The most common type comprises a set of black plastic tubes about 6 inches in diameter and several feet long in a glass-covered box. Usually mounted in a tilted position, the tubes are filled each morning with cold water in which solar heat is collected throughout the day. The filling can be accomplished by a float-controlled valve and a small supply tank. Late in the day, heated water can be drained from the tubes for household use. In typical Japanese installations, non-pressurized hot-water service is thus provided. Heat loss from the system is sufficiently high at night that hot water is usually not available until several hours after sunrise.

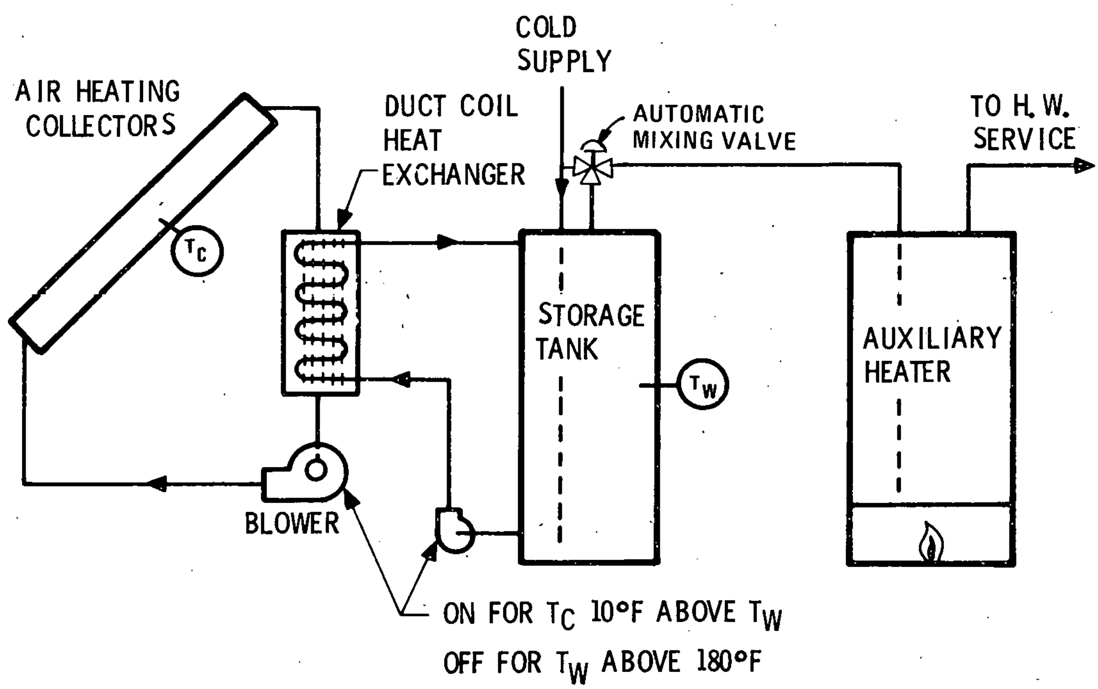


Figure 4-6. Solar Hot Water Heater With Air Collectors

Auxiliary Heat

A dependable supply of hot water requires the availability of auxiliary heat for supplementing the solar source. The numerous methods of providing auxiliary heat vary in cost and effectiveness. A general principle for maximizing solar supply and minimizing auxiliary use is the avoidance of 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 only the solar system 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-storage system. Figures 4-3 and 4-4 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. Alternatively, a "fast response", in-line heater can be employed. It is evident that auxiliary heat supply in these designs cannot adversely affect the operation of the solar system.

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 Figure 4-2. Temperature stratification in the tank, accomplished by bringing cold water from the main into the bottom and circulating it through the collector from the bottom 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. In effect, the two tanks shown in Figures 4-3 and 4-4 are combined into one, with temperature stratification providing a separation. The total amount of storage is, of course, reduced unless the one tank is increased in size. If relatively high-temperature water is desired, there may be an undesirable influence of auxiliary supply on collector efficiency because of some mixing in the tank.

Although the description of the above systems refers to direct circulation of water through the collector, the same factors apply to the systems involving heat-exchange with antifreeze solutions or air circulating through the collector. In all cases, auxiliary heat should be supplied downstream from the solar storage tank, regardless of whether the water itself is circulated through the collector or whether heat is exchanged between the domestic water and a solar heat transfer fluid.

Location of Collectors

If the slope and orientation of a roof is suitable, the most economical location for a solar collector in a residential water heating system is on the south-facing portion of the roof. The cost of a structure to support the collector is thereby eliminated, and pipe or duct connections to the conventional hot-water system are usually convenient. In new dwellings, most installations can be expected on the house roof. Even in retrofitting existing dwellings with solar water heaters, a suitable roof location can usually be provided.

If the mounting of collectors on the roof is impractical, for any of several reasons, a separate structure adjacent to the house may be used. A sloping platform supported on a suitable foundation can be the base for the collector. Pumps, storage tank, and heat exchanger, if used, can be located inside the dwelling. Effective insulation on ducts and piping must be provided, however, so that cold-weather operation will not be handicapped by excessive heat losses. In cold climates, collectors in which water is directly heated must be located so that drainage of the collector and exterior piping can be dependably and effectively accomplished.

Temperature Stratification in Solar Hot Water Tank

As in a conventional hot-water heater, the temperature in the upper part of a solar hot-water tank will normally be considerably higher than at the bottom. The lower density of hot water permits this stratification, provided that turbulence at inlet and outlet connections is not excessive. The supply of relatively cold water from the bottom of the tank to the collector permits the collector to operate at its highest possible efficiency under the prevailing ambient conditions. With a circulation rate such that a temperature rise through the collector of 15°F to 20°F occurs, the upper part of the storage tank is furnished to the collector for maximum effectiveness. If not much hot water is withdrawn from the tank during a sunny day, the late afternoon temperature at the bottom of an 80-gallon tank connected to a 40- to 50-square foot collector may be well above 100°F - even approaching the temperature in the top of the tank. Collection efficiency thus varies throughout the day, depending not only on solar availability but also on the temperature of water supplied to the collector from the bank bottom.

Temperature Control Limit

In addition to the differential temperature control desirable in most solar water heating systems (which sense temperature difference between collector and storage), protection against excessive water temperature may be necessary. Several possible methods can be used. In nearly all types of systems, whether direct heating of the potable water or indirect heating through a heat exchanger, a thermostatically controlled mixing valve can be used to provide constant temperature water for household use. Figure 4-7 illustrates one method by which this type of temperature control can be accomplished. Cold water is admitted to the hot water line immediately downstream from the auxiliary heater in sufficient proportion to secure the desired preset temperature. The solar hot-water tank is allowed to reach any temperature attainable, and the auxiliary heater furnishes additional energy only when the auxiliary tank temperature drops below the thermostat set point. Maximum solar heat delivery is thus achieved, and no solar heat needs to be discarded except that which might sometimes be delivered when the main storage (preheat) tank is at the boiling point. Any additional solar heat collected under that condition would be dumped through a pressure relief valve, steam escaping to the surroundings. Figure 4-7 shows an optional second mixing valve for control of delivery temperature by admitting regulated amounts of solar-heated water into the flow from the auxiliary heater.

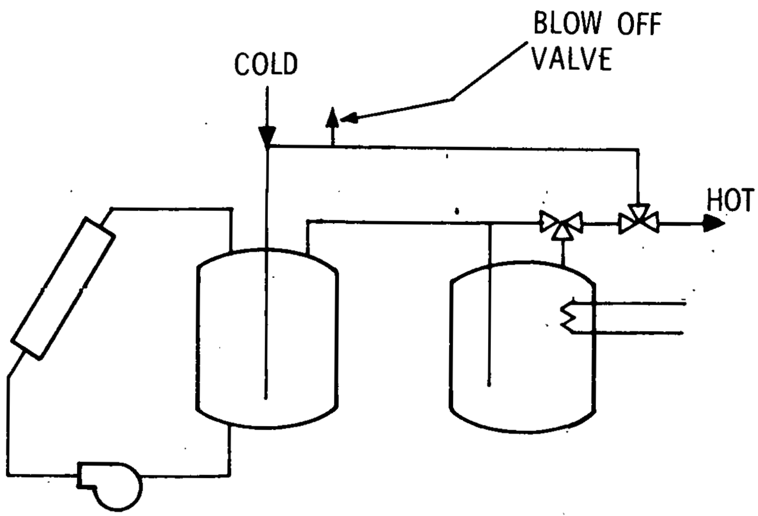


Figure 4-7. Direct Solar Water Heating with Mixing Valve

A steam vent from the solar hot water system involving a dual liquid design, with heat exchange, should normally be in the hot water loop rather than the collector loop. Loss of collector fluid by vaporization is thereby avoided. It is necessary, however, in this design, that the collector tubes and associated piping be capable of withstanding pressure at least as high as developed when the steam vent valve in the storage loop is actuated. If, for example, the blow-off valve in the storage circuit is set for 50 psi, and if the collector loop containing 50 percent ethylene glycol normally operates at a temperature 20°F above the storage tank temperature, pressure in the collector loop would also be about 50 psi when the storage tank vent is actuated. (Approximate equality of pressure is due to similarity between boiling point elevation and temperature difference in the heat exchanger.)

An alternative to the high-pressure collector capability described above is available in the form of an organic heat transfer fluid having a high boiling point. Dowtherm J or Therminol 55 have boiling points above 300°F, so if one of these fluids is used, the development of pressure in the collector loop would not occur, even when the storage system is venting steam at 50 psi.

This option appears considerably more practical than the pressurized collector required with aqueous systems, if the dual-liquid design is utilized.

Still another option for high-temperature protection is available if the collector is used as a heater for a high-boiling organic liquid or for air. To prevent the storage tank from reaching a temperature higher than desired, a limiting thermostat in that tank can be used simply to discontinue circulation of the heat transfer fluid (organic liquid or air) through the collector and heat exchanger. No additional heat is therefore transferred to the water storage tank, and the excess solar heat is dissipated in the form of collector heat loss. The collector temperature rises substantially, frequently above 300°F, but if properly designed, the collector suffers no damage. This system is probably the safest and most dependable of those herein described. With a reliable limit switch in the storage tank, there can be no dangerous pressure developments anywhere in the system. In addition, there is no loss of water (in the form of steam) even when there is no use of hot water for long periods.

If the hot-water/cold-water mixing valve downstream from the auxiliary heater is not used, a temperature limit control in the solar storage tank can be set at the maximum desired temperature of service hot water. Water therefore cannot be delivered at any temperature higher than the set point in the solar storage tank or the set point in the auxiliary heater, whichever is higher. Less solar storage capability would be involved in this design, however, because the solar storage tank is prevented from achieving higher temperatures, even when solar energy is available.

In a direct type of solar water heater operating at service pressure, with potable water circulating through the collector, a venting valve is provided near the top of the collector. It would have to be set for release at a pressure several pounds higher than the maximum in the service supply, so the collector-storage system must withstand pressure usually above 50 psi. Occasional water loss through venting of steam would be expected.

If a non-pressurized direct type of solar water heater is used, with a float valve in the storage tank, the pressure relief valve can be set to operate at a pressure only slightly above atmospheric. Alternatively, the collector or storage tank may be continuously vented. Oversupply or under use of solar-heated water results in boiling and venting of the storage tank.

Performance of Typical Systems

General Requirements -- A typical family of four persons requires, in the United States, about 80 gallons of hot water per day. At a customary supply temperature of about 140°F, the amount of heat required if the cold inlet is at 60°F is about 50,000 Btu per day.

There is a wide variation in the solar availability from region to region and from season to season in a particular location. There are also the short-term radiation fluctuations due to cloudiness and the day-night cycle.

Seasonal variations in solar availability result in a 200 to 400 percent difference in the solar heat supply to a hot-water system. In the winter, for example, an average recovery of 40 percent of 1200 Btu of solar energy per square foot of sloping surface would require approximately 100 square feet of collector for the 50,000 Btu average daily requirement. Such a design would provide essentially all of the hot water needs on an average winter day, but would fall short on days of less than average sunshine. By contrast, a 50 percent recovery of an average summer radiant supply of 2000 Btu per square foot would involve the need for only 50 square feet of collector for satisfying the average hot-water requirements.

It is evident that if a 50-square foot collector were installed, it could supply the major part, perhaps nearly all, of the summer hot water requirements, but it could supply less than half the winter needs. If, on the other hand, a

100-square foot collector were employed in order that winter needs could be more nearly met, the system would be oversized for summer operation and excess solar heat would have to be wasted. In such circumstances, if an aqueous collection medium were used, boiling of the system would occur and collector or storage venting of steam would have to be provided.

The more important disadvantage of the oversized collector (for summer operation) is the economic penalty associated with investment in a collector which is not fully utilized. Although the cost of the 100 square foot collector system would not be double that of the 50 square foot unit, its annual useful heat delivery would be considerably less than double. It would, of course, deliver about twice as much heat in the winter season, when nearly all of it could be used, but in the other seasons, particularly in summer, heat overflow would occur. The net effect of these factors is a lower economic return, per unit of investment, by the larger system. Stated another way, more Btus per dollar of investment (hence cheaper solar heat) can be delivered by the smaller system.

If based on average daily radiation in the sunniest months, the unit will be slightly oversized and a small amount of heat will be wasted on days of maximum solar input. And quite naturally, on partly cloudy days during the season, some auxiliary heat must be provided. In the month of lowest average solar energy delivery, typically one-half to one-third as much solar heated water can be supplied, or actually the same quantity of water but with a temperature increase above inlet only one-half to one-third as high. Thus, fuel requirements for increasing the temperature of solar heated water to the desired (thermostatted) level could involve one-half to two-thirds of the total energy needed for hot-water heating in a mid-winter month.

Quantitative Performance -- Although hundreds of thousands of solar water heaters have been used in the United States and abroad, quantitative performance data are extremely limited. In households where no auxiliary heat was used, the solar system probably supplied hot water most of the time, but failed during bad weather. If booster heat was used, hot water was always available, but the relative contributions of solar and auxiliary were seldom measured.

In a few research laboratories, particularly in Australia, some analytical studies of solar water heater performance, confirmed in part by experimental measurements, have been performed. More recently, analytical studies at the University of Wisconsin have been carried out. Table 4-1, based on an Australian study, shows the performance of a double-glazed, 45-square foot solar water heater in several regions of the country. Variable solar energy and ambient temperature throughout the year result in 1.4 to 2.5 times as much solar heat supply to water in summer than in winter. Climatic differences produced a solar heat percentage ranging from 60 percent to 81 percent of the annual total hot-water requirements. Table 4-2 shows monthly performance of the same system, in Melbourne, Australia, with average collection efficiency varying between 29 and 40 percent of incident radiation. Variation in inlet, outlet, and ambient temperature in a typical thermosiphon type of solar water heater is shown in Figure 4-8.

In a simulation study at the University of Wisconsin, hot-water usage was programmed for a hypothetical residential user. The results show only slight variation in solar heat utilization at several use schedules and indicate only minor influence of storage temperature stratification on collector efficiency.

In summary, the normal output of well designed solar water heating systems can be roughly estimated by assuming approximately 40 percent solar collection efficiency. Average monthly solar radiation multiplied by collector area and 40 percent delivery efficiency can provide a rough measure of daily or

Table 4-1. Daily Means for Twelve Consecutive Months of Operation of Solar Water Heaters at Various Localities

Location	Adelaide	Brisbane*	Canberra	Deniliquin	Geelong	Melbourne	Sydney
Hot water discharge**(gallons, U.S.)	54.2	54.6	51.4	50.9	50.4	54.6	53.9
Electrical energy consumed (kWh)	3.5	2.5	3.4	2.5	3.8	4.6	4.4
Cold water temperature (°C)	17.7	21.6	12.7	16.8	15.9	16.1	16.6
Hot water temperature (°C)	58.9	56.4	58.4	60.3	58.7	57.4	57.7
Energy required to heat water (kWh)	9.8	8.4	10.3	9.7	9.5	9.9	9.8
Heat loss from storage tank (kWh)	2.2	1.9	2.5	2.5	2.2	1.9	1.9
Total energy consumed (kWh)	12.0	10.3	12.8	12.2	11.7	11.8	11.7
Solar energy contributed (kWh)	8.5	7.8	9.4	9.7	7.9	7.2	7.3
Solar energy contributed (%)	71.0	76.0	73.0	81.0	67.0	61.0	62.0
Solar contribution best month (%)	99.0	94.0	98.0	100.0	92.0	95.0	70.0
Solar contribution worse month (%)	47.0	57.0	43.0	57.0	45.0	38.0	51.0
Ratio best to worst	2.1	1.6	2.3	1.8	2.0	2.5	1.4

* Hail screens suspended above the absorbers. No correction made for reduction of absorbing area.

** Water discharged at 6:00 a.m. daily.

Double-glazed, flat-black, 45 square-foot solar collector tilted toward equator at latitude angle plus 2.5 degrees. Storage tank 84 gallons (U.S.) Thermosiphon circulation. Electric auxiliary heat.

Table 4-2. Solar Water Heater Performance in Melbourne, Australia*

Month	Mean Insolation on Absorber	Mean Daily Supplementary Energy	Mean Daily Solar Energy Contribution		System Efficiency
	Btu/ft^2 Day	kWh	Percent	kWh	Percent
January	1630	2.9	75	8.9	40
February	2220	0.5	95	9.5	32
March	1690	2.6	74	7.4	33
April	1240	5.2	52	5.6	34
May	1290	6.2	47	5.5	32
June	1220	7.7	39	4.9	30
July	1290	8.1	38	5.0	29
August	1530	6.1	50	6.1	30
September	1600	4.9	59	7.1	33
October	1860	3.9	67	7.9	32
November	1880	3.7	68	7.9	32
December	1790	3.5	72	9.0	38
Year	1610	4.6	61	7.2	35

* Solar water heater as in Table 4-1.

monthly Btu delivery. The total Btu requirements for the hot-water supply, based on the volume used and the temperature increase set, then serves the basis for computation of percentage contribution from solar and the portion required to be supplied by fuel or electricity.

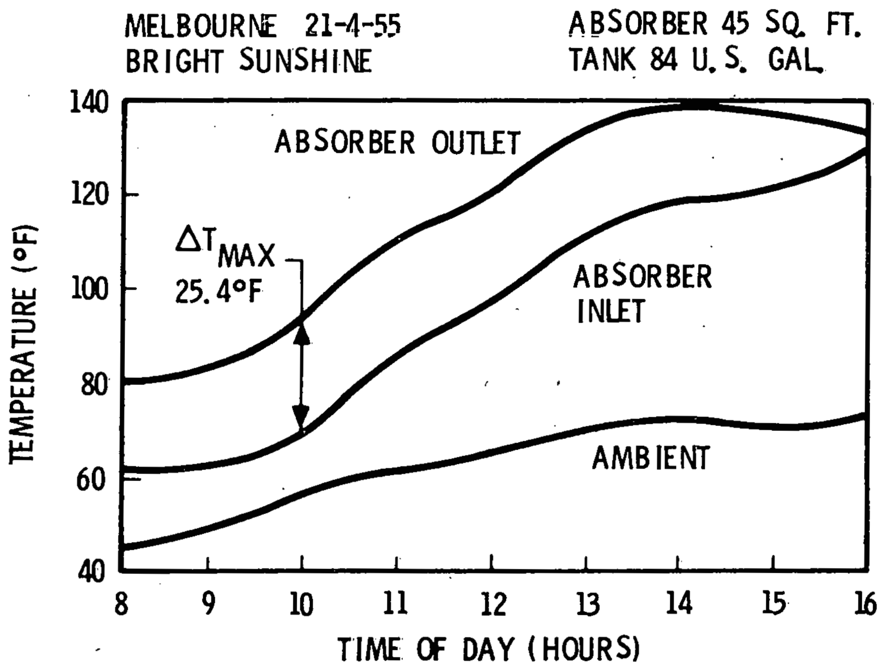


Figure 4-8. Absorber and Tank Temperatures for Thermosiphon Flow During a Typical Day

Sizing the Collectors

The curves shown in Figure 4-9 may be used to estimate the solar collector size required for hot-water service in residential buildings having typical hot-water systems. The system is assumed to be pumped liquid type, with liquid-to-liquid heat-exchanger, delivering hot water to scheduled residential uses from 6:00 a.m. until midnight. The shaded band represents results of computer calculations for eleven different locations in the United States. The cities included in the study are Boulder, Colorado; Albuquerque, New Mexico; Madison, Wisconsin; Boston, Massachusetts; Oak Ridge, Tennessee;

Albany, New York; Manhattan, Kansas; Gainesville, Florida; Santa Maria, California; St. Cloud, Minnesota; and Washington, D. C. The separate curve above the shaded band is the result for Seattle, Washington, and is distinctly different from other areas of the country. The hot-water loads used in the computations range from 50 gallons per day (gpd) to 2000 gpd. The sizing curves are approximate and should not be expected to yield results closer than 10 percent of actual value.

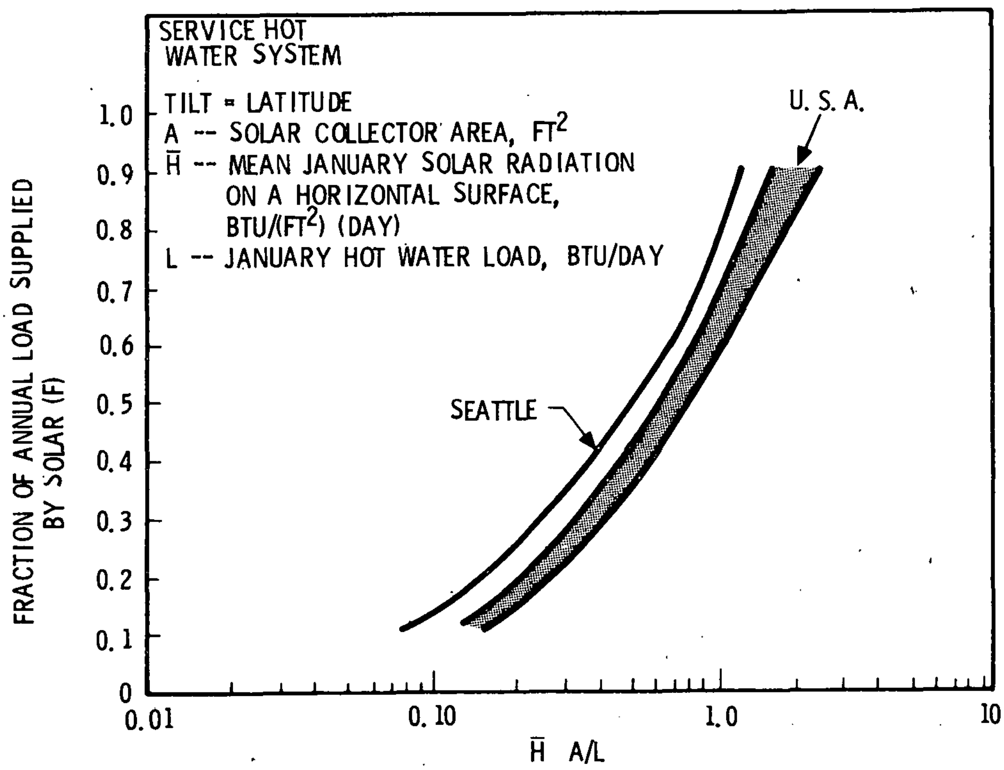


Figure 4-9. Fraction of Annual Load Supplied by Solar as a Function of January Conditions (Water System).

The vertical axis shows the fraction of the annual water heating load supplied by solar. The horizontal axis shows values of the parameters, $\overline{H}A/L$, which involves the average daily January radiation on a horizontal surface, $\overline{H}$; the required collector area, A; to supply a certain percentage of the daily hot water load, L. The January average daily total radiation at locations in the United States can be estimated from the radiation map in Figure 4-10. Values on the map are given in Btu/(ft^2)(day). The curves are not applicable for values of f greater than 0.9.

It should be remembered that the service hot-water load will be nearly constant throughout the year while solar energy collected will vary from season to season. A system sized for January, with collectors tilted at the latitude angle, will deliver high-temperature water and may even cause boiling in the summer. On the other hand, a system sized to meet the load in July will not provide all of the load in the winter months. Orientation of the collector can partially overcome month to month fluctuations in radiation and temperature.

Sizing Examples

Example 4-1 -- Determine the approximate size of collector needed to provide hot water for a family of four in a residential building in Kansas City, Missouri.

Solution: The average daily service hot-water load in January is:

$$L = 80 \text{ gallons/day} \times 8.34 \text{ pounds/gallon} \times 1 \text{ Btu/(lb)}(^\circ\text{F}) \times (140^\circ\text{F} - 50^\circ\text{F}) = 60{,}048 \text{ Btu}$$

The desired service water temperature is 140°F and the temperature of the cold water from the main is 50°F. The total average solar radiation, $\overline{H}$, available in January, from Figure 4-10, is 680 Btu per square foot per day. For a water system to provide 60 percent of the annual load, from Figure 4-9, $\overline{H}A/L$ is about 1.0. Therefore:

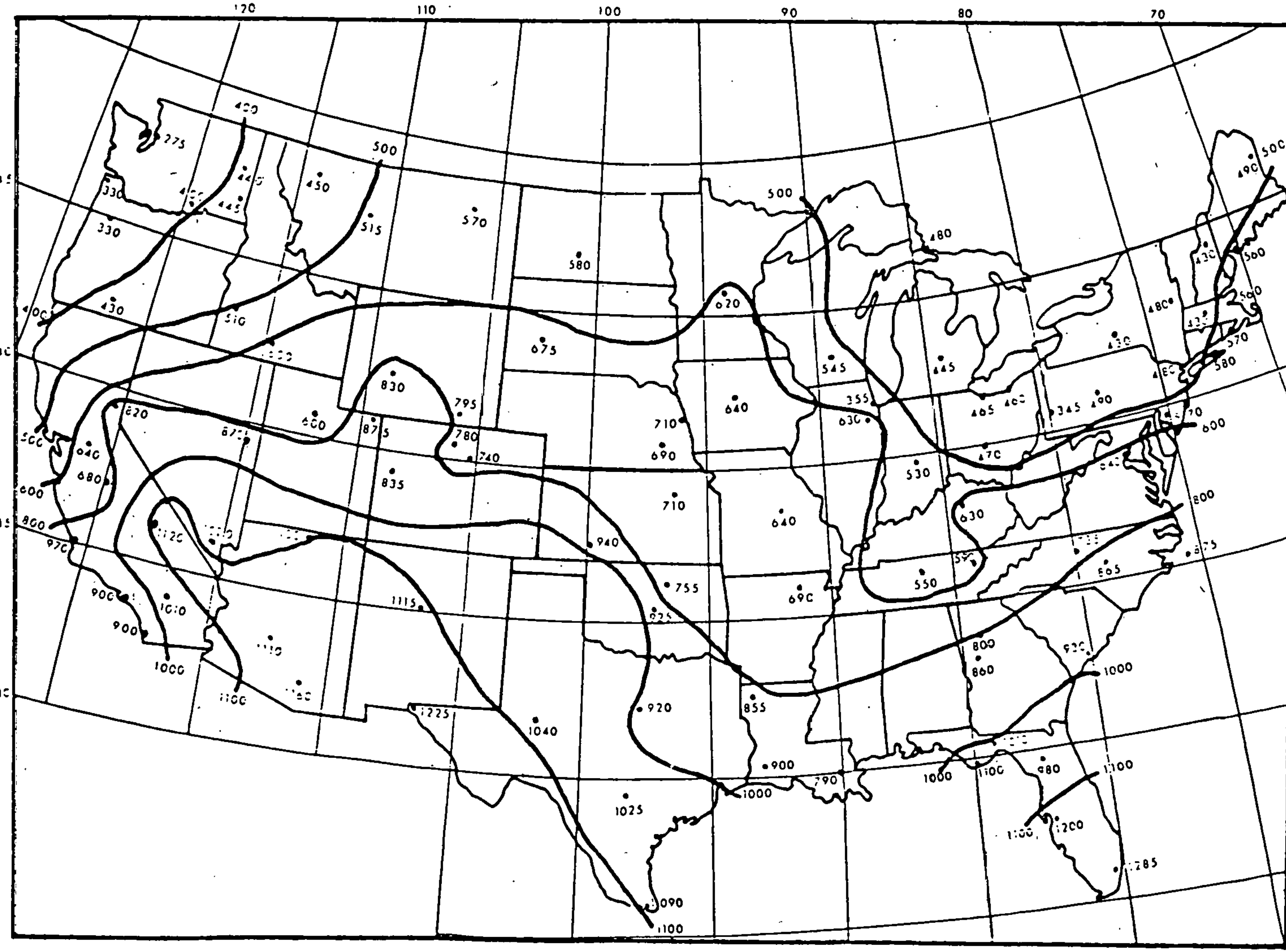


Figure 4-10. Average Solar Radiation (Btu/ft^2) on a Horizontal Surface in the Month of January

$$A = 1.0 \times L/\bar{H} = (1.0 \times 60048)/680 = 88.3 \text{ square feet.}$$

If 3 by 8-foot collector modules are available, 3.7 units would be required. Four collector units should therefore be used.

Example 4-2 -- Determine the size of collector needed to provide hot water for a family of four in Albuquerque, New Mexico.

Solution: The monthly load will be approximately the same as in Example 4-1:

$$L = 60,048 \text{ Btu}$$

From Figure 4-10, $\bar{H} = 1151$ Btu/(ft^2)(day). For a system to provide 60 percent of the annual load, Figure 4-9 shows that $\bar{H}A/L$ is approximately 1.0. The collector area required is:

$$A = (1.0 \times 60048)/1151 = 52.2.$$

Using 3 by 6-foot collector modules, 2.9 units would be required for the system, so three modules should be used.

Costs

The cost of installing a solar water heater (exclusive of the hardware) may range from about $300 for a system with a roof-mounted collector to over $1000 for a collector mounted on a stand adjacent to a house. In a recent procurement of several types of solar water heaters for ground mounting next to existing houses, an electric utility company spent $1500 to $2000 for each system, including hardware, totally installed. Non-freezing collectors of about 50 square feet, 80-gallon water tanks, pumps, fans, and controls were included.

A solar collector manufacturer has announced the availability of a solar water heater "package" having a retail price of $995. The package consists of a 40-square foot drainable collector, an 80-gallon storage tank, pumps, and controls. Installation and hook-up to the conventional systems are not included.

As designs are standardized and manufacturing volume increases, it may be anticipated that the total installed cost of an average-sized residential solar water heating system will be less than $1000. Assuming a collector area of about 50 square feet and a reasonably sunny climate, this unit should be able to deliver at least 250,000 Btu per square foot of collector per year, for a total of 12.5 million Btu annually. With an average daily requirement for 50,000 Btu of heat for hot water, the 18 million Btu annually required could be two-thirds solar. If electric heat at five cents per kilowatt-hour (about $14 per million Btu) is being replaced, an annual electric saving of about $175 is achieved. A $1000 solar water heater could thus pay for itself from electric savings in about six years. Or, if conventionally financed at 8 percent interest, an annual cost of interest plus principal of, say, 12 percent, or $120 per year, would be less than the electric savings by something over $50 per year. This favorable economic comparison for solar water heaters is applicable now in many parts of the country and should prevail very generally in the next few years.

SPACE HEATING WITH LIQUID SYSTEM

Solar Heating Systems with Water Heating Collectors and Water Storage

A liquid-heating solar system commonly uses water, with or without anti-freeze and corrosion inhibitor additives, as the heat transfer and storage fluid. A basic solar space heating system is shown in Figure 4-11. 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.

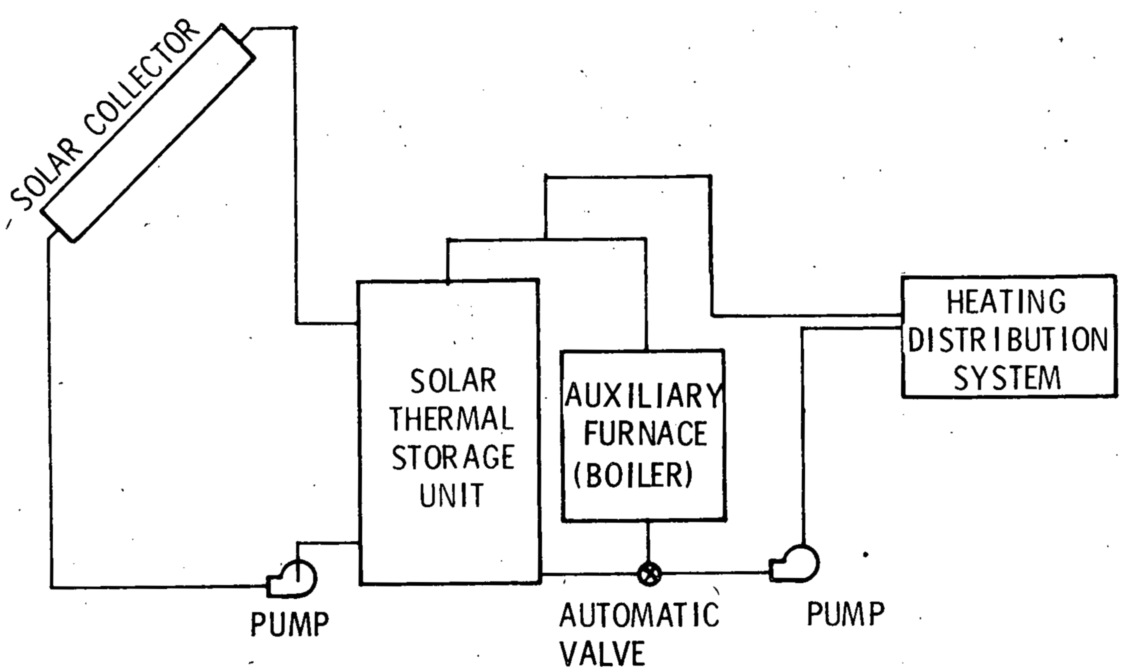


Figure 4-11. An Alternative Solar Heating System

Another liquid type in use is shown in Figure 4-12. It differs from the basic type in Figure 4-11 by use of a dual liquid collection and storage system; and by providing service hot water as well as space heating.

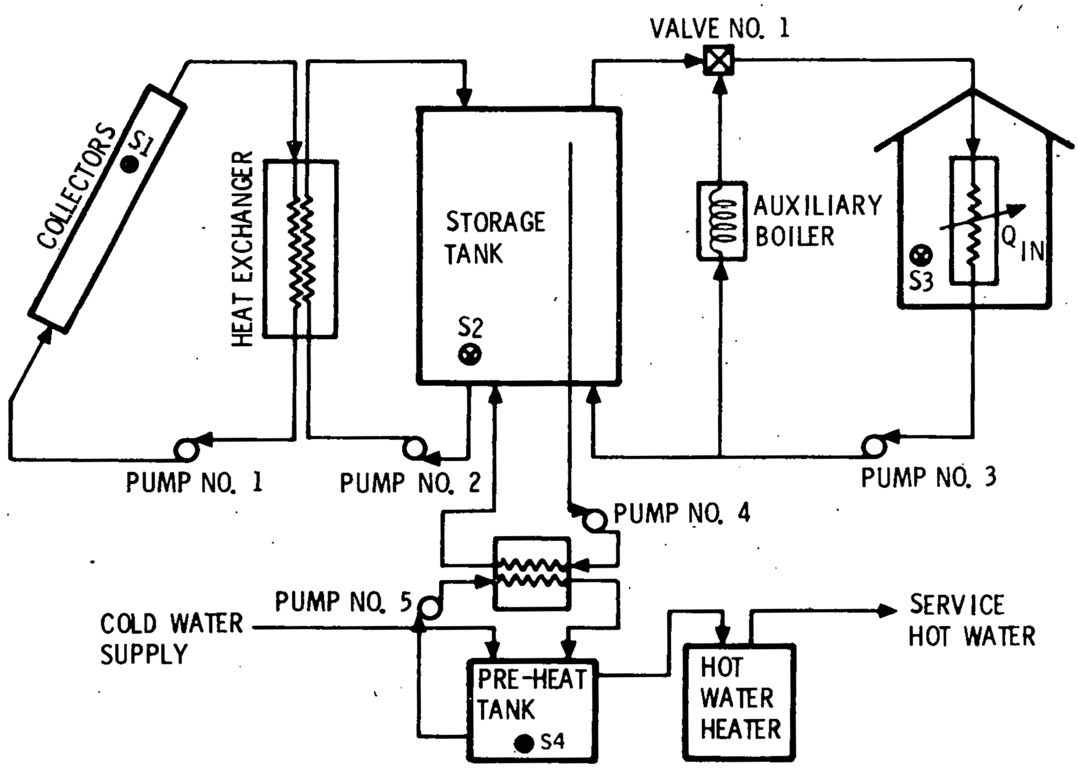


Figure 4-12. A Representative Solar Space and Service Hot Water System

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 is used. However, zoned control with two or more fan coil units can also be used with this system, provided costs are justifiable. In a solar system, a fan coil unit is preferred to baseboard heat radiators and convectors, because by that means, 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. When higher efficiency collectors (such as the evacuated tubular types) become economical, and collector operation at higher temperatures does not materially reduce system performance, baseboard radiators may be considered for the heat distribution system.

The preheating of service water will take place when the temperature at S4 exceeds the storage temperature, S2, by a preset amount. Pumps 4 and 5 circulate water from the storage tank and through the preheat tank, respectively. If the preheat tank reaches a maximum temperature, a thermostatic switch shuts off the pumps to prevent overheating of the 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 to the solar heating loop. If the temperature of the water in the storage tank is not sufficient to provide the heating requirements 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 is 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 to 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, and of course the house must always be heated to the required comfort conditions.

One of the main disadvantages of the previously described systems is that they do not have the ability to heat the space directly from the collectors. Since collector efficiency is a function of collector inlet temperature, the systems must always operate above storage tank temperature and hence at a higher collector inlet temperature. In systems where heating directly from the collectors is possible, lower temperature water (90°F) can be used to effectively heat the space. Analysis has shown that up to an additional 25 percent of collected energy can be provided with systems of this type.

Figure 4-13 is an example of this type of system. Pump P_1 circulates fluid, usually a glycol and water mixture, through the collector. Pump P_2 operates to supply heated fluid to the solar heat coil through valve V_2. If no space heating is required, then the system charges the storage tank. Pump P_3 discharges the storage tank at night or whenever there is no energy available from the collectors. Thus the system can

(1) Heat directly from the collectors

(2) Discharge storage for heating

(3) Charge storage when there is no heating demand.

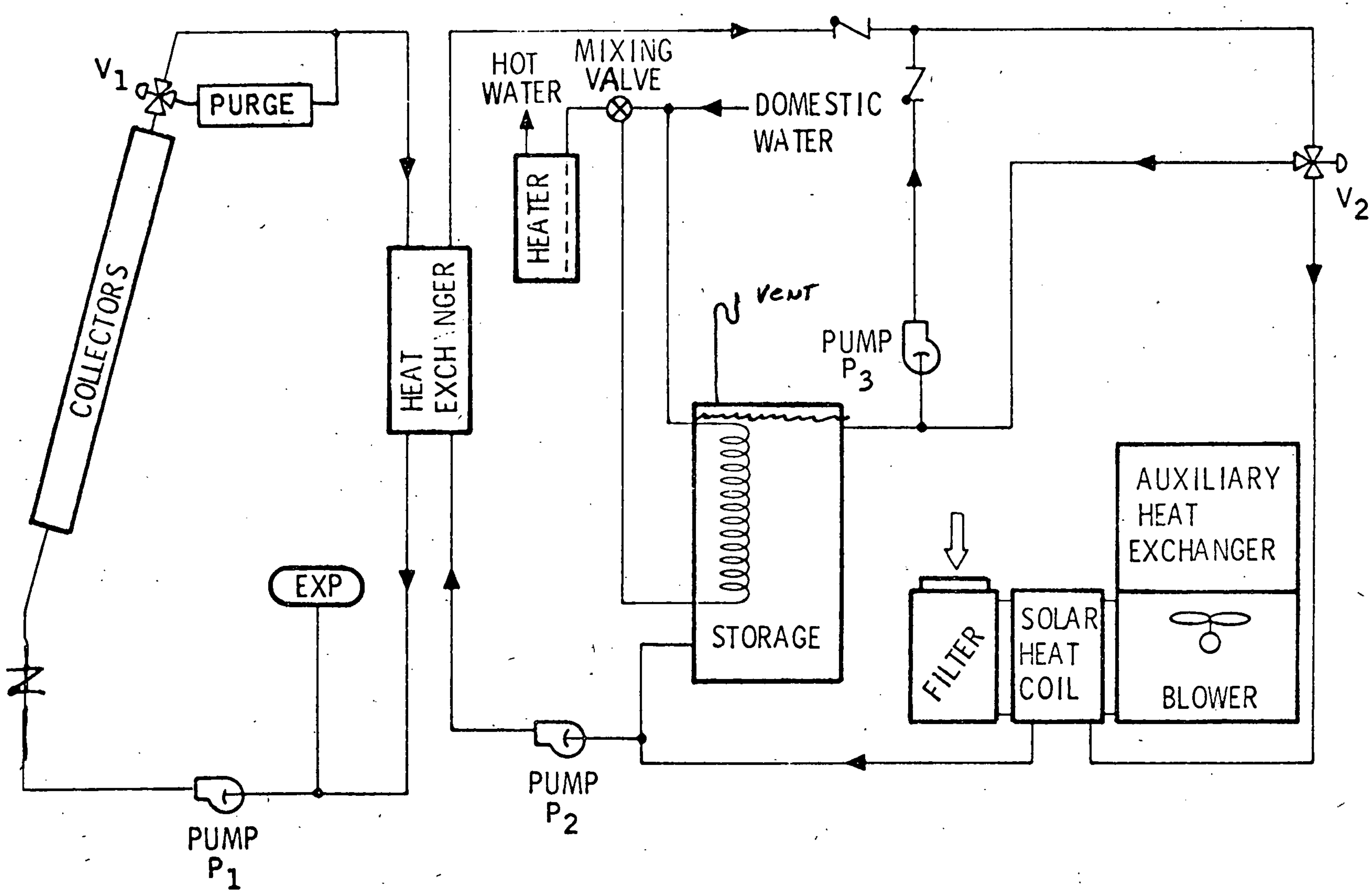


Figure 4-13. Single-Family Residential Heating System Schematic

The auxiliary heat exchanger can be a gas or oil fired section, hot water coil, heat pump coil or electric heaters. The domestic water section is passive in that the coil in the storage tank is heated by storage water and supplies heated water to the existing hot water heater whenever there is a hot water draw. A mixing valve prevents over-temperature water from entering the existing hot water heater.

The storage tank can be a low pressure, flat-head type with appropriate venting. A suitable lining in the tank will enable ordinary water to be used as the storage medium. Various check valves are utilized in the circuit to prevent flow in undesirable directions. The check valve in the collector loop is an anti-gravity type which will prevent thermal-siphoning of the collector loop on cold nights.

System control is shown in Figure 4-14. The control sequence is as follows:

First Stage Heating from Collector

- The thermostat positions system valve VS through a control relay to direct flow to the load coil.
- If the collector plate temperature is greater than 90°F (adjustable), then pump P1 will operate through the appropriate relays. An adjustable time delay will delay pump P1 shutdown to prevent short cycling. Pump P2 operates only when pump P1 is operating and is controlled by the differential temperature relay.
- Valve VS is controlled by relay to direct flow to the coil. When heating is satisfied, valve VS diverts flow to the storage tank. The furnace fan will operate in first or second stage heating or in the cooling mode.

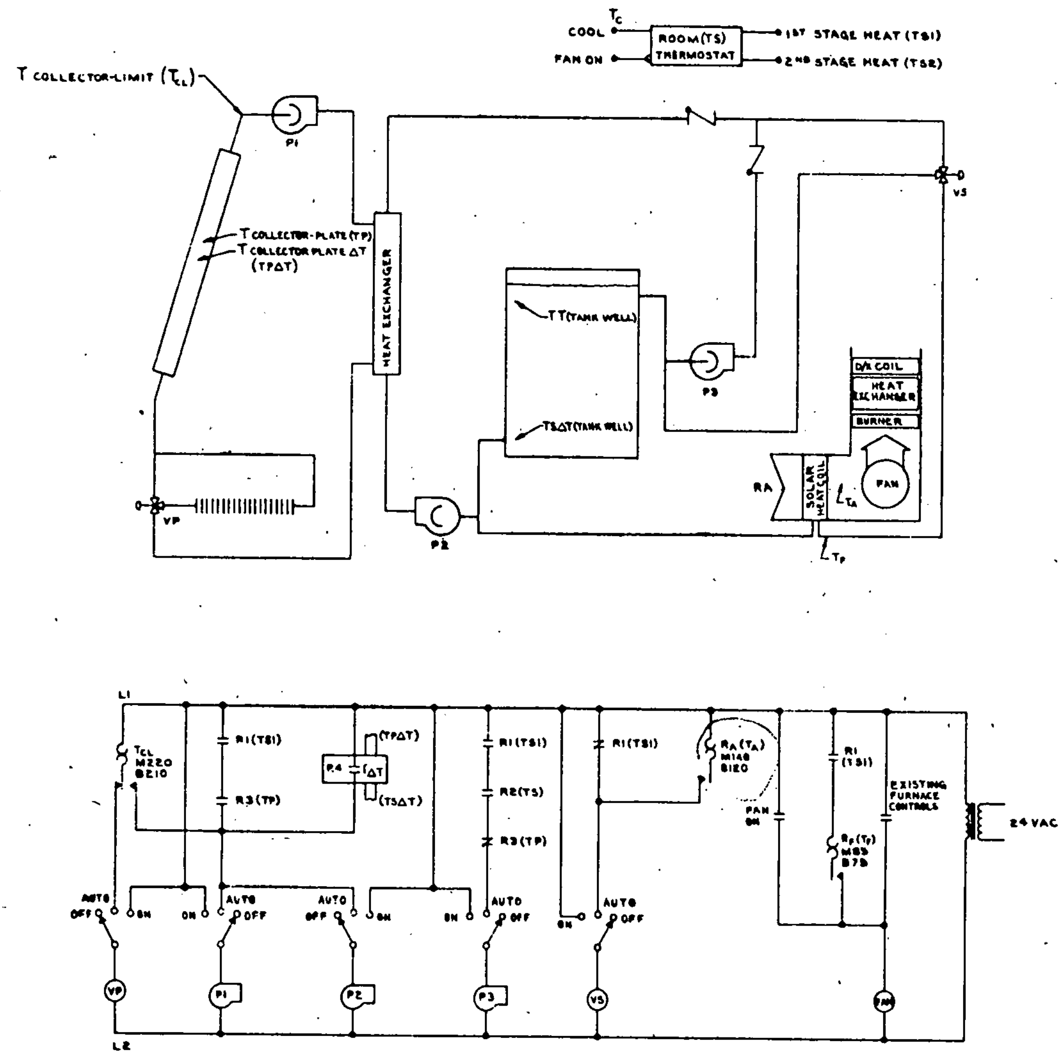


Figure 4-14. System Control Schematic

First Stage Heating from Storage

- Heating from storage is accomplished whenever energy is not available from the collectors, a heating demand occurs and energy is available from storage.

- On a call for heat the space thermostat will enable pump P3 to operate through the proper relays. Valve VS is positioned to divert flow to the furnace coil. Pump P2 is interlocked with pump P3 to prevent pumps P2 and P3 from operating at the same time. Pump P3 will operate if the storage tank temperature at the top is greater than 90°F (adjustable).

First Stage Heating from Furnace

- On a call for heat, if none is available from the collector panel or storage tank, a relay is energized bringing on the gas furnace. Second stage operates when the space thermostat senses a space temperature 3°F (adjustable) below the setpoint of first stage heating.

Second Stage Heating

- If first stage heating cannot be satisfied from direct use of heat from the collectors or the storage tank, then the space thermostat calls for second stage heating. First stage heating continues during second stage heating. Existing furnace controls are activated by the second stage heating thermostat contact. Second stage operates when the thermostat senses a space temperature 3°F (adjustable) below the setpoint of first stage heating.

Cooling

- Conventional controls and sequences are used for cooling.

Storage Tank Charging

- Charging is accomplished by diverting flow to storage through valve VS. Storage can occur only when there is no call for heating. With no call for heating pumps P1 and P2 are under the control of the differential temperature sensor. Pumps P1 and P2 will run so long as there is sufficient temperature difference (3°F). A time delay relay prevents short cycling of pump P1.

Figure 4-15 shows storage and collector temperatures as a function of time of day as controlled on a cold clear day by two data temperature controllers.

Figure 4-16 shows a system activated to the one described installed and operating. The system is inexpensive to operate and install. As with any system utilizing pumps, the pumping power can be kept to a minimum by careful selection of components to minimize pressure drop and then carefully matching pump performance to system pressure-flow characteristics.

System Design Principles

The collectors of the solar system for a new building can be readily placed on the roof. The building design can be made to be architecturally pleasing, structurally sound, and suited for solar energy collection. Although collector placement on the roof somewhat restricts the building orientation, collectors

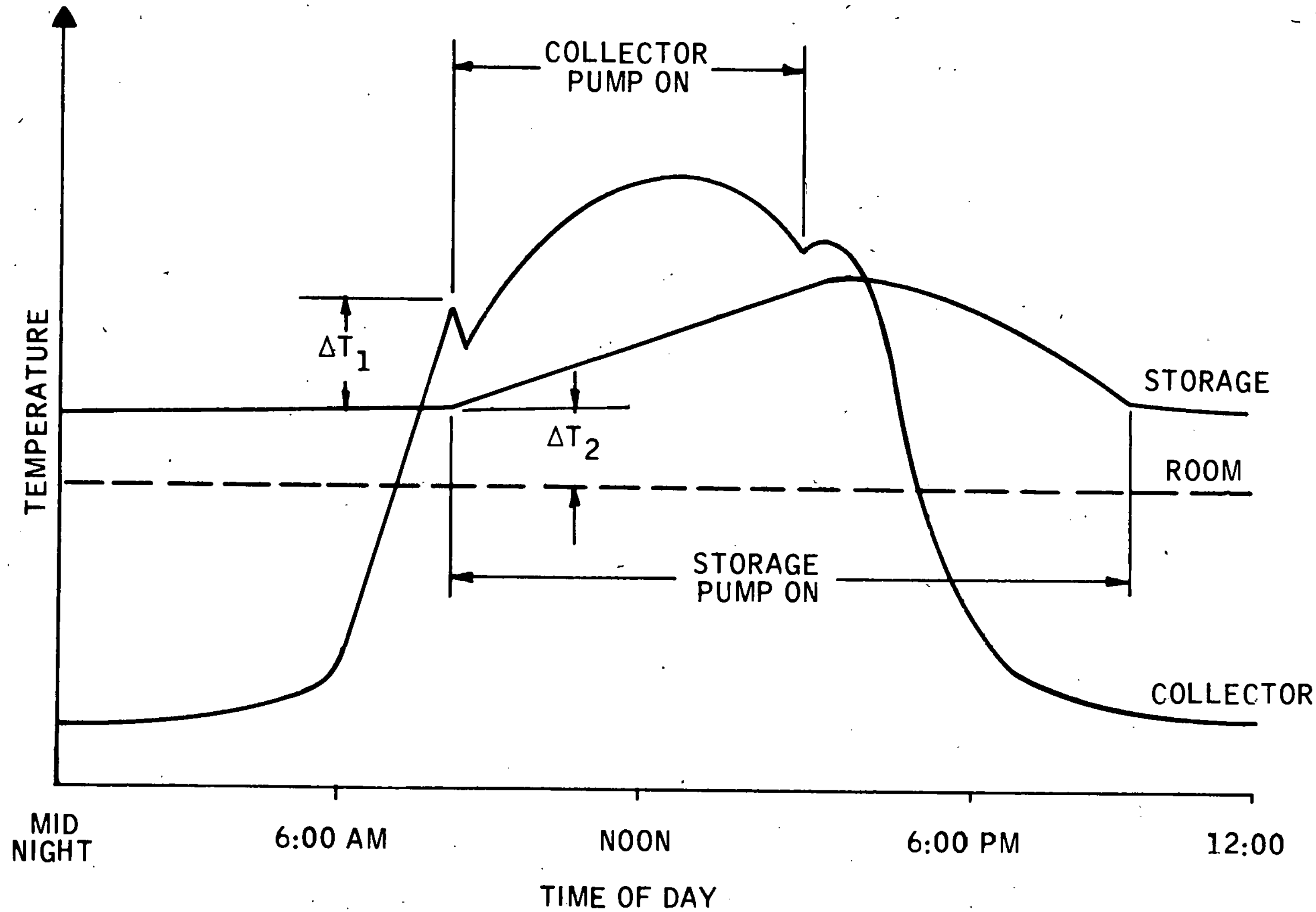


Figure 4-15. Operating Cycle

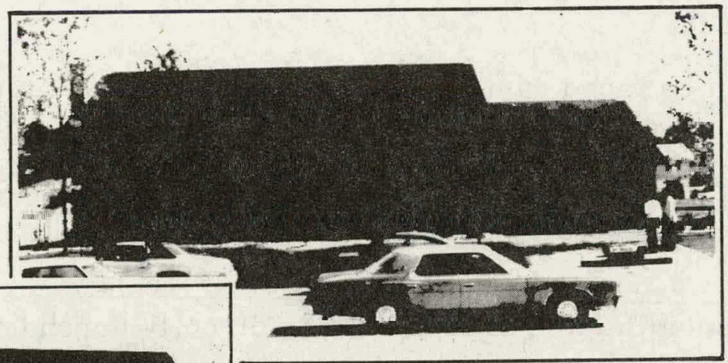


FIG. 1. EQUINOX SOLAR HOME -FRONT VIEW

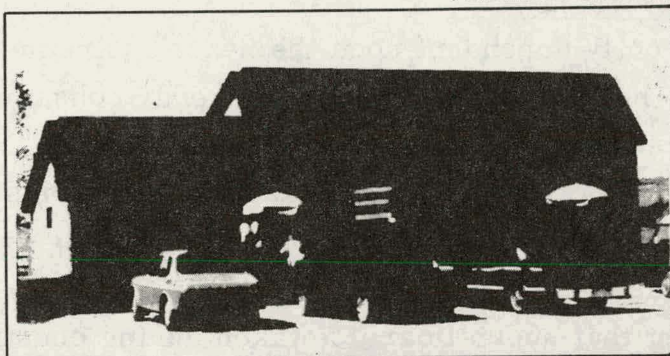


FIG. 2. EQUINOX SOLAR HOME- REAR VIEW

FIG. 3. EQUINOX SOLAR HOME SYSTEM PLUMBING

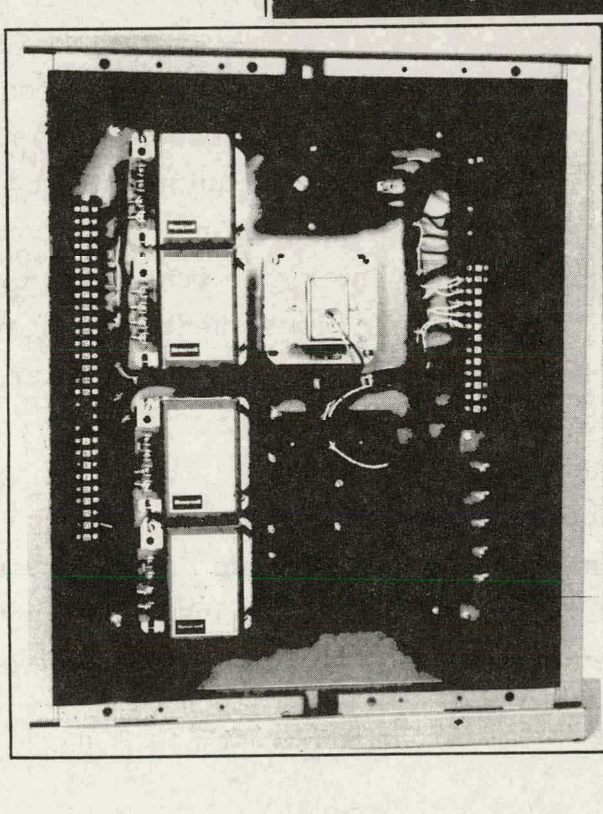


FIG. 4. SOLAR CONTROL PANEL

Figure 4-16. System Installation

can be faced east or west of due south by as much as 30 degrees without excessive performance loss. Depending upon the latitude and collector slope, the reduction in solar energy collection by an off-south orientation can be compensated by adding up to 15 percent additional collector area.

The collection area needed is directly dependent upon the heat requirements of the building. It is important, therefore, that economic energy conservation measures be adopted in the building design to reduce the heat load. Reduction of unnecessary window area, using double-glazed windows or storm windows, and using quality insulation in the walls and above the ceiling are effective energy conservation measures that have high economic returns. Beyond the design, it is important that special care be taken during construction to minimize cracks and uninsulated spaces around windows and doors. Insulating the floor above crawl spaces or around the perimeter of crawl spaces can be effective in reducing heat losses. Where basements are constructed, the space above the concrete walls between the floor joists should be sealed and well insulated, as this region is particularly susceptible to high infiltration losses.

The hot water storage tank should be located in the building whenever possible to take advantage of the heat losses from the tank. When a basement is available, the storage tank, auxiliary furnace and appurtenant equipment are readily accommodated. All of the equipment should be confined to a room with venting possible to the outside. During the winter, the vent to the outside would be closed and heat losses from the tank, pipes, heat exchangers and pump surfaces can be utilized to heat the house. During the summer, the heat in the equipment room can be vented to the outside.

If there is no reasonable alternative but to locate the storage tank underground, the tank should be well insulated, the ground around the tank should be well drained, and provisions should be made to keep the insulation dry with a moisture barrier. If water penetrates the insulation, the effectiveness of the insulation is lost.

The pre-heat tank for service hot water should be of such size as to store the equivalent of one-day use. The quantity of hot water needed varies with the family, but on a national average, about 20 gallons of hot water per person per day is used. For a family of four, this amounts to 80 gallons of hot water per day, so the size of the pre-heat tank should be about 80 gallons. The rapid-heating conventional hot water tank should be about 40 gallons capacity.

The heat exchanger for the service hot water should be double-walled to comply with the plumbing codes in many areas. The purpose is to prevent contamination of the potable water by any leaks from the non-potable storage tank water. Local codes should be consulted when choosing the heat exchanger.

The fan coil unit in the building may be of conventional design, available readily from any HVAC equipment supplier. Separate fan coil units for each zone in the house is a possibility, but a central air heating distribution system is more common in the United States.

SOLAR HEATING SYSTEMS WITH AIR COLLECTORS AND PEBBLE-BED STORAGE

Introduction

Although not as widely available as liquid types, solar air heating systems have been experimentally used over the past three decades.

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. Rather than being in tubes, the air may contact the entire surface of the absorber plate. To enhance the heat transfer coefficient, fins, corrugations, or other types of extended surfaces on the absorber may be employed. It has been found that good performance is achieved with air collectors operating at approximately the same mass flow rate as used in liquid collectors, about 10 pounds per hour per square foot of collector surface, roughly 2 cubic feet per minute 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 temperature are, at inlet and outlet, respectively, about 70°F and 140°F.

Other types of solar air heaters have been experimentally used in solar heating systems. The overlapped glass plate collector has been used in a Denver house for 20 years; a porous screen or matrix type was used for several years in an Arizona house; an extensively finned absorber plate has been used in a recent experimental house in Delaware; and a Vee-corrugated absorber plate has been employed for heating air in Australia. Although choice of glazings is independent of the absorber configuration or the collection medium, all of the recent commercial installations, as well as the experimental systems on which performance data have been published, have employed single or double-glass sheets.

Over one-half of the single-family residences in the United States are provided with warm-air heating systems. The use of solar air collectors thus permits direct heating of these types of buildings without need for heat exchange. Typical warm-air temperatures in these systems also match the capability of solar air collectors. And probably of the greatest importance is the fact that return air from the rooms, to the collector, is always at a low temperature of about 70°F. This comparatively low temperature, even though greatly increased in the collector, results in a much higher collection efficiency than if hot air were being returned.

Heat storage in an air system for the best collection efficiency 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 experienced with air returning from the rooms. 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°F 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 feet 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 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 though it were returning from the rooms of the house. A practical quantity of storage material is about 50 pounds (approximately 1/2 cubic foot) of pebbles per square foot of collector.

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 in 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 as necessary.

It is evident from the description of the heat storage process and the effect of temperature on solar collector efficiency that stratified, non-isothermal storage of heat in an air system is highly desirable. The stratification in a pebble bed storage system will result in an improvement of approximately 5 percent in system performance over that attainable with an unstratified storage system with the same thermal capacitance. Transfer of heat to a tank of water, or to an isothermal phase-change material, would penalize the performance of the system. There is moreover a substantial cost advantage in the use of economical pebble-bed systems, the typical 15- to 20-ton container rarely involving more than $300 cost, and the gravel itself seldom requiring more than a $100 outlay. The primary drawback of pebblebed storage is the large volume and floor space required relative to phase change or water storage systems.

Solar air heaters, as well as solar liquid collectors, may be multiples of factory-built modules suitably interconnected on site, or they may be built in place as a single large unit. The latter design may reduce the number of connections and duct material, but much more installation labor is required. Although some air collectors have been built on site from basic materials, the assembly of factory-built modules assures not only a better quality installation but also a more economical one. The practical trend in both air and liquid systems is heavily on the side of completely factory-built modules of 10 to 30 square feet collector area, ready for placement on supports and for interconnection with suitable conduits.

Manifolding of collector modules, typically about twenty square feet each, may be costly if each module must be provided with inlet and outlet conduits in the field. Designs which minimize the use of such materials and labor will clearly have cost advantages. An example of such a design is a collector in which air manifolds are integral parts of the collector modules.

System Design Principles

A basic arrangement for space heating with a solar air system is shown in Figure 4-17. By positioning a three-way damper (or its functional equivalent) and turning two blowers on and off, three modes of operation are provided:

1. Heating the building directly from the collectors

2. Heating the storage unit from the collectors

3. Heating the building from the storage unit

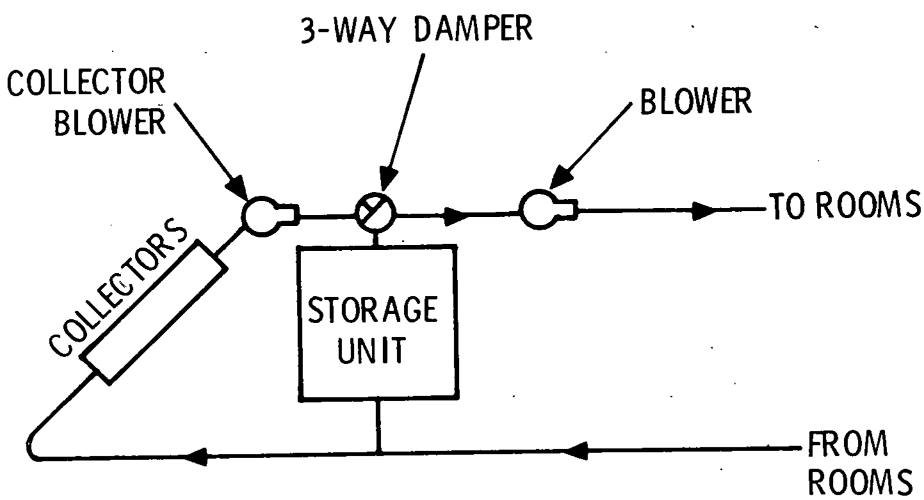


Figure 4-17. Basic Arrangement for Space Heating with Solar Air System

Since there are periods when neither the collectors nor the storage unit can meet the demand for heat, an auxiliary (fuel or electric) heater having the capacity to carry the maximum heating load is required. Solar and auxiliary heat may be supplied to the building by the same distribution system. The air-type solar system may use a conventional warm-air furnace directly on the hot-air supply duct, as shown in Figure 4-18. Fuel is supplied to the auxiliary unit only when solar heat is insufficient to maintain the desired room temperature.

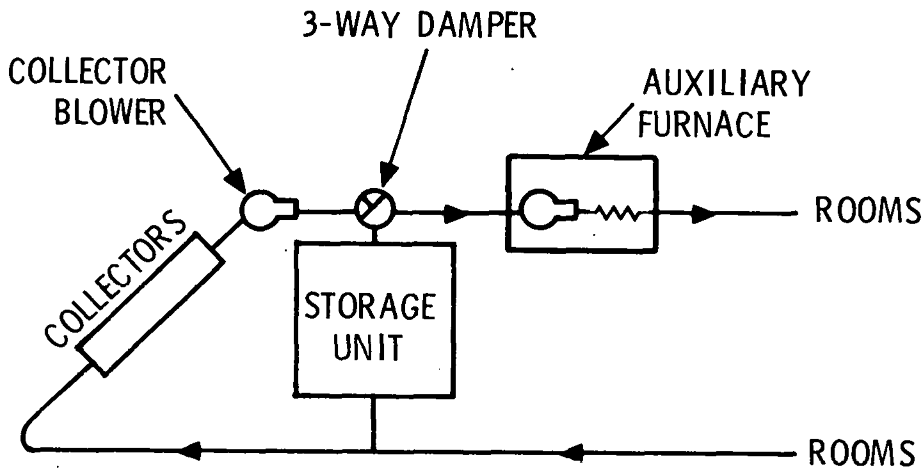


Figure 4-18. Air System for Solar Space Heating with Duct Furnace Auxiliary

Solar Air Heating System

Double Blower Design -- The schematic design of a two-blower air-type solar system shown in Figure 4-19 comprises four principal components: solar collector, heat storage unit, air blower, and auxiliary heater. By combining the blower and dampers into an "air handler," construction and operation of the system can be simplified. Figures 4-20, 4-21, and 4-22 show the operation of such a system in its several modes as shown in Table 4-3 (MD signifies motorized damper, BD signifies back draft damper or check damper).

So that the domestic hot-water supply can be solar heated in the summer when no space heating is needed, the heat storage unit and heated space can be by-passed as shown in Figure 4-22. A manual damper is opened in the by-pass duct so that air is curculated in a closed loop between collector, water heating coil, and the collector blower. Damper MD1 in the closed position prevents flow of hot air to storage or the rooms.

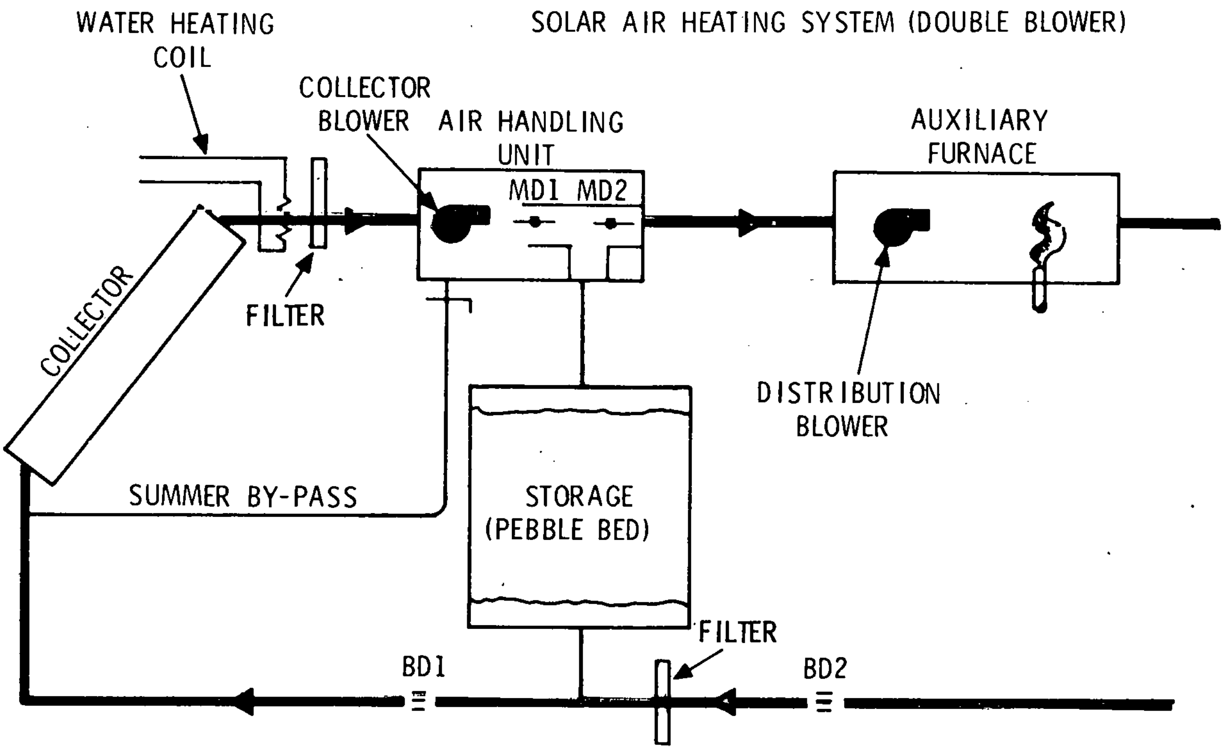


Figure 4-19. Heating Building Directly from Collectors

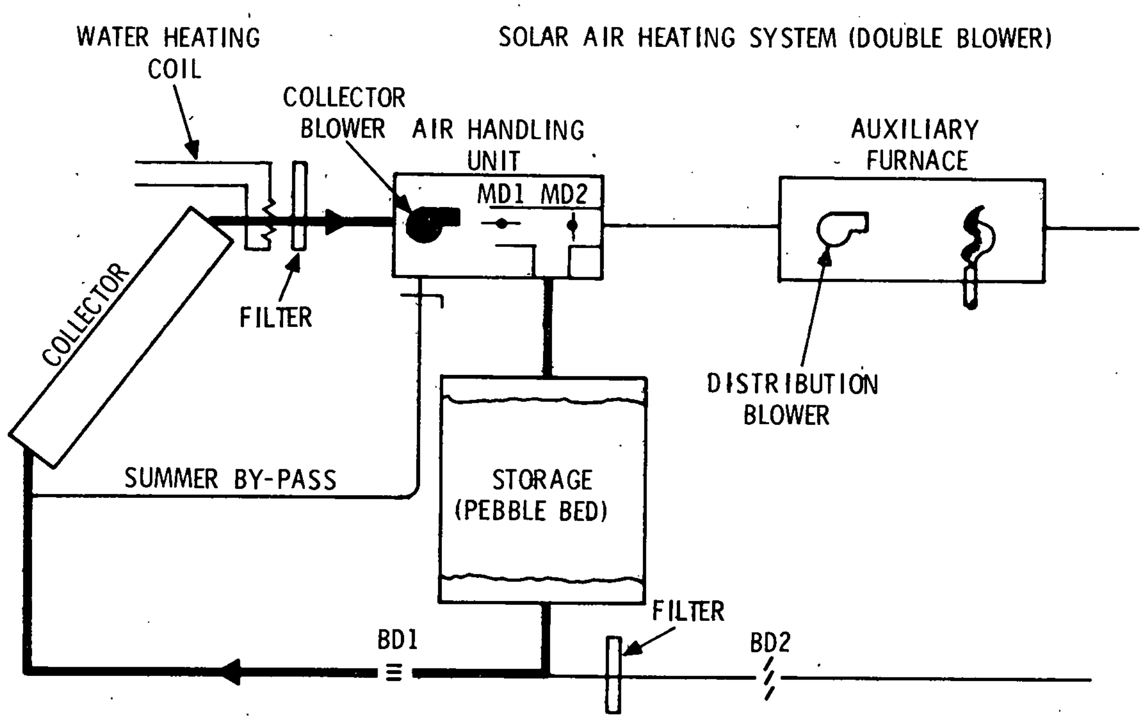


Figure 4-20. Storing Heat from Collectors

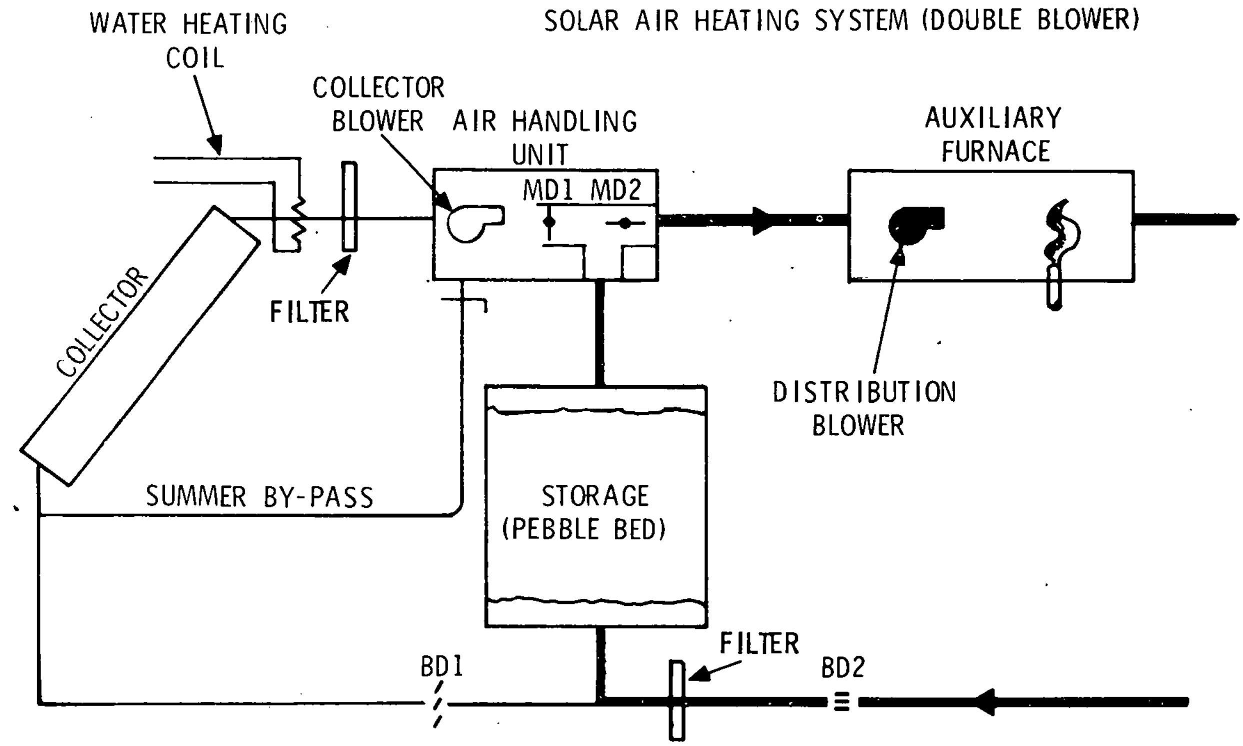


Figure 4-21. Heating Building from Storage Unit (Also Heating from Auxiliary)

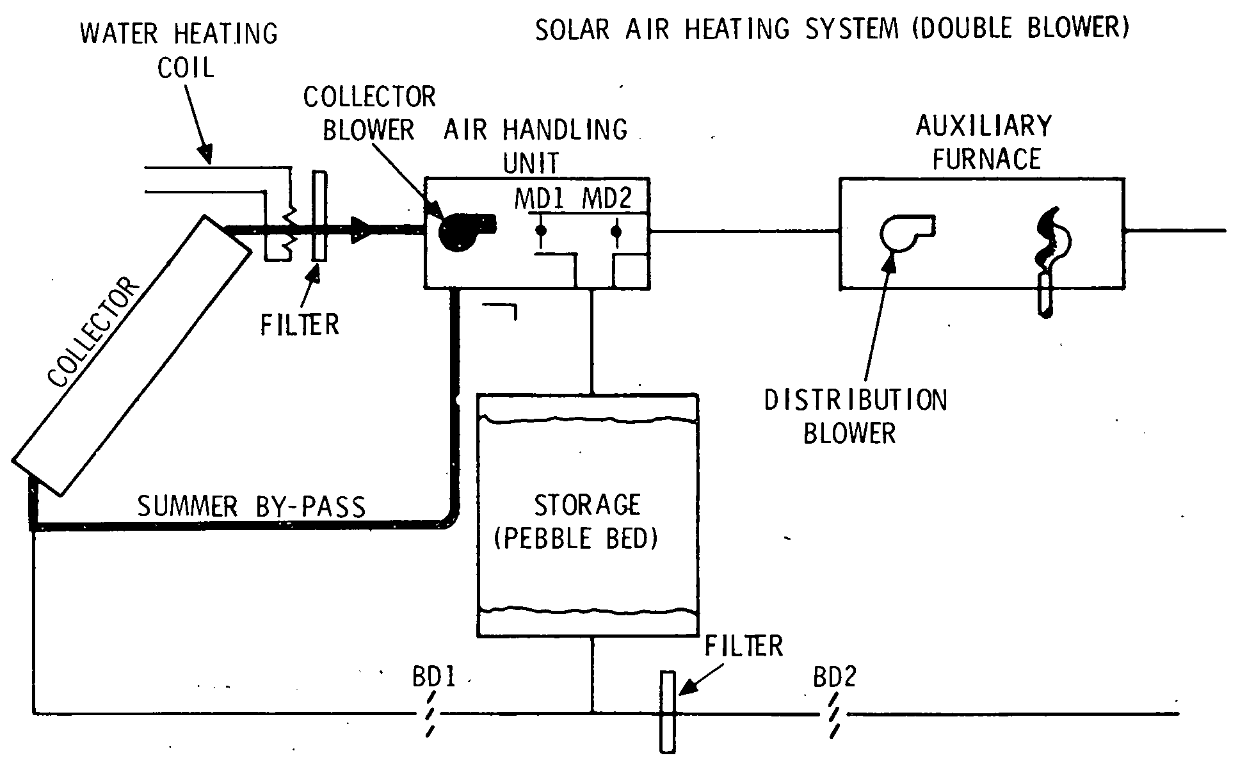


Figure 4-22. Service Hot Water Heating (Summer Operation)

Table 4-3. Two-Blower, Air-Type Solar System Operation

	MD1	MD2	BD1	BD2	Collector Blower	Distribution Blower
Room Heating from Collector (Figure 4-19)	Open	Open	Open	Open	On	On
Heating Storage (Figure 4-20)	Open	Closed	Open	Closed	On	Off
Room Heating from Storage (Figure 4-21)	Closed	Open	Closed	Open	Off	On
Room Heating from Auxiliary (Figure 4-21)	Closed	Open	Closed (auxiliary on)	Open	Off	On

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 furance blower is used in the normal manner for distributing warm air being supplied either from the collectors or from storage. The solar system blower operates only when air is circulated through the collector.

Single Blower Design -- Another damper arrangement does not require the furnace blower, so only the solar system blower is needed. Four motorized dampers are required (rather than two) but only two actuators are needed. This system type is shown in Figure 4-23, with the blower and motorized dampers in an "air handler" cabinet.

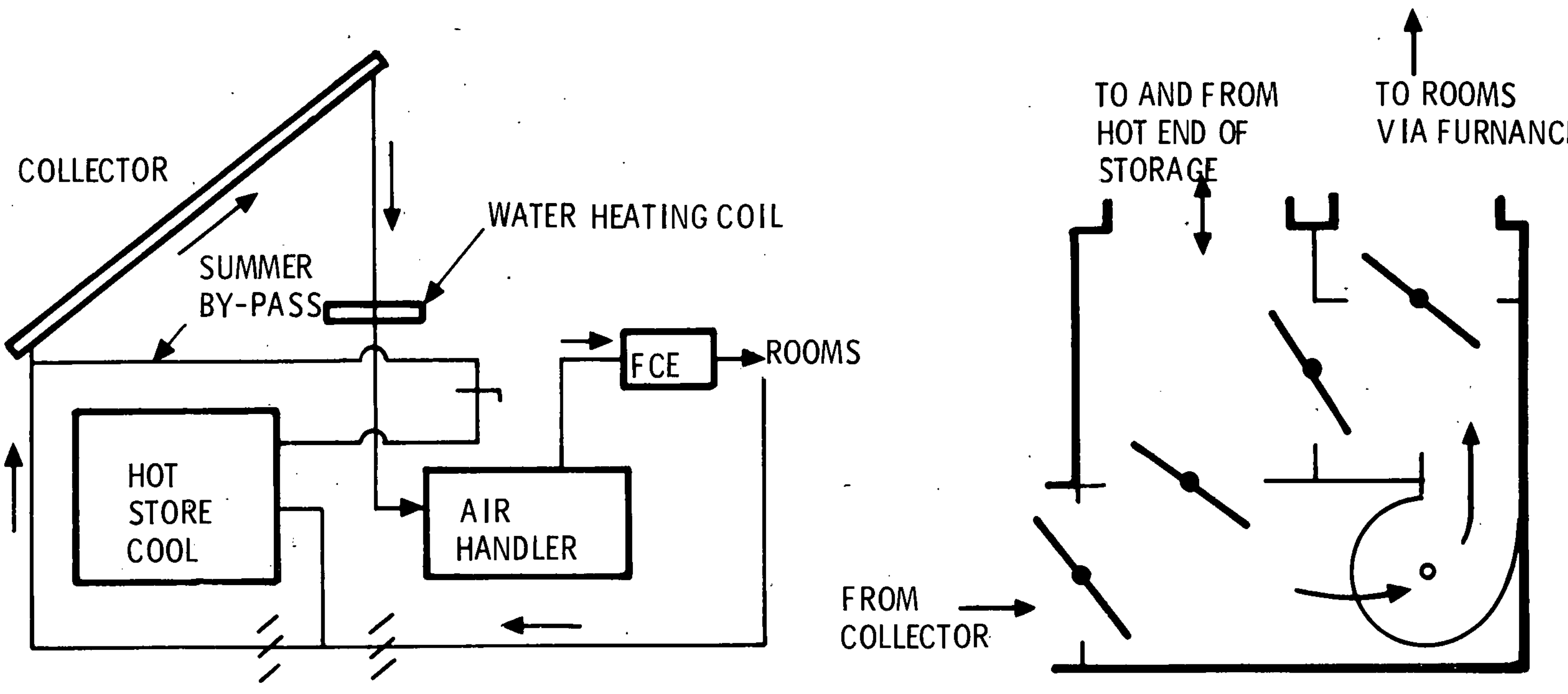


Figure 4-23. Air Handler, Single Blower System Design
(Inset shows use in complete system)

Collector Subsystem

Among numerous types of solar air collectors, a simple double-glazed, thin-air duct, coated with black paint or enamel, in an insulated steel tray is one of the most practical, durable, and economical.

Air collectors have been described and their functional requirements outlined. Whether modular or site-fabricated, permanent attachment to the roof or other structure is necessary. Air inlets and outlets must be provided to each module or to groups of modules in a manner such that nearly uniform air flows through the array are assured. Normally, a roof penetration is required for each air connection unless ductwork above the roof is acceptable. Internal manifolding of modules, if provided by collector design as in Figure 4-24, can be a material factor in reducing the number of duct connections and roof penetrations. Figure 4-25 shows an example of such an arrangement. When exterior ductwork is acceptable, only a single penetration of the roof is necessary.

Storage Subsystem

Pebble-Bed Operation -- Solar-heated air is passed directly through the pebble-bed from top to bottom. As the air passes through the pebbles, heat is transferred from the air to the rocks so that the rock temperature rises. The cool air which leaves the bottom of the pebble-bed is returned to the collectors to be reheated. The top of the pebble-bed will be warmer than the bottom because of hot air supply from the collectors. After sundown and discontinuance of air circulation, the pebble-bed will maintain this temperature stratification because heat conduction through the bed from one pebble to another is very slight.

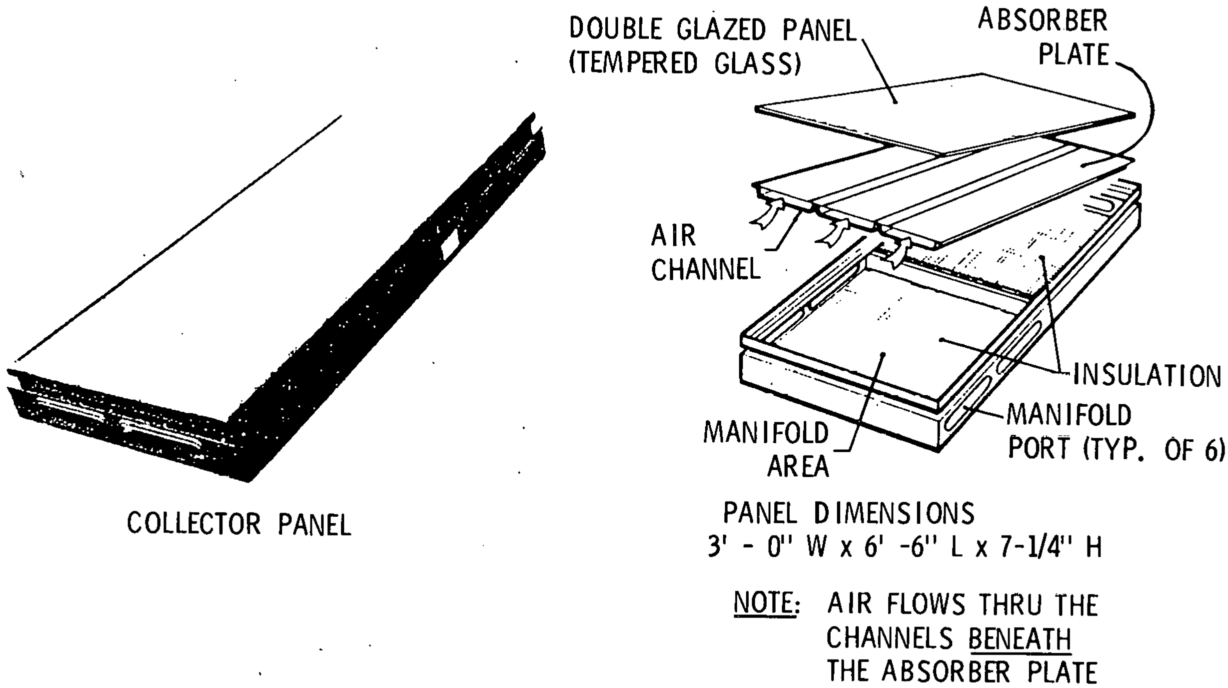


Figure 4-24. Air Collector Module with Internal Manifolds

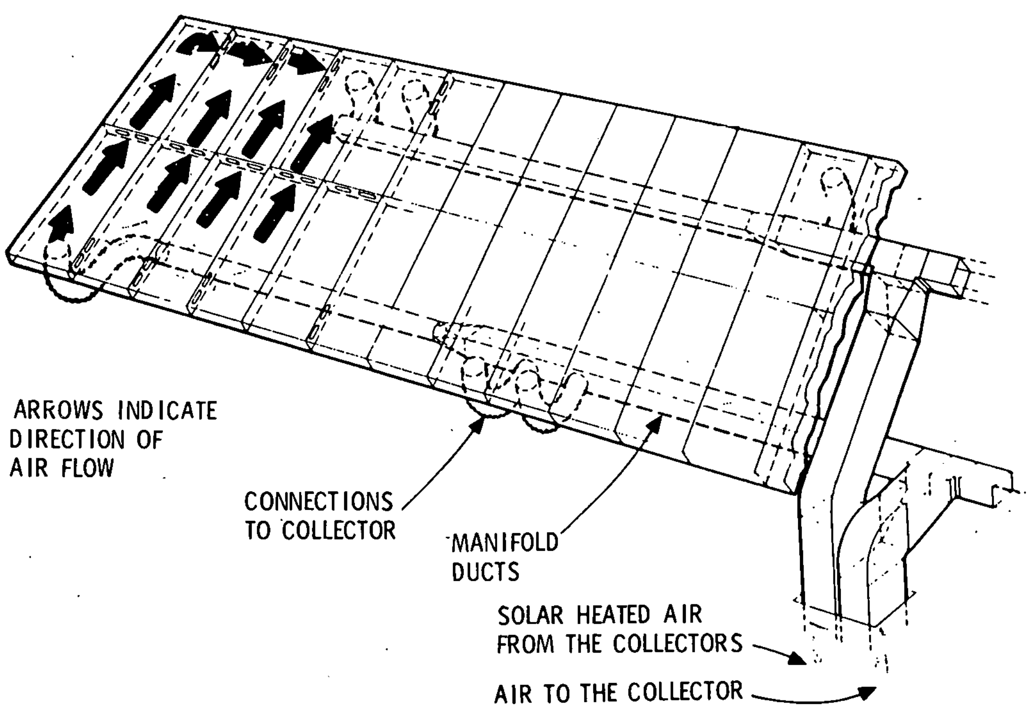


Figure 4-25. Typical Arrangement of Internally Manifolded Collector Modules in an Array

The supply of stored heat to the building is accomplished by circulating room air through the pebble-bed in the direction opposite to that involved in the storing cycle. Cool (70°) air from the rooms flows upward through the pebbles and is progressively heated nearly to the temperature of the rocks near the top of the bed. This warm air then passes to the rooms. The entire process of storing and using this solar heat provides a supply of lowest temperature air to the collector for maximum collector efficiency and the supply of the warmest available air to the building.

The hot end, or collector supply end, of the pebble-bed is preferably at the top to prevent heat loss to the floor. If the layout requires the hot end at the bottom, two inches of rigid fiberglass board should be placed under the unit to reduce heat loss to the floor.

Pebble-Bed Installation -- 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 size and uniformity of the pebbles. At a typical air velocity of about 20 feet per minute through five feet of 0.75 to 1.5-inch gravel, the pressure drop will be about 0.3 inch water gauge.

As shown in Figure 4-26, 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 percent for lightweight screen support. If a heavy mesh woven or welded wire screen is used, the block spacing can be greater.

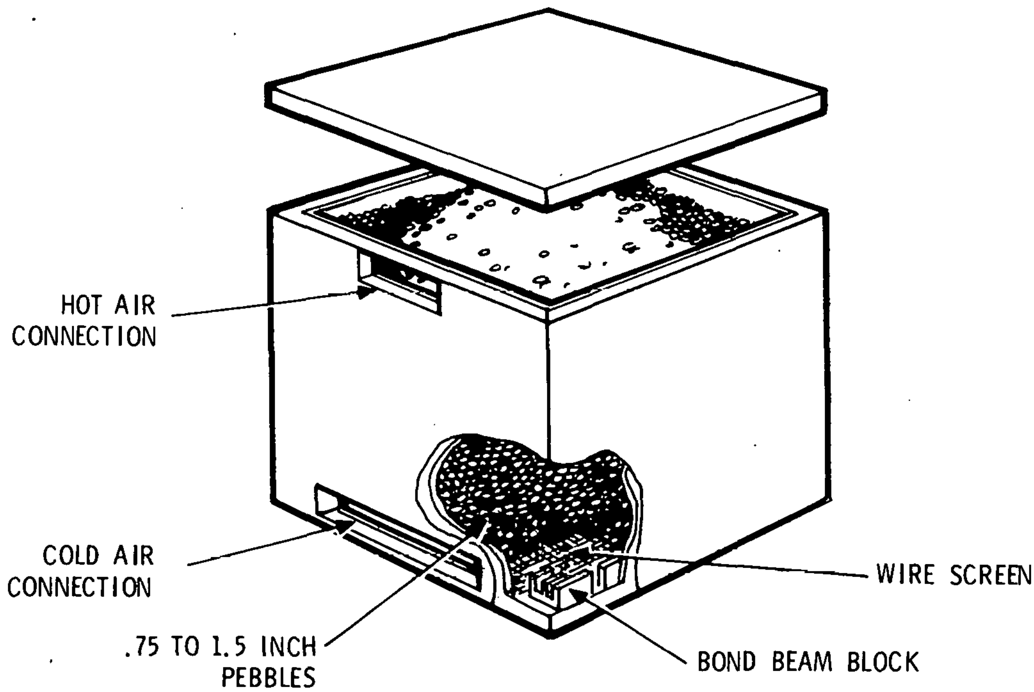


Figure 4-26. Pebble-Bed Heat Storage Unit

Although horizontal flow has occasionally been used in pebble-beds, heat exchange effectiveness has been lower 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 primarily vertical, alternately up and down.

Pebble-Bed Containers -- Pebble-beds may be contained in wood frame boxes, poured concrete walls, concrete block walls, or cylindrical steel bins. Wood frame boxes can be built in places where access is limited. Steel wires or tie rods should be placed across the box to prevent the sides from bulging under the pressure of the pebbles. Framing should be of construction-grade

2 x 4's on one-foot centers. One-half inch plywood can be used on both sides of the 2 x 4 studs, and the space filled with three and one-half inch fiberglass roll insulation. For fire protection and leak reduction, sheet rock should be used to cover the interior plywood.

Steel bins make convenient pebble-bed containers. They can be assembled by bolting the curved sections together on the job site. A durable caulking compound must be used between the overlapping joints to prevent air leakage. Two-inch foam insulation should be cut into segments and placed around the outside of the bin.

Concrete block may also be used for the pebble-bed walls. Steel reinforcing rods three-eights inch (3/8") in diameter should be placed across the bed every two to three feet to support the walls. Two-inch rigid fiberglass insulating board should be used to line the inside of the block walls.

A poured concrete bin should be considered when a basement is being built with poured concrete walls. Two additional walls in one corner, with suitable openings provided by the forms, can be economically provided. Rigid insulation on the inside or outside, although not essential, can be added for thermal loss reduction. After filling, an insulated plywood cover on a 2 x 4 frame can then be installed.

Rock for the Pebble-Bed -- Any type of rock suitable for concrete aggregate can be used in the pebble-bed. Size uniformity is important, so good screening is a requirement. The usual size employed passes a 1.5-inch screen but is held on a 0.75-inch screen. Even a few percent finer (less than one-half inch) causes a reduction in air flow or increase in pressure loss. Rescreening and washing of poorly screened or dirty rock is sometimes necessary. Although round pebbles are preferable, crushed rock is acceptable if clean and well screened. The pebble-bed should be filled by use of a chute so that fracturing will be minimized and damage to the walls and bottom from falling rock will be avoided.

Solar Air System Materials, Components, and Construction

Important operating considerations in the air-type systems are blower power requirements and air leakage. A well designed air system has approximately equal pressure loss in the collectors and pebble-bed, typically about 0.3 inch of water in each unit. With ducting and filters, the total system pressure difference can approach one inch of water. The pressure loss in an air-type solar system is about twice that usually encountered in a conventional forced-air distribution system, so additional blower power (typically one-half to three-fourths horsepower for a 1500 cfm system) is required. The blowers also run for longer periods than in the conventional system because of their use both for solar heat collection and for heat distribution. A one-inch pressure loss is therefore about the maximum acceptable from the standpoint of blower power cost.

Leakage of air in ducts, collectors, and storage is of greater concern in a solar heating system than in a conventional system because the pressure is higher, there is more ducting, the system runs for longer periods, and there may be more ducting through unheated space. All ducts should therefore be tightly made with taped or sealed joints and tightly fitted dampers. The ducts may be of fiberglass board or insulated sheet metal. Insulation is needed to reduce heat loss through duct walls, particularly in unheated spaces. At least one inch of fiberglass with a rating of R-4 is recommended for duct insulation.

It is especially important with a solar air system that a well scheduled installation be made. More space and access must be provided in the building for ducting than for pipes in a liquid system. Ductwork and component assembly can be done at the same time that the distribution ducts and furance are installed in a typical construction schedule. There must be provision for construction and installation space and for full access to the space (spaces through house between collector and storage, handy openings in pebble-bed, and so on) for the system and components.

Air ducts may be fiberglass ductboard of fiberglass-lined sheet metal. If ductboard is used, it should not be in locations where it can be damaged by moving objects or occupants. Joints should be well sealed with tapes or mastics recommended by the industry. Duct bends should be provided with turning vanes to reduce pressure losses. Ducts should be sized for air velocities between 700 and 1000 feet per minute.

Blowers, dampers, and auxiliary heaters may be provided by a single solar system supplier or they may be purchased separately. If separately purchased, blowers should be forward-curved squirrel cage-type, belt-driven at 900 to 1700 rpm. Direct-coupled blowers with motors in the air stream may have shorter service life because of motor operation in high-temperature air, so type B or type C motors should be used if in the air stream. Flexible connections between blowers and ducts are recommended.

Louver-type dampers with live silicone rubber seals are recommended for positive shut off and smooth stroking. Damper drive motors should be located on the outside of ducts and direct coupled to the damper shafts or through linkages. Damper pairs (Figure 4-23) may be operated by the same drive motor so that one is closed when the other is open. Damper motors are available which operate on low voltage (24 volts) and have spring returns.

As shown in Figures 4-19 through 4-23, a factory-made air handler can replace the separately purchased and installed components, i.e., blower and motor, two or four automatic dampers, and two damper actuators. In such a unit, the components can all be properly sized in relation to each other and factory adjusted for proper operation. On-site labor involves setting the air handler in place, making suitable duct connections to the several air openings, and making electrical connections to the power source and to the temperature sensors and thermostat.

Back-draft dampers are used in ducts to prevent reverse flow (Figures 4-19 through 4-24). Back-draft dampers may be of the flexible flap type or shutter type. They must be mounted to provide a positive seal against reverse air flow.

To avoid fouling and pressure loss, filters should be installed in the air streams entering both ends of the pebble-bed. They should be changed or cleaned every few weeks during the first several months of operation to remove the initial dust in the system and building.

Provision for supply of domestic hot water can easily be made in the air system by use of an air-to-water heat exchanger in the hot-air duct between collector and blower. The heat exchanger coil is a finned type, with one or two rows of tubes. A small pump circulates water from the bottom of an insulated tank (usually about 80-gallon capacity) through the coil, back to the top of the tank. As in the typical solar water heating system (space heating not involved), cold water enters this solar-heated tank and warm water flows to a conventional automatic water heater whenever a hot-water faucet is opened in the building. A duct bypass, as shown in Figure 4-22, permits operation of the service hot-water coil in the summer without heating the pebble-bed.

The complete solar heating installation will require heating and sheet metal workers to install collectors, ducts, dampers, and the conventional system, electricians to wire blowers and dampers, plumbers to connect the domestic water heating system, and carpenters or masonry workers to construct the pebble-bed walls. Consequently, the general contractor and the solar system contractor coordinate their activities so that each task is accomplished at the most appropriate and convenient stage during construction. Quality installation is an important requirement of a high-performance air-heating system.

SPACE COOLING

Introduction

There are three categories of space cooling methods for residential buildings:

1. Refrigeration
2. Evaporative cooling
3. 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 in tons of refrigeration. A ton of refrigeration is the removal of heat at a rate of 12,000 Btu per hour. Another often used term in connection with refrigeration equipment is coefficient of performance, COP. The COP expresses the effectiveness of a refrigeration system as the ratio of useful refrigeration effect to net energy supplied to the machine. The COP is determined by the simple equation below:

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

The COP of a mechanical vapor-compression refrigeration machine is characteristically about two and can be as high as four. The COP of a lithium-bromide-water absorption refrigeration machine is about 0. 8 and more often operates in the range from 0. 6 to 0. 7. A COP less than 1. 0 means that more energy is supplied to the machine than heat energy is removed from the room air. From the cooling capacity and COP the energy consumption rate by the machine to produce the cooling 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 per hour. With a COP of 0. 6, the quantity of heat needed at the generator is 60,000 Btu per hour (36,000 ÷ 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 then into an absorber where it recombines with the absorbent. In a lithium-bromide-water absorption machine, water is the refrigerant and lithium bromide is the absorbent. An absorbent is a liquid which 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 is explained with the aid of Figure 4-27. The cycle begins when water in the liquid mixture in the generator is boiled off and superheated with solar energy at temperatures between 170°F 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 in the evaporator coils. The heat in the room air or water which is brought in contact with the evaporator is removed by the cool refrigerant. The refrigerant then passes to the absorber where

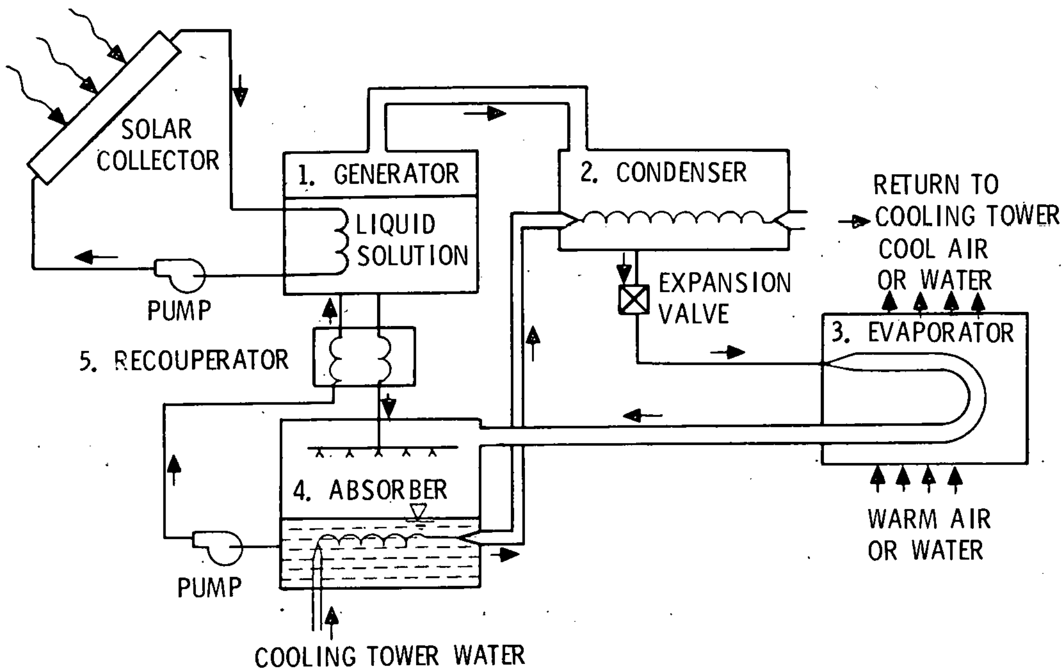


Figure 4-27. Absorption Air Conditioner--Schematic Drawing

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 recouperator in the diagram is a heat exchanger which preheats the dilute solution as it flows from the absorber to the generator and at the same time cools the hot concentrated solution which 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 from about 170°F to 210°F. The heat input to the generator must be sufficiently high to boil the refrigerant water from the solution in the generator. The temperature must be at least 170°F. The upper temperature is normally limited to 210°F because the hot water to the generator in a solar system is provided from storage and the temperature in storage will be less than the boiling temperature 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 recouperator. If the temperature is too low in the recouperator, and the concentration of the lithium-bromide-water solution is high, the lithium-bromide will solidify in the outlet tube leading from the recouperator to the absorber and eventually in the generator as the water continues to be boiled off and the concentration of lithium-bromide increases. Provided the temperature in the generator is between 170°F and 210°F, the unit will operate satisfactorily.

Solar Heating and Cooling System

System Components -- A schematic diagram of a solar heating and cooling system with service hot-water heating is shown in Figure 4-28. The components that are added to the heating system are as follows:

1. An absorption water or air chiller
2. Wet cooling tower
3. A pump to circulate cooling water from the chiller to the tower
4. A pump to circulate chilled water
5. Associated piping, valves, and controls

The collector, with or without the heat exchanger, provides hot water to the storage tank. In the event that 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

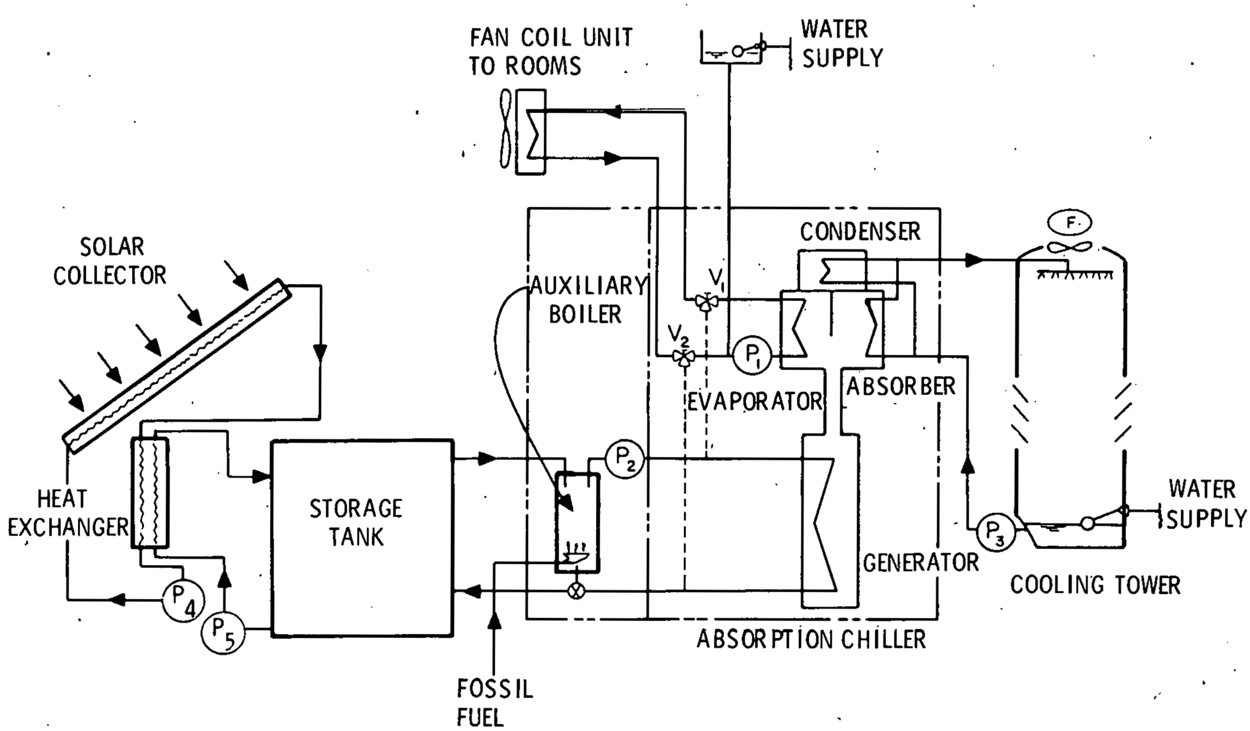


Figure 4-28. Flow Chart of a Water Chiller Operation

the generator of the absorption chiller by pump P2 and returned to the bottom of the tank. It will be noted that, in this arrangement, the flow from the tank is through the auxiliary boiler. This is a particular arrangement which allows the use of one pump for circulating water from the storage tank and the same pump for circulating the water through the auxiliary boiler. When the temperature in the storage tank is insufficient to operate the absorption chiller, the auxiliary boiler is used to provide heat to the generator. When the auxiliary boiler is used, the three-way valve at the bottom of the auxiliary boiler circulates the return water only through the auxiliary 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 the pressure drop and heat losses from the pipeline.

A wet cooling tower is needed with the absorption chiller to discharge the heat from the condenser and the absorber to the atmosphere. The size of the cooling tower needed depends upon 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 cooling 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°F to 85°F. A pump labeled 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 individualized units for different zones within the building.

System Operating 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 per hour for the 3-ton unit. If the temperature of the hot water is, say 195°F, this means the flow rate must be about 10 gpm to the generator with a temperature difference of 10°F between entering and exit temperatures from the generator. The heat removal rate at the condenser is about 38,000 Btu per hour, and at the absorber about 43,000 Btu per hour. The cooling water from the tower will be at a temperature near 75°F, and will return to the cooling tower at a temperature of about 90°F. The flow rate should be about 12 gpm. The heat rejection rate of the cooling tower will be 81,000 Btu per hour, which is equal to the cooling capacity, 36,000 Btu per hour, plus the heat added to the generator, 45,000 Btu per hour.

If the cooling water temperature of 75°F cannot be achieved because of rise in wet-bulb temperature of the outside air or because the tower is not sized properly, the performance of the system can be expected to reduce. If the temperature rises to 85°F, then the COP can be expected to 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 can be expected to decrease. It is important to follow the manufacturer's sizing recommendations for cooling tower and pumps for a particular cooling unit size at a given geographic location because of system sensitivity to the cooling water temperature and flow rates.

Another important factor in solar cooling unit operation and performance involves frequent on-off cycling. When the cooling load is less than the cooling capacity of the machine, the unit will turn on when the temperature in the building rises above the threshold level and turn off when the building cools to the comfort level desired. These temperatures depend upon the thermostat settings, but could be, for example, 80°F and 75°F. Because the cooling unit has 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 the building. Cycling can be a problem, particularly for air chillers, but can be reduced for water chillers by providing chilled water storage. With chilled water storage, the cooling unit can operate continuously. When cooling is not needed for the building, the chilled water can be stored. When the building calls for cooling, valves can 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 which 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 should be located close to the system also. However, aesthetic considerations may dictate the location of the tower relative to the building.

The higher operating temperatures of water in the storage tank necessitate insulation of the storage tank, pipes, and equipment. Despite well-insulated surfaces, 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.

Rankine Cycle Refrigeration

The Rankine Cycle refrigeration system shown in Figure 4-29 uses solar energy and is presently being developed and demonstrated in several residential and commercial solar heating and cooling projects in the United States. The system features solar energy supplied to a Rankine Cycle (R/C) power system which in turn generates shaft horsepower input for a conventional vapor compression air conditioner (A/C) or water chiller (W/C). Typically a fluorocarbon fluid (Freon derivative) is employed as the working fluid in both the R/C and A/C systems.

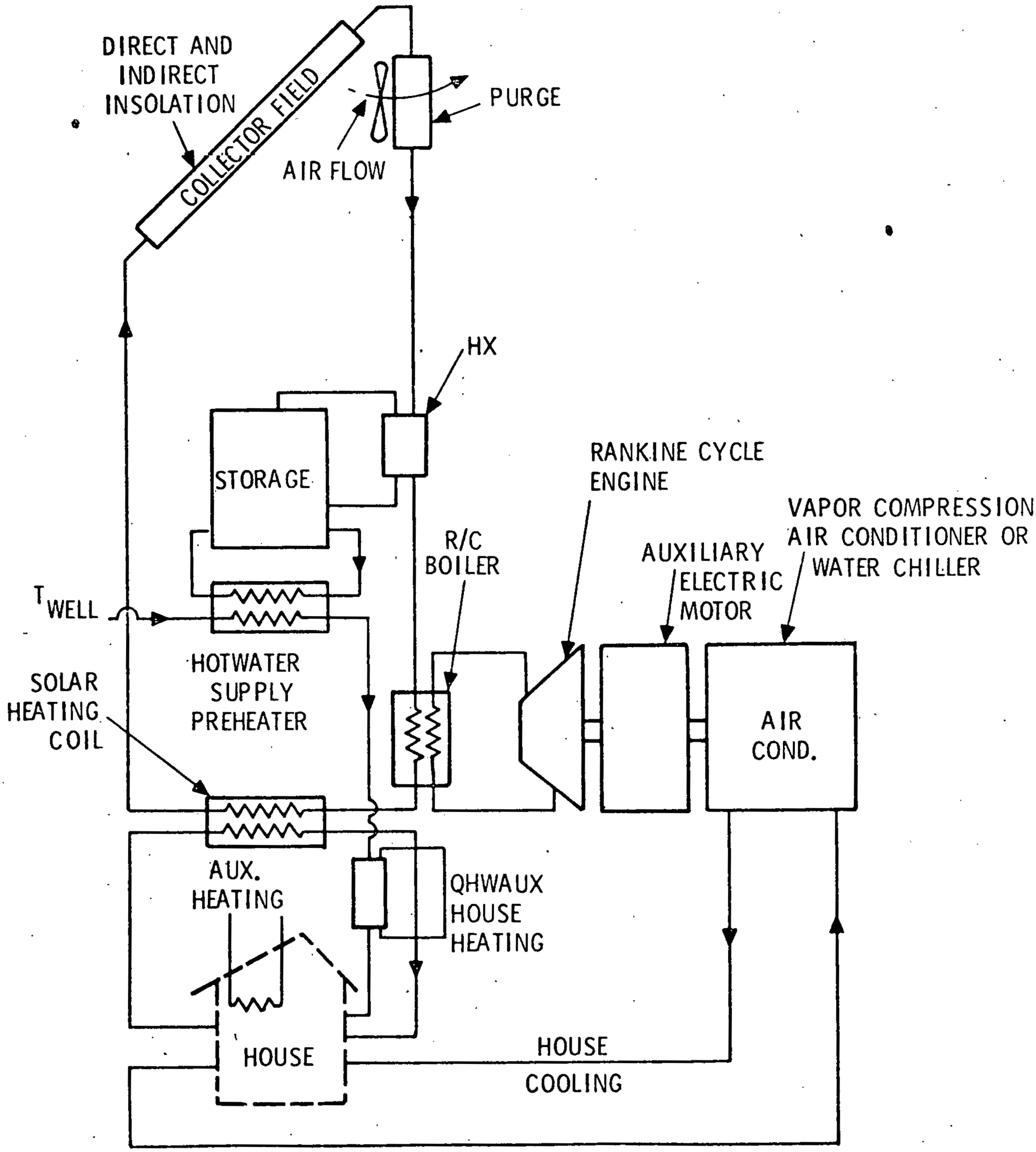


Figure 4-29. Schematic Diagram of a House Equipped with a Solar HVAC System

A more detailed schematic of the R/C-A/C cycle is presented in Figure 4-30. In the Rankine cycle, working fluid is pumped from a water-cooled condenser through a regenerator to the boiler, which extracts heat from solar collector fluid. The regenerator is a liquid-to-vapor performance improvement heat exchanger operating within the R/C loop. Vapor leaving the boiler is admitted to nozzles which feed a turbine rotor. Turbine exhaust vapor passes through the vapor side of the regenerator and returns to the condenser, completing the Rankine cycle.

Turbine rotational speed is reduced by a gearbox whose low-speed shaft is connected by an overrunning clutch to a motor-generator and air-conditioning compressor. This configuration permits total input shaft power to the A/C loop from the solar-powered R/C. If the R/C system cannot keep up with the cooling demand (i.e., if it is a partially cloudy day), rated cooling can be maintained with the help of the electric motor mounted on the drive shaft.

In the air-conditioning cycle, a compressor receives low-pressure refrigerant vapor from the evaporator (or chiller) and pressurizes it. The high-pressure vapor then enters a water-cooled condenser where the latent heat of vaporization is removed, leaving high-pressure liquid refrigerant. This liquid is allowed to pass through a thermal expansion valve to the low-pressure portion of the loop (i.e., evaporator). The expansion of this high-pressure liquid produces a mixture of refrigerant liquid droplets and vapor at a low temperature (about 45°F). This low temperature provides sufficient temperature difference to extract heat from air or water, as desired, and thus supply cooling. The energy taken from the air or water in the cooling process supplies heat of vaporization to the droplets of refrigerant liquid, producing refrigerant vapor. This low-temperature, low-pressure vapor then flows to the compressor, completing the A/C cycle.

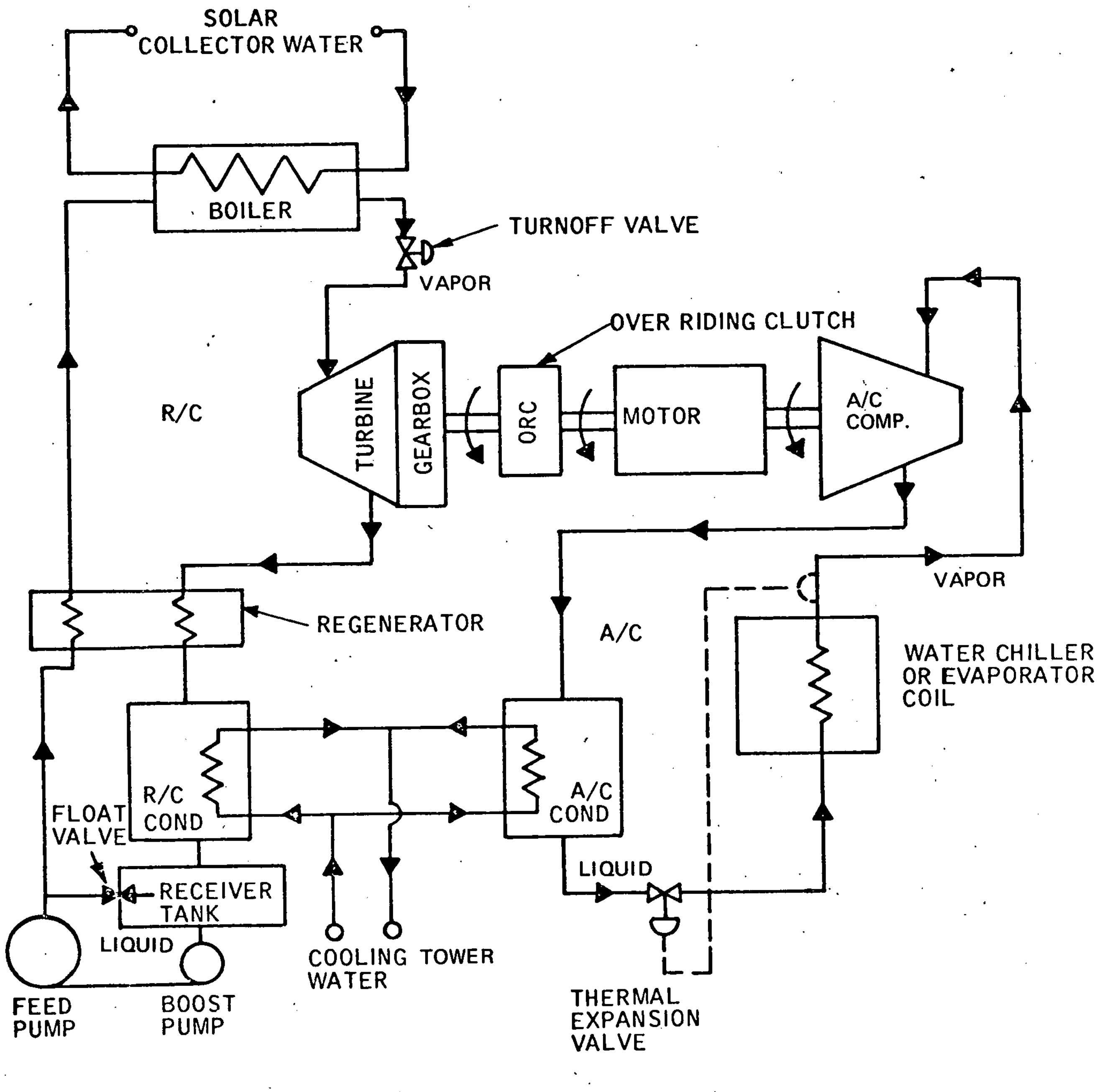


Figure 4-30. General System Schematic for Rankine-Cycle Air-Conditioning System

The efficiency of the R/C systems being presently developed range from 8 to 10 percent for solar heat supplied at 200°F to 220°F and at cooling tower temperatures of 75°F to 85°F. The A/C system may exhibit a COP of between 5 and 6 when coupled with a liquid cooling tower capable of heat rejection at 85°F. Thus, the overall COP ($\eta_{R/C} \times COP_{A/C}$) for an R/C-A/C cooling system may be expected to range from 0.4 to 0.6. The system suffers the same variation in performance with cooling tower temperature level as discussed previously for the absorption cooling cycle.

The solar powered R/C-A/C system is presently in the development and demonstration phase. The system appears to offer several advantages for cooling with solar energy:

1) The R/C may be operated over a larger temperature range than the absorption cycle system. This is an important feature for heat supply temperature levels in a typical solar collector system vary over a large range. The R/C system may be designed to operate at temperatures as low as 150°F and lower, a temperature level relatively easily achieved by less efficient and lower cost solar collector systems. The R/C may also be designed to operate at very high temperature levels, since its performance is not dependent on a chemical equilibrium process as in the absorption cycle. Thus, as high temperature concentrating collectors are developed in the future, the R/C system efficiency can be expected to exceed 15 and 20 percent at temperature levels between 300°F and 400°F. This represents an overall R/C-A/C coefficient of performance ranging from 0.9 to 1.2.

2) The auxiliary energy source for the R/C-A/C system is electric power. This energy form does not appear to suffer the risk of future unavailability that other fuel sources (gas, oil) offer.

At present the only disadvantages that the R/C system may offer is the relatively high cost of the R/C-A/C hardware and the uncertainty of its long term operational performance. These concerns are expected to diminish with future development, production, and performance demonstration.

Evaporative Cooling with Rock Bed Storage

A simple evaporator cooler can be used to cool warm air by passing the air through an air washer. Depending upon the velocity of air and wet bulb temperature, warm air may be evaporatively cooled to a desired dry bulb temperature. As an example, outside air at 100°F dry bulb temperature and 70°F wet bulb temperature (relative humidity 22 percent) can be cooled by an air washer to about 77°F. Strictly speaking, evaporative cooling is not a solar system. However, because the rock bed of an air heating solar system can be used for storing "cool" air in the summer time, 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 Figures 4-31 and 4-32. Night air is evaporatively cooled and circulated through the rock bed to cool down the pebbles in the storage unit as shown in Figure 4-31. During the day warm air from the building can be cooled by passing the air through the cool pebble-bed, as shown in Figure 4-32.

An evaporative cooling system coupled to an air heating system is shown schematically in Figure 4-33. Two additional motorized dampers are added to the heating system along with the evaporative cooler in the duct which draws the outside air. To cool the rock bed storage, air is drawn from outdoors and evaporatively cooled by the EVC. All dampers are positioned by the controller so that the cooled air is blown through storage (top to bottom) and discharges outdoors. The evaporative cooling of the rock bed storage is

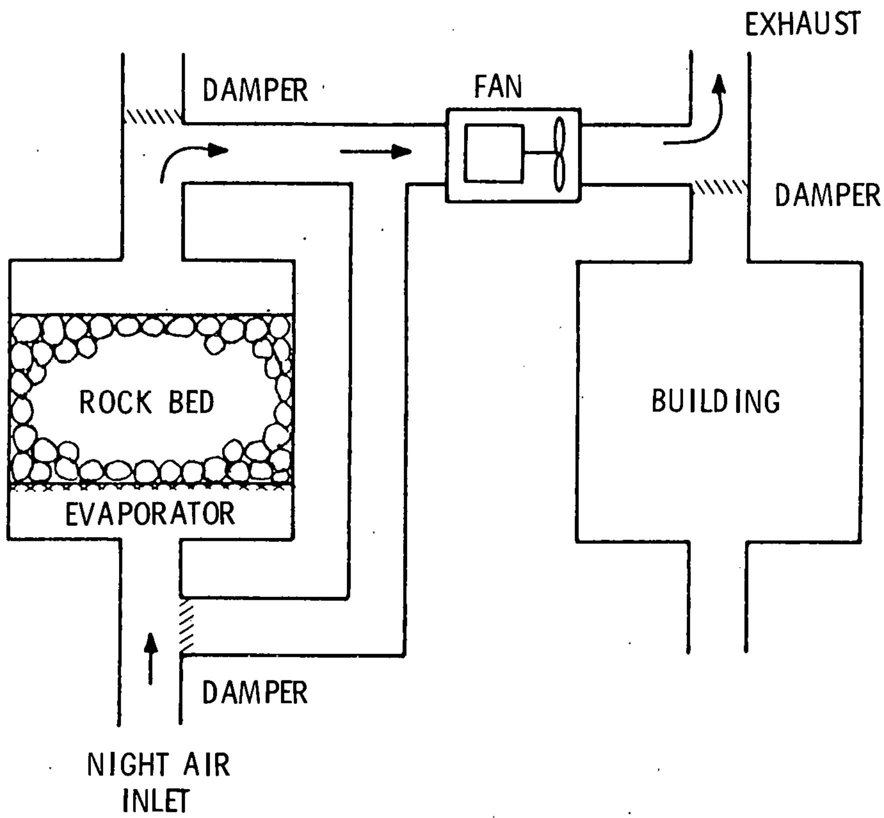


Figure 4-31. Night Charging of Rock Bed

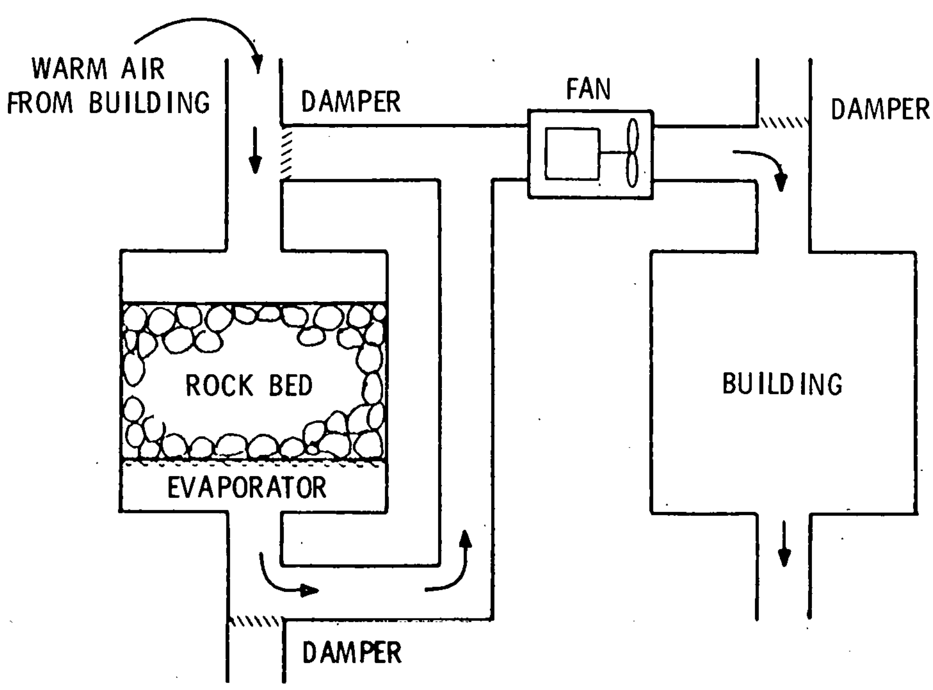


Figure 4-32. Day Cooling of Building

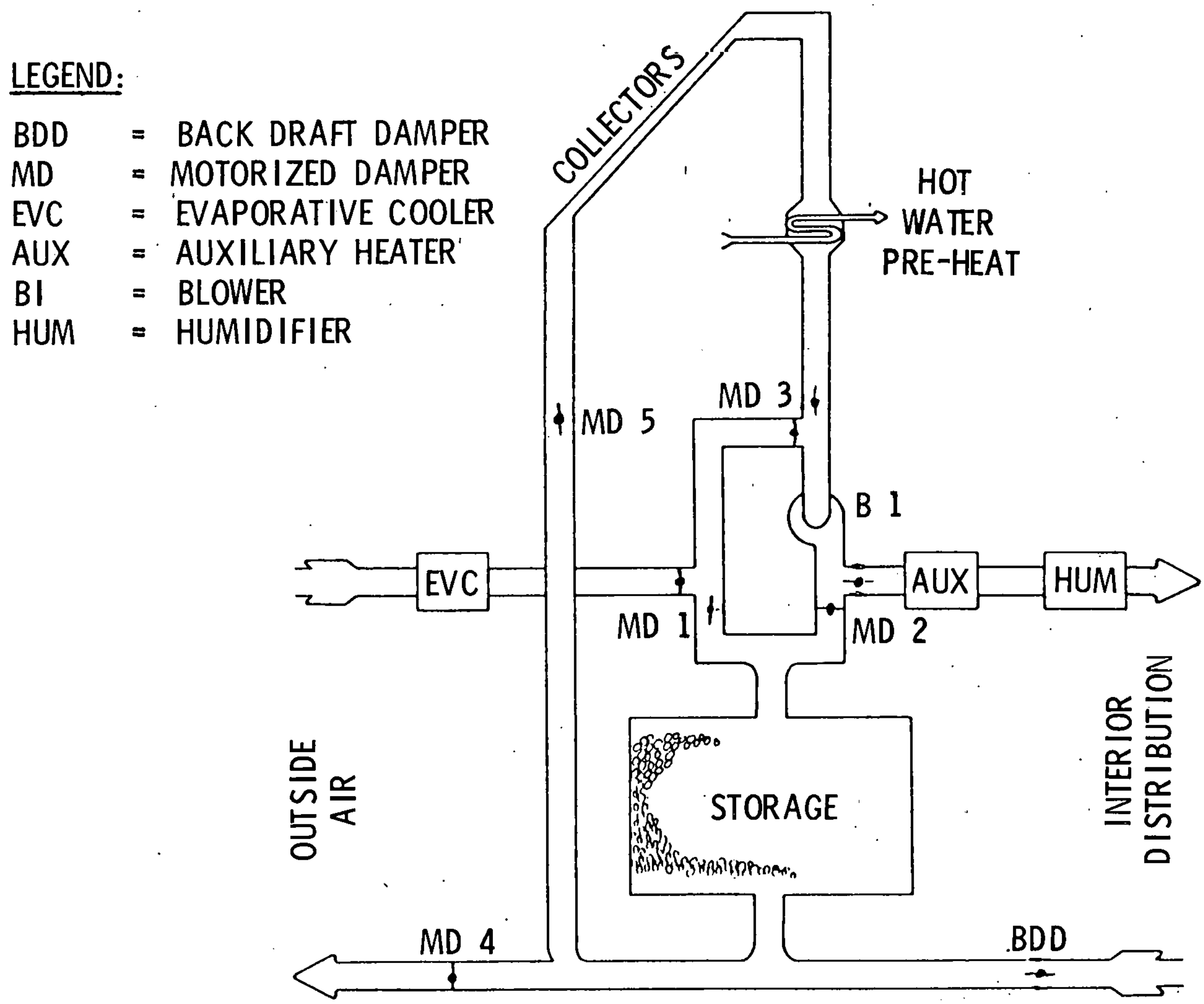


Figure 4-33. Schematic of an Air Heating System With an Evaporative Cooler Unit

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 (bottom to top) and distributed back to the rooms. When the cooling capability of the rock bed has been depleted, the evaporator cooler may also be used directly to cool the building.

The installation of an evaporative cooler to the solar heating system is relatively simple. There is no unusual feature about the system. 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.

<u>System Performance Example</u> -- The design guidelines for sizing the rock bed storage of a solar air heating system is one-half to one cubic foot per square foot of collector. The air flow rate recommended is 2 cfm per square foot of collector. Therefore, for this example, the volume of rocks and air flow rate for 500 square feet of collectors on a house would be 250 to 500 cubic feet and 1000 cfm, respectively.

Let it be assumed that the rock bed can cool down to 55°F at night with an evaporative cooler and 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:

$$\text{Cooling rate} = (\text{air flow rate}) \times (\text{air density}) \times (\text{air heat capacity}) \times (\text{temperature differential}).$$

For this example, the cooling rate capable by the system is:

$$\begin{aligned}\text{Cooling rate} &= (100\ \text{ft}^3/\text{min}) \times (0.073\ \text{lb/ft}^3) \times (0.24\ \text{Btu/lb}^\circ\text{F}) \times (75 - 55^\circ\text{F}) \times (60\ \text{min/hr}) \\ &= 21,024\ \text{Btu/hr} \\ &= 1.75\ \text{tons of cooling.}\end{aligned}$$

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 cubic feet of rock bed:

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

$$= 105{,}000\ \text{Btu}$$

At a cooling rate of 21,024 Btu per hour, there are about 5 hours (105,000 ÷ 21,024) of cooling capability provided by 250 cubic feet of rock bed storage.

If the storage size is 500 cubic feet, the cooling time is increased from 5 hours to 10 hours, but the rate of cooling is the same at 1.75 tons. It is therefore advantageous to consider the largest rock bed storage permissible for the solar heating system when contemplating an evaporative cooling unit coupled with it.

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

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

$$= 26{,}280\ \text{Btu/hr.}$$

The EVC is sized by the air flow rate in cfm. However, 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 semi-arid regions of the country where there are cool nights and low wet bulb temperatures.

Solar Desiccant Cycle

A cooling system that features desiccant drying, solar heat addition, and evaporative cooling (humidification) is shown in Figure 4-34. The solar desiccant cycle is presently in the research and development stage and thus its applicability for residential and commercial cooling must be demonstrated in the future.

The cycle features thermodynamic operations on two air streams. Room or outside air in one stream is dried by desiccant adsorption (Silica Gel or Lithium Chloride), followed by cooling through a heat exchange wheel, and finally rehumidified in an evaporative cooler. The other air stream follows essentially a reverse sequence of processes with an added heat addition process (by solar and conventional fuel energy), and a drying wheel regeneration process in place of the drying process. The COP of this cycle appears to lie between 0.5 and 1.0. The system potentially may offer a simple and low cost approach to solar cooling since the system features relatively low technology hardware, very low wheel rotation rates, and no costly cooling towers.

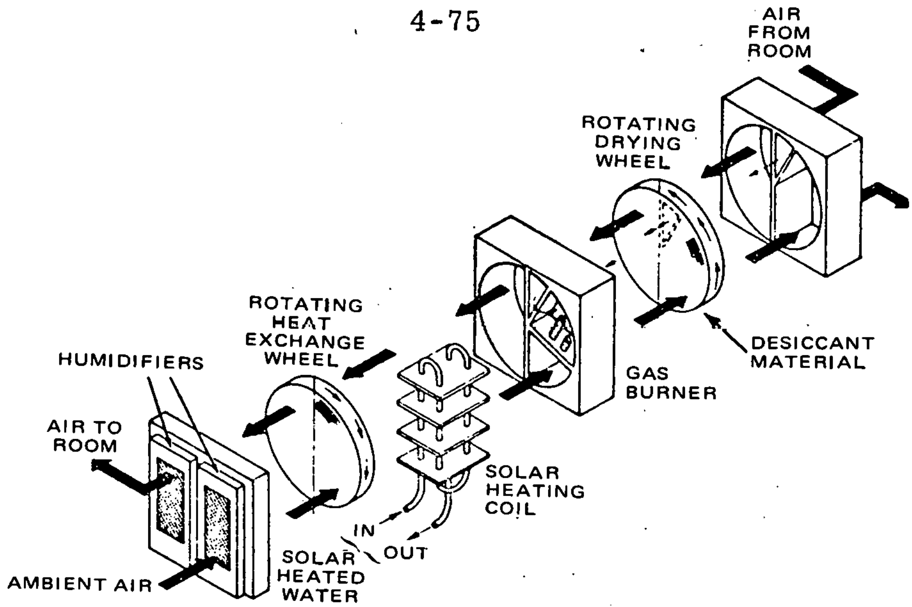


Figure 4-34. Schematic of Adsorption Cycle (courtesy of the Institute of Gas Technology)

HEAT PUMPS

Introduction

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 frost-free refrigerator, but much larger in size to heat and cool the entire building.

A typical heat pump unit which uses the energy in the outside air is shown in Figure 4-35. 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. The liquid refrigerant is then expanded to form cold vapor in the outdoor section and 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 Figure 4-36. The functions of the outdoor and indoor coils are reversed, so that the indoor coil draws heat from the room air, thus cooling the air, and the heat is rejected at the outdoor coil, just as it is in a standard refrigeration unit.

Figures 4-35 and 4-36 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 Figure 4-35 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 and 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.

Heat pumps have been used as residential heat sources for years, particularly in the Southern part of the country. Their limitation in the North is due to the fall off of coefficient of performance (COP) with reduced temperatures. The coefficient of performance is the ratio of the heat produced to the energy required to run the machine. Hence a COP of 2.0 means that one BTU of energy input will result in a heating effect of 2.0 BTU's. Figure 4-37 shows a typical curve of COP versus out door temperature for a heat pump. At temperatures above 25°F, a heat pump produces more than twice the heat than resistance heaters do, while at temperatures below 0°F, a heat pump is essentially no better than resistance heaters.

Further, as shown in Figure 4-38, the capacity of a heat pump falls off with temperature reduction until a "break point" is reached at about 35°F where the heat pump will no longer meet the increasing building load.

The heat pump's best operating range is between about 40°F and about 80°F. This just also happens to be a range where solar collectors will operate efficiently but where the solar system cannot utilize energy.

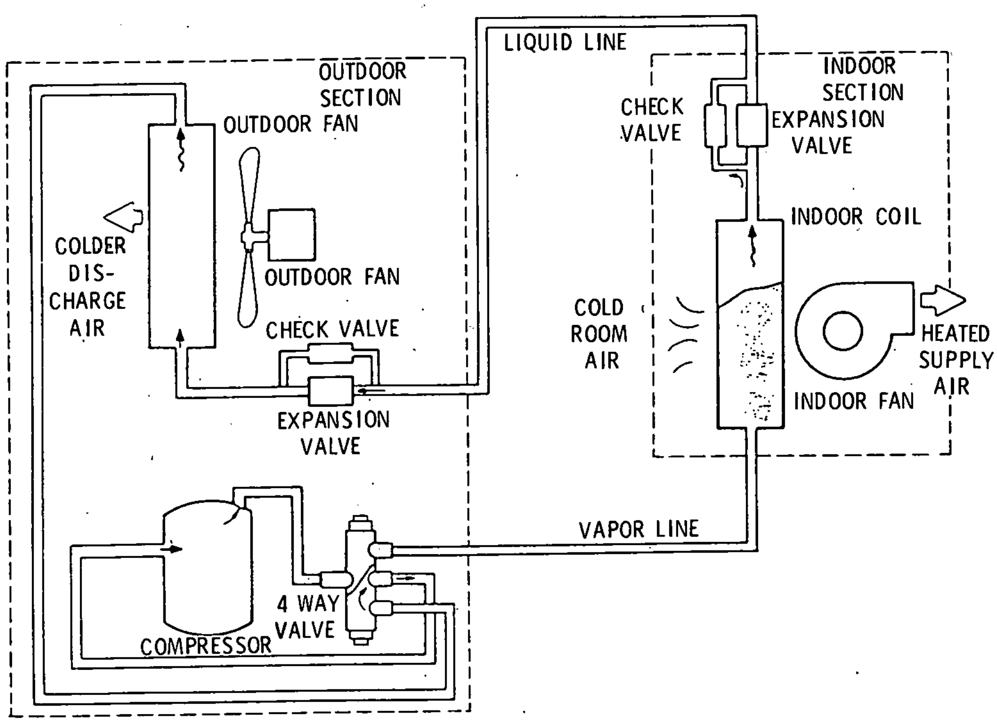


Figure 4-35. Heat Pump in a Heating Mode

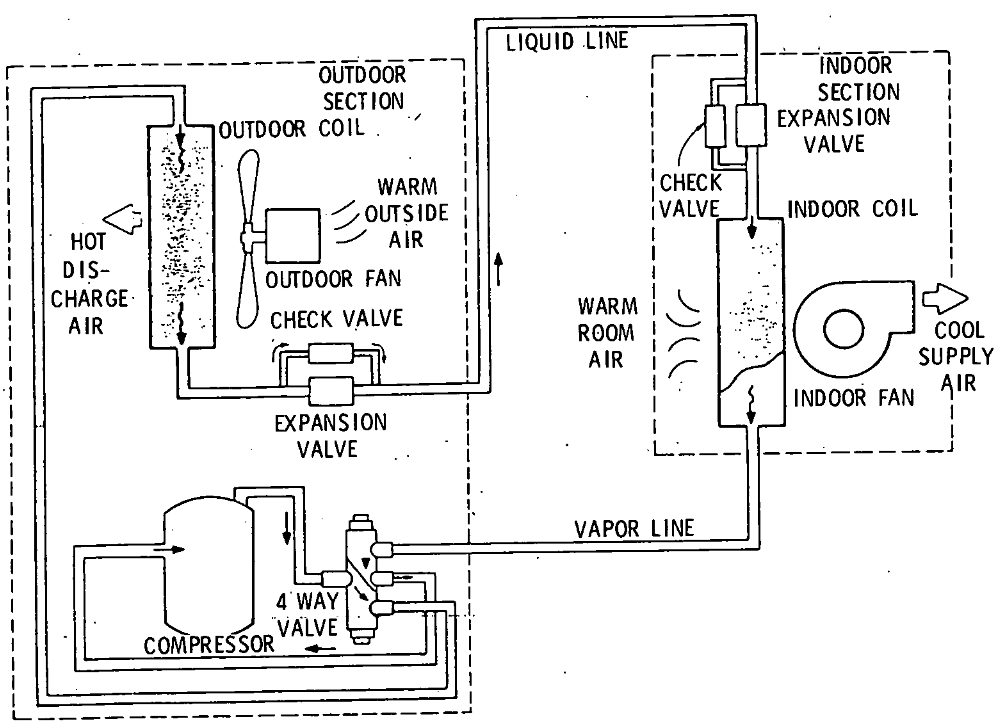


Figure 4-36. Heat Pump in a Cooling Mode

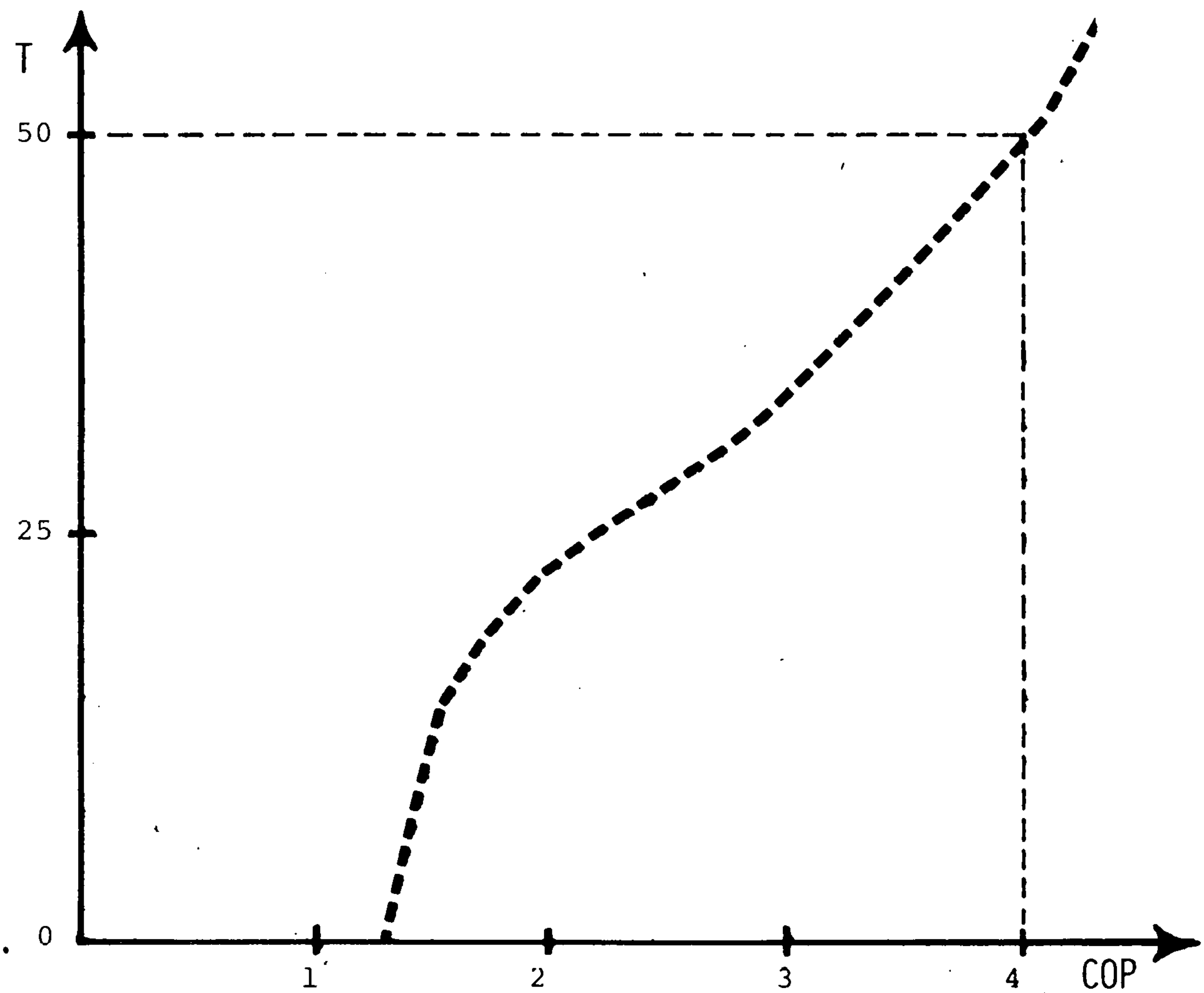


Figure 4-37. Heat Pump Coefficient of Performance

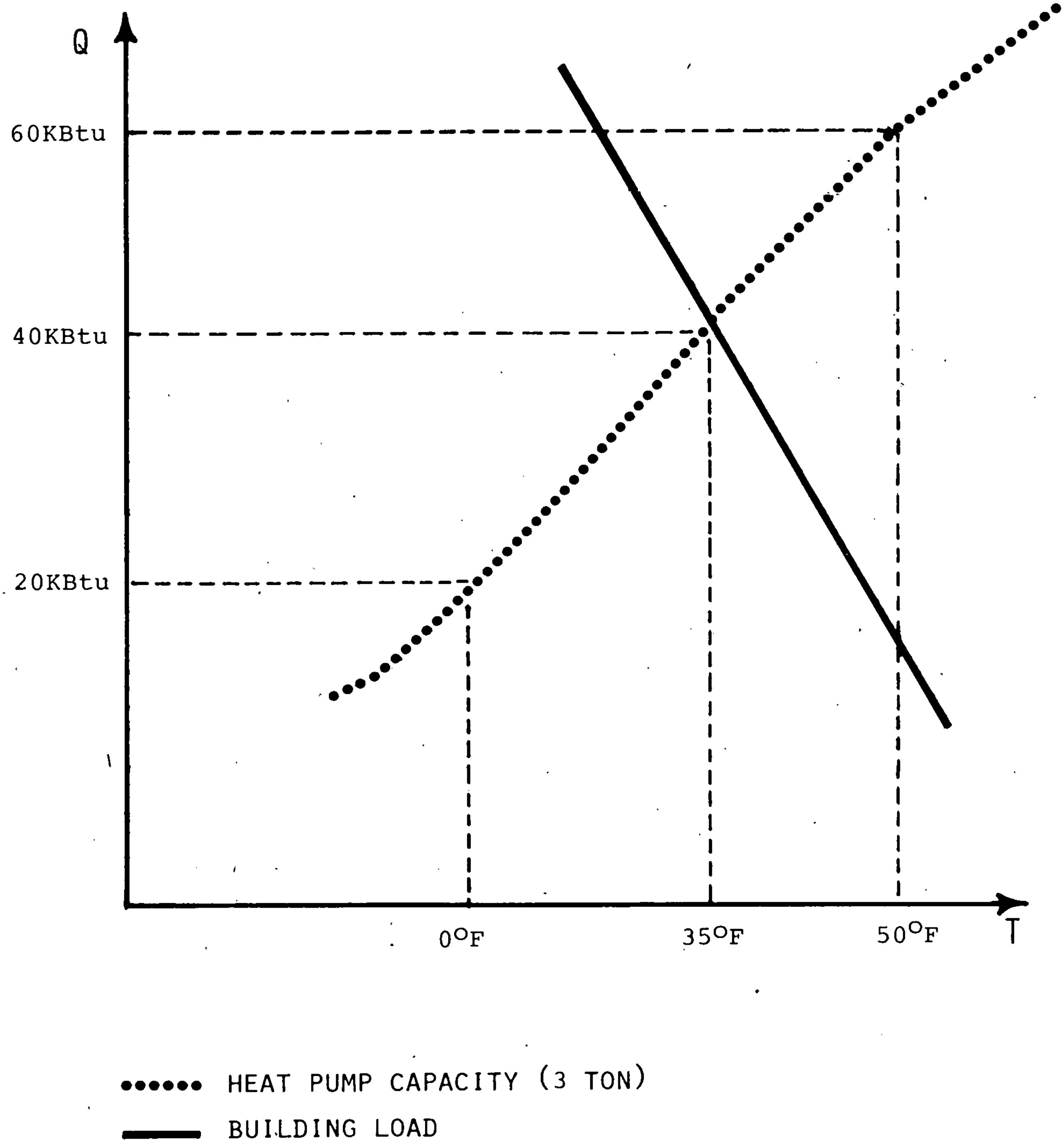


Figure 4-38. Heating with a Heat Pump

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 from solar collectors. Because the temperatures are low, the collectors operate more efficiently than for direct solar space heating.

The heat is usually stored on the low-temperature side of the heat pump because it 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 Figure 4-39. The collectors may be air heating with a pebble-bed storage unit or liquid-heating collectors 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).

The system illustrated in Figure 4-39 is called a "series" system. This system does not heat directly with solar so very low-cost, low-efficiency collectors can be used. The heat pump in the series system runs whenever heat is desired. If an attempt is made to heat directly from storage, bypassing the heat pump, energy will be saved. However, the storage tank will seldom be hot enough to permit this. This difficulty can be overcome by using a "two tank" system as illustrated in Figure 4-40. This system saves "hot" heat in a separate tank whenever it is available. Any "cooler" heat is stored for the heat pump source. Figure 4-40 also shows how a reverse cycle liquid/air heat pump can be used for a summer air conditioner.

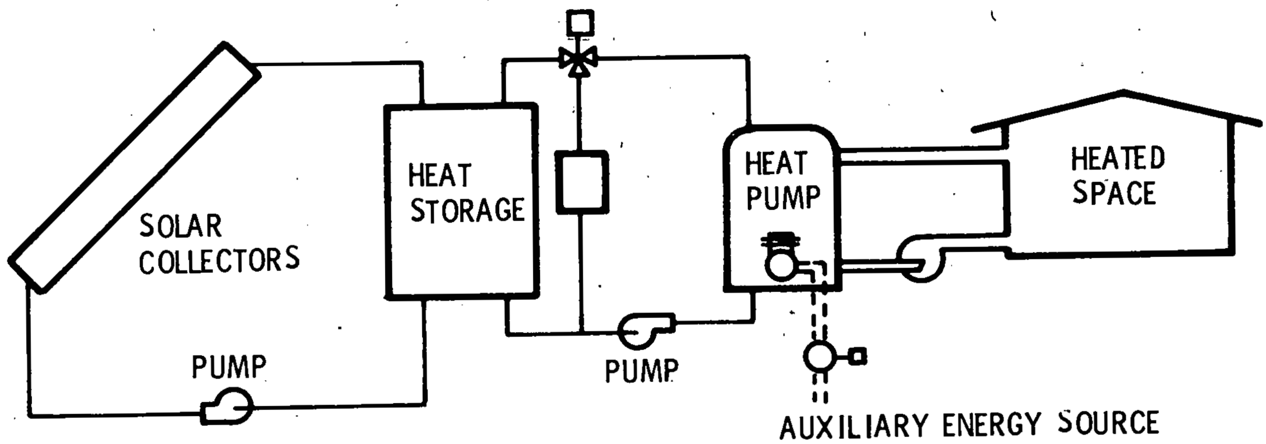


Figure 4-39. Simplified Diagram of a Solar Assisted Heat Pump System Series Arrangement

There is not yet a clear indication of what heat pump arrangement is going to prove best. With an air system, it appears that the heat pump can be most advantageously used if operated simply as the auxiliary furnace normally would be used; that is, to boost the temperature of the air coming from the pebble-bed to the rooms. Outdoor air is used as the source. Figure 4-41 illustrates this system. In the liquid systems, whether the heat pump should be used in a similar fashion, or whether the source should be the solar storage tank, is not yet clear. At this time, an engineer and the heat pump manufacturer should be consulted to assist in the design of a solar heat pump combination.

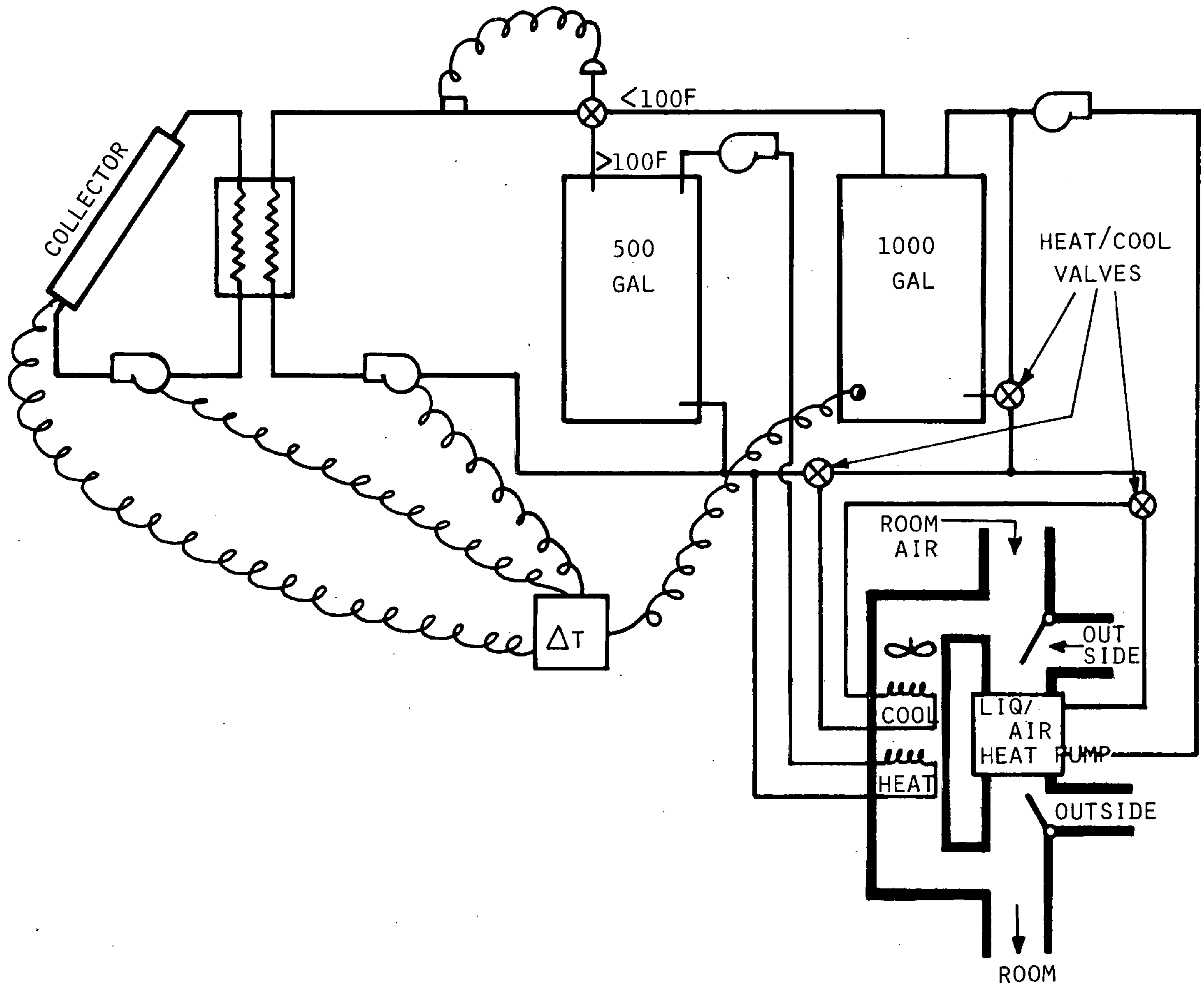


Figure 4-40. Solar Assisted Heat Pump with Dual Level Storage

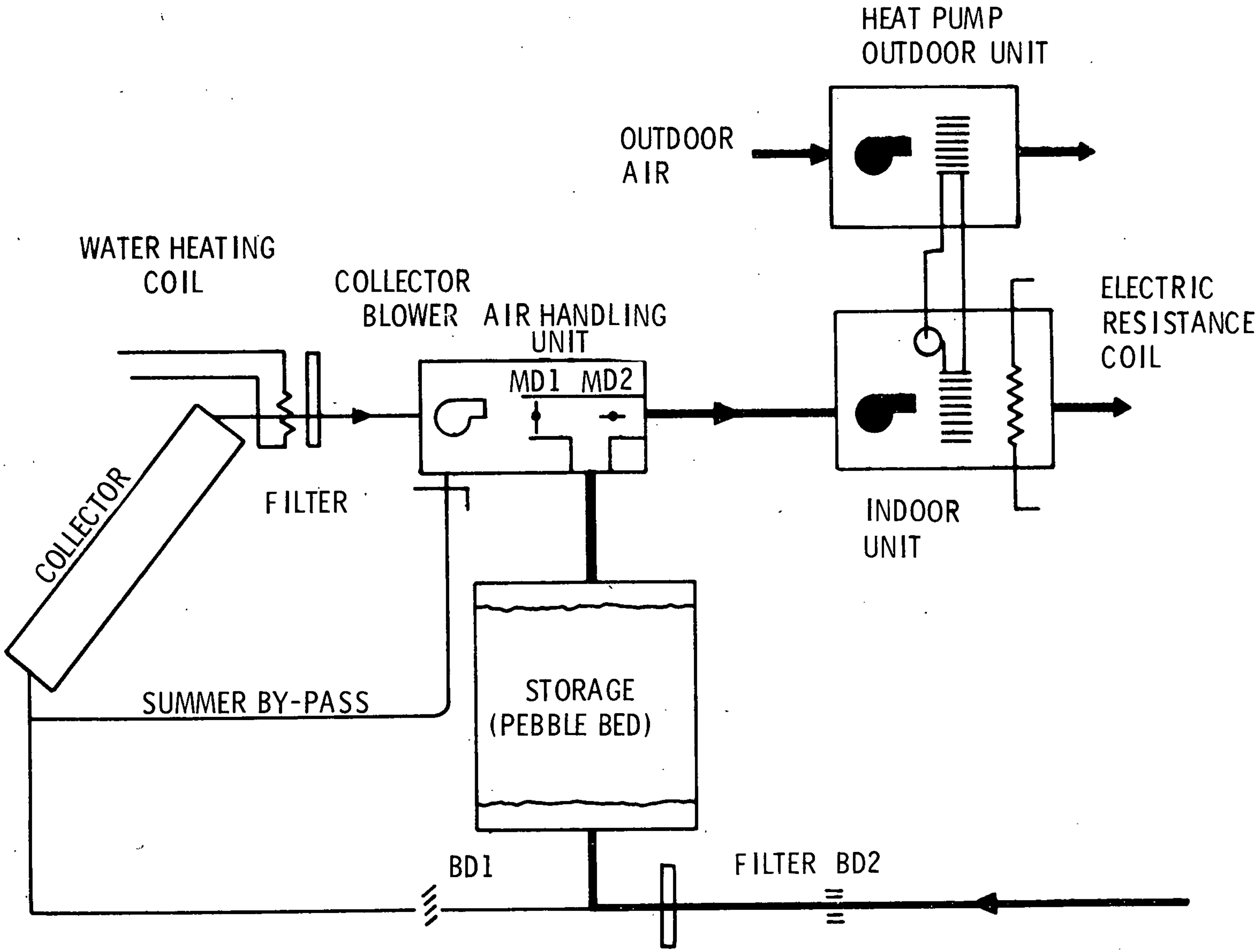


Figure 4-41. Solar Heating System with Air-to-Air Heat Pump Auxiliary (Heating Building from Storage with Heat Pump Supplementary Supply)

SECTION V
COMPONENT PERFORMANCE CRITERIA

INTRODUCTION

The design of solar heating (and cooling) systems is critically dependent upon the heating (or cooling) load in the house. Traditionally, heating systems have been oversized for houses because the added cost of a furnace to furnish more than the necessary heat is not significant. This reasoning does not hold for solar systems because the cost of collectors depends directly on their size. It is important, therefore, that the heating requirements of a building be carefully determined when solar heating is being designed. When energy conservation measures can be used to reduce heat losses, a smaller solar system can be used, or a given solar system can supply a greater fraction of the total heat requirements.

Solar systems should not be designed to provide 100 percent of the heating needs in a building. Because of the variability of sunshine through a heating season, there will be several continuous sunless days in every region of the United States. In order to provide 100 percent heating from solar energy, there would have to be enough heat stored to carry the heating load for those sunless days, and a large collector area would be needed to collect the solar energy during the sunny days to provide the heat to storage. It is practical to design a solar system to store all the heat deliverable from a collector during one to two days. There should be enough collector area to deliver heat to the house during the sunshine hours, and also store enough heat at the same time to heat the house through the night and a few hours into the next day. Solar heating systems for houses should usually be designed to provide more than half the seasonal heating requirements of a building, but not such a large fraction that the waste of heat in mild weather during spring and fall is excessive.

HEAT LOSSES FROM BUILDINGS

Heat transmission losses, or more simply heat losses, from buildings result from: (1) the heat losses through walls, floor, ceiling, glass and other surfaces and (2) the infiltration losses, through open doors and windows, and cracks and crevices around the doors and windows. The infiltration of cold air into a house is called heat loss because the cold air displaces the warm air and the air must be heated to the comfort level in the building.

Heat Transmission Through Building Surfaces

Heat is transferred from warm room air to outdoor air by a three-step process. Heat is transferred from the room air to the inside surface of a wall or window, through the wall or window, and from the outside surface to the outdoor air. The rate of heat flow from the building to the outdoors depends upon the surface area, A, an overall heat transfer coefficient, U, and the air temperature difference between the inside, T_i, and outside, T_o. Expressed in equation form:

$$Q = UA\,(T_i - T_o) \tag{5-1}$$

where Q is heat flow rate, Btu/hr; A is wall area, ft^2; U is the overall heat transfer coefficient, Btu per (hr) $(ft)^2$; T_i is indoor temperature, °F; and T_o is outdoor temperature, °F.

The overall heat transfer coefficient, often called the U factor is determined by the reciprocal of the total thermal resistance, R_T, to heat flow:

$$U = \frac{1}{R_T} \tag{5-2}$$

and

$$R_T = R_1 + R_2 + R_3 + R_4 + \text{etc.} \tag{5-3}$$

where R_1, R_2, etc., are R factors, the individual resistances of the wall components.

The transfer of heat from the inside air to the wall is visualized as taking place through a thin film of air adjacent to the wall surface. This thin film has resistance, R_i, to heat flow determined by the film conductance, U_i,

$$R_i = \frac{1}{U_i} \tag{5-4}$$

and should be included in the determination of the overall U factor. Similarly, there is a thin film at the outside surface, the conductance of which, symbolized by U_o, is dependent upon the wind speed. The resistance of the outside film, U_o, is

$$R_o = \frac{1}{U_o} \tag{5-5}$$

During summer months when the outside temperature is greater than the indoor temperature, heat is conducted into the building. The principles are the same as heat loss from the house during winter, and the heat flow rate is determined by

$$Q = UA\,(T_o - T_i) \tag{5-6}$$

where T_o and T_i have been interchanged from Equation (5-1) and the negative sign indicates that heat flow is into the building.

Surface conductances and resistances for air films for interior and exterior surfaces, for winter and summer, are listed in Table 5-1. The winter values are based on wind velocity of 15 mph and summer values are based on wind velocity of 7 mph.

Table 5-1. Surface Conductances and Resistances for Air Films; Conductance: Btu/(hr) (ft^2) (°F) Resistance: (hr) (ft^2) (°F)/Btu

Items	Winter		Summer	
	$U_{i,o}$	$R_{i,o}$	$U_{i,o}$	$R_{i,o}$
Interior Surfaces				
Ceiling	1.63	0.61	1.08	0.92*
Sloped ceiling 45°	1.60	0.62	1.32	0.76*
Walls and windows	1.46	0.68	1.46	0.68
Floor	1.08	0.92	1.08	0.92
Exterior Surfaces				
Roofs, walls and windows	6.00	0.17**	4.00	0.25†

*Heat flow direction reversed from winter conditions

**15 mph wind

†7.5 mph wind

Dead air spaces between walls offer thermal resistance. The resistance values are listed in Table 5-2 for 3/4-inch and 4-inch spaces for winter and summer conditions. For spaces between 3/4 and 4 inches, values may be interpolated.

Table 5-2. Resistance Values for Air Spaces (hr) (ft^2) (°F)/Btu

Item	Winter		Summer	
	Air Space (in.)		Air Space (in.)	
	3/4	4	3/4	4
Flat roof	1.02	1.12	0.87	0.94
Wall	1.28	1.16	1.01	1.01

Resistance values for common building materials are listed in Table 5-3. U-factors for windows and patio doors are listed in Table 5-4, and U-factors for solid doors are listed in Table 5-5, with and without storm doors. The values in these tables correspond with more complete tables listed in Chapter 20, ASHRAE Handbook of Fundamentals, 1972.

Table 5-3. Resistance Values for Building Materials (hr)(ft^2)(°F)/Btu

Type and Material		R
Building Board		
Asbestos cement	1/8 in.	0.03
	1/4 in.	0.06
Gypsum	3/8 in.	0.32
	1/2 in.	0.45
Plywood	1/4 in.	0.31
	3/8 in.	0.47
	1/2 in.	0.62
	3/4 in.	0.93
Insulating board	25/32 in.	2.06
Regular	1/2 in.	1.32
Laminated paper	3/4 in.	1.50
Acoustic tile	1/2 in.	1.25
	3/4 in.	1.89
Hardboard	3/4 in.	0.92
Particle board	5/8 in.	0.82
Wood subfloor	3/4 in.	0.94
Masonry		
Concrete	6 in.	0.48
	8 in.	0.64
	10 in.	0.80
Concrete blocks, 3 oval core		
Sand and gravel	4 in.	0.71
	8 in.	1.11
	12 in.	1.28
Cinder	4 in.	1.11
	8 in.	1.72
	12 in.	1.89
Lightweight	4 in.	1.50
	8 in.	2.00
	12 in.	2.27
Concrete blocks, 2 rect. core		
Sand and gravel	8 in.	1.04
Lightweight	8 in.	2.18
Common brick	2 in.	0.40
	4 in.	0.80
Face brick	2 in.	0.22
	4 in.	0.44
Building paper		
15# felt		0.06

Type and Material		R
Siding		
Asbestos cement		0.21
Wood shingles, 16 in.		0.87
Wood bevel, 1/2 x 8		0.81
Wood bevel, 3/4 x 10		1.05
Wood plywood, 3/8		0.59
Aluminum or steel		0.61
Insulating board:		
3/8 in. normal		1.82
3/8 in. foiled		2.96
Finish Flooring		
Carpet and fibrous pad		2.08
Carpet and rubber pad		1.23
Cork tile, 1/8 in.		0.28
Terrazo, 1 in.		0.08
Tile, asphalt, linoleum, vinyl, rubber		0.05
Hardwood		0.08
Insulation		
Blanket and batt:	2 to 2-3/4 in.	7.0
	3 to 3-1/2 in.	11.0
	5-1/4 to 6-1/2 in.	19.0
Loose fill		
Cellulose, per inch		3.7
Sawdust, per inch		2.2
Perlite, per inch		2.7
Mineral fibre (rock, slag, glass)	3 in.	
	4-1/2 in.	13.0
	6-1/4 in.	19.0
	7-1/2 in.	24.0
Vermiculite, per inch		2.2
Roofing		
Asphalt		0.44
Wood		0.94
3/8 in. built-up		0.33
Woods: oak, maple per inch		0.91
fir, pine, softwoods per inch		1.25
	3/4 in.	0.94

Table 5-4. U-Factors for Windows and Patio Doors Btu/(hr) (ft^2) (°F)

Description	Winter
Single glass	
Metal sash	1.13
Wood sash, 80% glass	0.02
Double glass	
1/4 in. air space	
Metal sash	0.65
Wood sash, 80% glass	0.62
Wood sash, 60% glass	0.55
1/2 in. air space	
Metal sash	0.70
Wood sash, 80% glass	0.49
Triple glass	
1/4 in. air space	
Metal sash	0.56
Wood sash, 80% glass	0.45
Storm windows	
1 to 4 in. air space	
Wood	0.50
Metal	0.56
Sliding Patio Doors	
Single glass	
Wood frame	1.07
Metal frame	1.13
Double glass, 1/2 in. air space	
Wood frame	0.58
Metal	0.64

Table 5-5. U-Factors for Solid Doors
Btu/(hr)(ft^2)(°F)

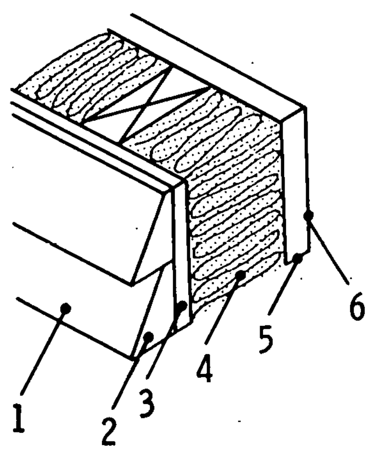
Thickness (in.)	Winter			Summer
	Without Storm Door	With Storm Door, 50% Glass		Without Storm Door
		Wood	Metal	
1	0.64	0.30	0.39	0.61
1-1/4	0.55	0.28	0.34	0.53
1-1/2	0.49	0.27	0.33	0.47
2	0.43	0.24	0.29	0.42

Transmission Coefficients

The procedure for determining the overall heat transmission coefficients, U, for typical wall, roof, ceiling, and floor construction are presented in this subsection. The values of R used are found in Tables 5-1 through 5-3. U-factors for composite construction are determined in the following examples. U-factors for other types of construction may be calculated by following these examples.

Example 5-1: Frame Wall (2 x 4 studs) --

	Item	R
1.	Outside film (15 mph wind, winter)	0.17
2.	Siding, wood (1/2 x 8 lapped)	0.81
3.	Sheathing (1/2 inch regular)	1.32
4.	Insulation batt (3 to 3-1/2 inch)	11.00
5.	Gypsum wall board (1/2 inch)	0.45
6.	Inside surface (winter)	0.68
	Total Resistance, R_T	14.43
	$U = 1/R_T$	0.07



The calculated U factor applies to the area between 2 x 4 studs. Because the resistance to heat flow through the 2 x 4 stud is different from the insulation, a correction is sometimes applied. However, the corrections usually amount to less than the accuracy of the R values. Corrections are therefore considered unnecessary.

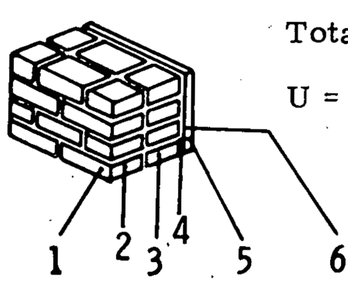
Example 5-2: Frame Wall (2 x 6 Studs) --

From Example 5-1, R_T	14.43
Replace 3-1/2 inch insulation, subtract	11.00
	3.43
Add 5-1/2 inch insulation	19.00
New R_T	22.43
$U = 1/R_T$	0.04
Difference in U from Example 4-1	0.03
Percent Difference from 2 x 4 wall	43 percent

There is 43 percent reduction in heat loss for a 2 x 6 wall as compared to a 2 x 4 wall with correspondingly thicker insulation in the 2 x 6 wall.

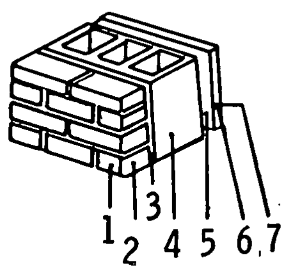
Example 5-3: Solid Masonry Wall --

	Item	R
1.	Outside film (15 mph wind, winter)	0.17
2.	Face brick (4 inch)	0.44
3.	Common brick (4 inch)	0.44
4.	Air space (3/4 inch)	1.28
5.	Gypsum board (1/2 inch)	0.45
6.	Inside surface	0.68
	Total Resistance, R_T	3.82
	$U = 1/R_T$	0.26



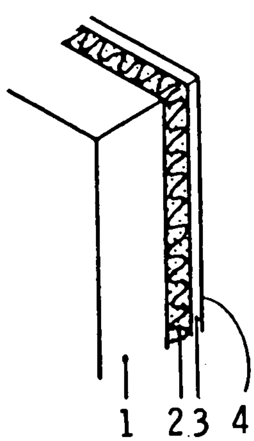
Example 5-4: Masonry Walls --

	Item	R
1.	Outside surface (15 mph)	0.17
2.	Face brick (4 inch)	0.44
3.	Cement mortar (1/2 inch)	0.10
4.	Cinder block (8 inch)	1.72
5.	Air space (3/4 inch)	1.28
6.	Gypsum board (1/2 inch)	0.45
7.	Inside surface	0.68
	Total Resistance, R_T	4.84
	$U = 1/R_T$	0.21



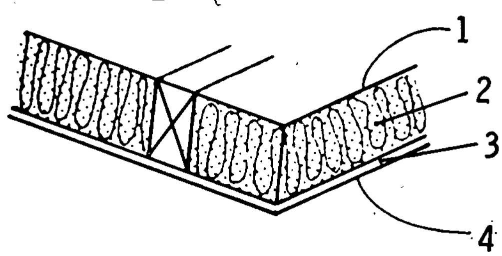
Example 5-5: Basement Wall --

	Item	R
1.	Concrete wall (8 inch)	0.64
2.	Insulation batt (2 inch)	7.00
3.	Gypsum board (1/2 inch)	0.45
4.	Inside surface	0.68
	Total Resistance, R_T	8.77
	$U = 1/R_T$	0.11



Example 5-6: Insulated Ceiling, 6 inches --

	Item	R
1.	Inside surface	0.68
2.	Insulated batt (6 inch)	19.00
3.	Gypsum board (1/2 inch)	0.45
4.	Inside surface	0.68
	Total Resistance, R_T	20.81
	$U = 1/R_T$	0.05



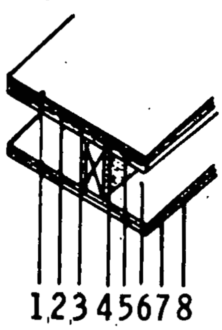
Example 5-7: Insulated Ceiling, 9 inches --

1.	Inside surface	0.61
2.	Insulation (9 inch)	24.00
3.	Gypsum board (1/2 inch)	0.45
4.	Inside surface	0.68
	Total Resistance, R_T	25.74
	$U = 1/R_T$	0.04

Decrease of U with 9-inch insulation over 6-inch insulation = 20 percent.

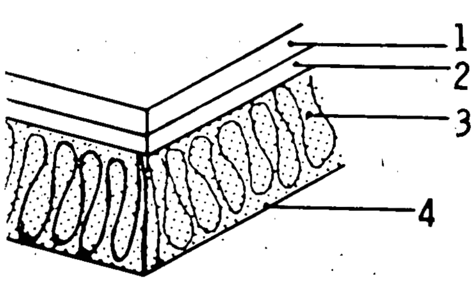
Example 5-8: Floor --

	Item	R
1.	Top surface	0.61
2.	Linoleum or tile	0.05
3.	Felt	0.06
4.	Plywood (5/8 inch)	0.78
5.	Wood subfloor (3/4 inch)	0.94
6.	Air space	0.85
7.	Acoustic ceiling tile (3/4 inch)	1.89
8.	Surface	0.61
	Total Resistance, R_T	5.79
	$U = 1/R_T$	0.17



Example 5-9: Floor --

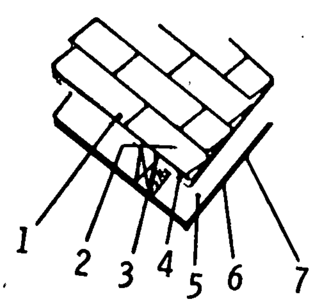
	Item	R
1.	Carpet and fibrous pad	2.08
2.	Plywood (3/4 inch)	0.93
3.	Insulation (9 inch)	24.00
4.	Surface (still air)	0.61
	Total Resistance, R_T	26.62
	$U = 1/R_T$	0.04



Example 5-10: Basement -- The heat loss from a heated basement should be based on a heat transfer coefficient for both wall and floor of U = 0.10. The temperature adjacent to basement walls and floor varies with the rate of heat transfer through the walls. The more heat that flows through the walls, the warmer will be the ground temperature. Below basement floors, a ground temperature equal to the ground water temperature is sometimes used. A temperature of 45°F is recommended as a rule of thumb, however, if conditions warrant, a different temperature may be used.

Example 5-11: Pitched Roofs (Heat Flow Up) --

	Item	R
1.	Outside surface (15 mph)	0.17
2.	Asphalt shingle roofing	0.44
3.	Building paper	0.06
4.	Plywood deck (5/8 inch)	0.78
5.	Inside surface	0.61
	Total Resistance, R_T	2.06
	$U = 1/R_T$	0.49

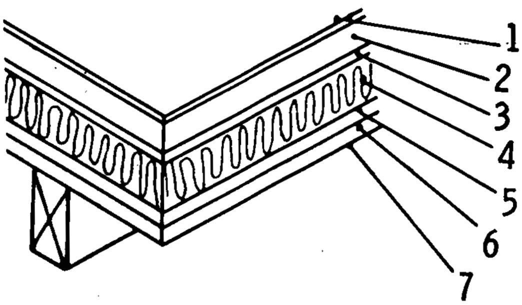


Example 5-12: Pitched Roof with Air Space and Sheathing (Heat Flow Up) -- See Example 4-11.

	Item	R
1.	Outside surface	0.17
2.	Wood shingle	0.94
3.	15-pound felt	0.06
4.	Plywood ceck (5/8 inch)	0.78
5.	Air space	1.00
6.	Gypsum (1/2 inch)	0.45
7.	Inside surface	0.61
	Total Resistance, R_T	4.01
	$U = 1/R_T$	0.25

Example 5-13: Pitched Roof with Mounted Collector (At Night) --

	Item	R
1.	Outside surface	0.17
2.	Glass	1.13
3.	Air space (3/4 inch)	1.75
4.	Insulation	7.00
5.	15-pound felt	0.06
6.	Plywood (3/4 inch)	0.93
7.	Inside surface	0.61
	Total Resistance, R_T	11.65
	$U = 1/R_T$	0.09



Heat Loss by Infiltration

Calculation of infiltration losses can be very complex. Experience and judgment are important to provide reasonable estimates. Of two methods used for calculating infiltration rates, only the simpler "Air Change" method is discussed here and readers are referred to the ASHRAE Handbook of Fundamentals for details of the "Crack" method. In either method the objective is to determine the amount of heat required to raise the temperature of cold air which enters a building through cracks, open windows, and doors.

The volume of cold air expected to enter a room through cracks during a one-hour period depends on such factors as wind direction and speed, pressure differences inside and outside the building, storm windows, air locks on outdoor entrances, and whether room doors are closed. The entering volume of cold air is expressed in terms of air changes per hour in the room under consideration. It is normally expected that storm doors and windows, or tight-fitting double-glazed windows will soon be widely adopted in new construction, particularly for solar heated and cooled houses. The average air changes for rooms with various fenestrations listed in Table 5-6 are in accordance with Chapter 19, ASHRAE Handbook of Fundamentals (1972).

Table 5-6. Air Changes for Average Residential Conditions

Kind of Room	Air Change per Hour	
	Winter	Summer
Room with no windows or exterior doors	1/3	1/6
Rooms with windows or exterior doors on one side	2/3	1/2
Rooms with windows or exterior doors on two sides	1	2/3
Rooms with windows or exterior doors on three sides	1-1/3	1
Entrance halls and air locks	1-1/2	1

From the air change rate the volume of air change per hour, V, is determined from the room volume. The heat loss from infiltration is calculated from

$$Q = 0.018\ V\ (T_i - T_o) \qquad (5\text{-}7)$$

where V is the volume change per hour; Q is Btu per hour.

When moisture is added to the air to maintain winter comfort conditions, heat will be required to evaporate the water vapor added to the building air. The rate of heat addition is most conveniently calculated from the equation below:

$$Q = 79.5\ V\ (W_i - W_o) \qquad (5\text{-}8)$$

where V is the infiltration rate, cfh; W_i is humidity ratio of indoor air, dimensionless; W_o is humidity ratio of outdoor air, dimensionless.

Infiltration occurs primarily because of wind impacting on the building from a given direction. Therefore, only the rooms on one side of the building would be affected at a given time. The values in Table 5-6 account for this factor.

Temperatures of Unheated Spaces --

Attic Temperature -- The attic temperature is determined from a balance of heat flow into and out of the attic. Heat flow into the attic is from the ceiling, heat flow out is through the roof surfaces and end walls. The general formula for determining attic temperature is:

$$T_{at} = \frac{A_c U_c T_c + T_o (A_r U_r + A_w U_w)}{A_c U_c + A_r U_r + A_w U_w} \tag{5-9}$$

where

T_{at} is attic temperature, °F

T_c is room temperature, °F

T_o is outside temperature, °F

A_c is ceiling area, ft^2

A_r is roof area, ft^2

A_w is roof wall area, ft^2

U_c is ceiling U factor, Btu/(hr)(ft^2)(°F)

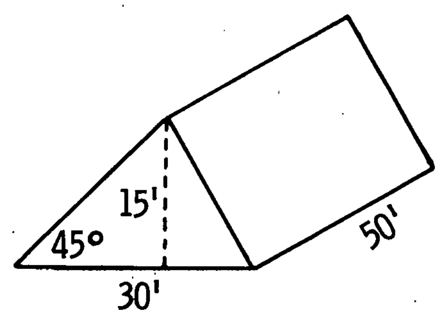
U_r is roof U factor, Btu/(hr)(ft^2)(°F)

U_w is wall U factor, Btu/(hr)(ft^2)(°F)

Example 5-14: Attic Temperature for a Wood Shingled Roof -- Calculate attic temperature for a wood shingled roof with the given dimensions. T_o is -9°F, T_c is 68°F. See Example 5-6 for ceiling U factor $U_c = 0.05$. See Example 5-12 for roof U factor, $U_r = 0.25$. For Example 5-1, for no insulation and 3-1/2 inch air space, U factor for the end walls is:

R_T from Example	14.43
Subtract insulation	-11.00
Subtract gypsum board	- 0.45
Total Resistance, R_T	2.98
$U_w = 1/R_T$	0.34

Calculate Area:



$$A_c = 30 \times 50 = 1500 \text{ ft}^2$$

$$A_r = \sqrt{2} \times 15 \times 50 \times 2 = 2120 \text{ ft}^2$$

$$A_w = 15 \times 15 \times 1/2 \times 2 = 225$$

$$T_{at} = \frac{(1500)(0.05)(68) + (-9)\left[(2120)(0.25) + (450)(0.34)\right]}{(1500)(0.05) + (2120)(0.25) + (450)(0.34)}$$

$$T_{at} = \frac{5100 - 5458}{75 + 530 + 76.5} = -0.5°\text{F}$$

Example 5-15 - Attic Temperature with Mounted Collector -- Calculate the attic temperature with a collector mounted on one side of roof. From Example 5-13, U_r with collector is 0.09. $A_r U_r$ in Equation (5-9) consists of two parts:

A_r (with collector) = 1060 ft^2

A_r (without collector) = 1060 ft^2

U_r (with collector) = 0.09

U_r (without collector) = 0.25

$$A_r U_r = (1060)(0.09) + 1060(0.25) = 360$$

$$T_{at} = \frac{(1500)(0.05)(68) + (-9)[360 + (450)(0.34)]}{(1500)(0.05) + 360 + (450)(0.34)}$$

$$T_{at} = \frac{5100 - 4617}{588} = 0.9°F$$

When ventilation is provided at 0.5 cfm per square foot of ceiling, the attic temperatures must be reduced from those calculated in Examples 5-14 and 5-15. Thus, the attic temperature approaches outdoor temperature. Attic temperature may be assumed to be the outdoor temperature with well-insulated ceilings without significant error in heat loss calculation.

Unheated Garage -- With similar detailed calculations, the temperature in any unheated garage may be calculated. For ease of calculation of heat losses, the garage temperature may be assumed to be the mean of the indoor and outdoor temperature, thus:

$$T_G = \frac{T_o + T_i}{2} \qquad (5\text{-}10)$$

Example: With outdoor temperature of -9°F, indoor temperature of 68°F, the garage temperature is:

$$T_G = \frac{(-9) + 68}{2} = 30°F$$

Heat Loss Calculation

Procedure --

1) Select the winter design outdoor temperature, T_o, for selected cities from Table 2-2 in Section II.

2) Select the indoor design temperature, T_i, at 68°F. (If zone controls or clock thermostats are used to lower the temperature of unused rooms at night, consideration should be given to selecting other indoor temperatures for specific periods of time.)

3) Determine net areas, A, of walls, roof, ceiling, windows, doors, and floor for each different type of construction.

4) Select U-factors from Examples 5-1 through 5-13, or calculate appropriate U-factors for specific wall type.

5) Calculate heat transmission loss rate from [Equation (5-1)*]:

$$Q = UA(T_i - T_o)$$

through each type of surface.

6) Sum the transmission losses.

7) Determine infiltration losses.

8) Add the infiltration loss to the transmission losses to obtain the total heat loss from the building.

---

*See section on temperatures for unheated spaces.

9) Determine the design heat loss rate for the building for each degree day.

Example Heat Loss Calculation -.- An example heat loss calculation is presented below for a house in Fort Collins shown in Figure 5-1, with the description of materials given in Figure 5-2. The windows in all bedrooms are 3' x 4', double hung, single pane, wood sash with storm windows having 3-inch air space. The window in the bathroom is 2' x 2', double hung, single pane, wood sash with storm window. The window in the living room is 4' x 8', wood sash, double glass with 1/2 inch air space. The window in the kitchen is 2.5' x 4' double hung, single pane, wood sash with storm window. The window in the breakfast nook is 3' x 4', double glass, wood sash with 1/3 inch air space. The 6' x 6' sliding patio door in the family room is double glass wood frame with 1/2 inch air space. The basement windows are 1-1/2' x 1-1/2' and will be ignored in this calculation. Bathrooms and kitchen are ventilated.

The heat worksheet shown in Table 5-7 is used to facilitate calculations. The design temperature is -9°F for Fort Collins, Colorado. The design indoor temperature is 68°F. The total heat loss from the building for the design temperatures is 53,215 Btu per hour. The heat load per degree day is determined as follows:

$$\frac{\text{Btu loss per hour x 24}}{\text{65 - design atmospheric temperature}} = \text{Btu required per degree day}$$

For the example of Table 5-7, the denominator is [65 - (-9)] = 74 degrees, therefore:

$$\frac{53,215 \times 24}{65 - (-9)} = 17,260 \ \frac{\text{Btu}}{\text{DD}}$$

It is interesting to note that the heat loss factor based on floor area in the living space (above ground) as computed in Table 5-7 is:

$$U_o = \frac{(53,215 - 7,920)}{2,078 \times 77} = 0.28 \text{ Btu/(hr)(ft}^2\text{) (°F)}$$

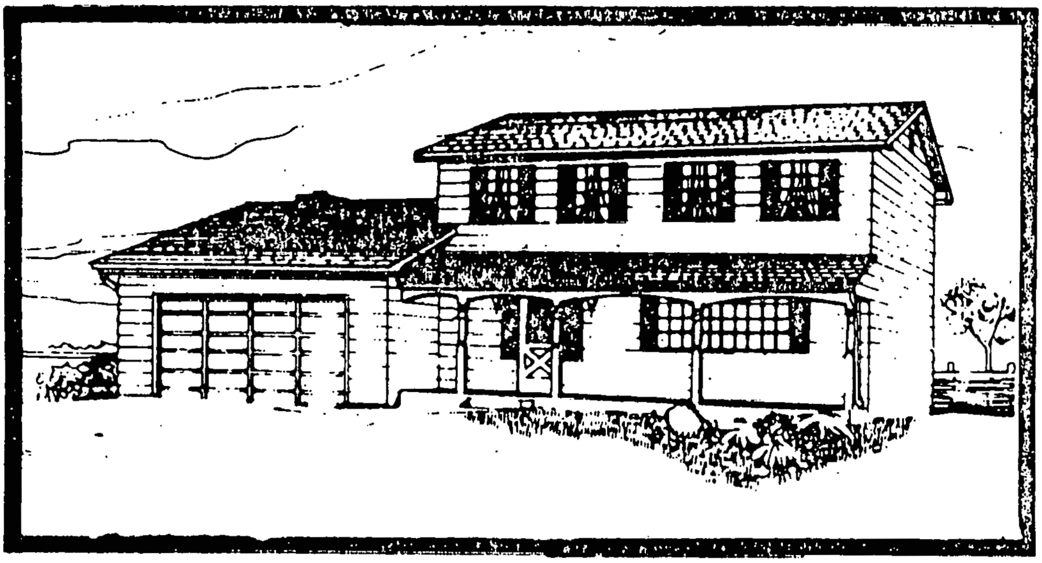
where 2078 is the total area of the two upper floors.

For the entire house, including the 1182 square foot basement,

$$U_o = \frac{53,215}{3260 \times 77} = 0.21 \text{ Btu/(hr)(ft}^2\text{)(°F)}$$

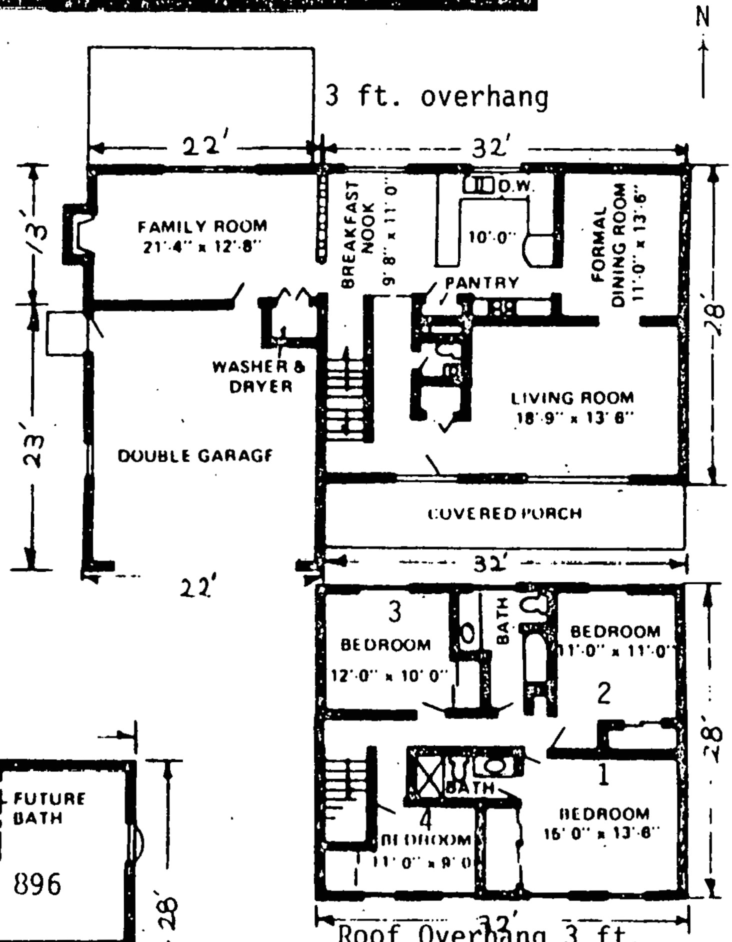
Table 5-7. Heating Worksheet for Example Building

Building Section	Size or Volume	Net Area or Volume	U Coeff.	Temp. Diff. [68-(-9)]	Heat Loss	Totals
Bedroom 1						
South wall	(15+3)x8	120	0.07	77	647	
East wall	13.5x8	108	0.07	77	282	
Windows (2)	3x4	24	0.50	77	924	
Infiltration	2/3x15x13.6x8	1,088	0.018	77	1,508	3,361
Bedroom 2						
East wall	14x8	112	0.07	77	604	
North wall	11x8	76	0.07	77	410	
Window	3x4	12	0.50	77	462	
Infiltration	2/3x11x11x8	645	0.018	77	894	2,370
Bathroom						
North wall	8x8	60	0.07	77	323	
Window	2x2	4	0.50	77	154	
Infiltration	3/4x7.5x11x8	495	0.018	77	686	1,163
Bedroom 3						
North wall	12x8	84	0.07	77	453	
West wall	10x8	80	0.07	77	431	
Window	3x4	12	0.50	77	462	
Infiltration	2/3x10x12x8	640	0.018	77	887	2,233
Bedroom 4 and Hallway						
West wall	16x8	128	0.07	77	690	
South wall	14x8	88	0.07	77	474	
Window	2x3x4	24	0.50	77	924	
Infiltration	2/3x14x16x8	1,195	0.018	77	1,656	3,744
Living Room						
South wall	32x8	203	0.07	77	1,094	
Door	3x7	21	0.26	77	420	
Window	4x6	32	0.62	77	1,528	
East wall	13.5x8	108	0.07	77	582	
Infiltration	2/3x19x13.5x8	1,368	0.018	77	1,896	5,520
Dining Room						
East wall	13.5x8	108	0.07	77	582	
North wall	11x8	88	0.07	77	474	
Infiltration	1/3x11x13.5x8	396	0.018	77	549	1,605
Kitchen, Breakfast						
North wall	18x8	122	0.07	77	657	
Window	2.5x4	10	0.50	77	385	
Window	3.4	12	0.50	77	462	
Infiltration	1x18x11x8	1,584	0.018	77	2,195	3,699
Family Room						
North wall	21.5x8	136	0.07	77	733	
Patio door	6x6	36	0.58	77	1,608	
West wall	13x8	104	0.20	77	1,602	
South wall	22x8	176	0.52	38	3,478	
Infiltration	2x13x22x8	4,576	0.018	77	6,342	13,763
Hall						
West wall	17x8	136	0.52	38	2,686	
Infiltration	1x8x8x17	1,088	0.018	77	1,508	4,195
Basement						
North wall	54x8	432	0.10	23	994	
West wall	28x8	224	0.10	23	515	
South wall	54x8	432	0.10	23	994	
East wall	28x8	224	0.10	23	515	
Floor	32x28	896	0.10	23	2,061	
Floor	13x22	286	0.10	23	658	
Infiltration	1/6x54x13x8+ 1/6x15x32x8	1,576	0.018	77	2,184	7,921
Ceiling						
Second floor	32x28	896	0.04	77	2,760	
Family room	13x22	286	0.04	77	681	3,641
				TOTAL		53,215



CASTLE

TOTAL FLOOR AREA
2078 ft²-2 floor
plus 1182 ft²-Base.
3260 ft²



Colonial two-story with all the necessary size and luxury for a large or growing family • Four Bedrooms and Two Baths on the Second Floor • Large Entry With Open Stairway • Spacious Living Room • Formal Dining Room • U-Shape Kitchen With Eating Space • Family Room With Fireplace Located Next To Kitchen • Full Unfinished Basement • Two Car Garage • Paneling

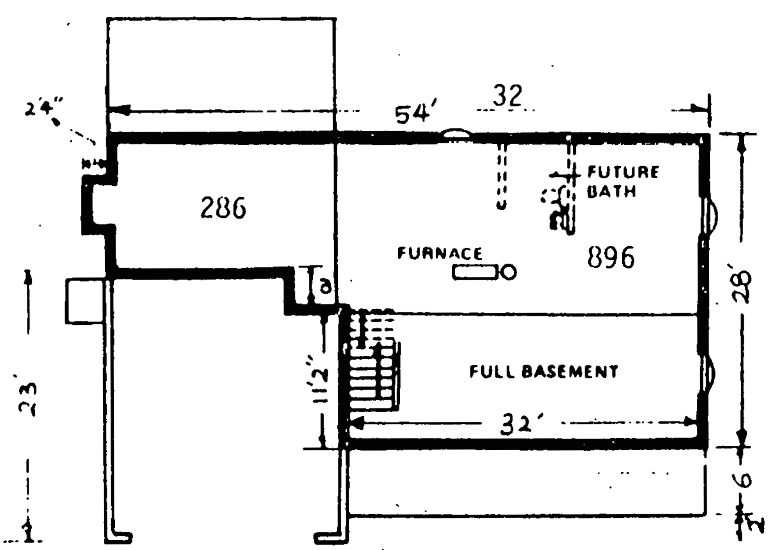


Figure 5-1. Example Residential Building Plan

PLAN 809

U.S. DEPARTMENT OF HOUSING AND URBAN DEVELOPMENT
FEDERAL HOUSING ADMINISTRATION

FHA Form 2005
VA Form 26-1852
Rev. 2/74

For accurate register of carbon copies, form may be separated along above fold. Staple completed sheets together in original order.

Form Approved
OMB No. 63-R0055

☐ Proposed Construction

DESCRIPTION OF MATERIALS

No. ______ (To be inserted by FHA or VA)

☐ Under Construction

Property address ______ City ______ State ______

Mortgagor or Sponsor ______ (Name) ______ (Address)

Contractor or Builder Bartran Homes, Inc. (Name) ______ (Address)

INSTRUCTIONS

1. For additional information on how this form is to be submitted, number of copies, etc., see the instructions applicable to the FHA Application for Mortgage Insurance or VA Request for Determination of Reasonable Value, as the case may be.

2. Describe all materials and equipment to be used, whether or not shown on the drawings, by marking an X in each appropriate check-box and entering the information called for in each space. If space is inadequate, enter "See misc." and describe under item 27 or on an attached sheet. THE USE OF PAINT CONTAINING MORE THAN FIVE-TENTHS OF ONE PERCENT LEAD BY WEIGHT IS PROHIBITED.

3. Work not specifically described or shown will not be considered unless required, then the minimum acceptable will be assumed. Work exceeding minimum requirements cannot be considered unless specifically described.

4. Include no alternates, "or equal" phrases, or contradictory items. (Consideration of a request for acceptance of substitute materials or equipment is not thereby precluded.)

5. Include signatures required at the end of this form.

6. The construction shall be completed in compliance with the related drawings and specifications, as amended during processing. The specifications include this Description of Materials and applicable Minimum Property Standards.

1. EXCAVATION:

Bearing soil, type Clay

2. FOUNDATIONS:

Footings: concrete mix 5 sack ; strength psi 2500# Reinforcing none

Foundation wall: material concrete Reinforcing see plans

Interior foundation wall: material ______ Party foundation wall ______

Columns: material and sizes see plans Piers: material and reinforcing see plans

Girders: material and sizes see plans Sills: material ______

Basement entrance areaway ______ Window areaways see plans

Waterproofing hot spray asphalt Footing drains none

Termite protection ______

Basementless space: ground cover 55# felt ; insulation ______ ; foundation vents bird screen

Special foundations ______

Additional information: ______

3. CHIMNEYS:

Material metal Prefabricated *(make and size)* ______

Flue lining: material ______ Heater flue size 8" Fireplace flue size 9" I.D.

Vents *(material and size)*: gas or oil heater ______ ; water heater ______

Additional information: ______

4. FIREPLACES:

Type: ☒ solid fuel; ☐ gas-burning; ☐ circulator *(make and size)* ______ Ash dump and clean-out ______

Fireplace: facing Brick Veneer ; lining metal ; hearth brick ; mantel wood

Additional information: Heatilator Mark 123 Model 3036

5. EXTERIOR WALLS:

Wood frame: wood grade, and species N.C. const. fir ☐ Corner bracing. Building paper or felt ______

Sheathing insul. board ; thickness ½" ; width ______ ; ☒ solid; ☐ spaced ______" o. c.; ☐ diagonal;

Siding wood ; grade ______ ; type ______ ; size ______ ; exposure ______"; fastening galv. nails

Shingles ______ ; grade ______ ; type ______ ; size ______ ; exposure ______"; fastening galv. nails

Stucco ______ ; thickness ______"; Lath ______ ; weight ______ lb.

Masonry veneer ______ Sills ______ Lintels none Base flashing metal

Masonry: ☐ solid ☐ faced ☐ stuccoed; total wall thickness ______"; facing thickness ______"; facing material ______

Backup material ______ ; thickness ______"; bonding ______

Door sills ______ Window sills ______ Lintels ______ Base flashing ______

Interior surfaces: dampproofing, ______ coats of ______ ; furring ______

Additional information: ______

Exterior painting: material Jones Blair exterior paint ; number of coats 2

Gable wall construction: ☒ same as main walls; ☐ other construction ______

6. FLOOR FRAMING:

Joists: wood, grade, and species N.C. const. fir other ______ ; bridging 1x3 ______ ; anchors 1½x1½"

Concrete slab: ☒ basement floor; ☐ first floor; ☐ ground supported; ☐ self-supporting; mix 5 sack ; thickness 4"

reinforcing 6/6-10/10 WWF ; insulation ______ ; membrane polyurethane

Fill under slab: material gravel ; thickness 4 ". Additional information: ______

7. SUBFLOORING: *(Describe underflooring for special floors under item 21.)*

Material: grade and species 3/4" tung and groove ; size 4x8 ; type CD

Laid: ☒ first floor; ☐ second floor; ☐ attic ______ sq. ft.; ☐ diagonal; ☒ right angles. Additional information: ______

8. FINISH FLOORING: *(Wood only. Describe other finish flooring under item 21.)*

Location	Rooms	Grade	Species	Thickness	Width	Bldg. Paper	Finish
First floor							
Second floor							
Attic floor ______ sq. ft.							

Additional information: ______

Figure 5-2. Description of Materials

9. PARTITION FRAMING:
Studs: wood, grade, and species W.C. coast fir size and spacing 2x4 @ 24" o.c. Other
Additional information: Bearing Walls: 2x4 @ 16" o.c.

10. CEILING FRAMING:
Joists: wood, grade, and species Other Bridging
Additional information: truss (see attached detail)

11. ROOF FRAMING:
Rafters: wood, grade, and species Roof trusses (see detail): grade and species 45 ° pitch
Additional information: truss (see attached detail)

12. ROOFING:
Sheathing: wood, grade, and species ½" C.D. plywood ; ☒ solid; ☐ spaced ____" o.c.
Roofing Asphalt ; grade 235# ; size ; type
Underlay Felt ; weight or thickness 15 ; size ; fastening galv. nails
Built-up roofing ; number of plies ; surfacing material
Flashing: material galv. metal ; gage or weight 30 ; ☐ gravel stops; ☐ snow guards
Additional information:

13. GUTTERS AND DOWNSPOUTS:
Gutters: material galv. ; gage or weight 26 ; size 12 ; shape moulded
Downspouts: material galv. ; gage or weight 26 ; size 3 ; shape square ; number 4
Downspouts connected to: ☐ Storm sewer; ☐ sanitary sewer; ☐ dry-well. ☒ Splash blocks: material and size ~~redwood~~ Concrete
Additional information:

14. LATH AND PLASTER
Lath ☐ walls, ☐ ceilings: material ; weight or thickness Plaster: coats ; finish
Dry-wall ☒ walls, ☒ ceilings: material gyp. bd. ; thickness ½" ; finish texture ;
Joint treatment tape

15. DECORATING: *(Paint, wallpaper, etc.)*

Rooms	Wall Finish Material and Application	Ceiling Finish Material and Application
Kitchen	(1) prime &(2) enamel coats	same
Bath	"	"
Other	(1) coat rubber base	"

Additional information: applies only to finished areas (see plans)

16. INTERIOR DOORS AND TRIM:
Doors: type wood flush ; material mahogany ; thickness 13/8"
Door trim: type S. line ; material white pine Base: type S. line ; material white pine ; size 3½"
Finish: doors Fill, (2) coats stain ; trim (1) prime, (2) enamel coats
Other trim *(item, type and location)* window sills: formica
Additional information: closet doors: metal bi-fold/louvered

17. WINDOWS: General Aluminum Corp. TARTAN TEL. 321-4316
Windows: type sliding ; make Series 1800 ; material aluminum ; sash thickness
Glass: grade insulated ; ☐ sash weights; ☐ balances, type ; head flashing
Trim: type ; material Paint ; number coats
Weatherstripping: type ; material Storm sash, number
Screens: ☐ full; ☒ half: type ; number all ; screen cloth material galv.
Basement windows: type sliding ; material aluminum ; screens, number all ; Storm sash, number
Special windows
Additional information:

18. ENTRANCES AND EXTERIOR DETAIL:
Main entrance door: material Mahogany ; width 36" ; thickness 1 3/4" Frame: material select fir , thickness 1 3/8
Other entrance doors: material Fir ; width 32" ; thickness 1 3/8" Frame: material " ; thickness "
Head flashing galv. metal Weatherstripping: type ; saddles
Screen doors: thickness 1 "; number 1 ; screen cloth material galv. Storm doors: thickness ____", number
Combination storm and screen doors: thickness 1 "; number 1 ; screen cloth material galv.
Shutters: ☐ hinged; ☐ fixed. Railings , Attic louvers
Exterior millwork: grade and species Paint ; number coats
Additional information:

19. CABINETS AND INTERIOR DETAIL: Manufactured by Alpine cabinet Co.
Kitchen cabinets, wall units: material Timnath, Colo. ; lineal feet of shelves see plans ; shelf width 12"
Base units: material ; counter top formica ; edging same
Back and end splash formica Finish of cabinets wood grain vinyl ; number coats
Medicine cabinets: make ; model
Other cabinets and built-in furniture bath vanities per plans
Additional information:

20. STAIRS:

Stair	Treads		Risers		Strings		Handrail		Balusters	
	Material	Thickness	Material	Thickness	Material	Size	Material	Size	Material	Size
Basement	fir	5/4	pine	3/4	W.C.fir	2x12	wood	2"	W.I.	3/4"
Main										
Attic										

Disappearing: make and model number
Additional information:

Figure 5-2. Description of Materials (Continued)

21. SPECIAL FLOORS AND WAINSCOT:

	Location	Material, Color, Border, Sizes, Gage, Etc.	Threshold Material	Wall Base Material	Underfloor Material
Floors	Kitchen	Armstrong or equal		rubber	plywood
	Bath	"		"	"
	entry	"		"	"
	other	Carpet (finished areas only) (see attached)		pine	"

	Location	Material, Color, Border, Cap, Sizes, Gage, Etc.	Height	Height Over Tub	Height in Showers (From Floor)
Wainscot	Bath	Ceramic tile	72"	63"	72"

Bathroom accessories: ☒ Recessed; material chrome; number (1) per bath; ☐ Attached; material chrome; number (2) per bath

Additional information:

22. PLUMBING:

Fixture	Number	Location	Make	Mfr's Fixture Identification No.	Size	Color
Sink	1	kitchen	Briggs	3401	21x32	white
Lavatory	1	bath	Amer. Standard	51007.056	19" Dia.	"
Water closet	1	"	Kohler	R3512-PB		"
Bathtub	1	"	Briggs	2000	30x60	"
Shower over tub △	1	"				
Stall shower △						
Laundry trays						

△☒ Curtain rod △☐ Door ☐ Shower pan: material

Water supply: ☒ public; ☐ community system; ☐ individual (private) system.★

Sewage disposal: ☒ public; ☐ community system; ☐ individual (private) system.★

★*Show and describe individual system in complete detail in separate drawings and specifications according to requirements.*

House drain (inside): ☐ cast iron; ☐ tile; ☒ other ABS House sewer (outside): ☐ cast iron; ☒ tile; ☐ other

Water piping: ☐ galvanized steel; ☒ copper tubing; ☐ other Sill cocks, number 2

Domestic water heater: type Gas; make and model A. O. Smith; heating capacity 42,000 BTU

35.3 gph. 100° rise. Storage tank: material glass lined; capacity 40 gallons.

Gas service: ☒ utility company; ☐ liq. pet. gas; ☐ other Gas piping: ☐ cooking; ☒ house heating.

Footing drains connected to: ☐ storm sewer; ☐ sanitary sewer; ☐ dry well. Sump pump; make and model

; capacity ; discharges into

23. HEATING:

☐ Hot water. ☐ Steam. ☐ Vapor. ☐ One-pipe system. ☐ Two-pipe system.

☐ Radiators. ☐ Convectors. ☐ Baseboard radiation. Make and model

Radiant panel: ☐ floor; ☐ wall; ☐ ceiling. Panel coil: material

☐ Circulator. ☐ Return pump. Make and model ; capacity gpm.

Boiler: make and model Output Btuh.; net rating Btuh.

Additional information:

Warm air: ☐ Gravity. ☒ Forced. Type of system perimeter 120 - 150 BTU.

Duct material: supply galv.; return galv. Insulation , thickness ☐ Outside air intake.

Furnace: make and model Lennox Input see plans Btuh.; output see plans Btuh.

Additional information:

☐ Space heater; ☐ floor furnace; ☐ wall heater. Input Btuh.; output Btuh.; number units

Make, model Additional information:

Controls: make and types Lennox

Additional information:

Fuel: ☐ Coal; ☐ oil; ☐ gas; ☐ liq. pet. gas; ☐ electric; ☐ other ; storage capacity

Additional information:

Firing equipment furnished separately: ☐ Gas burner, conversion type. ☐ Stoker: hopper feed ☐, bin feed ☐

Oil burner: ☐ pressure atomizing; ☐ vaporizing

Make and model Control

Additional information:

Electric heating system: type Input watts; @ volts; output Btuh.

Additional information:

Ventilating equipment: attic fan, make and model , capacity cfm.

kitchen exhaust fan, make and model see item # 26

Other heating, ventilating, or cooling equipment

24. ELECTRIC WIRING:

Service: ☐ overhead; ☒ underground. Panel: ☐ fuse box; ☒ circuit-breaker; make Klinsco AMP's 100 No. circuits 15

Wiring: ☐ conduit; ☐ armored cable; ☒ nonmetallic cable; ☐ knob and tube; ☐ other

Special outlets: ☒ range; ☐ water heater; ☒ other dryer

☒ Doorbell. ☒ Chimes. Push-button locations front door Additional information:

25. LIGHTING FIXTURES:

Total number of fixtures see plans Total allowance for fixtures, typical installation, $ 150.00

Nontypical installation

Additional information:

DESCRIPTION OF MATERIALS

Figure 5-2. Description of Materials (Continued)

26. INSULATION:

Location	Thickness	Material, Type, and Method of Installation	Vapor Barrier
Roof			
Ceiling	6"	blown rock wool R-30 TIMBER LINE INSULATION	
Wall	3½"	batt R-11 482-1059	
Floor		482-3181	

HARDWARE: *(make, material, and finish.)* Stanley, brass, smooth
Privacy lock at master bedroom and bathrooms; keyed locks at all entrance doors including garage doors; all other doors passage knobs.

SPECIAL EQUIPMENT: *(State material or make, model and quantity. Include only equipment and appliances which are acceptable by local law, custom and applicable FHA standards. Do not include items which, by established custom, are supplied by occupant and removed when he vacates premises or chattles prohibited by law from becoming realty.)*

Garbage Disposal - Insinkerator Badger
Dishwasher - Frigidaire DW 3CDUU
Range - " RBE 353
Hood - Nautilus
Optional fireplace - Heatilator Mark 123 Model 3036
Optional Medicine Cabinet - Recessed Kent Model WAL 1420

27. MISCELLANEOUS: *(Describe any main dwelling materials, equipment, or construction items not shown elsewhere; or use to provide additional information where the space provided was inadequate. Always reference by item number to correspond to numbering used on this form.)*

Provide hot & cold water for washer
" 110 outlet for washer
" 220 outlet for dryer

PORCHES:

see plans

TERRACES:

see plans

GARAGES:

attached see plans

WALKS AND DRIVEWAYS:

Driveway: width 17'; base material gravel; thickness 4"; surfacing material concrete; thickness 4"
Front walk: width 3'; material concrete; thickness 4". Service walk: width ____; material ____; thickness ____"
Steps: material concrete; treads 12"; risers 6". Cheek walls ____

OTHER ONSITE IMPROVEMENTS:
(Specify all exterior onsite improvements not described elsewhere, including items such as unusual grading, drainage structures, retaining walls, fence, railings, and accessory structures.)

LANDSCAPING, PLANTING, AND FINISH GRADING:

Topsoil 4" thick: ☒ front yard; ☒ side yards; ☒ rear yard to all feet behind main building
Lawns *(seeded, sodded, or sprigged)*: ☒ front yard sodded; ☐ side yards ____; ☐ rear yard ____
Planting: ☐ as specified and shown on drawings; ☐ as follows:

____ Shade trees, deciduous, ____" caliper. ____ Evergreen trees, ____' to ____', B & B
____ Low flowering trees, deciduous, ____' to ____' ____ Evergreen shrubs, ____' to ____', B & B
____ High-growing shrubs, deciduous, ____' to ____' ____ Vines, 2-year
____ Medium-growing shrubs, deciduous, ____' to ____'
____ Low-growing shrubs, deciduous, ____' to ____'

IDENTIFICATION.—This exhibit shall be identified by the signature of the builder, or sponsor, and/or the proposed mortgagor if the latter is known at the time of application.

Date 21 January 1975 Signature ____

Signature ____

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VA Form 26-1852

Figure 5-2. Description of Materials (Concluded)

HEAT GAINS

Heat transmission into a building takes place by radiation and conduction from building surfaces and by infiltration of warm air into conditioned space. The detailed procedure is quite complex, taking into account the thermal and optical properties of the building materials, time of day, day of the year, solar radiation intensity, etc. The procedure described in this model is based on a simplified method using a design equivalent temperature difference.

Heat gain is computed by:

$$Q = UA(DTD) \tag{5-11}$$

where

- Q is rate of heat gain, Btu/hr
- A is area of surface, ft^2
- U is heat transmission coefficient, Btu/(hr)(ft^2)(°F)
- DTD is design equivalent temperature difference

The DTD for three design outdoor temperatures are listed in Table 5-8. U factors for typical construction may be computed in the manner shown in Examples 1 through 13. Heat gain through windows depends upon exposure to solar radiation; therefore, heat gains will differ for different window orientations. Heat gains directly in terms of Btu/(hr)(ft^2) are listed in Table 5-9. No credit is given for shade line below an overhang in the table. When a permanent overhang is provided, the shaded window is treated as a north facing window. Average shade lines below an overhang for various latitudes and window orientation are given in Table 5-10. The overhang width multiplied by the shade factor determines the average effective shadow lines below the level of the overhang. Data are for August 1, averaged over 5 hours.

Table 5-8. Design Equivalent Temperature Differences (°F)

Design Outdoor Temperature	85	95		105
Temperature Range During Day	15-25	15-25	>25	>25
Walls and Doors				
Wood frame and doors	14	24	19	29
Masonry	6	16	11	21
Ceilings and Roof				
Under vented attic, dark roof	34	44	39	49
Built-up roof (no ceiling), light roof	26	36	31	41
Floors				
Over unconditioned rooms and open crawl space	5	15	10	20
Over basement, enclosed crawl space	0	0	0	0

Infiltration

Infiltration in the summer is less than in winter because the temperature difference and wind velocity are less. Air changes per hour for the summer are listed in Table 5-6. Sensible heat gain is determined by Equation (5-7) and latent heat gain by Equation (5-8). Residential cooling loads are almost always based on sensible heat gains.

Occupancy

Heat gain from human beings in a residence is usually assumed to be about 200 to 250 Btu per hour per person. For normally equipped kitchens, heat gain from appliances is assumed to be 1200 Btu per hour for determining cooling loads.

Table 5-9. Design Heat Gains Through Windows
Btu/(hr) (ft^2)

Outdoor Design Temperature	Single Pane			Double Pane		
	85	95	105	85	95	105
No Awnings or Inside Shading						
North	23	31	38	19	24	28
Northeast; Northwest	56	64	71	46	51	55
East and West	81	89	96	68	73	77
Southeast; Southwest	70	78	85	59	64	68
South	40	48	55	33	38	42
With Draperies or Ven. Blinds						
North	15	23	30	12	17	21
Northeast; Northwest	32	40	47	27	32	36
East and West	48	56	63	42	47	51
Southeast; Southwest	40	48	55	35	40	44
South	23	31	38	20	25	29
Roller Shades, Half Down						
North	18	26	33	15	20	24
Northeast; Northwest	40	48	55	38	43	47
East and West	61	69	76	54	59	63
Southeast; Southwest	52	60	67	46	51	55
South	29	37	44	26	32	36
Awnings						
North	20	28	35	13	18	22
Northeast; Northwest	21	29	36	14	19	23
East and West	22	30	37	14	19	23
Southeast; Southwest	21	29	36	14	19	23
South	21	28	35	13	18	22

Table 5-10. Shade Line Factors*
(5 hour average, 1 August)

Window Orientation	Latitude					
	25	30	35	40	45	50
East and West	0.8	0.8	0.8	0.8	0.8	0.8
Southeast; Southwest	1.9	1.6	1.4	1.3	1.1	1.0
South	10.1	5.4	3.6	2.6	2.0	1.7

*Multiply shade line factors by width of overhang to determine shadow line below overhang.

Solar Equipment

Heat gains from solar equipment in a residence, i.e., motors, heated pipes and ducts, will add to the cooling load. The heat gain could be significant from water storage tanks if the equipment room is not vented. While there is as yet insufficient data from solar heated and cooled houses to provide design tables, a heat gain equivalent to the kitchen load, 1200 Btu per hour, may be assumed.

Latent Heat

Latent heat load of 30 percent of the sensible heat load may be used.

COOLING LOAD

The differences between heat gains and cooling loads are important in calculating residential cooling loads. The cooling loads in residential buildings are primarily due to sensible heat flow and not internal heat gains. It must be remembered that only a few days each season are design days, and a partial load condition exists for many hours during a season. Thus, an oversized system does not perform effectively with short-term or intermittent operating cycles. Equipment should be of the smallest possible capacity, and designed to operate for 24 hours a day, using the thermal storage available in interior walls and furnishings to reduce temperature excursions in the building.

Procedure for Calculation

1. Determine the design outdoor summer temperature from Table 2-2.

2. Establish an indoor design temperature (usually 75°F).

3. Determine net areas of building sub-structures.

4. Select U factors from Examples 1 through 13 or calculate U factor from appropriate tables.

5. Select the Design Equivalent Temperature Difference (DTD) from Table 5-8.

6. For windows, use heat gain rates given in Table 5-9, corrected for shading factors given in Table 5-10.

7. Calculate the sensible heat gain from conduction and radiation, using Equation (5-11)

$$Q = UA(DTD) \tag{5-11}$$

8. Calculate the sensible heat gain due to infiltration, using Table 5-6.

9. Add heat gain from occupants and fixed appliances.

10. Sum the sensible heat gains.

11. Add 30 percent for latent cooling load.

12. Total the latent load and sensible heat gains to determine the total cooling load.

Example -- The cooling load for the house of Figure 5-1 is calculated as shown in Table 5-11. The outdoor design temperature is 89°F. The indoor design temperature is 75°F. The U-factors for walls, ceiling and door are the same as for winter conditions. Refinement in U-factors were not made in these computations although the R factors in air films in Tables 5-1 and 5-2 would result in slightly different R factors.

The overhangs over the south-facing windows effectively reduce the heat transfer rates equivalent to the north-facing windows, and there are no east and west facing windows. No credit was taken for shades or drapes over the windows.

The temperature in the garage was assumed to be the mean between indoor and outdoor design temperatures, and the design temperature differences (DTD) given in Table 5-8 were interpolated for the design outdoor temperature of 89°F.

The total cooling load for the building is calculated to be 16,321 Btu per hour. This low cooling load is a result of low design outdoor temperature in Fort Collins, 89°F, and a building that is insulated properly with shading over windows. The values used apply for average summer conditions, and it is likely that cooling loads for days when temperatures reach 95°F will require greater cooling capacity. If the air conditioner is operating 24 hours per day, even for these days, the temperature excursion inside the building should not be large.

Based on a cooling load of 16,300 Btu/hr, a temperature difference of 14°F and above grade floor area, the overall heat transfer coefficient for the building is 0.56 Btu per hour per square foot of floor space for each °F temperature difference between design outdoor and indoor temperatures.

Table 5-11. Cooling Worksheet for Example Building

Building Section	Size or Volume	Net Area or Volume	U or Unit Heat Gain	DDT	Heat Gain	Totals
Bedroom 1						
South wall	18x8	120	0.07	19	160	
East wall	13.5x8	108	0.07	19	144	
Windows	3x4	24	27		648	
Infiltration	1632	816	0.018	14	205	1,157
Bedroom 2						
East wall	14x8	112	0.07	19	149	
North wall	11x8	76	0.07	19	101	
Window	3x4	12	27		324	
Infiltration	968	484	0.018	14	122	696
Bathroom						
North wall	8x8	60	0.07	19	80	
Window	2x2	4	27		108	
Infiltration	660	660	0.018	14	166	354
Bedroom 3						
North wall	12x8	84	0.07	19	112	
West wall	10x8	80	0.07	19	106	
Window	3x4	12	27		324	
Infiltration	960	480	0.018	14	121	663
Bedroom and Hallway						
West wall	16x8	128	0.07	19	170	
South wall	14x8	88	0.07	19	117	
Window	3x4	24	27		648	
Infiltration	1792	896	0.018	14	226	1,161
Living Room						
South wall	32x8	203	0.07	19	270	
Door	3x7	21	0.47	19	188	
Window	4x8	32	21		672	
East wall	13.5x8	108	0.15	11	672	
Infiltration	2052	1,026	0.018	14	258	1,566
Dining Room						
East wall	13.5x8	108	0.07	19	144	
North wall	11x8	88	0.07	19	117	
Infiltration	1188	198	0.018	14	50	311
Kitchen, Breakfast						
North wall	1848	122	0.07	19	162	
Windows		22	27		594	
Infiltration	1584	1,584	0.918	14	399	1,155
Family Room						
North wall	21.5x8	136	0.07	19	180	
West wall	13x8	104	0.20	19	395	
South wall	22x8	176	0.52	7	640	
Patio Door	6x6	36	21		756	
Infiltration	2288	2,288	0.018	14	577	2,548
Hall						
West wall	17x8	136	0.52	7	495	
Infiltration	1088	1,088	0.018	14	274	
Ceiling						
Second floor	32x28	896	0.04	39	1,398	
Family room	13x22	286	0.04	39	446	1,844

TOTAL	10,455
4 occupants x 225	900
Kitchen Appliances	1,200
Total Sensible Heat Gain	12,555
Latent + Sensible Heat Gain	16,321
Cooling Load, Btu/hr	13,321

No load is calculated for basement. No credit for cool basement taken.

SOLAR COLLECTOR CHARACTERISTICS

The purpose of solar collectors is to intercept (collect) solar radiation and transform radiant solar energy into heat energy. The heat is then transferred to a fluid and transported into the building to be used directly to heat service water and building space or stored for later use.

A collector that has the same solar energy intercepting area as absorber area is called a flat-plate collector. A collector that concentrates the radiation from a larger intercepting area to a smaller absorbing area is called a concentrating collector. Concentrating collectors are not, as yet, considered practical for residential solar systems because moving parts are involved, tracking is necessary in most cases, and considerable maintenance will probably be required to keep the system in proper operating condition. When very high temperature heat is required, for example to generate steam for process heat uses in industry or to operate steam turbines to develop mechanical power, concentrating collectors are necessary. For residential solar energy systems, flat-plate collectors can produce heat at sufficiently high temperatures to heat the house and operate the cooling unit. Many types of flat-plate collectors are being manufactured today and are available in quantity for commercial applications.

Types of Flat-Plate Collectors

Flat-plate collectors consist of two types, liquid-heating and air-heating collectors. The important parts of a "typical" flat-plate collector unit are shown in Figure 5-3.

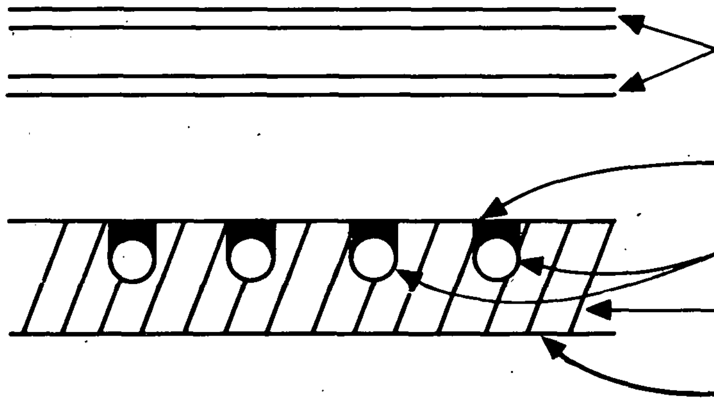


Figure 5-3. "Typical" Flat-Plate Collector

The main component of a collector is the black absorber plate that converts radiation to heat and transfers the heat to the fluid. Absorber plates are usually made of copper, aluminum or steel, with a flat black coating on the surface. The cover plates reduce the heat losses from the absorber plate because, although they are transparent to solar radiation, they are opaque to infrared radiation that is emitted from the absorber. The air gaps between the covers and the lower cover and absorber plate also act as insulation. Likewise, the insulation below the absorber plate reduces heat losses from below the absorber plate. The spacing between the glass plates and between the lower cover glass and the absorber may vary from 1/2 to 1 inch and is typically about 3/4 inch. The insulation is from 2 to 3 inches thick.

The arrangement of fluid tubes on the absorber plate shown in Figure 5-3 is typical for liquid-heating collectors. For air-heating collectors, the tubes are replaced by a thin duct. The flow of liquid through tubes is sufficient to convey the heat away from the absorber, but because air is less dense than liquids, and the heat capacity of air is less than most liquids, a greater contact area between the absorber and the fluid in a solar air heater improves its performance.

In addition to these primary types of flat-plate collectors, several widely differing designs have been used. Some of these collectors and associated systems have been commercialized, while others are in an experimental stage.

Performance and cost data are available for collectors of the evacuated tubular type. By enclosing the radiation absorber in an evacuated glass tube (similar to a large, transparent thermos bottle), water can be solar heated at substantially higher efficiency (because of very low heat loss) than in a conventional collector. Test marketing of one type and experimental development of other types are in progress. Costs are currently high, but high-volume manufacture could result in large price reductions.

Another flat-plate type of collector involves water trickling over the black absorber surface rather than flowing up through closed passages. The lower efficiency (compared to conventional types) caused by evaporative heat loss is partially offset by low price.

Heat collection and storage in the same component have also been demonstrated, but performance and cost data are not available. A large, shallow water reservoir on a flat roof can add heat capacity to a building so that in a mild climate, temperature variation in the structure can be reduced. Sliding panels of insulation can be employed to decrease nocturnal heat loss in winter and reduce solar heat gain in the summer. Drums of water inside double-glazed, south-facing windows may be used in the same way for heat collection and storage. These combined collector-storage systems dictate certain structural and architectural features which limit their general applicability.

For heating water to temperatures below 100°F, such as for swimming pools, solar collectors need not be glazed and the absorber may be a low cost black plastic material in which tubes for water circulation are formed. Solar pool heaters of this type are commercially available. The covering of a water pool with a commercial transparent plastic cover also provides ample solar heat and suppresses heat loss.

Numerous variations of solar air heaters have been designed and tested. The characteristics of the absorbing surface and the manner of contacting air with it constitute the principal differences. Porous metal screens, overlapped glass plates, corrugated surfaces, and finned plates with air flowing through, under or above the absorbers have been built. To date, none of these types has proved superior, in performance or economy, to the ducted type described above.

Collector Efficiency

Solar collector efficiency is 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 vary from 20 to 60 percent, depending upon fluid and ambient air temperatures. Figure 5-4 shows the factors affecting collector efficiency. When the fluid flow rate through the collector is low, the fluid heats up to a high temperature as does the absorber plate. The high absorber plate temperature leads to large heat losses from the collector, with consequent low collector efficiency. Conversely, with a large 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 from 100°F to 140°F in an operating system, efficiencies of 35 to 40 percent are typical for a flat-plate collector.

Collector efficiency is affected not only by fluid and ambient temperatures, but also by the number of transparent covers and the type of black surface coating on the absorber plate. If the collector is provided with only one transparent cover, the amount of solar radiation reaching the absorber plate will be greater than if two cover plates are provided. However, in most areas of the country with cold ambient air temperatures during the winter, the heat losses through the top cover from the absorber plate would be

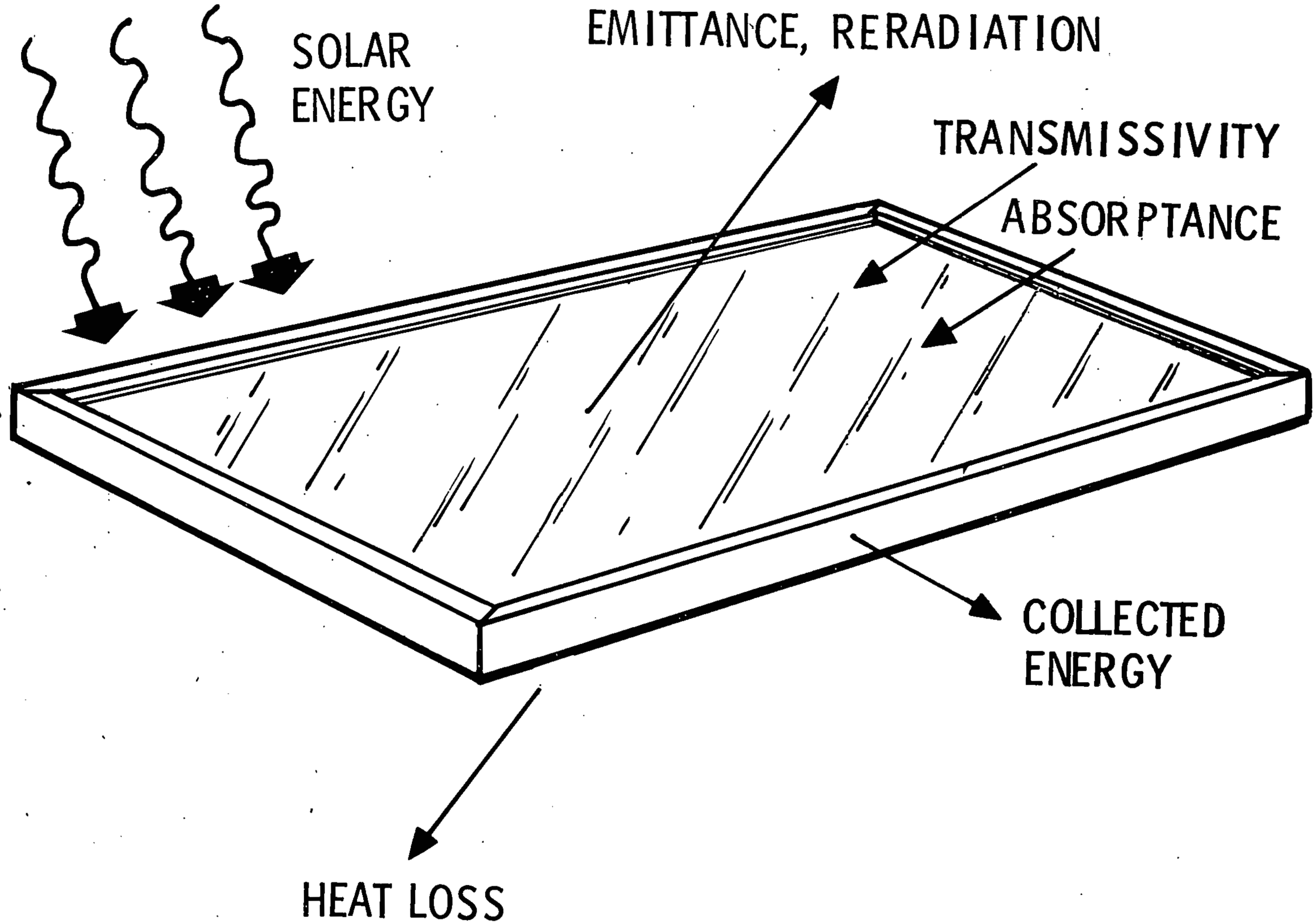


Figure 5-4. Systems Design and Development Function

greater than the additional solar energy gain. Therefore, efficiencies of collectors with only one glass or transparent cover are less than for two covers. Adding a third cover plate would reduce the heat losses, but it will also reduce the solar energy reaching the absorber plate, with the net result that collector efficiency would be less. Flat-plate collectors with two cover plates provide best efficiencies in most areas of the United States.

A flat black coating absorbs a high percentage of solar radiation incident on the absorber plate of the collector. Absorptances of 92 to 96 percent are typical. However, flat black coatings also have a high emittance factor, generally equal to the absorptance. Thus, when solar radiation is absorbed and converted to heat, the hot absorber plate radiates a large amount of heat energy, depending upon the temperature of the plate. A selective black coating, such as black nickel, black chrome, and copper oxide, has the property that absorptance of solar energy is high and emittance of heat energy is low. Thus, with a selective coating on the absorber, the collection and conversion of solar energy to heat is high and heat loss by radiation is low, and this increases the collector efficiency. Many types of selective surface coatings are commercially available. Most involve processes that add substantially to the cost of manufacturing the collectors. Within the next few years there should be improvements in materials and methods of application to make selective surfaces economically justifiable for flat-plate collectors.

Most of the manufacturers of solar collectors provide performance data on their equipment. Some of the information is derived from measurements made by the manufacturer, and supplementary data procured by testing organizations may also be available. Since the efficiency of a solar collector is highly dependent on the test conditions, meaningful results require full specifications of the significant variables. Examples of manufacturer's data on collector efficiency are shown in Figures 5-5 (for a liquid type collector) and 5-6 (for an air type collector). In the future, National Standards will require testing and data presentation in accordance with ASHRAE Test Procedure 93-77.

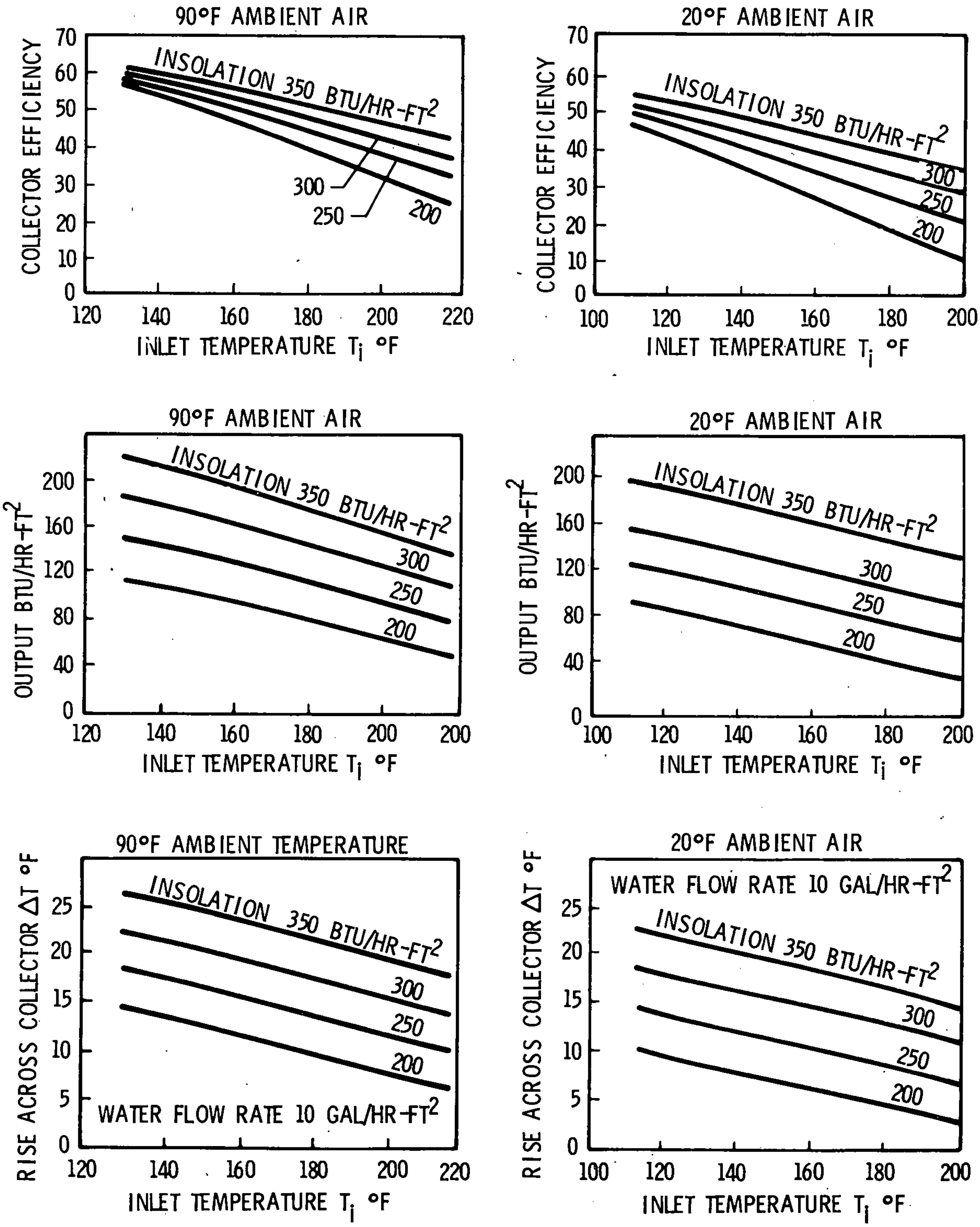


Figure 5-5. Collector Performance Data, Water-Heating Collector

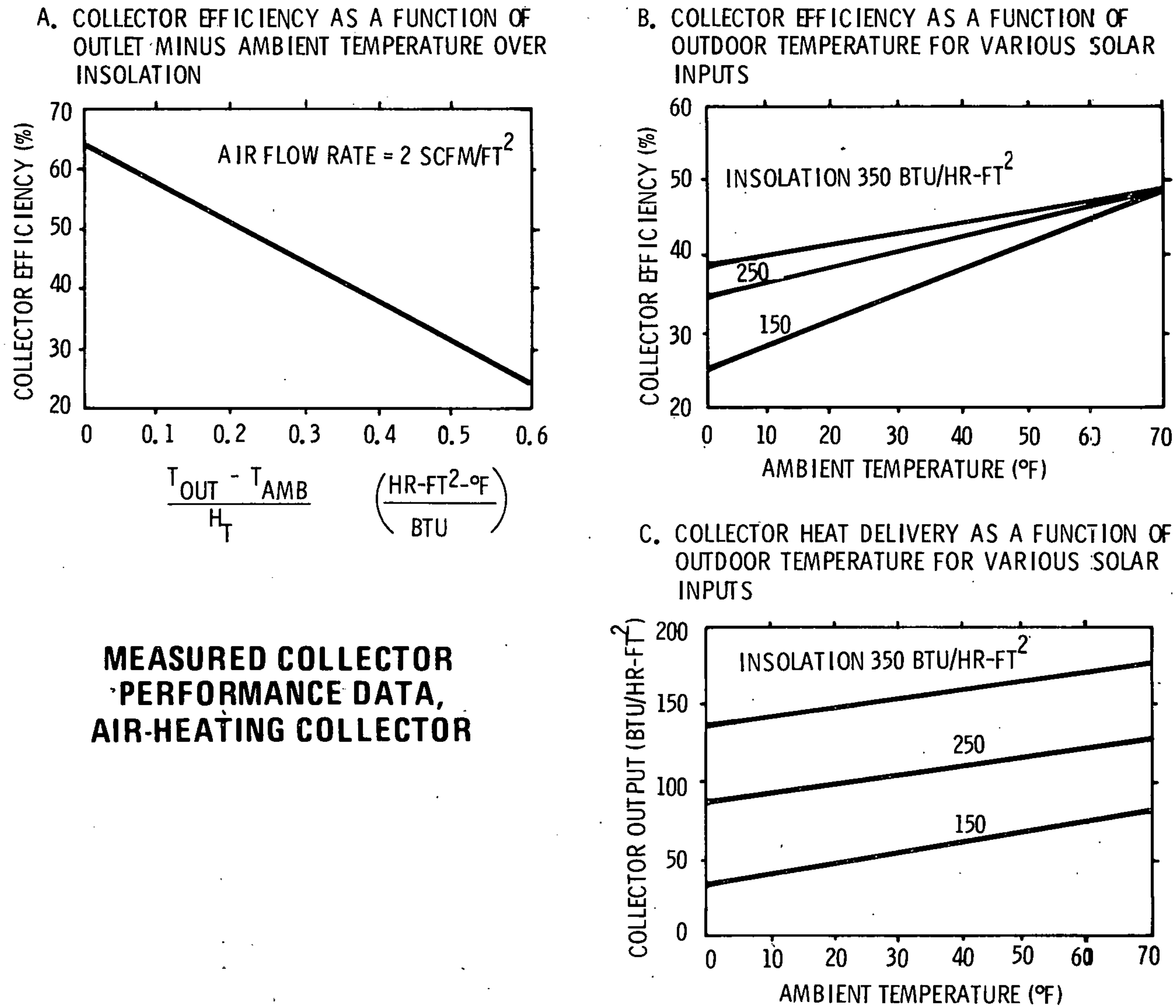


Figure 5-6. Measured Collector Performance Data, Air Heating Collector

For convenience in computing the performance of solar heating systems being designed for specific buildings (Section VI), the efficiency of a solar collector may be correlated with the ratio:

$$\frac{\text{Collector inlet temperature - atmospheric temperature}}{\text{Solar radiation per hour per square foot of surface}}$$

When so correlated, the efficiency of a specific collector is approximately a straight line on a graph having this ratio on one of the scales. Figure 5-7 shows the efficiency of a typical liquid type collector on this basis, and Figure 5-8 contains the results of testing different types of liquid collectors, with efficiency as a function of:

$$\frac{T_{in} - T_{ambient}}{\text{Solar energy rate}}$$

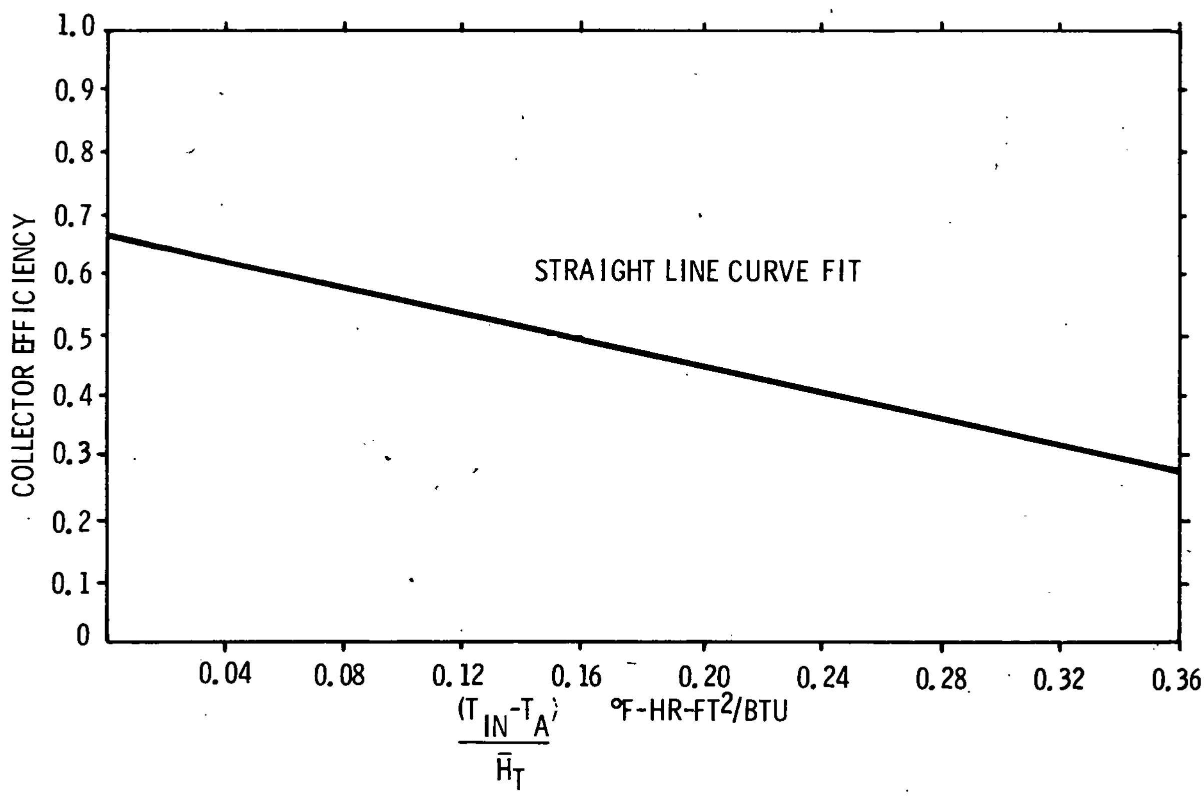


Figure 5-7. Efficiency of a Typical Liquid-Type Collector

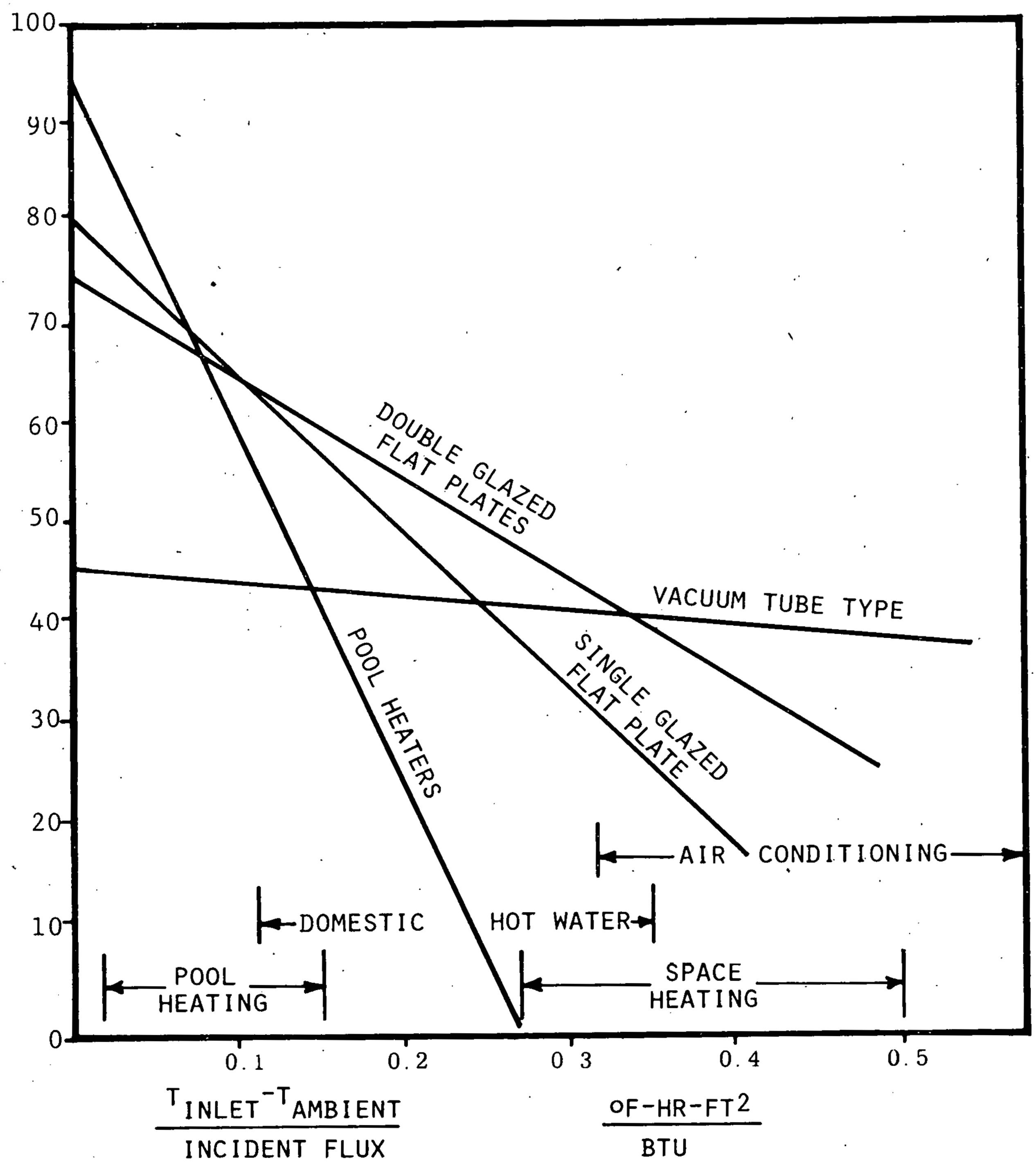


Figure 5-8. Collector Efficiencies of Various Liquid Collectors

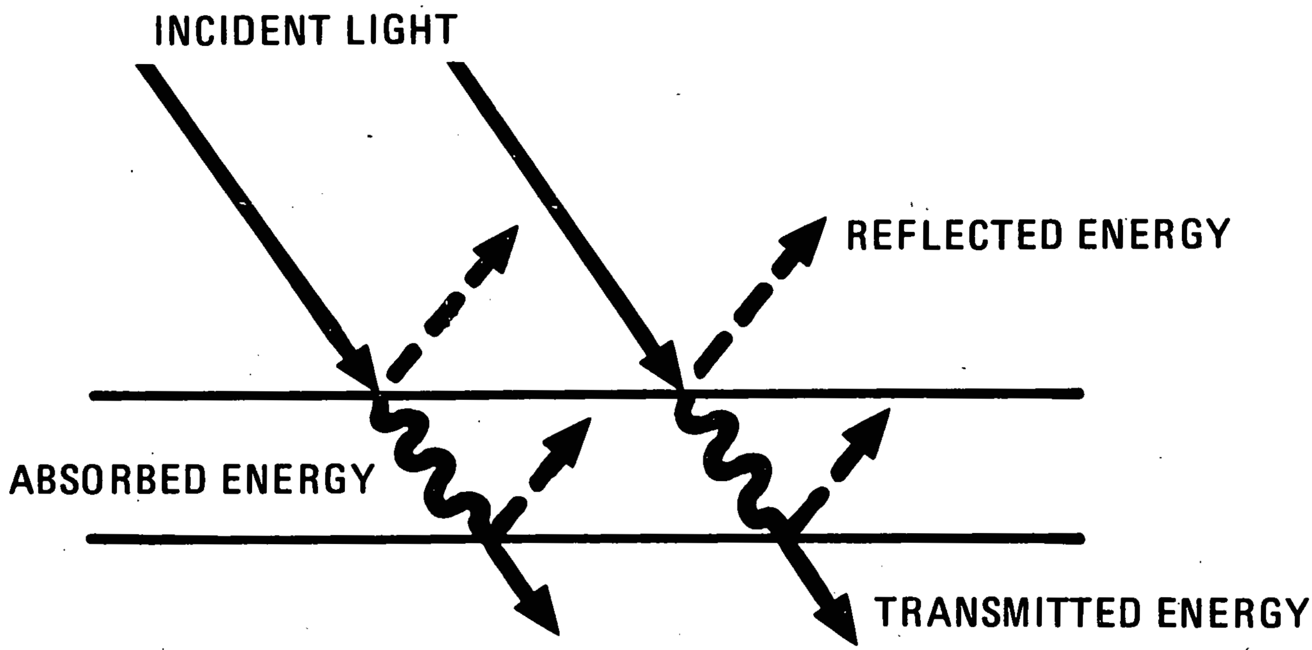
As shown in Section VI, the slope of the efficiency line on a graph of this type, and the point at which the line intersects the vertical axis, may be conveniently used as measures of collector properties and performance in design calculations.

As shown in Figure 5-8 the type and amount of glazing is an important factor in determining the slope and intercept of the efficiency curves. For example, it can be seen that a single glazed collector is superior to double glazed at low temperatures while the opposite is true at high temperatures.

Most solar collectors are glazed with glass although clear and opaque plastics are also used. Some energy does not pass through the glazing because it is reflected and some is absorbed in the glazing material as shown in Figure 5-9. A higher transmittance can be obtained by reducing the iron content of the glass, thereby reducing absorptance. Low iron glass can be obtained with a transmittance of 0. 90. Water white glass, which contains no iron, will transmit 0. 94.

Reflectance can be reduced by using anti-reflective coatings. One such coating involves etching the surfaces of the glass. The resulting increase in transmittance as a function of incidence angle is shown in Figure 5-10.

It is important to obtain the highest possible transmittance because a high transmittance will increase efficiency at all temperatures. The black absorber surface is also an important element in efficiency. Good black paints can be obtained that will absorb up to 0.98 of incident energy. Some energy will be lost by reradiation of energy at a wavelength corresponding to the absorber plate temperature. The emittance of this radiated loss is the same as the absorptance when black paint is used. In other words, up to 0. 98 of the potential loss due to radiation will occur.



TRANSMITTANCE = 1 – REFLECTANCE – ABSORPTANCE

$$\tau = 1 - \rho - a$$

TYPICAL WINDOW GLASS:

$$\tau = 1 - 0.08 - 0.10$$
$$= 0.82$$

Figure 5-9. Losses of Light Transmitted

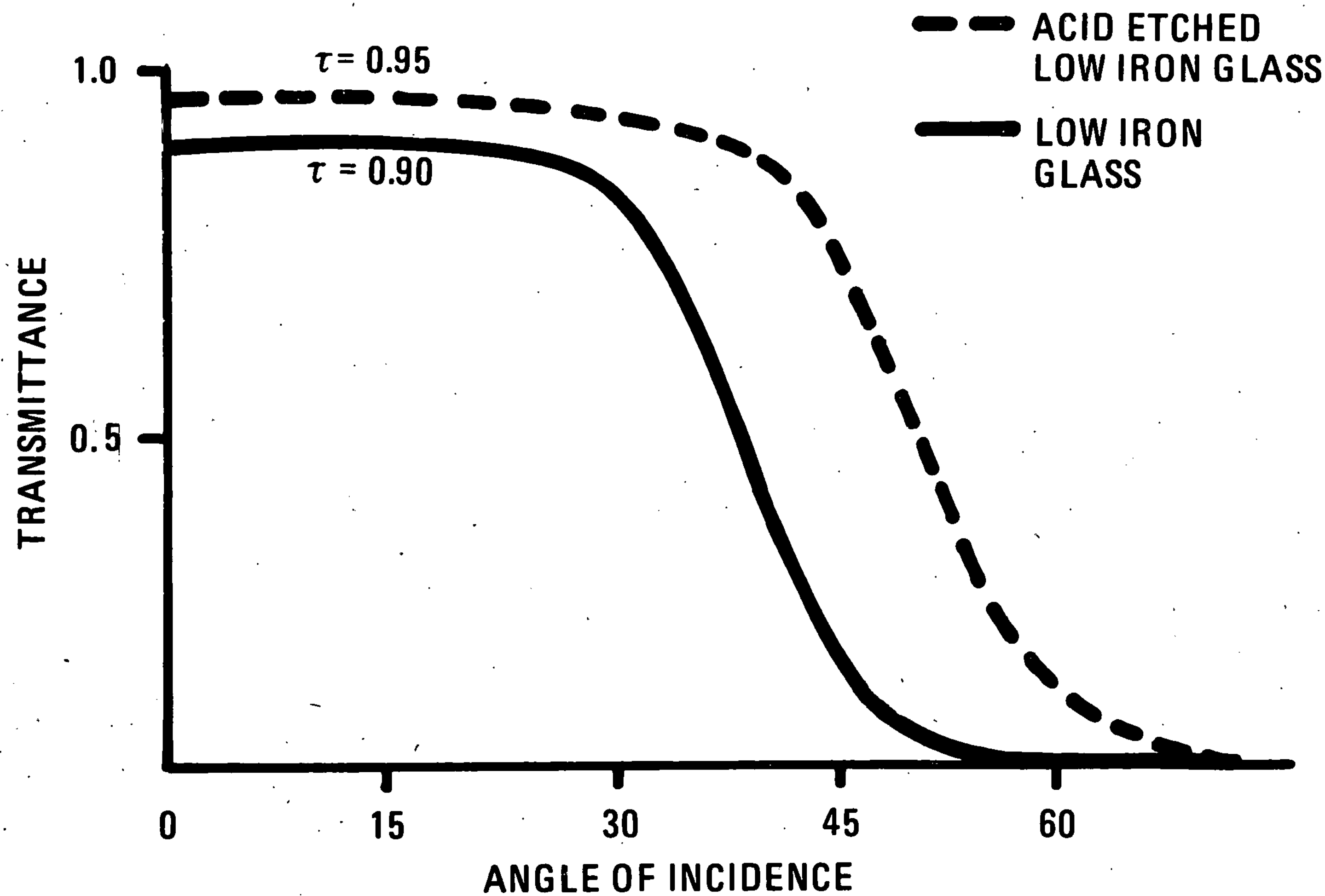


Figure 5-10. Glass Transmittance vs. Angle of Incidence

Selective coatings are available that absorb well in the visible part of the light spectrum but emit poorly at wavelength corresponding to absorber plate temperatures. This is possible by making the coating thin enough so that it has no effect on longer wavelength energy. A typical selective coating, black chrome, is illustrated in Figure 5-11. The effect of a selective coating on efficiency as opposed to black paint is illustrated in Figure 5-12. Since selective coatings do add cost to the collector, it can be seen that they will be cost effective only on high temperature applications.

Liquid-Heating Collectors

Heat is transferred from the hot absorber plate to the heat transport fluid by conduction and convection. In most liquid-heating flat-plate collectors, the liquid flows through tubes that are in good thermal contact with the absorber plate and heat transfer to the liquid is then satisfactory. Because the rate of heat conduction through a 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. The tubes can be either bonded to the plate, or passages can be incorporated into the plate. A prototypical tube-in-plate absorber plate is shown in Figure 5-13.

An alternative method for heat transfer to a liquid in the collector is to trickle the liquid over the absorber plate. The chief disadvantage with this type of collector is that the liquid temperature is limited to about 110°F with reasonable collector efficiency of about 30 percent, and the efficiency drops rapidly with higher fluid temperature. The advantage, on the other hand, with trickle-type collectors is that they are self draining and freeze protection is not needed.

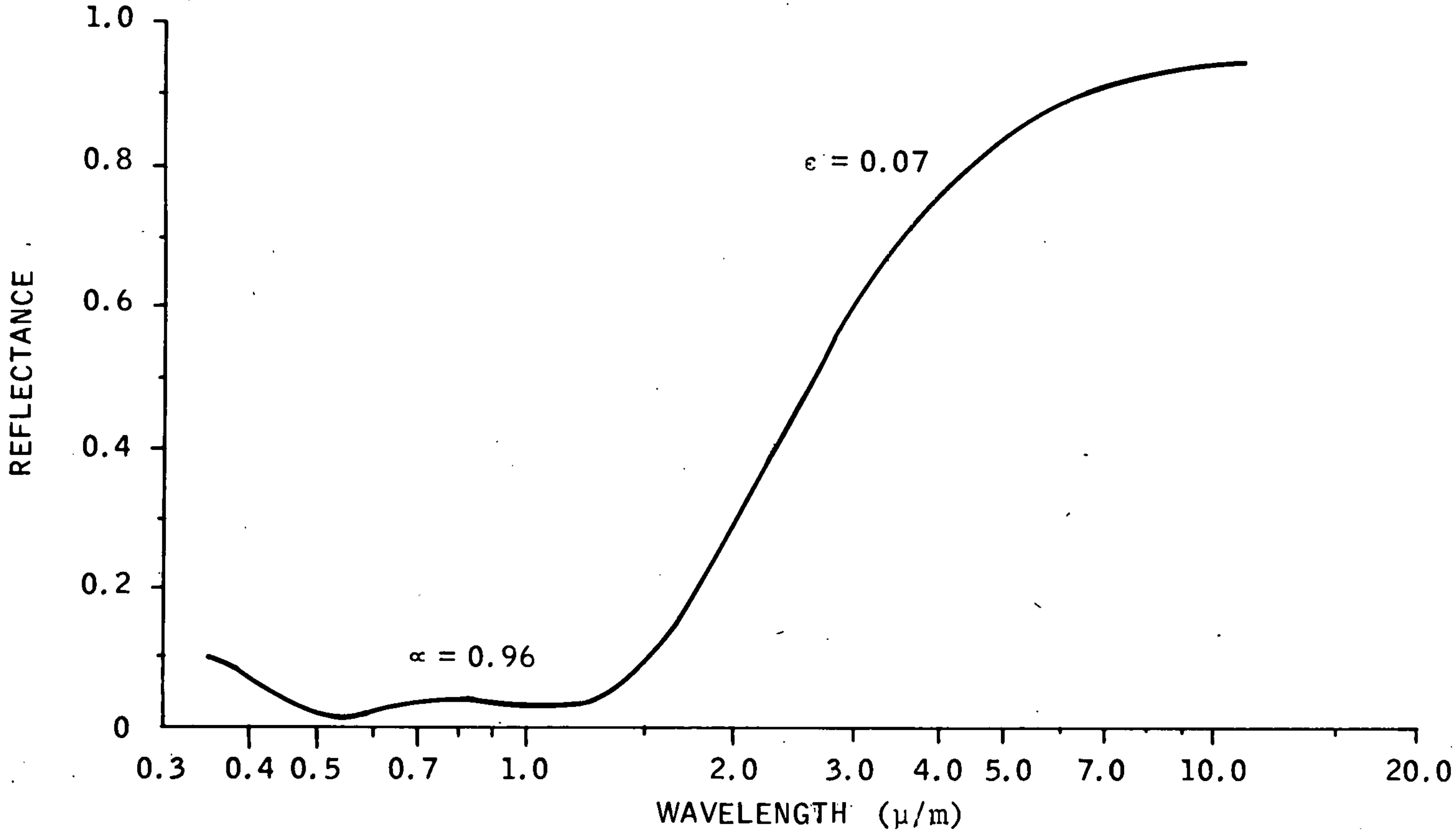


Figure 5-11. Typical Selective Coating, Black Chrome

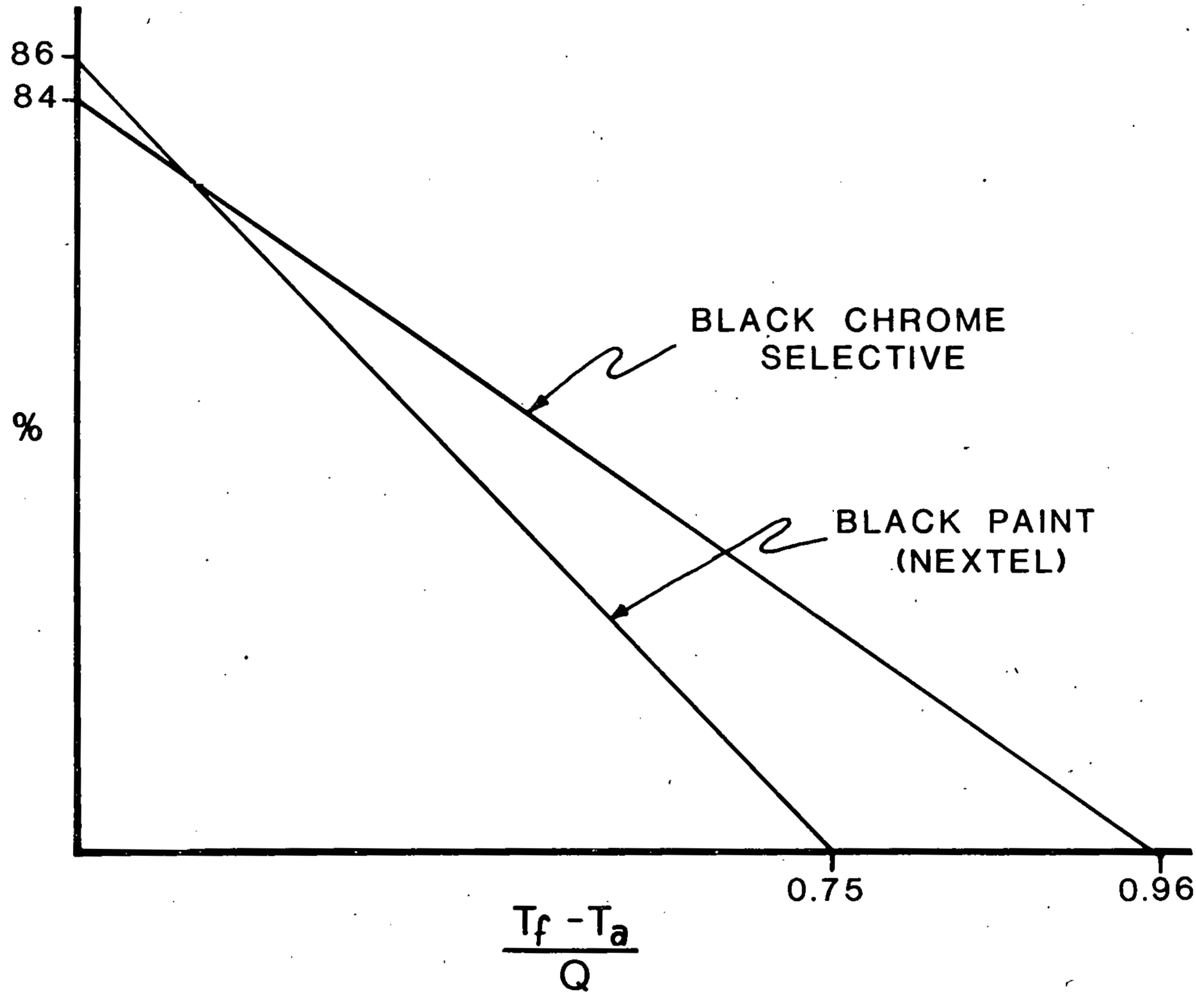


Figure 5-12. Selective Coating vs. Black Paint

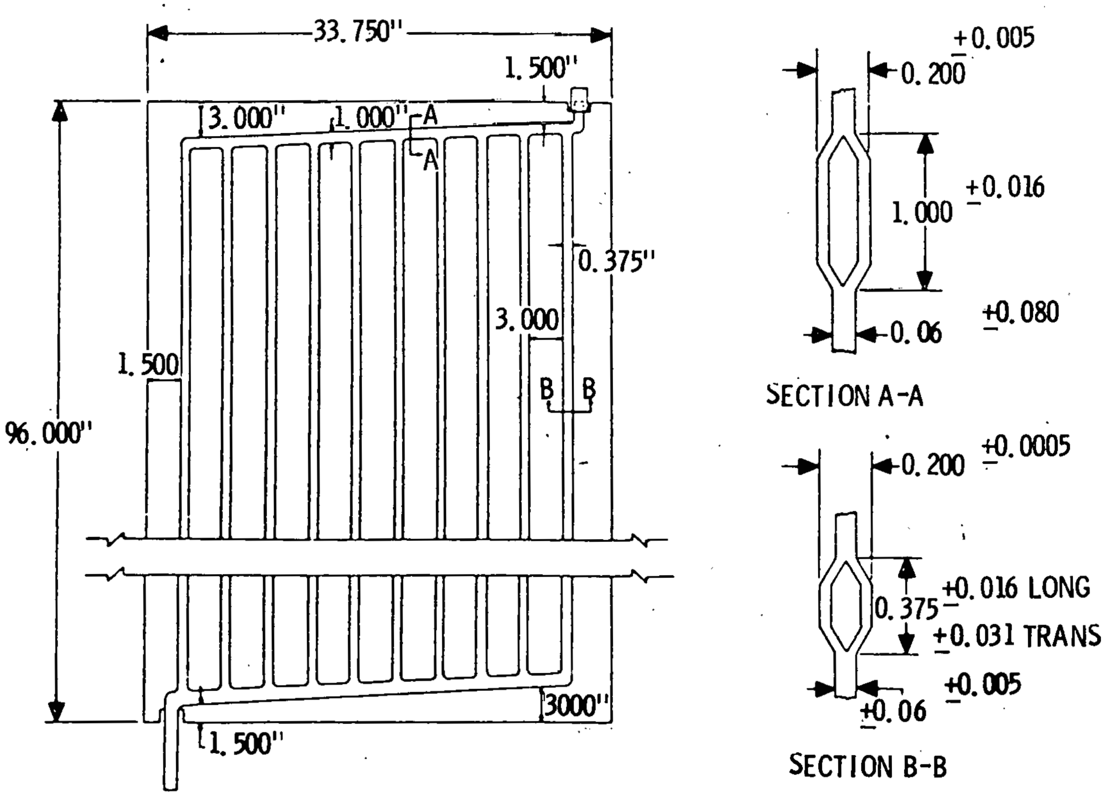


Figure 5-13. Tube Spacing and Dimensions in a Prototypical Liquid-Heating Collector

Freeze Protection -- Water is by far the most economical liquid to use in liquid-heating solar collectors, but is subject to freezing in cold climates, so antifreeze solutions should be added to protect the collector during non-sunshine hours. Ethylene glycol is a satisfactory antifreeze additive and 30 to 40 percent solution will prevent freeze damage to the collectors in most areas of the United States. The addition of ethylene glycol 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 potable water supply) to separate the fluid flowing through the collectors from the water flowing into the heat storage tank as shown in Figure 5-14. A counter-flow heat exchanger will transfer the heat from the collector loop to the storage loop. The volume of liquid in the collector loop will be about 30 gallons for a normal residential installation, while the volume in storage will be about 1000 gallons. Because freeze protection is required only in the collector loop, the quantity of antifreeze needed for a 40 percent concentration would be 12 gallons. If the flow loops were not separated, the cost of the antifreeze that would have to be used throughout the large volume would be prohibitive.

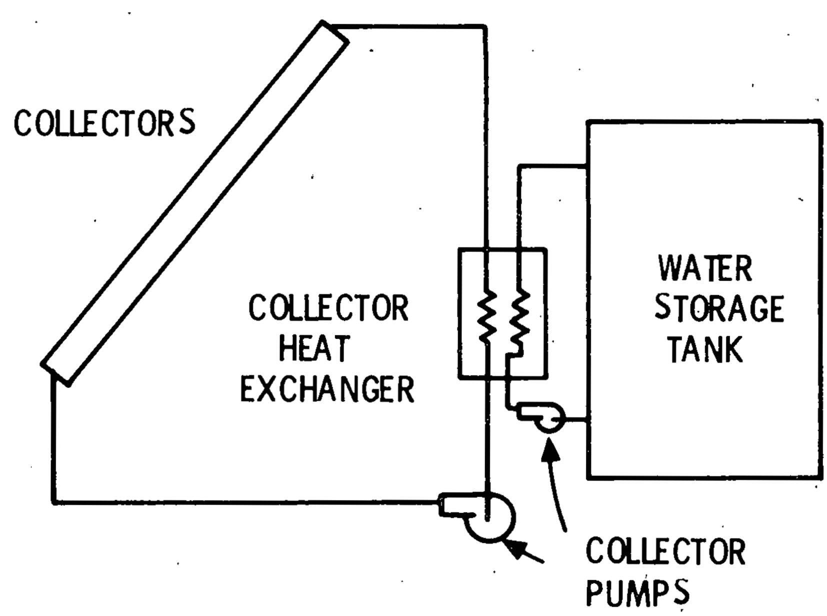


Figure 5-14. Water-Type Solar Space Heating System

An alternative design for freeze protection is an automatic collector 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 total drainage of the collector must be assured without fail.

An important consideration in choosing an antifreeze solution is high temperature stability. The glycols do break down at the high temperatures reached during stagnation requiring periodic inhibiting and replacement. The glycols are also toxic which introduces handling and storage considerations. Some designers are overcoming both of these difficulties by using hydrocarbon oils or silicon fluids. These fluids are more stable at high temperatures but are not as efficient as heat transfer fluids.

Corrosion Protection -- It is advisable to add corrosion inhibitors to the water if the collector absorber plate is aluminum or steel. Automotive-grade ethylene glycol has corrosion inhibitors included in the solution, and with antifreeze concentrations of about 30 percent, additional corrosion inhibitor is not needed. Corrosion inhibitor should be added, however, if an antifreeze additive is used that does not provide for corrosion protection or if pure water is used in the collector loop.

Flow Rates -- The rate of useful heat delivered from the collector is dependent upon the mass flow rate of the fluid through the collector. A mass flow rate of about 0.18 pound per minute of water per square foot of collector, or volumetric flow rate of 0.02 gallon per minute per square foot, is satisfactory. 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 to mid-day and decreases in the afternoon. A lower flow rate than 0.02 gpm per square foot will create a greater temperature rise in the transport fluid and reduction of collection efficiency. A greater flow rate will result in 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 ducts are used instead of the liquid tubing in contact with the absorber plates. Heat transfer to the air then occurs over the entire absorber surface area. Air flow could take place between the lower glass plate and the black absorber surface, that is, over the absorber rather than below it, but that arrangement has the disadvantage of causing greater heat loss through the top covers. It is better to design the collector with the duct below the absorber, even though more material is used, because the collector efficiency is greater. Also, it is easier to construct airtight metal ducts than airtight passages with glass as one surface and metal on the other three sides.

If coupled with a stratified heat storage unit, such as a pebble-bed, the efficiency of air-heating collectors is about equal to liquid-heating flat-plate collectors with a slightly smaller mass flow rate. With 0.15 pound per minute of air per square foot of collector, the volumetric flow rate is about 2 cubic feet per minute per square foot, which has resulted in satisfactory collector efficiencies in operating systems.

There are several advantages of air-heating collectors over water-heating collectors. With air collectors there is no problem with freezing or corrosion. With no corrosion, the collectors have long lifetimes and maintenance is minimal. Minor leaks in the system do not result in damage to the building or its contents, although there is degradation in system performance. Air that is heated in the collector can be circulated directly to heat the building. The disadvantages are a greater storage volume and the lack of an effective space cooling unit operable with hot air.

Concentrating Collectors

Concentrating collectors have not been used much for residential heating and cooling because the higher temperatures obtained have not been necessary and the extra cost of a tracking mechanism makes them cost ineffective. It is possible that the future will see more concentrating collectors used for cooling applications because of the higher efficiencies obtained with solar-powered coolers when driving temperatures are increased. Low cost tracking mechanism and the development of fixed concentrators will enhance this development.

Durability of Collectors

At the present time durability tests have not yet been standardized for solar collectors. Durability is an important consideration in selecting a collector because a long life collector is essential to economic payback. Certain tests can be done and information on results will be supplied by most manufacturers.

The pressure rating of the collector is important. The ability of the collector to withstand roof loads must be known. Hail resistance of the glazing is a consideration. The general ability of the collector material and finishes to withstand weathering is probably the most important consideration.

STORAGE CHARACTERISTICS

The purpose of thermal (or heat storage) in a solar heating and cooling system is to provide heat overnight and over intermittent daytime cloudy periods. The heat must be easily stored from the collectors, readily supplied to the heating and cooling system, have few internal losses or losses to the environment, be inexpensive and not take up an excessive amount of floor space.

There are limitations to storage size for a given collector area. Several factors, the most important of which is cost, dictate that storage should be designed to service an 18- to 30-hour time period.

The two principal storage media, water and rock, are associated with specific types of collection 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. Heat is stored in water with hydronic systems, in a rock bed with air systems. Water has a high capacity for heat storage and, although rocks have one-fifth the heat storage capacity of water or about one-third on a volumetric basis, both are used because they are inexpensive.

Another possible heat storage medium is a chemical that melts at a convenient temperature in the 100 to 150 degree range. These materials store latent as well as sensible heat. That is, they utilize the heat of liquidification as the primary means of storing heat. Large amounts of heat can be stored and released by the process of melting and solidifying without change in temperature. The principal advantage in the use of these materials is smaller storage size. However, there are a number of problems associated with these materials that have not as yet been resolved, and therefore they 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. Thus, the temperature of the entire tank is gradually increased. For nonpressurized tanks, the temperature is limited to slightly below the boiling point of water. A nonpressurized tank should be vented, and the system size should be designed to operate below boiling temperature. A pressurized tank is expensive and should not be considered for a normal residential heating and cooling system.

Water has a specific heat of one Btu per pound per degree Fahrenheit. On a volume basis, water can store one Btu/lb °F x 62.4 lb/ft^3 or 62.4 Btu per cubic foot for each degree Fahrenheit rise in temperature. One thousand gallons, or 134 cubic feet of water in a storage tank, can store about 8360 Btu per °F (134 ft^3 x 62.4 Btu/ft^3 °F) of heat. Thus, if the 1000-gallon tank is at 195°F and the tank is drawn down to 95°F (195°F - 95°F) x 8360 Btu/°F, 736,000 Btu of useful energy would be provided. Suppose a house has a heating load of 16,000 Btu per °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 1 day]. Thus, the storage tank would have sufficient capacity to carry the building load for about 23 hours.

Water storage tanks should be insulated to prevent excessive heat losses. If the tank is located inside the building enclosure, the heat is not lost, but there is uncontrolled heat delivery to a localized region. In summer, the heat from the tank would add to the cooling load. If the tank is located underground, the heat is lost from the solar system.

The minimum useful temperature in a water storage tank for direct heating systems is 90°F. For solar cooling systems, the minimum temperature is about 170°F for a lithium-bromide water absorption cooler. These lower temperatures and the boiling temperature are the limits which determined the useful ranges for temperatures and are used to determine the tank size for the system.

Rock Bed Storage

Heat is stored in a rock bed by circulating heated air from the collectors directly through the rock bed. In contrast to the water storage tank, the rock bed is not heated uniformly, but is heated in layers nearly to the temperature of the air stream coming from the collector. This results in temperature stratification (Figure 5-15), where the inlet end of a rock bed (usually the top) is close to the collector air temperature and the outlet end, or bottom of the rock bed, is at room temperature. The advantages in stratification are that cool air is returned to the collector from the bottom of storage so that the collector operates more efficiently; when heating the house from storage at night, the air temperature always is high--being nearly at the same temperature as it was delivered from the collector during the day. In contrast, the water storage temperature is nearly uniform throughout the tank and the temperature of water returning to the collector is about the same as the water temperature delivered to the heat exchanger to heat the rooms.

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 rock sizes. This is about one-third the heat capacity of water per cubic foot of volume. Thus, to have the same heat storage capacity as the water tank, the 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 temperatures as low as room temperature, about 70 degrees, is 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 14°F average ambient temperature, there is enough heat stored to supply the equivalent of 19 hours.

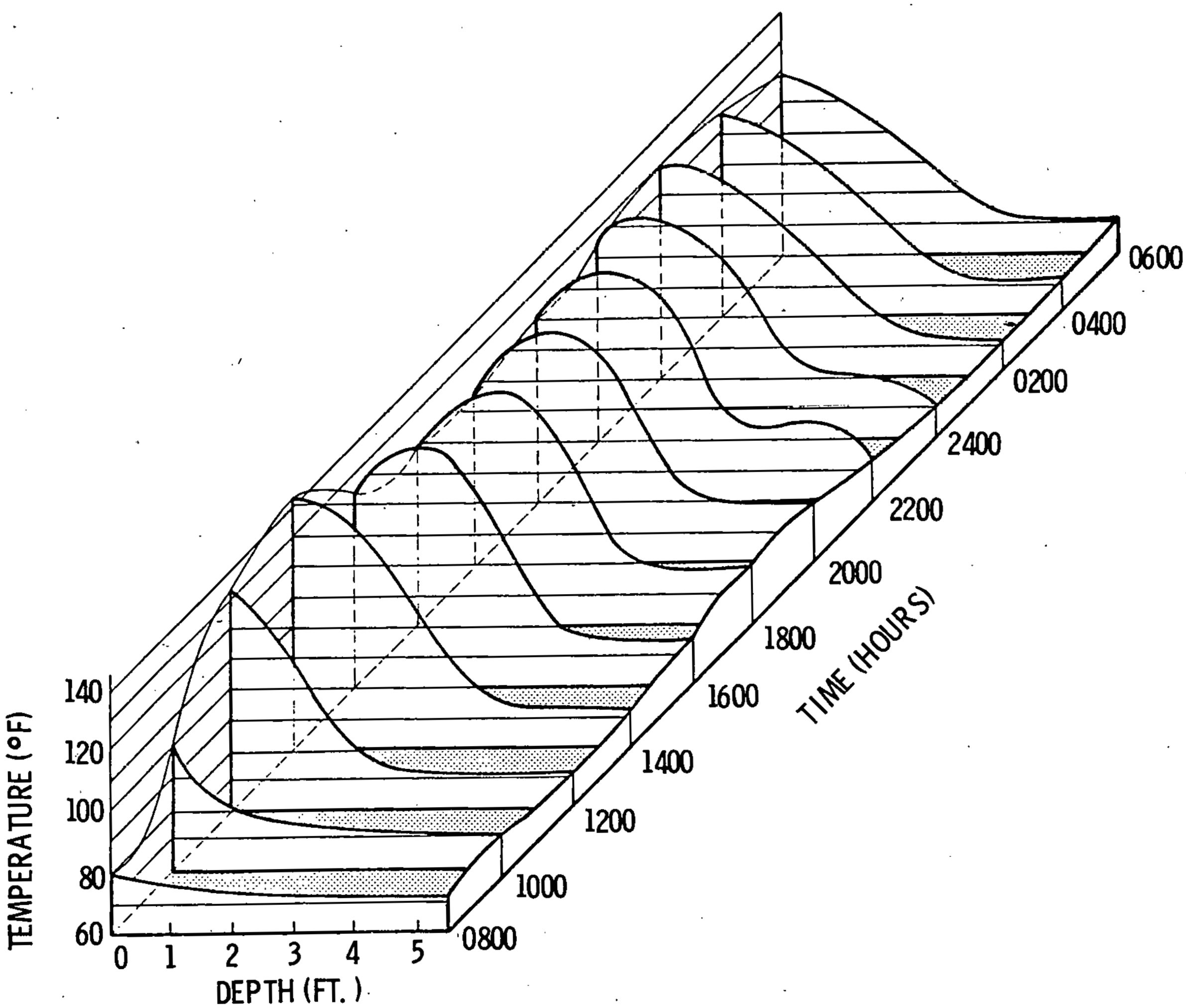


Figure 5-15. Propagation of Pebble-Bed Temperature Profile (During Heat Storage Charge-Discharge Cycle), 7-8 February 1976

SECTION VI
DETERMINING SOLAR SYSTEM THERMAL PERFORMANCE AND ECONOMIC FEASIBILITY

INTRODUCTION

The performance of any solar-heating system must be related to the climatological conditions that prevail at the prospective site, the end use of the energy, and the specific system design and control strategy. Only generalized computer simulation programs are flexible enough to accurately predict the performance of any conceivable solar-heating system. These programs require hour-by-hour meteorological data and the resulting performance predictions apply only over the time period of the data.

By specifying the details of the system used to collect solar energy and by specifying the end use, simplified design procedures can be derived. The f-chart method described below can be used to predict the performance of "standard" solar systems that provide energy for space heating and domestic hot-water heating. F-charts are available for two "standard" systems. Figure 6-1 shows the "standard" active solar-heating system using liquid as the heat transfer fluid; Figure 6-2 is the analogous system using air as the transfer fluid. Currently only the performance of these systems using flat-plate collectors can be obtained with f-charts.

In order to use the f-charts, meteorological data in the form of long-term monthly average values of total solar radiation, degree-days and ambient temperature are required. This data is tabulated for 122 locations in the U.S. in Section II. Solar radiation data for other locations can be processed as described in "Calculation of Monthly Average Insolation on Tilted Surfaces," by S. A. Klein, to be published in the Solar Energy Journal.

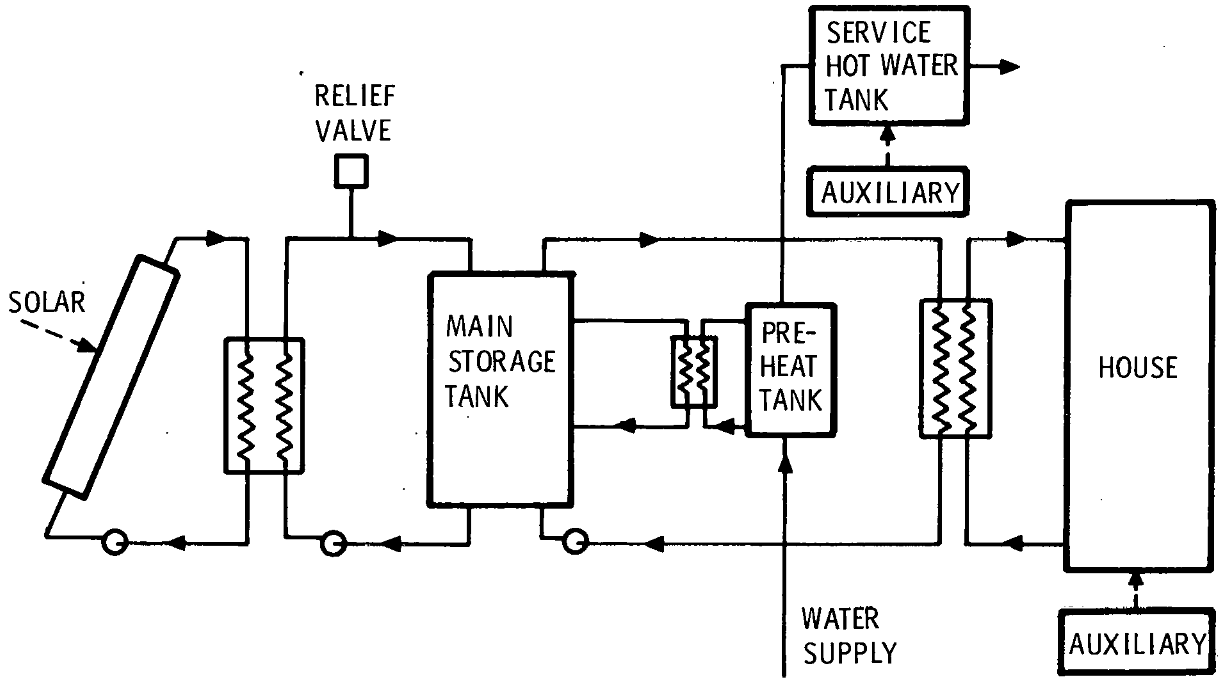


Figure 6-1. Schematic Diagram of a Liquid-Based Solar Space and Water Heating System

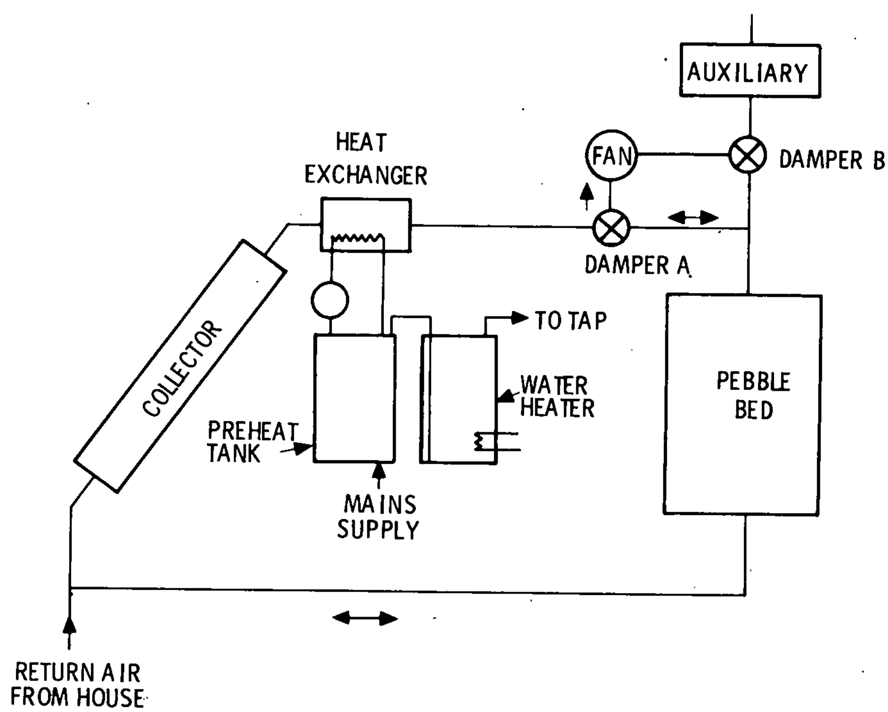


Figure 6-2. Schematic Diagram of an Air-Based Solar Space and Water Heating System

The systems shown in Figures 6-1 and 6-2 are generally considered the most practical air and liquid-based solar-heating systems currently available. After many computer simulations, experiments, and years of practical experience, several rules of thumb in the design of these systems have been suggested (Table 6-1). They are to be used only as general guidelines since component or solar system manufacturers may have their own recommendations. The terminology used in this table will be fully explained in later sections.

USING THE f-CHART METHOD TO PREDICT THERMAL PERFORMANCE

General Procedure

To predict the thermal performance of the solar heating systems in Figures 6-1 or 6-2, two-dimensionless parameters hereafter referred to as X and Y must be calculated for each month. Then f, the fraction of the monthly energy demand supplied by solar energy, can be obtained from graphs. Knowing f and the energy demand for each month, $\mathcal{F}_g$ the fraction of the annual energy demand supplied by solar energy can be calculated.

Several worksheets have been prepared to organize the required calculations. Worksheets labeled TA have to do with the thermal analysis, those prefaced with EA are for the economic analysis. Worksheet TA-1 should be used to calculate the monthly total-energy demands on the solar-heating system. The remaining items which combine to form X and Y are conveniently organized on Worksheet TA-2. The fraction of the total heating load supplied by solar energy for several collector areas can be tabulated on Worksheet TA-3.

Table 6-1. Rules of Thumb

Solar Liquid Heating Systems (Figure 6-1)	
Collector Flow Rate	$0.02 \times \left(\frac{C_p \text{ of Storage liquid}}{C_p \text{ of Collector liquid}} \right)$ gpm/ft^2 of collector
Collector Slope	(Latitude + 15°) ± (15°)
Water Storage Tank Size	1.25 - 2.5 gallons/ft^2 of collector
Pressure Drop Across Collector	0.5 - 10 psi/collector module
Load Heat Exchanger	$1 < \frac{\varepsilon_L (\dot{m}C_p)_{min}}{UA} < 5$
Collector Heat Exchanger	$F_R'/F_R > 0.9$
Solar Air Heating Systems (Figure 6-2)	
Collector Flow Rate	2-5 CFM/ft^2 of collector
Collector Slope	(Latitude + 15°) ± (15°)
Pebble Bed Storage Size	0.5 - 1.0 ft^3 of rock/ft^2 of collector
Rock Depth	4-8 ft in air flow direction
Pebble Size	3/4" - 1-1/2" dia round washed river rock screened to uniform size
Pressure Drops:	
Pebble-bed	0.1 - 0.3 in. W. G.
Flat plate collector (12-14 ft. lngth)	0.2 - 0.3 in. W. G.
Flat plate collector (18-20 ft. lngth)	0.7 - 0.8 in. W. G.
Ductwork	0.08 in. W. G. /100 ft. duct lngth
Insulation on duct exposed to unconditioned spaces	1 in. fiberglass minimum
Solar Domestic Hot-Water Heating Systems (Figures 6-1 and 6-2)	
Pre-Heat Tank Size	1.5 - 2.0 times conventional water heater size
Air-Water Coil Size (Figure 6-2)	$0.2 < \varepsilon < 0.5$
Water-Water Coil Size (Figure 6-1)	$0.5 < \varepsilon < 0.8$

The parameter X represents the ratio of solar collector energy losses at a reference operating condition, to the total system heating demand. Y is the ratio of solar energy absorbed by the collector to the total system heating demand. These ratios are calculated for each month of the year. In equation form:

$$X = \frac{F_R' U_L A(T_{ref} - \bar{T}_a)\Delta\tau}{L} = F_R U_L \left[\frac{F_R'}{F_R}\right] \frac{A(T_{ref} - \bar{T}_a)\,\Delta\tau}{L}$$

$$Y = \frac{F_R' (\overline{\tau\alpha})\, A H_T}{L} = F_R(\tau\alpha)_n \left[\frac{F_R'}{F_R}\right]\left[\frac{\bar{\tau}}{\tau_n}\right]\left[\frac{\bar{\alpha}}{\alpha_n}\right] \frac{A H_T}{L}$$

where

1) $F_R U_L$ and $F_R\,(\tau\alpha)_n$ are from flat plate collector manufacturer's specification sheets.

2) F_R'/F_R is the collector-tank heat exchanger performance penalty.

3) A is the collector area.

4) T_{ref} is 212°F.

5) $\bar{T}_a$ is the average ambient temperature for the month and location from Section II.

6) $\Delta\tau$ is the number of hours in the month.

7) L is the sum of the space heating and domestic hot water energy requirements over the month.

8) $\bar{\tau}/\tau_n$ is 0.95 for near optimum collector orientations.

9) $\bar{\alpha}/\alpha_n$ is 0.95 for near optimum collector orientations.

10) H_T is the solar radiation incident on the collector from Section II.

The following sections explain how to fill in Worksheets TA-1, TA-2 and TA-3. The text tells how to calculate or obtain each of the items which make up X and Y.

Worksheet TA-1

The monthly energy demand (L) is the sum of space heating and domestic water heating requirements. The space heating load (SHL) can be estimated as follows:

$$SHL = (24)(UA)(\text{degree days}) \ [\text{Btu}]$$

where

$$UA = \frac{\text{Design heat loss rate}}{\text{Design temp. difference}} \ \left[\frac{\text{Btu}}{\text{hr}\,^\circ\text{F}}\right]$$

Degree days from Section II (or ASHRAE guide)

The design heat loss rate is calculated in the conventional manner with indoor and outdoor design temperatures as recommended by ASHRAE or required by code.

The domestic water heating load (DWL) is estimated as follows:

$$DWL = (\text{demand})(\text{specific heat of water})(T_{supply} - T_{main})$$

Assuming water is supplied to the taps at 140°F and main or well water enters the system at 55°F, this equation simplifies to:

$$DWL = (\text{gal/day})\ (706\ \text{Btu/gal})\ (\text{days/month}) \ [\text{Btu}]$$

then

$$L = SHL + DWL \ [\text{Btu}].$$

WORKSHEET TA-1

HEATING LOADS

$UA = \frac{\text{Design SHL=}}{\text{Design } \Delta T\text{=}}$ ______________________ = ______________________ [Btu/hr - °F]

Water Usage = ____________ [gal/day]

Month	Heating Degree Days [°F-day]	SHL [Btu] (1)	DWL [Btu] (2)	L [Btu] (3)
Jan				
Feb				
Mar				
Apr				
May				
Jun				
Jul				
Aug				
Sep				
Oct				
Nov				
Dec				
Total				

(1) SHL = (24)(UA)(Degree-Days from Section III)

(2) DWL = (gal/day usage)(706 Btu/gal)(days per month)

(3) L = SHL + DWL

Worksheet TA-2

Lines A and B -- F_RU_L and $F_R(\tau\alpha)_n$ are parameters which characterize the performance of flat-plate collectors. They are obtained from plots of collector efficiency (η) versus collector inlet temperature minus ambient temperature divided by incident solar radiation (i.e. $(T_{in} - T_a)/H_T$). The plots are straight-line fits of experimental data and should be supplied by the collector manufacturer. The experimental data must be taken for the collector flow rate with which your system will operate. As seen in the sample plot in Figure 6-3, $F_r(\tau\alpha)_n$ is the η-axis intercept and F_RU_L is the slope.

For an air-type collector, the efficiency data is often presented in a different format than water type collectors. If an air system is being simulated, a correction to the collector efficiency slope and intercept must be made. A detailed explanation of this correction is presented on pages 6-57 through 6-58.

F_R'/F_R is a factor which accounts for the performance penalty due to the heat exchanger between the collector and water storage tank in liquid-based systems like the one in Figure 6-1. The value of F_R'/F_R can be obtained from Figure 6-4 if $(\dot{m}C_p)_c/(F_RU_LA)$ and $\epsilon_c(\dot{m}C_p)_{min}/(\dot{m}C_p)_c$ are known.

$(\dot{m}C_p)_c$ is the mass flow rate times the specific heat of the fluid flowing through the collector. $(\dot{m}C_p)_{min}$ is the mass flow rate times the specific heat of either the collector fluid or the tank side heat exchanger fluid, depending on which is smallest. A is the collector area and ϵ_c is the effectiveness of the heat exchanger. Knowing the fluids and flow rates to be used on both sides of the heat exchanger and the size of the heat exchanger, ϵ_c can be calculated from relations given in Chapter 2 of the 1972 ASHRAE Handbook of Fundamentals. A typical value of ϵ_c is approximately 0.7. Exact values can be obtained from manufacturers heat exchanger data.

When designing a system it is easiest to choose an allowable heat exchanger penalty (e.g., $F_R'/F_R = 0.9$); use Figure 6-4 to determine ϵ_c and go to manufacturer's specification data to select the heat exchanger. Several values of F_R'/F_R can be tried, and using f-chart and the companion economic analysis, an economic heat exchanger size can be determined.

WORKSHEET TA-2

ITEMS MAKING UP X AND Y

A. $F_R U_L (F_R'/F_R)$ = ________________.

B. $F_R (\tau\alpha)_n (F_R'/F_R)$ = ________________.

	C1	C2	C3	C4	C5	C6	C7	C8
	L (1)	$(T_{ref}-\bar{T}_a)$ (2)	$\Delta\tau$	$\frac{(C2)(C3)}{(C1)}$	$\bar{\tau}/\tau_n$ (3)	$\bar{\alpha}/\alpha_n$ (4)	H_T (5)	$\frac{(C5)(C6)(C7)}{(C1)}$ $(\frac{days}{mo.})$
Jan			744					
Feb			672					
Mar			744					
Apr			720					
May			744					
Jun			720					
Jul			744					
Aug			744					
Sep			720					
Oct			744					
Nov			720					
Dec			744					

(1) L from Worksheet TA-1

(2) T_{ref} is 212°F, $\bar{T}_a$ from Section III

(3) $\bar{\tau}/\tau_n$ is .95 for near optimum collector orientations

(4) $\bar{\alpha}/\alpha_n$ is .95 for near optimum collector orientations

(5) from Section II

(6) Column C8 is the number (C5) x (C6) x (C7) x (days per month)/(C1)

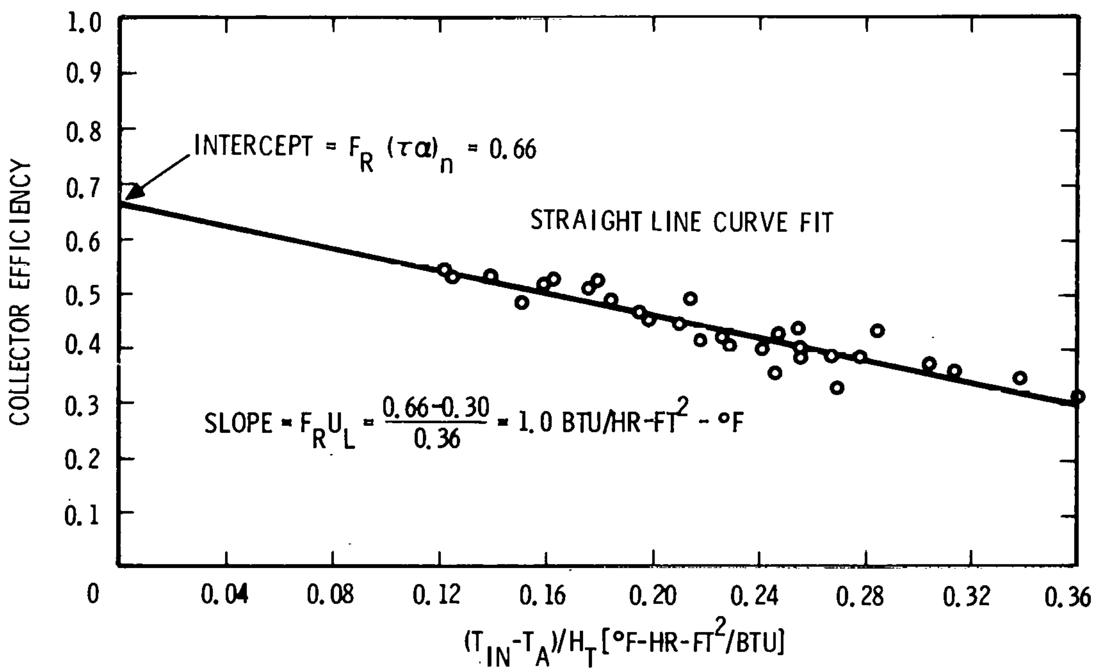


Figure 6-3. Experimental Collector Performance

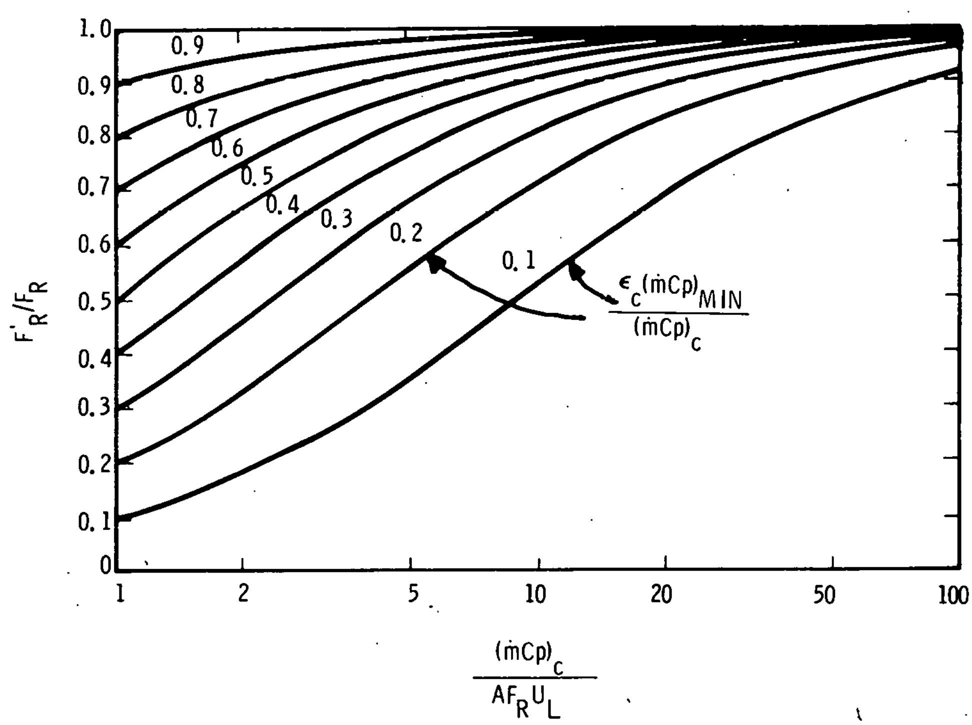


Figure 6-4. Collector Heat Exchanger Correction Factor

$F_R'/F_R = 1$ for air systems or liquid based systems that drain the collectors at night, since no heat exchanger is used between the collector and storage unit.

Column 1 -- Transcribe the monthly energy demands, L, from Worksheet TA-1.

Column 2 -- T_{ref} is 212°F. $\bar{T}_a$ is obtained from Section II.

Column 5 -- $\bar{\tau}/\tau_n$ is the ratio of the monthly average collector cover transmittance to the transmittance at normal incidence. For collectors facing due south and tilted at angles between the latitude and the latitude plus 20°, $\bar{\tau}/\tau_n = 0.95$ is a good approximation. For more extreme orientations $\bar{\tau}/\tau_n = 0.90$ is usually conservative although there are cases where the ratio is lower.

Column 6 -- $\bar{\alpha}/\alpha_n$ is the ratio of the collector surface solar absorptance to the solar absorptance at normal incidence. Experimental data quantifying the effect of angle of incidence on the collector plate solar absorptance is presently not available. Although it is not expected that selective and non-selective coatings are affected in the same way, for most collector orientations $\bar{\alpha}/\alpha_n = 0.95$ can be used as a conservative approximation for both coatings.

Column 7 -- Long term average values of solar radiation incident on collector surfaces of various orientations are tabulated in Section II.

Column 8 -- Product of (C5) by (C6) by (C7) by the number of days in each month divided by (C1).

Worksheet TA-3

Worksheet TA-3 is used to summarize the f-chart performance predictions. Room is available for three different collector areas. The dimensionless parameters X and Y, which describe the system, are calculated as:

X = (Column 4, Worksheet TA-2)(Line A, Worksheet TA-2)
(Collector area)

WORKSHEET TA-3

	L (1)	X (2)	Y (3)	Corrected X (4)	Corrected Y (5)	Area = ____ f (6)	fxL (7)	Area = ____ f (6)	fxL (7)	Area = ____ f (6)	fxL (7)
Jan											
Feb											
Mar											
Apr											
May											
Jun											
Jul											
Aug											
Sep											
Oct											
Nov											
Dec											
total						total		total		total	

Annual Fraction by Solar = (total, column 7)/(total, column 1) = ________ = ________ = ________

(1) L from Worksheet TA-1

(2) X = (TA-2, Column 4)(TA-2, line A)(Collector Area)

(3) Y = (TA-2, Column 8)(TA-2, line B) (Collector Area)

(4),(5) Corrected X and Y accounting for storage size, load heat exchanger size or collector flow rate

(6) f from Figure 8 or 9

Y = (Column 8, Worksheet TA-2)(Line B, Worksheet TA-2)
(Collector area)

for each month.

If the system being analyzed is liquid-based as in Figure 6-1, X and Y have been calculated assuming a certain size storage unit and load heat exchanger. The default storage size is two gallons of water per square foot of collector. For different sized storage units, X for each month must be adjusted as follows:

$$X = X_o \left(\frac{X}{X_o}\right)$$

where

X_o = the old value of X

$\left(\frac{X}{X_o}\right)$ from Figure 6-5.

The default heat exchanger is sized so that $\epsilon_L(\dot{m}C_p)_{min}/UA = 2$ where ϵ_L is the effectiveness of the load heat exchanger. $(\dot{m}C_p)_{min}$ is the mass flow rate times specific heat of either the storage tank side fluid or the load side fluid, whichever is smaller. UA has been calculated on Worksheet TA-1. For different sized heat exchangers, Y for each month must be modified as follows:

$$Y = Y_o \left(\frac{Y}{Y_o}\right)$$

where

Y_o = the old value of Y

$\left(\frac{Y}{Y_o}\right)$ from Figure 6-6.

ϵ_L can be calculated with the relations given in Chapter 2 of the 1972 ASHRAE Handbook of Fundamentals.

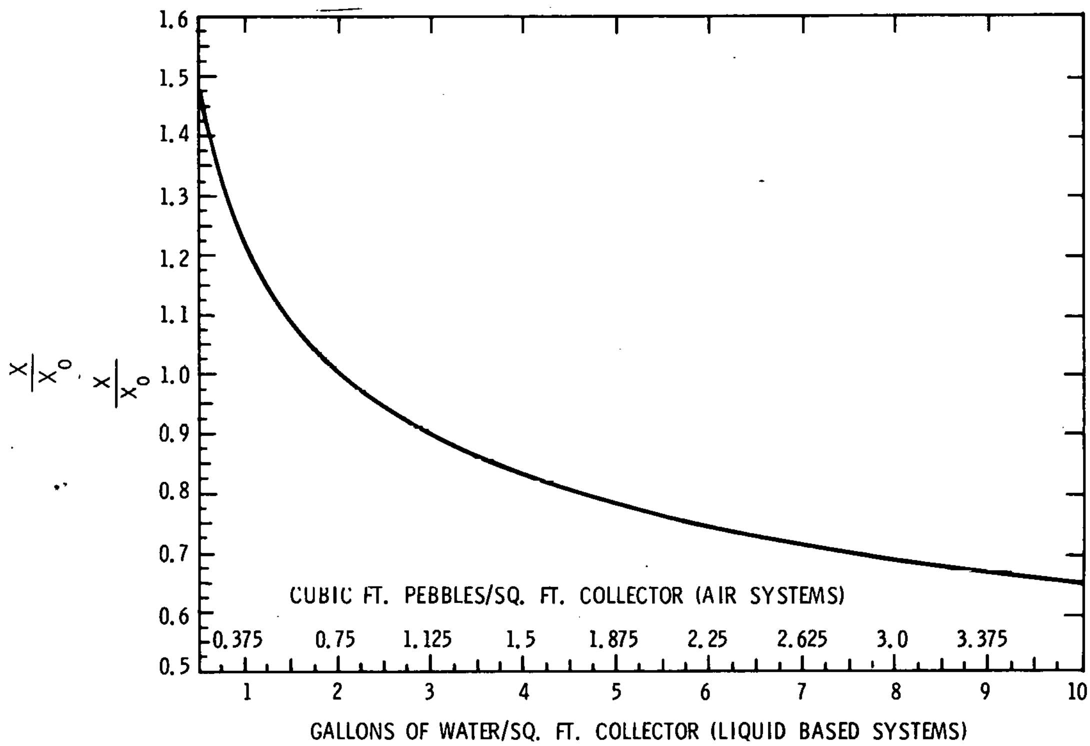


Figure 6-5. Storage Size Correction Factor

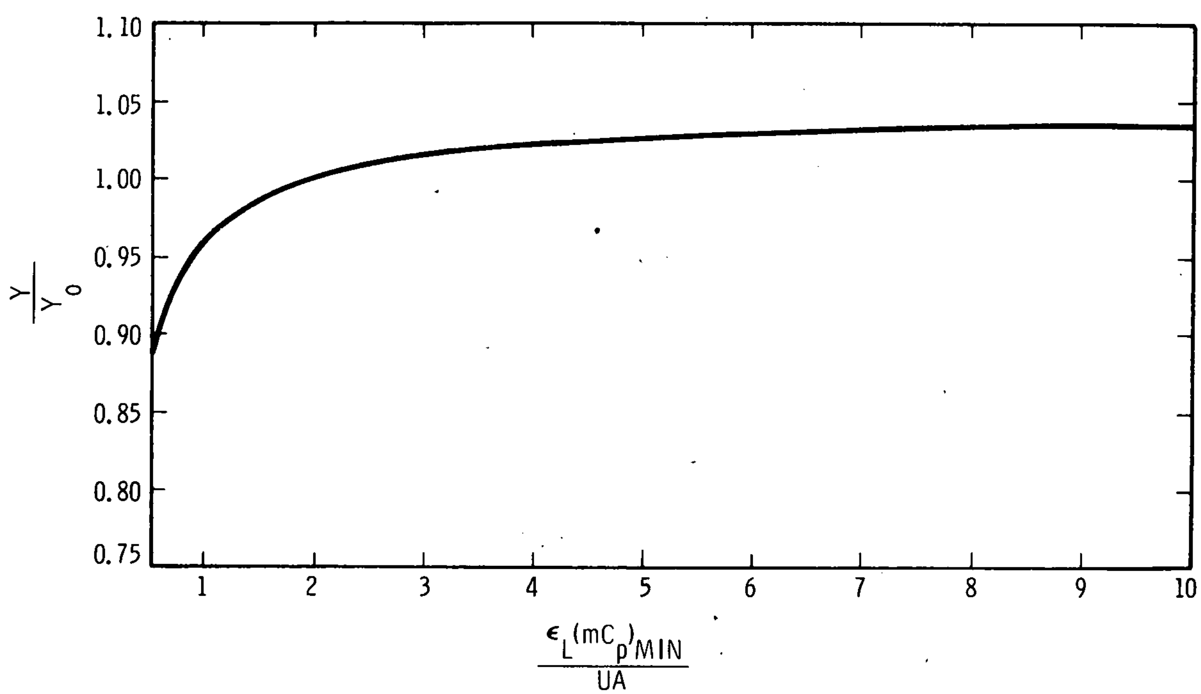


Figure 6-6. Load Heat Exchanger Correction Factor

If the system being analyzed is an air heating system as in Figure 6-2, X and Y have been calculated assuming a certain size storage unit and collector flow rate. The default storage size is 0.75 cubic feet of pebbles per square foot of collector. For different storage sizes correct X each month as

$$X = X_o \left(\frac{X}{X_o}\right)$$

where

X_o = the old value of X

$\left(\frac{X}{X_o}\right)$ from Figure 6-5.

The default value of collector flow rate is 2 SCFM per square foot of collector. For other flow rates, correct X as follows:

$$X = X_o \left(\frac{X}{X_o}\right)$$

where

X_o = the old value of X

$\left(\frac{X}{X_o}\right)$ from Figure 6-7.

Space is available on Worksheet TA-3 for both X and Y and the corrected values of X and Y. Using the corrected values in Figure 6-8, for liquid systems, and Figure 6-9, for air systems, yields f, the fraction of the load supplied by solar energy for the month.

The monthly loads can be transcribed from Worksheet TA-1. Then the energy supplied by the solar system each month can be calculated as f x L. The ratio of the annual energy supplied by solar to the annual load can then be expressed as

$$\mathcal{F}_g \text{ annual load fraction by solar} = \frac{\sum_{i=1}^{12} f_i \times L_i}{\sum_{i=1}^{12} L_i}$$

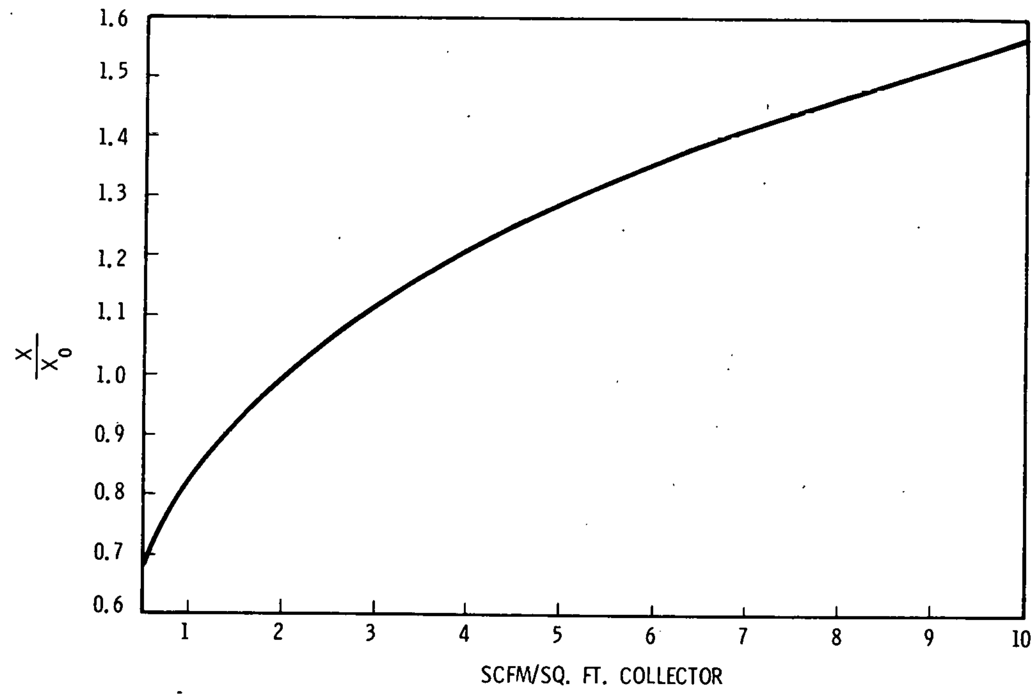


Figure 6-7. Collector Air Flow Rate Correction Factor

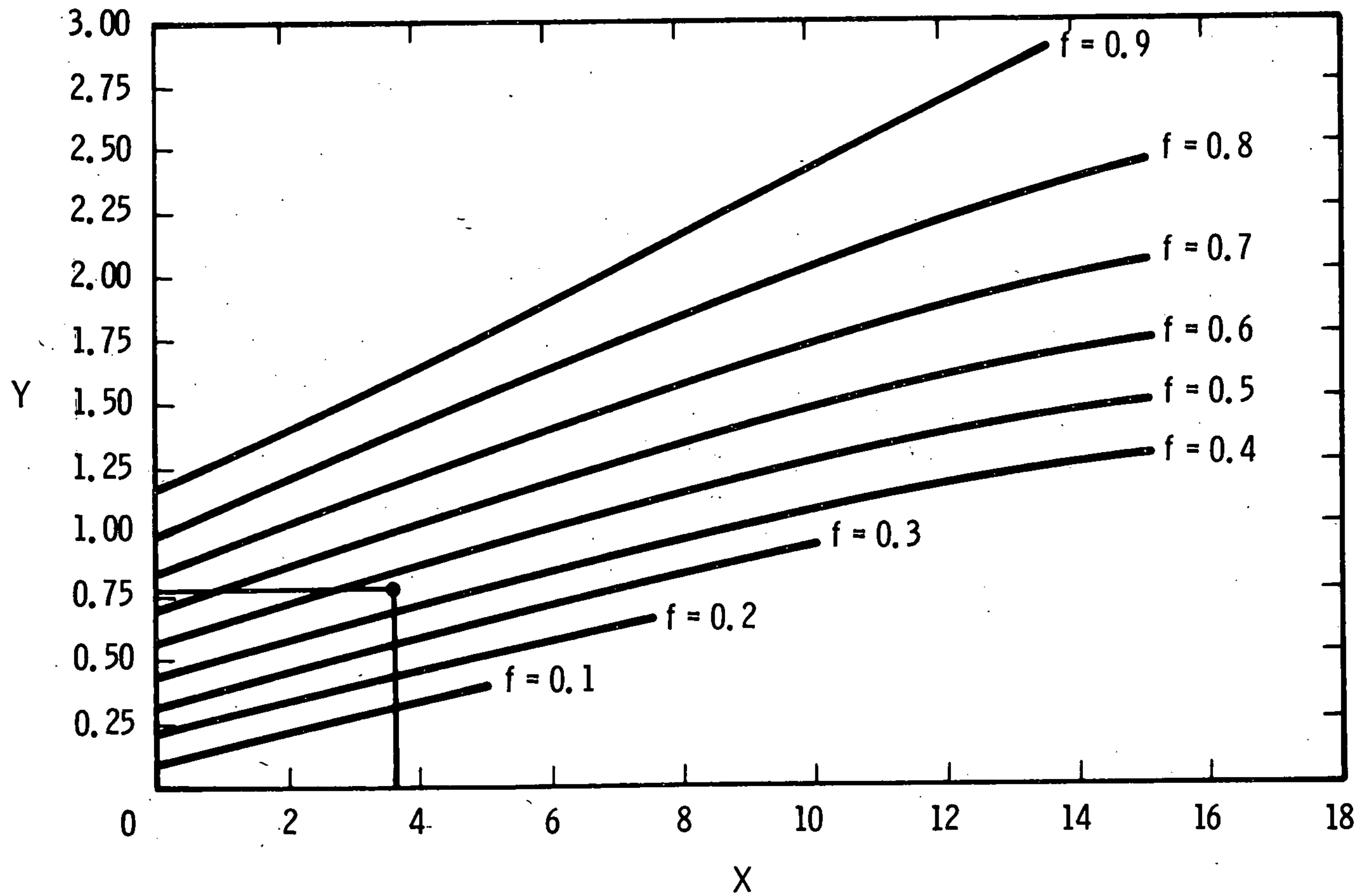


Figure 6-8. f - Chart for Liquid-Based Solar Heating Systems

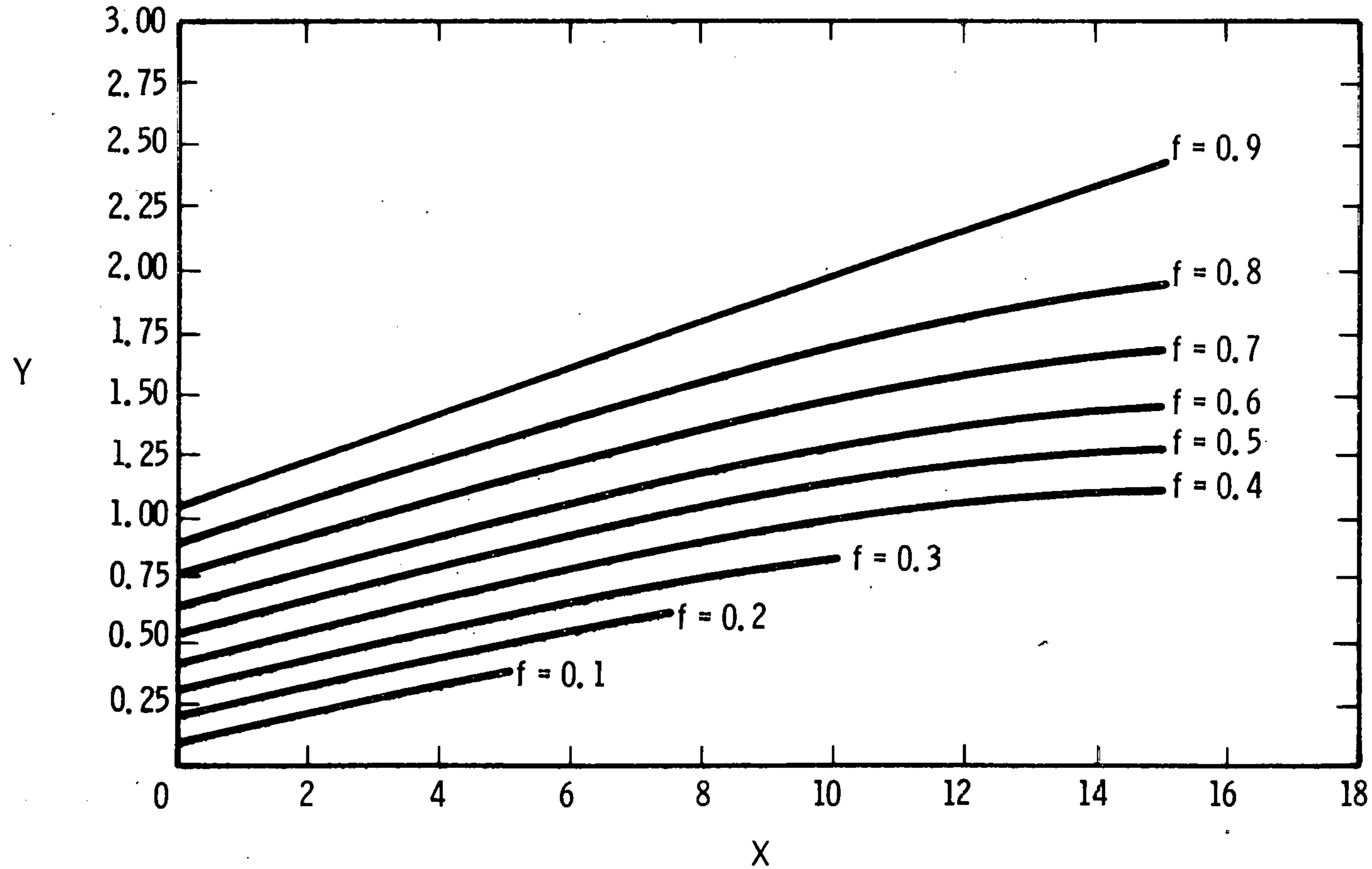


Figure 6-9. f - Chart for Solar Air Heating Systems

Once the X and Y coordinates have been determined for a specific collector area, it is very easy to determine performance for other collector areas using a simple graphical construction. Draw a line on Figure 6-8 or 6-9 between the coordinates (o, o) and (X, Y) for each month. The endpoint of each line determines f for the month for the original collector area. Simply double the length of each line and read off f for a system with twice the collector area, etc. Worksheet TA-3 has room for tabulating the system performance for three different collector areas.

ECONOMIC ANALYSIS

General Procedure

The previous subsection enables the user to start with a given solar energy system and predict the fraction of the load supplied by solar energy for various collector areas. An economic analysis is necessary to decide which collector area is most economic, and to decide whether the optimum collector area will save or lose money as compared to a conventional heating system.

The economic analysis presented here is the life-cycle cost approach. Building owner cash flows are calculated for each year of the analysis for both solar and non-solar space and water-heating installations. By comparing the present values of the yearly costs of the solar and non-solar systems, the economic feasibility of the solar system is determined. This approach is the most realistic economic analysis because it accounts for the time value of money.

For completeness, the yearly costs include property and income taxes. The "yearly cost with solar" should include all of the additional cash flows due to the solar heating system that would not be present had a conventional system been installed. The cost can be represented as follows:

$$\text{yearly cost with solar} = \text{mortgage payment} + \text{backup system fuel cost} + \text{misc. cost} + \text{property tax increase} - \text{"solar" income tax credit}$$

$$\text{yearly cost w/o solar} = \text{conventional system fuel costs} - \text{"non-solar" income tax credit}$$

where, for residential buildings

$$\text{"solar" income tax credit} = \text{tax rate} \times \{\text{interest paid} + \text{property tax paid}\}$$

$$\text{"non-solar" income tax credit} = 0$$

for commercial buildings (income producing buildings)

$$\text{"solar" income tax credit} = \text{tax rate} \times \{\text{interest} + \text{property tax paid} + \text{misc. expense} + \text{backup system fuel cost} + \text{depreciation}\}$$

$$\text{"non-solar" income tax credit} = \text{tax rate} \times \{\text{conventional system fuel costs}\}$$

The yearly costs are calculated each year for as long a period of analysis as you desire. This usually corresponds to the term of the mortgage, the expected life of the building, or the depreciated life of the building. Then all costs are discounted to the present so that the solar and non-solar system costs can be compared at the same point in time.

Worksheet EA-1

This sheet is used to calculate the initial investment in the solar system, the mortgage payments and the fraction of the mortgage payments that represent interest. The interest portion of the mortgage payments are tax deductible. Space is provided for three different collector areas.

The investment in the solar system is calculated as:

$$\text{Investment} = (\$/\text{unit collector})(\text{collector area}) + \text{constant costs.}$$

($/unit collector area) refers to the cost of collectors, storage, and all other expenses which depend on collector area. The constant costs are those not dependent on collector area such as controls, piping, ductwork, etc. It is assumed that the solar backup system is identical to the conventional heating system; therefore, the solar investment includes only the cost of additional equipment, architectural modifications, and the additional installation and construction costs associated with them.

After the down payment, annual mortgage interest rate (i), and the term of the mortgage (n) are entered on Worksheet EA-1, the annual mortgage payment can be calculated as:

$$\begin{array}{c}\text{Annual}\\ \text{Mortgage}\\ \text{Payment}\end{array} = \left(\text{Investment} - \begin{array}{c}\text{Down}\\ \text{Payment}\end{array}\right)\left(\begin{array}{c}\text{Value from}\\ \text{Table, Part G of Worksheet EA-1}\end{array}\right)$$

Since interest payments are tax deductible, the table in Part H of Worksheet EA-1 can be used to determine the portion of the mortgage payment that goes to interest.

WORKSHEET EA-1

A. Collector Area (from Worksheet TA-3) ______ ______ ______
B. Investment in Solar System (__$/area×A+constant costs) ______ ______ ______
C. Down Payment ______ ______ ______
D. Mortgage Principle in 1st Year (B-C) ______ ______ ______
E. i, Annual Mortgage Interest Rate ______ ______ ______
F. n, Term of Mortgage ______ ______ ______
G. Annual Mortgage Payment [(D)×(value from table below)] ______ ______ ______

Annual Mortgage Payment Interest Rate

Term of Mortgage

n	7	7-1/2	8	8-1/2	9	9-1/2	10	10-1/2	11	11-1/2	12
1	1.070	1.075	1.080	1.085	1.090	1.095	1.100	1.105	1.110	1.115	1.120
2	.553	.557	.561	.565	.568	.572	.576	.580	.584	.588	.592
3	.381	.385	.389	.392	.395	.399	.402	.406	.409	.413	.416
4	.295	.299	.302	.305	.309	.312	.315	.319	.322	.326	.329
5	.244	.247	.250	.254	.257	.260	.264	.267	.271	.274	.277
6	.210	.213	.216	.220	.223	.226	.230	.233	.236	.240	.243
7	.186	.189	.192	.195	.199	.202	.205	.209	.212	.216	.219
8	.167	.171	.174	.177	.181	.184	.187	.191	.194	.198	.201
9	.153	.157	.160	.163	.167	.170	.174	.177	.181	.184	.188
10	.142	.146	.149	.152	.156	.159	.163	.166	.170	.173	.177
11	.133	.137	.140	.144	.147	.150	.154	.158	.161	.165	.168
12	.126	.129	.133	.136	.140	.143	.147	.150	.154	.158	.161
13	.120	.123	.127	.130	.134	.137	.141	.144	.148	.152	.156
14	.114	.118	.121	.125	.128	.132	.136	.139	.143	.147	.151
15	.110	.113	.117	.120	.124	.128	.131	.135	.139	.143	.147
16	.106	.109	.113	.117	.120	.124	.128	.132	.136	.139	.143
17	.102	.106	.110	.113	.117	.121	.125	.129	.132	.136	.140
18	.099	.103	.107	.110	.114	.118	.122	.126	.130	.134	.138
19	.097	.100	.104	.108	.112	.116	.120	.124	.128	.132	.136
20	.094	.098	.102	.106	.110	.113	.117	.121	.126	.130	.134

H. Fraction of Mortgage Payment Which is Interest

Annual Mortgage Interest Rate

Yrs. Left on Mortgage	7	7½	8	8½	9	9½	10	10½	11	11½	12
20	.742	.765	.785	.804	.822	.837	.851	.864	.876	.887	.896
19	.723	.747	.768	.788	.806	.822	.836	.850	.862	.874	.884
18	.704	.728	.750	.770	.788	.805	.820	.834	.847	.859	.870
17	.683	.708	.730	.750	.769	.786	.802	.817	.830	.843	.854
16	.661	.686	.708	.729	.748	.766	.782	.798	.812	.825	.837
15	.638	.662	.685	.706	.725	.744	.761	.776	.791	.805	.817
14	.612	.637	.660	.681	.701	.719	.737	.753	.768	.782	.795
13	.585	.609	.632	.654	.674	.693	.710	.727	.742	.757	.771
12	.556	.580	.603	.624	.644	.663	.681	.698	.714	.729	.743
11	.525	.549	.571	.592	.612	.631	.650	.667	.683	.698	.713
10	.492	.515	.537	.558	.578	.596	.614	.632	.648	.663	.678
9	.456	.478	.500	.520	.540	.558	.576	.593	.609	.625	.639
8	.418	.439	.460	.479	.498	.516	.533	.550	.566	.581	.596
7	.377	.397	.417	.435	.453	.470	.487	.503	.518	.533	.548
6	.334	.352	.370	.387	.404	.420	.436	.451	.465	.480	.493
5	.287	.303	.319	.335	.350	.365	.379	.393	.407	.420	.433
4	.237	.251	.265	.278	.292	.304	.317	.329	.341	.353	.364
3	.184	.195	.206	.217	.228	.238	.249	.259	.269	.279	.288
2	.127	.135	.143	.151	.158	.166	.174	.181	.188	.196	.203
1	.065	.070	.074	.078	.083	.087	.091	.095	.099	.103	.107

Worksheet EA-2

This worksheet helps summarize the calculation of the building owner's yearly costs for backup system fuel and for the solar investment, assuming a solar system is installed.

Line A -- Enter the cost of fuel used by the backup system on Line A. For the purpose of calculating $\$/10^6$ Btu

Natural gas

1 therm = 10^5 Btu

1 million cubic feet = 10^9 Btu

Electricity

1 kWh = 3413 Btu

Oil

No. 2 = 140,000 Btu/gal

No. 5 = 150,000 Btu/gal

LP gas

1 gal = 9100 Btu

Line B -- Enter on Line B.1 the annual fraction of the total system load supplied by solar energy, obtained from Worksheet TA-3 for each of the three collector areas. Line B.2, the annual load, is obtained from Worksheet TA-1. The furnace efficiency is needed to calculate the actual amount of energy which must be used in order to deliver the required backup energy to the heated space. Average operating efficiencies of installed furnaces are approximately:

Natural gas	65%
Oil	60%
Electric	100%

These values can be used for Line B.3. Then the fuel expense in the first year is:

$$\begin{matrix}\text{1st Year}\\\text{Fuel Expense}\end{matrix} = \left(1 - \begin{matrix}\text{Fraction}\\\text{Solar}\end{matrix}\right)(\text{Load})\left(\begin{matrix}\text{Cost of}\\\text{Fuel}\end{matrix}\right)/(\text{Furnace efficiency})$$

WORKSHEET EA-2

With Solar

A. Present Cost of Backup System Fuel [$/$10^6$ Btu] ____________ [$]

B. Fuel Expenses in 1st Year (1-B.1)(B.2)(A.)/(B.3) ____ ____ ____ [$]

B.1 Annual Fraction Solar (Worksheet TA-3) ____ ____ . ____ [%/100]

B.2 Annual Load (Worksheet TA-1) ____________ [10^6 Btu]

B.3 Efficiency of Backup Furnace ____________ [%/100]

C. Extra Insur., Maint., Misc. Costs Due to Solar System in 1st Year ____________ [$]

D. Extra Property Tax Paid per Year Due to the Solar Investment (D.1)(D.2)(D.3) ____ ____ ____ [$]

D.1 Tax Rate Based on Assessed Value ____________ [%/100]

D.2 Ratio-Assessed Value to Initial Cost ____________

D.3 Solar Investment (Worksheet EA-1) ____ ____ . ____ [$]

E. Effective Income Tax Rate (E.1) + (E.2) - (E.1)(E.2) ____________ [%/100]

E.1 Federal Income Tax Rate ____________ [%/100]

E.2 State Income Tax Rate ____________ [%/100]

Without Solar

F. Fuel Expenses in 1st Year (B.2)(A.)/(B.3) ____________ [$]

Line C -- Enter the sum of all extra annual costs due to the solar system that are not included elsewhere. There may be extra insurance premiums because of the larger investment required to build a solar-heated building or because the risk of property damage is considered higher due to increased glass areas, etc. Since a solar system requires extra equipment, maintenance costs may increase proportionately. Other extra costs may be for cleaning collectors, replacing antifreeze, etc.

Line D -- On line D. 1 enter your local property tax rate. In most districts property is assessed at a constant fraction of the market value. Enter this fraction on line D. 2 since the market value of the solar investment can be approximated by its initial cost. Transcribe the solar investment from Worksheet EA-1 onto line D. 3. Then the extra property tax paid per year due to the solar investment is:

$$\text{Property Tax} = (\text{rate})\left(\frac{\text{Assessed value}}{\text{Initial investment}}\right)(\text{Initial investment})$$

Line E -- The effective income tax rate is the actual tax rate you pay because of state and federal income taxes. Since state income taxes are deductible on your federal return, the effective income tax rate is:

$$\text{Effective Income Tax Rate} = \text{Federal Rate} + \text{State Rate} - (\text{Federal Rate})(\text{State Rate})$$

Line F -- The fuel expense in the first year for a non-solar system is the total load times the present cost of fuel divided by the furnace efficiency.

Worksheet EA-3

EA-3 is a summary of the estimated cash flows each year due to the solar system and backup fuel cost, assuming a solar system is installed. Columns C1 through C8 are manipulations of numbers previously tabulated on other worksheets. In addition, an estimate of the fuel inflation rate and the general inflation rate is required. EA-3 has room for only one collector area.

Column 1 -- Transcribe mortgage payment from Worksheet EA-1.

Column 2 -- The fraction of the mortgage payment that is interest is tabulated in Table H, Worksheet EA-1. The fraction depends on the number of years left on the mortgage. Note that if the term of the mortgage is 20 years, there are 20 years left the first year, 19 the second, etc. The interest paid each year is calculated as:

$$\text{Interest Paid} = \left(\text{mortgage payment}\right)\left(\frac{\text{interest portion of payment}}{\text{mortgage payment}}\right)$$

Column 3 -- The backup system fuel expense in the first year is taken from Worksheet EA-2, Line B. An estimate of the fuel inflation rate in the future is needed and can be recorded on Line A. Table 6-2 lists inflation factors. Knowing the inflation rate and the year, the fuel expense each year is calculated as:

$$\text{Backup System Fuel Expense} = \left(\text{Expense in 1st year}\right)\left(\text{Inflation Factor from Table 6-2}\right)$$

Column 4 -- The miscellaneous extra expenses due to the solar system in the first year are given on Line C of Worksheet EA-2. It is assumed that these rise at the general inflation rate, which should be entered on Line B. The miscellaneous costs each year are then:

$$\text{Misc. Expense} = \left(\text{Expense in 1st year}\right)\left(\text{Inflation Factor from Table 6-2}\right)$$

WORKSHEET EA-3

EXPENSES WITH SOLAR ENERGY

A. Backup system fuel inflation rate ________ Collector Area = ________________

B. General inflation rate ________

C. Annual cash flow

Year	C1 Mortgage Payment	C2 Interest Paid	C3 Backup System Fuel Expense	C4 Extra Misc. Expenses	C5 Extra Property Tax	C6 Depreciation Deduction	C7++ Income Tax Credit	C8 Expense With Solar
1								
2								
3								
4								
5								
6								
7								
8								
9								
10								
11								
12								
13								
14								
15								
16								
17								
18								
19								
20								

C1 = EA-1, line G
C2 = (value from EA-1, Table H)(C1)
C3 = (EA-2; line B)(value from Table 2 using the inflation rate from line A)
C4 = (EA-2, line C)(value from Table 2 using the general inflation rate from line B)

C5 = EA-2 line D
C6 = EA-4
C7 = (EA-2, line E)(C2+C5) for residential
= (EA-2, line E)(C2+C3+C4+C5+C6) for commercial, industrial

C8 = (C1+C3+C4+C5-C7)

++ does not include state or federal tax deductions designed to encourage the use of solar energy

TABLE 6-2

INFLATION FACTORS

Inflation Rate

Year	0%	1%	2%	3%	4%	5%	6%	7%	8%	9%	10%	11%	12%	13%
1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2	1.00	1.01	1.02	1.03	1.04	1.05	1.06	1.07	1.08	1.09	1.10	1.11	1.12	1.13
3	1.00	1.02	1.04	1.06	1.08	1.10	1.12	1.14	1.17	1.19	1.21	1.23	1.25	1.28
4	1.00	1.03	1.06	1.09	1.12	1.16	1.19	1.23	1.26	1.30	1.33	1.37	1.40	1.44
5	1.00	1.04	1.08	1.13	1.17	1.22	1.26	1.31	1.36	1.41	1.46	1.52	1.57	1.63
6	1.00	1.05	1.10	1.16	1.22	1.28	1.34	1.40	1.47	1.54	1.61	1.69	1.76	1.84
7	1.00	1.06	1.13	1.19	1.27	1.34	1.42	1.50	1.59	1.68	1.77	1.87	1.97	2.08
8	1.00	1.07	1.15	1.23	1.32	1.41	1.50	1.61	1.71	1.83	1.95	2.08	2.21	2.35
9	1.00	1.08	1.17	1.27	1.37	1.48	1.59	1.72	1.85	1.99	2.14	2.30	2.48	2.66
10	1.00	1.09	1.20	1.30	1.42	1.55	1.69	1.84	2.00	2.17	2.36	2.56	2.77	3.00
11	1.00	1.10	1.22	1.34	1.48	1.63	1.79	1.97	2.16	2.37	2.59	2.84	3.11	3.39
12	1.00	1.12	1.24	1.38	1.54	1.71	1.90	2.10	2.33	2.58	2.85	3.15	3.48	3.84
13	1.00	1.13	1.27	1.43	1.60	1.80	2.01	2.25	2.52	2.81	3.14	3.50	3.90	4.33
14	1.00	1.14	1.29	1.47	1.67	1.89	2.13	2.41	2.72	3.07	3.45	3.88	4.36	4.90
15	1.00	1.15	1.32	1.51	1.73	1.98	2.26	2.58	2.94	3.34	3.80	4.31	4.89	5.53
16	1.00	1.16	1.35	1.56	1.80	2.08	2.40	2.76	3.17	3.64	4.18	4.78	5.47	6.25
17	1.00	1.17	1.37	1.60	1.87	2.18	2.54	2.95	3.43	3.97	4.59	5.31	6.13	7.07
18	1.00	1.18	1.40	1.65	1.95	2.29	2.69	3.16	3.70	4.33	5.05	5.90	6.87	7.99
19	1.00	1.20	1.43	1.70	2.03	2.41	2.85	3.38	4.00	4.72	5.56	6.54	7.69	9.02
20	1.00	1.21	1.46	1.75	2.11	2.53	3.03	3.62	4.32	5.14	6.12	7.26	8.61	10.20

Column 5 -- The extra property tax due to the solar system in the first year can be obtained from Line D or Worksheet EA-2. The property taxes will likely increase at the general inflation rate although our worked out examples show this column to be a constant cost.

Column 6 -- If the building is a residence, skip column 6. However, for income-producing buildings, the government allows several depreciation schemes for capital expenditures. Worksheet EA-4 is designed to organize these calculations. Transcribe the yearly deductions from Worksheet EA-4 into column 6.

Column 7 -- The income tax credit allowable depends upon whether or not the structure is an income-producing building. For residences, only interest and property tax payments are deductible, therefore:

$$\text{Income tax Credit} = (\text{Effective Tax Rate})(\text{Interest Paid} + \text{Extra Property Tax Paid})$$

For income-producing buildings all business expenses are deductible, therefore:

$$\text{Income Tax Credit} = (\text{Effective Tax Rate})(\text{Int. Paid} + \text{Fuel Exp.} + \text{Misc. Exp.} + \text{Property Tax Paid} + \text{Depr. Deduct.})$$

Using the effective income tax rate for this calculation assumes that the state allows the same deductions as the federal government. This is true of most states.

Column 8 -- The annual cash flow is calculated as:

$$\text{Annual Expense} = \text{Mortgage Payment} + \text{Fuel Expense} + \text{Misc. Expense} + \text{Property Tax} - \text{Income Tax Credit}$$

Worksheet EA-4 (for Commercial Buildings Only)

This worksheet is used to calculate income tax deductions due to depreciation of the solar investment. Only one of the three methods need be used.

Line A -- Straight-line depreciation means an equal deduction is taken every year throughout the depreciation life of the building. The deduction is calculated as:

$$\text{Deduction} = (\text{Solar Investment} - \text{Salvage Value})/(\text{Depreciation Lifetime})$$

Line B -- Declining balance depreciation can be calculated at several rates which are usually referenced to the straight-line rate. Thus B. 1 is the ratio of the declining balance rate to the straight-line rate. Then the deduction each year is calculated as:

$$\begin{matrix}\text{Deduction}\\ \text{in year i}\end{matrix} = \left(\begin{matrix}\text{Solar}\\ \text{Investment}\end{matrix} - \sum_{j=1}^{i-1} \text{Deductions}\right)(\text{B. 1})/(\text{Depreciation Lifetime})$$

where

$$\sum_{j=1}^{i-1} \text{Deductions} = \text{total depreciation deductions claimed in past years}$$
$$= \text{cumulative depreciation to date}$$

The depreciation and cumulative depreciation can be tabulated in Table D.

Line C -- The sum of years digits method of calculating depreciation uses the following formula:

$$\begin{matrix}\text{Deduction}\\ \text{in year i}\end{matrix} = \left(\begin{matrix}\text{Depr.}\\ \text{Life}\end{matrix} - i + 1\right)\left(\begin{matrix}\text{Solar}\\ \text{Invest.}\end{matrix} - \begin{matrix}\text{Salvage}\\ \text{Value}\end{matrix}\right)(2)/\left[\left(\begin{matrix}\text{Depr.}\\ \text{Life}\end{matrix}\right)^2 + \left(\begin{matrix}\text{Depr.}\\ \text{Life}\end{matrix}\right)\right]$$

WORKSHEET EA-4
DEPRECIATION

A. Straight Line (A.1 - A.3)/A.2 ____________ [$/yr]

A.1 Solar Investment (EA-1, line B) ________ [$]

A.2 Depreciation Lifetime __________ [yr]

A.3 Salvage Value __________ [$]

B. Declining Balance (use Table D)

B.1 Ratio-Declining balance rate to straight line rate __________ [%/100]

B.2 Calculation: $Depr_i = (A.1 - DP_{i-1})(B.1)/A.2$

where DP_{i-1} = total depreciation subtracted to date

i = the year

C. Sum of Years Digits (use Table D)

C.1 Calculation: $Depr_i = (A.2-i+1)(A.1-A.3)(2)/[(A.2)(A.2)+A.2]$

where i = the year

D. Table

Year	Depreciation	Cumulative Depreciation (Declining Balance Only)
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		
11		
12		
13		
14		
15		
16		
17		
18		
19		
20		

Worksheet EA-5

The economic comparison between the solar and non-solar alternatives can be summarized on Worksheet EA-5 for several collector areas. This allows the user to study the feasibility of a solar system as well as to optimize the collector arca.

Line A - Persons investigating the possibility of buying a solar-heating system are usually conscious of other investment opportunities and wish to spend their money on the alternative that yields the highest rate of return. To properly account for the time value of money, the discount rate used in a solar-system feasibility study should equal the rate of return on the best alternative investment. Typical market discount rates are:

For homeowners: general inflation rate plus 1 or 2%

For business: general inflation rate plus 3 or 4%

Column C1 -- The expense without a solar system refers to the cost of energy required to fuel the conventional HVAC system. For commercial and industrial buildings fuel bills are considered tax deductible business expenses; therefore, the expense without solar is calculated as:

$$\text{Expense w/o Solar} = \left(\text{1st Year Fuel Bill}\right)\left(\text{Inflation Factor from Table 6-2}\right) \text{ for residential}$$

$$\text{Expense w/o Solar} = \left(\text{1st Year Fuel Bill}\right)\left(\text{Inflation Factor from Table 6-2}\right)\left(1 - \text{Effective Income Tax Rate}\right) \text{ for commercial, industrial}$$

Column C2 -- Transcribe the expense with solar from Worksheet EA-3, Column C8.

WORKSHEET EA-5

ECONOMIC SUMMARY

A. Market discount rate, i.e. rate of return on your best alternative investment ____________.

B. Comparison of costs with and without solar for several collector areas.

		Collector Area = ________			Collector Area = ________			Collector Area = ________		
Year	C1 Expense w/o Solar	C2 Expense with Solar	C3 Solar Savings	C4 Present Worth of Savings	C2 Expense with Solar	C3 Solar Savings	C4 Present Worth of Savings	C2 Expense with Solar	C3 Solar Savings	C4 Present Worth of Savings
1										
2										
3										
4										
5										
6										
7										
8										
9										
10										
11										
12										
13										
14										
15										
16										
17										
18										
19										
20										
			total*			total*			total*	

C1 = (EA-2, line F)(value from Table 2 using EA-3, line A inflation rate) for residential
= [C1 for residential][1-(EA-2, line E)] for commercial, industrial

C2 = EA-3, column C8

C3 = C1-C2

C4 = (C3)(value from Table 3 using the discount rate from line A)

*If a down payment was made, subtract EA-1, line C from the total present worth of savings

Column C3 -- The solar savings each year is the difference between the expenses with and without the solar system.

Column C4 -- The present worth of each year's savings is calculated by multiplying the savings by present worth factors obtained by entering Table 6-3 with the discount rate listed on the top line. The sum of column C4 is then the present worth of all of the yearly savings if no down payment was made on the solar system. If a down payment was made, subtract it from the sum of column C4 to obtain the present worth of the yearly savings. The optimum collector area will have the largest sum of present worths. If the largest sum is still negative, it means that a solar system with the optimum collector area will still lose money compared to a conventional system.

TABLE 6-3

PRESENT WORTH FACTORS

Discount Rate

Year	0%	1%	2%	3%	4%	5%	6%	7%	8%	9%	10%	11%	12%	13%
1	1.000	.990	.980	.971	.962	.952	.943	.935	.926	.917	.909	.901	.893	.885
2	1.000	.980	.961	.943	.925	.907	.890	.873	.857	.842	.826	.812	.797	.783
3	1.000	.971	.942	.915	.889	.864	.840	.816	.794	.772	.751	.731	.712	.693
4	1.000	.961	.924	.888	.855	.823	.792	.763	.735	.708	.683	.659	.636	.613
5	1.000	.951	.906	.863	.822	.784	.747	.713	.681	.650	.621	.593	.567	.543
6	1.000	.942	.888	.837	.790	.746	.705	.666	.630	.596	.564	.535	.507	.480
7	1.000	.933	.871	.813	.760	.711	.665	.623	.583	.547	.513	.482	.452	.425
8	1.000	.923	.853	.789	.731	.677	.627	.582	.540	.502	.467	.434	.404	.376
9	1.000	.914	.837	.766	.703	.645	.592	.544	.500	.460	.424	.391	.361	.333
10	1.000	.905	.820	.744	.676	.614	.558	.508	.463	.422	.386	.352	.322	.295
11	1.000	.896	.804	.722	.650	.585	.527	.475	.429	.388	.350	.317	.287	.261
12	1.000	.887	.788	.701	.625	.557	.497	.444	.397	.356	.319	.286	.257	.231
13	1.000	.879	.773	.681	.601	.530	.469	.415	.368	.326	.290	.258	.229	.204
14	1.000	.870	.758	.661	.577	.505	.442	.388	.340	.299	.263	.232	.205	.181
15	1.000	.861	.743	.642	.555	.481	.417	.362	.315	.275	.239	.209	.183	.160
16	1.000	.853	.728	.623	.534	.458	.394	.339	.292	.252	.218	.188	.163	.141
17	1.000	.844	.714	.605	.513	.436	.371	.317	.270	.231	.198	.170	.146	.125
18	1.000	.836	.700	.587	.494	.416	.350	.296	.250	.212	.180	.153	.130	.111
19	1.000	.828	.686	.570	.475	.396	.331	.277	.232	.194	.164	.138	.116	.098
20	1.000	.820	.673	.554	.456	.377	.312	.258	.215	.178	.149	.124	.104	.087

SOLAR HEATING SYSTEM DESIGN PROBLEM USING THE f-CHART METHOD

Determine the collector area leading to the most economical heating system for the house described in the table below. Orientation of the collector is indicated. The collectors to be used have measured performance curves as shown in Figure 6-10, and their costs are indicated below.

Location	Madison
Design temperatures (from ASHRAE or local codes)	
Indoor	65°F
Outdoor	-9°F
Design heat loss (see example in Section V)	53,215 Btu/hr
Collector slope	60°
Collector azimuth angle	0°
Solar system type	Liquid based
Collector cost, per installed area	$15/ft^2
Installed solar system costs independent of collector area	$1000

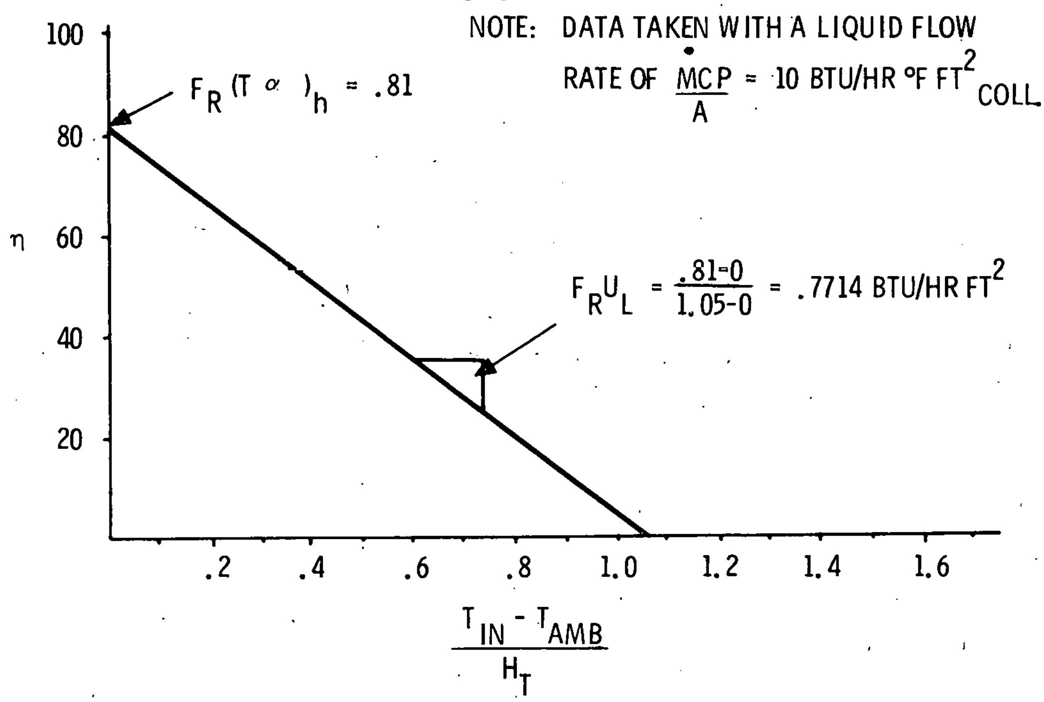


Figure 6-10. Collector Efficiency versus $(T_{in}-T_{amb})/H_T$

The performance of the system depends on the storage size, flow rates (i.e., pump size and head of piping system), and the quality of heat exchange equipment. Parameters for these are as follows:

Storage size	1.5 gal H_2O/ft^2 collector
Collector heat exchanger (between collector and storage):	
Fluid on collector side	50% water, 50% ethylene glycol
Mass flow rate, collector side	0.025 gpm/ft^2 collector
Specific heat of fluid, collector side	0.80 Btu/lbm °F
Effectiveness of exchanger	0.7
Mass flow rate, storage side	0.02 gpm/ft^2 collector
Specific heat of storage fluid (water)	1.0 Btu/lbm °F

Load heat exchanger (between storage and the load):

Mass flow rate, storage side	2000 lbm/hr
Effectiveness of exchanger	0.48
Mass flow rate, air side	6300 lbm/hr (1400 SCFM)
Specific heat of air	0.24 Btu/lbm °F

The hot water needs in the house are usually met, in part, by solar heat. The quantity and temperature required are given below:

Average daily demand	75 gal/day
Hot water delivery temperature	140°F
Cold water supply temperature	55°F

The solar heating system will be financed by increasing the mortgage on the house above that required to pay for the same house without solar heat. The down payment and terms of the loan are indicated in the table below. Since interest and property tax payments are tax deductible and the owner could make an alternative investment rather than buy a solar heating system, data on these factors is also given below.

Down payment, % of investment	20%
Term of mortgage	20 yr
Interest rate on mortgage	9%
Estimated system lifetime	20 yr
Federal income tax bracket	30%
State income tax bracket	11%
Rate of return on alternative investment	8%
Property tax rate, % of investment	2%/yr

It can be expected that maintenance and insurance costs will be higher for a solar heated home since more mechanical equipment is required. These costs will rise as labor and replacement parts become more expensive. Estimates of these factors are given below.

Maintenance and insurance on solar system in first year of operation	\$100
General inflation rate	6%/yr

The costs of energy from other sources than solar must be known in order to determine the most economical combined system (i.e., solar with auxiliary backup). The present cost of the alternative, and the rate at which it is expected to increase in the future, is given,

Present cost of conventional fuel (electricity)	$\$8/10^6$ Btu
Expected inflation rate	10%/yr

The calculations are shown on the following worksheets. The final results, from Worksheets EA-5 and TA-3, have been plotted on Figure 6-10. In this example, the optimum area is 630 square feet with solar carrying 56 percent of the total annual load. Note that the savings curve is greatly expanded and that the optimum is actually rather broad. A design with 530 or 730 square feet of collector will reduce the total savings by less than \$100 out of \$3500.

The results of the thermal analysis need not be repeated for another house in the same location using the same collectors and orientation. Doubling the load and doubling the solar system size (including heat exchangers and storage) will give the same fraction of the load supplied by solar. Therefore, the upper curve of Figure 6-11 can be used for other systems by multiplying the area axis by the ratio of the new annual load to the old annual load.

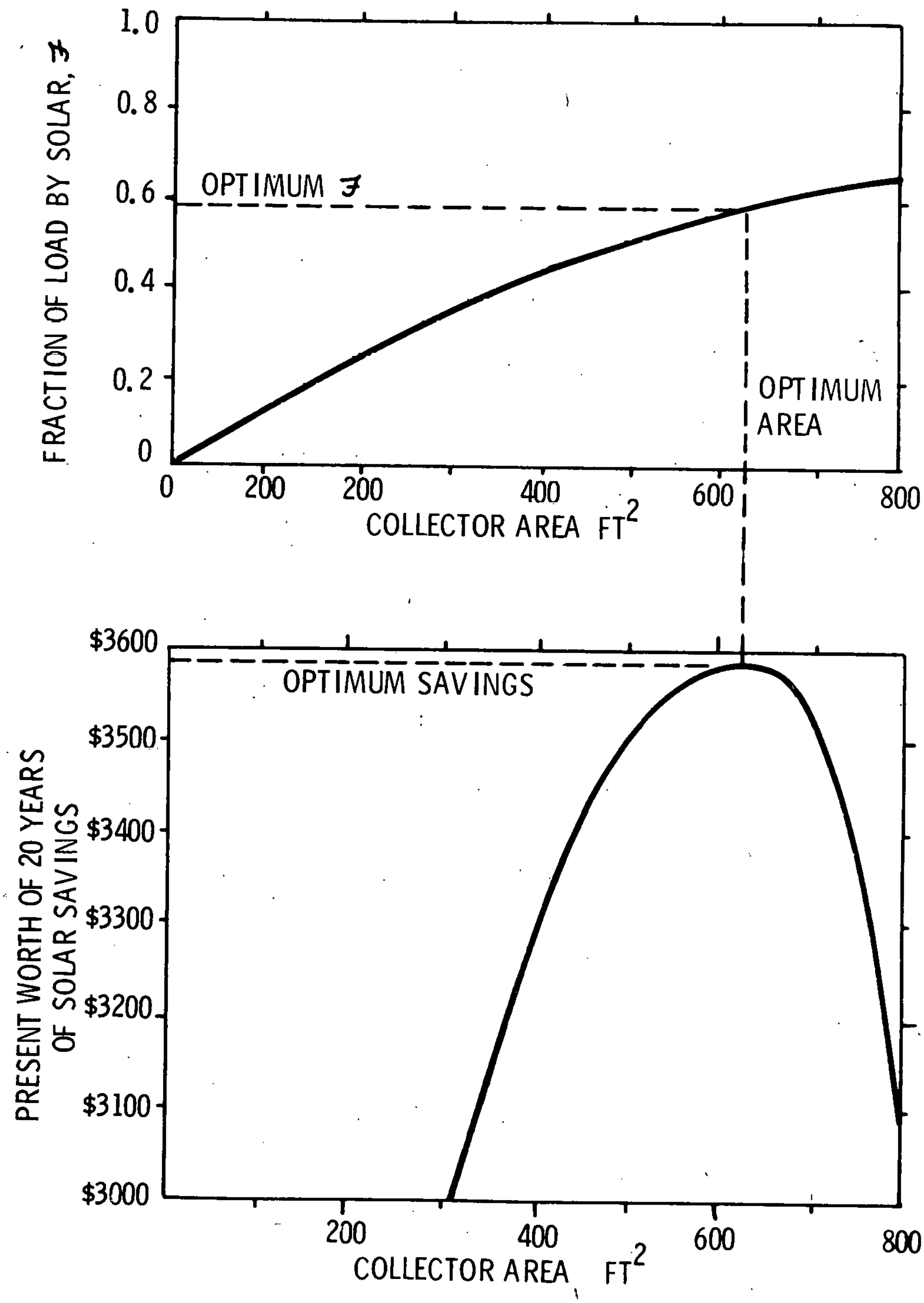


Figure 6-11. Results of Madison Example

WORKSHEET TA-1

HEATING LOADS

UA = $\frac{\text{Design SHL} = 53215}{\text{Design } \Delta T = 74}$ = 719 [Btu/hr - °F]

Water Usage = 75 [gal/day]

Month	Heating Degree Days [°F-day]	SHL [Btu] (1)	DWL [Btu] (2)	L [Btu] (3)
Jan	1494	$25.78 (10)^6$	$1.65 (10)^6$	$27.43 (10)^6$
Feb	1252	21.6	1.49	23.09
Mar	1079	18.62	1.65	20.27
Apr	591	10.2	1.6	11.8
May	297	5.13	1.65	6.78
Jun	72	1.24	1.6	2.84
Jul	14	.24	1.65	1.89
Aug	39	.67	1.65	2.32
Sep	173	2.99	1.6	4.59
Oct	474	8.18	1.65	9.83
Nov	909	15.69	1.6	17.29
Dec	1336	23.05	1.65	24.7
Total		$133.39 (10)^6$	$19.44 (10)^6$	$152.83 (10)^6$

(1) SHL = (24)(UA)(Degree-Days from Section III)

(2) DWL = (gal/day usage)(706 Btu/gal)(days per month)

(3) L = SHL + DWL

MADISON WI (LAT. 43.1)

	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEP	OCT	NOV	DEC	
HORIZONTAL RAD.	560	810	1230	1460	1750	2030	2050	1740	1440	990	560	500	(BTU/DAY-FT2)
FRAC. OF MAX.	.49	.50	.54	.49	.51	.56	.58	.56	.58	.55	.44	.48	
AVE. TEMP.	19.4	21.2	32.0	44.6	55.4	66.2	69.8	68.0	59.0	50.0	33.8	23.0	(F)
DEGREE-DAYS	1494.	1252.	1079.	591.	297.	72.	14.	39.	173.	474.	909.	1336.	(F-DAYS)

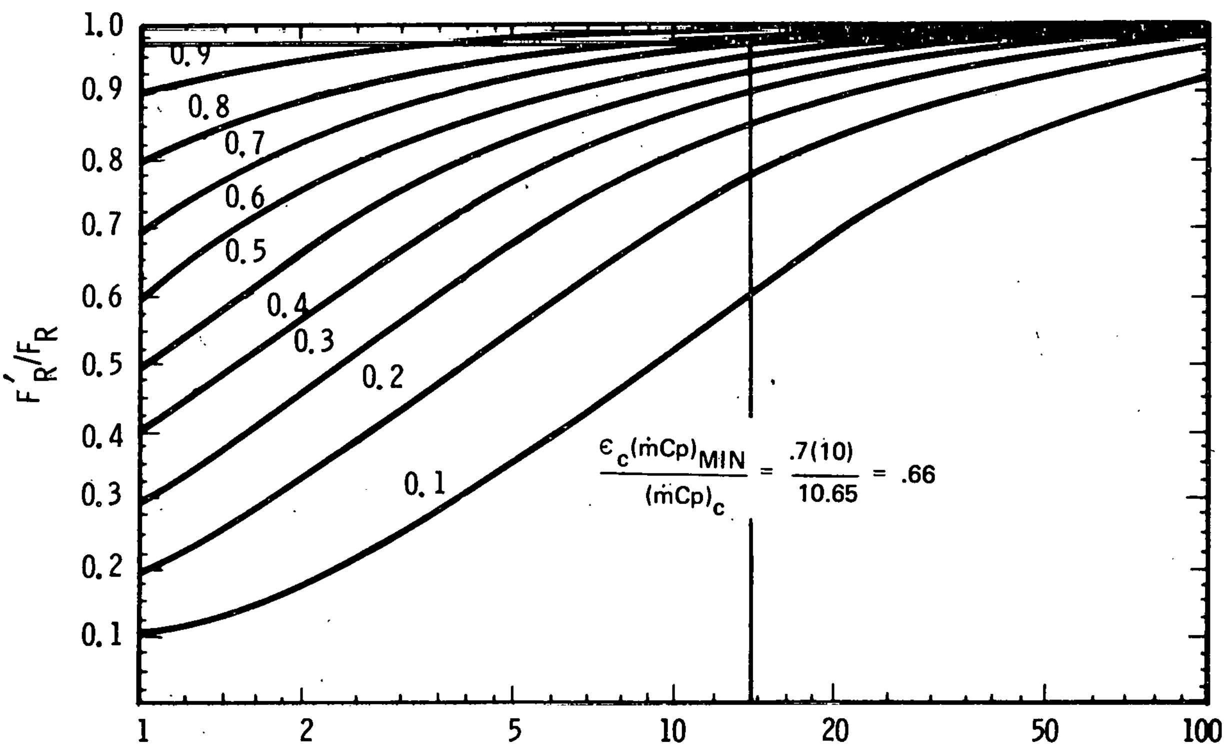
AVERAGE DAILY RADIATION ON TILTED SURFACES (BTU/DAY-FT2)

SLOPE	AZIMUTH	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEP	OCT	NOV	DEC
20	0	850	1090	1470	1560	1750	1970	2020	1810	1660	1290	800	790
30	0	970	1190	1540	1560	1700	1890	1940	1790	1710	1390	890	910
40	0	1060	1260	1580	1520	1610	1770	1830	1730	1720	1460	960	1000
50	0	1120	1300	1570	1460	1500	1620	1680	1630	1680	1500	1010	1070
60	0	1160	1310	1530	1360	1360	1440	1510	1500	1610	1500	1030	1110
70	0	1160	1280	1450	1240	1190	1250	1310	1340	1500	1450	1030	1120
80	0	1140	1230	1340	1090	1010	1040	1100	1160	1360	1380	1000	1100
90	0	1080	1140	1200	920	830	830	880	960	1190	1270	940	1060
20	15	840	1070	1460	1560	1750	1970	2020	1810	1650	1280	790	780
30	15	950	1170	1530	1560	1700	1890	1950	1790	1700	1380	880	890
40	15	1040	1240	1560	1530	1620	1780	1840	1740	1710	1440	950	980
50	15	1100	1270	1560	1470	1510	1630	1700	1640	1680	1470	990	1050
60	15	1130	1280	1520	1370	1370	1460	1530	1520	1610	1470	1010	1080
70	15	1130	1250	1440	1250	1220	1270	1340	1370	1510	1420	1000	1090
80	15	1100	1200	1330	1110	1040	1070	1130	1190	1370	1340	970	1070
90	15	1050	1110	1190	950	860	860	920	1000	1200	1230	920	1020
20	30	810	1050	1440	1550	1750	1980	2020	1810	1630	1250	760	750
30	30	900	1130	1500	1550	1710	1910	1960	1790	1680	1330	840	850
40	30	980	1180	1530	1530	1640	1810	1870	1750	1690	1390	900	920
50	30	1030	1210	1520	1470	1540	1680	1750	1670	1660	1410	930	980
60	30	1050	1210	1480	1390	1420	1520	1590	1560	1600	1400	940	1010
70	30	1050	1180	1410	1280	1280	1350	1420	1420	1500	1350	930	1010
80	30	1010	1120	1300	1150	1120	1160	1230	1260	1370	1280	900	980
90	30	960	1030	1170	1000	950	970	1030	1080	1220	1170	840	930
20	45	760	1000	1400	1530	1750	1990	2030	1800	1600	1200	730	700
30	45	840	1070	1450	1540	1720	1930	1980	1790	1630	1270	790	780
40	45	890	1110	1470	1510	1660	1850	1900	1750	1640	1310	830	840
50	45	930	1130	1460	1460	1570	1740	1800	1680	1610	1330	850	870
60	45	940	1120	1420	1390	1470	1600	1660	1580	1560	1310	860	890
70	45	930	1090	1350	1290	1340	1450	1510	1460	1470	1260	840	880
80	45	890	1030	1260	1170	1190	1280	1340	1310	1350	1190	800	860
90	45	840	950	1140	1040	1040	1110	1160	1160	1220	1090	750	810

$$\frac{(\dot{m}Cp)}{A}\,H_2O = \frac{.02\ \text{gal}}{\text{Min Ft}^2}\ (1)\ \frac{\text{Btu}}{\text{lbs}\,^\circ F}\ (8.33)\ \frac{\text{lbs}}{\text{gal}}\ (60)\ \frac{\text{Min}}{\text{hr}} = 10\ \frac{\text{Btu}}{\text{HR}\,^\circ F\ FT_c^2}$$

$$\frac{(MCp)}{A}\ \text{ANTI FREEZE} = 0.025\ (.8)\ (8.33)\ (1.065)\ (60) = 10.65$$

SPECIFIC GRAVITY OF 50-50 ETHYLENE GLYCOL-WATER IS 1.065
SPECIFIC HEAT GLYCOL-WATER IS 0.8



$$\frac{(\dot{m}Cp)_c}{AF_RU_L} = \frac{10.65}{.77} = 13.83$$

Figure 6-12. Collector Heat Exchanger Correction Factor

WORKSHEET TA-2

ITEMS MAKING UP X AND Y

A. $F_R U_L (F'_R / F_R)$ = .77(.963) = .74.

B. $F_R (\tau\alpha)_n (F'_R / F_R)$ = .81(.963) = .78.

	C1	C2	C3	C4	C5	C6	C7	C8
	L (1)	$(T_{ref} - \bar{T}_a)$ (2)	$\Delta\tau$	$\frac{(C2)(C3)}{(C1)}$	$\bar{\tau}/\tau_n$ (3)	$\bar{\alpha}/\alpha_n$ (4)	H_T (5)	$\frac{(C5)(C6)(C7)}{(C1)}$ $(\frac{days}{mo.})$
Jan		193	744	$5.23(10)^{-3}$	.95	.95	1160	$1.18(10)^{-3}$
Feb		191	672	5.56	"	"	1310	1.43
Mar	See	180	744	6.61			1530	2.11
Apr		167	720	10.19			1360	3.12
May	TA-1	157	744	17.23			1360	5.61
Jun		146	720	37.01			1440	13.73
Jul	"	142	744	55.9	"	"	1510	22.35
Aug		144	744	46.18			1500	18.09
Sep		153	720	24.0			1610	9.50
Oct	"	162	744	12.26			1500	4.27
Nov		178	720	7.41	"	"	1030	1.61
Dec		189	744	5.69			1110	1.26

(1) L from Worksheet TA-1

(2) T_{ref} is 212°F, $\bar{T}_a$ from Section III

(3) $\bar{\tau}/\tau_n$ is .95 for near optimum collector orientations

(4) $\bar{\alpha}/\alpha_n$ is .95 for near optimum collector orientations

(5) H_T from Section III

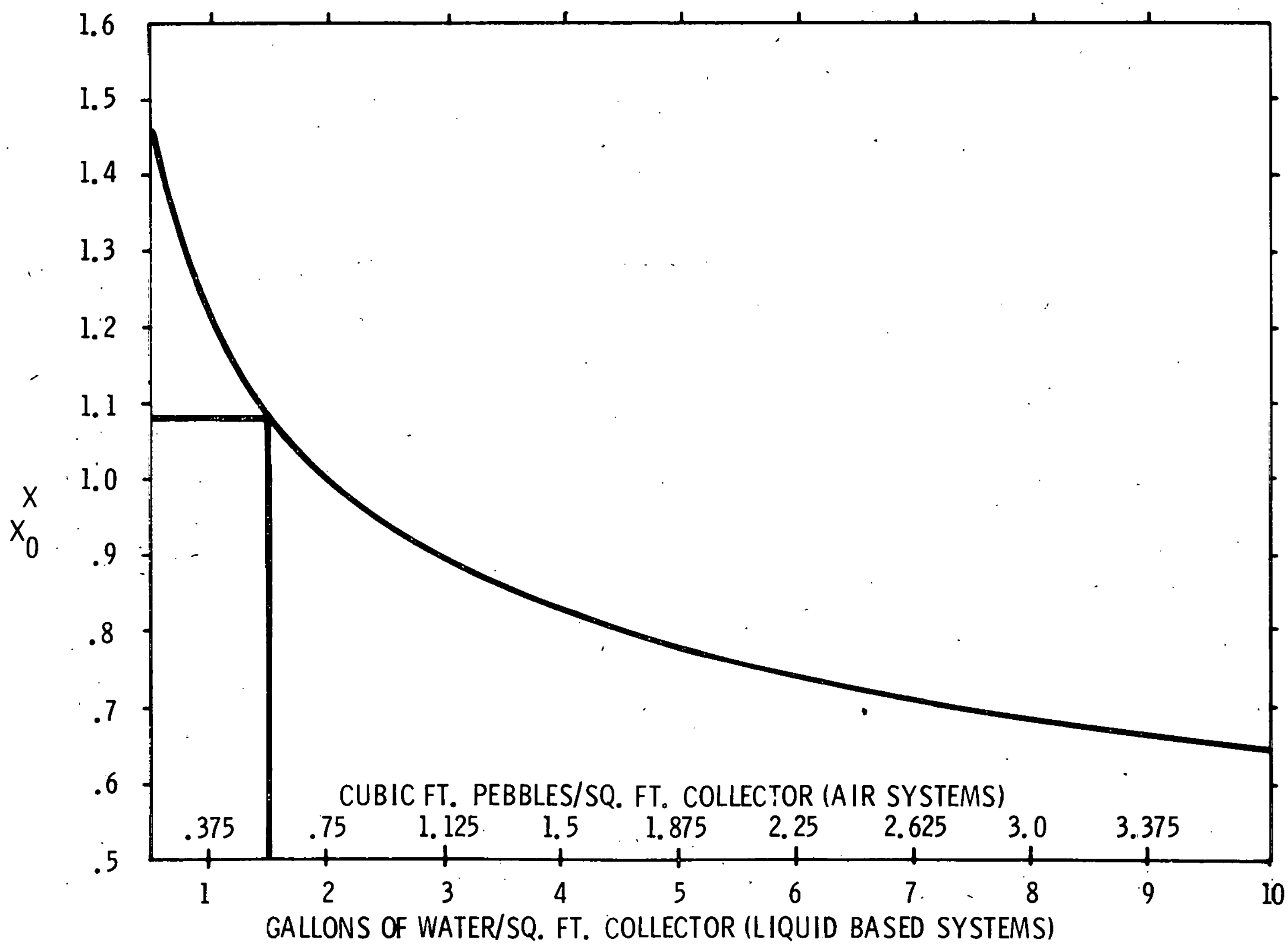
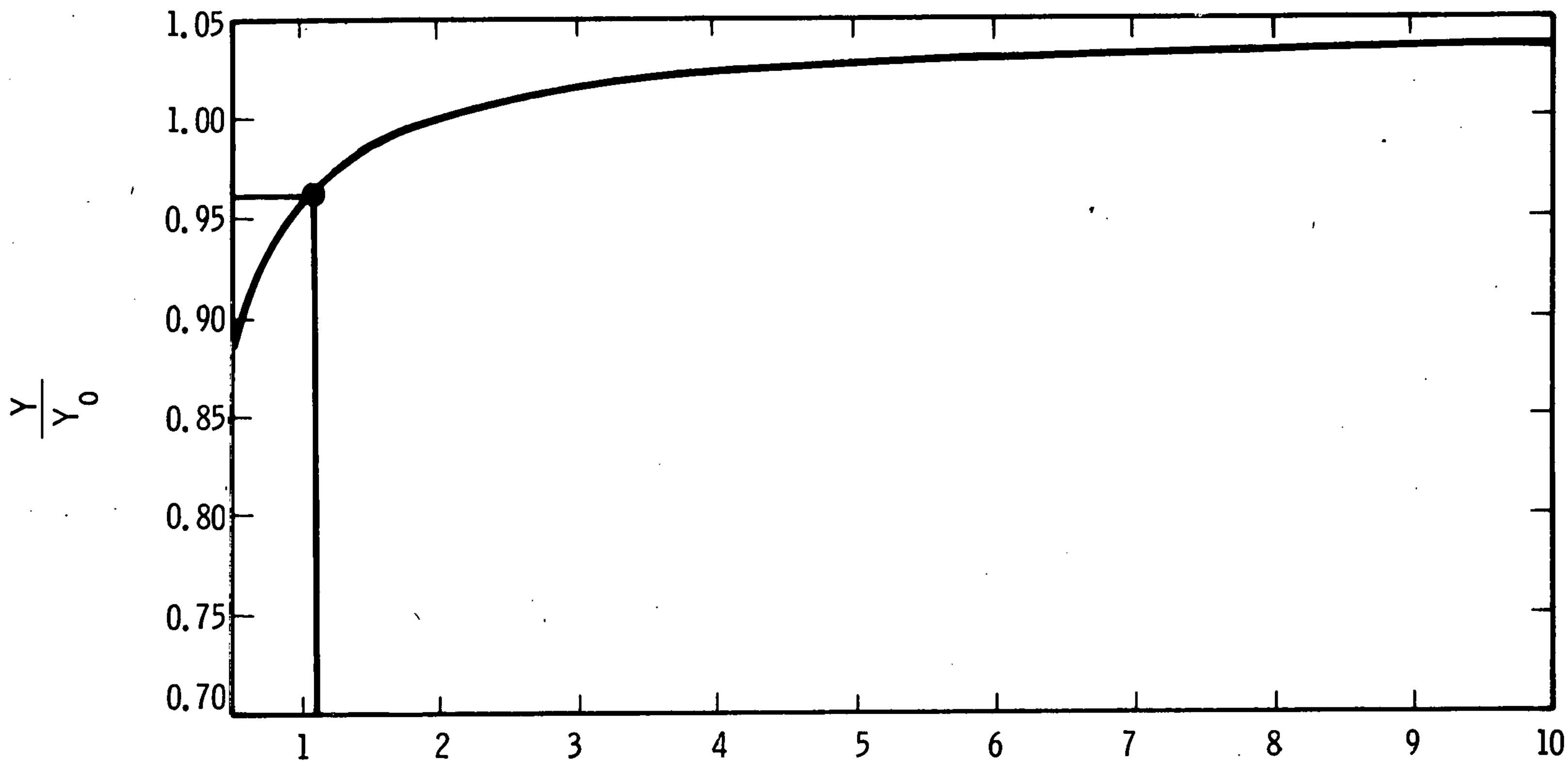


Figure 6-13. Storage Size Correction Factor



$$\frac{\epsilon_L (\dot{m}C_p)_{MIN}}{UA} = \frac{(.48)(6300)(.24)}{719} = 1.0$$

Figure 6-14. Load Heat Exchanger Correction Factor

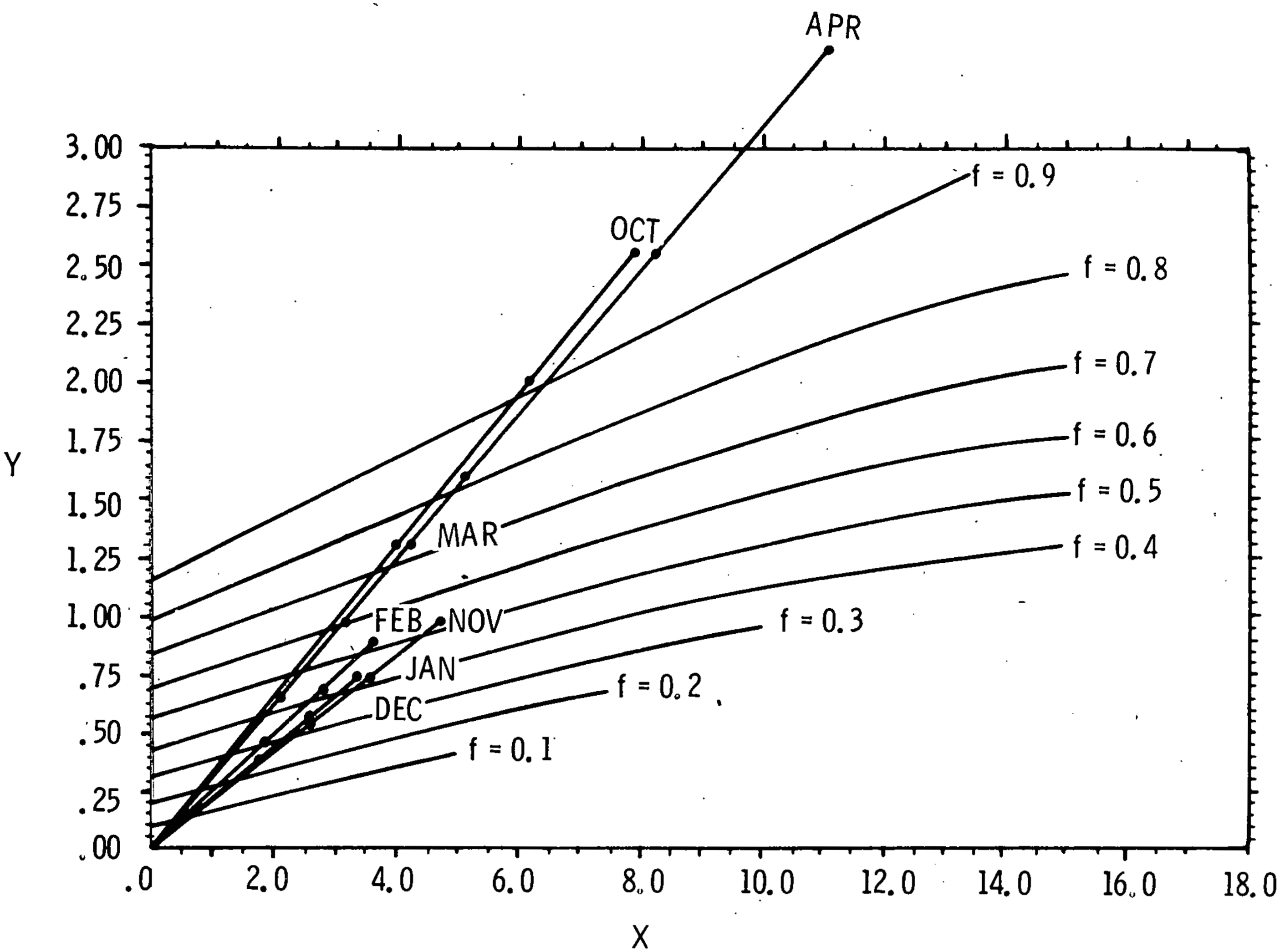


Figure 6-15. f - Chart for Liquid-Based Solar Heating System

WORKSHEET TA-3

		@ 800 ft		Corrected	Corrected	Area = 400 ft		Area = 600		Area = 800	
	L (1)	X (2)	Y (3)	X (4)	Y (5)	f (6)	fxL (7)	f (6)	fxL (7)	f (6)	fxL (7)
Jan		3.1	.74	3.3	.71	.25	$6.86(10)^6$	.35	$9.6(10)^6$	.44	$12.07(10)^6$
Feb		3.3	.89	3.6	.85	.30	6.93	.43	9.93	.53	12.24
Mar		3.9	1.32	4.2	1.27	.44	8.92	.61	12.36	.73	14.8
Apr	See	6.0	1.95	6.5	1.87	.57	6.73	.74	8.73	.85	10.03
May		10.2	3.5	11.0	3.36	.81	5.49	.94	6.37	.99	6.71
Jun	TA-1	21.9	8.57	23.6	8.23	1.0	2.84	1.0	2.84	1.0	2.84
Jul		33.1	13.95	35.7	13.39	1.0	1.89	1.0	1.89	1.0	1.89
Aug	"	27.3	11.29	29.5	10.84	1.0	2.32	1.0	2.32	1.0	2.32
Sep		14.2	5.93	15.3	5.69	1.0	4.59	1.0	4.59	1.0	4.59
Oct		7.3	2.67	7.9	2.56	.76	7.47	.92	9.04	.99	9.73
Nov	"	4.4	1.0	4.7	.96	.31	5.36	.43	7.43	.54	9.34
Dec		3.4	.79	3.7	.76	.25	6.17	.36	8.89	.45	11.12
total						total	65.72	total	84.06	total	97.8

Annual Fraction by Solar = (total, column 7)/(total, column 1) = .43 = .55 = .64

(1) L from Worksheet TA-1

(2) X = (TA-2, Column 4)(TA-2, line A)(Collector Area)

(3) Y = (TA-2, Column 8)(TA-2, line B) (Collector Area)

(4),(5) Corrected X and Y accounting for storage size, load heat exchanger size or collector flow rate

(6) f from Figure 8 or 9

WORKSHEET TA-1

A.	Collector Area (from Worksheet TA-3) 1000	400	600	800
B.	Investment in Solar System (15$/area×A+constant costs)	7000	10000	13000
C.	Down Payment	1400	2000	2600
D.	Mortgage Principle in 1st Year (B-C)	5600	8000	10400
E.	i, Annual Mortgage Interest Rate	9%	9%	9%
F.	n, Term of Mortgage	20	20	20
G.	Annual Mortgage Payment [(D)×(value from table below)]	613	876	1139

Annual Mortgage Payment Interest Rate

n.	7	7-1/2	8	8-1/2	9	9-1/2	10	10-1/2	11	11-1/2	12
1	1.070	1.075	1.080	1.085	1.090	1.095	1.100	1.105	1.110	1.115	1.120
2	.553	.557	.561	.565	.568	.572	.576	.580	.584	.588	.592
3	.381	.385	.388	.392	.395	.399	.402	.406	.409	.413	.416
4	.295	.299	.302	.305	.309	.312	.315	.319	.322	.326	.329
5	.244	.247	.250	.254	.257	.260	.264	.267	.271	.274	.277
6	.210	.213	.216	.220	.223	.226	.230	.233	.236	.240	.243
7	.186	.189	.192	.195	.199	.202	.205	.209	.212	.216	.219
8	.167	.171	.174	.177	.181	.184	.187	.191	.194	.198	.201
9	.153	.157	.160	.163	.167	.170	.174	.177	.181	.184	.188
10	.142	.146	.149	.152	.156	.159	.163	.166	.170	.173	.177
11	.133	.137	.140	.143	.147	.150	.154	.158	.161	.165	.168
12	.126	.129	.133	.136	.140	.143	.147	.150	.154	.158	.161
13	.120	.123	.127	.130	.134	.137	.141	.144	.148	.152	.156
14	.114	.118	.121	.125	.128	.132	.136	.139	.143	.147	.151
15	.110	.113	.117	.120	.124	.128	.131	.135	.139	.143	.147
16	.106	.109	.113	.117	.120	.124	.128	.132	.136	.139	.143
17	.102	.106	.110	.113	.117	.121	.125	.129	.132	.136	.140
18	.099	.103	.107	.110	.114	.118	.122	.126	.130	.134	.138
19	.097	.100	.104	.108	.112	.116	.120	.124	.128	.132	.136
20	.094	.098	.102	.106	.110	.113	.117	.121	.126	.130	.134

H. Fraction of Mortgage Payment Which is Interest

Annual Mortgage Interest Rate

Yrs. Left on Mortgage	7	7½	8	8½	9	9½	10	10½	11	11½	12
20	.742	.765	.785	.804	.822	.837	.851	.864	.876	.887	.896
19	.723	.747	.768	.788	.806	.822	.836	.850	.862	.874	.884
18	.704	.728	.750	.770	.788	.805	.820	.834	.847	.859	.870
17	.683	.708	.730	.750	.769	.786	.802	.817	.830	.843	.854
16	.661	.686	.708	.729	.748	.766	.782	.798	.812	.825	.837
15	.638	.662	.685	.706	.725	.744	.761	.776	.791	.805	.817
14	.612	.637	.660	.681	.701	.719	.737	.753	.768	.782	.795
13	.585	.609	.632	.654	.674	.693	.710	.727	.742	.757	.771
12	.556	.580	.603	.624	.644	.663	.681	.698	.714	.729	.743
11	.525	.549	.571	.592	.612	.631	.650	.667	.683	.698	.713
10	.492	.515	.537	.558	.578	.596	.614	.632	.648	.663	.678
9	.456	.478	.500	.520	.540	.558	.576	.593	.609	.625	.639
8	.418	.439	.460	.479	.498	.516	.533	.550	.566	.581	.596
7	.377	.397	.417	.435	.453	.470	.487	.503	.518	.533	.548
6	.334	.352	.370	.387	.404	.420	.436	.451	.465	.480	.493
5	.287	.303	.319	.335	.350	.365	.379	.393	.407	.420	.433
4	.237	.251	.265	.278	.292	.304	.317	.329	.341	.353	.364
3	.184	.195	.206	.217	.228	.238	.249	.259	.269	.279	.288
2	.127	.135	.143	.151	.158	.166	.174	.181	.188	.196	.203
1	.065	.070	.074	.078	.083	.087	.091	.095	.099	.103	.107

WORKSHEET EA-2

With Solar

A. Present Cost of Backup System Fuel [$/10^6 Btu] ____8.00____ [$]

B. Fuel Expenses in 1st Year (1-B.1)(B.2)(A.)/(B.3)

A = 400 ___697___ A = 600 ___551___ A = 800 ___439___ [$]

B.1 Annual Fraction Solar A = 400 600 800
(Worksheet TA-3) ___.43___ ___.55___ ___.64___ [%/100]

B.2 Annual Load
(Worksheet TA-1) ___152.83___ [10^6 Btu]

B.3 Efficiency of Backup
Furnace ___1.0___ [%/100]

C. Extra Insur., Maint., Misc. Costs Due to Solar System in
1st Year ___100.00___ [$]

D. Extra Property Tax Paid per Year Due to the Solar Investment (D.1)(D.2)(D.3)

A = 400 ___140___ 600 ___200___ 800 ___260___ [$]

D.1 Tax Rate Based on Assessed
Value ________ [%/100]

D.2 Ratio-Assessed Value to
Initial Cost ________

(D.1 and D.2: given information, (D.1)x(D.2) = .02)

D.3 Solar Investment A = 400 600 800
(Worksheet EA-1) ___7000___ ___10000___ ___13000___ [$]

E. Effective Income Tax Rate (E.1) + (E.2) - (E.1)(E.2) ___.38___ [%/100]

E.1 Federal Income Tax
Rate ___.30___ [%/100]

E.2 State Income Tax
Rate ___.11___ [%/100]

Without Solar

F. Fuel Expenses in 1st Year (B.2)(A.)/(B.3) ___1222.64___ [$]

$A_{coll.} = 400 \, ft^2$

WORKSHEET EA-3

EXPENSES WITH SOLAR ENERGY

A. Backup system fuel inflation rate 10%/yr

B. General inflation rate 6%/yr

C. Annual cash flow

Year	C1 Mortgage Payment	C2 Interest Paid	C3 Backup System Fuel Expense	C4 Extra Misc. Expenses	C5 Extra Property Tax	C6 Depreciation Deduction	C7++ Income Tax Credit	C8 Expense With Solar
1	613	504	697	100	140	0	245	1305
2	"	494	766	106	"	"	241	1385
3		483	843	112			237	1472
4		472	927	119			232	1567
5		459	1020	126			228	1672
6	"	445	1122	134			222	1787
7		430	1234	142	"	"	217	1913
8		413	1357	150			210	2051
9		395	1493	159			203	2203
10		376	1642	169			196	2369
11	"	354	1807	179	"		188	2551
12		331	1987	190		"	179	2752
13		306	2186	201			169	2971
14		278	2405	213			159	3213
15		248	2645	226	"		147	3477
16	"	215	2910	240		"	135	3768
17		179	3201	254			121	4087
18		140	3521	269			106	4437
19		97	3873	285	"	"	90	4822
20	"	51	4260	303			72	5244

C1 = EA-1, line G
C2 = (value from EA-1, Table H)(C1)
C3 = (EA-2; line B)(value from Table 2 using the inflation rate from line A)
C4 = (EA-2, line C)(value from Table 2 using the general inflation rate from line B)

C5 = EA-2 line D
C6 = EA-4
C7 = (EA-2, line E)(C2+C5) for residential
= (EA-2, line E)(C2+C3+C4+C5+C6) for commercial, industrial

C8 = (C1+C3+C4+C5-C7)

++ does not include state or federal tax deductions designed to encourage the use of solar energy

$A_{Coll.} = 600$ ft²

WORKSHEET EA-3

EXPENSES WITH SOLAR ENERGY

A. Backup system fuel inflation rate 10%/yr

B. General inflation rate 6%/yr

C. Annual cash flow

Year	C1 Mortgage Payment	C2 Interest Paid	C3 Backup System Fuel Expense	C4 Extra Misc. Expenses	C5 Extra Property Tax	C6 Depreciation Deduction	C7++ Income Tax Credit	C8 Expense With Solar
1	876	720	551	100	200	0	350	1377
2	"	706	606	106			344	1444
3		691	666	112	"		338	1517
4		674	733	119		"	332	1596
5		656	806	126			325	1684
6	"	636	887	134			318	1779
7		614	976	142			309	1884
8		591	1073	150			300	1999
9		565	1180	159	"	"	291	2126
10		537	1298	169			280	2264
11		506	1428	179			268	2415
12	"	473	1571	190			256	2582
13		437	1728	201			242	2764
14		397	1901	213	"	"	227	2964
15		354	2091	226			210	3183
16	"	307	2300	240			193	3424
17		256	2530	254			173	3688
18		200	2783	269	"	"	152	3977
19		139	3062	285			129	4295
20		72	3368	303			103	4643

C1 = EA-1, line G
C2 = (value from EA-1, Table H)(C1)
C3 = (EA-2; line B)(value from Table 2 using the inflation rate from line A)
C4 = (EA-2, line C)(value from Table 2 using the general inflation rate from line B)

C5 = EA-2 line D
C6 = EA-4
C7 = (EA-2, line E)(C2+C5) for residential
= (EA-2, line E)(C2+C3+C4+C5+C6) for commercial, industrial

C8 = (C1+C3+C4+C5-C7)

++ does not include state or federal tax deductions designed to encourage the use of solar energy

$A_{Coll.} = 800\ \phi$

WORKSHEET EA-3

EXPENSES WITH SOLAR ENERGY

A. Backup system fuel inflation rate 10%

B. General inflation rate 6%

C. Annual cash flow

Year	C1 Mortgage Payment	C2 Interest Paid	C3 Backup System Fuel Expense	C4 Extra Misc. Expenses	C5 Extra Property Tax	C6 Depreciation Deduction	C7++ Income Tax Credit	C8 Expense With Solar
1	1139	936	439	100	260	0	454	1484
2		918	483	106			448	1541
3	"	898	532	112	"	"	440	1603
4		876	585	119			432	1672
5		852	643	126			423	1746
6		827	708	134			413	1828
7		798	779	142			402	1918
8	"	768	856	150			391	2016
9		734	942	159	"	"	378	2123
10		698	1036	169			364	2241
11		658	1140	179			349	2369
12		615	1254	190			332	2511
13		568	1379	201			314	2665
14	"	516	1517	213			295	2835
15		460	1669	226	"	"	274	3021
16		399	1836	240			250	3224
17		332	2019	254			225	3448
18	"	260	2221	269			197	3693
19		180	2444	285	"	"	167	3961
20		94	2688	303			135	4255

C1 = EA-1, line G

C2 = (value from EA-1, Table H)(C1)

C3 = (EA-2; line B)(value from Table 2 using the inflation rate from line A)

C4 = (EA-2, line C)(value from Table 2 using the general inflation rate from line B)

C5 = EA-2 line D

C6 = EA-4

C7 = (EA-2, line E)(C2+C5) for residential

= (EA-2, line E)(C2+C3+C4+C5+C6) for commercial, industrial

C8 = (C1+C3+C4+C5-C7)

++ does not include state or federal tax deductions designed to encourage the use of solar energy

WORKSHEET EA-5

ECONOMIC SUMMARY

A. Market discount rate, i.e. rate of return on your best alternative investment 8%.

B. Comparison of costs with and without solar for several collector areas.

Year	C1 Expense w/o Solar	Collector Area = 400 C2 Expense with Solar	C3 Solar Savings	C4 Present Worth of Savings	Collector Area = 600 C2 Expense with Solar	C3 Solar Savings	C4 Present Worth of Savings	Collector Area = 800 C2 Expense with Solar	C3 Solar Savings	C4 Present Worth of Savings
1	1222		-83	-77		-155	-143		-262	-243
2	1344		-40	-34	SEE	-99	-85	SEE	-196	-168
3	1479	SEE	8	6		-37	-29		-124	-98
4	1626		60	44	EA-3	31	23		-44	-32
5	1789		118	80		106	72	EA-3	44	30
6	1968	EA-3	187	115	Ac=600#	190	120	Ac=800#	141	89
7	2165		253	147		282	164		248	145
8	2381	Ac=400#	332	179		383	207		367	198
9	2619		418	209		495	247		498	249
10	2881		514	238	"	619	287	"	642	297
11	3170		620	266		756	324		802	344
12	3487	"	737	293		907	360		978	388
13	3835		866	319		1073	395		1172	431
14	4219		1008	343	"	1257	427		1386	471
15	4641		1165	367		1460	460	"	1622	511
16	5105		1339	391		1684	492		1883	550
17	5615	"	1531	413		1930	521		2170	586
18	6177		1743	436		2203	551		2487	622
19	6794		1976	458		2503	581		2837	658
20	7474		2234	480		2834	609		3222	693
			total*	4673 - 1400 = 3273		total*	5583 - 2000 = 3583		total*	5721 - 2600 = 3121

C1 = (EA-2, line F) (value from Table 2 using EA-3, line A inflation rate) for residential
= [C1 for residential][1-(EA-2, line E)] for commercial, industrial

C2 = EA-3, column C8

C3 = C1-C2

C4 = (C3)(value from Table 3 using the discount rate from line A)

*If a down payment was made, subtract EA-1, line C from the total present worth of savings

TABLE 2

INFLATION FACTORS

Inflation Rate

Year	0%	1%	2%	3%	4%	5%	6%	7%	8%	9%	10%	11%	12%	13%
1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2	1.00	1.01	1.02	1.03	1.04	1.05	1.06	1.07	1.08	1.09	1.10	1.11	1.12	1.13
3	1.00	1.02	1.04	1.06	1.08	1.10	1.12	1.14	1.17	1.19	1.21	1.23	1.25	1.28
4	1.00	1.03	1.06	1.09	1.12	1.16	1.19	1.23	1.26	1.30	1.33	1.37	1.40	1.44
5	1.00	1.04	1.08	1.13	1.17	1.22	1.26	1.31	1.36	1.41	1.46	1.52	1.57	1.63
6	1.00	1.05	1.10	1.16	1.22	1.28	1.34	1.40	1.47	1.54	1.61	1.69	1.76	1.84
7	1.00	1.06	1.13	1.19	1.27	1.34	1.42	1.50	1.59	1.68	1.77	1.87	1.97	2.08
8	1.00	1.07	1.15	1.23	1.32	1.41	1.50	1.61	1.71	1.83	1.95	2.08	2.21	2.35
9	1.00	1.08	1.17	1.27	1.37	1.48	1.59	1.72	1.85	1.99	2.14	2.30	2.48	2.66
10	1.00	1.09	1.20	1.30	1.42	1.55	1.69	1.84	2.00	2.17	2.36	2.56	2.77	3.00
11	1.00	1.10	1.22	1.34	1.48	1.63	1.79	1.97	2.16	2.37	2.59	2.84	3.11	3.39
12	1.00	1.12	1.24	1.38	1.54	1.71	1.90	2.10	2.33	2.58	2.85	3.15	3.48	3.84
13	1.00	1.13	1.27	1.43	1.60	1.80	2.01	2.25	2.52	2.81	3.14	3.50	3.90	4.33
14	1.00	1.14	1.29	1.47	1.67	1.89	2.13	2.41	2.72	3.07	3.45	3.88	4.36	4.90
15	1.00	1.15	1.32	1.51	1.73	1.98	2.26	2.58	2.94	3.34	3.80	4.31	4.89	5.53
16	1.00	1.16	1.35	1.56	1.80	2.08	2.40	2.76	3.17	3.64	4.18	4.78	5.47	6.25
17	1.00	1.17	1.37	1.60	1.87	2.18	2.54	2.95	3.43	3.97	4.59	5.31	6.13	7.07
18	1.00	1.18	1.40	1.65	1.95	2.29	2.69	3.16	3.70	4.33	5.05	5.90	6.87	7.99
19	1.00	1.20	1.43	1.70	2.03	2.41	2.85	3.38	4.00	4.72	5.56	6.54	7.69	9.02
20	1.00	1.21	1.46	1.75	2.11	2.53	3.03	3.62	4.32	5.14	6.12	7.26	8.61	10.20

TABLE 3

PRESENT WORTH FACTORS

Discount Rate

Year	0%	1%	2%	3%	4%	5%	6%	7%	8%	9%	10%	11%	12%	13%
1	1.000	.990	.980	.971	.962	.952	.943	.935	.926	.917	.909	.901	.893	.885
2	1.000	.980	.961	.943	.925	.907	.890	.873	.857	.842	.826	.812	.797	.783
3	1.000	.971	.942	.915	.889	.864	.840	.816	.794	.772	.751	.731	.712	.693
4	1.000	.961	.924	.888	.855	.823	.792	.763	.735	.708	.683	.659	.636	.613
5	1.000	.951	.906	.863	.822	.784	.747	.713	.681	.650	.621	.593	.567	.543
6	1.000	.942	.888	.837	.790	.746	.705	.666	.630	.596	.564	.535	.507	.480
7	1.000	.933	.871	.813	.760	.711	.665	.623	.583	.547	.513	.482	.452	.425
8	1.000	.923	.853	.789	.731	.677	.627	.582	.540	.502	.467	.434	.404	.376
9	1.000	.914	.837	.766	.703	.645	.592	.544	.500	.460	.424	.391	.361	.333
10	1.000	.905	.820	.744	.676	.614	.558	.508	.463	.422	.386	.352	.322	.295
11	1.000	.896	.804	.722	.650	.585	.527	.475	.429	.388	.350	.317	.287	.261
12	1.000	.887	.788	.701	.625	.557	.497	.444	.397	.356	.319	.286	.257	.231
13	1.000	.879	.773	.681	.601	.530	.469	.415	.368	.326	.290	.258	.229	.204
14	1.000	.870	.758	.661	.577	.505	.442	.388	.340	.299	.263	.232	.205	.181
15	1.000	.861	.743	.642	.555	.481	.417	.362	.315	.275	.239	.209	.183	.160
16	1.000	.853	.728	.623	.534	.458	.394	.339	.292	.252	.218	.188	.163	.141
17	1.000	.844	.714	.605	.513	.436	.371	.317	.270	.231	.198	.170	.146	.125
18	1.000	.836	.700	.587	.494	.416	.350	.296	.250	.212	.180	.153	.130	.111
19	1.000	.828	.686	.570	.475	.396	.331	.277	.232	.194	.164	.138	.116	.098
20	1.000	.820	.673	.554	.456	.377	.312	.258	.215	.178	.149	.124	.104	.087

EFFICIENCY DATA FOR AIR HEATING COLLECTORS

The performance data for solar collectors which have air as the working fluid, is often presented in a different way than is the data for water type collectors. For a water collector, the performance data usually is a plot of collector efficiency plotted versus the term $(T_{IN} - T_A)/H_T$ where

T_{IN} = the collector water inlet temperature (^oF)
T_A = the outside ambient air temperature (^oF)
H_T = incident solar flux on the collector surface (BTU/(hr-ft^2))

The air collector data is usually plotted in the form collector efficiency versus the term $(T_{out} - T_A)/H_T$, where

T_{out} = the collector air outlet temperature (^oF)

while T_{out} and H_T are the same as above. This difference in notation is not trivial. The slope (FRCUA) and the intercept (FR $(\tau\alpha)$ you will need for the F-chart methodology in Chapter VI must be corrected before they can be used. The procedure is to read off the slope and intercept as usual and solve the formulas below for the corrected values, i.e.,

$$FR(\tau\alpha)^{IN} = \frac{FR(\ \alpha)^{out}}{\left[1.0 + \dfrac{FR(UL)^{out}}{1.08\,\dfrac{SCFM}{ft^2}}\right]}$$

$$FR(UL)^{IN} = \frac{FR(UL)^{out}}{\left[1.0 + \dfrac{FR(UL)^{out}}{1.08\,\dfrac{SCFM}{ft^2}}\right]}$$

where

$FR(\tau\alpha)^{IN}$ = the desired intercept value in the T_{IN} notation

$FR(\tau\alpha)^{out}$ = the available intercept in the T_{out} notation

$FR(UL)^{IN}$ = the desired slope in the T_{IN} notation

$FR(UL)^{out}$ = the available slope in the T_{out} notation

$\frac{SCFM}{ft^2}$ = air flow rate through the collector associated with the test conditions for the data available in standard cubic feet per minute per square foot of collector area.

Example

In the upper left hand corner of page 7-43 is shown a performance plot for the Solaron air type collector. Notice the plot is in the T_{out} notation. The intercept of the curve in T_{out} notation ($FR(\tau\alpha)^{out}$) is 0.63. The slope in T_{out} notation ($FR(UL)^{out}$) is 0.58. Both these numbers are taken directly from the plot without correction. Notice also that the airflow associated with the test is marked on the graph (2.0 $SCFM/ft^2$). Plugging this data into the above equations yields:

$$FR(\tau\alpha)^{IN} = \frac{0.63}{\left[1.0 + \frac{0.58}{1.08 \cdot 2.0}\right]}$$

$$= \frac{0.63}{\left[1.0 + 0.27\right]} = 0.49$$

$$FR(UL)^{IN} = \frac{0.58}{\left[1.0 + \frac{0.58}{1.08 \cdot 2.0}\right]}$$

$$= \frac{0.58}{\left[1.0 + 0.27\right]} = 0.46$$

Thus, for the Solaron air heater, the values 0.49 and 0.46 should be used for $FR(\tau\alpha)$ and $FR(UL)$, respectively.

SECTION VII
REQUIREMENTS, AVAILABILITY AND APPLICATION OF SOLAR HEATING SYSTEMS

INTRODUCTION

In addition to understanding the design and operation of solar heating systems, suppliers and users should be acquainted with several other aspects of solar heating. In order that intelligent selection of equipment can be made, knowledge of industry standards, equipment warranties, performance evaluation data, building codes and their relation to solar equipment, and related topics is necessary. If evaluations have been performed, their results need to be available to the supplier and user. The kinds of data required for such appraisal must be understood. The advantages and the disadvantages of the main system types for a specific application are particularly important. Knowledge of the types of hardware available, their cost, and their compatibility with other components in the system is essential. And in addition to their involvement in building codes, such items as safety and durability are additional criteria for equipment evaluation and selection.

In the following subsections, the main points enumerated above are addressed, and a guide to their consideration is presented. Because of (a) the newness of the solar equipment industry, (b) limited experience in the use of fully commercial systems in non-subsidized installations, (c) developing criteria for system evaluation and certification, and (d) lack of information on durability, marketability, and other factors, much of the material here outlined is tentative, rapidly changing, and highly variable in time and place. The following information should therefore be considered a guide rather than a set of specifications.

AVAILABILITY OF SYSTEMS, CONTROLS AND COMPONENTS

A directory of manufacturers and suppliers of solar heating (and cooling) equipment has been published by the Department of Energy under the title, "Catalog on Solar Heating and Cooling Products." It was published in November 1975, and is designated as ERDA-75. Among scores of organizations listing themselves as manufacturers of solar heating equipment, possibly a dozen firms have supplied or could furnish solar collectors in quantities of thousands of square feet with one- to two-month delivery. A listing of some such firms is shown in Table 7-1. The list is not intended to be complete nor is the inclusion of a firm intended to imply relative usefulness (efficiency, durability, cost, etc.) of thc product. The list contains, however, most of the firms having sold collectors, for space heating, to residential users and to the federal government in total quantities of thousands of square feet. The type of collector manufactured and miscellaneous comments are also presented.

Table 7-1. Selected Collector Manufacturers

Name of Firm	Collector Type	Collector Materials
Ametek	Liquid	Copper, glass (1) or (2)
Chamberlain	Liquid	Steel, glass (2)
General Electric	Liquid	Aluminum, lexan (2)
Grumman	Liquid	Copper, glass (2)
Honeywell	Liquid	Copper-steel, glass (2)
Lennox	Liquid	See Honeywell
Owens-Illinois	Liquid	Glass (evacuated tube)
PPG	Liquid	Copper, glass (2)
Revere	Liquid	Copper, glass (1) or (2)
Solaron	Air	Steel, glass (2)
Sunsource	Liquid	
Sunworks	Liquid or air	Copper, glass (1)

In addition to the equipment listed above, another commercially available component is the control system. The special unit in most solar heating control systems is the differential thermostat with its temperature sensors for insertion in collector and storage. Also available are control panels for connection of the differential thermostat, the room thermostat, and the various relays and motor actuators for blowers, pumps, and valves and dampers. The controllers may be of the conventional electromechanical type with bimetallic temperature sensors or thermocouples or thermistors, along with mechanical relays for energizing motors. Also available are solid-state controllers with thermistor and thermocouple inputs and solid-state switches and relays producing appropriate electric outputs to motors. Electromechanical types are more familiar to heating system installers and service personnel, whereas solid-state units will probably emerge as the more compact and economical system.

Suppliers of control components and special control systems for solar heating include long-established firms in the general control business, as well as new companies and groups specializing in specific solar control equipment. A representative list of companies offering differential temperature controllers and complete solar control systems is shown in Table 7-2, and a few examples of representative data sheets are appended to the back of this section.

Table 7-2. Selected Suppliers of Solar Heating Controls

Barber Coleman
Deko Labs
Hawthorne Industries, Inc.
Heliotrope General
Honeywell
Penn Controls
Ranco
Rho Sigma
Robertshaw Controls Company
Solar Controls (formerly Zia Associates)

Another important component of the solar heating system is the heat storage unit, but there appears to be no commercial offering of that item. In the liquid system, a conventional tank of some type is purchased. With the air system, a bin is usually constructed on site by the contractor and filled at a suitable time with screened gravel.

Several collector manufacturers also provide complete solar heating systems. Their products consist of collectors, accessory hardware for collector support and connection, pumps and/or blowers, preassembled fluid handlers comprising motors, blowers, automatic dampers, filters, water heating coils (for the air system), and motors, pumps, automatic valves (for the liquid system) and controls, including sensors and circuitry for actuating the various motors in the system. Some companies also supply water heating accessories, including heat exchanger and tanks, when that option is involved. The suppliers of complete solar heating systems do not usually furnish a heat storage unit, because its size and local availability usually makes its local procurement more practical. Sizing, layout, and detailed design are also offered by some system suppliers. These firms provide the information necessary for installation of their equipment by heating and plumbing contractors having little or no experience in solar equipment installation. Table 7-3 lists a few of the known suppliers of complete solar heating systems.

Table 7-3. Selected Solar Heating System Suppliers

Name of Firm	Type of System
Daystar	Nonfreezing liquid collection and storage
General Electric	Nonfreezing liquid collection and storage
Honeywell	Nonfreezing liquid collection and storage
Piper Hydro	Water collection (nondraining) and storage
Reynolds	Water collection (drainable) and storage
Solaron	Air collection, pebble-bed storage
Solar Utilities Co.	Water collection (nondraining) and storage

CONSULTING AND ENGINEERING SERVICES

In the planning and design of solar energy systems, particularly for large buildings, mechanical engineers, preferably with solar design experience, are a desirable, if not necessary, group to be involved. Unless a project comprises a complete system from one supplier, the sizing and selection of components, usually from various sources, their incorporation into a workable and efficient design, and their integration with the conventional heat supply and the building structure require engineering design. Even in residential installations, particularly if the components are separately purchased, the owner, architect, or heating system installer may require the services of a professional engineer.

Solar energy technology, in practical application, is so recent that substantial engineering experience in this field is lacking. Numerous individuals and firms offer services in this field, but some may not have carried out even one design, and others may have only one or two to their credit.

Mechanical engineering firms, specializing in heating and cooling system design for architects and contractors can be a source of expertise, particularly if they have had prior experience with solar system design or if they can retain an experienced solar consulting engineer for advice and assistance. At least one company that markets entire solar heating systems offers engineering and design of the system in residential and commercial buildings. This service is provided to architects, homeowners, mechanical engineering firms involved in heating system design for commercial and industrial buildings, and to heating and air conditioning contractors.

Private consultants with varying amounts of experience in solar heating design are also becoming available. These individuals, and the firms in which they are involved, can undertake the integration of subsystems into complete heating and cooling assemblies for various types of buildings. Some of the more experienced people in this category are members of university engineering faculties with previous experience in the design and operation of solar heating systems they have been developing.

It may be noted that in most large cities there are now listings of "solar engineers" in the "Yellow Pages" of the telephone directories. Qualifications of these people vary tremendously, from those with extensive experience to those with little competence. Without further information about the individuals and firms in such a listing, choice would be risky.

An extensive list of persons and organizations offering services in solar heating technology is contained in "Survey of Solar Energy Products and Services," May 1975, Committee print prepared by the Congressional Research Service of the Library of Congress for the Committee on Science and Technology of the U.S. House of Representatives.

COLLECTOR PERFORMANCE DATA

Most of the suppliers of solar heating system components provide technical data on their performance. Most of the collector data sheets contain information on solar heat collection efficiency at various temperatures and radiation levels. Some include information and instructions for sizing solar heating systems and installation procedures. At least one firm offers an extensive manual covering its products, instructions on their selection and sizing, and their assembly, installation and servicing.

It should be recognized that some of the manufacturers' literature contains information that has not been verified by impartial analysis, and that the data may not be representative of performance under typical operating conditions. There are cases of deceptive claims in some materials. The user is advised to proceed with caution in applying manufacturers' performance figures that have not been independently verified.

Standardized procedures and instrumentation for testing solar equipment have been developed by the American Society of Heating Refrigeration and Air Conditioning Engineers (ASHRAE) the results of their work is published in two standards:

- "Method of Testing Solar Collectors Based on Thermal Performance," ASHRAE 93-77.
- "Method of Testing Thermal Storage Devices Based on Thermal Performance," ASHRAE 94-78.

The testing procedures described in these reports will probably be mandatory for the rating of equipment, as solar codes develop.

Numerous solar collectors of the liquid heating type have been tested independently by the NASA-Lewis Research Center in Cleveland. Reports of their performance over a range of conditions are available, and can be used as a guide to equipment selection. These test results may also be compared with the performance claimed by the manufacturers in their data sheets. Additional testing of liquid heating collectors is also in progress in several independent laboratories.

There have been no independent evaluations and tests of solar air heaters, but facilities are being established at the National Bureau of Standards and at the NASA-Marshall Test Center in Huntsville, Alabama.

Facilities for testing and evaluation of complete solar heating systems are extremely limited. Colorado State University has three identical residential-type buildings in which various systems are being developed and evaluated. This program is producing information that can guide the choice of general system type, and will also yield detailed operating data on specific systems.

SELECTION OF COMPONENTS AND SYSTEMS

Choice of equipment for solar heating involves a knowledge of the characteristics that are significant -- and critical -- and the advantages and disadvantages of each system type. Besides the information contained in this manual, reference may be made to a helpful government publication, "Buying Solar," published by the Federal Energy Administration, June 1976.

Among the factors most important in equipment choice are the quality of materials and workmanship in the collector, controls, and fluid-handling equipment, the suitability of the materials and equipment to the application (involving such factors as durability, dependability, and safety), heat recovery efficiency over the range of operating conditions encountered, equipment cost, and installation cost. The system types requiring choice are primarily the flat-plate liquid-heating collector and associated equipment, and the flat-plate air-heating collector with its pebble-bed storage and air handling facility. Another possible choice is a system incorporating an evacuated glass tubular collector in either an air heating or water heating system. So-called passive systems involving collection and storage of heat by materials on or in roofs and walls of buildings rarely are candidates for selection because (a) their practicality has not been proven, (b) there is no manufacturer of such equipment, and (c), if used, these systems are essentially part of the building rather than a heating system. Finally, a system based on use of a focusing collector, although one is commercially available, would seldom be a candidate for residential use because of high cost, tracking requirements, and maintenance demands. Even for commercial buildings, the high cost is a deterrent to general use.

Durable materials and high-quality workmanship are necessary for efficient, trouble-free operation of solar-heating systems. Visual inspection will often separate the good and poor equipment. Other criteria are records of satisfactory use in previous installations, compliance with minimum property standards, and recommendations from impartial specialists. With liquid systems, the collector, storage unit, heat exchangers, if used, pumps and piping, should be made of materials that are completely compatible with the liquids being used in order that corrosion will not prematurely damage or destroy the system or its components. The collector and other parts of the system must also be able to withstand the maximum and minimum temperatures to which they are exposed. The absorber plate in an efficient collector of the flat-plate type can reach temperatures above 350°F when fluid circulation is interrupted accidentally or purposely, and there should be no material in the collector not capable of withstanding no-flow temperatures for prolonged periods. Wood or other materials that can outgas at these temperatures should never be used in a solar collector. If inspection shows the presence of such materials, the collector is clearly unsuited to normal space-heating applications.

If a liquid system is used in a freezing climate, it is essential that the collector be of the self-draining (fail-safe) type or that a nonfreezing liquid be used in the collector for heat exchange to water storage. If water is used, access to air to the collector tubes must be provided so that drainage will be complete. If water or aqueous antifreeze solutions are used in the collector, there must also be provision for protection against overpressure resulting from boiling, should circulation be lost. Collector venting or drainage is required, and convenient means for recharging the system with liquid to replace that vaporized must be incorporated.

The efficiency of the collector in recovering solar energy in a heated fluid is the primary determinant of the size of collector required for supply of a particular fraction of the total heat requirements of a building. And although this is an important criterion for collector selection, installed cost per unit area is equally significant. Assuming two styles of collectors have equal durability, the one having the higher heat delivery per dollar of first cost is the superior choice, regardless of the efficiency and the cost themselves. In other words, an increase of a few percentage points in efficiency that might be achieved by doubling the cost per square foot is not advantageous. The purchaser should therefore base the choice among various collectors of the general type selected on reliable efficiency measurements, delivered price of the collectors, and the cost of installation determined by installer's bid or the cost of installing similar systems on other buildings. Unless the solar collection efficiency claimed by the manufacturer has been independently verified or reliably confirmed by theoretical analysis, it should not be accepted without question.

As noted elsewhere, the sizing of a solar collector and associated equipment for carrying a certain fraction of the total heating load cannot be based on some collector efficiency measurement at "ideal" conditions characterized by full sun at near vertical angle with respect to the collector and at small to moderate temperature difference between collector fluid and the surrounding atmosphere. Seldom is the collector operating at such favorable conditions in normal use, so average efficiencies are far below such a level. In the selection of solar equipment, however, performance of collectors among a single general type can be compared at the ideal conditions. If collector efficiency is reported over a range of solar intensities and temperature conditions, comparison can be made at poor operating conditions as well as the better ones.

The two items probably most commonly overlooked in the selection of solar collectors and other system components are the durability, or apparent useful life, of the equipment and the cost of its installation in the building. The annual cost of ownership of the equipment is approximately inversely proportional to the useful life. In other words, if a solar collector must be replaced in 15 years, there is no advantage in its purchase at half the price of another collector having a 30-year life. Numerous collectors are on the market today that cannot be expected to operate satisfactorily even for 10 years, so their purchase at prices as low as $5 per square foot appears unwise. A collector that costs $12 to $15 per square foot that can be expected to function satisfactorily over the entire life of the building is a far better investment.

COMPARISON OF SYSTEM TYPES

The two major types of systems now available commercially are those that employ a liquid for transfer of heat from collector to storage and those that utilize air for the same purpose. The so-called passive types, in which collection and storage are combined, are not commercially manufactured because they are so closely associated with the design and construction of the building that they are primarily architectural considerations.

Nearly all of the air and water system types involve collectors employing flat-metal absorber plates overlaid with flat-glass sheets. A modification of this design is applied in the several variations on the evacuated tubular collector for air or water heating. A focusing type of collector employing a transparent plastic Fresnel lens is also receiving specialized experimental use.

Selection of one of the two commercial system types requires consideration and comparison of air and liquid handling in the system. Each has advantages and disadvantages. The primary advantages of the liquid system are due to use of a low-cost fluid with high heat capacity. Relatively small piping for transfer of heat from collector to storage, and, if the hydronic distribution system is used, for transferring heat from storage to the heated space, are economic advantages, particularly in large buildings. The volume of water in which a given quantity of heat can be stored is much lower than required of any other material not undergoing a phase change of some type. Heat storage in materials undergoing phase changes is not commercially practical, so water is the most compact heat storage material now available.

Another advantage of the liquid system is its capability for solar air conditioning. Although such systems are not fully developed, they do have practical possibilities, particularly in larger industrial and commercial buildings. An additional advantage in the liquid system is the number of commercial manufacturers of liquid heating solar collectors. Various styles, materials (aluminum, copper, and steel), transparent coverings (glass, plastic films, and heavy plastics), and sizes are available. Finally, a large amount of experience is available with liquid collectors (originally used for hot-water supply), including theory as well as practice.

The disadvantages of liquid systems result primarily from the chemical and physical properties of water. Its freezing point, boiling point, and chemical reactivity with metals require designs and materials that can add substantial cost to a solar heating system. In nearly all parts of the United States, water would occasionally freeze in a solar collector and cause extensive damage. A fail-safe drainage system must therefore be provided if water is used in the collector, or a nonfreezing liquid must be used, with heat exchange to water storage in a part of the building where freezing cannot occur. A self-draining collector imposes some design restrictions, and the periodic filling of the collector tubes with air imposes limitations on the types of metal that can be used. Nonaqueous heat transfer liquids may be used in the collector loop, but their practical utility has yet to be adequately demonstrated.

The corrosiveness of water in contact with aluminum and steel, in the presence of air, is a factor that must be considered in the design and use of water-heating solar collectors. Galvanic corrosion (in the presence of other metals) of aluminum in water must be avoided by suitable nonconducting connections in the system. Pitting corrosion of aluminum in the presence of slight metallic impurities as well as dissolved oxygen and impurities in the water may result in early failure of the aluminum tubes, particularly if thin-walled. Breakdown of antifreeze solutions (ethylene glycol for example) to acidic compounds can accelerate corrosive attack, and must be avoided by suitable preventive maintenance.

Steel is less subject to attack than aluminum, but precautions must nevertheless be taken. The probable life of a steel collector is greater than that of an aluminum collector having the same tube thickness. Periodic draining and filling with air must, however, be avoided. Copper, at least for tubes, appears to be the most durable and dependable material. The only disadvantage is its substantially higher cost. A plate-type copper collector requires an outlay roughly three dollars per square foot in excess of that for aluminum. At the retail level, this difference could be expected to show as a five to six dollar difference in selling price.

With any of the metals used for water-heating collectors, corrosion inhibitors can be added to the solution (whether freeze-protected or not), thereby substantially extending the life of the equipment. The inhibitor itself, however, must be maintained at suitable concentration by periodic checking and addition.

Another disadvantage of the water system is the boiling that occurs if circulation is lost during sunny weather. The system must be designed with appropriate vents or relief valves to permit discharge of steam when these failures occur. If the condition persists for several hours, there can be so much loss of fluid that recharge is then necessary. For typical residential and commercial installations, a maintenance man would then have to be called, and additional antifreeze agent (if used), corrosion inhibitor, and water would have to be added. These requirements impose costs that must be considered in any comparison of systems.

In a well-designed and maintained liquid system, damage to the building and its contents from liquid leakage should not occur. However, poor maintenance or careless operation can contribute to leakage of collector fluid or of water from the storage system through one of many joints and connections, or through corrosion sites, and result in expensive damage. Good preventive maintenance is therefore a primary requirement of satisfactory operation of a liquid system.

The advantages and disadvantages of an air system are essentially the reverse of those associated with a liquid system. Advantages are the absence of problems associated with corrosion, freezing, boiling, fluid replacement, monitoring of fluid composition, and potential damage by system leakage. A disadvantage of the air system is the larger volume required for heat storage -- approximately three times that for the equivalent heat storage capacity in water. This requirement imposes a need for floor space having a linear dimension approximately 60 percent greater than for a cylindrical storage tank. Equal heat storage can be provided, for example, in an eight-foot cube of pebbles and in a tank of water five feet in diameter and eight feet high.

Another air system disadvantage is the size of ductwork between collector and storage. About four square feet is required for two ducts between collector and storage in a typical residential installation, with correspondingly larger space for ductwork in commercial and industrial systems. Distribution ductwork is also larger, but this is a characteristic of the heat distribution system rather than of the solar choice. Warm air heating is used in over 80 percent of buildings in the United States, so this factor has already been dealt with in most installations. A third disadvantage, as pointed out above, is the current lack of air conditioning equipment operable with a solar-heated air supply. This situation is not yet a deterrent to air system use, however, because no solar air conditioning system is yet commercial.

Performance and costs of the two systems must, of course, be considered. In terms of system efficiency, or annual heat delivery per unit collector area, the two systems have comparable performance. Several studies have shown that the difference in heat output is small, and that one system may be slightly better under some conditions and the other superior in other situations. The most recent information on two identical adjacent houses shows nearly one-third more heat was supplied by the air system from equal collector areas. But a conservative appraisal is that the two systems have approximately equal heat delivery capability per square foot of collector area.

The final and conclusive basis for comparison is cost per unit heat delivered. If efficiency, useful life, and maintenance costs are equal, the system requiring the least maintenance per square foot of collector is the best choice. System costs are not yet sufficiently established for positive selection on this basis. However, examination of published prices of solar collectors and consideration of the costs of other components in the system suggest that the total installed cost of the air system is lower than that of the liquid system for equal heat output. Evidence in support of this indication is not conclusive, however, so unless actual quotations can be compared, it should be assumed that the cost difference is not large, possibly not over 10 percent of the total investment, and that any difference is probably in favor of the air system.

Another important factor bearing on solar heat cost is the useful life of the system and the cost of maintaining and repairing it. On these points, there is little doubt that the air system involves lower annual expense. The absence of corrosion, the use of moderate-priced metal (mild steel), and the absence of servicing requirements indicate that the air system will have a longer life and lower maintenance cost than the liquid system.

With respect to evacuated tubular collectors, their high efficiency is a great advantage. These units are not yet being made for general sale, so it is difficult to make comparisons with flat-plate systems. Manufacturing costs are much higher, and current prices may not reflect true costs. But if these units can be produced in large volume (e.g., a thousand tons of glass per month), costs might reach a competitive range. Selection of evacuated tubular systems today would have to be based on criteria other than cost, such as the need for experimentation and evaluation. But when demand reaches the level justifying automated tubular collector production with a furnace used exclusively for this product, costs may become very attractive.

There is also a focusing collector (Fresnel lens) that has been used experimentally. It requires a tracking mechanism, and the cost is substantially higher than the other systems. Unless high temperatures, well above 200°F, were a specific requirement as, for example, for absorption air conditioning, there appears to be no advantage in the use of this low-concentration focusing system. Its considerably higher cost, its inability to focus diffuse radiation, and the need for moving hardware, plus maintenance, appear to preclude its practical use for space heating.

In the final choice of a solar heating system, consideration must be given to specific circumstances. As previously indicated, liquid systems appear to have some advantages over air systems in large installations where maintenance is customary and where cooling may now or later be provided by solar energy. Other circumstances might also provide incentives for liquid system use. It is evident that both systems have potential for widespread application.

Comparison of the advantages and disadvantages of solar heating system types outlined above leads to the conclusion that the air system is superior insofar as durability and freedom from maintenance are concerned. Experience with a limited number of systems bears out this generalization. As to compactness and wide availability of hardware, the liquid system appears to be the better choice. These relative advantages suggest that air systems may predominate in residential installations where maintenance is notoriously neglected, where compactness is often not considered essential, and where durability is important. Liquid systems, on the other hand, may predominate in commercial and industrial installations where maintenance is routinely practiced, where space is frequently at a premium, and where occasional equipment replacement is acceptable if economically desirable.

CRITERIA AND STANDARDS

Possibly the most important element is the development and adaptation of standards which reflect the proper degree of technological advancement on the one hand and which the industry is willing to and can support in the marketplace.

Definitive performance criteria and standards will define the limits within which an industry can develop and flourish. The data collected from the demonstration program will provide a sound basis for the consensus standards process to function. To date three major steps have been made in this area:

a) Interim Performance Criteria have been published.[1]

b) Intermediate Minimum Property Standards for Solar Heating and Domestic Hot Water Systems have been published for review and comment.[2]

c) Plan for the Development and Implementation of Standards for the Solar Heating and Cooling Applications has been developed.[3]

Both a and b make extensive use of existing standards of both the performance and prescriptive types. However, where standards do not exist, they are imposed as mandatory standards whenever government contracts are involved.

This last item is an important step because the plan has been developed in conjunction with the ANSI Steering Committee on Solar Energy Standards Development. Figures 7-1 and 7-2 from the plan show the overall relationships of the concensus standards mechanism and how the various documents fit into the evolutionary process.

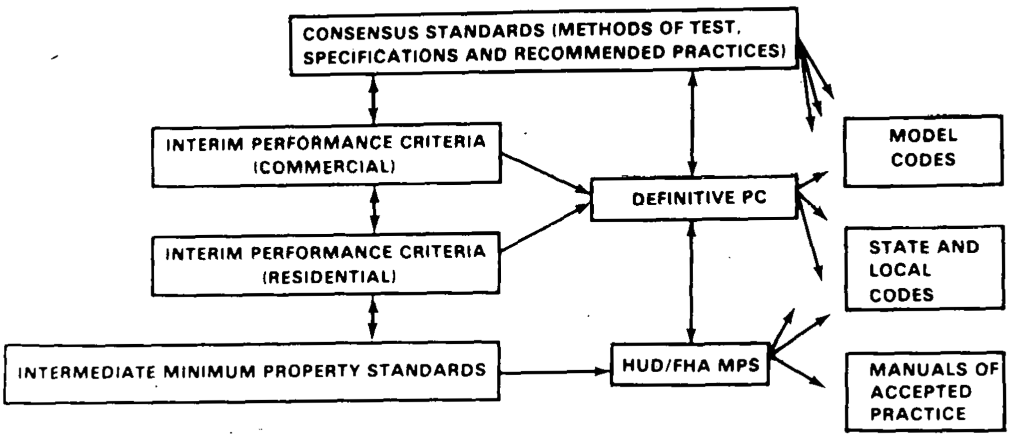


Figure 7-1. Definitive Performance Criteria Process

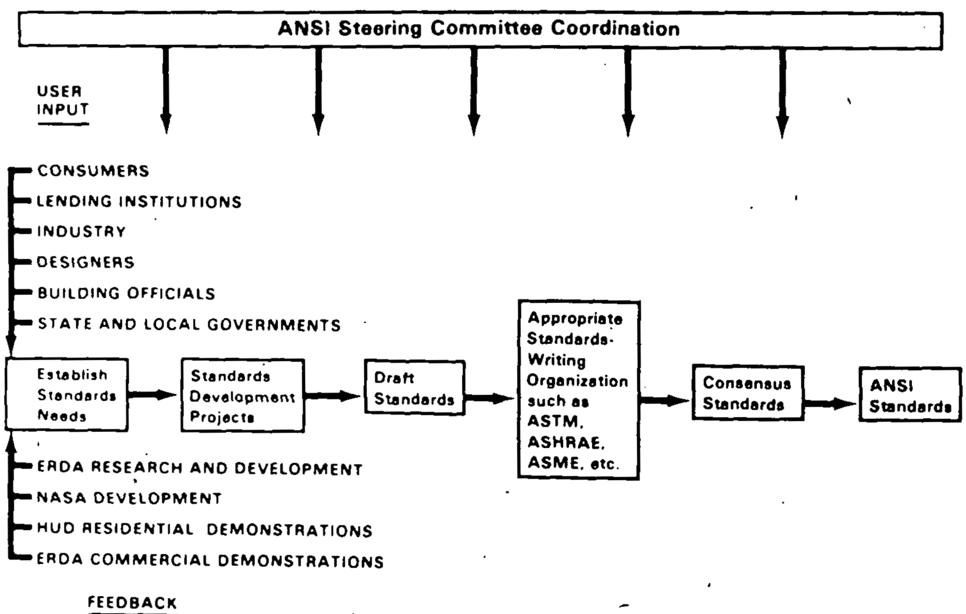


Figure 7-2. Solar Standards Development

This country has a unique system of voluntary concensus standards written by independent standard writing organizations. These organizations are being coordinated by the ANSI steering committee and are actively working on the elements of the plan(3).

A key element in the acceptability of consensus standards is a valid consensus. The standard writing body must have a tentative standard reviewed by all potential users and they must resolve all negative feedback before ANSI will accept the standard as an Americal National Standard.

If these consensus standards can be developed in time to form the basis for a Definitive Performance Criteria, they will be used in place of mandatory standards issued by government agencies. Several important standards are complete or near completion. One example is a Solar Collector Test Procedure (4) issued by ASHRAE; another is a system sizing method(5) published by SMACNA.

WARRANTIES

The types of warranties offered by manufacturers of solar heating equipment vary considerably. At the present time, if a supplier provides any warranty, it is of the "limited" type. Under its terms, the equipment is warranted to be free of defects in materials and workmanship, and that if such defects are found within a certain period of time after initial use, correction or replacement will be made without cost to the user. Most of the suppliers of solar equipment do not currently offer any type of warranty. A few, larger companies involved in solar equipment manufacture are offering one-year limited warranties. One company marketing an air system offers a 10-year limited warranty.

There appear to be no manufacturer's guarantees as to thermal efficiency or heat delivery capability of solar equipment. Although manufacturers are providing that type of information in their sales literature, they are not guaranteeing the performance in the field. To a certain degree, this omission is due to the inability of the manufacturer to control the quality of the installation. In addition, manufacturers supplying only certain components of a system, such as the collector, cannot be assured that the other components in the system are correctly selected or integrated with their own product. Thus, inferior performance might well be due to factors other than those controlled by the collector manufacturer. A performance warranty would thus be difficult to establish and maintain.

Still another problem in providing a meaningful performance warranty is the great variation in climate encountered and the practical difficulty in accurately measuring the output of the installed equipment. Instrumentation is usually not provided, so measurement of performance is likely to be an expensive investigation by an experienced engineer. Disputes, litigation, and other problems would be inevitable.

Practical performance warranties should become available for complete solar heating systems provided by a single manufacturer, assembled and installed by a single responsible individual or firm. Under such conditions, the manufacturer has sufficient control of the system design and the quality of the installation to have assurance of performance. The manufacturer could then guarantee the system to the installing firm which, in turn, would guarantee it to the purchaser. In case of dispute, the installer could measure system performance in the presence of the owner and a third party, if demanded, for determination of conformance. If inadequate, corrections would be made in compliance with the warranty, and the installer and manufacturer would establish responsibility for the departure from specifications.

Such developments as the Home Owners Warranty (HOW) program, sponsored by the National Association of Home Builders, can be expected to have an influence on solar heating equipment guarantees. Under the HOW program, all defects in a residential structure will be corrected at no cost to the owner during the first three years of use. It may be expected that solar heating equipment will have warranties conforming with such a program. Manufacturers will then be required to guarantee to the dealer and installer the necessary support for compliance with this program.

BUILDING CODES

There are few building codes in the United States that deal specifically with solar heating systems or components thereof. Some efforts toward establishment of specific codes have been started, but until criteria and standards have been set by national agencies, the information on which local authorities must base their codes for solar equipment is not available.

Most building codes, however, have provisions that can be applied to solar heating equipment as part of the structural and heating components of a building. Requirements as to roof load capability, structural integrity, flammability of materials, ventilation requirements, and so on, have restrictive as well as proscriptive influence on solar equipment. It is therefore necessary for an installer and owner of a solar heating system to comply with such terms in the local codes. In turn, the manufacturer will be required to conform if his hardware is to be sold and used in a particular area. For example, if a local code requires Underwriters Laboratory certification on heating units in a building, the manufacturer and installer would be required to use only such equipment in the solar system.

To the present time, building inspectors appear to have encountered no serious problems in approving solar heating installations. With probably over a thousand solar heating systems in the United States, it is evident that the lack of specific codes on solar heating equipment has not significantly deterred its use.

Since a full-capacity conventional heat supply is required in practically all areas where building codes apply, there is no appreciable danger that a solar heating system would fail to keep a building at a comfortable and safe temperature. Even if the efficiency of a solar heating system is far less than expected, a code authority could therefore approve such a system without transgressing code requirements.

As a general rule, an owner or contractor planning to install a solar heating system should contact the local building inspector prior to the expenditure of major effort on the project in order that any questions relating to compliance with the code can be resolved in advance. If a particular solar heating system or component clearly violates a code requirement, a change to some other type of hardware can be made prior to expenditure of significant funds on a system that would not be acceptable.

REFERENCES

(1) Interim Performance Criteria for Solar Heating and Cooling and Combined Heating/Cooling Systems and Dwellings, ERDA, Division of Solar Energy.

Interim Performance Criteria for Commercial Solar Heating and Cooling and Combined Heating/Cooling Systems and Facilities, November 1976. ERDA, NBSIR 76-1187.

(2) Intermediate Minimum Property Standards for Solar Heating and Domestic Hot Water Systems, 1977 edition, HUD, 4930.2

(3) Plan for the Development and Implementation of Standards for Solar Heating and Cooling Applications, ERDA, NBSIR 76-1143.

All of the above documents are available through the DOE Technical Information Center, P.O. Box 62, Oak Ridge, Tennessee 37830.

(4) Method of Testing Solar Collectors Based on Thermal Performance, ASHRAE 93-77. American Society of Heating, Refrigeration and Air Conditioning Engineers.

(5) Heating and Air Conditioning System, Installation Standards for One and Two Family Dwellings and Multifamily Housing Including Solar Sheet Metal and Air Conditioning, Contractors National Association, Inc.

SECTION VIII

SOURCES OF ADDITIONAL INFORMATION

For information on solar energy write to:

National Solar Heating & Cooling Information Center
Box 1607
Rockville, Maryland 20850
or call toll free -- 800-523-2929

Detailed information about building a home using solar energy can be obtained from these societies:

AMERICAN INSTITUTE OF ARCHITECTS

1735 New York Avenue N. W.
Washington, D. C. 20006

THE AMERICAN SOCIETY OF HEATING REFRIGERATING AND AIR CONDITIONING ENGINEERS

345 East 47th Street
New York, N. Y. 10017

SOLAR ENERGY INDUSTRIES ASSOCIATION

1001 Connecticut Avenue N. W.
Washington, D. C. 20036

ENERGY READING LIST

GENERAL READING

Direct Use of Sun's Energy
Farringtorn Daniels
Ballantine Books, $1.95

Solar Energy – Technology and Application
J. Richard Williams
Ann Arbor Science Publishers, Inc. $6.95

The Coming Age of Solar Energy
D. S. Halacy
Avon Publishing

Solar Heated Buildings – A Brief Survey
W. A. Shurcliff
19 Appleton St.
Cambridge, Mass. 02138 $7.00

Energy for Survival
Wilson Clark
Doubleday & Co., Inc. $4.95

Putting the Sun to Work, A History and Directory of Applications
State of Arizona, Arizona State Fuel and Energy Office
1624 West Adams
Phoenix, Arizona 85007

Energy, Environment, and Building
Phillip Steadman
Cambridge University Press $14.95

Future Energies
R. Meadon
Ann Arbor Science Publishers, Inc. $1.95

Project Independence – Solar Energy Task Force Report
GPO Stock No. 4118-00012, $6.20

An Assessment of Solar Energy as a National Energy Resource
GPO Stock No. 3800-00164

Systems Analysis of Solar Energy Programs
PB 231-142/AS $7.25

Report and Recommendation of Solar Energy Data Workshop
GPO Stock No. NSF-RA-N-47-062

Inventory of Current Energy R&D; Volumes-I, II, III
GPO Stock No. 5270-02172, 5270-02173, 5270-02174, $9.80, $3.10, $5.00

TECHNICAL READING

Solar Energy Thermal Processes
J. Duffie & Beckman
Wiley Publishing $16.95

"Solar Energy Utilization," ASHRAE Handbook, Chap. 59
Amer. Society of Heating, Refrigeration, & Air-Conditioning Engrs.
345 E. 47th Street
New York, N. Y. 10017 $1.00

Solar Energy for Man
B. J. Brinkworth
John Wiley & Sons, Inc. $9.95

Low-Temperature Engineering Application of Solar Energy
Technical Committee on Solar Energy Utilization
Amer. Society of Heating, Refrigeration & Air Conditioning Engrs. $9.00

Solar Energy Digest
P.O. Box 17776
San Diego, Ca. 92117 $27.50/year

Solar Energy, A Bibliography – TID 3351
U. S. Energy Research and Development Administration
National Technical Services
Springfield, Va. 22151 $10.50

Solar Thermal Energy Utilization, 1957 – 1975
Energy Information Center
University of New Mexico
Albuquerque, N.M. 87131 $37.50

Proceedings of World Symposium on Applied Solar Energy
Johnson Reprint Corp.
111 Fifth Ave.
New York 10003 $15.00

Criteria for Preliminary Design of Solar Heated Buildings
E.M. Barber & D. Watson
Sunworks, Inc.,
Guilford Ct. 06437 $10.00

TECHNICAL READING

Interim Performance Criteria for Solar Heating/Cooling Systems & Dwellings
GPO Stock No. 0324–01043, $1.90

Solar Heating/Cooling for Buildings Workshop
GPO Stock No. 3800-00171, $2.50

Proceedings of Solar Heating/Cooling for Buildings Workshop
GPO Stock No. 3800-00171

Design and Test Report for Transportable Solar Laboratory
GPO Stock No. 3800-00171

Solar Cooling for Buildings Workshop
GPO Stock No. 3800-00189

Solar Energy Architectural Study Reports – 7 Volumes
AIA Research Corp.
1735 New York Ave. N. W.
Washington, D. C. 20546 $100/Set

How to Build Solar Swimming Pool Heater
Copper Development Association
605 Lexington Ave.
New York, N. Y.

Note: GPO Documents are available from
U. S. Government Printing Office
Washington, D. C. 20402

PB Documents are available from
National Technical Information System
Department of Commerce
Springfield, Virginia 22151

United States
Department of Energy
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