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SOLAR RADIATION

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INTRODUCTION

Solar energy is becoming increasingly emphasized as an alternative to fossil fuels as an energy source. Since the use of solar energy is very dependent on weather and climate, the National Weather Service (NWS) is increasingly being asked to provide solar users with various weather-related information. There is a lot of information on solar energy available and much useful weather information for the user. Unfortunately, the information is scattered among numerous sources, not all of which have been available at National Weather Service Offices.

It is the purpose of this publication to be a central source of solar information and a reference for weather data necessary for solar users. Many publications have been examined, and portions of them have been incorporated here for easy reference.

The paper is broken down into two main parts. Section I discusses uses and methods of use of solar energy. It is intended to give NWS personnel a background in solar energy so that they (we) may better serve the (our) solar users. A person well-versed in solar energy may want to skip this section.

Section II deals with the impact of weather and climate on solar use. Weather information necessary for the user of various solar methods is discussed and sources of this information are given.

As an overview, this paper touches on many facets of solar energy, without going into great detail on any. One requiring further detailed information will find the Bibliography helpful in locating adequate sources.

I. SOLAR ENERGY

Solar energy is electromagnetic waves that travel through space at the speed of 186,000 miles per second. These waves arrive at the top of the earth's atmosphere carrying energy at a near-constant rate of 444 Btu's per hour for every square foot of area. After some of this energy is absorbed by the atmosphere, reflected by cloud cover, etc., the average amount over a year's time falling on a square foot of ground in the United States is about 13% of this or 58 Btu's per hour (17 watts).

Man has used solar energy throughout time; it is not new. What is new is the various ways man is now trying to better collect, store, and use this energy. The emphasis being placed on solar energy, as a major energy replacement of fossil fuels, is also new.

There are various methods of using solar energy. Some are direct uses of the electromagnetic waves, while others are not.

The direct methods use the sun's energy to heat a fluid or generate electricity. The indirect methods take some medium that is a direct result of the sun's insolation and use it to heat a fluid or generate electricity. The wind (direct result of differential heating from the sun), vegetation, and animal wastes for biomass conversion (direct result of solar energy stored in plants and waste and solar energy decomposing them), ocean waves (direct result of the wind which is generated by the sun), and ocean thermocline (direct result of sun heating upper layers of the ocean) are examples of indirect solar methods.

MEASURING SOLAR ENERGY

Solar radiation, as all types of radiation, is measured in many different units. Table 1 lists the many units used for radiation and conversion factors from one to another. One must be careful not to confuse solar radiation with sunlight values. Sunlight is usually measured in foot candles (see Table 2 for other units and conversion factors) and is only the visible portion of the solar spectrum (Figure 1). It cannot be directly converted to solar energy which includes all wavelengths of the solar spectrum. Approximate conversions may be given for specific conditions such as clear skies or overcast skies (see Table

3). A graph for converting, minutes of sunshine to solar radiation is given in Figure 2, which is taken from the Smithsonian Meteorological Tables. This graph may be helpful where long-term averages are needed. Large errors may result if used on a daily basis, however, as the relationship of minutes of sunshine to total solar energy received at the surface is very dependent on the time of day that the sunshine minutes are accumulated. Twenty minutes of sunshine at noon delivers much more energy than twenty minutes of sunshine near sunrise or sunset.

The National Oceanic and Atmospheric Administration (NOAA) operates a 38-station NWS network taking solar radiation observations at locations shown in Figure 3. All stations now measure total radiation on a horizontal surface with an instrument called a pyranometer (see Figure 4 for sketches of solar radiation measuring instruments). Soon, all stations will also monitor the radiant energy coming from just the sun's disk and its immediate vicinity, called direct radiation. This is accomplished by a pyrheliometer which tracks the sun with a telescope-like tube.

Additionally, 10 stations shown on the map (Figure 3) operate a pyranometer with rings that shade the instrument from the direct rays of the sun. These observations measure the diffused or scattered solar radiation. The sum of the direct and diffuse radiation is the total or global radiation.

HOW MAN IS PUTTING SOLAR ENERGY TO WORK

Solar energy, although largely used to provide heat via a collector, is used in many other ways. It can also involve photovoltaic energy, the direct conversion of the sun's energy into electricity; bioconversion, solar decomposition of agricultural or municipal wastes to provide fuel; wind, harnessing wind energy to generate electricity or drive pumps; solar thermal electric, concentrating the sun's rays to obtain high temperatures and thus generate electric power; and ocean-stored energy, utilizing temperature differences between the surface waters and ocean depths or using ocean waves. These various means are discussed below.

A. Using Collectors to Gather Solar (Thermal) Energy.

By using collectors, large amounts of energy can be gathered and used in one smaller location. If large storage devices are used, this energy can be saved and used to produce heat through extended periods of cold weather and/or overcast conditions. Normally, it is too costly to provide storage facilities to handle the rare, extended, very cold periods. Thus, solar energy does not usually supply all the necessary energy. Backup heating facilities are then used to supplement these solar systems (the average system is 70% solar, 30% backup).

The typical solar collector is an insulated box which uses solar energy to heat a fluid (liquid or gas). (See Figure A1.) The fluid can be the medium that is to be heated, or it can be an intermediate fluid that will later transfer heat to the desired medium. The selected fluid is one which has a large heat capacity (able to hold a lot of heat).

A system that collects heat and stores it until it is needed is an <u>active system</u>. One that merely best utilizes solar energy when it is available and collects and stores it in one location is a <u>passive system</u>. Active systems are generally able to provide a larger percentage of the users energy needs, but are more costly to install. These two systems are explained in more detail and diagramed in Appendix 1.

The collecting fluid used in many collectors is water. For this reason, solar energy can additionally be used to heat culinary water for residential and commercial use. This is a very efficient use of solar energy, and is presently the most cost-effective use. A typical water heating system is outlined in Appendix 2.

B. Photovoltaic Conversion.

This method directly converts solar radiation to electricity. As with flat-plate thermal collectors, this method works only when the sun is shining and receives most energy under direct lighting and at solar noon on a clear day. For off-peak use, battery storage is required with regulators to keep a steady flow of electricity.

The basic solar cell is diagramed in Figure 5. A silicon solar cell has a thin n-layer (phosphorous-silicon) overlaying a thin junction and p-layer (boron-silicon). When sunlight delivers energy to the p-layer, electrons are knocked out of some of the silicon atoms, leaving "holes" in the electronic structure. These free and energetic electrons move across the junction to the n-layer and then through the wire to the load, where their energy is converted to useful work. The electrons then go to the p-layer and re-enter its electronic structure at the "holes".

Solar cells are very reliable and have a long life. Nothing is consumed in the cell so it doesn't wear out. It does lose effectiveness with time, however, as the n-layer gradually clouds up reducing its ability to let light pass through to the p-layer. This lowers the cells efficiency. The factor limiting widespread photovoltaic cell use is the cost of manufacturing the cell. The expense is due to the handcrafting process to fabricate it.

A single crystal of extremely pure silicon is artificially grown in the form of an ingot. Wafers are then cut from the ingot and are polished and trimmed. The impurities are diffused into the silicon in an oven. Finally electrical connectors are added and the finished cells are mounted in arrays.

These arrays or modules are combined to meet the particular system requirements.

In 1976, solar-cell modules for land use were priced from \$15 - \$20 per peak watt, which is quite expensive when compared to other forms of electrical generation. Research into mass producing these cells and possible use of other semiconductors of lower production costs may bring the costs down. The Department of Energy's efforts are aimed at bringing the price down to \$.50 per peak watt by the mid-1980's.

C. Bioconversion.

Bioconversion uses nature's acid-producing bacteria and the sun's heat to anaerobically decompose organic material into gases and a liquid/solid residue. The gases are methane, carbon dioxide, hydrogen, and traces of other gases. Of these, methane is a combustible gas which can be burned to produce heat. The slurry (residue) is a high nitrogen content material which makes an excellent fertilizer. Thus, the waste materials are turned into two useful products.

D. Wind.

Wind power is a transfer of the energy in the wind $(1/2\rho AV^3)$ to a generator (windmill) able to produce electricity.

The windmill gathers this energy from the air with density (ρ) over a large area (A) and uses batteries to store the energy when conditions of light winds (V) exist. Figure 6 shows two common types of windmills.

E. Solar Thermal Electric.

Normal solar collectors (flat, plate type) that use a liquid fluid operate at temperatures between freezing and boiling (0^oC and 100^oC). This allows ample heat collection without needing a high-pressure system to avoid damage from expansion and contraction. Special concentrating collectors are designed to reach very high temperatures so that water can be boiled. The steam from boiling water is then used in a compressor (steam engine) to generate electricity.

F. Ocean.

Ocean methods are largely experimental as they are quite costly to be practical. The cost is in the retrieval of the energy, even though the energy itself is abundant. The ocean acts as a large heat storage medium like those used in active solar systems. This method uses convective currents to generate electricity (see Figure 7). Like the atmosphere, the ocean temperature changes with depth (warm above, cool below). Though the atmosphere may have stronger temperature gradients, the ocean has much more heat readily available for conversion than the atmosphere (specific heats of water and air at 50^oC cal/gram are .99829 and .2480 cal/gram, respectively).

The various methods described above all have certain advantages and disadvantages to their usefulness. None have been seriously investigated as energy-conversion methods in the past, because the cost per unit of energy was significantly higher than fossil fuel energy. Now, with fossil fuels becoming less available and more costly, solar methods are becoming more cost-effective. This trend will continue as long as fossil fuel prices continue to rise. Additionally, the costs involved in manufacturing solar collectors and heating systems are expected to decline in the future or at least stay near present levels despite general economic inflation. This will be brought about by mass production. Right now the demand (although increasing rapidly) is still low on solar devices, so most are made by hand.

The most promising area of solar use for the future is in individual residence heating (air and water) systems. Near-term increases in solar heating will be largely determined by government efforts to make it more attractive.

Initial costs of building a home with active solar heating rather than electric or gas heating may be as much as $20,000.00 or more. Passive homes (see Appendix 1, Passive Systems) also are more costly to build than conventional homes. Even though the pay-back period may be reduced to make it cost-effective, the initial funds must be available. Tax incentives and government encouragement through lending institutions will determine the number of persons able to go this route. As of November 1977, 30 states had passed some type of tax-incentive legislation for solar devices. Because of this uncertainty, outlooks to the future are difficult. Since 20% of the Nation's energy is used to heat and cool homes, and solar devices on the average home provide about 70% of the total heating demand, a maximum of 14% energy reduction could be achieved by solar homes alone. Another 8% of the national energy need could be met by the year 2020 with large-scale processes to convert solar energy to electric power. Research may bring photovoltaic or "solar" cells into economic reach at $500 per kilowatt by 1985. The Energy Research and Development Administration is developing a series of wind machines with generating capacities from 100 kW to several mW (utility scale generation). Effectiveness and cost will determine its future course. Biomass conversion will mainly be used by agriculturalists and possibly by municipalities as part of waste treatment. Ocean-thermal conversion and ocean-wave conversion are largely experimental, and cost may prevent it from being fully utilized.

II. SOLAR DEPENDENCE ON WEATHER AND CLIMATOLOGY

AVAILABILITY OF SOLAR ENERGY

The amount of solar energy received at a location on earth is dependent on the angle of the sun, the length of day, and transmissivity of the atmosphere. Figure 8 demonstrates how latitude affects the sunlight received. The sun is much lower in the sky at point A than point A^1. Thus, the sun's rays are spread out over a larger area at point A and less heat per-square-foot is available to the earth's surface. To help remedy this problem, a solar collector can be tilted to be perpendicular to the incoming rays and concentrate this energy. This doesn't solve the problem entirely, however. The amount of air that the sunlight must pass through is greater at point A than point A^1 (segment AB is longer than A^1B^1). Thus more sunlight is absorbed or reflected by aerosols back to space at point A than point A^1.

The duration of sunlight is also less with increased latitude in the winter. For example, on December 21st Phoenix, Arizona, (about 33°N latitude) receives 9 hours 56 minutes of sunlight; Seattle, Washington, (about 48°N) receives 8 hours 27 minutes of sunlight, and Fairbanks, Alaska, (about 65°N) receives 3 hours 42 minutes of sunlight.

There are other factors altering this radiation. There can be a lot of aerosols in the air to scatter the energy from natural dust and man-made pollutants. This causes diffuse radiation which is more difficult to collect (less efficient). This is especially true of curved, concentrating collectors. They lose most of their effectiveness and are even less efficient than flat plate collectors, under diffuse radiation. Clouds and fog are other natural phenomena that scatter and reflect this radiation so that the ground doesn't receive all that is possible.

To briefly summarize, solar availability is affected by:

1) Angle of the sun above the horizon
2) Length of day
3) Transmissivity of the atmosphere
4) Cloud cover (and type of).

Solar users are then interested in the following information:

1) Amount of solar radiation available (langleys per day as in Figures 9-17) forecast amount, and daily observed amounts broken down by hours.

2) Length of day (available in sunrise/sunset tables).

3) Minutes of sunshine (forecasts in detail[1], daily observed amounts).

4) Amount and type of cloud cover and its duration (detailed sky observations and climatologies are needed). Information can be found in aviation observations (SA's and LCD's).

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[1] Forecasters at Quebec Forecast Office have shown that accurate forecasts of percent of possible sunshine can be made. For details see <u>Bulletin of American Meteorological Society</u>, May 1978, pages 581-584.

5) Visibility and air quality (forecasts, observations, and climatologies are needed--local forecasts and SA's and LCD's are sources).

TEMPERATURE

Temperature is important for many reasons. Since a large portion of solar use is for residential heating, the temperature determines the demand on the system. If the system cannot meet the demand, more costly back-up heating must be planned for and used.

System efficiencies are also altered by the outside temperature. Even though collectors are insulated, they lose more heat as the outside air gets colder. Active systems, that use water as a collecting fluid, are subject to freezing or boiling under certain circumstances. Special care must be taken at these times to avoid costly system damage. Hence, solar users are interested in:

1) Normal Temperatures (climatologies of maxima, minima degree days).

2) Extreme Temperatures (climatology, annual LCD's).

3) Observed Temperatures (from SA's, LCD's).

4) Forecast Temperature (detailed local short-term forecasts and long-range outlooks).

The above information is available at most NWS offices. Detailed information for all areas of the country is available at the National Climatic Center (NCC) in Asheville, North Carolina.

WIND

Wind information is crucial to wind power generation. Not only is average wind important for system design, but the variability of the wind is needed. Since wind power is proportional to the cube of the wind speed, a wind machine will generate more electricity from a wind that averaged a certain speed but was sometimes higher and lower than that, than a wind of that constant speed. The example below demonstrates this:

1/3 of day	$9^3 = 729$	$12^3 = 1728$
1/3 of day	$12^3 = 1728$	$12^3 = 1728$
1/3 of day	$15^3 = 3375$	$12^3 = 1728$
Total day	5832	5184

The power generated in a variable wind will be erratic and may be inadequately at the lower speeds and a surplus at the higher speeds. Wind has an additional effect of drawing heat away from and infiltrating an object not perfectly insulated. Solar collectors and the area being heated (water volume or home surface area) lose more heat to the atmosphere, making the demand greater and the efficiency lower.

Hence, the user needs:

1) Average wind conditions and variability (from LCD's, aviation climatologies).

2) Wind observations in detail for variability (gustiness, lulls, and averages from SA's and LCD's).

3) Forecasts of average winds and variability (local forecasts).

There are many, more-detailed publications available to the interested person from government agencies and private concerns for information not found in this paper. To understand where to go, a brief outline of government agencies and their objective dealing with solar energy are listed for further reference.

1) Energy Research and Development Administration (ERDA). <u>Purpose</u>: To develop all energy sources, to make the Nation basically self-sufficient in energy and to protect public health and welfare and the environment.

2) National Solar Heating and Cooling Information Center (Operated by U.S. Department of Housing and Urban Development and U.S. Department of Energy). Purpose: Provide a one-stop service facility for all information, domestic and foreign, technical and nontechnical, on any aspect of solar heating and cooling.

3) Federal Energy Administration; Department of Health, Education, and Welfare; Office of Consumer Affairs. Purpose: Provide consumers with information regarding energy systems.

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Solar Energy and Your Home, April 1978, HUD-PDR-183(8), U. S. Department of Housing and Urban Development (HUD), National Solar Heating and Cooling Information Center (NSHCIC), P. O. Box 1607, Rockville, Maryland 20850, Phone: 800-523-2929.

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Solar Radiation Data Sources, Applications and Network Design, April 1978. U.S. Department of Energy, HCP/T5362-01).

TABLE 1. RADIATION CONVERSION FACTOR

To Convert	To	Multiply by
Btu ft^{-2}	Ly	2.713×10^{-1}
Btu ft^{-2}	kWhm^{-2}	4.283×10^{-2}
Btu ft^{-2} h^{-1}	Ly min^{-1}	4.522×10^{-3}
Btu ft^{-2} h^{-1}	Wm^{-2}	3.155
Btu ft^{-2} h^{-1}	Ly s^{-1}	7.537×10^{-5}
Btu	cal	2.520×10^{2}
Btu	Joule	1.055×10^{3}
Btu	kWh	2.928×10^{-4}
Btu h^{-1}	W	2.930×10^{-1}
Ly (langley)	Jm^{-2}	4.186×10^{4}
Ly min^{-1}	kWh m^{-2} min^{-1}	1.162×10^{-2}
Ly min^{-1}	erg cm^{-2} s^{-1}	6.974×10^{2}
Ly s^{-1}	Wm^{-2}	4.186×10^{4}
Wm^{-2}	kWhm^{-2} s^{-1}	2.778×10^{-7}
To get	From	Divide by

TABLE 2. ILLUMINATION CONVERSION FACTORS

To Convert	To	Multiply by
foot candles	Lux	10.76
foot lambert	cd m^{-2}	3.426259
Lambert	cd m^{-2}	$3.1416 \text{x} 10^{4}$
To Get	From	Divide by

TABLE 3. ILLUMINATION/RADIATION CONVERSION FACTORS

An accurate conversion is impossible but a rough conversion is possible when the energy source is known.

To Convert	To	When	Multiply by
langleys per minute	foot-candles	cloudless day	6,700
langleys per minute	foot-candles	cloudy day	7,000
langleys per minute	foot-candles	100w light bulb	16100
langleys per minute	foot-candles	cool white florescent	21800
langleys per minute	foot-candles	warm white florescent	24900
langleys per minute	foot-candles	daylight florescent	19800
To get	From	When	Divide by

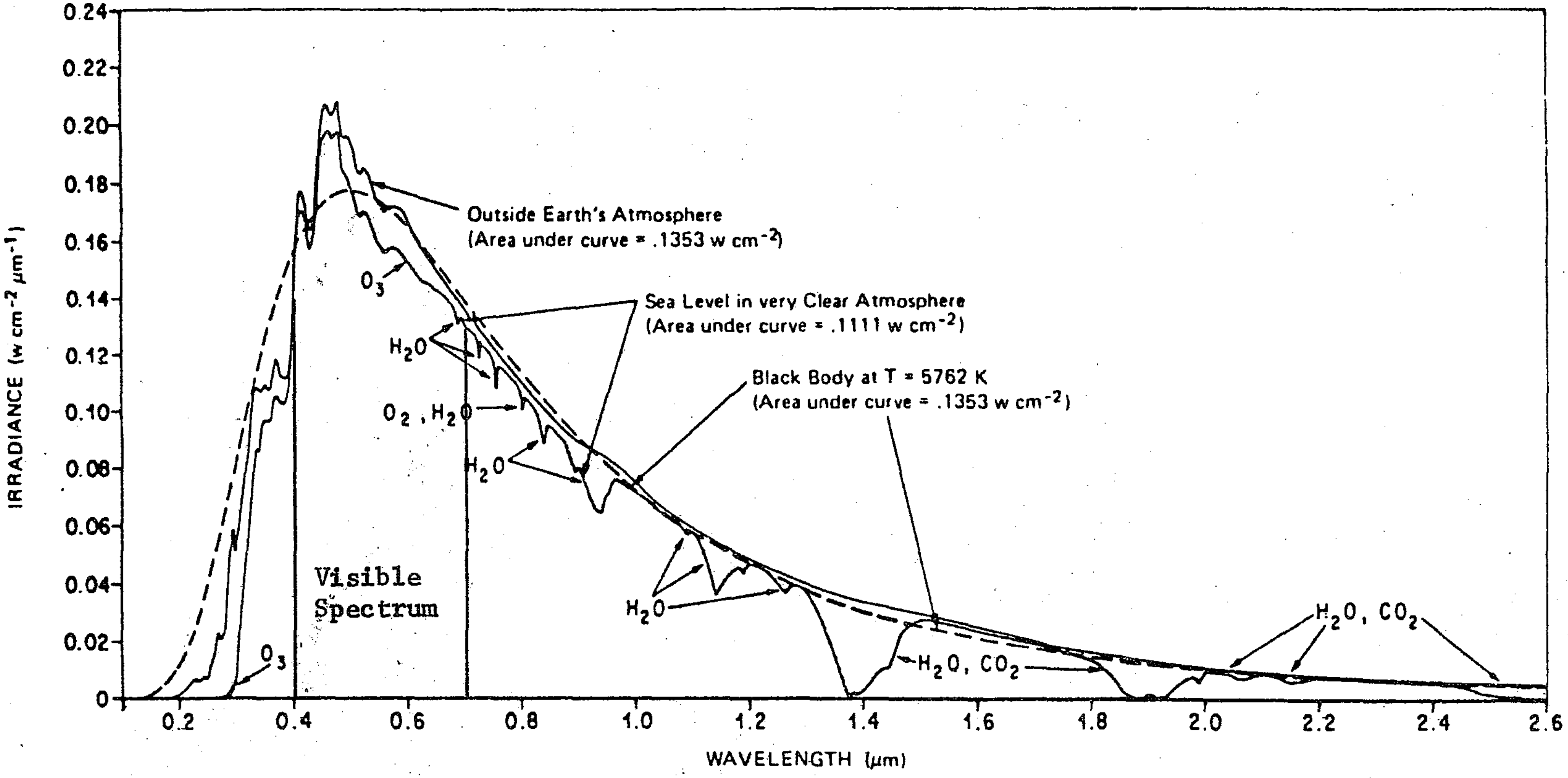


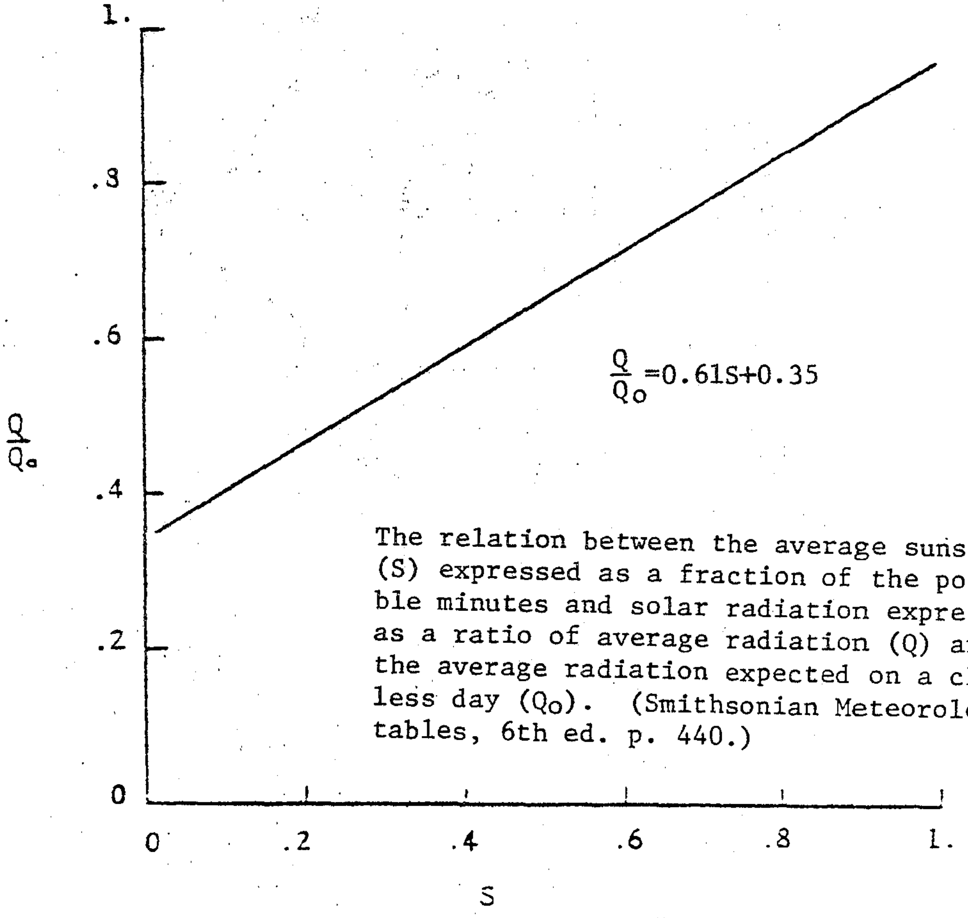
Figure 1. Normal Incident Solar Radiation at Sea Level on Very Clear Days, Solar Spectral Irradiance Outside the Earth's Atmosphere at 1 AU, and Black Body Spectral Irradiance Curve at T=5762°K (Normalized to 1 AU). From Daniels (1973).

Solar Constant

One solar constant is the amount of radiation striking a normally oriented surface above the earth's atmosphere. Radiation at the ground is usually less than the constant.

1 solar constant* =	1353.	Wm^{-2}
(Air mass zero)	135.3	$mW\ cm^{-2}$
	125.7	$W\ ft^{-2}$
	429.2	$B.T.U.\ ft^{-2}\ hr^{-1}$
	0.1192	$B.T.U.\ ft^{-2}\ sec^{-1}$
	1.353×10^6	$erg\ cm^{-2}\ sec^{-1}$
	1.937	$langley\ min^{-1}$
	0.0323	$cal\ cm^{-2}\ sec^{-1}$
	1.81	$hp\ m^{-2}$ (horsepower per sq. meter)

*Value from Solar Electromagnetic Radiation May 1971 NASA Special Publication SP-8005. The accepted value previous to 1971 was 3% higher than those given above.



The relation between the average sunshine (S) expressed as a fraction of the possible minutes and solar radiation expressed as a ratio of average radiation (Q) and the average radiation expected on a cloudless day (Q_o). (Smithsonian Meteorological tables, 6th ed. p. 440.)

Figure 2

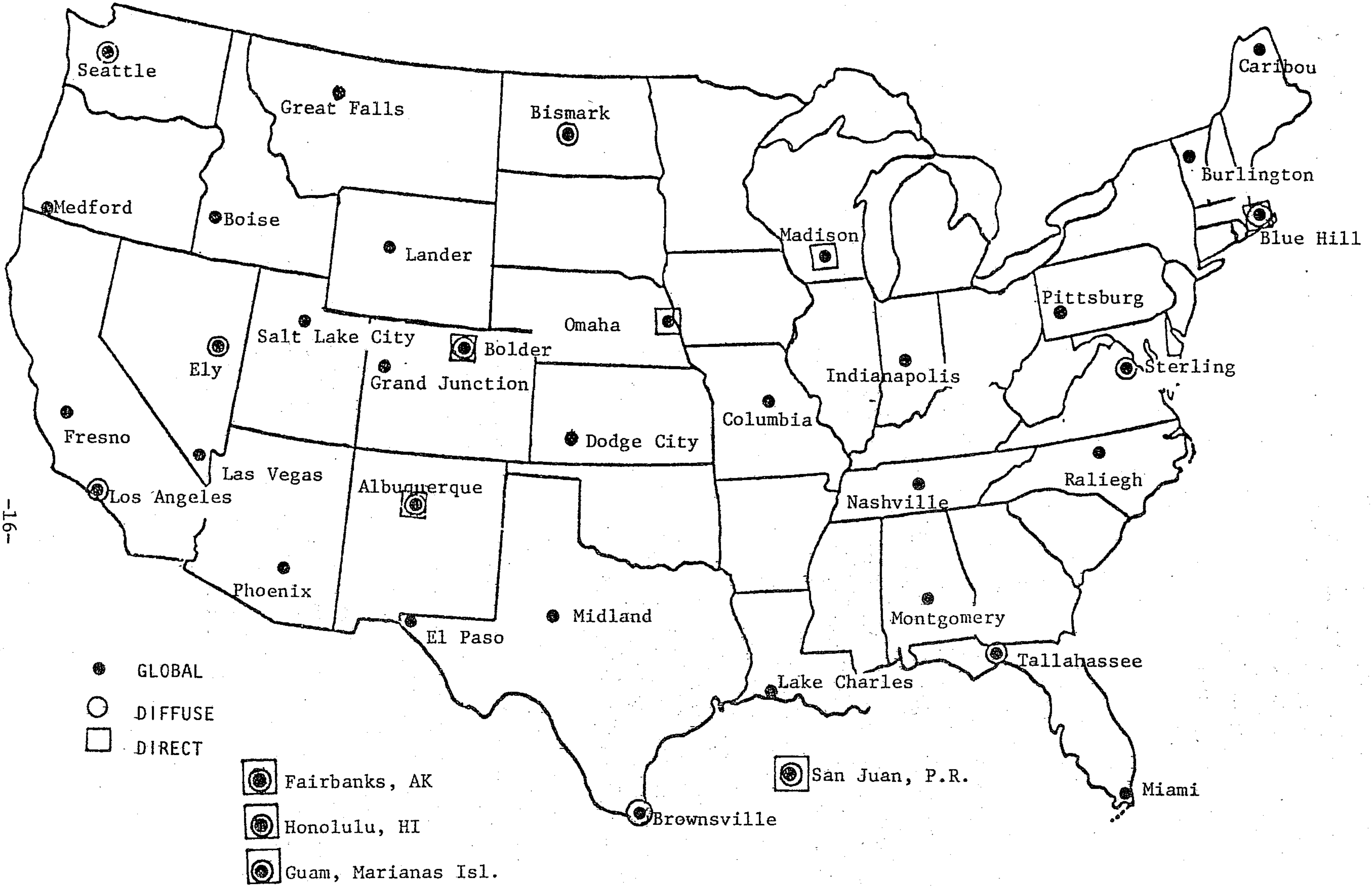


Figure 3. NOAA Solar Radiation Network, January 1978.

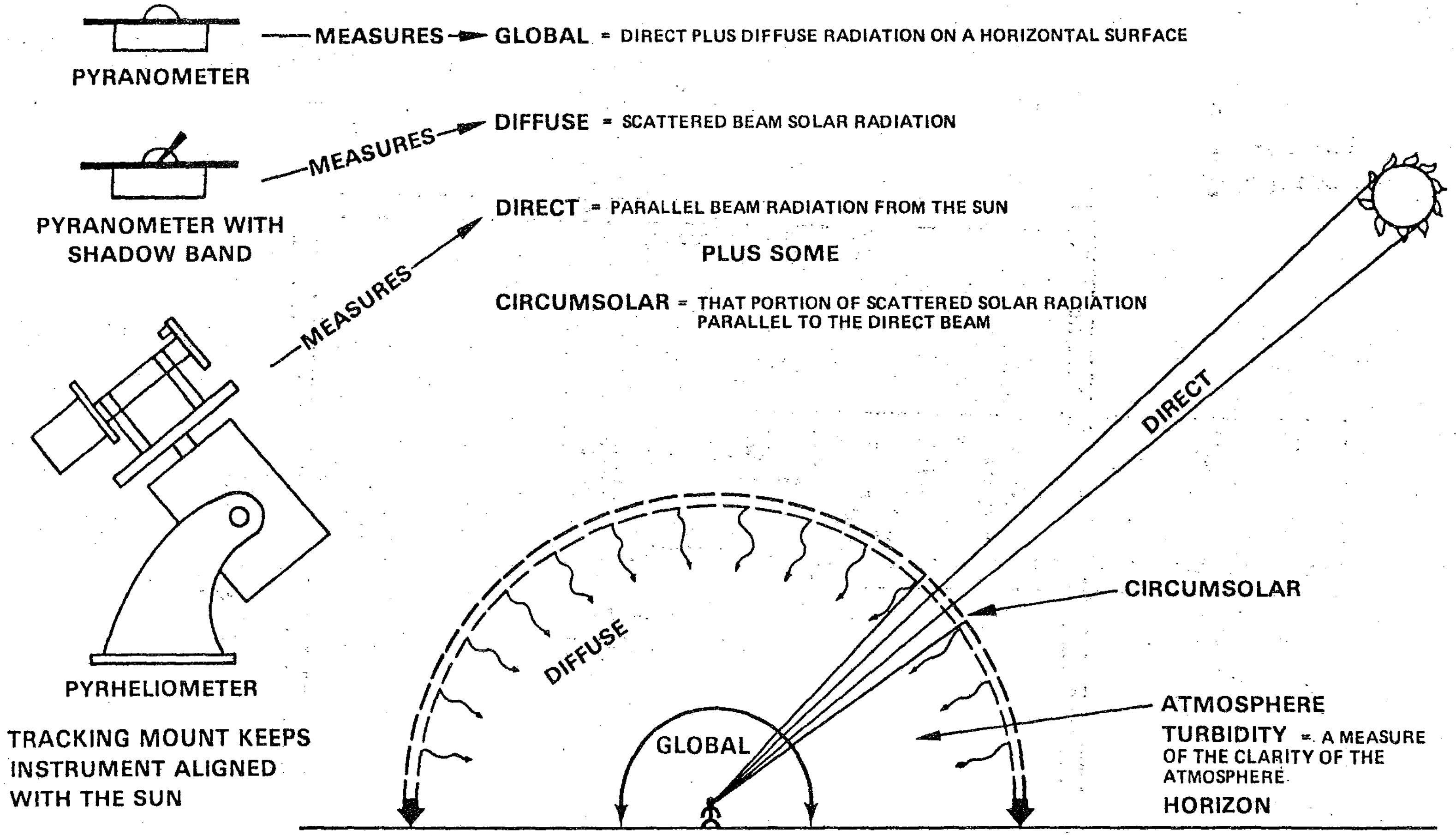


Figure 4. The Environmental and Resource Assessment Program has established a nationwide network to measure insolation. This sketch shows types of insolation and measuring instruments.

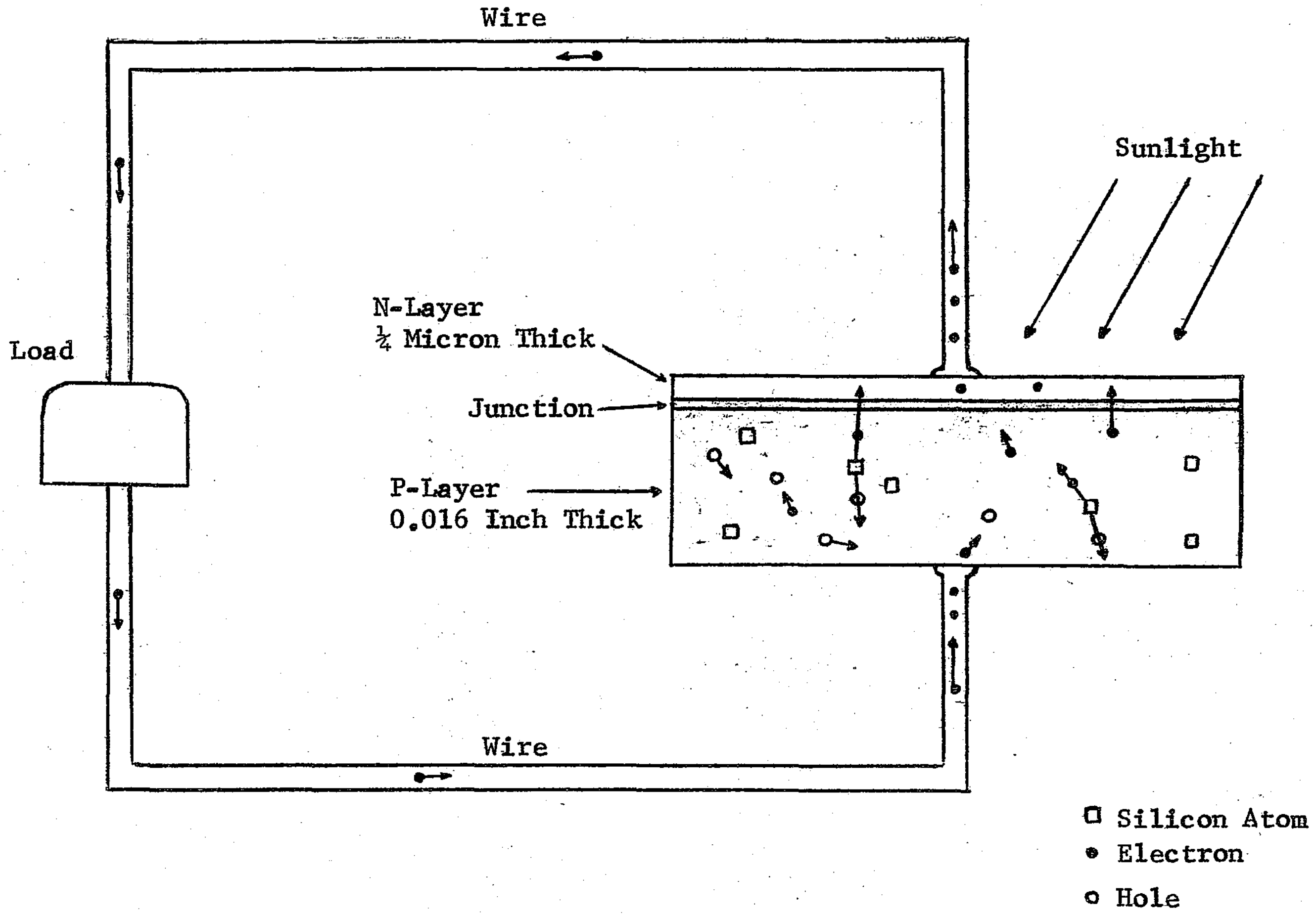


Figure 5. Silicon Solar Cell.

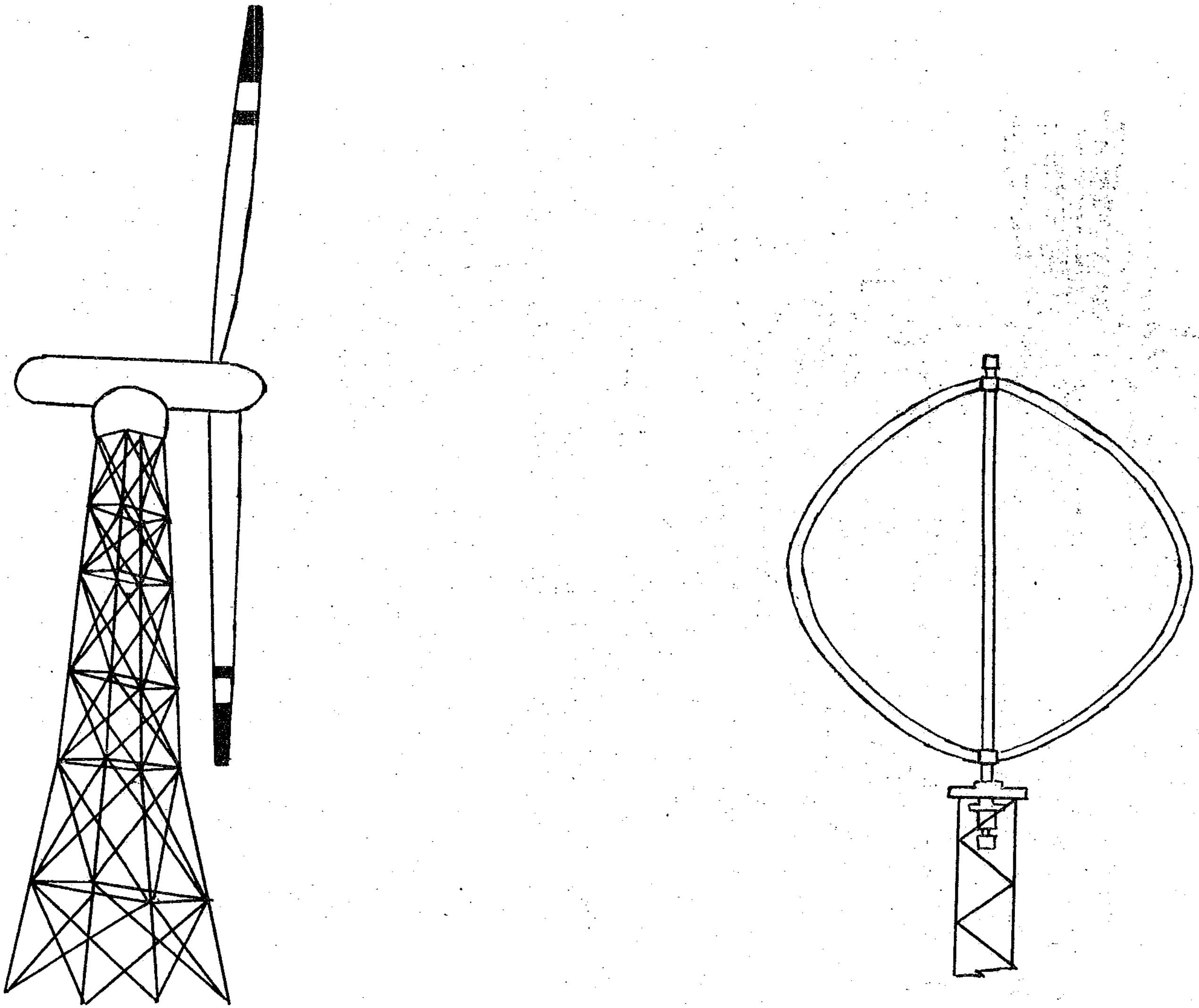


Figure 6. Two common types of windmills used for generation of electricity. Left is a propeller type and right is a vertical axis wind turbine.

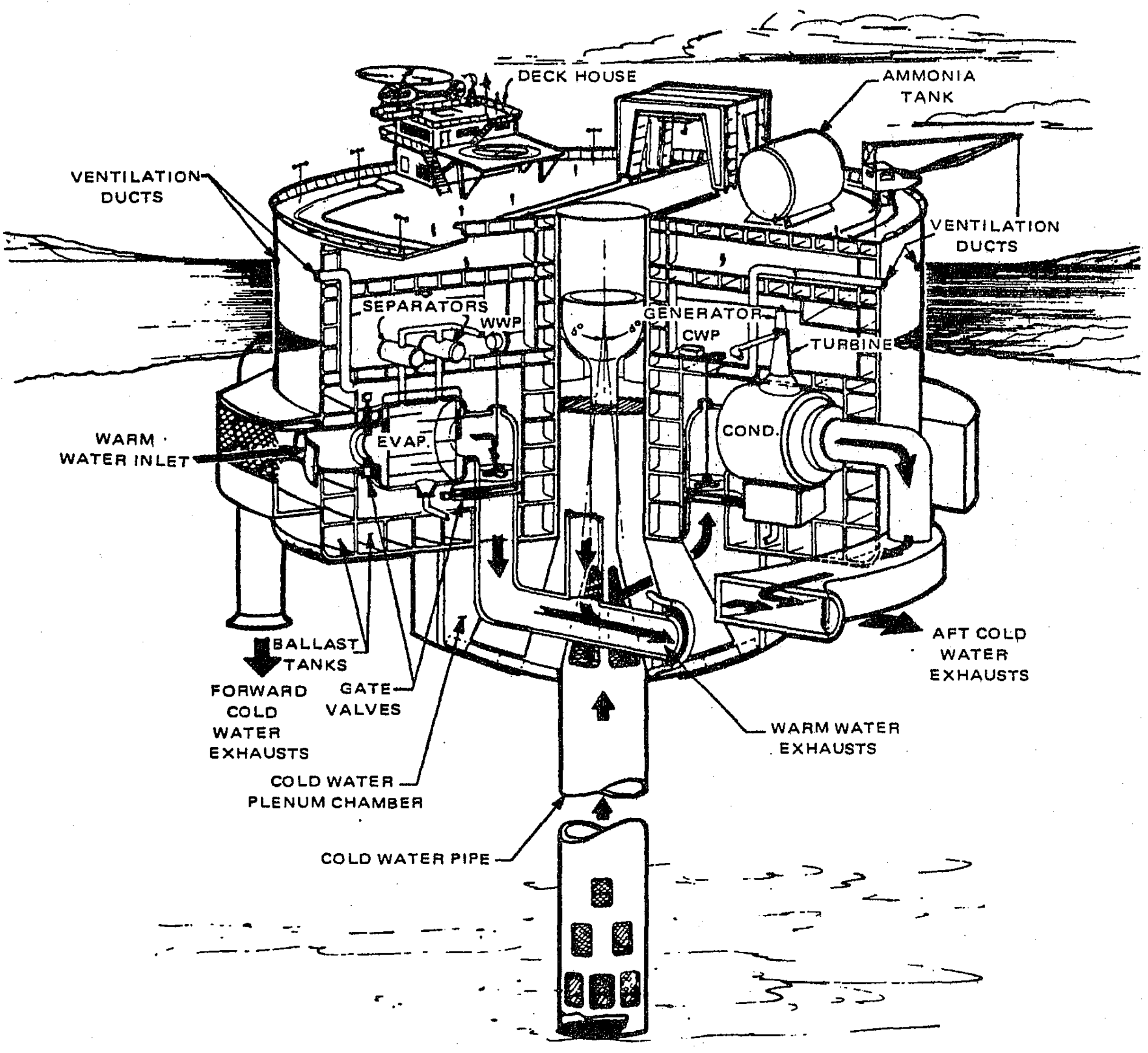


Figure 7. Artist's Conception of an Ocean Thermal Energy Conversion Plant.

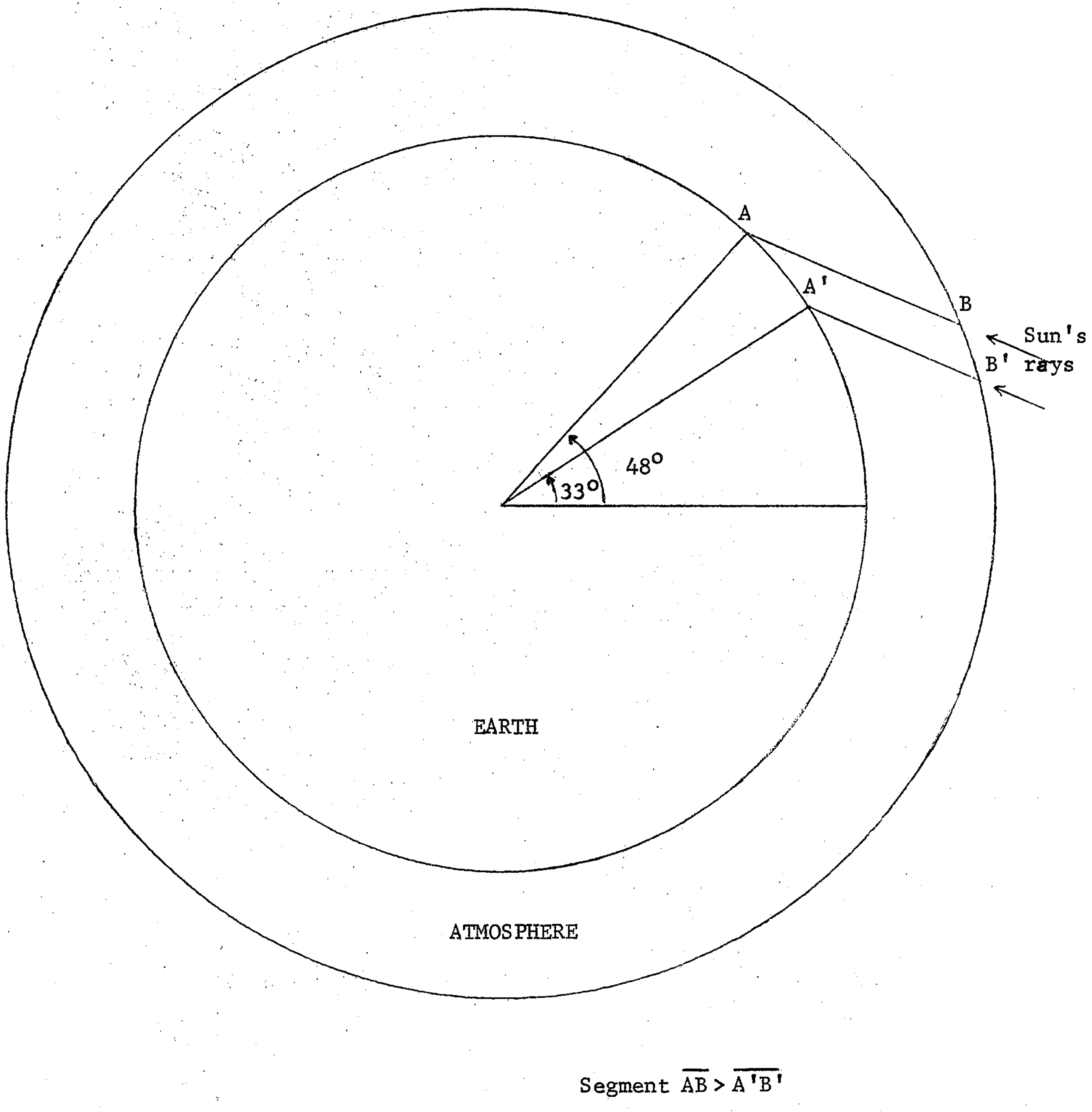
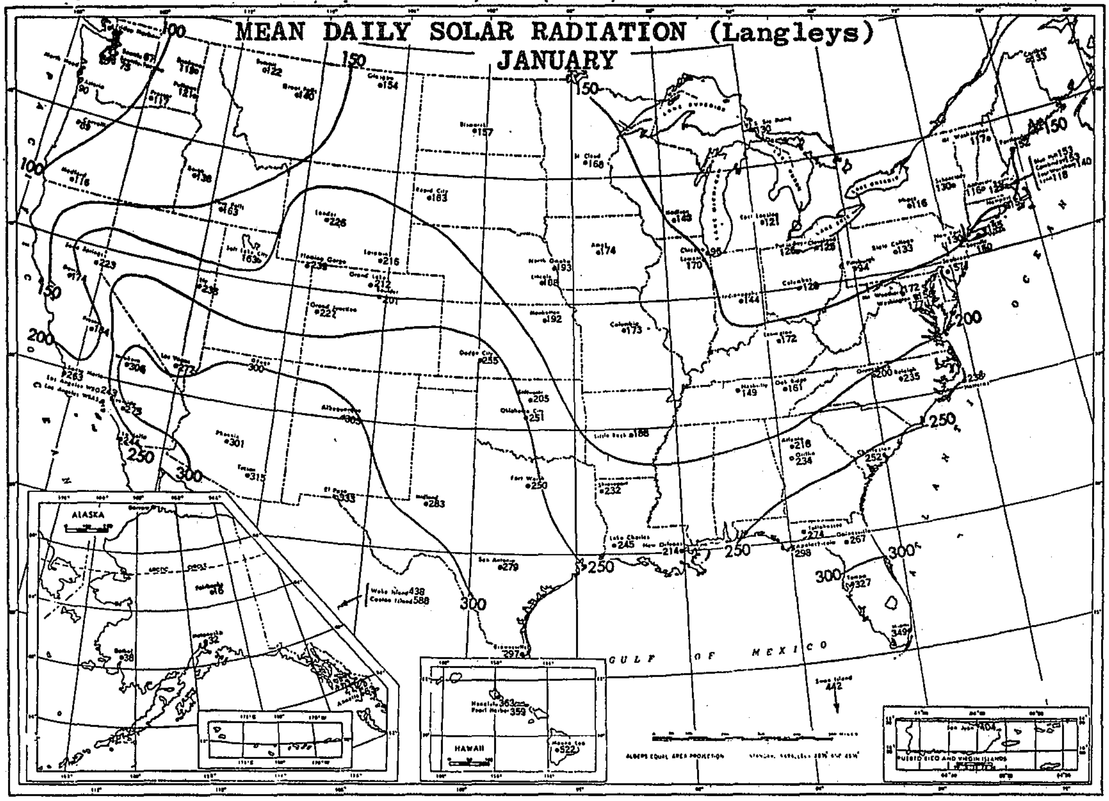


Figure 8. Solar Angle as Affected by Latitude (Winter).

U.S. Department of Commerce Figure 9a. **Weather Bureau**



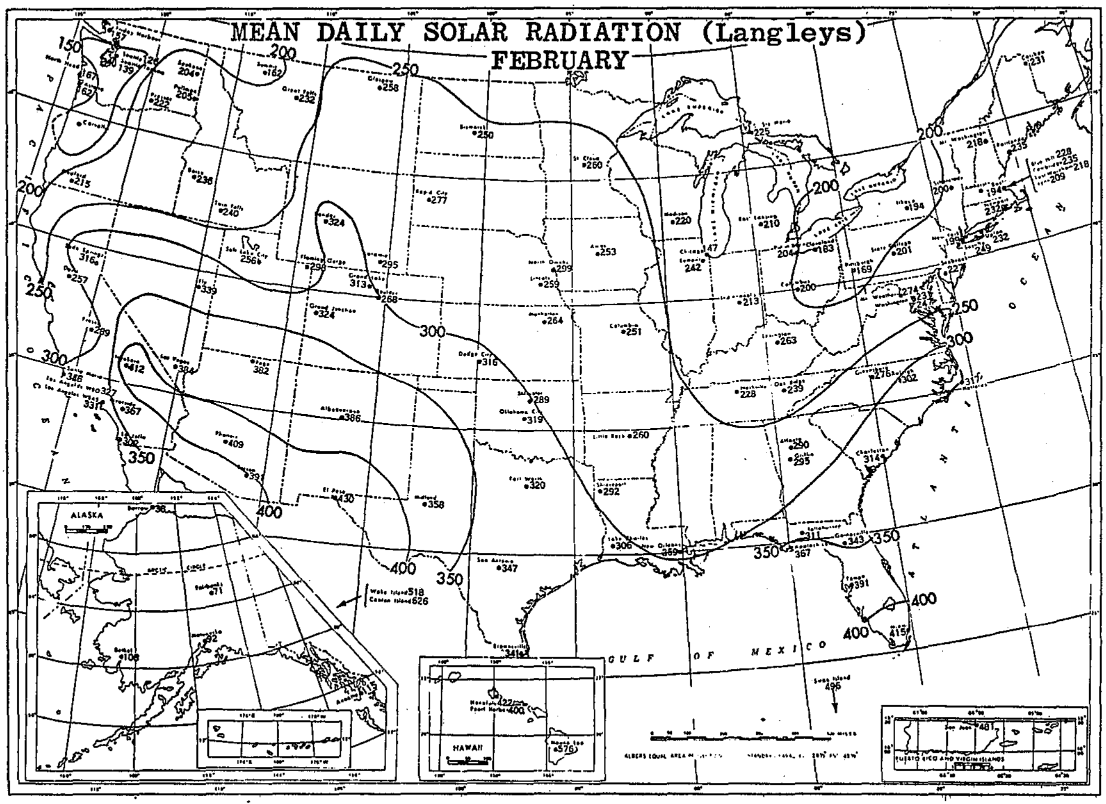
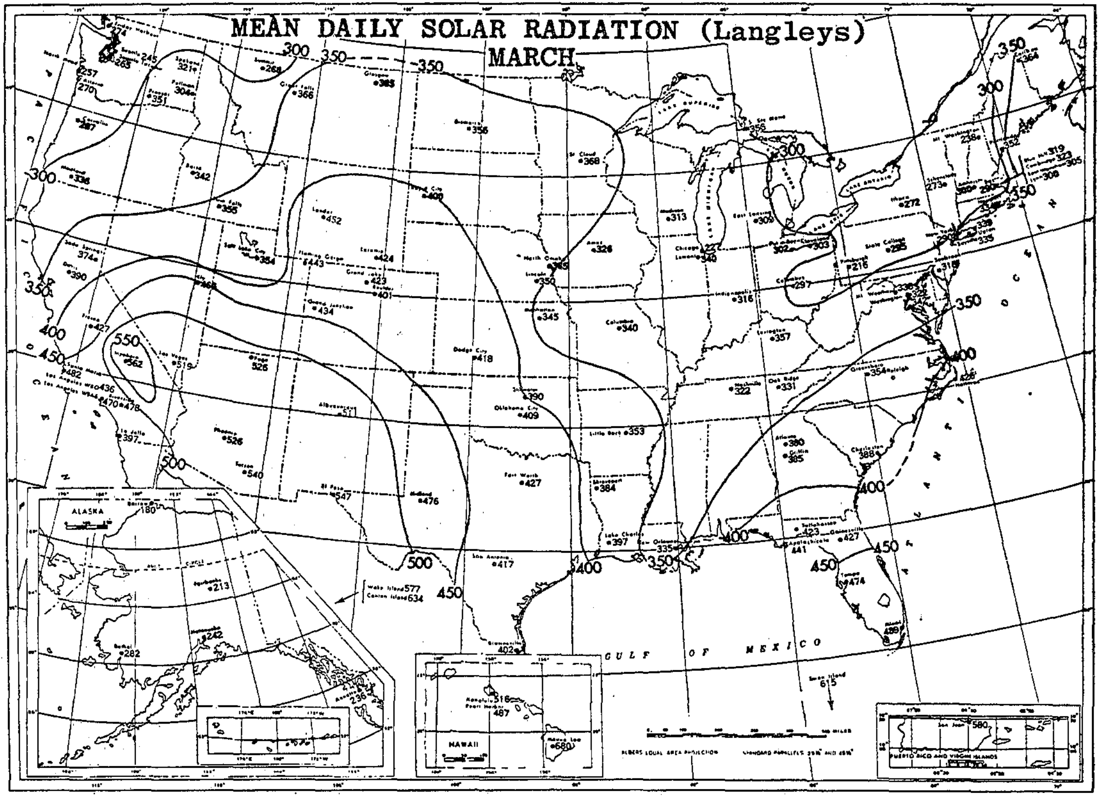


Figure 9b.

Mean Daily Solar Radiation, Monthly and Annual

U.S. Department of Commerce Figure 10a. **Weather Bureau**



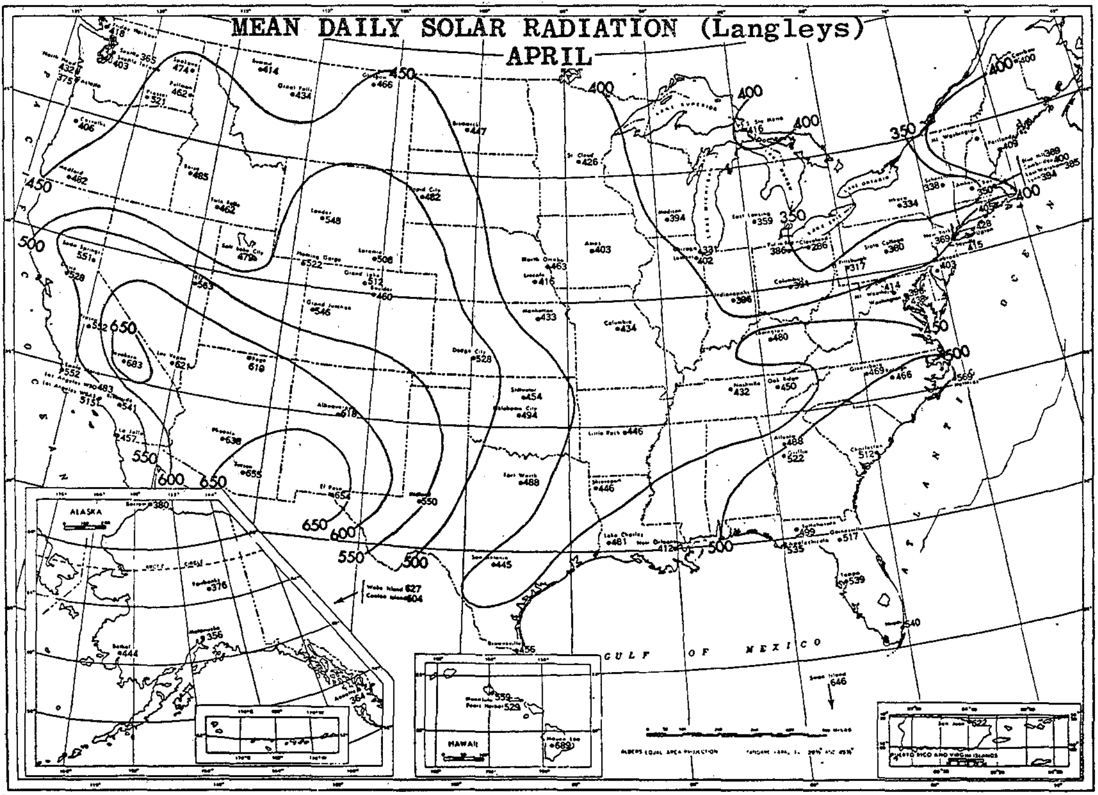
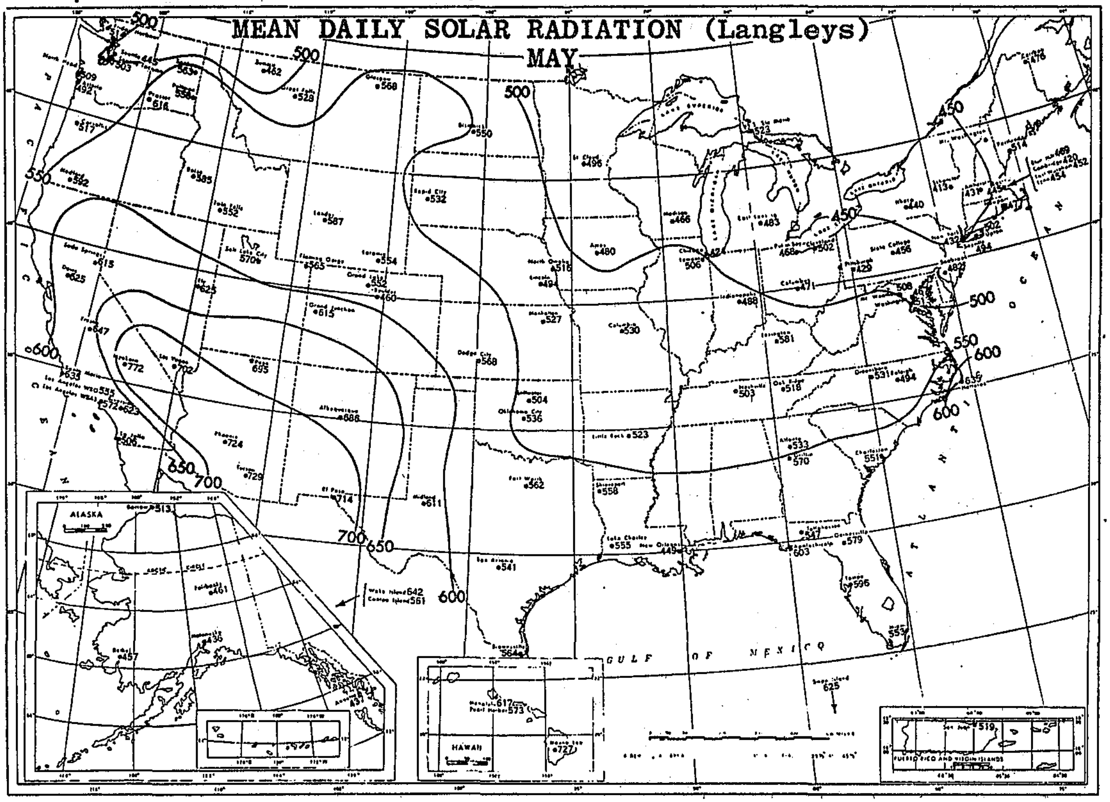


Figure 10b.

Mean Daily Solar Radiation, Monthly and Annual

U.S. Department of Commerce Figure IIa. **Weather Bureau**



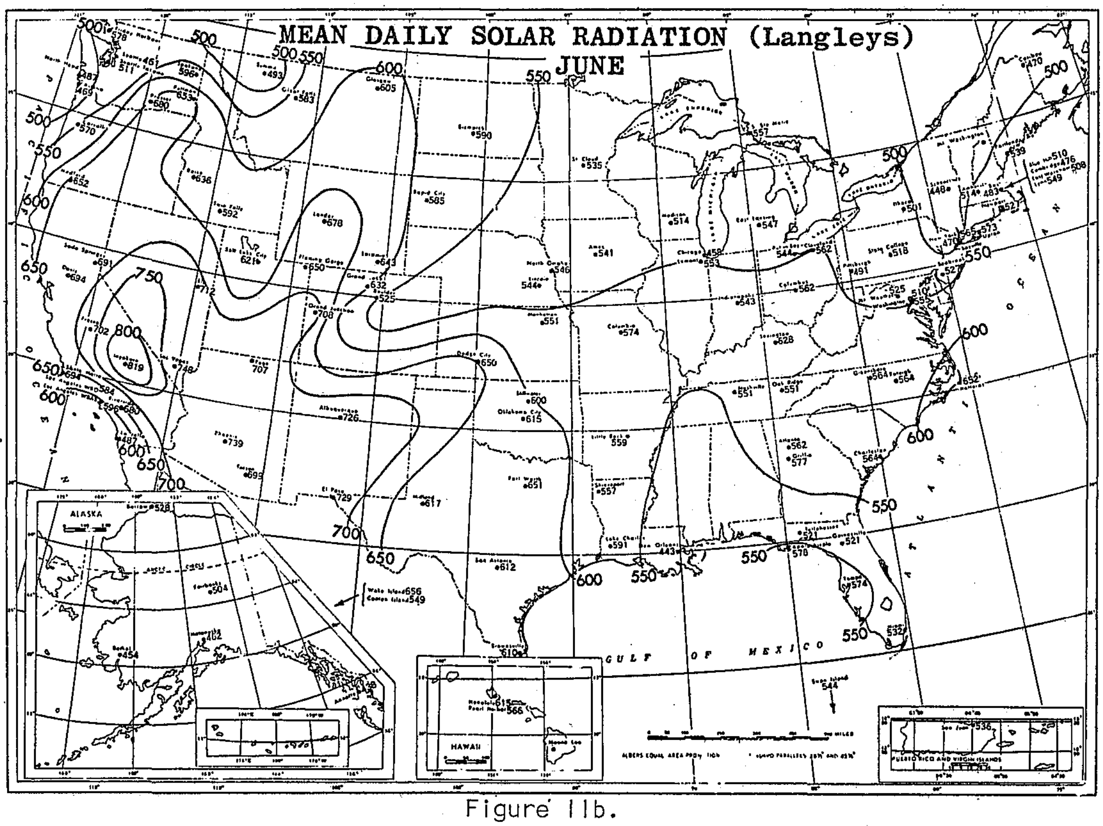
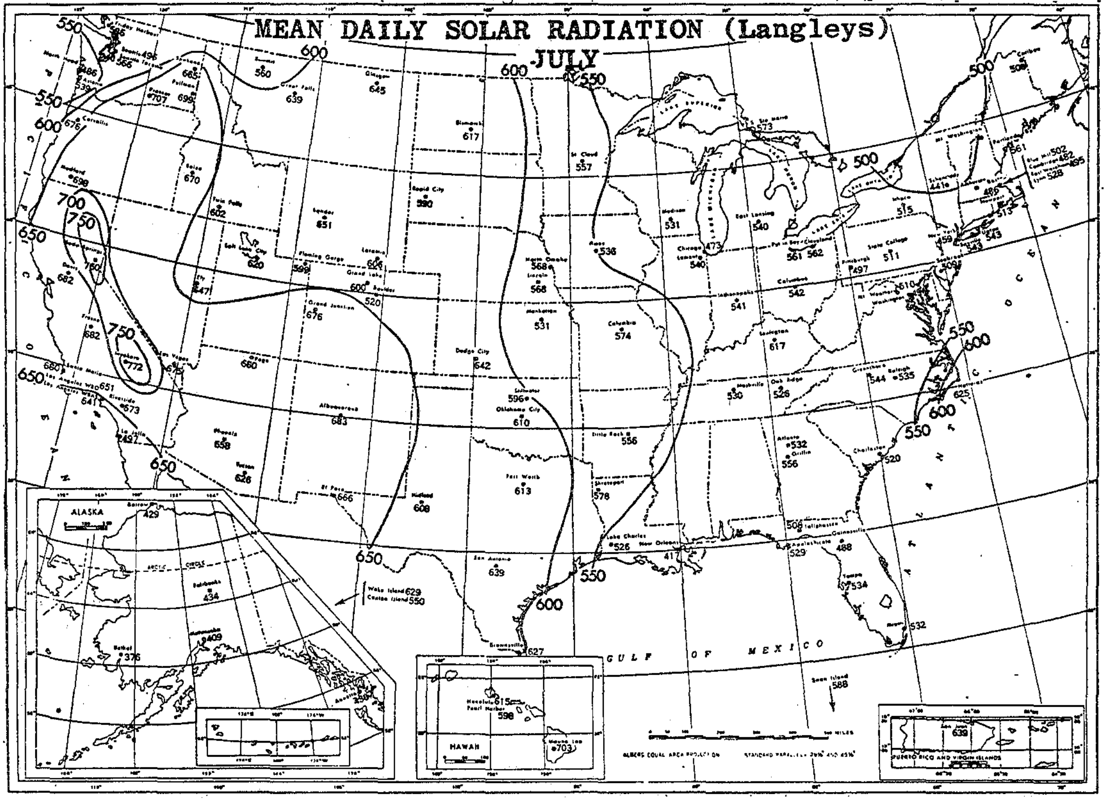


Figure IIb.

U.S. Department of Commerce Figure 12a. **Weather Bureau**



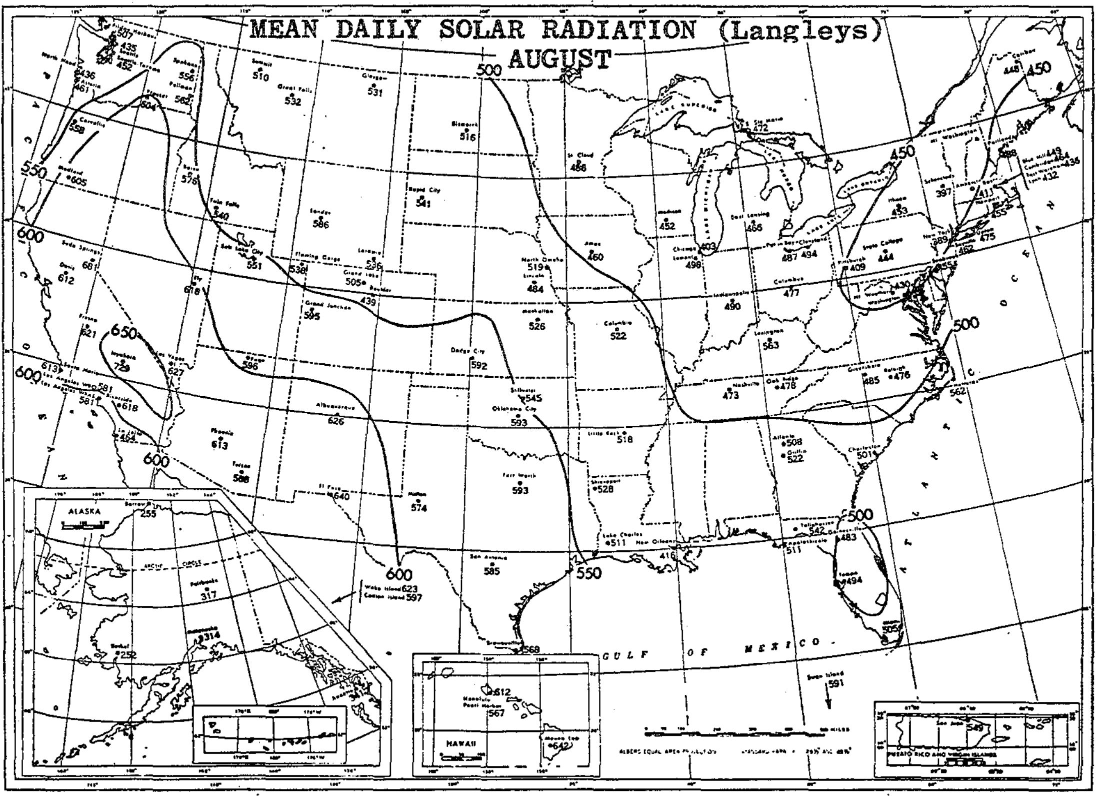
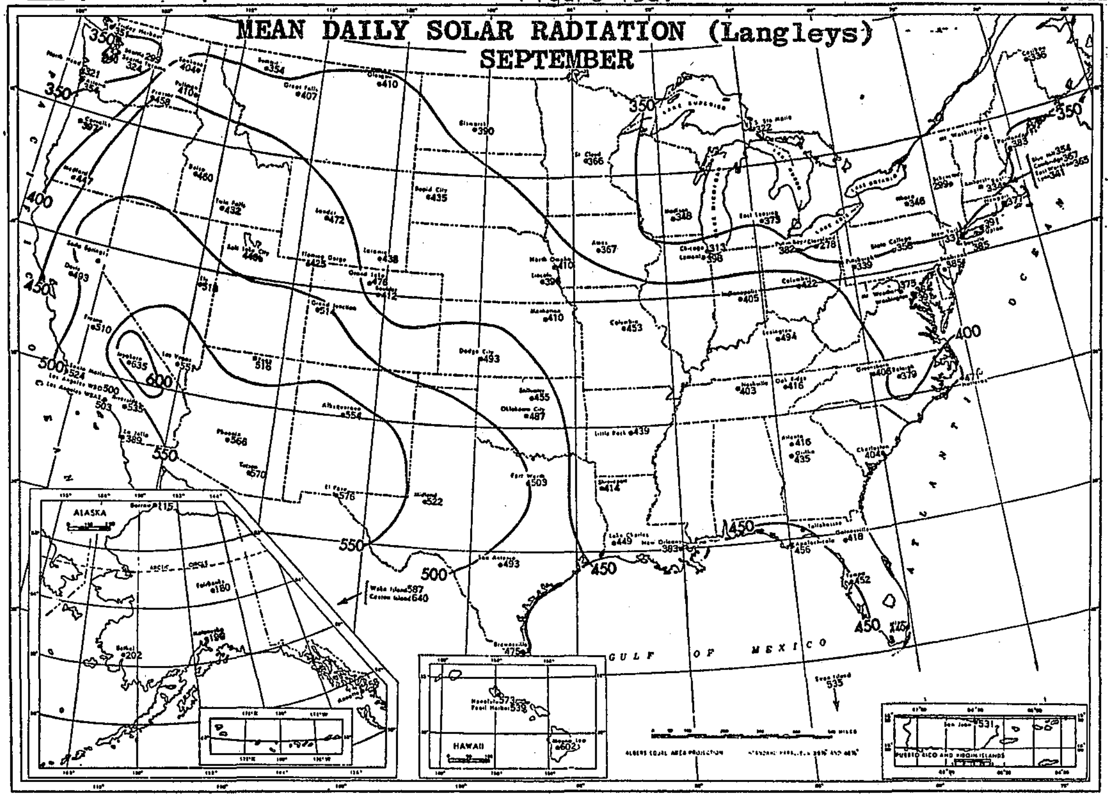


Figure 12b.

U.S. Department of Commerce Figure 13a. **Weather Bureau**



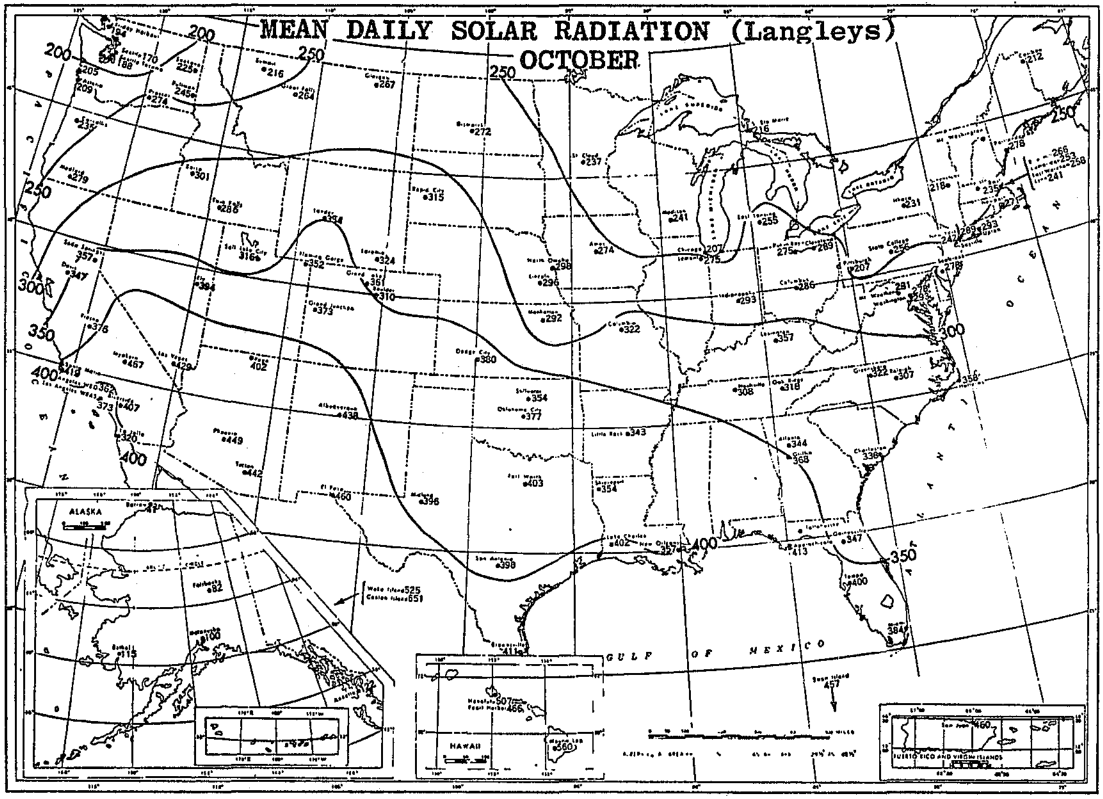
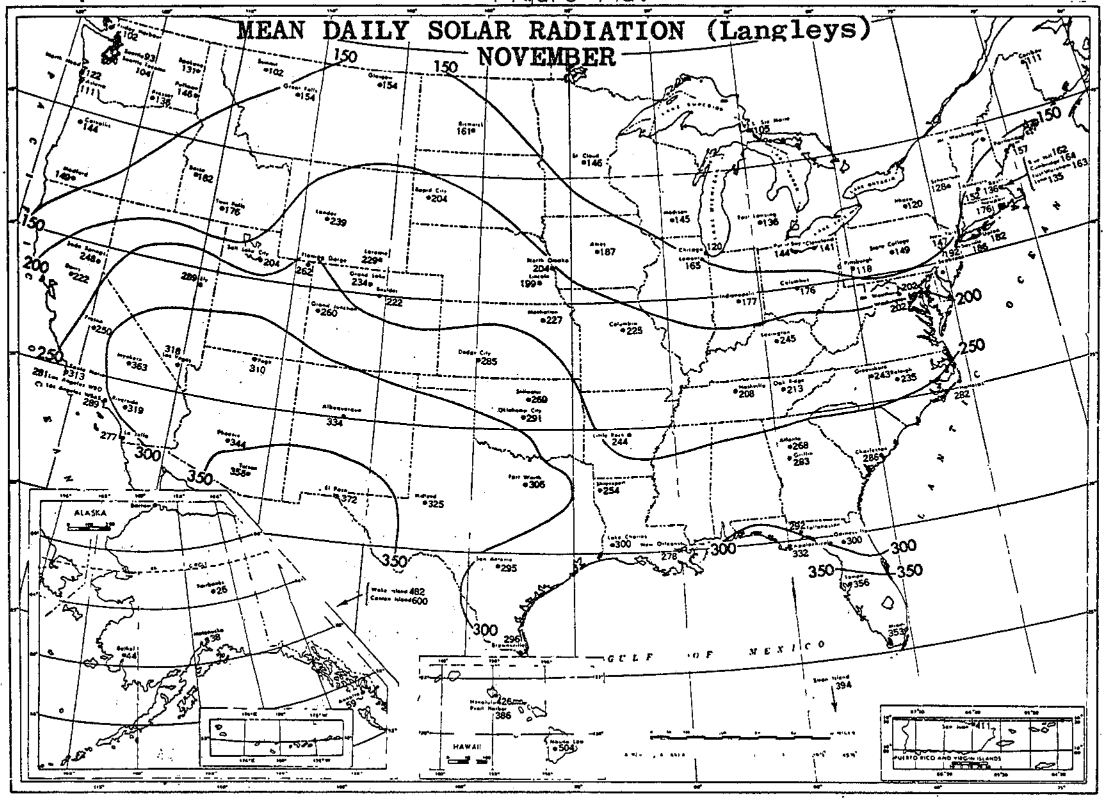


Figure 13b.

U.S. Department of Commerce Figure 14a. **Weather Bureau**



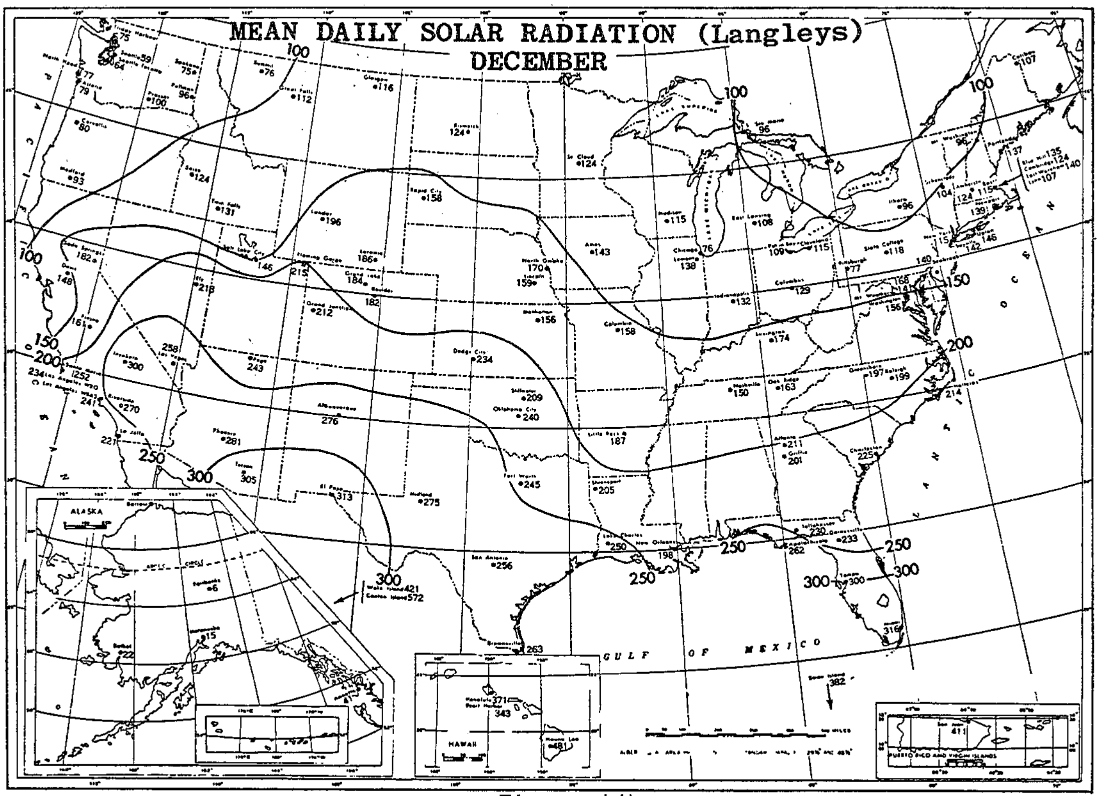
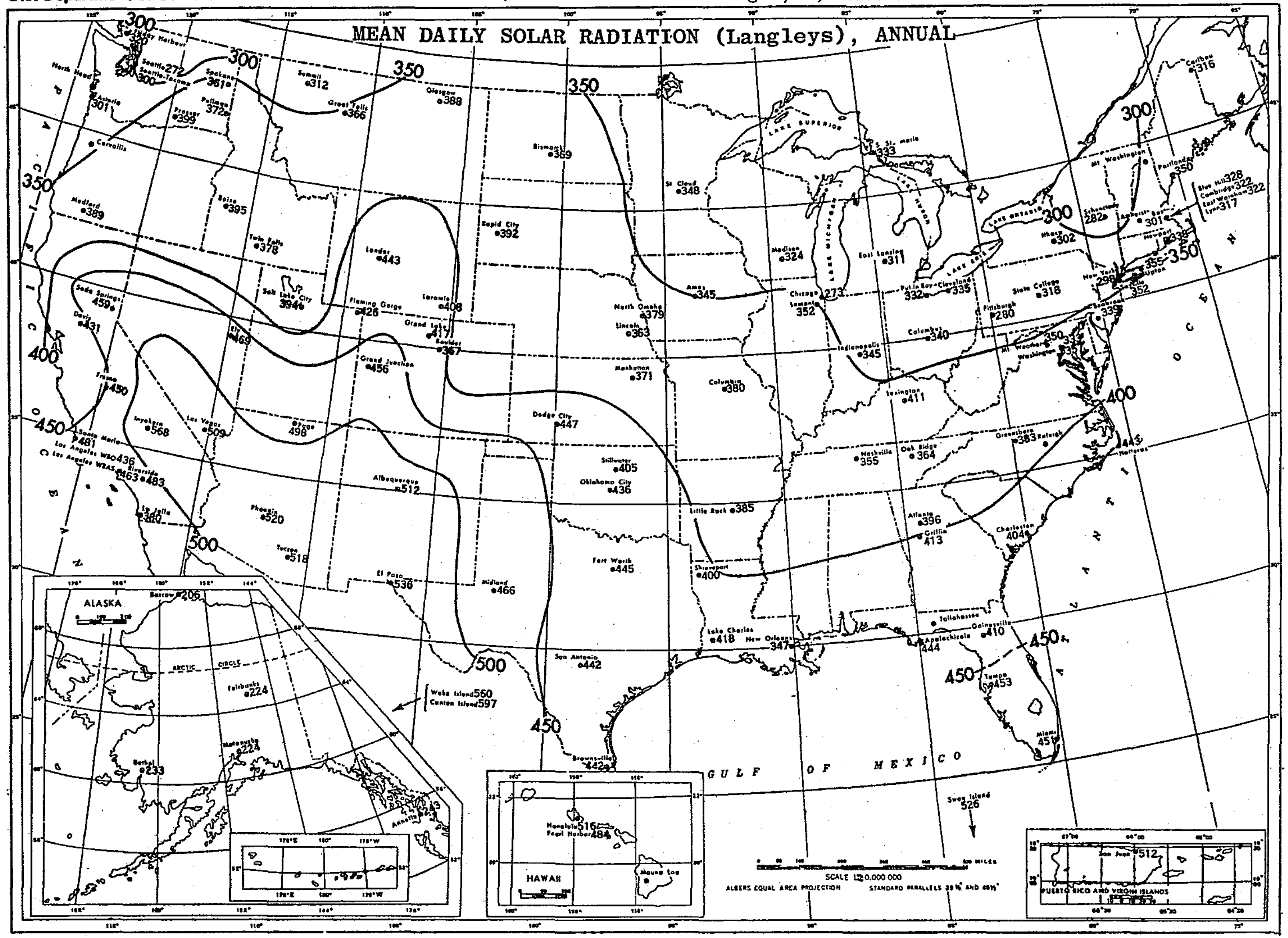


Figure 14b.

U.S. Department of Commerce FIGURE 15. Mean Daily Solar Radiation (Langleys), Annual. **Weather Bureau**



These charts and table are based on all usable solar radiation data, direct and diffuse, measured on a horizontal surface and published in the Monthly Weather Review and Climatological Data National Summary through 1962. All data were measured in, or were reduced to, the International Scale of Pyrheliometry, 1956.

Langley is the unit used to denote one gram calorie per square centimeter (1 langley = 1 gm. cal. cm^{-2}).

FIGURE 16a. Mean Daily Solar Radiation (Langleys) and Years of Record Used.

STATES AND STATIONS	JAN	YRS	FEB	YRS	MAR	YRS	APR	YRS	MAY	YRS	JUNE	YRS	JULY	YRS	AUG	YRS	SEPT	YRS	OCT	YRS	NOV	YRS	DEC	YRS	ANNUAL
ALASKA, Annette	63	6	115	6	236	7	364	7	437	6	438	6	438	6	341	6	258	7	122	7	59	7	41	7	243
Barrow	#		38	8	180	8	380	8	513	8	528	8	429	9	255	10	115	10	41	10	#		#		206
Bethel	38	9	108	10	282	9	444	10	457	10	454	10	376	10	252	10	202	10	115	10	44	9	22	9	233
Fairbanks	16	25	71	27	213	25	376	28	461	28	504	29	434	28	317	29	180	29	82	30	26	26	6	26	224
Matanuska	32	6	92	6	242	4	356	7	436	7	462	6	409	6	314	6	198	6	100	6	38	6	15	7	224
ARIZ., Page	300	2	382	3	526	3	618	2	695	2	707	2	680	3	596	3	516	3	402	3	310	3	243	3	498
Phoenix	301	11	409	11	526	11	638	11	724	11	739	11	658	11	613	11	566	11	449	11	344	11	281	11	520
Tucson	315	5	391	5	540	4	655	5	729	5	699	5	626	6	588	6	570	6	442	6	356	6	305	6	518
ARK., Little Rock	188	9	260	9	353	10	446	9	523	9	559	9	556	8	518	9	439	7	343	8	244	10	187	10	385
CALIFORNIA, Davis	174	18	257	17	390	18	528	18	625	18	694	18	682	18	612	18	493	18	347	19	222	19	148	19	431
Fresno	184	31	289	31	427	31	552	31	647	31	702	32	682	32	621	31	510	31	376	32	250	31	161	32	450
Inyokern (China Lake)	306	11	412	11	562	11	683	11	772	11	819	11	772	11	729	10	635	8	467	9	363	11	300	12	568
LaJolla	244	19	302	18	397	19	457	20	506	19	487	21	497	22	464	22	389	22	320	21	277	20	221	20	380
Los Angeles WBAS	248	10	331	10	470	10	515	10	572	9	596	9	641	9	581	10	503	10	373	10	289	10	241	10	463
Los Angeles WBO	243	9	327	9	436	9	483	9	555	9	584	9	651	9	581	10	500	10	362	10	281	10	234	10	436
Riverside ‡	275	8	367	8	478	9	541	9	623	9	680	9	673	9	618	9	535	9	407	9	319	9	270	9	483
Santa Maria	263	11	346	11	482	11	552	10	635	11	694	11	680	11	613	11	524	11	419	11	313	11	252	11	481
Soda Springs	223	4	316	3	374	4	551	4	615	3	691	4	760	3	681	3	510	3	357	4	248	4	182	3	459
COLO., Boulder	201	5	268	4	401	4	460	4	460	4	525	5	520	5	439	5	412	4	310	4	222	4	182	4	367
Grand Junction	227	9	324	9	434	8	546	8	615	9	708	8	676	8	595	8	514	8	373	10	260	10	212	10	456
Grand Lake (Granby)	212	6	313	7	423	7	512	8	552	8	632	8	600	8	505	7	476	6	361	7	234	6	184	7	417
D. C., Washington (C. O.)	174	3	266	3	344	2	411	2	551	2	494	2	536	2	446	3	375	3	299	3	211	3	166	3	356
American University	158	39	231	39	322	39	398	39	467	39	510	39	496	39	440	38	364	38	278	38	192	39	141	39	333
Silver Hill	177	7	247	6	342	7	438	7	513	7	555	7	511	7	457	7	391	8	293	8	202	7	156	6	357
FLA., Apalachicola	298	10	367	10	441	10	535	10	603	9	578	9	529	9	511	9	456	9	413	10	332	10	262	10	444
Belle Isle	297	10	330	10	412	10	463	10	483	10	464	10	488	11	461	10	400	10	366	11	313	11	291	10	397
Gainesville	267	11	343	10	427	12	517	12	579	12	521	10	488	10	483	8	418	9	347	8	300	10	233	10	410
Miami Airport	349	10	415	9	489	9	540	10	553	10	532	10	532	10	505	10	440	10	384	10	353	10	316	10	451
Tallahassee	274	2	311	2	423	3	499	3	547	3	521	3	508	3	542	2	*		*		292	2	230	2	---
Tampa	327	8	391	8	474	8	539	8	596	8	574	9	534	9	494	9	452	9	400	9	356	9	300	9	453
GA., Atlanta	218	11	290	11	380	11	488	11	533	11	562	11	532	10	508	10	416	10	344	11	268	11	211	11	396
Griffin	234	9	295	9	385	10	522	11	570	11	577	11	556	11	522	11	435	11	368	11	283	11	201	11	413
HAWAII, Honolulu	363	4	422	4	516	4	559	5	617	5	615	5	615	5	612	5	573	5	507	5	426	5	371	5	516
Mauna Loa Obs.	522	2	576	2	680	2	689	3	727	3	*		703	3	642	2	602	2	560	2	504	2	481	3	---
Pearl Harbor	359	5	400	4	487	4	529	5	573	5	566	5	598	5	567	5	539	5	466	5	386	5	343	5	484
IDAHO, Boise	138	10	236	9	342	9	485	9	585	10	636	9	670	10	576	10	460	10	301	11	182	11	124	11	395
Twin Falls	163	20	240	20	355	20	462	21	552	20	592	18	602	20	540	20	432	19	286	20	176	20	131	19	378
ILL., Chicago	96	19	147	19	227	19	331	19	424	19	458	18	473	19	403	18	313	19	207	20	120	20	76	20	273
Lemont	170	6	242	6	340	6	402	6	506	6	553	6	540	6	498	6	398	5	275	5	165	5	138	5	352
IND., Indianapolis	144	10	213	10	316	10	396	10	488	9	543	11	541	10	490	11	405	11	293	11	177	11	132	11	345
IOWA, Ames	174	5	253	5	326	5	403	5	480	5	541	5	436	6	460	6	367	6	274	7	187	7	143	7	345
KANS., Dodge City	255	7	316	7	418	7	528	7	568	7	650	7	642	8	592	9	493	9	380	9	285	10	234	10	447
Manhattan	192	3	264	3	345	3	433	3	527	4	551	4	531	4	526	4	410	4	292	4	227	4	156	4	371
KY., Lexington	172	9	263	9	357	10	480	10	581	10	628	9	617	10	563	10	494	10	357	9	245	9	174	11	411
LA., Lake Charles	245	11	306	11	397	11	481	11	555	11	591	11	526	11	511	11	449	11	402	11	300	10	250	10	418
New Orleans	214	14	259	14	335	15	412	16	449	14	443	13	417	15	416	15	383	15	357	13	278	13	198	14	347
Shreveport	232	3	292	3	384	3	446	4	558	4	557	4	578	4	528	4	414	4	354	4	254	4	205	4	400
MAINE, Caribou	133	8	231	9	364	8	400	10	476	10	470	10	508	11	448	11	336	11	212	11	111	11	107	9	316
Portland	152	7	235	8	352	7	409	8	514	9	539	9	561	9	488	8	383	7	278	9	157	8	137	9	350
MASS., Amherst	116	2	*		300	2	*		431	2	514	2	*		---		---		---		152	2	124	2	---
Blue Hill	153	27	228	27	319	26	389	26	469	27	510	27	502	26	449	27	354	28	266	28	162	28	135	28	328
Boston	129	16	194	17	290	17	350	17	445	16	483	16	486	16	411	16	334	17	235	16	136	16	115	15	301
Cambridge	153	4	235	3	323	3	400	3	420	3	476	3	482	4	464	4	367	4	253	4	164	4	124	4	322
East Wareham	140	13	218	13	305	12	385	14	452	14	508	14	495	14	436	14	365	13	258	14	163	14	140	13	322
Lynn	118	2	209	2	300	2	394	2	454	2	549	4	528	4	432	3	341	2	241	3	135	3	107	3	317
MICH., East Lansing	121	10	210	11	309	11	359	11	483	10	547	11	540	11	466	11	373	11	255	11	136	11	108	11	311
Sault Ste. Marie	130	10	225	9	356	10	416	10	523	10	557	11	573	11	472	10	322	10	216	9	105	9	96	9	333
MINN., St. Cloud	168	8	260	8	368	8	426	8	496	8	535	8	557	9	486	8	366	8	237	7	146	8	124	8	348
MO., Columbia (C. O.)	173	10	251	10	340	11	434	11	530	11	574	11	574	10	522	10	453	10	322	10	225	10	158	9	380
University of Missouri	166	5	248	6	324	6	429	6	501	6	560	6	583	6	509	6	417	6	324	5	177	5	146	5	365
MONT., Glasgow	154	6	258	8	385	7	466	8	568	8	605	8	645	9	531	10	410	10	267	8	154	8	116	7	388
Great Falls	140	8	232	9	366	9	434	8	528	8	583	8	639	9	532	9	407	10	264	10	154	10	112	10	366
Summit	122	3	162	2	268	3	414	3	462	3	493	3	560	2	510	2	354	2	216	2	102	2	76	2	312
NEBR., Lincoln	188	39	259	39	350	39	416	39	494	40	544	38	568	38	484	38	396	38	296	36	199	40	159	39	363
North Omaha	193	3	299	3	365	3	463	3	516	3	546	4	568	4	519	4	410	4	298	4	204	4	170	4	379

STATES AND STATIONS	JAN	YRS	FEB	YRS	MAR	YRS	APR	YRS	MAY	YRS	JUNE	YRS	JULY	YRS	AUG	YRS	SEPT	YRS	OCT	YRS	NOV	YRS	DEC	YRS	ANNUAL
NEV., Ely	236	7	339	9	468	9	563	9	625	10	712	10	647	11	618	11	518	11	394	10	289	10	218	10	469
Las Vegas	277	11	384	11	519	11	621	11	702	11	748	10	675	11	627	11	551	11	429	11	318	11	258	11	509
N. J., Seabrook	157	8	227	8	318	8	403	8	482	9	527	8	509	8	455	9	385	9	278	7	192	8	140	8	339
N. H., Mt. Washington	117	2	218	2	238	2	*		*		*		---		---		*		*		*		96	2	---
N. Mex., Albuquerque	303	13	386	13	511	13	618	13	686	13	726	13	683	12	626	13	554	14	438	15	334	15	276	14	512
N. Y., Ithaca	116	22	194	21	272	23	334	23	440	24	501	23	515	23	453	23	346	21	231	22	120	23	96	23	302
N. Y. Central Park	130	34	199	34	290	33	369	35	432	35	470	34	459	35	389	35	331	36	242	36	147	36	115	35	298
Sayville	160	11	249	11	335	10	415	10	494	10	565	10	543	10	462	10	385	10	289	10	186	10	142	11	352
Schenectady	130	8	200	9	273	9	338	9	413	9	448	8	441	8	397	8	299	8	218	8	128	8	104	8	282
Upton	155	8	232	8	339	8	428	8	502	8	573	8	543	7	475	7	391	7	293	6	182	7	146	7	355
N. C., Greensboro	200	7	276	9	354	9	469	9	531	10	564	10	544	10	485	10	406	10	322	10	243	10	197	8	383
Hatteras	238	10	317	9	426	8	569	9	635	10	652	10	625	10	562	11	471	11	358	11	282	11	214	11	443
Raleigh	235	3	302	2	*		466	3	494	2	564	2	535	3	476	3	379	3	307	3	235	3	199	3	---
N. D., Bismarck	157	7	250	8	356	6	447	8	550	8	590	9	617	10	516	11	390	11	272	11	161	10	124	10	369
OHIO., Cleveland	125	6	183	6	303	7	286	8	502	8	562	8	562	8	494	8	278	8	289	9	141	9	115	7	335
Columbus	128	7	200	7	297	7	391	7	471	6	562	4	542	5	477	4	422	4	286	4	176	4	129	5	340
Put-in-Bay	126	10	204	9	302	10	386	11	468	11	544	11	561	10	487	10	382	11	275	11	144	11	109	11	332
OKLA., Oklahoma City	251	10	319	10	409	9	494	10	536	10	615	7	610	8	593	8	487	9	377	10	291	9	240	9	436
Stillwater	205	8	289	8	390	9	454	9	504	9	600	10	596	10	545	10	455	11	354	10	269	9	209	8	405
OREG., Astoria	90	7	162	8	270	8	375	8	492	8	469	8	539	8	461	7	354	7	209	8	111	8	79	8	301
Corvallis	89	2	*		287	3	406	3	517	3	570	3	676	4	558	4	397	4	235	4	144	4	80	4	---
Medford	116	11	215	11	336	11	482	11	592	11	652	11	698	10	605	11	447	11	279	11	149	11	93	11	389
PA., Pittsburgh	94	6	169	5	216	6	317	6	429	6	491	6	497	7	409	6	339	6	207	5	118	6	77	5	280
State College	133	19	201	19	295	20	380	20	456	20	518	20	511	20	444	20	358	20	256	20	149	20	118	20	318
R. I., Newport	155	23	232	22	334	23	405	23	477	23	527	24	513	24	455	24	377	24	271	24	176	24	139	24	338
S. C., Charleston	252	11	314	11	388	11	512	11	551	11	564	11	520	11	501	11	404	11	338	11	286	11	225	11	404
S. D., Rapid City	183	11	277	11	400	11	482	11	532	11	585	11	590	11	541	11	435	11	315	10	204	10	158	10	392
TENN., Nashville	149	18	228	19	322	19	432	19	503	18	551	18	530	17	473	17	403	17	308	19	208	18	150	19	355
Oak Ridge	161	11	239	11	331	11	450	11	518	11	551	11	526	11	478	11	416	11	318	11	213	10	163	11	364
TEXAS, Brownsville	297	10	341	10	402	10	456	11	564	10	610	9	627	8	568	11	475	11	411	11	296	11	263	10	442
El Paso	333	11	430	11	547	10	654	11	714	11	729	11	666	11	640	10	576	11	460	11	372	11	313	11	536
Ft. Worth	250	11	320	11	427	11	488	11	562	11	651	11	613	11	593	11	503	11	403	11	306	11	245	9	445
Midland	283	7	358	8	476	9	550	8	611	8	617	8	608	7	574	8	522	9	396	9	325	8	275	8	466
San Antonio	279	9	347	9	417	9	445	9	541	9	612	9	639	9	585	9	493	10	398	10	295	10	256	8	442
UTAH, Flaming Gorge	238	2	298	2	443	2	522	2	565	2	650	2	599	3	538	3	425	3	352	3	262	3	215	3	426
Salt Lake City	163	8	256	8	354	8	479	8	570	7	621	7	620	6	551	7	446	8	316	8	204	8	146	9	394
VA., Mt. Weather	172	2	274	2	338	2	414	2	508	2	525	3	510	3	430	3	375	3	281	2	202	2	168	2	350
WASH., North Head	*		167	2	257	3	432	2	509	3	487	3	486	3	436	3	321	3	205	3	122	3	77	3	---
Friday Harbor	87	8	157	7	274	8	418	8	514	9	578	10	586	10	507	11	351	8	194	10	102	10	75	8	320
Prosser	117	4	222	4	351	4	521	5	616	4	680	4	707	4	604	4	458	4	274	4	136	4	100	4	399
Pullman	121	4	205	2	304	2	462	2	558	4	653	5	699	5	562	4	410	4	245	5	146	5	96	5	372
University of Washington	67	9	126	9	245	10	364	9	445	10	461	10	496	11	435	10	299	8	170	9	93	9	59	9	272
Seattle-Tacoma	75	9	139	9	265	9	403	9	503	9	511	9	566	9	452	10	324	10	188	10	104	9	64	10	300
Spokane	119	8	204	8	321	8	474	9	563	9	596	9	665	9	556	9	404	10	225	9	131	9	75	7	361
WIS., Madison †	148	46	220	46	313	45	394	47	466	47	514	47	531	47	452	47	348	47	241	47	145	44	115	46	324
WYO., Lander	226	8	324	9	452	9	548	11	587	11	678	11	651	11	586	10	472	8	354	9	239	9	196	9	443
Laramie	216	3	295	3	424	3	508	3	554	3	643	3	606	3	536	3	438	3	324	3	229	3	186	4	408
ISLAND STATIONS																									
Canton Island	588	9	626	7	634	7	604	9	561	9	549	8	550	9	597	9	640	9	651	9	600	8	572	8	597
San Juan, P. R.	404	5	481	4	580	4	622	4	519	5	536	6	639	5	549	6	531	6	460	6	411	6	411	6	512
Swan Island	442	6	496	7	615	6	646	6	625	6	544	8	588	8	591	7	535	8	457	7	394	8	382	8	526
Wake Island	438	7	518	7	577	7	627	7	642	8	656	6	629	7	623	7	587	6	525	7	482	7	421	7	560

NOTES:

* Denotes only one year of data for the month -- no means computed.
--- No data for the month (or incomplete data for the year).
Barrow is in darkness during the winter months.
† Madison data after 1957 not used due to exposure influences.
‡ Riverside data prior to March 1952 not used-instrumental discrepancies.

Langley is the unit used to denote one gram calorie per square centimeter.

FIGURE 16b. Mean Daily Solar Radiation (Langleys) and Years of Record Used.

APPENDIX 1

ACTIVE SYSTEM - HEATING AND COOLING

An active system utilizes collectors, heat storage units, and sophisticated controls to maintain the medium at the desired temperature. The system diagram is in Figure A2.

Collectors. The collector absorbs the sun's radiant energy and transfers that energy, in the form of heat, to a medium which can provide heat to the house. Radiant energy passes through the collector's layer(s) of glazing and is absorbed by a metal plate (Figure A1). Heat energy is transferred from the plate to a working fluid (water or air) being circulated through the collector tubes. The working fluid carries off heat for immediate use in the heating system or for storage.

Double glazing permits sunlight to enter the collector but limits the reradiation of energy from the metal plate. The absorber plate of a collector is also painted or plated to absorb the maximum energy and retard reradiation of energy. Insulation at the back of the collector retards energy loss there. Despite double glazing, selective plate coatings, and insulation, not all of the energy reaching the collector can be transferred to the fluid. Collectors typically operate at efficiencies ranging from 30% to 50%.

A variety of collector designs is available commercially at prices ranging from $7.00 to $12.00 per square foot. An average size home requires 500 to 700 square feet of collector depending on factors such as collector efficiency, location, orientation, area and layout of the house, and energy conserving features. Designing for conservation (careful siting, heavier insulation, smaller windows, well-placed shrubs and trees, etc.) can mean smaller collector and storage requirements, thus reducing some of the solar system costs while increasing operating efficiencies.

Heat Storage. Solar heating systems require storage for heat collected during sunny days for use at night and in overcast weather. Insulated tanks for heat storage can be placed above or below ground and can store heat in water or in rock beds. The size of the reserve storage tank will depend on the demands of local weather conditions.

Systems Controls. When heat is needed, a conventional thermostat can activate an automatic control system to deliver heat from the storage tank or, during prolonged periods of cloudy weather, from an auxiliary heater. When storage tank temperature exceeds collector temperature, the collector pump shuts off allowing water to drain from the collector back into the tank to avoid freezing.

Cooling. Solar energy can help to cool a building using the absorption refrigeration method. A refrigerant in a closed chamber evaporates, causing cooling, just as rubbing alcohol evaporating from the skin makes it cooler. The evaporating refrigerant is picked up by an absorber solution which promotes faster evaporation. Faster evaporation in turn hastens the cooling. As the absorber solution picks up refrigerant, it rejects heat to the outdoors. Thus heat is absorbed indoors, causing cooling, and is radiated outdoors.

Once the absorber has soaked up refrigerant, the two must be separated, or regenerated. Solar heated water is used to boil off refrigerant so refrigerant and absorber can be recycled to continue the cooling process.

PASSIVE SYSTEM

Passive solar energy systems utilize the sun's energy naturally with little mechanical hardware. The building is designed to best utilize the natural environment to reduce the demand for other forms of energy. Some passive design features are discussed below (also see Figure A3):

South Facing Glass Facade: By putting the main living areas to the south side of the building and with sufficient glass areas, solar radiation is allowed to enter. The energy can be stored in walls, floors, furniture, etc. Special dark, cement or rock walls, or walls with water stored in them increase the amount of energy that can be saved.

Natural Ventilation. Prevalent summer breezes can be used to help cool the building. Ideal orientation of the side of the house through which the breeze should enter is an oblique angle of 20^o to 70^o between the wall and the wind.

Shading. Overhangs, grilles, or awnings prevent excess heat gain through south windows in the summer, yet don't block out winter sun as the sun is at a lower angle in the winter. Deciduous trees on the south side of a building block out summer sun, but shed their leaves in winter to let the sun in.

Shutters. Since glass is a poor heat insolator, insulated shutters can be added to prevent winter heat loss at night through glass areas. This process can be reversed during summer where the shutters are opened at night, exposing the glass areas to the cool night.

Earth Berming. Although earth is not a good insulator, it is helpful in moderating temperature change. By building up the ground around the side of buildings or building partially underground, temperature variation between the interior and exterior is slowed and protection is provided from cold winter winds. Insolation should be used between the walls and the earth, so that the walls can be used to store heat.

Passive homes require careful planning to utilize all the above building features. Costs of building passive homes are more than current conventional homes mostly because of the added insolation used. The building costs are significantly less than active solar homes and can be as energy efficient.

SOLAR HOT WATER SYSTEMS

Solar hot water systems are very similar to space-heating systems. Water systems, however, frequently have one less heat exchange between mediums than do space-heating systems. The fluid used in the collector system is often the same water that is to be heated for culinary use. If freezing and/or corrosion in the collector is a problem, an antifreeze solution can be used and then heat is exchanged from this system to the water in the storage tank. Figure A4 diagrams common water heating systems.

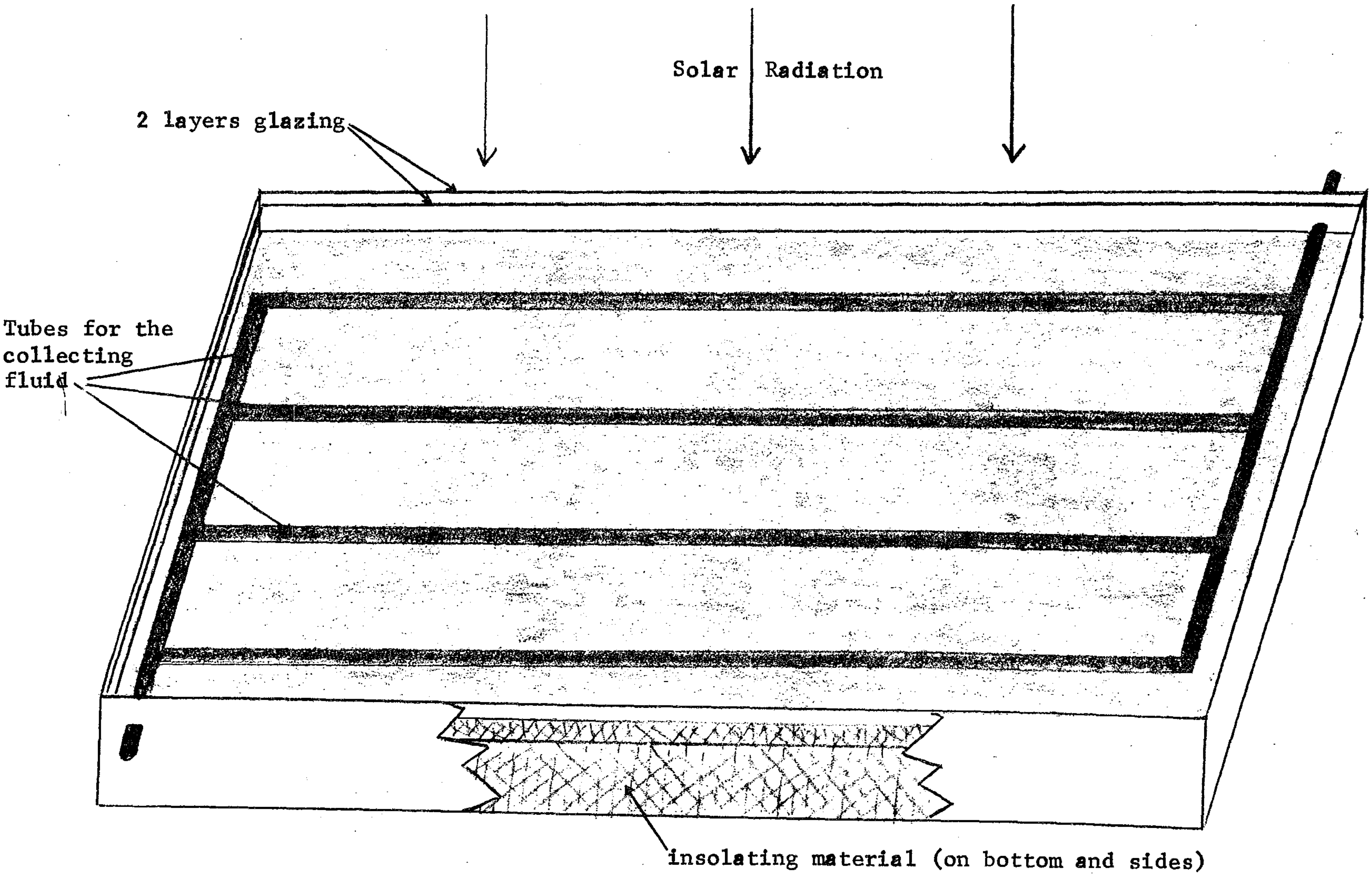


Figure A1. Sketch of a double-glazed flat plate collector.

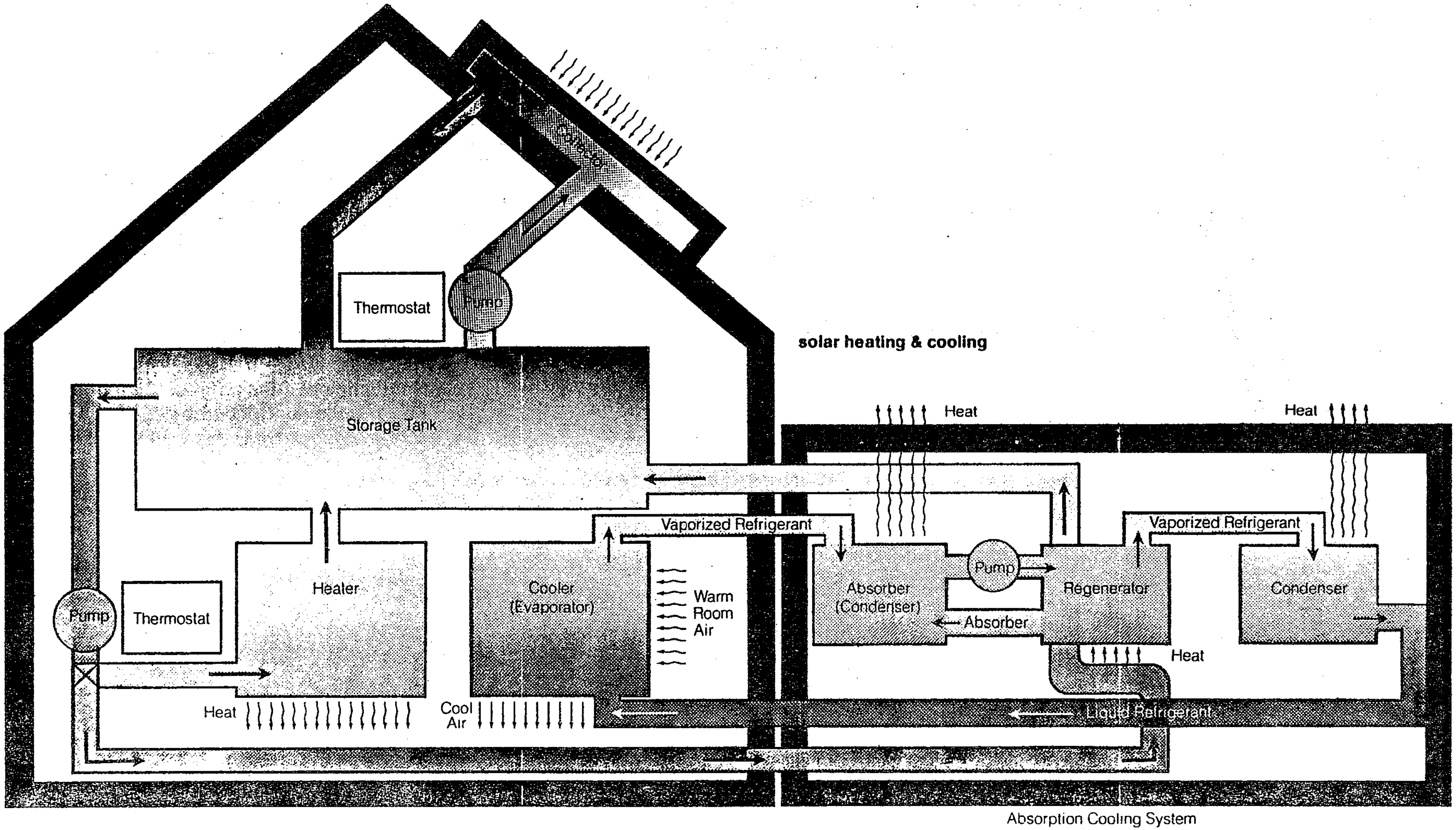
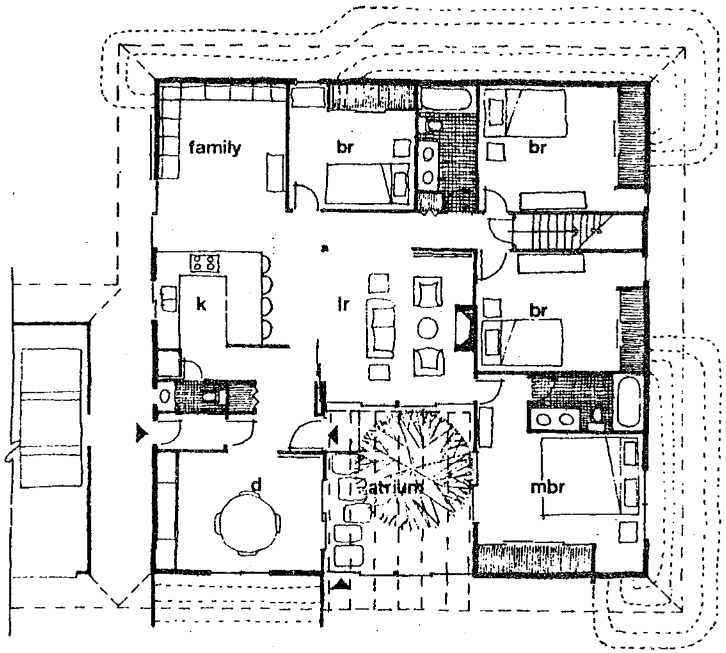
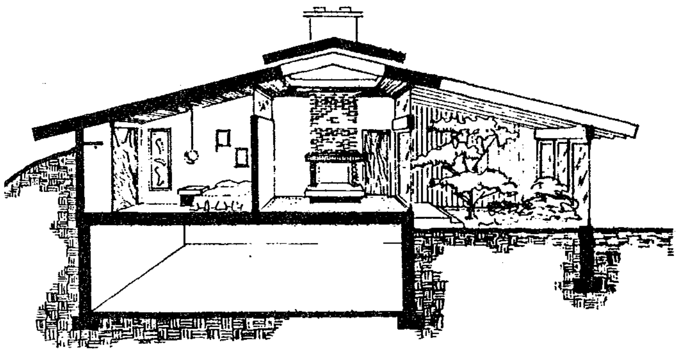


Figure A2. Schematic of an active heating and cooling system.

Energy Conscious House Floor Plan



Energy Conscious House Section



Energy Conscious House Perspective

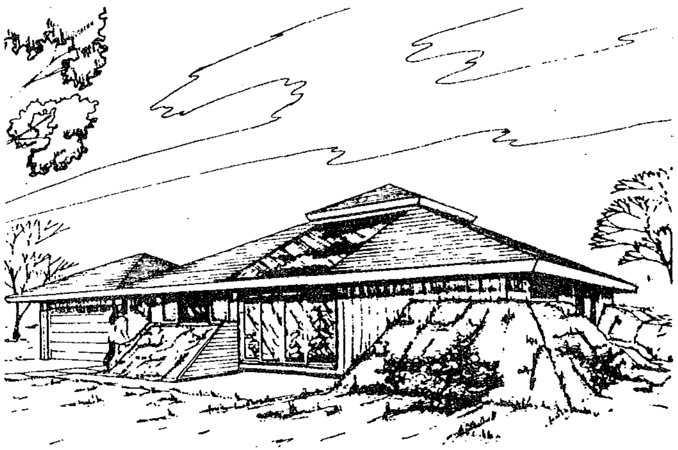


Figure A3. Passive Solar Home. This home utilizes south facing windows to collect daytime solar energy, earth berming around the outside and insolating materials in the roof and walls to cut heat losses, and an atrium and entry lock to keep outside air from coming in contact with inside air at the house entrance.

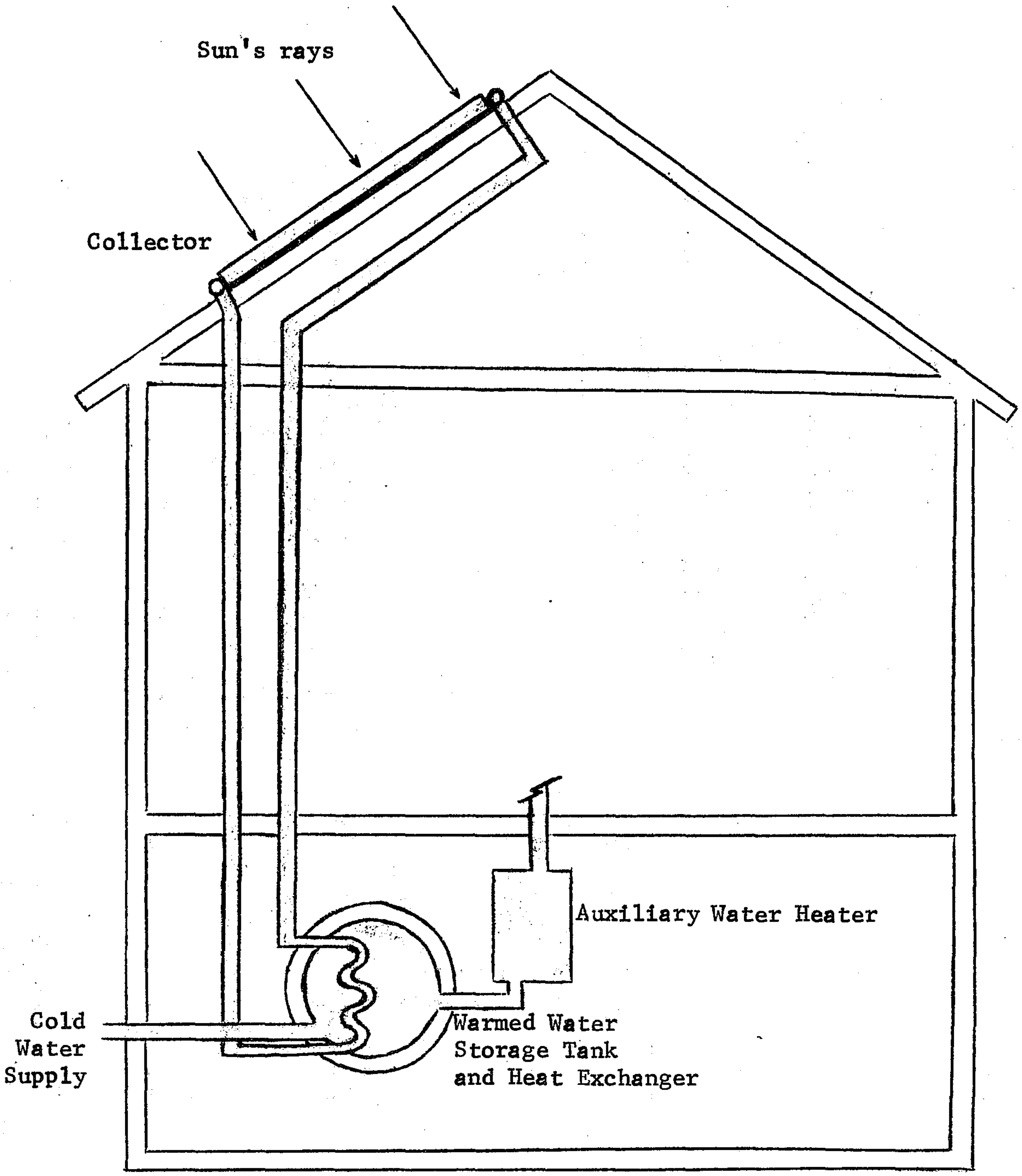


Figure A4. Schematic of an Active Solar Hot Water System.

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