SIERRA COLLEGE

Solar Energy Fundamentals

Lesson Plan

- NABCEP Learning Objectives:
  Solar Energy Fundamentals

Next week:

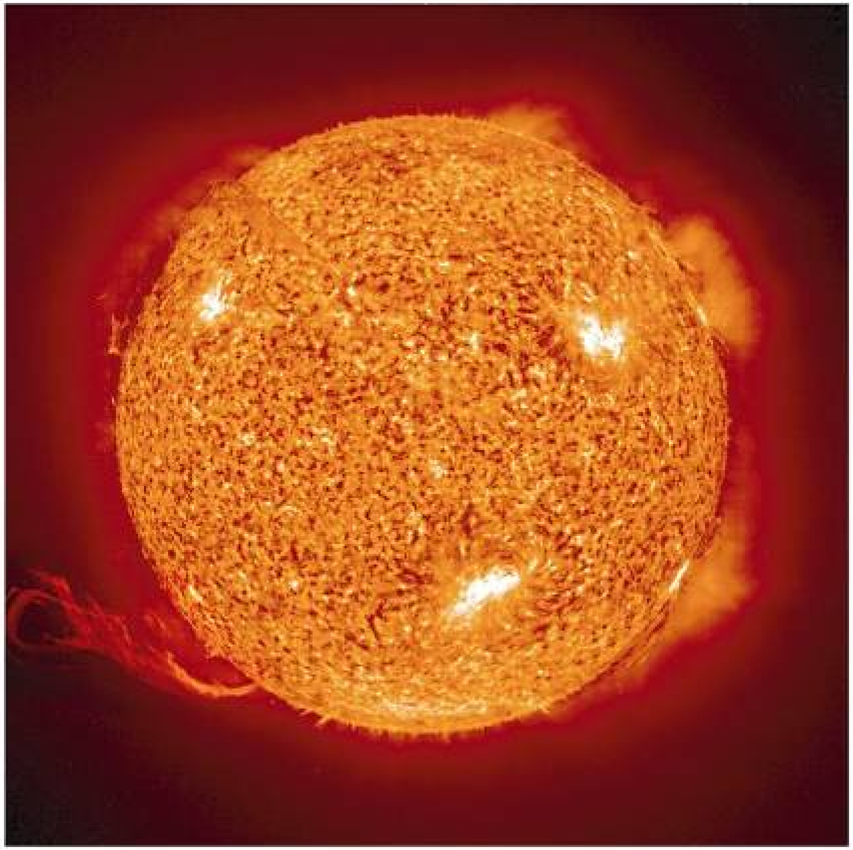
- NABCEP Learning Objectives:
  PV Modules Fundamentals

NABCEP Learning Objectives

Category	Course Time By %	Exam Items	Level of Testing	Study Materials
1. PV Markets & Applications	5%	3	Comprehension	References 1 and 5 below
2. Safety Basics	5%	3	Comprehension Application	References 1, 2 and 3 below
3. Electricity Basics	10%	6	Comprehension Problem Solving	References 1 and 5 below
4. Solar Energy Fundamentals	10%	6	Comprehension Application Problem Solving	References 1, 4 and 5 below
5. PV Module Fundamentals	10%	6	Comprehension Application Problem Solving	References 1, 4 and 5 below
6. System Components	15%	9	Comprehension Application Problem Solving	References 1, 4 and 5 below
7. PV System Sizing Principles	10%	6	Application Problem Solving Design	References 1, 4 and 5 below
8. PV System Electrical Design	15%	9	Application Problem Solving Design	References 1, 2, 4 and 5 below
9. PV System Mechanical Design	10%	6	Application Problem Solving Design	References 1, 4 and 5 below
10. Performance Analysis, Maintenance and Troubleshooting	10%	6	Analysis Problem Solving	References 1, 4 and 5 below
Totals	100%	60		

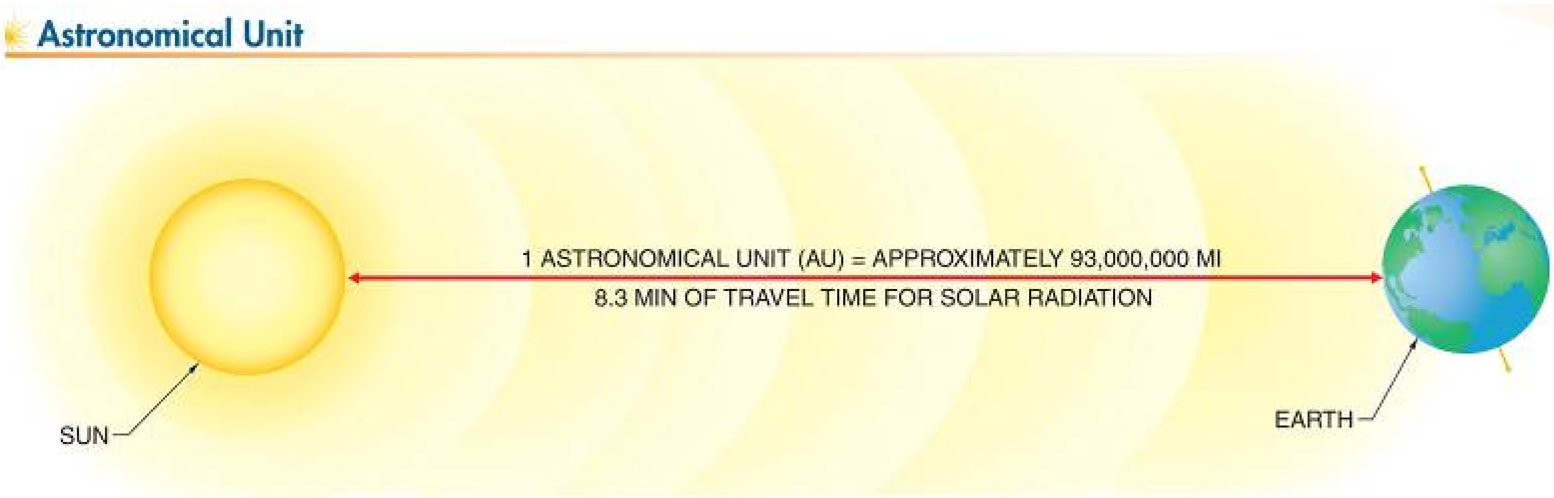
NABCEP Learning Objectives

4.	**Solar Energy Fundamentals** *Suggested Percentage Time Allotment: 10%*	**Learning Priority**
4.1	Define basic terminology, including solar radiation, solar irradiance, solar irradiation, solar insolation, solar constant, air mass, ecliptic plane, equatorial plane, pyranometer, solar declination, solstice, equinox, solar time, solar altitude angle, solar azimuth angle, solar window, array tilt angle, array azimuth angle, and solar incidence angle.	Critical
4.2	Diagram the sun's apparent movement across the sky over any given day and over an entire year at any given latitude, and define the solar window.	Important
4.3	For given dates, times and locations, identify the sun's position using sun path diagrams, and determine when direct solar radiation strikes the north, east, south and west walls and horizontal surfaces of a building.	Important
4.4	Differentiate between solar irradiance (power), solar irradiation (energy), and understand the meaning of the terms peak sun, peak sun hours, and insolation.	Critical
4.5	Identify factors that reduce or enhance the amount of solar energy collected by a PV array.	Important
4.6	Demonstrate the use of a standard compass and determine true geographic south from magnetic south at any location given a magnetic declination map.	Important
4.7	Quantify the effects of changing orientation (azimuth and tilt angle) on the amount of solar energy received on an array surface at any given location using solar energy databases and computer software tools.	Important
4.8	Understand the consequences of array shading and best practices for minimizing shading and preserving array output.	Critical
4.9	Demonstrate the use of equipment and software tools to evaluate solar window obstructions and shading at given locations, and quantify the reduction in solar energy received.	Important
4.10	Identify rules of thumb and spacing distances required to avoid inter-row shading from adjacent sawtooth rack mounted arrays at specified locations between 9 am and 3 pm solar time throughout the year.	Important
4.11	Define the concepts of global, direct, diffuse and albedo solar radiation, and the effects on flat-plate and concentrating solar collectors.	Important
4.12	Identity the instruments and procedures for measuring solar power and solar energy.	Important

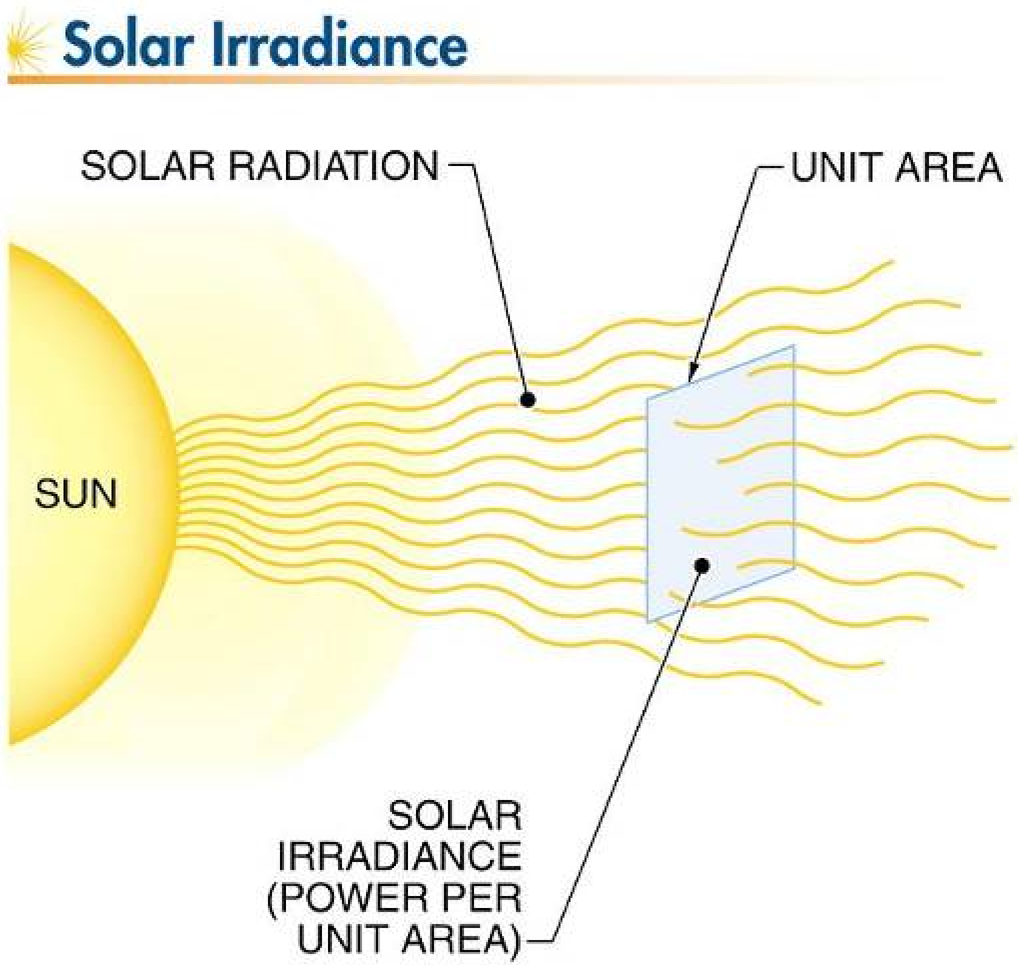


SOHO (ESA & NASA)

A false color image of the sun enhances the turbulent nature of the sun’s photosphere, including a roiling surface, sunspots, and giant flares.

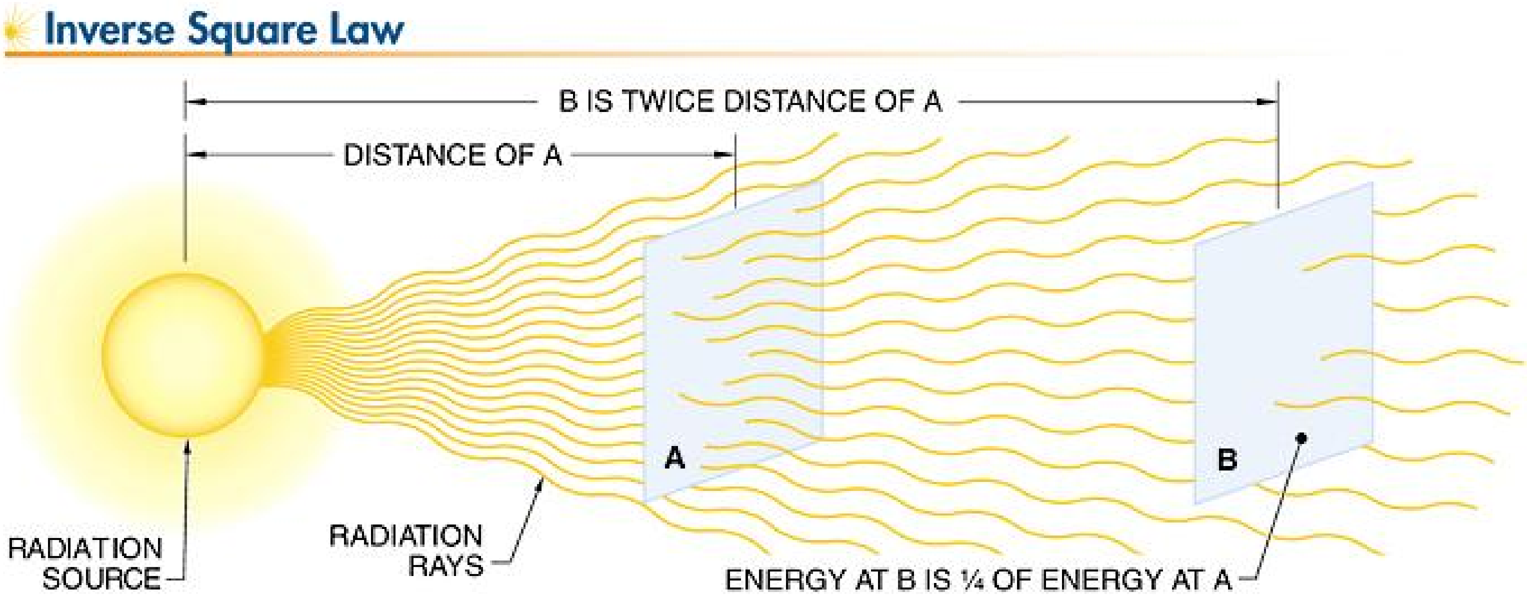


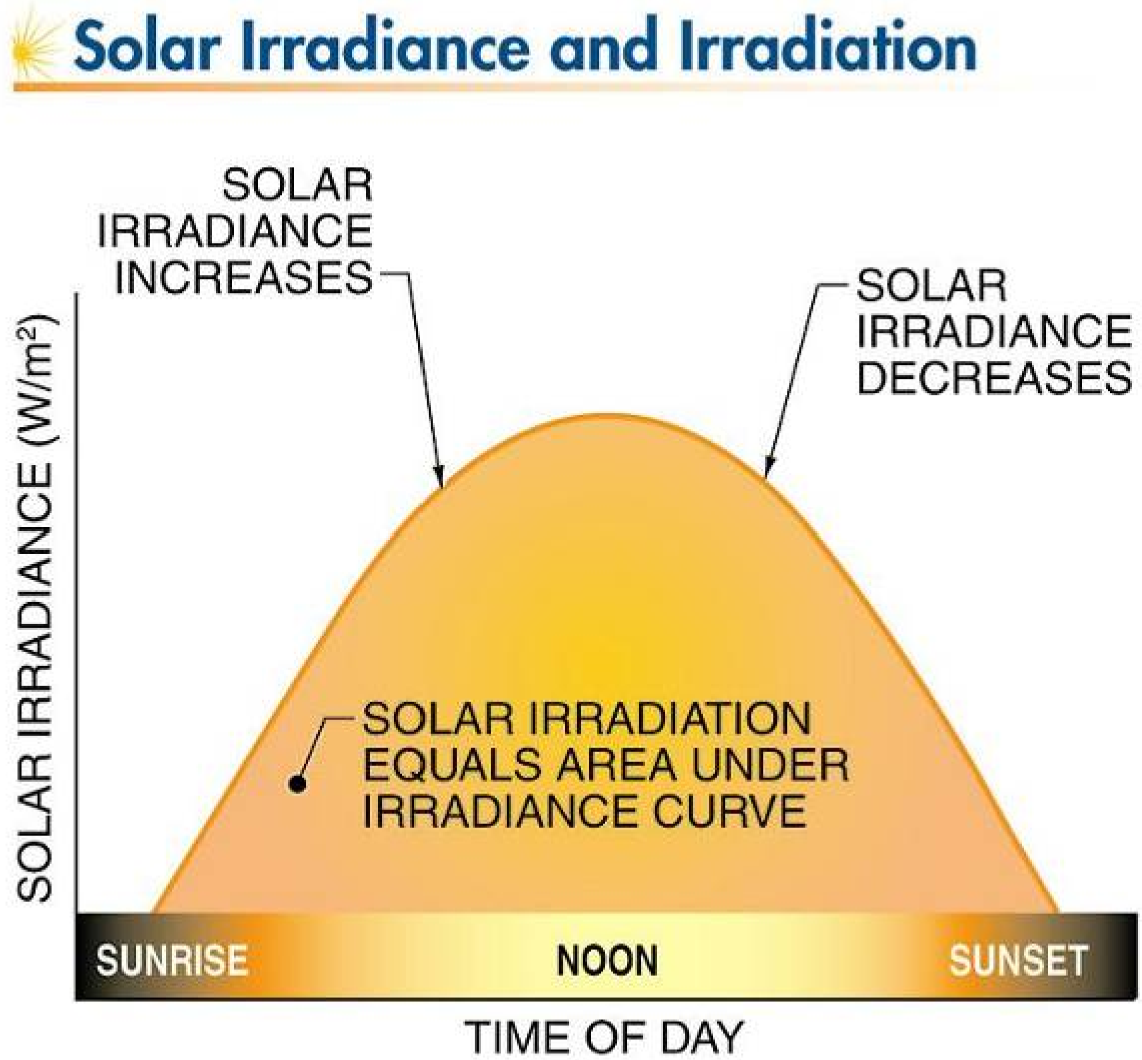
Even over the vast distance, an enormous amount of energy reaches Earth from the sun.



Solar irradiance is solar radiation power per unit area.

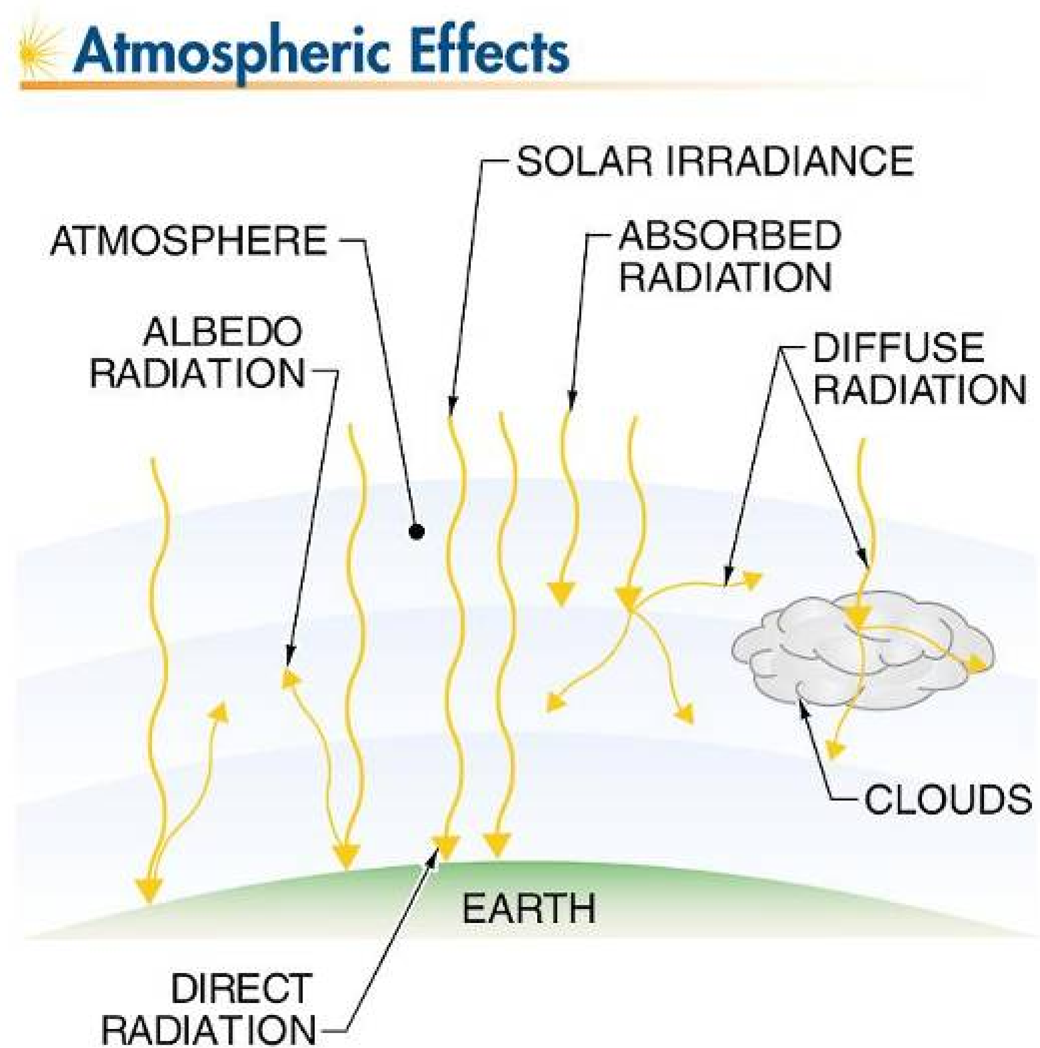
The inverse square law states that radiation energy is reduced in proportion to the inverse square of the distance from the source.

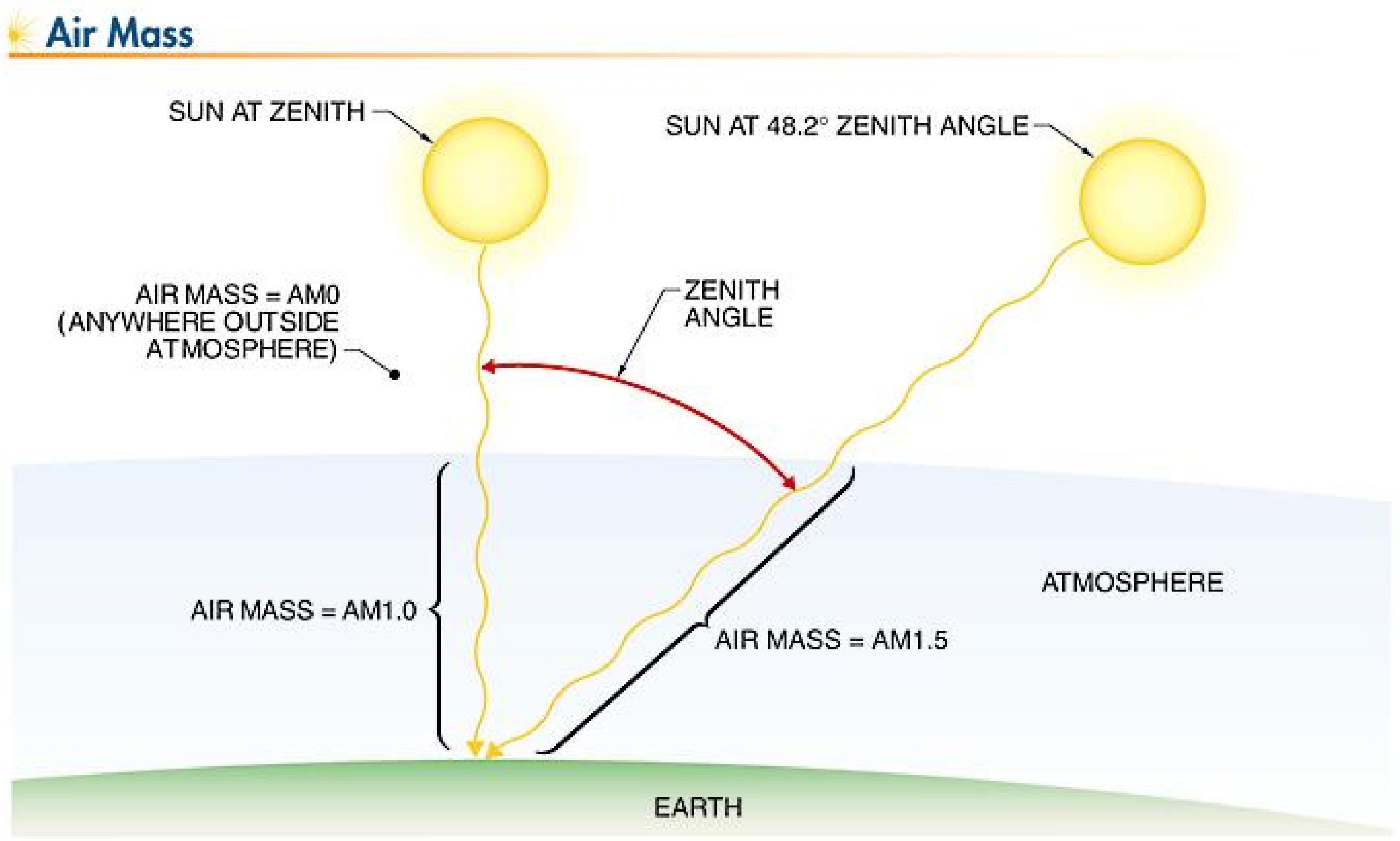




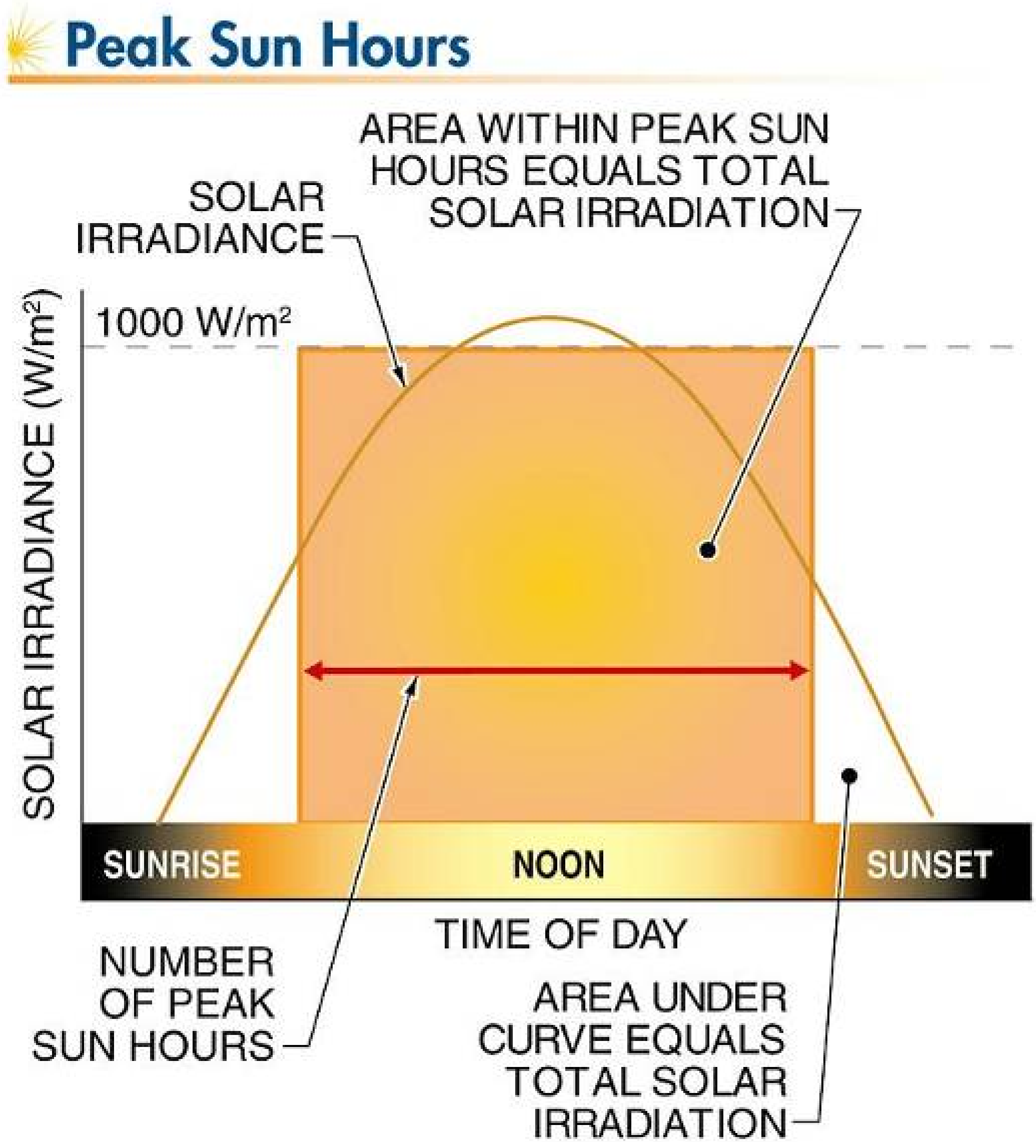
Solar irradiation equals the total solar irradiance over time.

Solar radiation entering Earth's atmosphere becomes direct, diffuse, or albedo radiation.

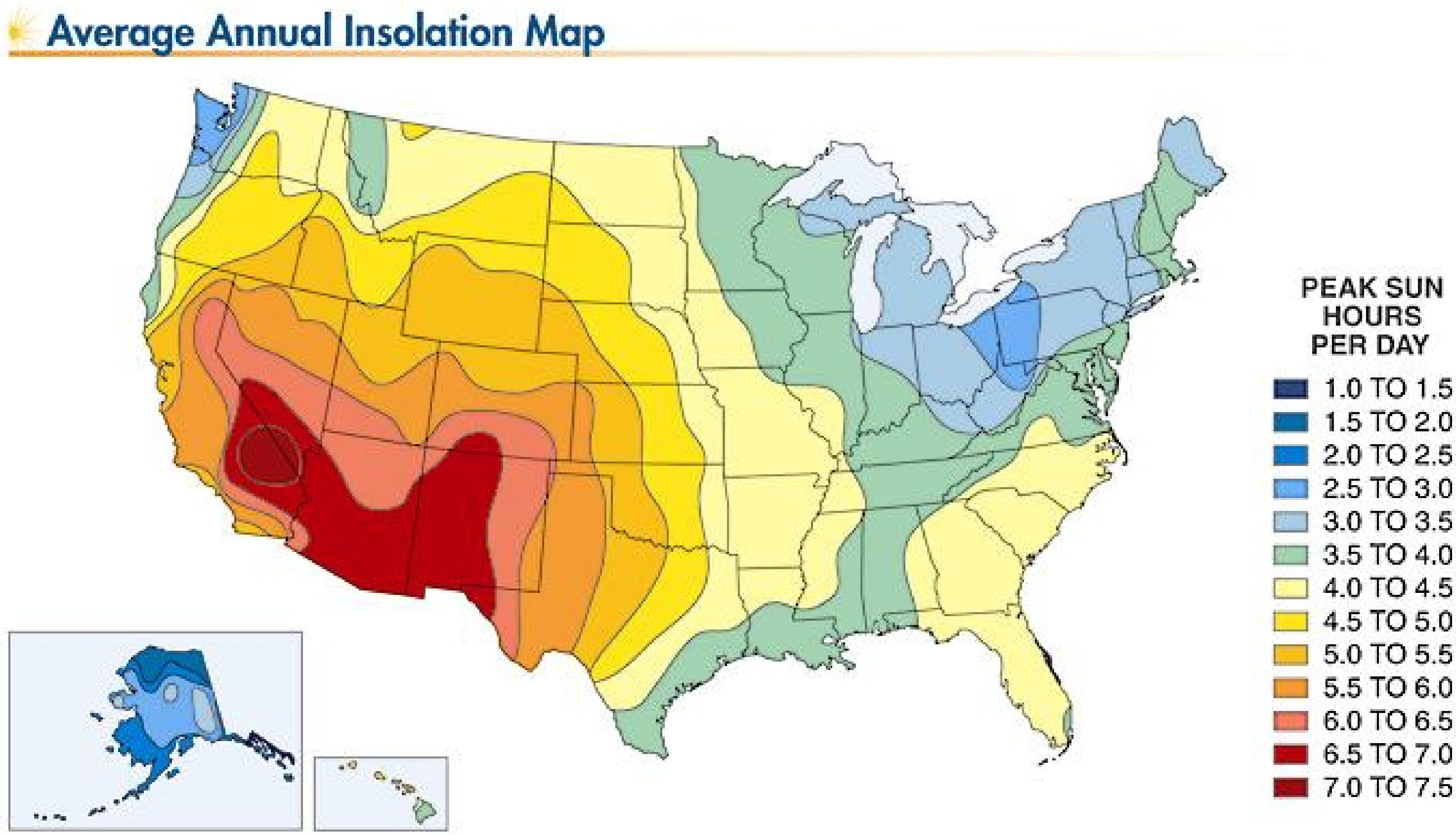




Air mass is a representation of the amount of atmosphere radiation that must pass through to reach Earth’s surface.

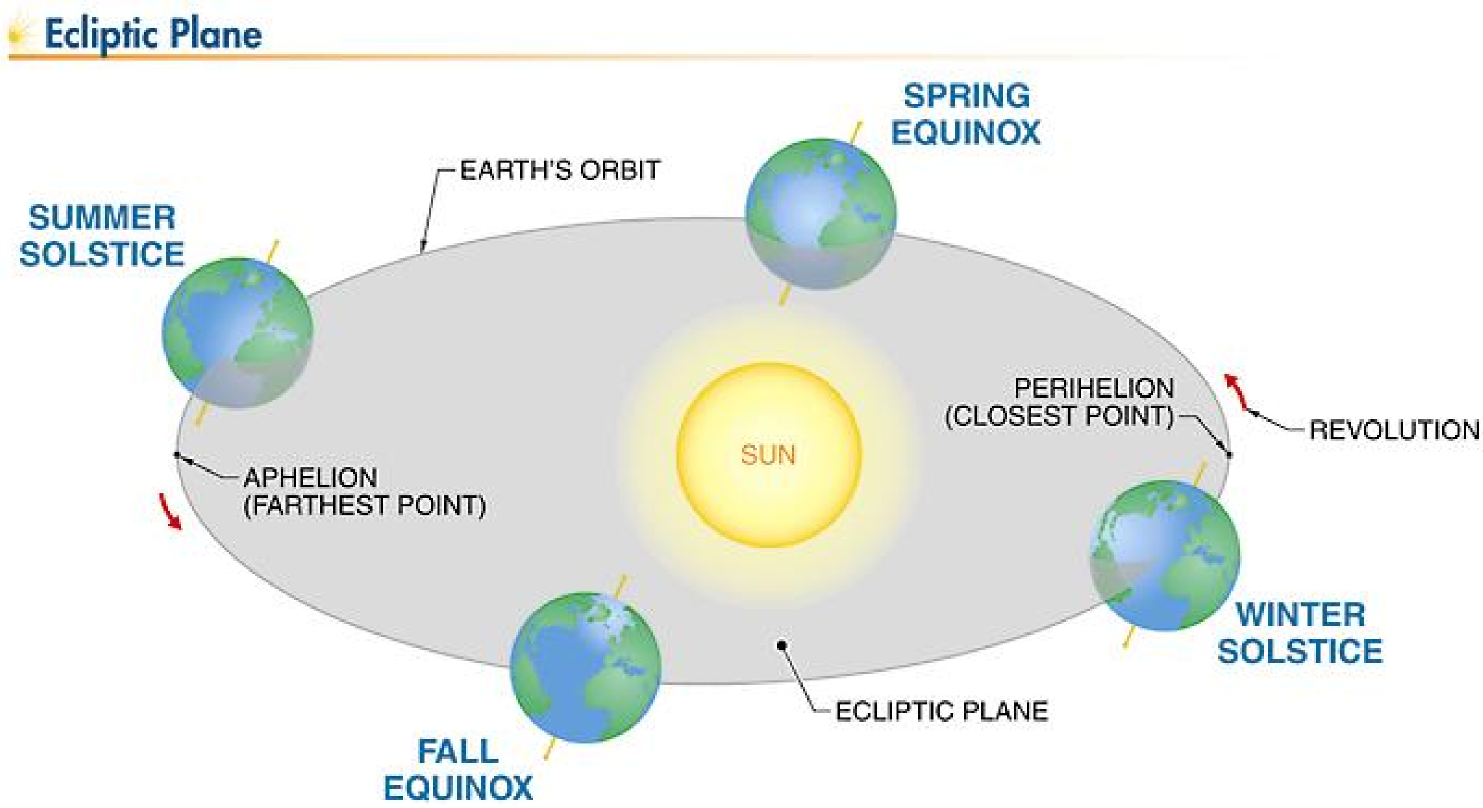


Peak sun hours is an equivalent measure of total solar irradiation in a day.

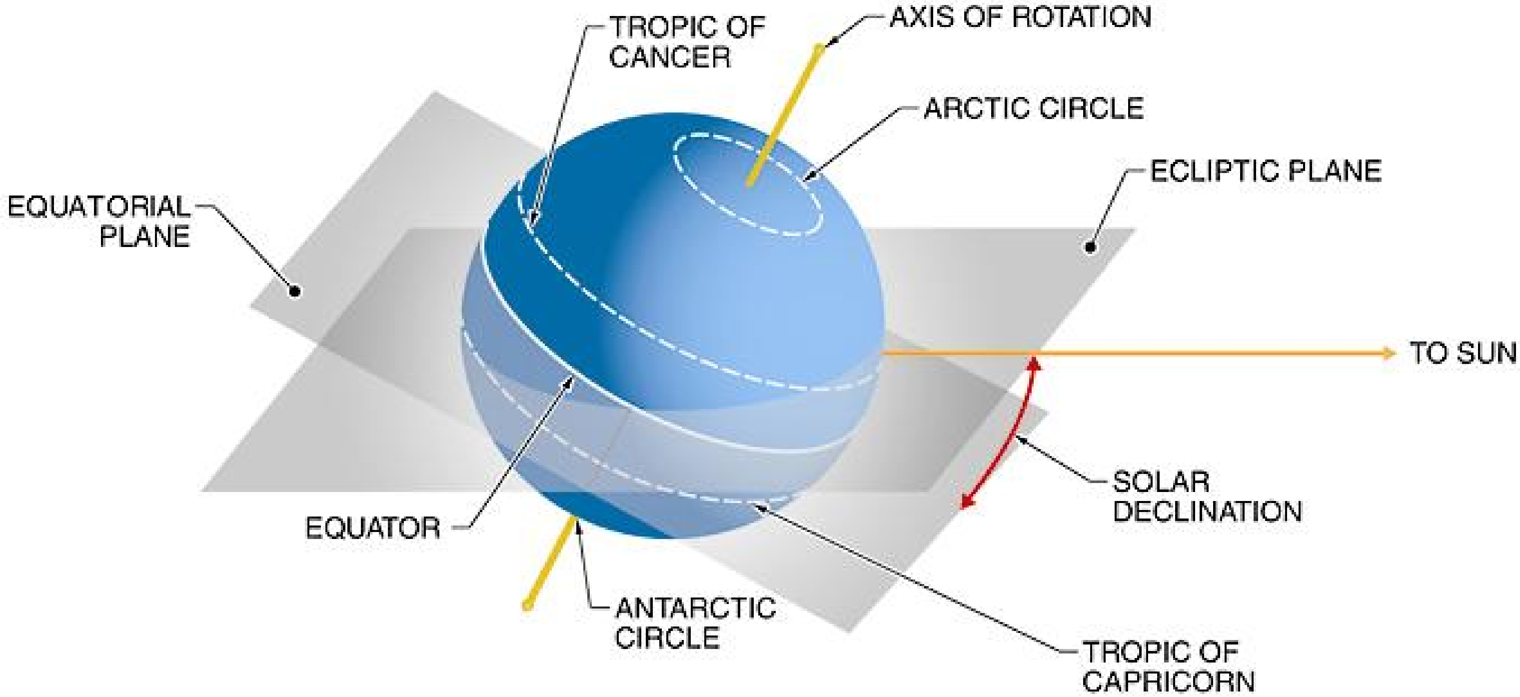


Insolation maps rate locations by their average daily peak sun hours.

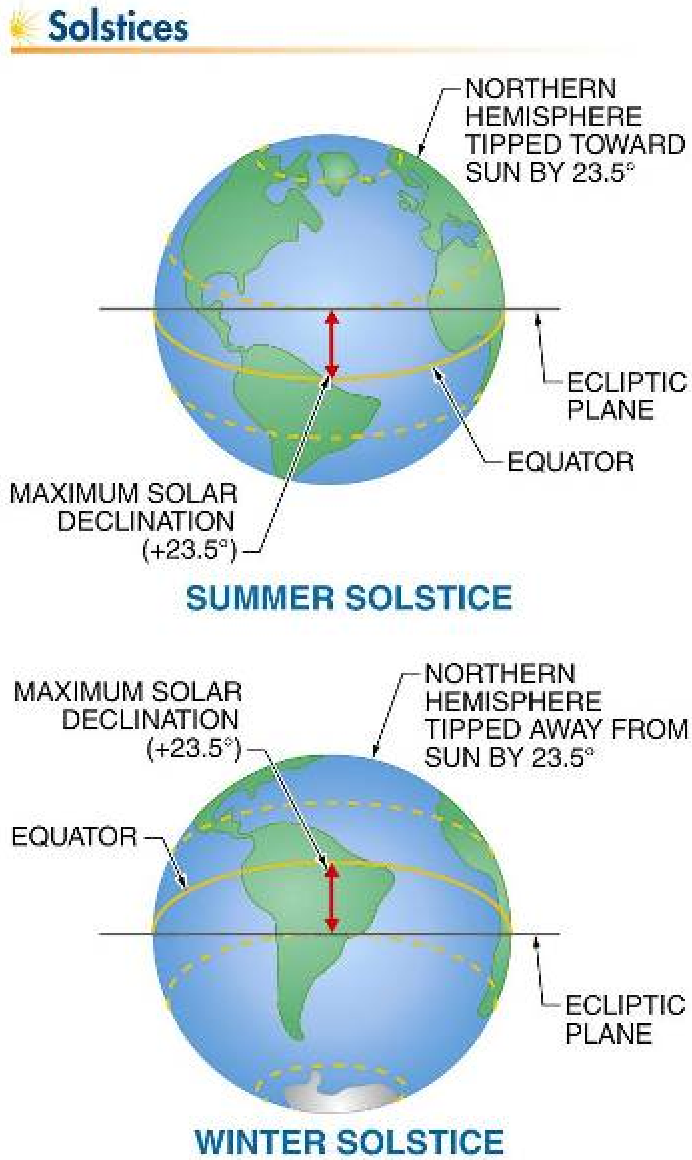
The ecliptic plane is formed by Earth's elliptical orbit around the sun.



Solar Declination

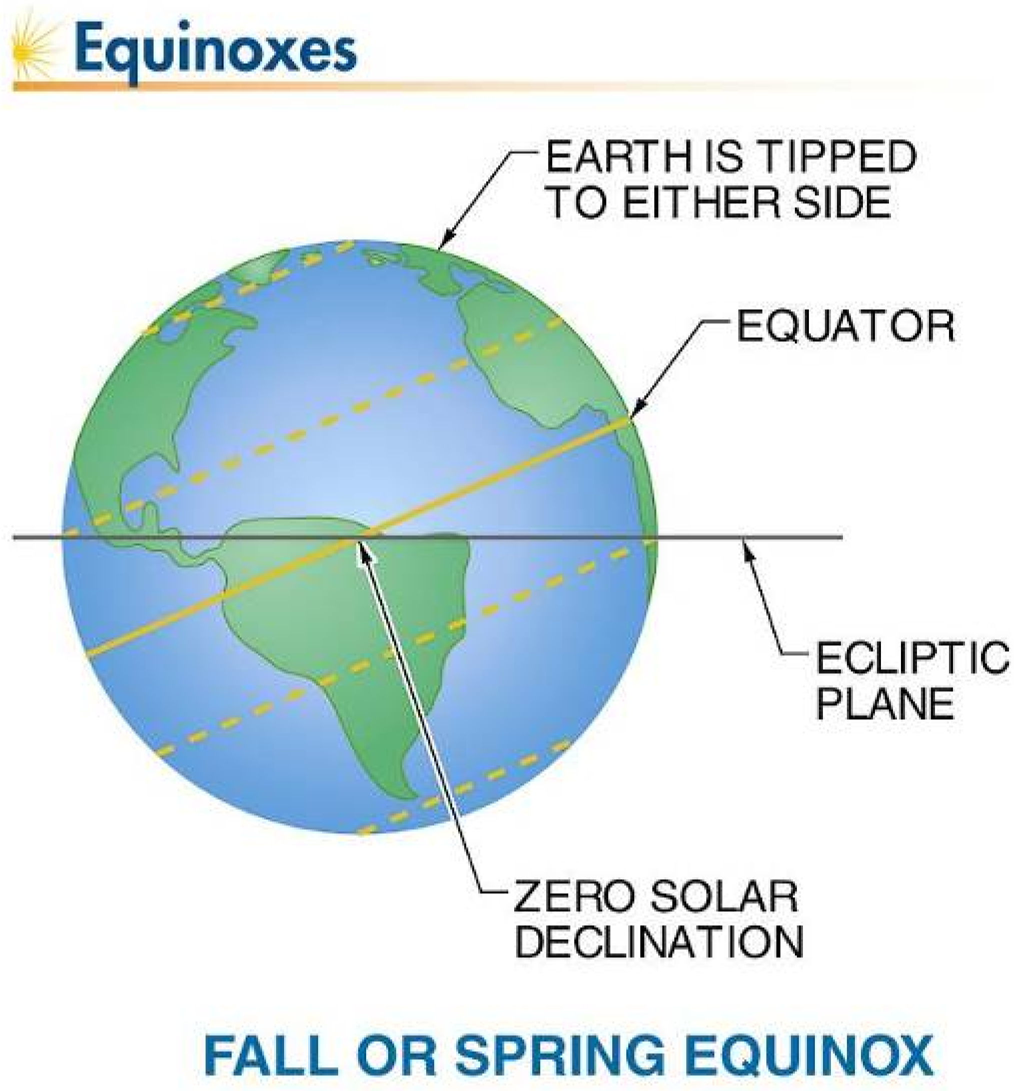


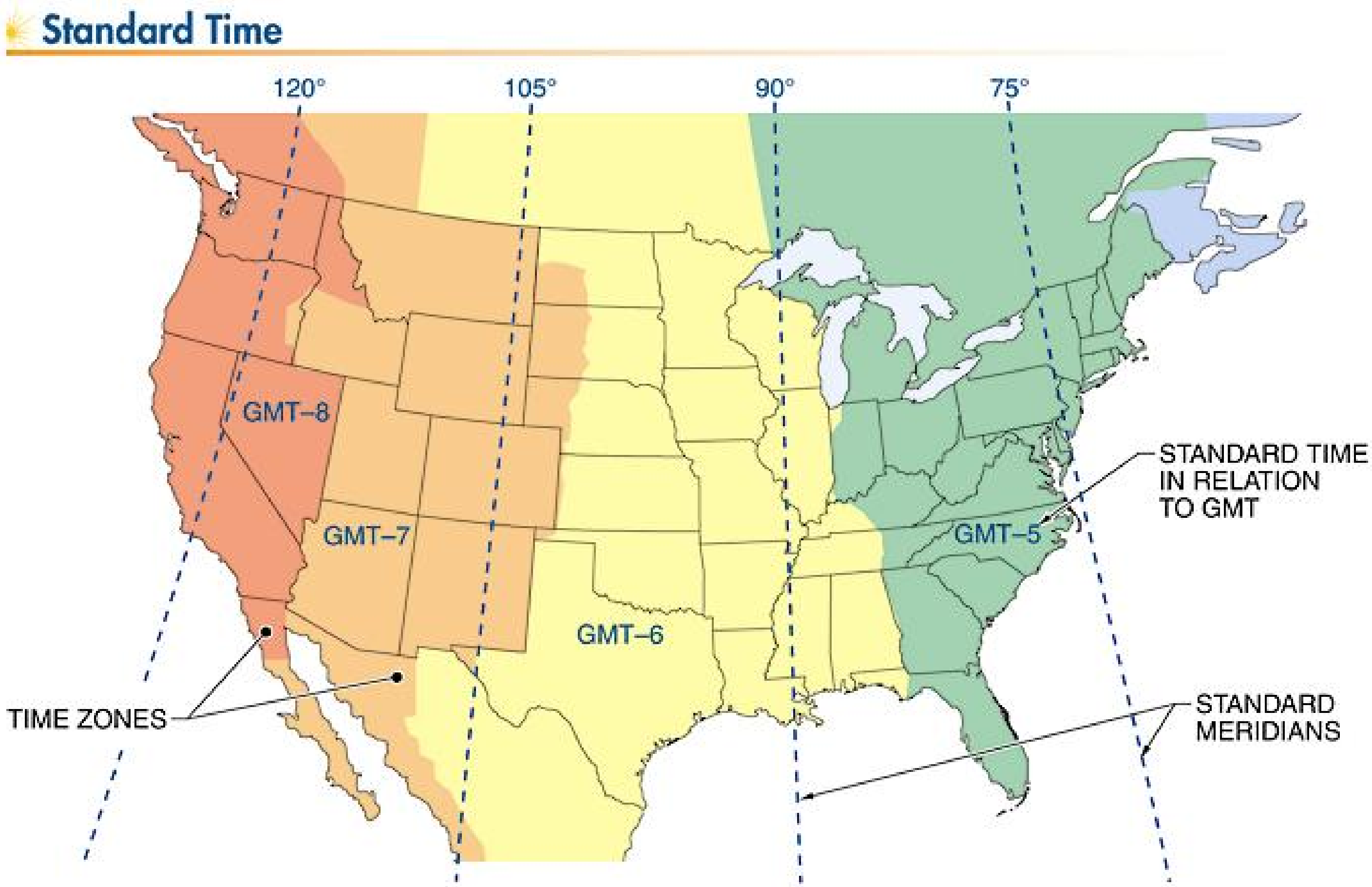
The equatorial plane is tipped 23.5° from the ecliptic plane. Over a year, this orientation produces a varying solar declination.



The summer solstice occurs when the Northern Hemisphere is tipped towards the sun. The winter solstice occurs when the Northern Hemisphere is tipped away from the sun.

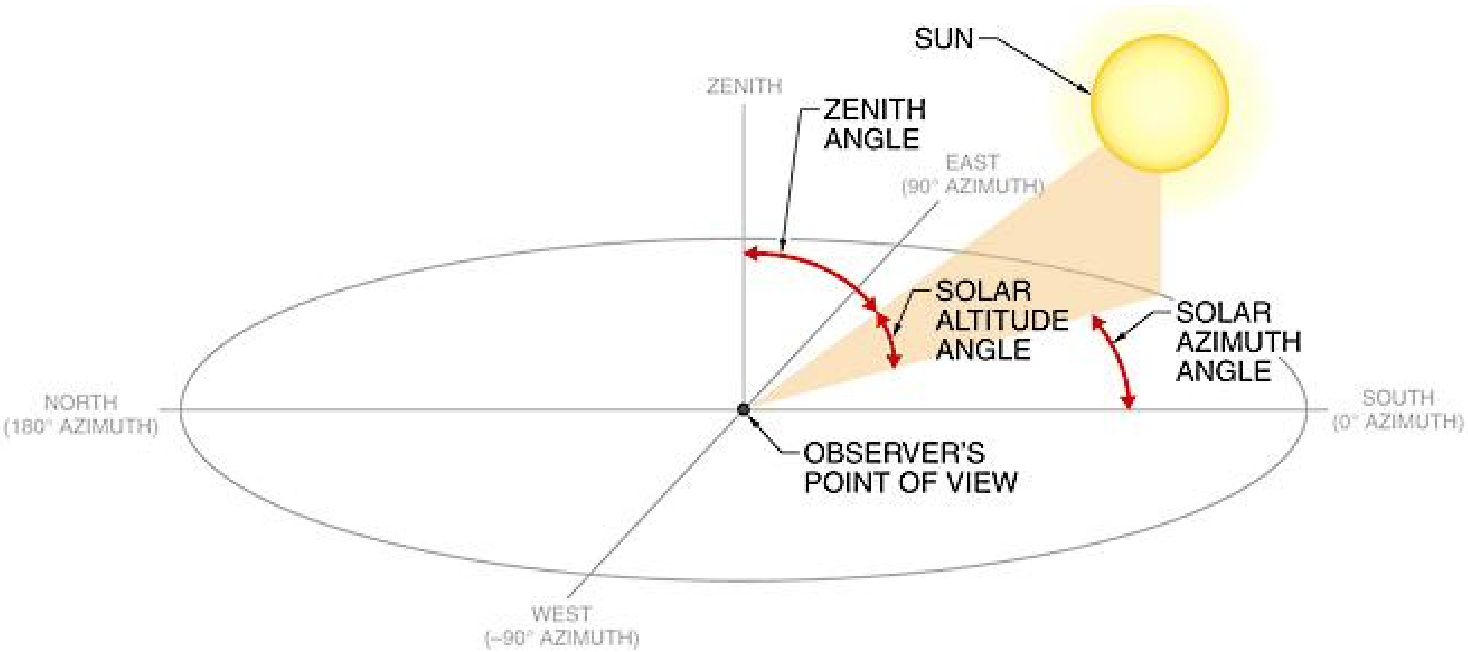
The fall and spring equinoxes occur when the sun is directly in line with the equator.





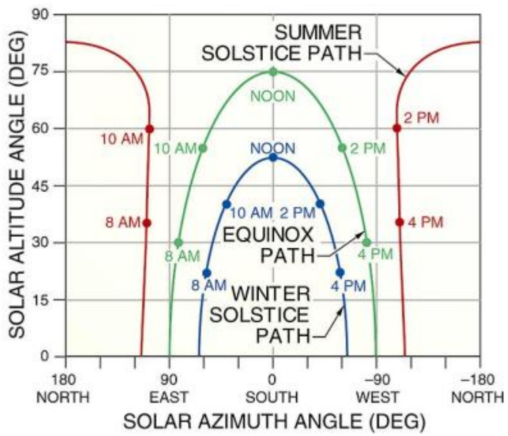
Standard time organizes regions into time zones, where every location in a time zone shares the same clock time.

Solar azimuth and altitude angles are used to describe the sun's location in the sky.

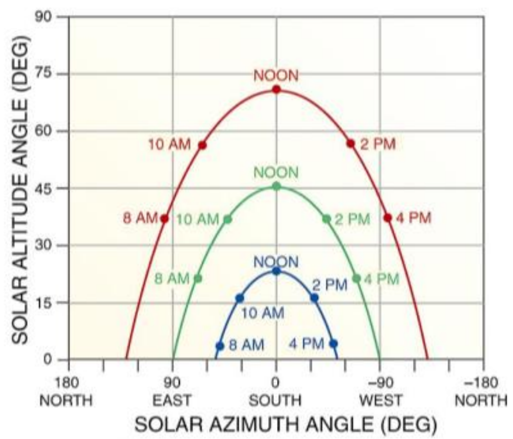


Sun Paths

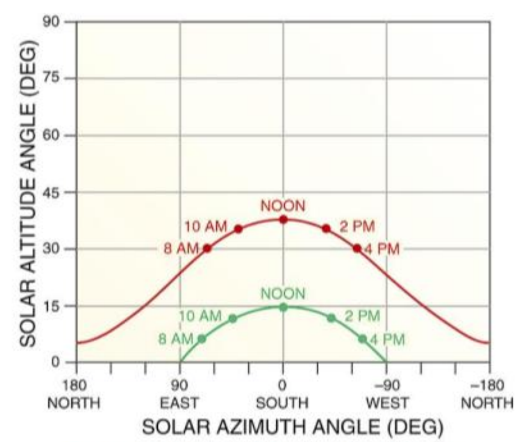
The sun's path across the sky at various times of the year can be illustrated on a diagram. The diagrams change for different latitudes.



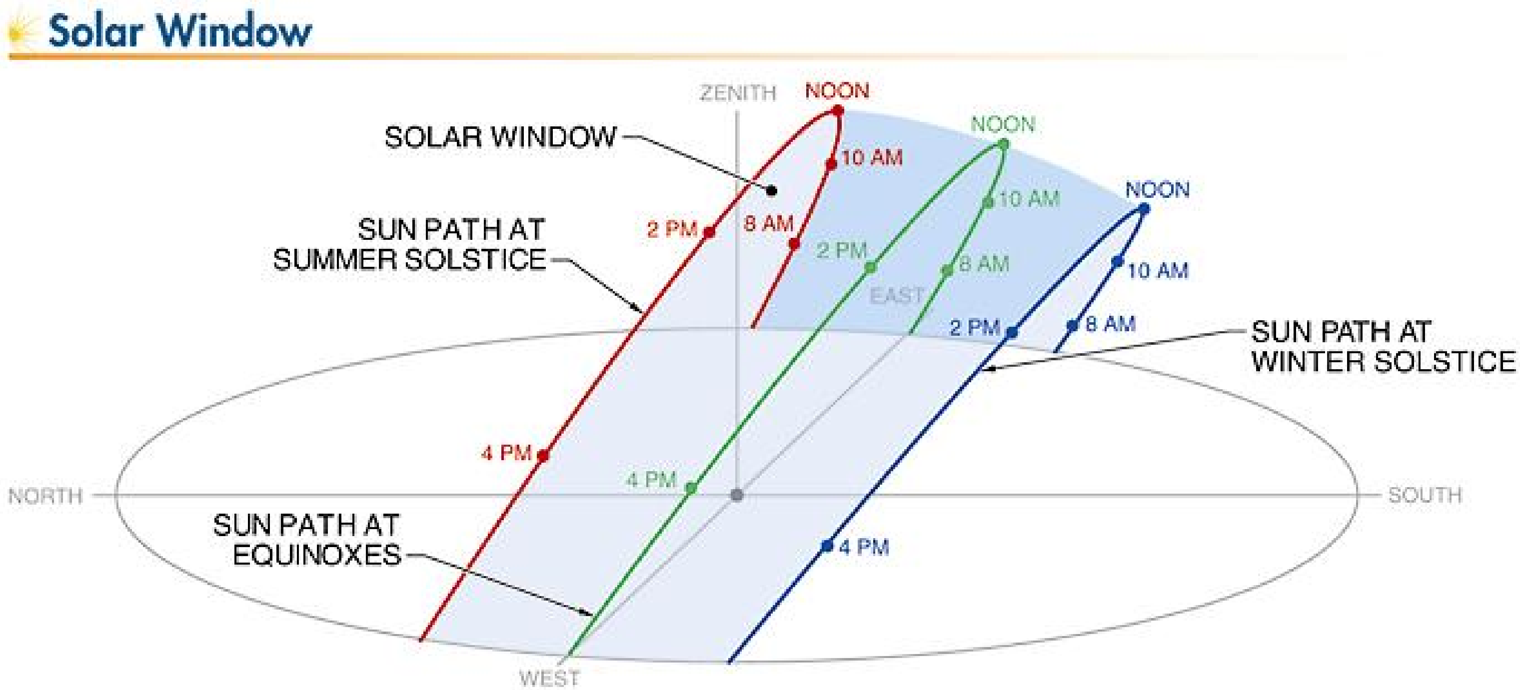
SUN PATHS FOR 15°N LATITUDE



SUN PATHS FOR 45°N LATITUDE

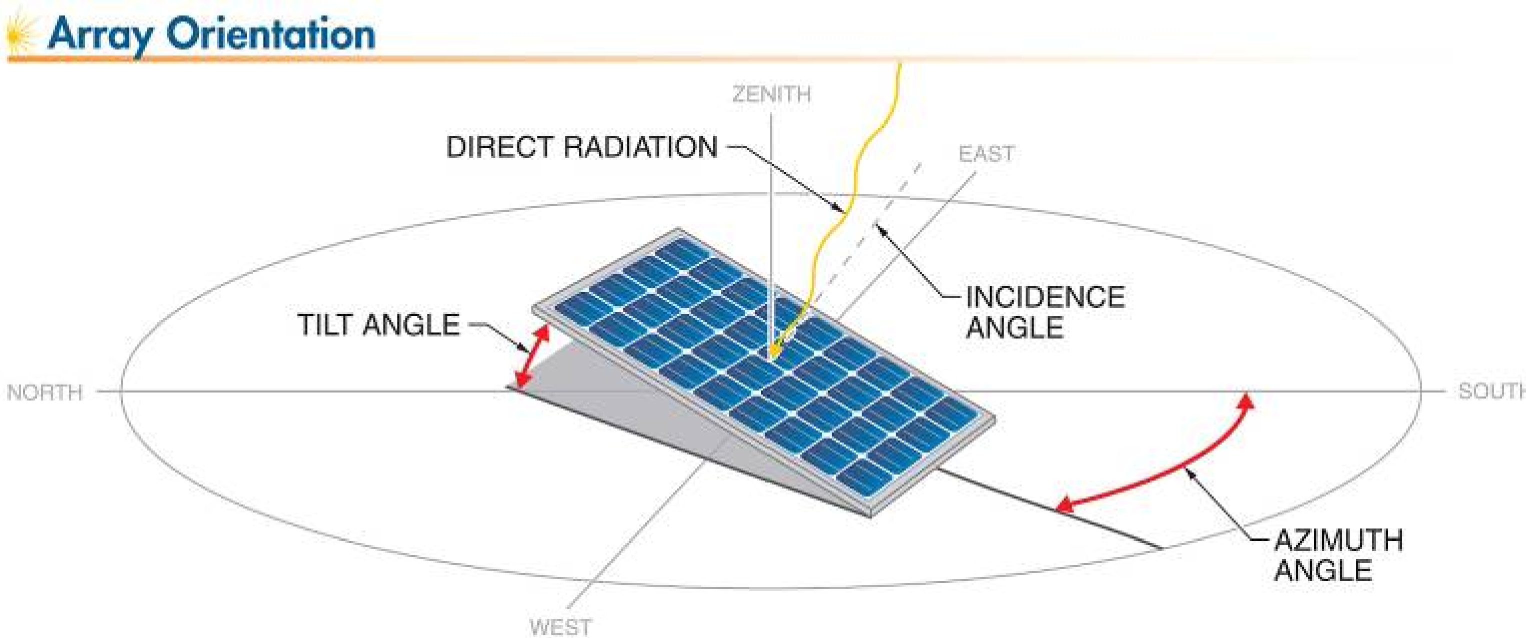


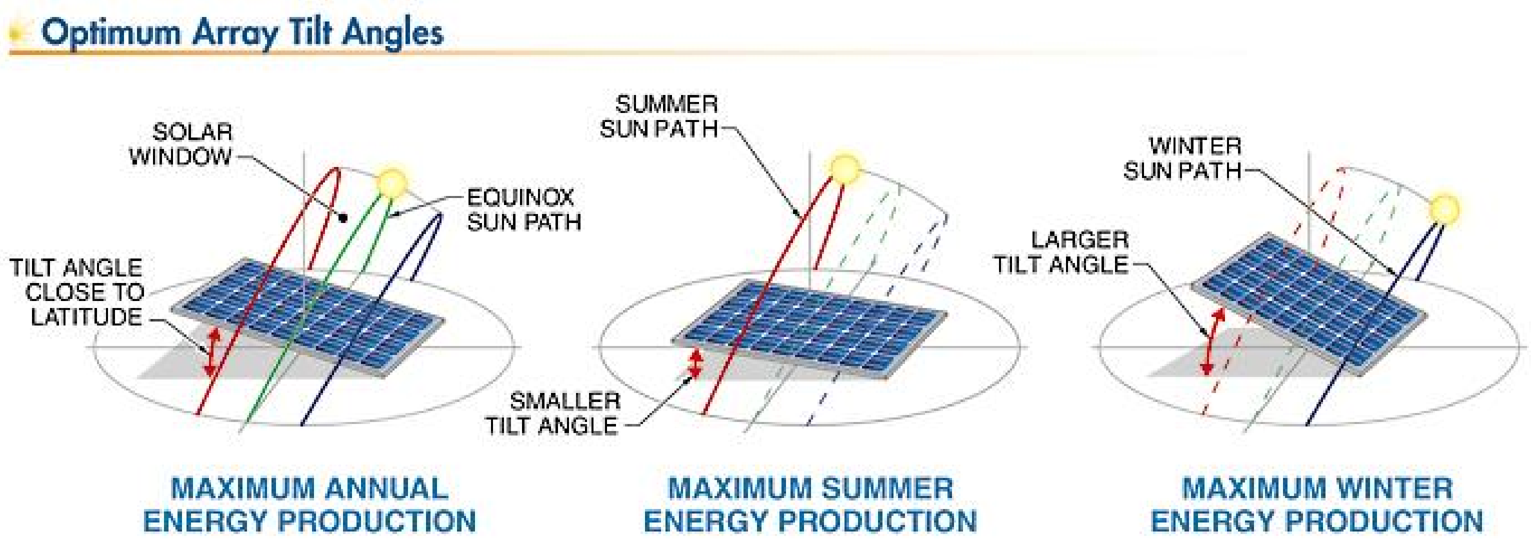
SUN PATHS FOR 75°N LATITUDE



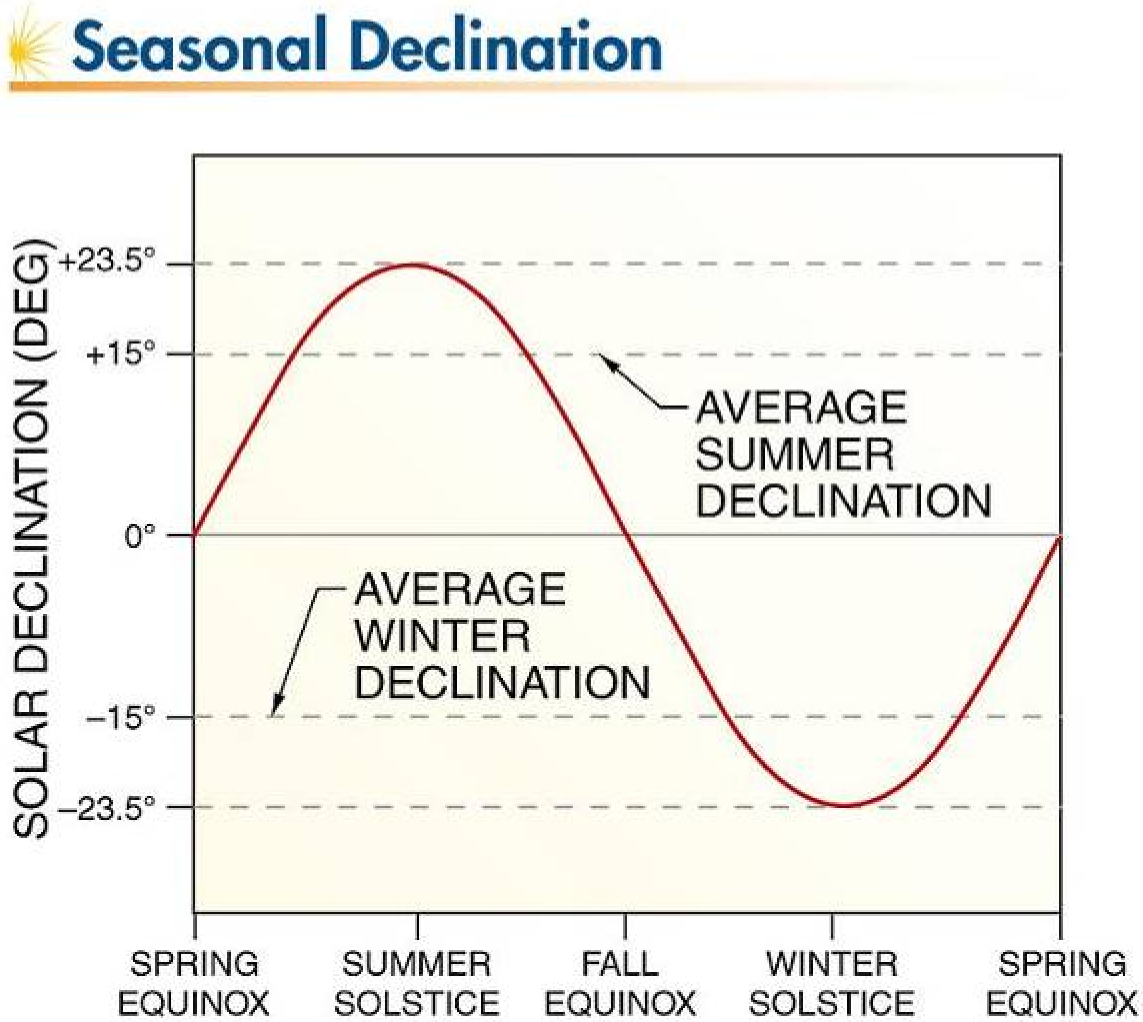
The solar window is the area of sky containing all possible locations of the sun throughout the year for a particular location.

Array orientation can be described using azimuth and tilt angles.





Energy production at certain times of the year can be optimized by adjusting the array tilt angle.



The average seasonal declinations define the optimal tilt angles for those periods.

SACRAMENTO, CA (38.5°N, 121.5°W)

Elevation: 8 m Pressure: 1015 mb

SOLAR RADIATION FOR FLAT-PLATE COLLECTORS FACING SOUTH AT A FIXED TILT*

Tilt		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
0°	Average	1.9	3.0	4.3	5.9	7.2	7.9	7.9	7.0	5.7	4.0	2.4	1.7	**4.9**
	Minimum	1.6	2.3	3.4	4.6	6.2	7.0	7.4	6.3	5.1	3.5	1.9	1.4	**4.6**
	Maximum	2.4	3.8	5.4	6.6	7.8	8.4	8.2	7.4	6.1	4.3	3.0	2.3	**5.1**
Lat – 15°	Average	2.6	3.9	5.2	6.5	7.3	7.6	7.8	7.5	6.7	5.3	3.3	2.4	**5.5**
	Minimum	1.9	2.8	3.9	4.9	6.2	6.8	7.3	6.7	5.9	4.4	2.3	1.7	**5.1**
	Maximum	3.6	5.3	6.6	7.2	7.9	8.1	8.1	7.9	7.2	5.8	4.5	3.7	**5.8**
Lat°	Average	2.9	4.2	5.4	6.3	6.8	7.0	7.2	7.2	6.9	5.7	3.7	2.7	**5.5**
	Minimum	2.0	2.9	3.9	4.7	5.9	6.2	6.7	6.4	5.9	4.8	2.5	1.8	**5.0**
	Maximum	4.1	5.9	6.9	7.1	7.4	7.4	7.5	7.6	7.3	6.3	5.1	4.4	**5.9**
Lat + 15°	Average	3.1	4.3	5.2	5.9	6.0	6.0	6.3	6.5	6.6	5.8	3.9	2.9	**5.2**
	Minimum	2.0	2.9	3.8	4.4	5.2	5.4	5.8	5.8	5.7	4.8	2.5	1.8	**4.7**
	Maximum	4.3	6.2	6.8	6.6	6.5	6.3	6.4	6.9	7.1	6.4	5.4	4.7	**5.6**
90°	Average	2.7	3.6	3.8	3.6	3.0	2.7	2.9	3.6	4.5	4.6	3.4	2.6	**3.4**
	Minimum	1.6	2.3	2.8	2.7	2.7	2.5	2.8	3.3	3.9	3.8	2.1	1.5	**3.0**
	Maximum	3.9	5.2	5.0	4.0	3.2	2.8	2.9	3.7	4.8	5.2	4.9	4.4	**3.8**

SOLAR RADIATION FOR 1-AXIS TRACKING FLAT-PLATE COLLECTORS WITH A NORTH-SOUTH AXIS*

Axis Tilt		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
0°	Average	2.5	4.0	5.9	8.1	9.9	10.8	11.1	10.0	8.3	5.8	3.3	2.2	**6.8**
	Minimum	1.7	2.7	4.1	5.7	8.2	9.2	10.1	8.8	6.8	4.8	2.2	1.5	**6.2**
	Maximum	3.4	5.7	7.9	9.3	11.1	11.9	11.7	10.8	9.0	6.5	4.5	3.5	**7.2**
Lat – 15°	Average	3.0	4.7	6.6	8.6	10.1	10.8	11.2	10.4	9.1	6.8	4.0	2.8	**7.3**
	Minimum	2.0	3.0	4.5	5.9	8.3	9.2	10.2	9.1	7.5	5.6	2.6	1.8	**6.5**
	Maximum	4.3	6.8	8.9	9.8	11.3	11.9	11.8	11.2	9.9	7.6	5.6	4.6	**7.8**
Lat°	Average	3.3	4.9	6.7	8.5	9.8	10.3	10.8	10.2	9.2	7.1	4.3	3.0	**7.4**
	Minimum	2.0	3.2	4.6	5.9	8.0	8.8	9.8	8.9	7.5	5.8	2.7	1.9	**6.5**
	Maximum	4.7	7.3	9.1	9.8	10.9	11.4	11.3	11.1	10.0	7.9	6.1	5.1	**7.9**
Lat + 15°	Average	3.4	5.0	6.6	8.2	9.2	9.7	10.1	9.8	9.0	7.2	4.5	3.2	**7.2**
	Minimum	2.1	3.2	4.5	5.6	7.6	8.2	9.2	8.5	7.4	5.8	2.7	1.9	**6.3**
	Maximum	4.9	7.4	9.0	9.4	10.3	10.6	10.6	10.6	9.8	8.0	6.4	5.4	**7.7**

SOLAR RADIATION FOR 2-AXIS TRACKING FLAT-PLATE COLLECTORS*

		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
2-Axis Tracking	Average	3.4	5.0	6.7	8.6	10.2	11.0	11.4	10.4	9.2	7.2	4.5	3.2	**7.6**
	Minimum	2.1	3.2	4.6	6.0	8.4	9.4	10.4	9.1	7.6	5.8	2.8	1.9	**6.7**
	Maximum	5.0	7.4	9.1	9.9	11.4	12.2	12.0	11.3	10.0	8.1	6.4	5.5	**8.1**

AVERAGE CLIMATIC CONDITIONS

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Average Temperature (°C)	7.3	10.4	12.0	14.6	18.5	22.0	24.3	23.9	21.9	17.9	11.8	7.4	**16.0**
Average Low (°C)	3.2	5.2	6.2	7.5	10.2	12.9	14.5	14.4	13.2	10.2	6.3	3.2	**8.9**
Average High (°C)	11.5	15.6	17.8	21.7	26.8	31.0	34.0	33.4	30.7	25.5	17.3	11.5	**23.1**
Record Low (°C)	-5.0	-5.0	-3.3	0.0	2.2	5.0	8.9	9.4	6.1	2.2	-3.3	-7.8	**-7.8**
Record High (°C)	21.1	24.4	31.1	33.9	40.6	46.1	45.6	42.8	42.2	38.3	30.6	22.2	**46.1**
Heating Degree Days†	341	222	198	128	44	7	0	0	9	43	195	339	**1527**
Cooling Degree Days†	0	0	0	16	49	117	184	174	117	29	0	0	**687**
Relative Humidity (%)	83	77	72	64	59	55	53	56	57	63	76	83	**66**
Wind Speed (m/s)	2.5	3.1	3.5	3.6	3.9	4.0	3.8	3.6	3.1	2.5	2.5	2.5	**3.2**

* in $kWh/m^2/day$, ±9%
† based on 18.3°C (65°F)