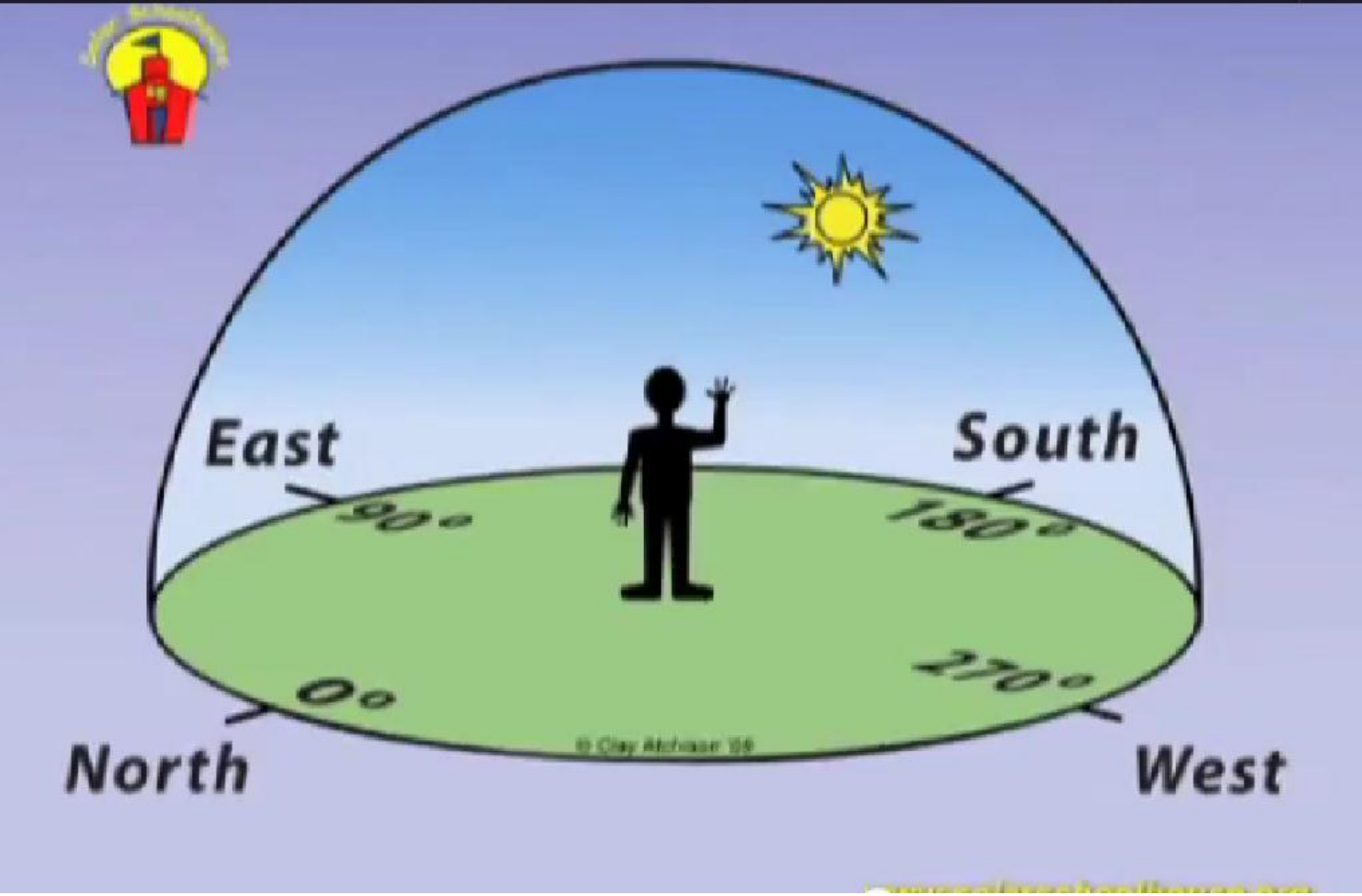
DIRECTION OF BEAM RADIATION

Dr. Osama Ayadi


East
South
90°
180°
270°
0°
North
West
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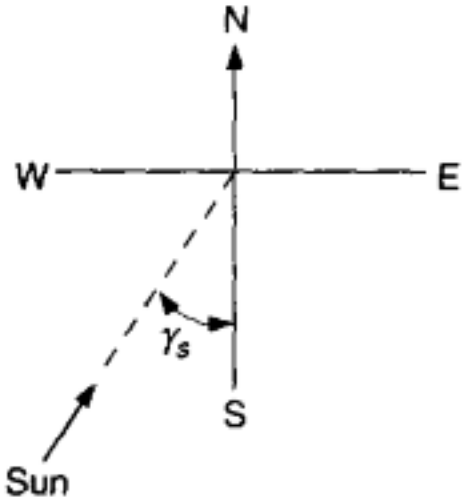
Solar azimuth angle γ_s

- An **azimuth** (ⁱ/ˈæzɪməθ/; from Arabic السمت *as-samt*, meaning "a way, a part, or quarter"[1]).
- The angular displacement from south of the projection of beam radiation on the horizontal plane.
- East of south are negative and west of south are positive.



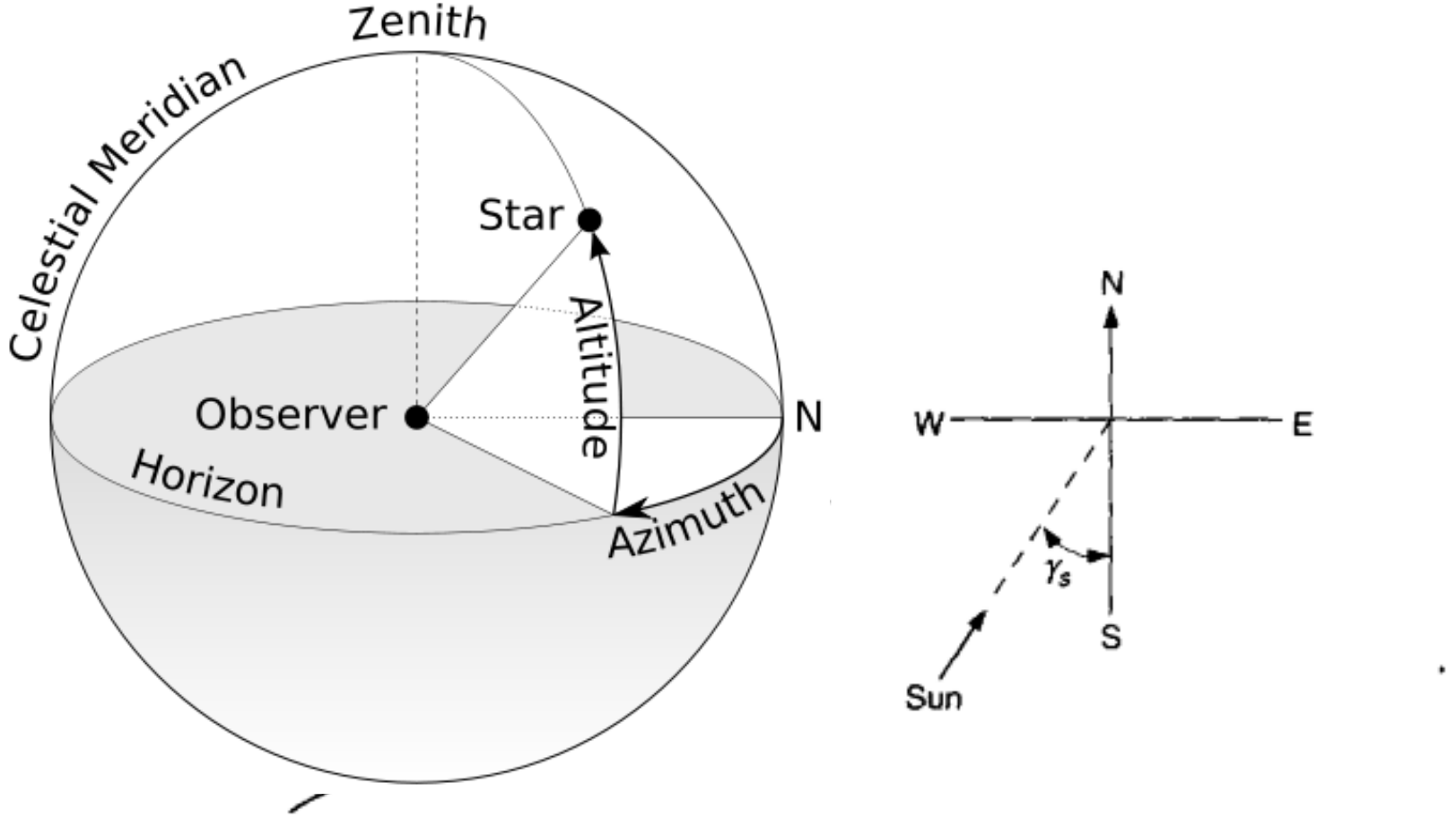
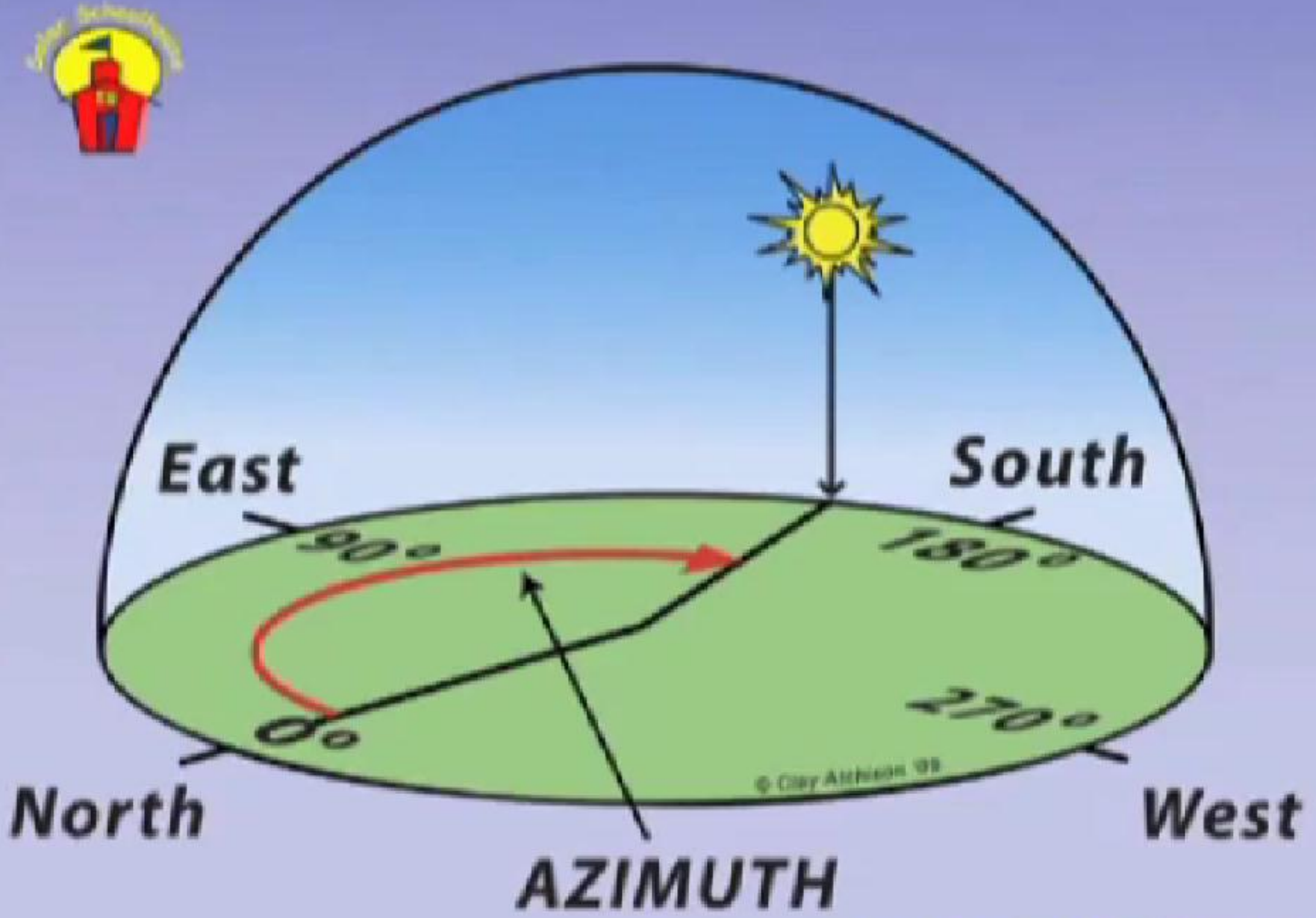


Figure 1.6.1 (a) Zenith angle, slope, surface azimuth angle, and solar azimuth angle for a tilted surface. (b) Plan view showing solar azimuth angle.


East
South
90°
180°
270°
0°
North
West
AZIMUTH
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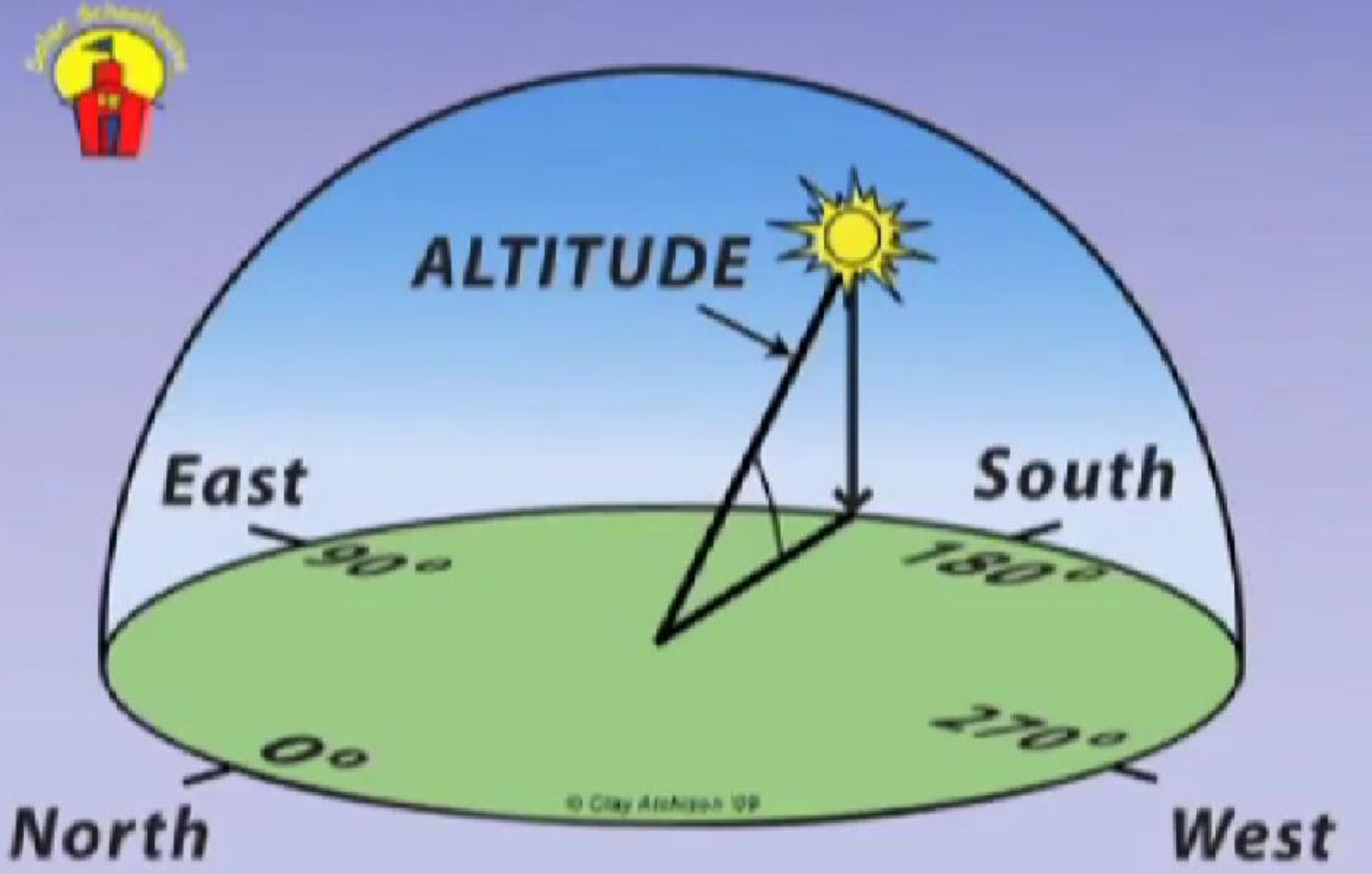
ALTITUDE
East
South
90°
180°
270°
0°
North
West
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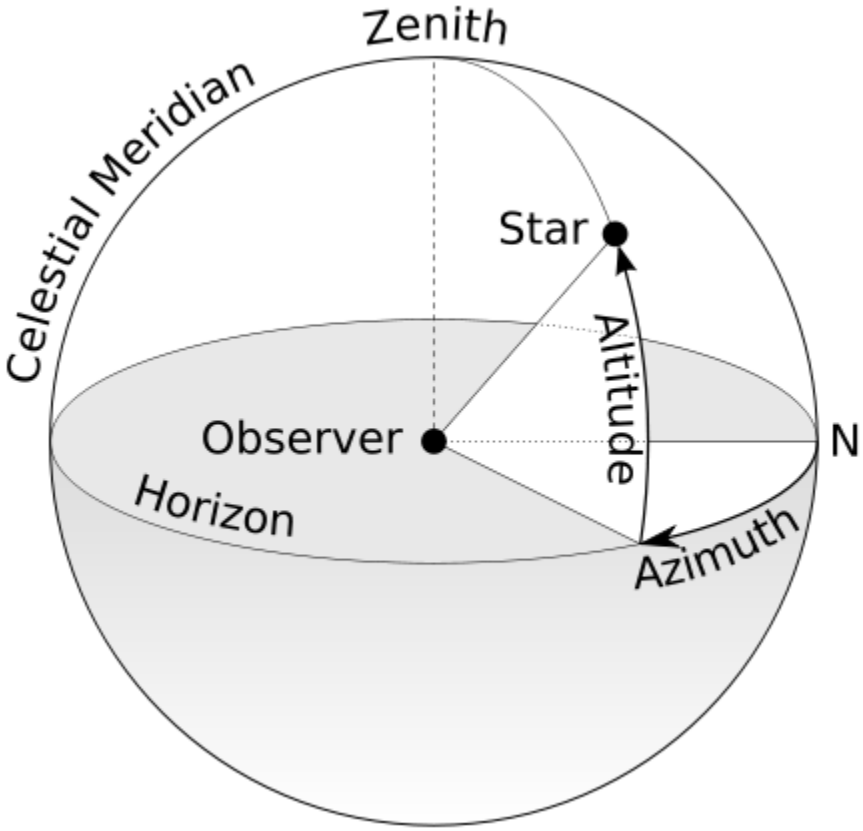
Zenith Angle

- The word "zenith" derives from the inaccurate reading of the Arabic expression) سمت الرأس samt ar-ra's.

- The angle between the vertical and the line to the sun, that is , the angle of incidence of beam radiation on a horizontal surface.


Zenith
Celestial Meridian
Star
Altitude
Observer
N
Horizon
Azimuth

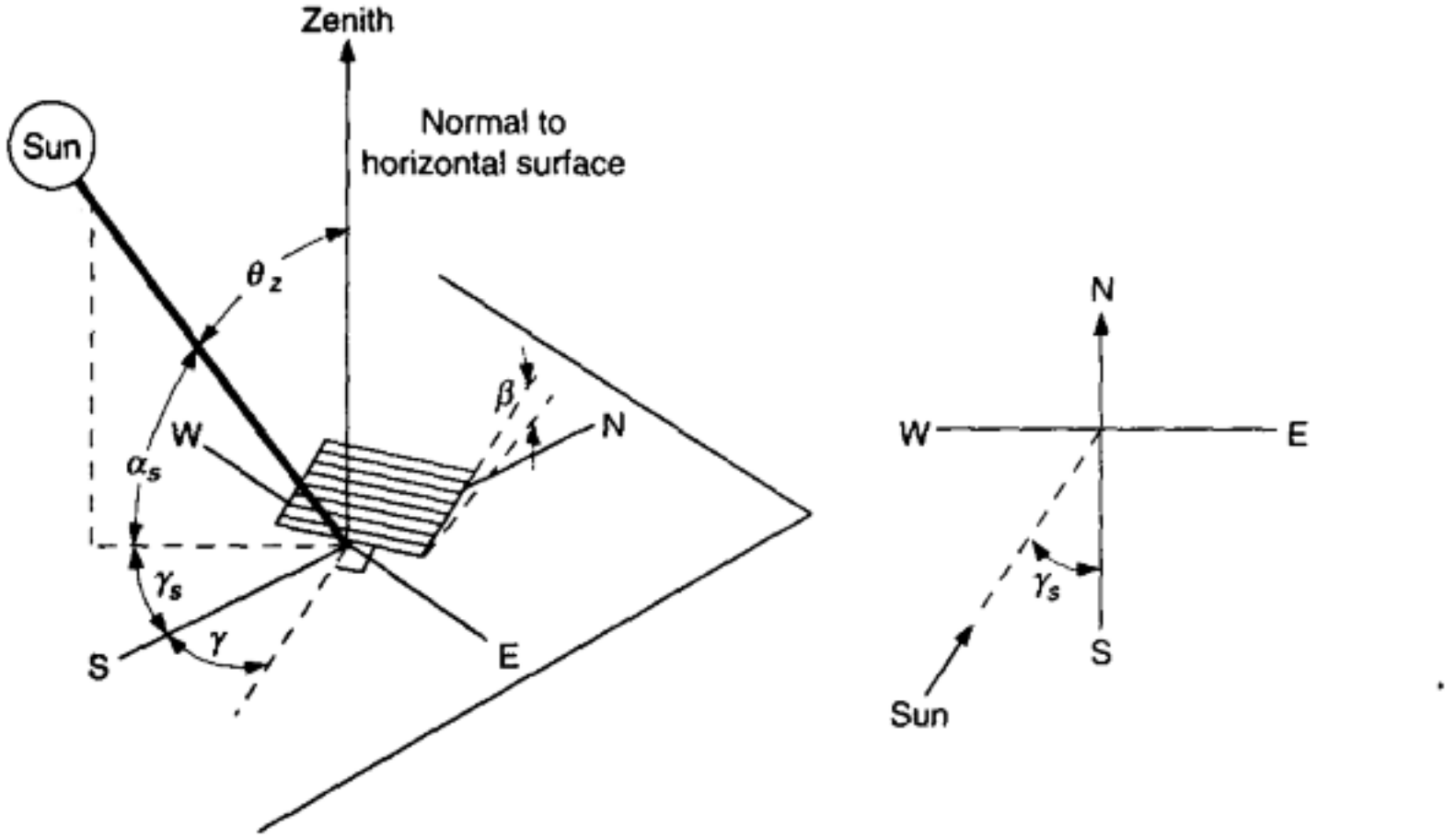
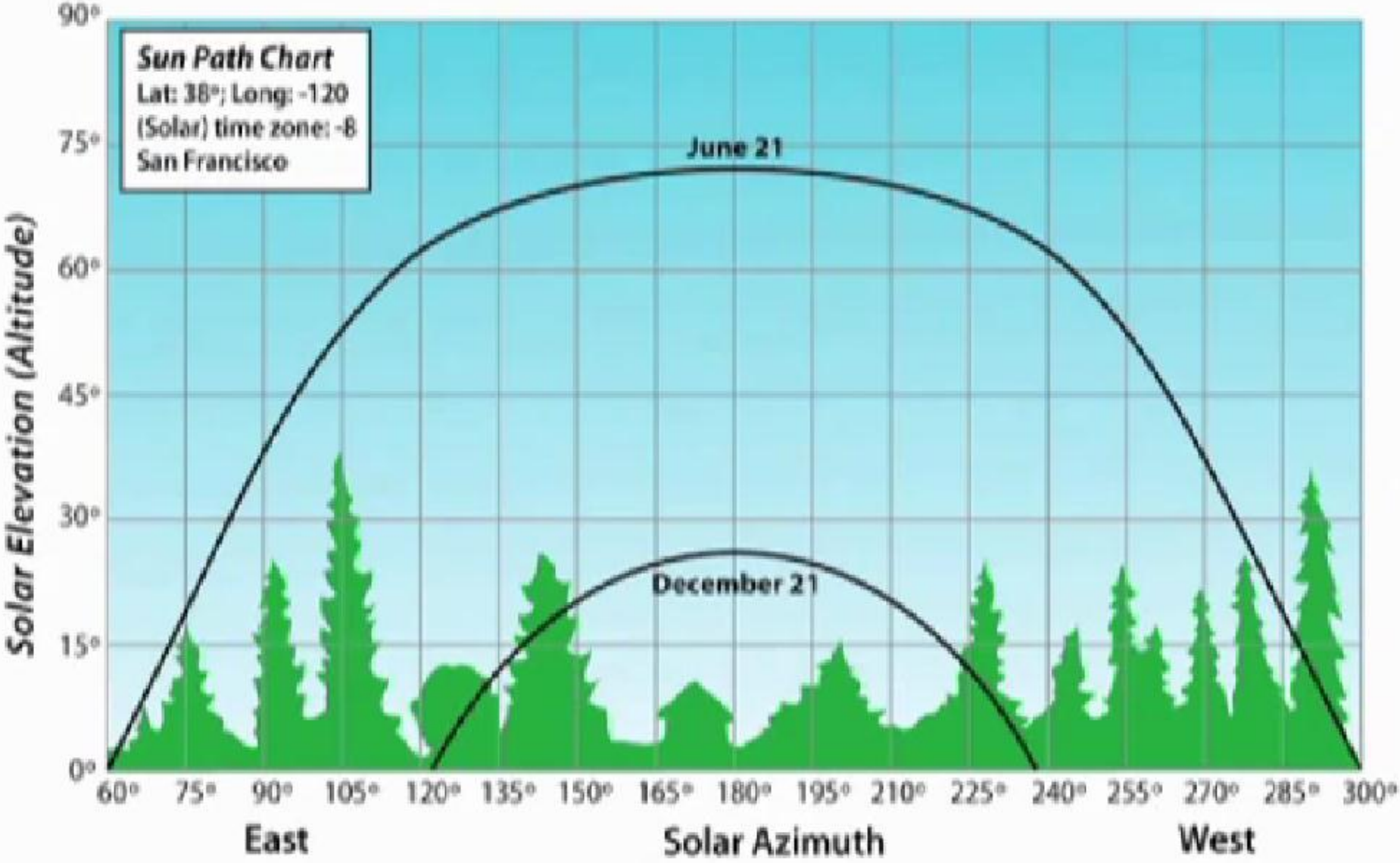
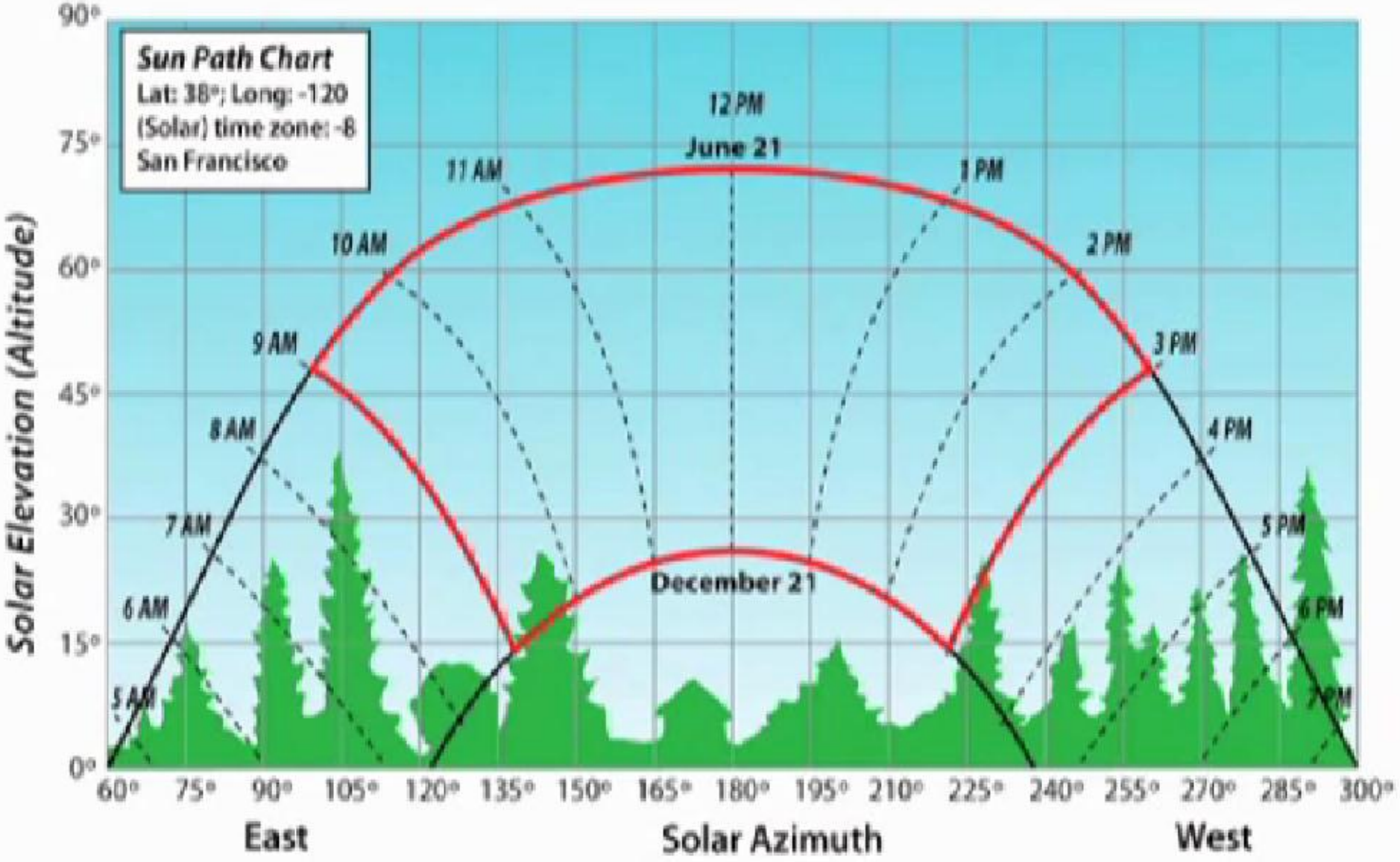
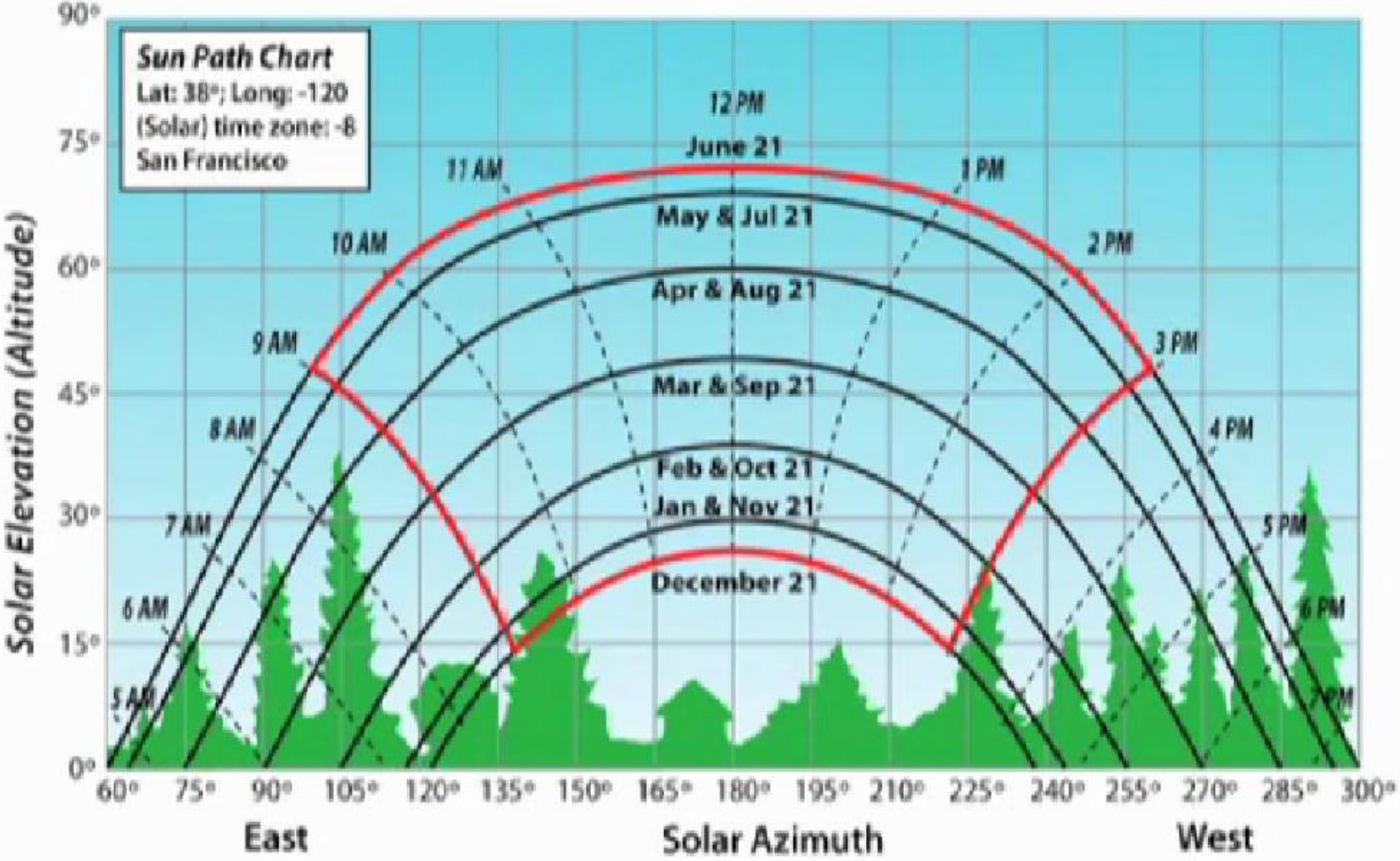
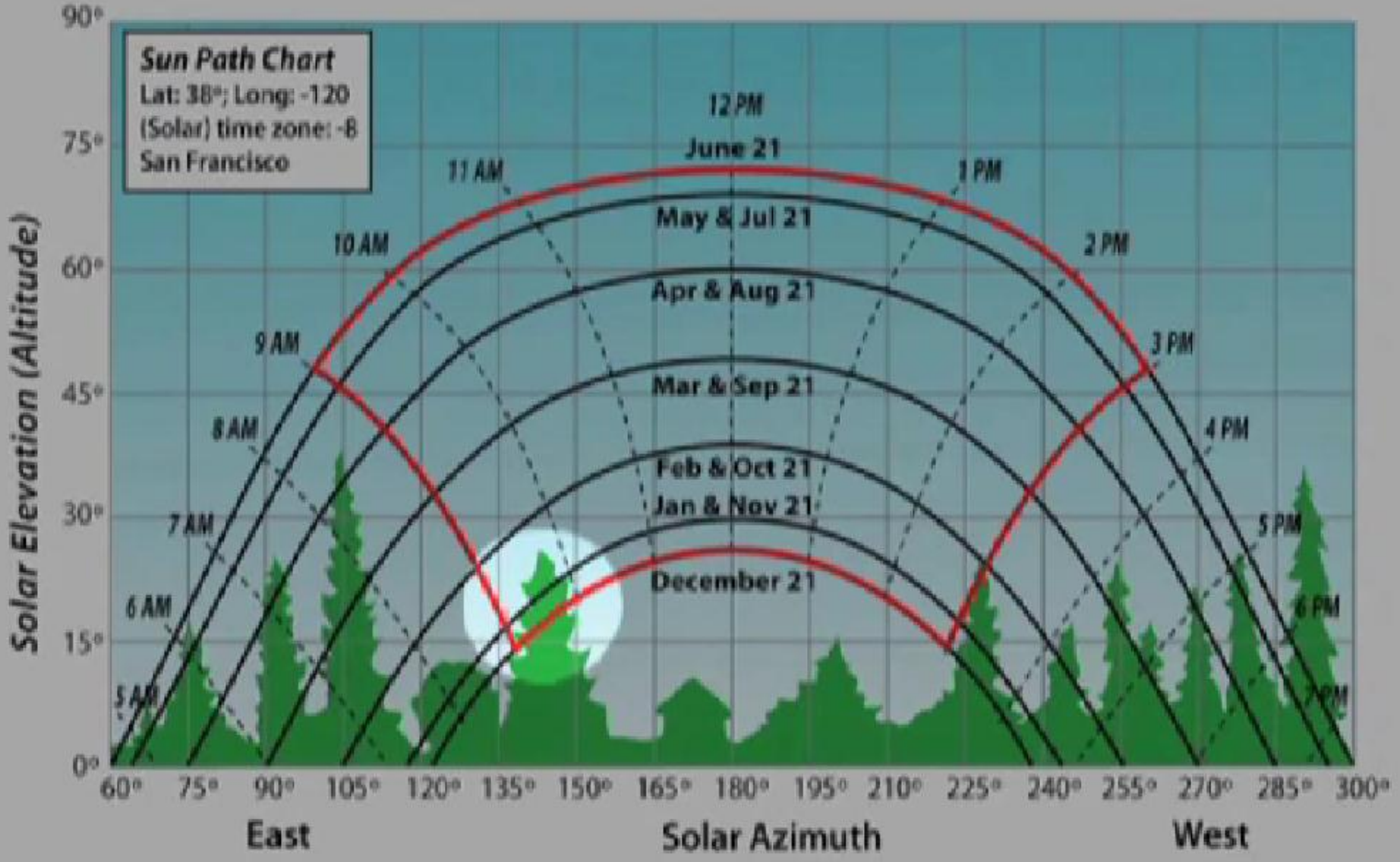


Figure 1.6.1 (a) Zenith angle, slope, surface azimuth angle, and solar azimuth angle for a tilted surface. (b) Plan view showing solar azimuth angle.


Sun Path Chart
Lat: 38°; Long: -120
(Solar) time zone: -8
San Francisco
June 21
December 21
Solar Elevation (Altitude)
90°
75°
60°
45°
30°
15°
0°
60° 75° 90° 105° 120° 135° 150° 165° 180° 195° 210° 225° 240° 255° 270° 285° 300°
East
Solar Azimuth
West


Sun Path Chart
Lat: 38°; Long: -120
(Solar) time zone: -8
San Francisco
12 PM
June 21
11 AM
1 PM
10 AM
2 PM
9 AM
3 PM
8 AM
4 PM
7 AM
5 PM
6 AM
6 PM
5 AM
December 21
90°
75°
60°
45°
30°
15°
0°
Solar Elevation (Altitude)
60° 75° 90° 105° 120° 135° 150° 165° 180° 195° 210° 225° 240° 255° 270° 285° 300°
East
Solar Azimuth
West


Sun Path Chart
Lat: 38°; Long: -120
(Solar) time zone: -8
San Francisco
12 PM
June 21
11 AM
1 PM
May & Jul 21
10 AM
2 PM
Apr & Aug 21
9 AM
3 PM
Mar & Sep 21
8 AM
4 PM
Feb & Oct 21
7 AM
Jan & Nov 21
5 PM
6 AM
December 21
6 PM
5 AM
7 PM
90°
75°
60°
45°
30°
15°
0°
Solar Elevation (Altitude)
60° 75° 90° 105° 120° 135° 150° 165° 180° 195° 210° 225° 240° 255° 270° 285° 300°
East
Solar Azimuth
West


Sun Path Chart
Lat: 38°; Long: -120
(Solar) time zone: -8
San Francisco
12 PM
June 21
11 AM
1 PM
May & Jul 21
10 AM
2 PM
Apr & Aug 21
9 AM
3 PM
Mar & Sep 21
8 AM
4 PM
Feb & Oct 21
Jan & Nov 21
7 AM
5 PM
December 21
6 AM
6 PM
5 AM
7 PM
90°
75°
60°
45°
30°
15°
0°
Solar Elevation (Altitude)
60° 75° 90° 105° 120° 135° 150° 165° 180° 195° 210° 225° 240° 255° 270° 285° 300°
East
Solar Azimuth
West

http://solardat.uoregon.edu/SunChartProgram.html

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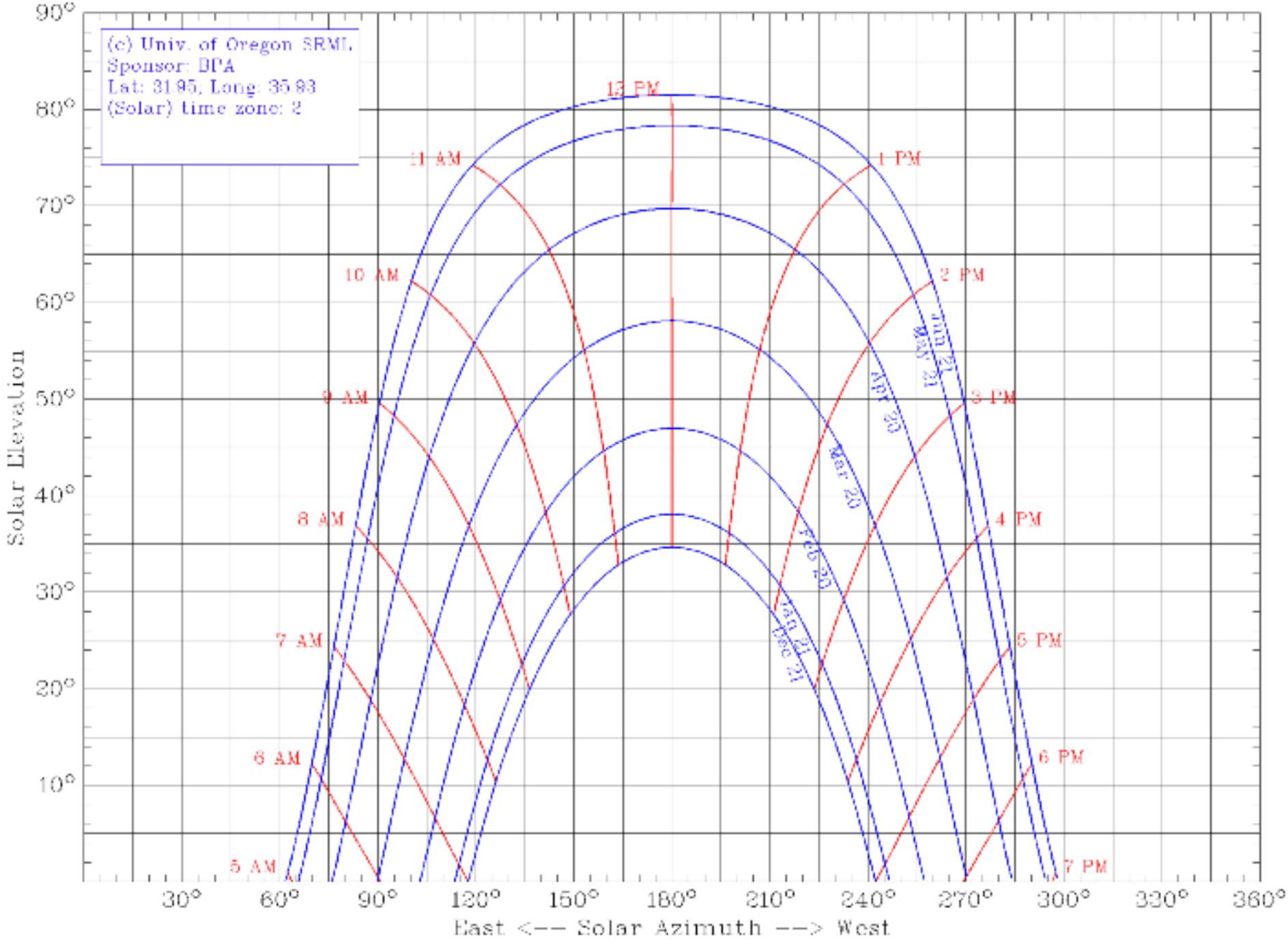

(c) Univ. of Oregon SRML
Sponsor: DPA
Lat: 31.95, Long: 35.83
(Solar) time zone: 2
12 PM
11 AM
1 PM
10 AM
2 PM
9 AM
3 PM
8 AM
4 PM
7 AM
5 PM
6 AM
6 PM
5 AM
7 PM
Jun 21
May 21
Apr 20
Mar 20
Feb 19
Jan 21
Dec 21
90°
80°
70°
60°
50°
40°
30°
20°
10°
Solar Elevation
30°
60°
90°
120°
150°
180°
210°
240°
270°
300°
330°
360°
East <-- Solar Azimuth --> West

NEXT LECTURE

- Introduction to the angles
- Solar time
- Air mass

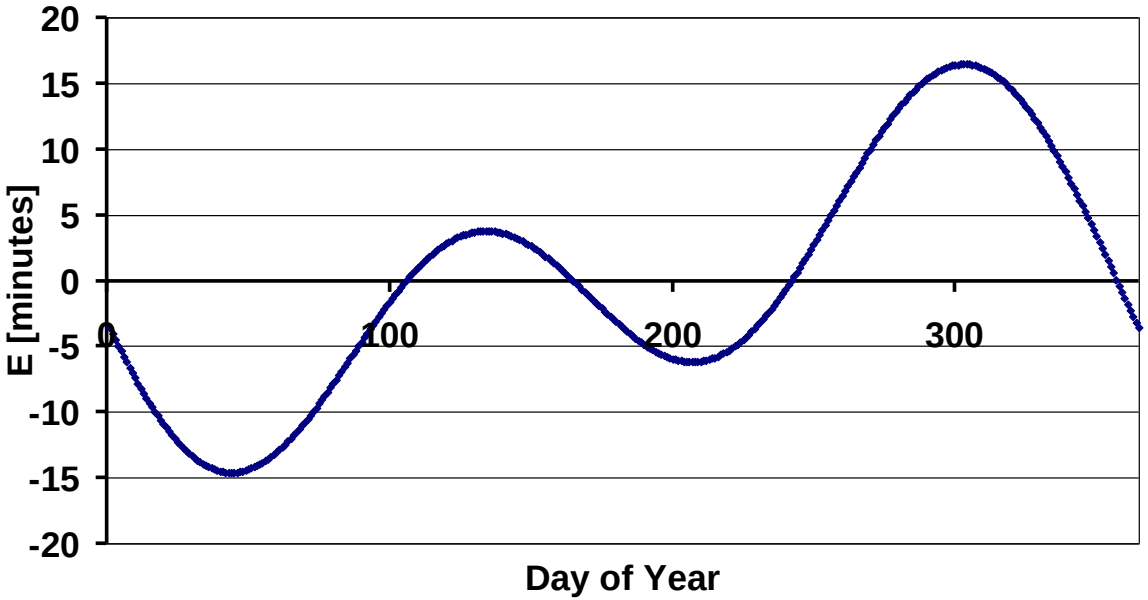
Solar Time 1

- All calculations concerning the Sun have to be performed in solar time
- Solar time does not coincide with the local time
- Solar time is location dependent!
- Solar time is calculated as:

$$\text{Solar Time} = \text{Standard Time} + E + 4\cdot(\Theta_{st} - \Theta_{loc})$$

Equation of Time, E

$$E = 229.2(0.000075 + 0.001868\cos B - 0.032077\sin B - 0.01315\cos 2B - 0.04089\sin 2B)$$



$$B = (n-1)\frac{360}{365}$$

Solar Time 1

- All calculations concerning the Sun have to be performed in solar time
- Solar time does not coincide with the local time
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The general equation for calculating the apparent solar time (AST) is

$$\mathrm{AST} = \mathrm{LST} + \mathrm{ET} \pm 4(\mathrm{SL} - \mathrm{LL}) - \mathrm{DS} \tag{2.3}$$

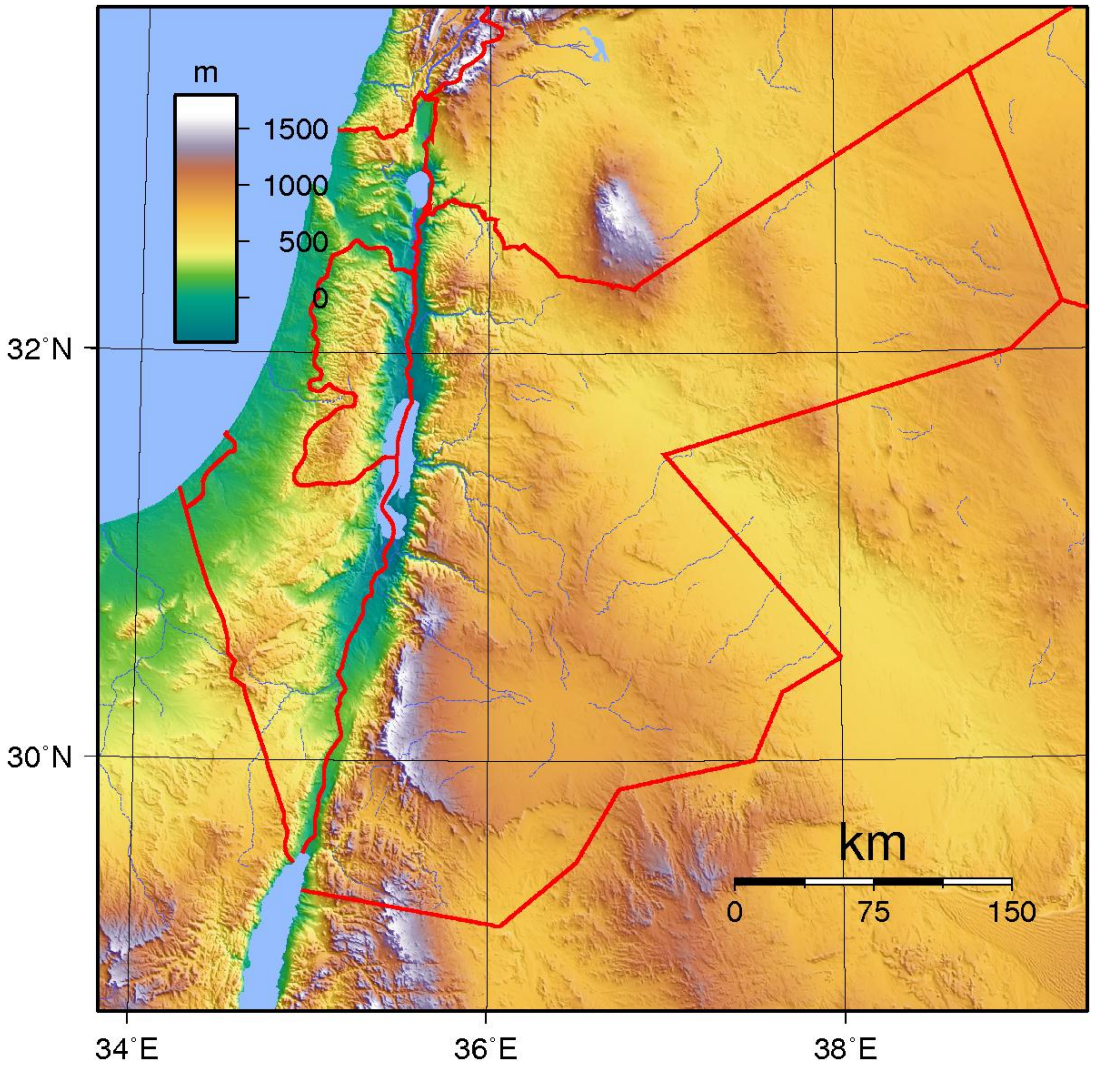
where
LST = local standard time.
ET = equation of time.
SL = standard longitude.
LL = local longitude.
DS = daylight saving (it is either 0 or 60 min).

If a location is east of Greenwich, the sign of Eq. (2.3) is minus (−), and if it is west, the sign is plus (+). If a daylight saving time is used, this must be subtracted from the local standard time. The term DS depends on whether daylight saving time is in operation (usually from end of March to end of October)

- Amman

Latitude : 31°57'N

Longitude: 35°52'E

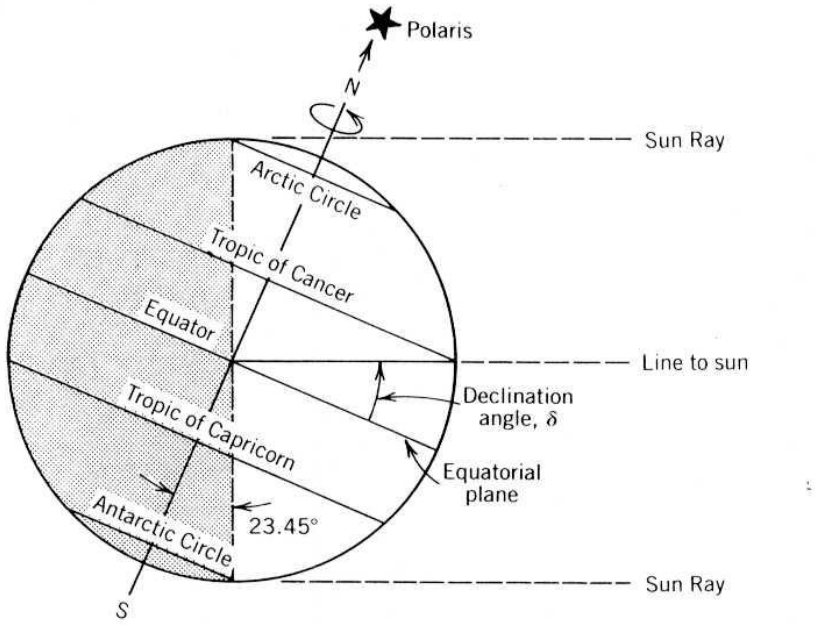


Solve ex. 1.5.1


RUSSIA
+4
NORWAY
SWEDEN
FINLAND
UNITED KINGDOM
REP OF IRELAND
POLAND
BELARUS
GERMANY
UKRAINE
KAZAKHSTAN
+6
FRANCE
ROMANIA
BULGARIA
AZORES
PORTUGAL
SPAIN
ITALY
+5
GREECE
TURKEY
MOROCCO
IRAN
+3.5
+4.5
IRAQ
ALGERIA
+1
LIBYA
EGYPT
+2
PAKISTAN
+5
INDIA
+5.5
WESTERN SAHARA
+0
SAUDI ARABIA
+3
U.A.E.
MAURITANIA
MALI
NIGER
SUDAN
OMAN
YEMEN
CHAD
LACCADIVE ISLANDS
NIGER
SOUTH SUDAN
ETHIOPIA
SOMALIA
CAMEROON
MALDIVES
GABON
CONGO
KENYA
SEYCHELLES
TANZANIA
ANGOLA
ZAMBIA
MAURITIUS
©www.timetemperature.com

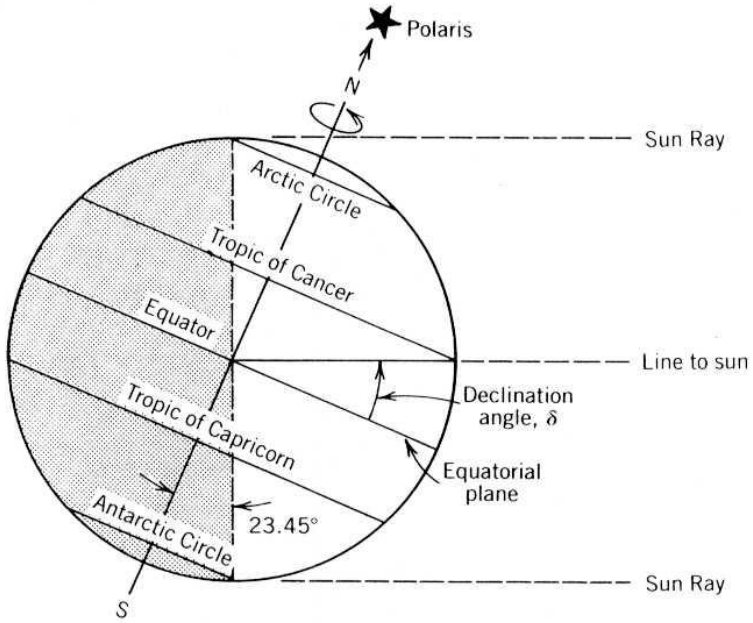
Declination angle

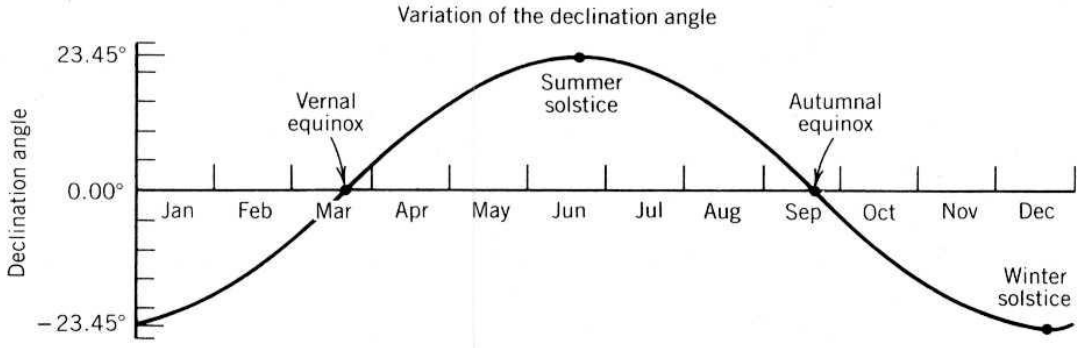
- The plane that includes the earth 's equator is called the *equatorial plane*.



- If a line is drawn between the center of the earth and the sun, the angle between this line and the earth's equatorial plane is called the *declination angle*.

$$\delta = 23.45 \sin\left(360\frac{284 + n}{365}\right)$$





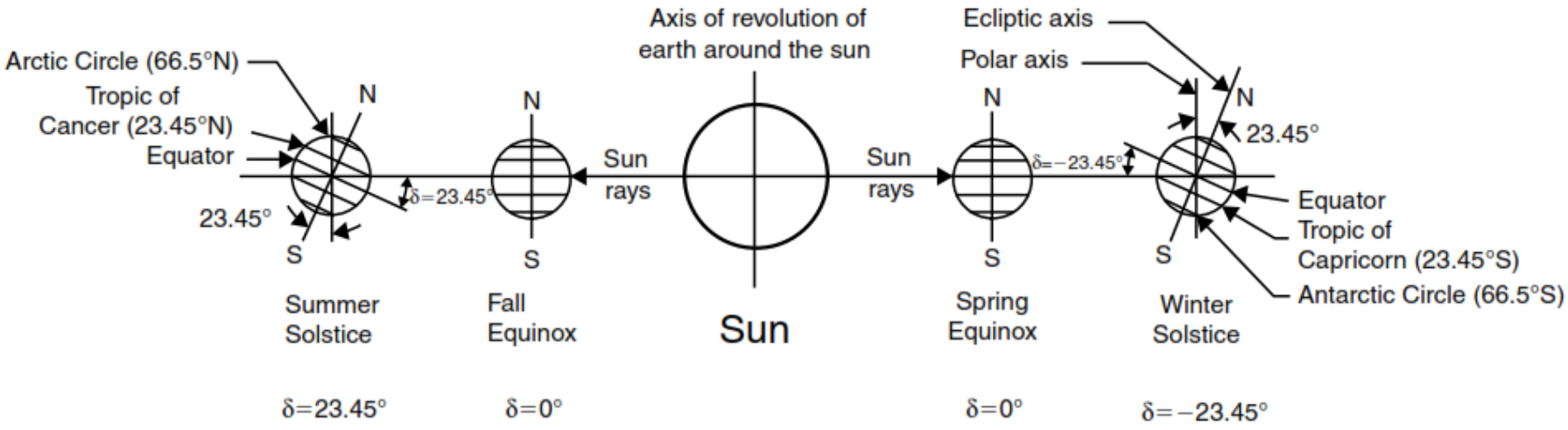
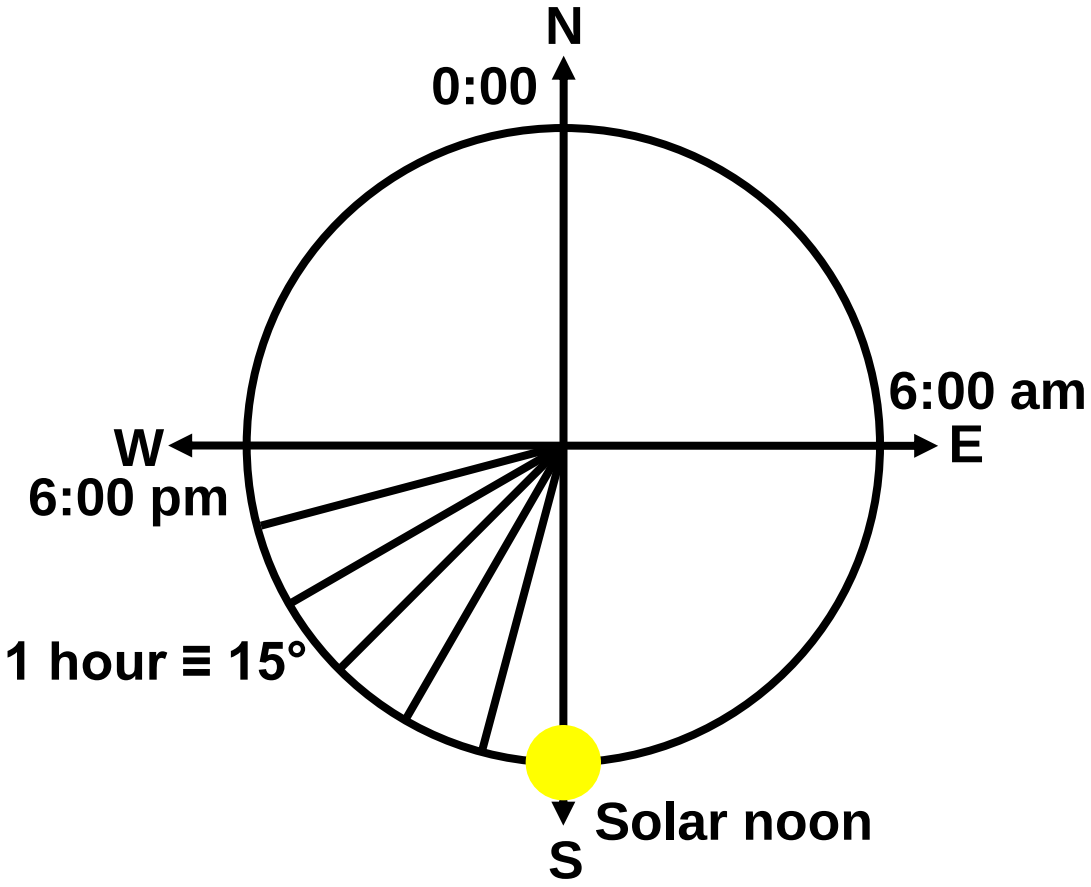


FIGURE 2.6 Yearly variation of solar declination.

Hour Angle, ω

- ‘the way the sun moves around you’
- 0 at solar noon
- Full turn in 24 h

⇒ 15° per hour



Hour angle , ω

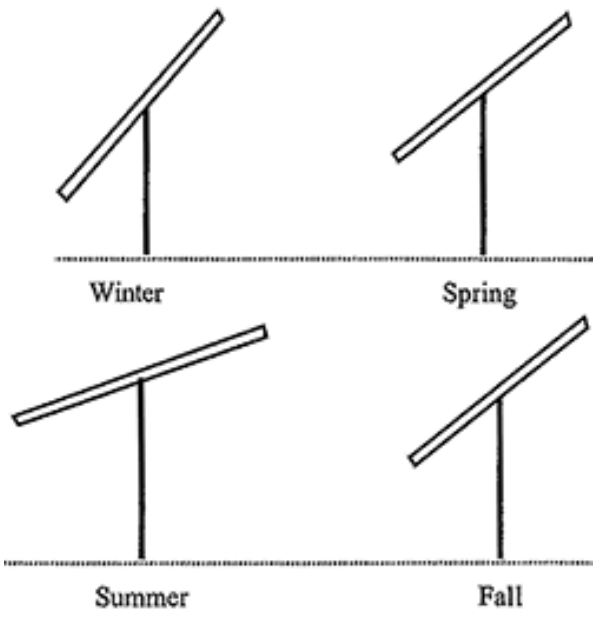
- The angular Displacement of the sun east or west of the local meridian due to rotation of the earth on its axis at 15 ° per hour;
  - morning negative,
  - afternoon positive.
  - The hour angle at local solar noon is zero,

EX. 10:30 (solar time)

$\omega = -22.5\ ^\circ$

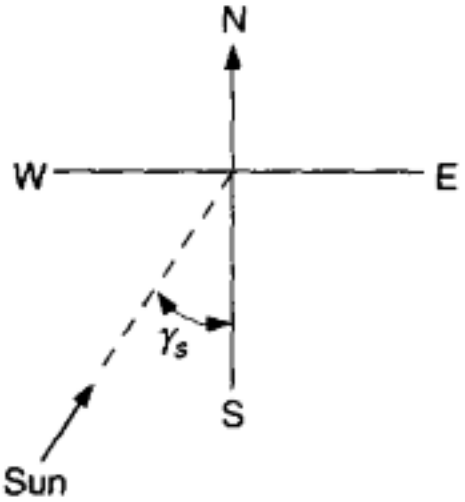
Slope (tilt), β

- The angle between the plane of the surface in question and the horizontal:
- $0° \leq \beta \leq 180°$
- $\beta \geq 90°$ means that the surface has a downward-facing component.



Solar azimuth angle γ_s

- An **azimuth** (/ˈæzɪməθ/; from Arabic السمت *as-samt*, meaning "a way, a part, or quarter"[1]).
- The angular displacement from south of the projection of beam radiation on the horizontal plane.
- East of south are negative and west of south are positive.



فادي يونس ، عمر الحوراني

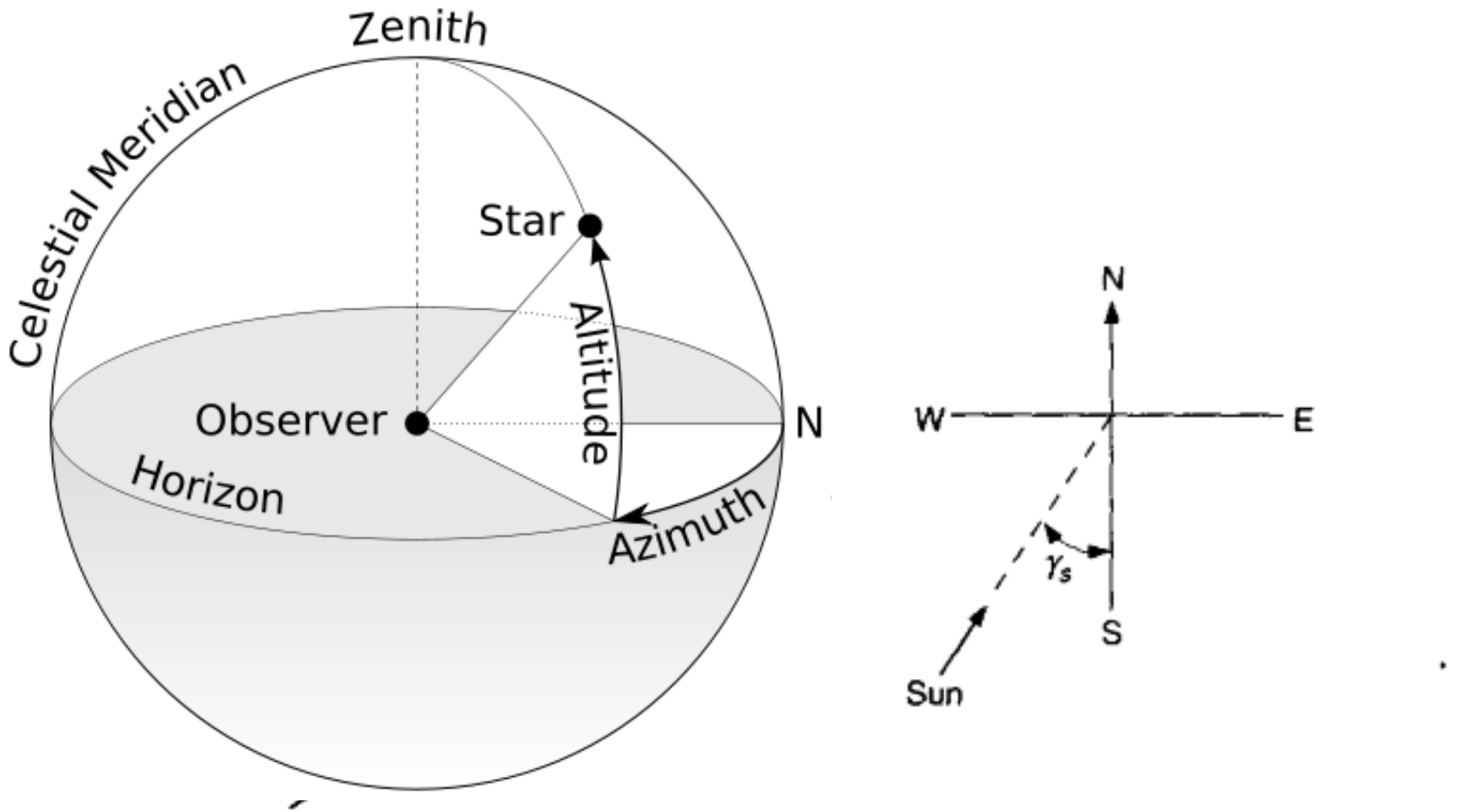


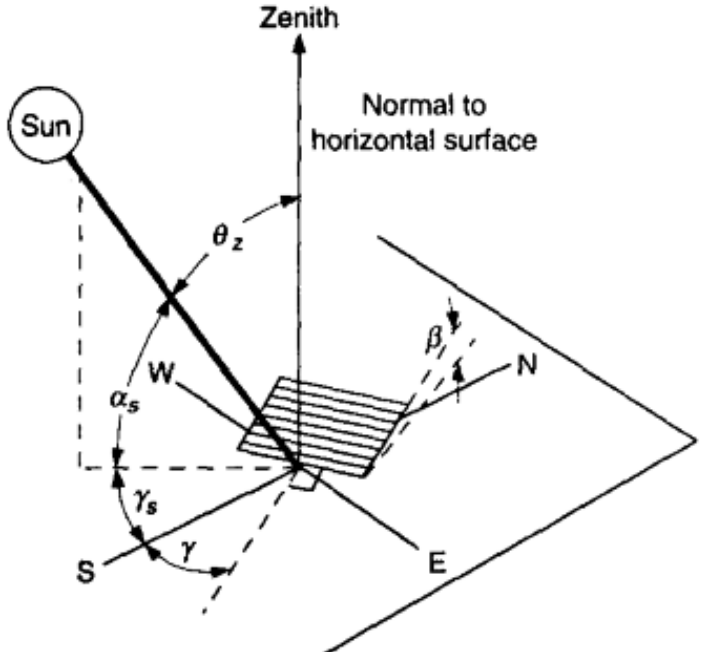
Figure 1.6.1 (a) Zenith angle, slope, surface azimuth angle, and solar azimuth angle for a tilted surface. (b) Plan view showing solar azimuth angle.

Surface azimuth, γ

- The deviation of the projection on a horizontal plane of the normal to the surface from the local meridian, with zero due south, east negative, and west positive.

Zenith Angle, θz

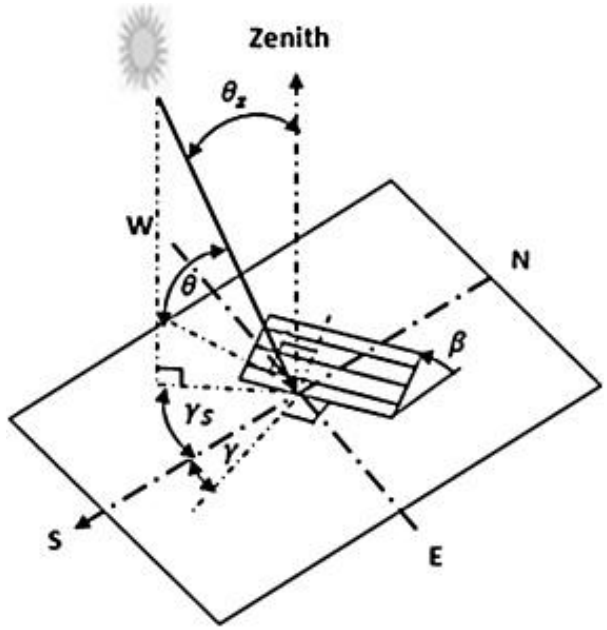
- The angle between the vertical and the line to the sun.



$$\cos \theta_z = \cos \phi \cos \delta \cos \omega + \sin \phi \sin \delta$$

INCIDENCE ANGLE, θ

- The angle between the sun's rays and the normal on a surface.
- For a horizontal plane, the incidence angle, **θ**, and the zenith angle, **θz**, are the same.



$$\cos\theta = \sin\delta\sin\phi\cos\beta - \sin\delta\cos\phi\sin\beta\cos\gamma + \cos\delta\cos\phi\cos\beta\cos\omega + \cos\delta\sin\phi\sin\beta\cos\gamma\cos\omega + \cos\delta\sin\beta\sin\gamma\sin\omega$$

$$\cos\theta = \cos\theta_z\cos\beta + \sin\theta_z\sin\beta\cos(\gamma_s - \gamma)$$

Calculate the angle of incidence of beam radiation on a surface located at Madison, WI at 10:30 (solar time) on February 13, if the surface is tilted 45° from the horizontal and pointed 15° west of south.

Under these conditions, n is 44, the declination δ from Equation 1.6.1 is −14°, the hour angle ω is −22.5° (15° per hour times 1.5 hours before noon), and the surface azimuth angle γ is 15°. Using a slope β of 45° and the latitude ϕ of Madison of 43°N, Equation 1.6.2 is

$$\begin{aligned}\cos\theta = {} & \sin(-14)\sin 43\cos 45 \\ & - \sin(-14)\cos 43\sin 45\cos 15 \\ & + \cos(-14)\cos 43\cos 45\cos(-22.5) \\ & + \cos(-14)\sin 43\sin 45\cos 15\cos(-22.5) \\ & + \cos(-14)\sin 45\sin 15\sin(-22.5)\end{aligned}$$

$$\cos\theta = -0.117 + 0.121 + 0.464 + 0.418 - 0.068 = 0.817$$

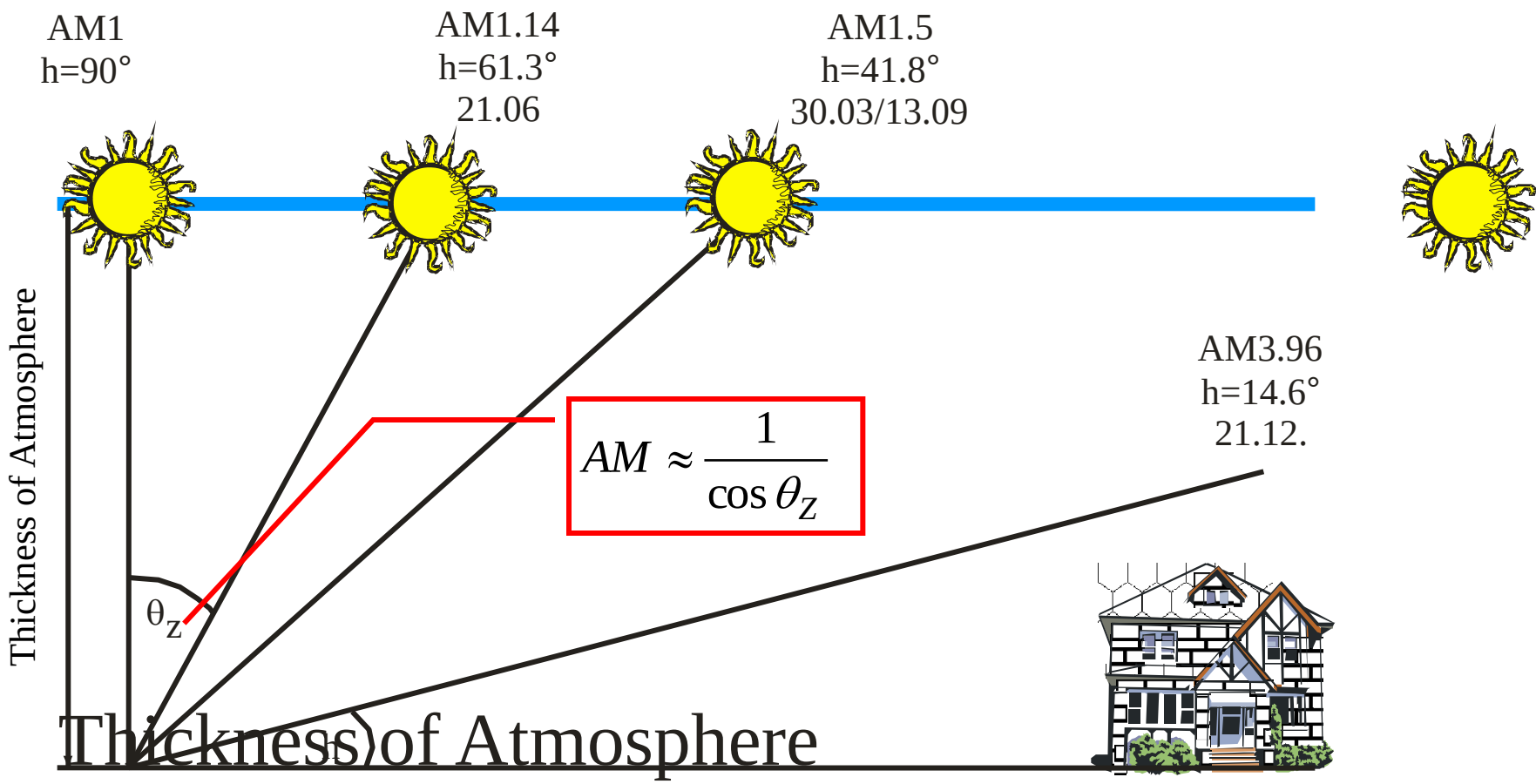
$$\theta = 35°$$

■

Air Mass

When the sun is vertically above a location the sunlight takes the shortest path through the atmosphere. However, if the sun is at a lower angle then the path through the atmosphere is longer. This causes increased absorption and scattering of the solar radiation and hence a lower radiation intensity. The *air mass factor* (AM) is a measure of the length of the path of the sunlight through the earth's atmosphere in terms of one atmosphere thickness. Using this definition, with the sun in the vertical position (elevation angle, $\gamma_S = 90°$), $AM = 1$ ($\text{AM} = 1/\sin \gamma_S$).

Air Mass

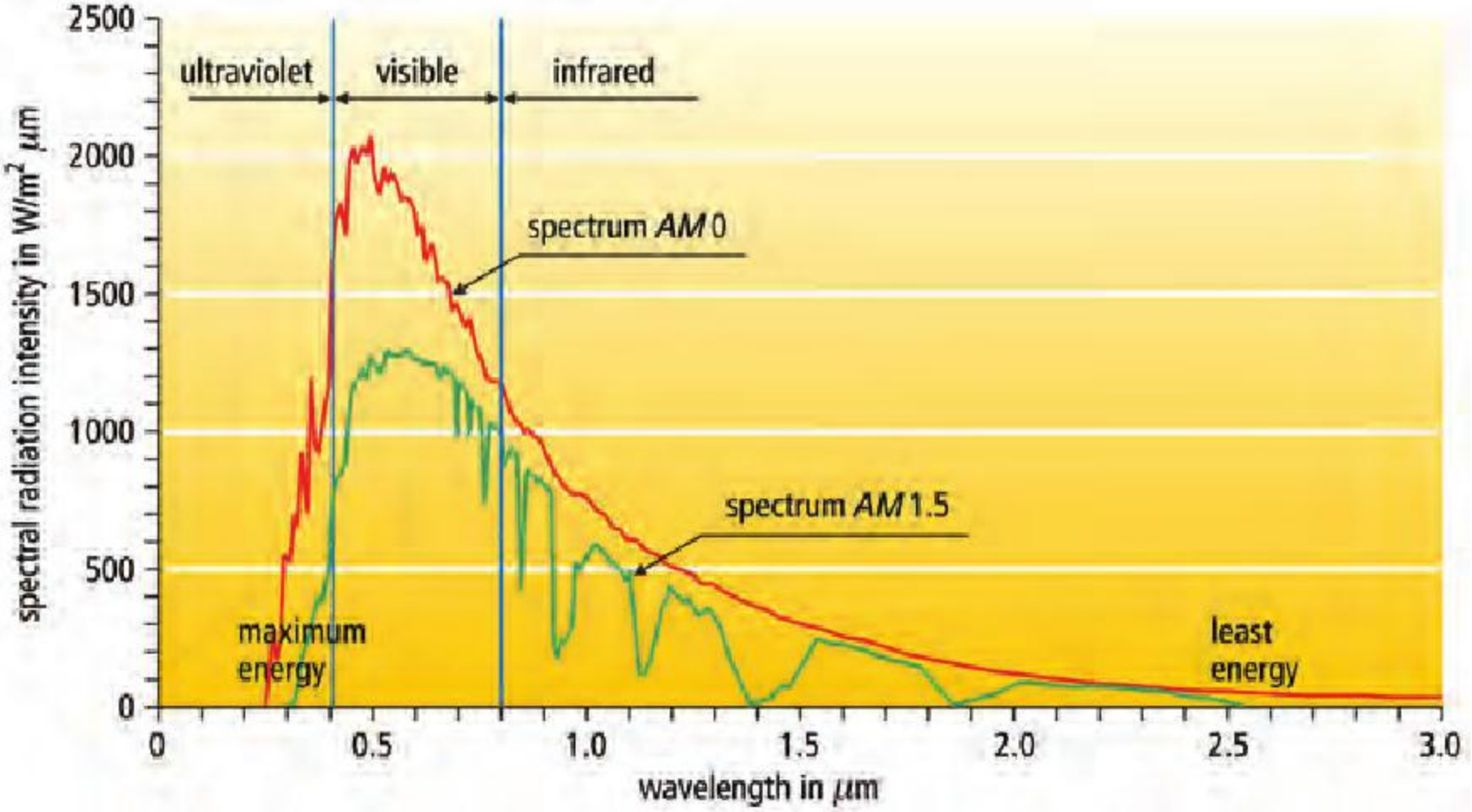

AM1
h=90°
AM1.14
h=61.3°
21.06
AM1.5
h=41.8°
30.03/13.09
AM3.96
h=14.6°
21.12.
$AM \approx \frac{1}{\cos\theta_Z}$
θz
Thickness of Atmosphere
Thickness of Atmosphere

The sun's radiation in space, without the influence of the earth's atmosphere, is described as *spectrum AM 0*. As it passes through the earth's atmosphere, the radiation intensity is reduced by:

- reflection caused by the atmosphere
- absorption by molecules in the atmosphere (O_3, H_2O, O_2, CO_2)
- Rayleigh scattering (scattering by the air molecules)
- Mie scattering (scattering by dust particles and contamination in the air).

Table 1.1 shows the dependence of the irradiation on the elevation angle, γ_S. Absorption and scattering increase when the sun's elevation is lower. Scattering by dust particles in the air (Mie scattering) is heavily dependent on the location. It is at its greatest in industrial areas.

γ_S	*AM*	Absorption (%)	Rayleigh scattering (%)	Mie scattering (%)	Total attenuation (%)
90°	1.00	8.7	9.4	0–25.6	17.3–38.5
60°	1.15	9.2	10.5	0.7–25.6	19.4–42.8
30°	2.00	11.2	16.3	4.1–4.9	28.8–59.1
10°	5.76	16.2	31.9	15.4–74.3	51.8–85.4
5°	11.5	19.5	42.5	24.6–86.5	65.1–93.8

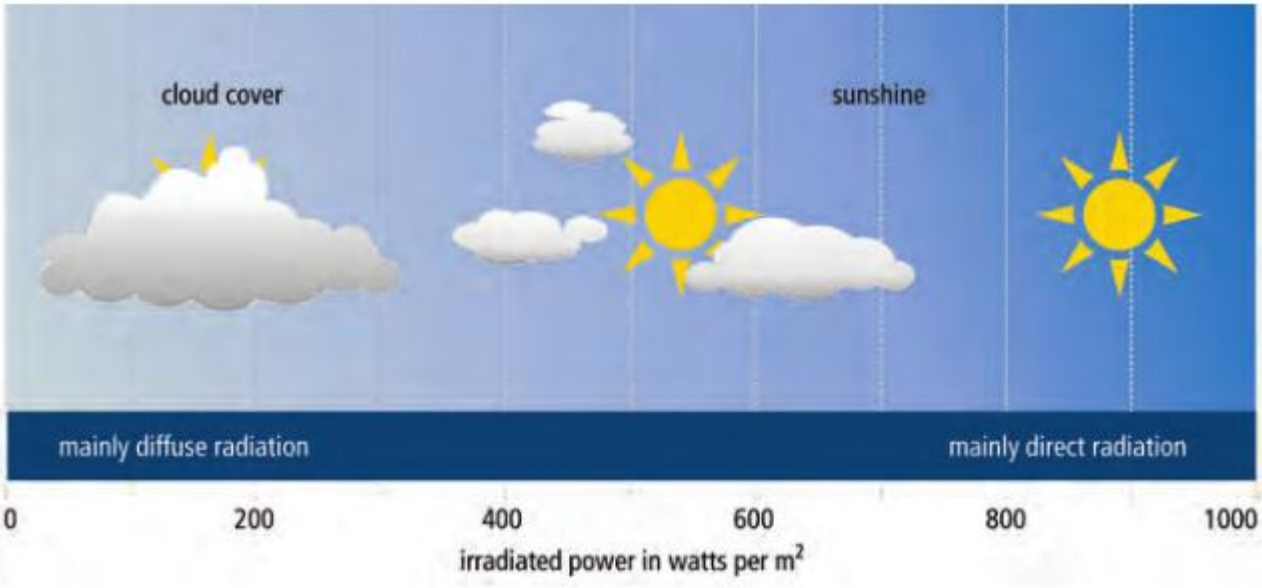

2500
2000
1500
1000
500
0
spectral radiation intensity in W/m² µm
ultraviolet
visible
infrared
spectrum AM 0
spectrum AM 1.5
maximum energy
least energy
0
0.5
1.0
1.5
2.0
2.5
3.0
wavelength in µm

Definitions

Air Mass

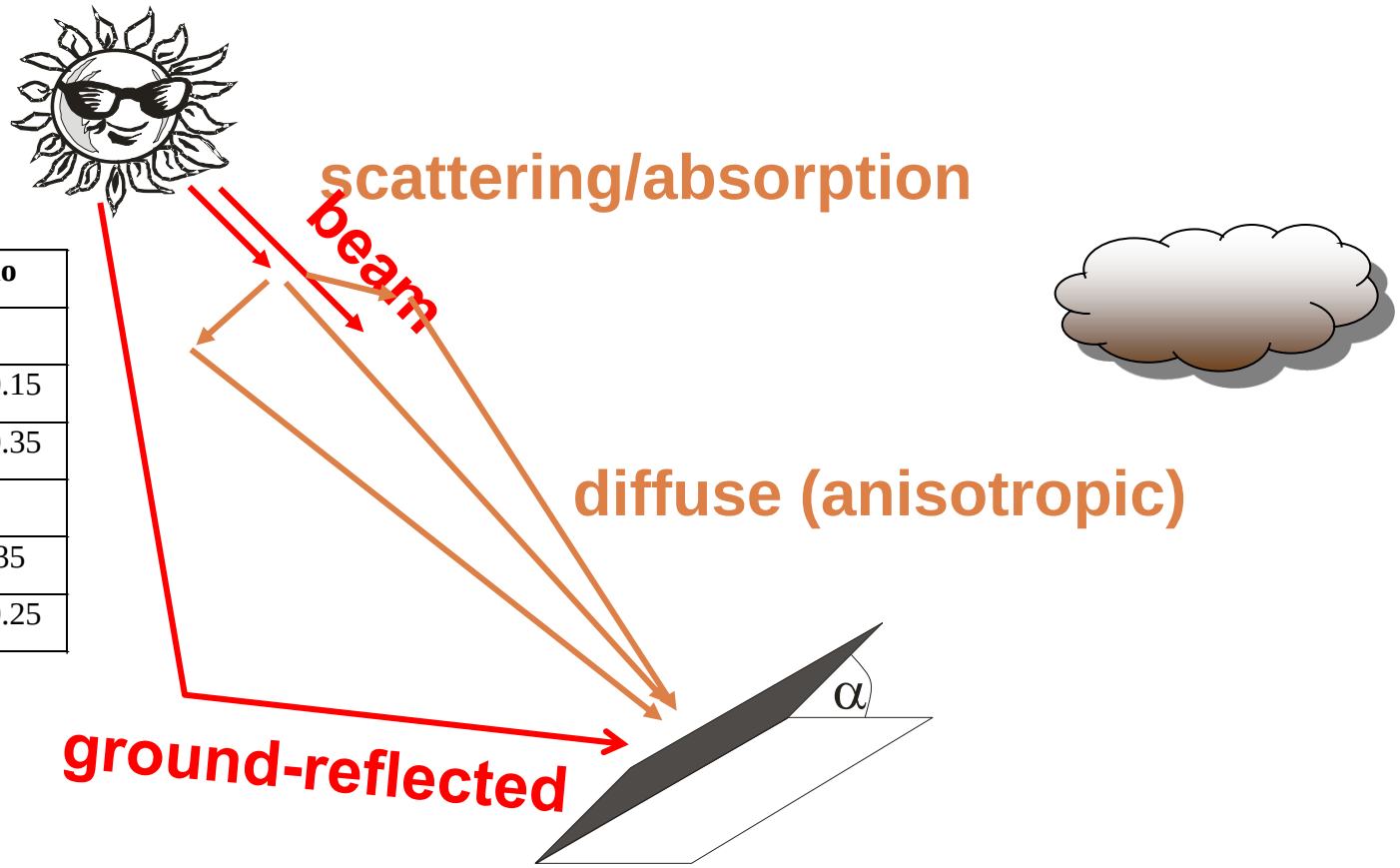
- The influence of the atmosphere depends on the length of path through the atmosphere, measured in Air Mass
- corresponding spectra are called AM1, AM1.5 etc.

After the general astronomical conditions, the cloud cover or state of the sky is the second decisive factor that has an effect on the supply of solar radiation: both the irradiated power and the proportions of direct and diffuse radiation vary greatly according to the amount of cloud (Figure 1.8).



Components of Radiation

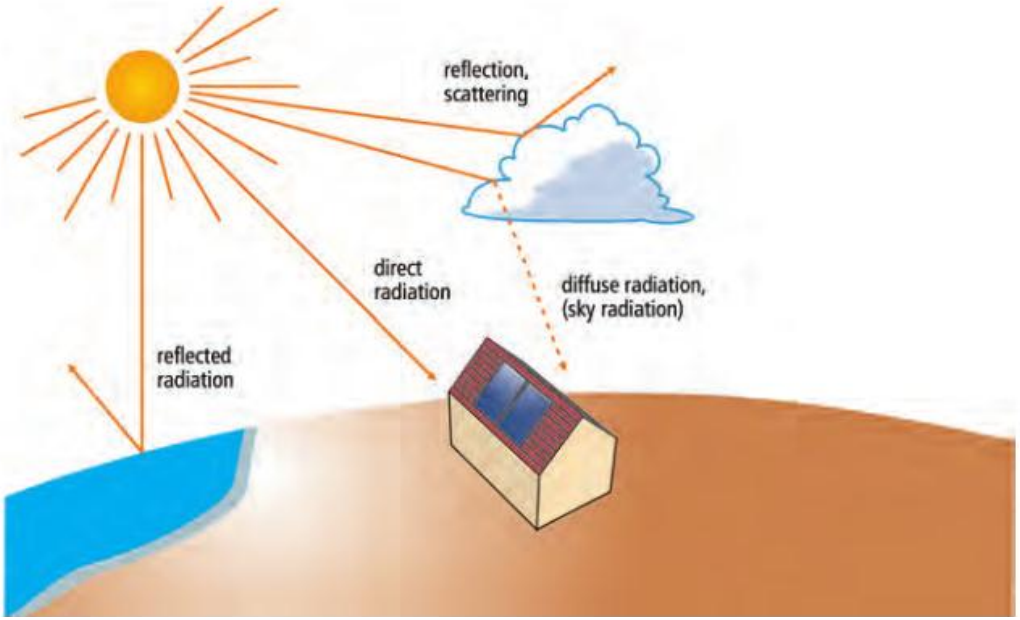
Material	Albedo
Aluminium	0.85
Asphalt	0.09-0.15
Concrete	0.25-0.35
Fresh Snow	0.82
Galvanised Steel	0.1-0.35
Grass	0.15-0.25



Global solar irradiance and its components

- Global
- Direct (Beam)
- Diffused

$$G_G = G_{dir} + G_{dif}$$



Even when the sky is clear and cloudless part of the sun's radiation comes from other directions and not just directly from the sun. This proportion of the radiation, which reaches the eye of the observer through the scattering of air molecules and dust particles, is known as *diffuse radiation*, G_{dif}. Part of this is also due to radiation reflected at the earth's surface. The radiation from the sun that meets the earth without any change in direction is called *direct radiation*, G_{dir}. The sum of direct and diffuse radiation is known as *global solar irradiance*, G_G (Figure 1.5).

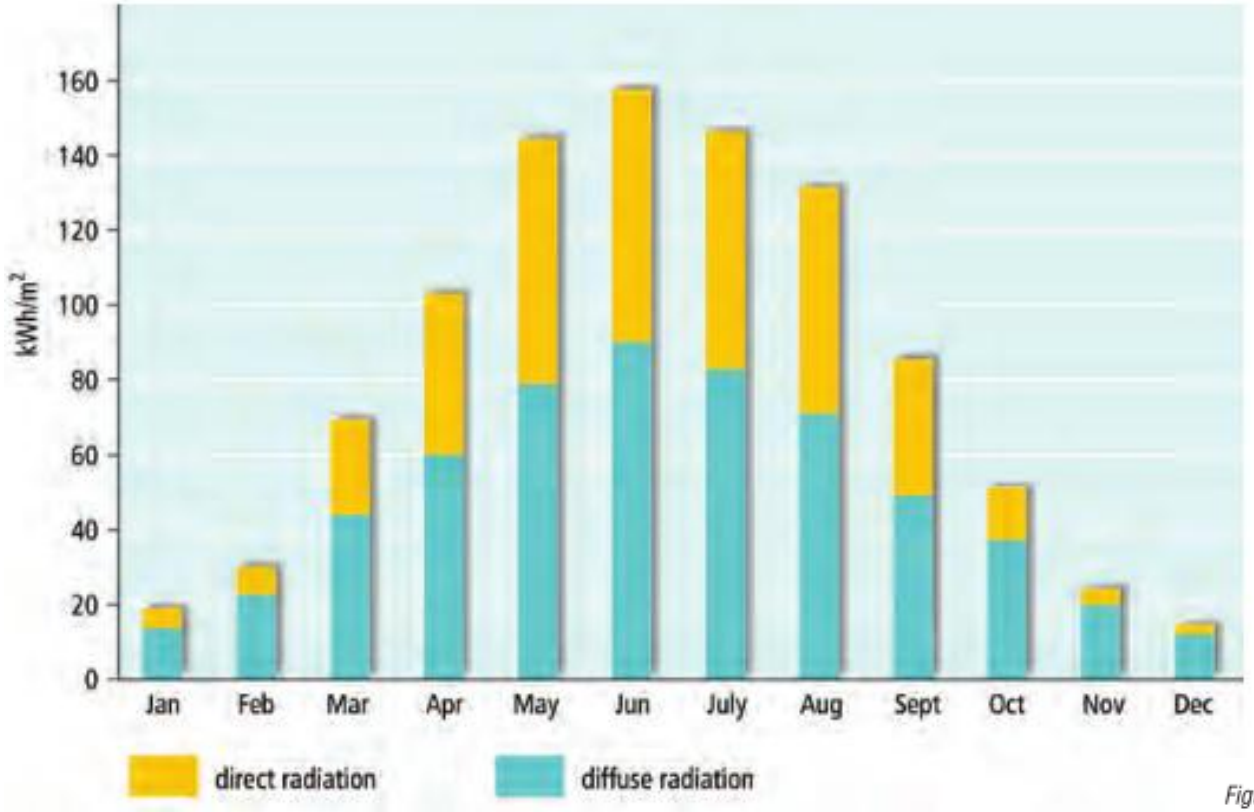
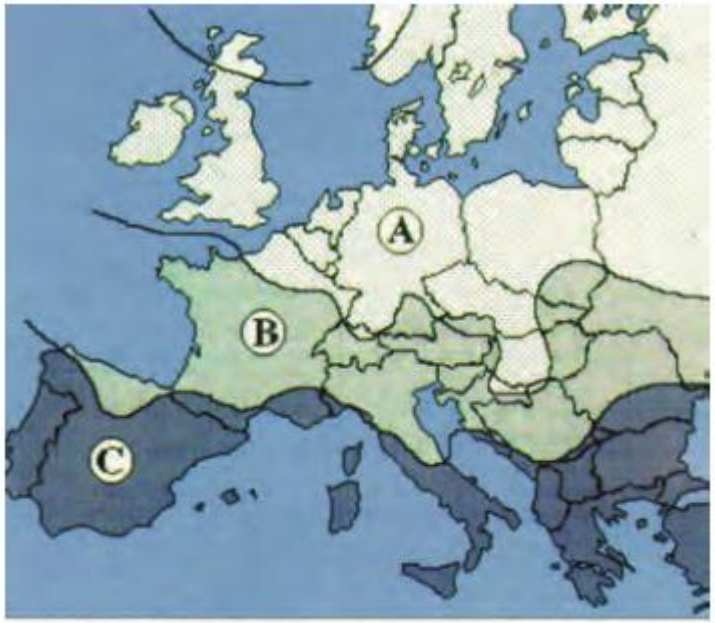


Figure 1.9a.
Berlin, Germany



Zone (see map above)	Average solar radiation on collector surface [kWh/m² day]	Solar system heat yield [kWh/m²y]
A	2.4 to 3.4	300 to 450
B	3.4 to 4.4	400 to 550
C	4.4 to 5.4	500 to 650

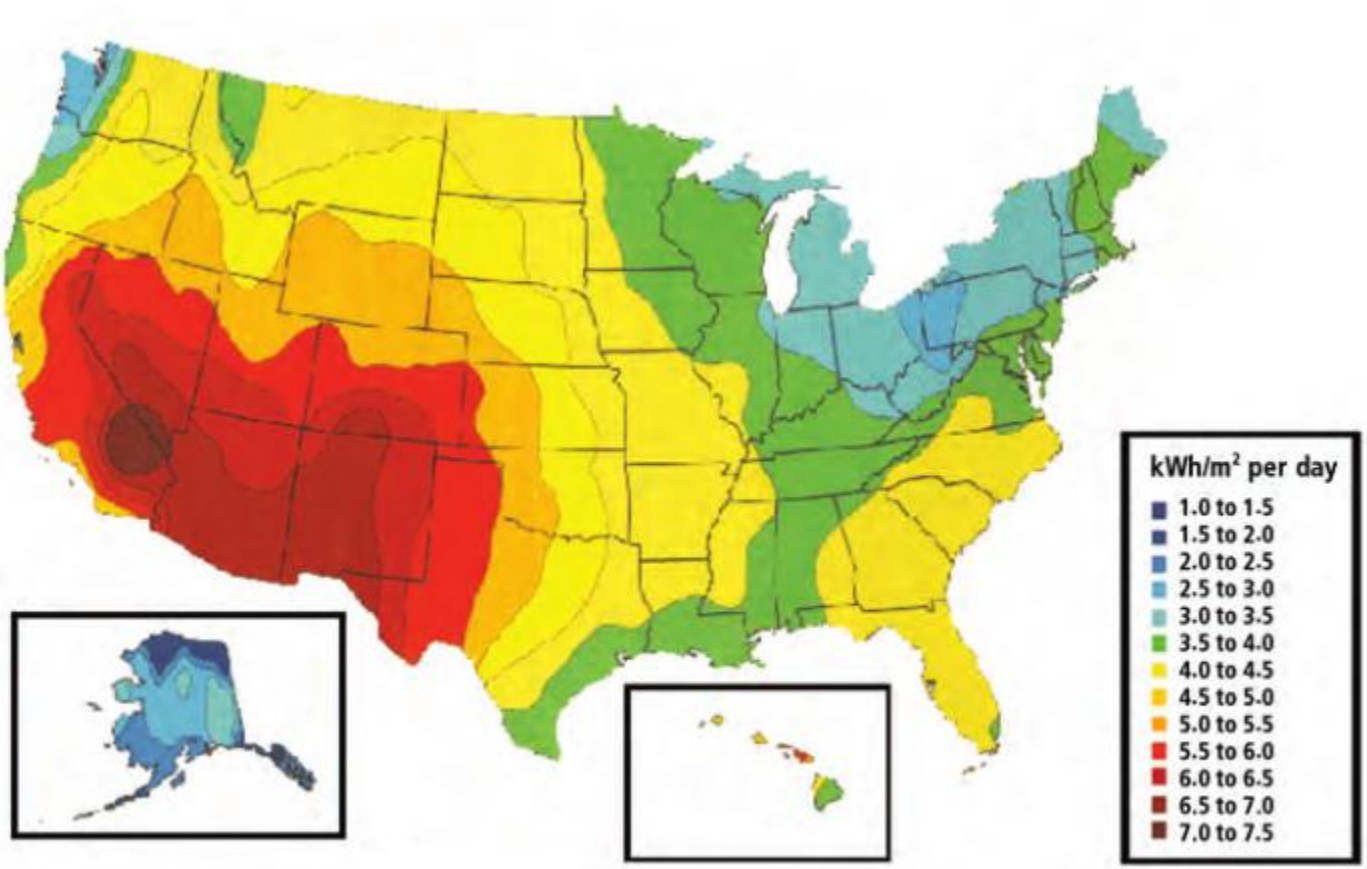


Figure 1.10b.
USA