ALMUSTAQBAL UNIVERSITY
Iraq - Babylon

RENEWABLE ENERGY TECHNOLOGY

Refrigeration and Air conditioning Techniques Engineering Department

Subject : Renewable Energy

Grade: 4th Class

Lecture :4 Components of the Solar Radiation

- **Dr.Eng. Azher M. Abed**

Dr.Haleemah J. Mohammed

Components of the Solar Radiation

1 Beam Radiation The solar radiation received from the sun without having been scattered by the atmosphere. (Beam radiation is often referred to as direct solar radiation; to avoid confusion between subscripts for direct and diffuse, we use the term beam radiation.)

2 Diffuse Radiation The solar radiation received from the sun after its direction has been changed by scattering by the atmosphere.

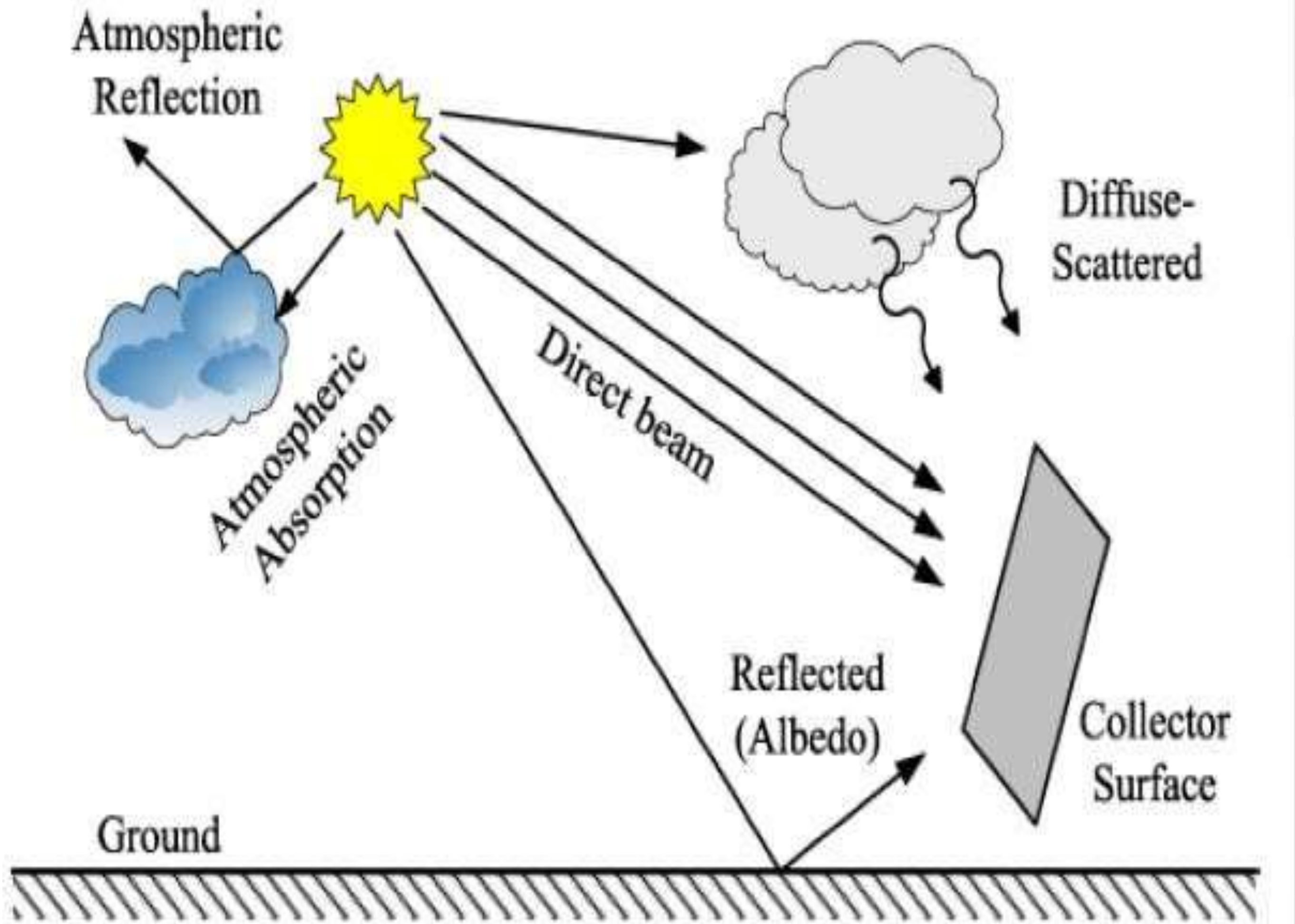
(Diffuse radiation is referred to in some meteorological literature as sky radiation or solar sky radiation; the definition used here will distinguish the diffuse solar radiation from infrared radiation emitted by the atmosphere.)

3- Total Solar Radiation The sum of the beam and the diffuse solar radiation on a surface. (The most common measurements of solar radiation are total radiation on a horizontal surface, often referred to as global radiation on the surface.)

4- Irradiance, W/m2 The rate at which radiant energy is incident on a surface per unit area of surface. The symbol G is used for solar irradiance, with appropriate subscripts for beam, diffuse, or spectral radiation.\

5- Irradiation or Radiant Exposure, J/m2 The incident energy per unit area on a surface, found by integration of irradiance over a specified time, usually an hour or a day.

The solar radiation on the earth's surface



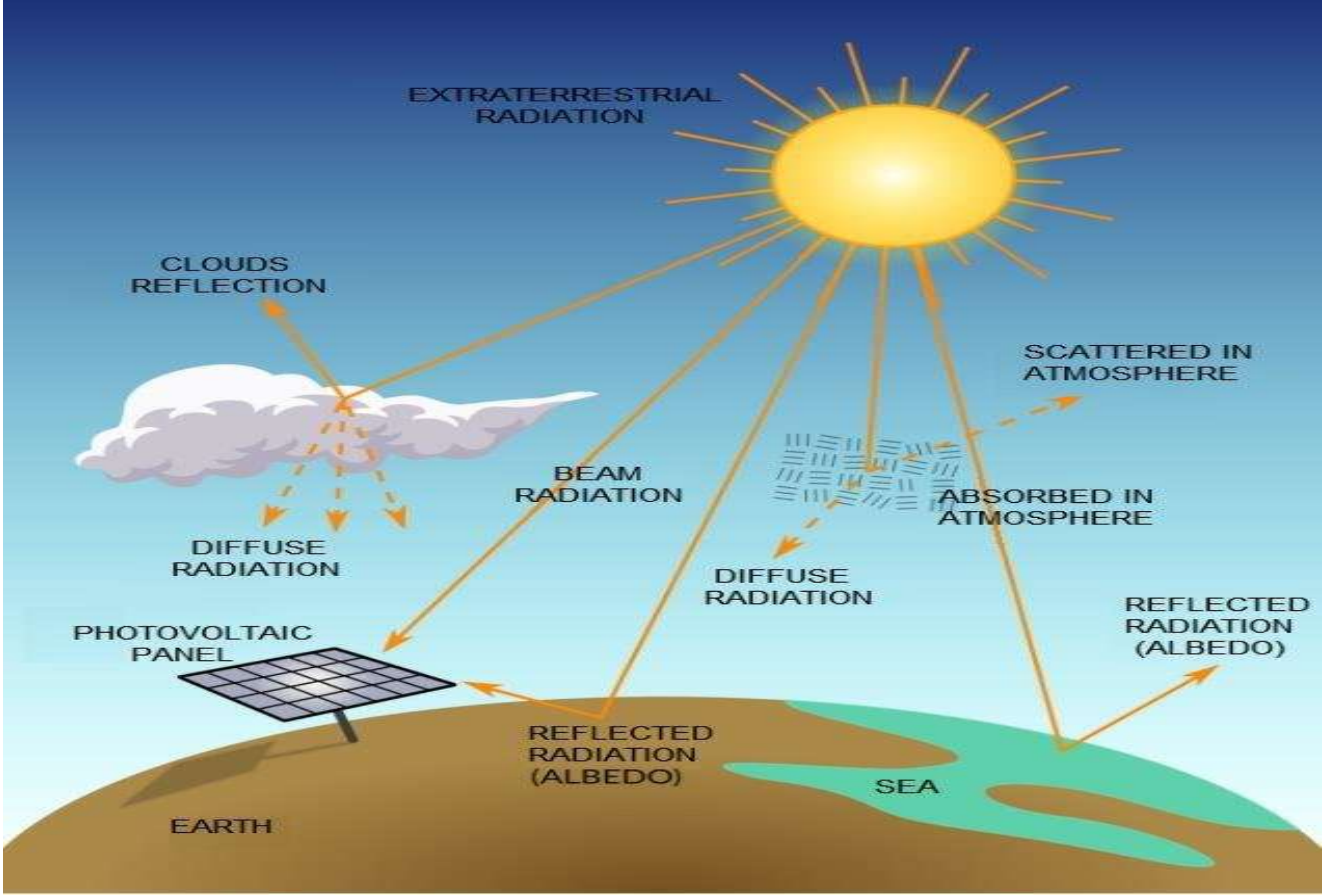
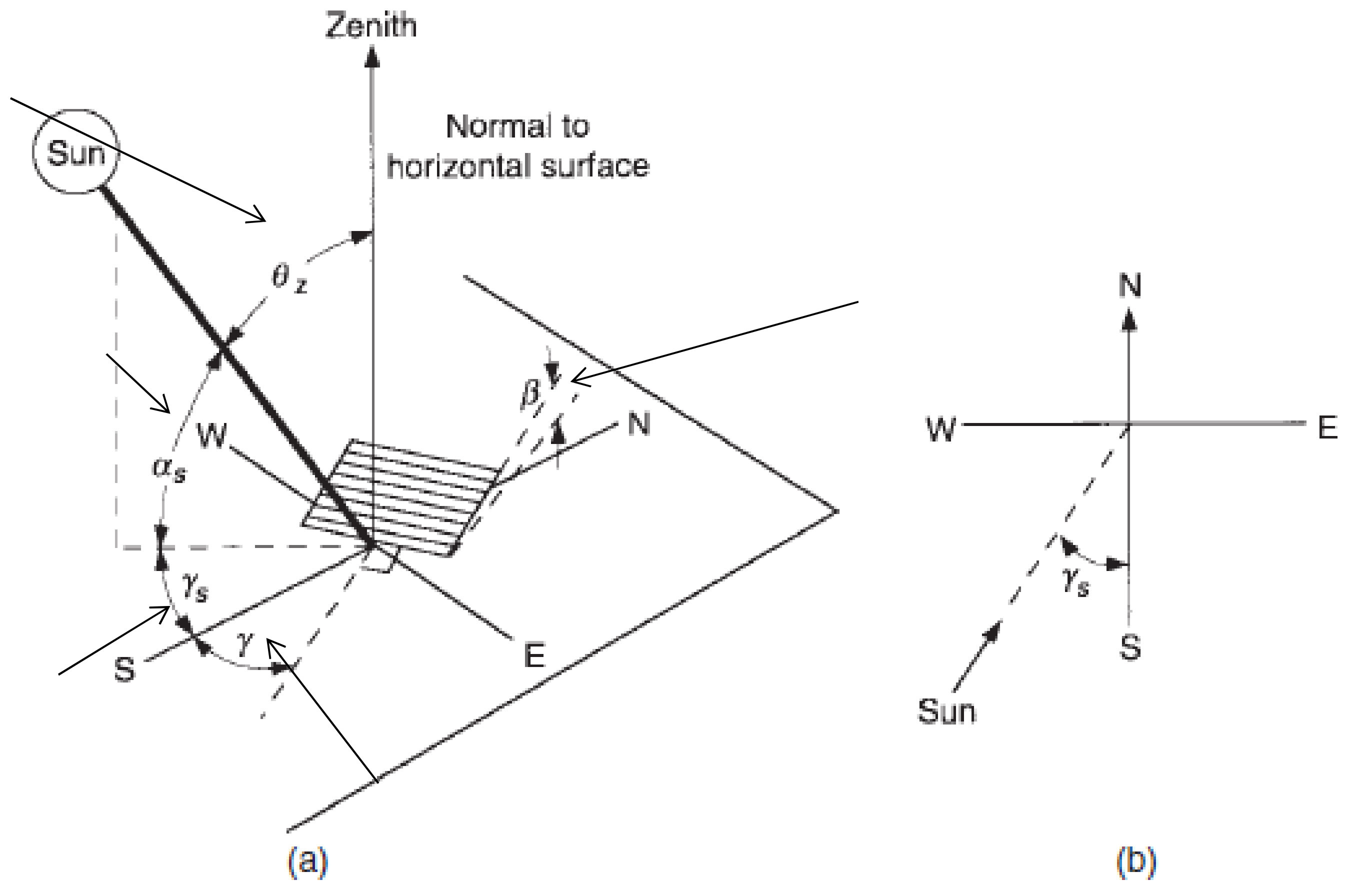


Figure Representation of Solar Radiation Components

Geometry of collector and the solar beam



4.1- Derived solar angles

- Besides the three basic angles, latitude, hour angle and sun's declination, certain additional angles are also useful in solar radiation analysis

- **Altitude angle α_s (solar altitude):** It is a vertical angle between the projection of the sun's rays on the horizontal plane and the direction of sun's rays (passing through point).

- **Zenith angle (θz):** It is a vertical angle between the sun's rays and a line perpendicular to the horizontal plane through the point.

- **Surface azimuth angle (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; $-180^\circ \leq \gamma \leq 180^\circ$
- **Slope (β):** the angle between the plane of the surface in question and the horizontal; $0^\circ \leq \beta \leq 180^\circ$. For horizontal surface $\beta = 0^\circ$; for vertical surface $\beta = 90^\circ$.
- **Angle of incidence (θ) :** the angle between the beam radiation on a surface and the normal to that surface

Angle between beam and collector

1- Incidence Angle

$$\cos\theta = (A-B)\sin\delta + [C\sin\omega + (D+E)\cos\omega]\cos\delta \qquad (4.1)$$

where

$$A = \sin\phi\cos\beta$$
$$B = \cos\phi\sin\beta\cos\gamma$$
$$C = \sin\beta\sin\gamma$$
$$D = \cos\phi\cos\beta$$
$$E = \sin\phi\sin\beta\cos\gamma$$

and

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

Angle between beam and collector

Solar Zenith angle, θ_z:

$$\cos(\theta_z) = \cos(\Phi)\cos(\delta)\cos(\omega) + \sin(\Phi)\sin(\delta) \quad (4.2)$$

At solar noon $\theta_{z\,noon} = \left| \Phi - \delta \right|$

3- Solar altitude angle, α_s:

$$\theta_z + \alpha_s = \pi/2 = 90^o \quad (4.3)$$

The mathematical expression for (α_s) is:

$$\sin(\alpha_s) = \cos(\theta_z)$$

Angle between beam and collector

At solar noon $\alpha_{s\ noon} = 90^o - \Phi + \delta$

4- **Solar azimuth angle, γ_s:** (4.4)

$$\sin \gamma_s = \frac{\cos(\delta)\sin(\omega)}{\sin(\theta_z)}$$

This is correct, provided that: **$\cos(\omega) > [\tan(\delta)/\tan(\Phi)]$.**

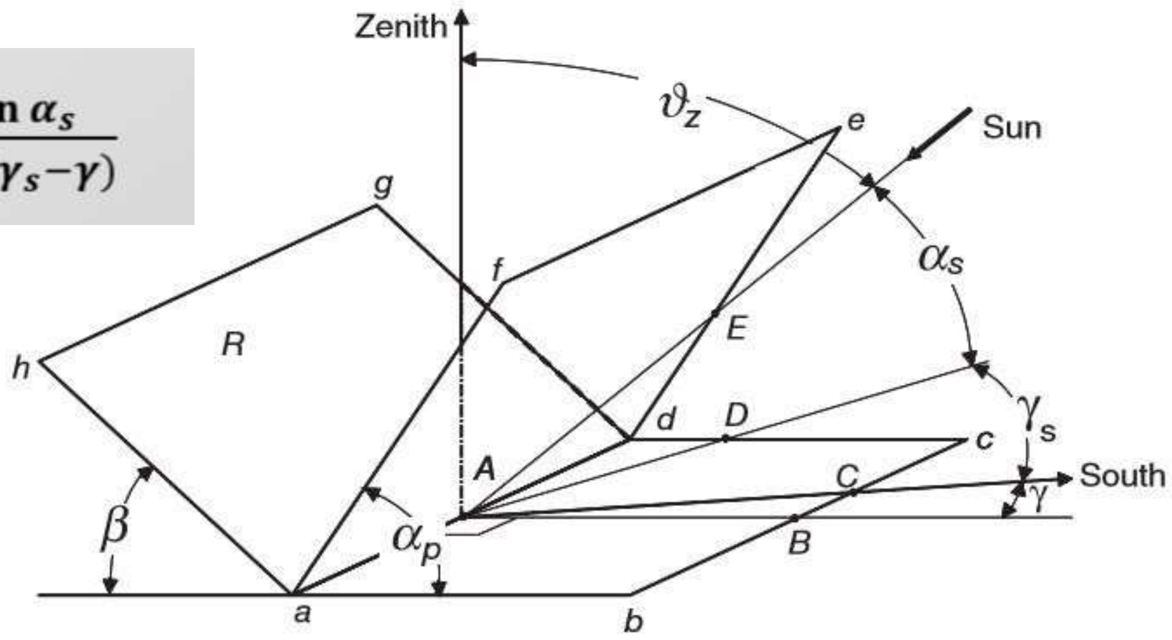
If not, then the (γ_s) for the morning hours is: $\gamma_s = -\pi + |\gamma_s|$

and for the afternoon hours is: $\gamma_s = \pi - \gamma_s$

Angle between beam and collector

5- **Profile angle (α_p):** (4.5)

$$\tan(\alpha_p) = \frac{\tan \alpha_s}{\cos(\gamma_s - \gamma)}$$



Angle between beam and collector

Example 4.1 Calculation of angle of incidence
Calculate the angle of incidence of beam radiation on a surface located at Glasgow (56°N, 4°W) at 10 a.m. on 1 February, if the surface is oriented 20° east of south and tilted at 40° to the horizontal.

Solution
1 February is day 32 of the year ($n = 32$), so

$$\delta = 23.45^\circ \sin[360^\circ(284 + 32)/365] = -17.5^\circ$$

Civil time in Glasgow winter is Greenwich Mean Time, which is solar time (±15 min) at longitude $\psi_{zone} = 0$. Hence $t_{solar} \approx 10\,\text{h}$, so

$$\begin{aligned}\omega &= (15^\circ\,\text{h}^{-1})(t_{solar} - 12\,\text{h}) \\ &= (15^\circ\,\text{h}^{-1})(t_{zone} - 12\,\text{h}) + \omega_{eq} + (\psi - \psi_{zone})\end{aligned}$$

$$\omega = -30^\circ.$$

We also have $\phi = +56^\circ$, $\gamma = -20^\circ$ and $\beta = +40^\circ$, so that

$$A = \sin 56^\circ \cos 40^\circ = 0.635$$
$$B = \cos 56^\circ \sin 40^\circ \cos(-20^\circ) = 0.338$$
$$C = \sin 40^\circ \sin(-20^\circ) = -0.220$$
$$D = \cos 56^\circ \cos 40^\circ = 0.428$$
$$E = \sin 56^\circ \sin 40^\circ \cos(-20^\circ) = 0.500$$

and so

$$\begin{aligned}\cos\theta &= (0.635 - 0.338)\sin(-17.5^\circ) + [-0.220 \sin(-30^\circ) \\ &\quad + (0.428 + 0.500)\cos(-30^\circ)]\cos(-17.5^\circ) \\ &= 0.783\end{aligned}$$

Thus

$$\theta = 38.5^\circ$$

Angle between beam and collector

- Example 4.2 Calculate the angle of incidence of beam radiation on a surface located at Madison, Wisconsin, at 10:30 (solar time) on February 13 if the surface is tilted 45° from the horizontal and pointed 15° west of south.
- Solution
- Under these conditions, $n = 31 + i = 44$,
- the declination $\delta = 23.45^\circ \sin [360/365\ (284+n) = -14^\circ$,

- the hour angle $\omega = -22.5^\circ$ (15° per hour times 1.5h before noon), and the surface azimuth angle $\gamma = 15^\circ$. Using a slope $\beta = 45^\circ$ and the latitude ϕ of Madison of 43°N, Equation 1.6.2 is

For certain cases equation (4.1) reduces to following forms :

- For **horizontal surfaces** $\beta=0$

$$\cos(\theta_z) = \cos(\Phi)\cos(\delta)\cos(\omega) + \sin(\Phi)\sin(\delta)$$

That mean for a horizontal plane, the incidence angle, (θ), and the zenith angle, (θ_z), are the same.

- For **vertical surfaces** $\beta=90$

$$\begin{aligned}\cos\theta = &- \sin\delta\cos\Phi\cos\gamma \\ &+ \cos\delta\sin\Phi\sin\beta\cos\gamma\cos\omega \\ &+ \cos\delta\sin\beta\sin\gamma\sin\omega .\end{aligned}$$

Angle between beam and collector

For a south – facing , tilted surface in the Northern Hemisphere
$\gamma = 0^\circ$, equation (4.1) reduces to following forms :

$$\cos\theta = \cos(\Phi - \beta)\cos\delta\cos\omega + \sin(\Phi - \beta)\sin\delta$$

For case of solar noon:

$$\theta_{noon} = |\Phi - \delta - \beta|$$

Also the angle of incidence (θ) on a surface of any orientation can be written as:

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

4.2 Sunrise , Sunset Time and Day Length

$$\cos\omega_s = -\frac{\sin\Phi\ \sin\delta}{\cos\Phi\cos\delta}$$

$$\cos\omega_s = -\tan\Phi\tan\delta$$

Sunrise hour $$h_{sr} = 12 - \frac{\omega_s}{15^\circ}$$

Sunset hour $$h_{ss} = 12 + \frac{\omega_s}{15^\circ}$$

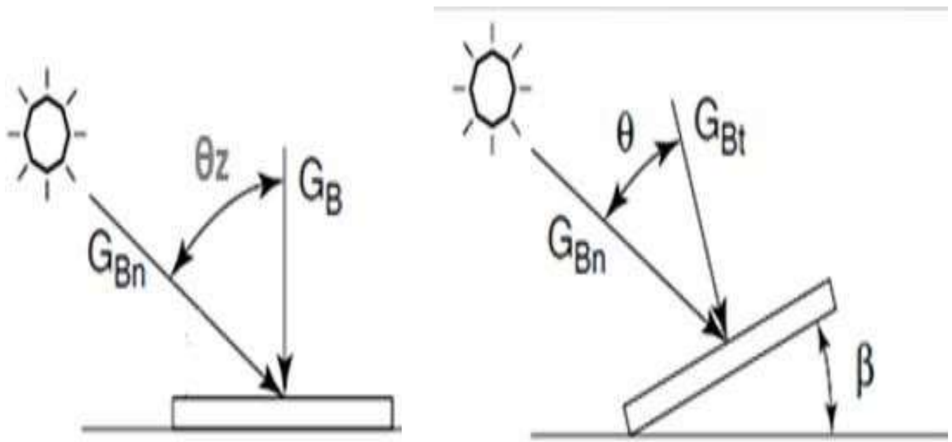
Day length

$$T_d = \frac{2}{15}\cos^{-1}(-\tan\Phi\tan\delta)$$

4.3 - DIRECTION OF BEAM RADIATION

A flat surface absorbs beam (G_{Bt}), diffuse (G_{Dt}), and ground-reflected (G_{Gt}) solar radiation; that is,

As shown in Figure:



$$G_t = G_{Bt} + G_{Dt} + G_{Gt}$$

G_B : Beam radiation on a tilted surface [W/m2]

G_B : Beam radiation on a horizontal surface[W/m^2]

DIRECTION OF BEAM RADIATION

The figure shows that

The beam radiation on a tilted surface is:

$$G_{Bt} = G_{Bn} \cos(\theta)$$

where θ is the angle between the beam and the normal to the collector surface. In particular,

and on horizontal surface:

$$G_B = G_{Bn} \cos(\theta z)$$

where θ_z is the (solar) zenith angle between the beam and the vertical. The total irradiance on any plane is the sum of the beam and diffuse components

$$G_t = G_{Bt} + G_{Dt} + G_{Gt}$$

DIRECTION OF BEAM RADIATION

R_b is ***beam radiation tilt factor***.

$$R_b = \frac{G_{Bt}}{G_B} = \frac{G_{Bn}\cos\theta}{G_{Bn}\cos\theta_z} = \frac{\cos\theta}{\cos\theta_z}$$

At solar noon:

$$R_{b\,noon} = \frac{\cos|\Phi-\delta-\beta|}{\cos|\Phi-\delta|}$$

Latitude, season and daily insolation

$$H = \int_{t=0\,h}^{t=24\,h} G\,dt$$

The daily insolation H is the total energy per unit area received in one day from the sun:

4.4 - Extraterrestrial Radiation on a Horizontal Surface

$$G_0 = I_{sc}\left(1 + 0.033\ \cos\frac{360\ n}{365}\right)\cdot\cos\theta_z$$

I_{sc} :the solar constant.

n: is the day of the year.

- **For a horizontal surface at any time between sunrise and sunset:**

$$G_0 = I_{sc}\left(1 + 0.033\ \cos\frac{360\ n}{365}\right)(\cos\Phi\cos\delta\cos\omega + \sin\Phi\sin\delta)$$

- **Daily solar radiation H_0 :**

$$H_0 = \frac{24 \times 3600\, I_{sc}}{\pi}\left[1 + 0.033\ \cos\frac{360\ n}{365}\right] \times \left[\cos\Phi\cos\delta\sin\omega_s + \frac{2\pi\omega_s}{360}\sin\Phi\sin\delta\right]$$

Extraterrestrial Radiation on a Horizontal Surface

- Monthly extraterrestrial radiation $\overline{H_0}$:

It can be calculate with above equation (eq. of daily solar radiation) using **n** and **δ** for the mean day of the month.

- Hourly radiation I_0:

$$= \frac{12 \times 3600\, I_{sc}}{\pi}\left[1 + 0.033 \cos\frac{360\, n}{365}\right] \times \left[\cos\Phi\cos\delta(\sin\omega_2 - \sin\omega_1) + \frac{\pi(\omega_2 - \omega_1)}{180}\sin\Phi\sin\delta\right]$$

Do You Have Any Questions