Formula Sheet-

Air mass factor

$$m = \sec \theta_z$$

Sun Radiation for normal surface

For a normal surface

$$E_n = E_o \tau^m$$

τ → Transmission coefficient: $= 0.1$ Overcast day; $= 0.8$ Clear day

E_o → Solar constant $= 1376$

For an inclined surface

$$E_i = E_n \cos \theta_i$$

θ_i → Incident angle between sun direction and the normal to surface

Declination Angle δ

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

n → Day of the year

Jan 1 → $n = 1$

Hour Angle

ω:
- $= 0$ at noon
- > 0 after noon
- < 0 before noon
- Add or substract $15°$ for each hour

$= \pm 15 \times$ # of hours from noon

9 A.m	10 A.m	11 A.m	At noon 12 p.m	1 p.m	2 p.m	3 p.m
$\omega = 3\times -15 = -45$	$\omega = -30$	$\omega = -15$	$\omega = 0$	$\omega = 15$	$\omega = 30$	$\omega = 3\times 15 = 45$

Note : For minutes $\omega = \omega_{Hours} + \omega_{minuts}$

$= \pm 15 \times Hours + \pm \frac{1}{4} \times$ Number of minuts

Zenith Angle

$$\underbrace{\cos\theta_z = \sin\alpha}_{\theta_z = 90 - \alpha} = \sin\phi \sin\delta + \cos\phi \cos\delta \cos\omega$$

ϕ → latitude (usually Given)

δ → Declination angle

ω → Hour Angle

α → Altitude angle

Incident Angle $\theta_{i,t}$ → Tilted surface at β

South facing Surfaces

$$\cos\theta_{i,t} = \sin(\phi - \beta)\sin\delta + \cos(\phi - \beta)\cos\delta\cos\omega$$

- At Solar noon ($\omega = 0$), when the sun is normal to the tilted surface ($\theta_{i,t} = 0$)

$\beta = \beta_n$ → constant

$$\boxed{\beta_n = \phi - \delta}$$

→ Changes

Non-South facing Surfaces

Tilting angle

$$\cos\theta_i = \sin\theta_z \sin\beta \cos(\alpha_s - \gamma) + \cos\theta_z \cos\beta$$

Zenith angle

$$\alpha_s = \sin^{-1}\left(\frac{\cos\delta \sin\omega}{\sin\theta_z}\right)$$

Angle between south meridian and normal surface as measured on horizontal plane (Usually Given)

- Solar tracking
- To track the sun, collector surface should be normal to sun's direction
  $\theta_i = 0 \longrightarrow \cos\theta_i = 1$
- The surface is rotated such that $\alpha_s = \gamma$ (fixed) and tilt angle β is adjusted to maintain $\beta = \theta_z$

Total radiation

Incident Angle

$$E_t = E_n \cos\theta_i + F_1 E_d + F_2 \rho (E_n \cos\theta_z + E_d)$$

Normal beam radiation | Diffuse Radiation | Ground reflectivity of radiation

$$F_1 = \frac{1+\cos\beta}{2}, \quad F_2 = \frac{1-\cos\beta}{2}$$

Tilting Angle

Useful heat

$$q_u = \text{Solar gain} - \text{heat losses}$$

Heat losses $= \dfrac{T_p - T_a}{R_{Th}}$

T_a ← Ambient air Temp

T_p ← Plate Temp

R_{Th} ← Thermal Resistant from plate to air

Collector efficiency

$$\eta = \frac{q_u}{\text{Solar Radiation}}$$

$$= F_R \left[\alpha\tau - \frac{U(T_i - T_a)}{G} \right]$$

T_i → Inlet fluid Temp

U → over all heat transfer coefficient

α

θ_z

at 11 am

Feb 23 at 30° N

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

$\sin 15$ $30°$ $\cos -15$

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

$$= 23.45 \sin\left(\frac{360}{365}(284+53)\right)$$

$= -10.87$

$\phi = 47$

May 15

$\delta = 19$

sunrise to sunset $= 14.9$ hours

$$\beta_n = \phi - \delta$$

$$= 47 - 19 = 28$$

$$\cos \theta_z = \cos\theta_z = \sin \alpha = \sin\phi \sin\delta + \cos\phi \cos\delta \cancel{\cos}\omega$$

$$\theta_z = 28$$

$$\alpha = 62$$

$$\cos \theta_{i,t} = \sin(\phi - \beta)\sin\delta + \cos(\phi - \beta)\cos\delta \cos\omega$$

$$= \sin(47 - 18) \sin 19 + \cos(47 - 18) \cos 19$$

$$\theta_i = 0$$

$$\beta = \beta_n = 28$$

$$T_a = 0.75$$

$$\beta_n - \beta = 10$$

$$28$$

$$\beta = 18$$

$$E_i = E_n \cos\theta_i$$

$$= E_0 \tau^{m} \cos\theta_i$$

$$m = \sec\theta_z$$

$$\cos\theta_i = \sin(\phi-\beta)\sin\delta + \cos(\phi-\beta)\cos\delta\cos\omega$$

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

$$= \sin 47\sin 19 + \cos 47\cos 19\cos\omega$$

$$\boxed{\cos\theta_z = 0.238 + 0.644\cos\omega}$$

$$\cos\theta_i = \sin(47-28)\sin 19 + \cos(47-28)\cos 19\cos\omega$$

$$\boxed{\cos\theta_i = 0.106 + 0.894\cos\omega}$$

at 3 p.m

$$\omega = 45^\circ$$

$$\boxed{\theta_z = 46.1}$$

$$\boxed{\theta_i = 42.43}$$

$$\sec\theta_z \; 1.442$$

$$E = (1361)\times(0.75)^{m}$$

$$= 898.7 \times \cos\theta_i = 663.33$$

$\beta = 50^\circ$

$\theta_z = 25$

$E_n = 760$

$\cos\theta_i = 0.8088$

$E_d = 190$

$$E_t = E_n \cos\theta_i + F_1 \underline{E_d} + F_2 \rho \left(E_n \cos\theta_z + E_d \right)$$

$\rho \to 0.22$

?

$$= 760 \times 0.8088 +$$

$$F_1 = \frac{1+\cos\beta}{2} \quad , \quad F_2 = \frac{1-\cos\beta}{2}$$

$$F_1 = \frac{1+\cos 50}{2} = 0.821$$

$$F_2 = \frac{1-\cos 50}{2} = 0.1786$$

$$E_t = 805$$

$$\omega = 30 + \left(\frac{1}{4}\right) \times 30$$

$\beta = 38$

$\delta = 15$

$\phi = 42$

$\gamma = 10$

$$\cos\theta_i = \sin\theta_z \sin\beta \cos(\alpha_s - \gamma) + \cos\theta_z \cos\beta$$

γ 10

$$\alpha_s = \sin^{-1}\left(\frac{\cos\delta \sin\omega}{\sin\theta_z}\right)$$