Formulae - Solar radiation and geometry

Extra-terrestrial solar radiation ($I_{sc}^{'}$) on any day of the year (n):

$$I_{sc}^{'} = I_{sc} \cdot \left[1 + 0.033 \cdot \cos\left(\frac{360n}{365}\right)\right]$$

where I_{sc} is the solar constant equal to $1367\,\mathrm{W\,m^{-2}}$ and n is the day of the year

Local apparent time (LAT) or Solar time = Standard clock time $\pm 4\times$(Standard time longitude − longitude of location) + (Equation of time correction)

(The negative sign in the first correction is applicable for the eastern hemisphere, while the positive sign is applicable for the western hemisphere. The longitude values are in degrees and both the longitude correction and the equation of time correction are in minutes.)

Equation of time correction (in minutes):

$$\begin{aligned} E = 229.18 \times [0.000075 + 0.001868\cos B \\ -0.032077\sin B - 0.014615\cos 2B - 0.04089\sin 2B] \end{aligned}$$

where

$$\begin{aligned} B &= (n-1) \times [360/365] \\ n &= \text{ day of the year} \end{aligned}$$

Relation between global (I_g), beam (I_b), and diffuse (I_d) radiation:

$$I_g = I_b + I_d$$

Relation between beam (I_b) and beam normal (I_{bn}) radiation:

$$I_b = I_{bn}\cos\theta_z$$

Radiation on a tilted surface (Liu and Jordan model):

$$I_{\mathrm{T}} = I_{\mathrm{b}} r_{\mathrm{b}} + I_{\mathrm{d}} r_{\mathrm{d}} + \left(I_{\mathrm{b}} + I_{\mathrm{d}}\right) r_{\mathrm{r}}$$

where

$$r_{\mathrm{b}} = \frac{\cos\theta}{\cos\theta_{\mathrm{z}}}$$

$$r_{\mathrm{d}} = \frac{1+\cos\beta}{2}$$

$$r_{\mathrm{r}} = \frac{\rho\cdot(1-\cos\beta)}{2}$$

Declination angle:

$$\delta = 23.45 \times \sin\left[(284+\mathrm{n})\cdot\left(\frac{360}{365}\right)\right]$$

Hour angle (convention followed here: negative in morning, positive in afternoon):

$$\omega = (\mathrm{LAT} - 12) \times 15^\circ$$

Angle of incidence:

$$\begin{aligned}\cos\theta = \sin\beta\cos\gamma\left[\cos\delta\cos\omega\sin\phi - \sin\delta\cos\phi\right] \\ +\sin\beta\sin\gamma\cos\delta\sin\omega \\ +\cos\beta\left[\cos\delta\cos\omega\cos\phi + \sin\delta\sin\phi\right]\end{aligned}$$

$$\cos\gamma_s = \frac{\cos\theta_z\sin\phi - \sin\delta}{\sin\theta_Z\cos\phi}$$

$$\cos\theta_z = \cos\theta \text{ at } \beta = 0$$

θ = Angle of incidence, β = Collector tilt angle, γ = Surface azimuth angle*, δ = Declination angle, ω = Hour angle, ϕ = Latitude, γ_s = Solar azimuth angle*, θ_z = Zenith angle

* Convention followed here for surface and solar azimuth angles: Negative east of south, postive west of south