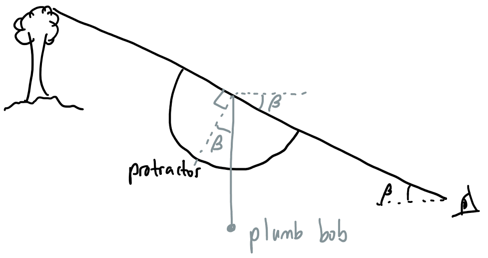
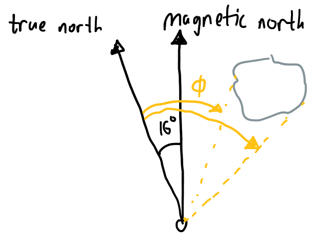
Solar Radiation

Tuesday, February 6, 2024 4:12 PM

Sun Path Diagram with Shading



altitude angle



azimuth angle

Total Solar Radiation

$$I_{tot} = I_B + I_D + I_R \quad [W/m^2]$$

i) I_B direct beam: passes through atmosphere in a straight line

ii) I_D diffuse: scattered by molecules in the atmosphere. Comes from all directions ~6% - 14% of I_B

iii) I_R reflected: bounces off ground/other nearby surfaces. Depends on a "surface reflectance"

$$\rho = 0.8 \text{ for snow}$$

$$\rho = 0.1 \text{ for shingle roof}$$

Focus on i), but can add ii) and iii) as desired.

For the direct beam component, as it passes through the atmosphere, it can

> get absorbed by various gases

> get scattered by various molecules

Empirical Model: (capture attenuation)

$$I_B = A e^{-km}$$

- On average, <50% reach the Earth
- On very good conditions, can be >70%

air mass ratio (used for flat Earth assumption)

optical depth (unitless)

$I_B = A e^{-km}$

· On very good conditions, can be >70%

- m: air mass ratio (used for flat Earth assumption)
- k: optical depth (unitless)
- A: "apparent" extraterrestrial radiation (relates to day number and solar spectrum)
- I_B: portion of the direct beam radiation that reaches Earth's surface

$$A \cong 1160 + 75 \sin\left(\frac{360}{365}(n-275)\right) \quad [W/m^2]$$

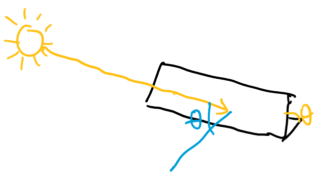
n: day number

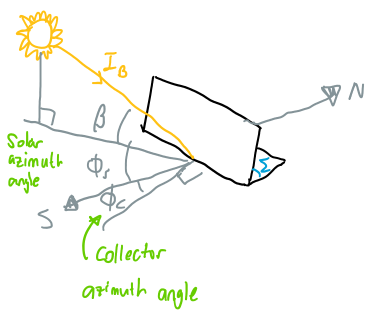
$$K \cong 0.174 + 0.035 \sin\left(\frac{360}{365}(n-100)\right)$$

$$m = \sqrt{(708 \sin\beta)^2 + 1417} - 708 \sin\beta$$

β: altitude angle

Direct Beam Radiation on a Solar Collector





$$I_{BC} = I_B \cos\theta$$

- I_{BC}: beam insolation striking line
- I_B: direct beam radiation
- θ: angle between vector normal to the collector surface and incoming beam

By convention:

- ϕ_c > towards east
- $\phi_s < 0$ towards west

$$\cos\theta = \cos\beta \cos(\phi_s - \phi_c) \sin\Sigma + \sin\beta \cos\Sigma$$

• Example 4.8 & 4.9

Direct beam radiation normal to Sun's rays at solar noon on a clear day in Atlanta ($L = 33.7°$) on May 21.

$$I_B = A e^{-km}$$

$$A = 1160 + 75 \sin\left(\frac{360}{365}(141-275)\right) = 1104 \ [W/m^2]$$

$$k = 0.174 + 0.035 \sin\left(\frac{360}{365}(141-100)\right) = 0.197$$

$$m = ?$$

$$\delta = 23.45° \sin\left(\frac{360}{365}(141-81)\right) = 20.14°$$

$m =$:

$\delta = 23.45° \sin\left(\frac{360}{365}(141-81)\right) = 20.14°$

$\beta_N = 90° - 33.7° + 20.14° = 76.44°$

$m = \sqrt{(708 \sin 76.44°)^2 + 1417} - 708 \sin 76.44° = 1.029$

$I_B = 1104 e^{-0.197 \times 1.029} = 902 \; [W/m^2]$

Suppose collector faces 20° toward southeast and tips up 52°.

$\Sigma = 52°$

$\phi_c = 20°$ by convention

$\cos\theta = \cos 76.44° \cos(\underbrace{0°}_{\text{Solar noon}} - 20°) \sin 52° + \sin 76.44° \cos 52° = 0.7725$

$I_{BC} = I_B \cos\theta = \underline{902} \times 0.7725 = \underline{696} \; [W/m^2]$

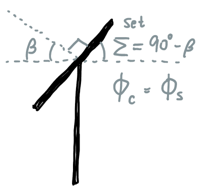
Compare these

What if $\cos\theta = 1$? → perfectly aligned

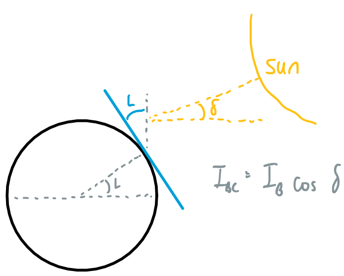
- This leads to tracking systems to maximize energy from the sun

Tracking Systems

- Type I: 2-axis tracker
  - tracks both β and ϕ_s such that I_B is always perpendicular to collector surface



Type I tracker



Type II tracker angles

- Type II: 1-axis tracker

• Type II: 1-axis tracker

 • tracks β or ϕ_s. More common to track ϕ_s and set β constant

Fix $\Sigma = L$, then set $\phi_c = \phi_s$. i.e. always at solar noon

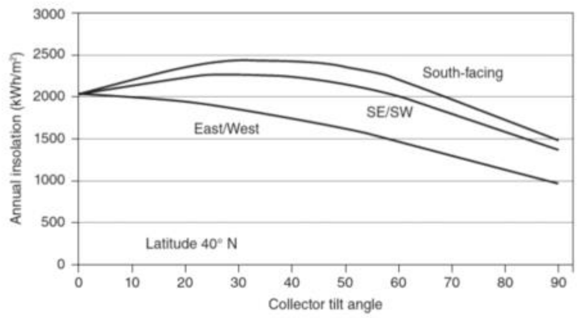


FIGURE 4.31 Annual insolation, assuming all clear days, for collectors with varying azimuth and tilt angles. Annual amounts vary only slightly over quite a range of collector tilt and azimuth angles.

No consideration for monthly variations
Okay for grid connected
But for stand-alone?

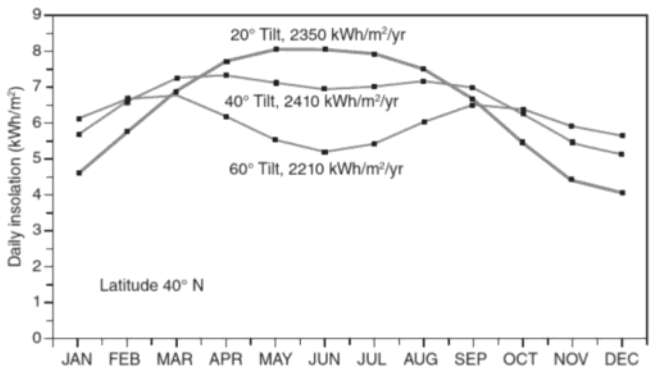


FIGURE 4.32 Daily clear-sky insolation on south-facing collectors with varying tilt angles. Even though they all yield roughly the same annual energy, the monthly distribution is very different.