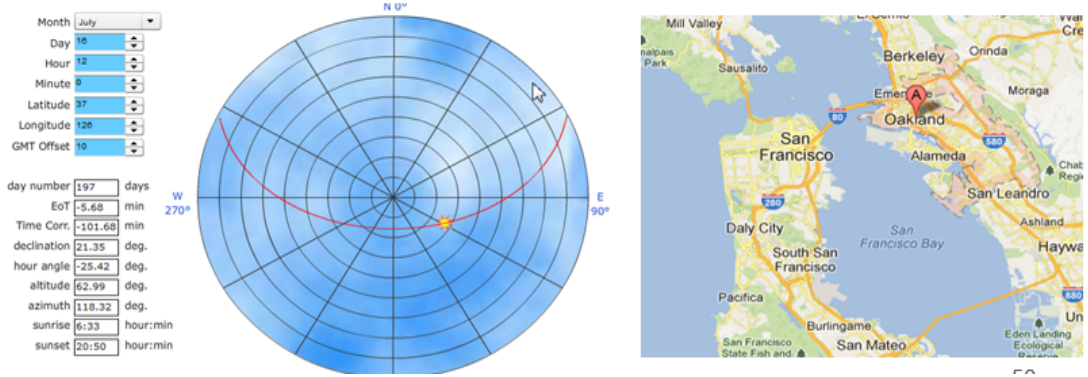
7 - 3 Average daily Insolation Daily

- Average ~~Monthly~~ Insolation on a Tilted Collector
- Average horizontal insolation (I_H) in Oakland, California (latitude 37.73◦N) in July 16 is 7.32 kWh/m^2-day. Assume ground reflectivity of 0.2.
- **Question**: Estimate the insolation on a south-facing collector at a tilt angle of 30◦ with respect to the horizontal.



- 0. Target
- 1. Sun declination (δ) for July 16 (n=197)
- 2. Sunrise Hour Angle (H_{SR}) using L=37.73°
- 3. Extraterrestrial Insolation (I_o) (with SC=1.37 kW/m^2)
- 4. Clearness Index (K^T)
- 5. Horizontal Diffuse Radiation (I_{DH})
- 6. Diffuse Radiation on the Collector (I_{DC})
- 7. Reflected Radiation on the Collector (I_{RC})
- 8. Horizontal Beam Radiation (I_{BH})
- 9. Sunrise Hour Angle on the Collector (H_{SRC})
- 10. Beam Tilt Factor (R_B)
- 11. Beam Radiation on the Collator (I_{BC})
- 12. Total Insolation on the Collector (I_C)

$IH := 7.32$ kWh /m^2-day **average** horizontal insolation

Collector tilt angle $\Sigma := 30$ *deg*

$SC := 1.37$

$L := 37.73$ Day number of May 21 $n := 197$

1 Sun Declination (δ)

Solar Declination Angle (δ)

$$\delta := 23.45 \cdot \sin\left(\frac{360}{365} \cdot (n - 81) \cdot \frac{\pi}{180}\right) = 21.3537 \quad deg$$

2 Sun Rise Hour Angle (HSR)

$$HSR := \operatorname{acos}\left(-\tan\left(L \cdot \frac{\pi}{180}\right) \cdot \tan\left(\delta \cdot \frac{\pi}{180}\right)\right) = 1.8781 \quad rad$$

$$H_{SR} = \cos^{-1}(-\tan L \tan \delta)$$

3 **Average** Extraterrestrial Insolation (I0) with SC= 1.37 kW/m^2

$$\overline{I}_0 = \left(\frac{24}{\pi}\right) \mathrm{SC}\left[1 + 0.034 \cos\left(\frac{360n}{365}\right)\right] (\cos L \cos\delta \sin H_{SR} + H_{SR} \sin L \sin\delta)$$

$$I0 := \left(\frac{24}{\pi}\right) \cdot SC \cdot \left[1 + 0.034 \cdot \cos\left(\frac{360 \cdot n}{365} \cdot \frac{\pi}{180}\right)\right] \cdot \left[\cos\left(L \cdot \frac{\pi}{180}\right) \cdot \cos\left(\delta \cdot \frac{\pi}{180}\right) \cdot \sin(HSR) + HSR \cdot \sin\left(L \cdot \frac{\pi}{180}\right) \cdot \sin\left(\delta \cdot \frac{\pi}{180}\right)\right] \quad \frac{kW}{m^2}$$

4 Clearness Index (KT)

$$K_T = \frac{\overline{I}_H}{\overline{I}_0}$$

$$KT := \frac{IH}{I0} = 0.6454$$

$$\frac{\overline{I}_{DH}}{\overline{I}_H} = 1.390 - 4.027 K_T + 5.531 K_T^2 - 3.108 K_T^3$$

5 **Average** Horizontal Diffuse Radiation (IDH)

$$IDH := IH \cdot \left(1.390 - 4.027 \cdot KT + 5.531 \cdot KT^2 - 3.108 \cdot KT^3\right) = 1.8982 \quad \text{kWh /m^2-day}$$

6 **Average** Diffuse Radiation on the Collector (IDC)

$$\bar{I}_{DC} = \bar{I}_{DH}\left(\frac{1+\cos\Sigma}{2}\right)$$

$$IDC := IDH \cdot \left(\frac{1+\cos\left(\Sigma \cdot \frac{\pi}{180}\right)}{2}\right) = 1.771$$ kWh /m^2-day

7 **Average** Reflected Radiation on the Collector (IR(

$$\bar{I}_{RC} = \rho\,\bar{I}_{H}\left(\frac{1-\cos\Sigma}{2}\right)$$

$$\rho := 0.2$$

$$IRC := \rho \cdot IH \cdot \left(\frac{1-\cos\left(\Sigma \cdot \frac{\pi}{180}\right)}{2}\right) = 0.0981$$ kWh /m^2-day

8 **Average** Horizontal Beam (only) Radiation (IBH)

$$\bar{I}_{BH} = \bar{I}_{H} - \bar{I}_{DH}$$

$$IBH := IH - IDH = 5.4218$$ kWh /m^2-day

9 Sunrise Hour Angle on the Collector (HSRC)

$$H_{SRC} = \min\{\cos^{-1}(-\tan L \tan\delta), \cos^{-1}[-\tan(L-\Sigma)\tan\delta]\}$$

$$HSRC1 := \operatorname{acos}\left(-\tan\left(L \cdot \frac{\pi}{180}\right) \cdot \tan\left(\delta \cdot \frac{\pi}{180}\right)\right) = 1.8781$$

$$HSRC2 := \operatorname{acos}\left(-\tan\left((L-\Sigma) \cdot \frac{\pi}{180}\right) \cdot \tan\left(\delta \cdot \frac{\pi}{180}\right)\right) = 1.6239$$

$$HSRC := \min\left(\left[\begin{array}{cc} HSRC1 & HSRC2 \end{array}\right]\right) = 1.6239$$

$$A := \left[\begin{array}{cc} 2 & 5 \end{array}\right]$$

$$\min(A) = 2$$

10 **Average** Beam Tilt Factor (RB)

$$\overline{R}_B = \frac{\cos(L-\Sigma)\cos\delta\sin H_{SRC} + H_{SRC}\sin(L-\Sigma)\sin\delta}{\cos L\cos\delta\sin H_{SR} + H_{SR}\sin L\sin\delta}$$

$$RB := \frac{\cos\left(\left(L-\Sigma\right)\cdot\frac{\pi}{180}\right)\cdot\cos\left(\delta\cdot\frac{\pi}{180}\right)\cdot\sin\left(HSRC\right)+HSRC\cdot\sin\left(\left(L-\Sigma\right)\cdot\frac{\pi}{180}\right)\cdot\sin\left(\delta\cdot\frac{\pi}{180}\right)}{\cos\left(L\cdot\frac{\pi}{180}\right)\cdot\cos\left(\delta\cdot\frac{\pi}{180}\right)\cdot\sin\left(HSR\right)+HSR\cdot\sin\left(L\cdot\frac{\pi}{180}\right)\cdot\sin\left(\delta\cdot\frac{\pi}{180}\right)}$$

$RB = 0.8934$

$$\overline{I}_{BC} = \overline{I}_{BH}\overline{R}_B$$

11 **Average** Beam Radiation on the Collector (IBC)

$IBC := IBH \cdot RB = 4.8438$ kWh /m^2-day

12 Total Average Insolation on the Collector

$$\overline{I}_C = \overline{I}_{BC} + \overline{I}_{DC} + \overline{I}_{RC}$$

$IC := IBC + IDC + IRC = 6.7129$ kWh /m^2-day