ME410 SOLAR ENERGY FORMULA SHEET

$$E = 229.2(0.000075 + 0.001868\cos B - 0.032077\sin B - 0.014615\cos 2B - 0.04089\sin 2B)$$

$$\text{Solar time} - \text{standard time} = 4(L_{st} - L_{loc}) + E$$

*Remember to use minus for the east of central meridian; plus for west of the central meridian.

$$F'' = \frac{F_R}{F'} = \frac{\dot{m}C_p}{A_c U_L F'}\left[1 - \exp\left(-\frac{A_c U_L F'}{\dot{m}C_p}\right)\right] \qquad \eta = \frac{Q_u}{I_T A_C}$$

$$H_o = \frac{24 \times 3600 G_{sc}}{\pi}\left(1 + 0.033\cos\frac{360n}{365}\right) \times \left(\cos\phi\cos\delta\sin\omega_s + \frac{\pi\omega_s}{180}\sin\phi\sin\delta\right)$$

$$Q_u = A_c \cdot F_r\left[I_T \cdot (\tau\alpha)_{avg} - 0.0036 \cdot U_l \cdot hr \cdot (T_i - T_a)\right]$$

$$I_T = I_b R_b + I_d\left(\frac{1+\cos\beta}{2}\right) + I\rho_g\left(\frac{1-\cos\beta}{2}\right)$$

$$B = (n-1)\frac{360}{365} \qquad \delta = 23.45\sin\left(360\frac{284+n}{365}\right)$$

$$\cos\omega_s = -\frac{\sin\phi\sin\delta}{\cos\phi\cos\delta} = -\tan\phi\tan\delta$$

$$\cos\theta_z = \sin(90 - \theta_z) = \sin\alpha_s$$

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

Month	n for ith Day of Month	For Average Day of Month		
		Date	n	δ
January	i	17	17	−20.9
February	$31 + i$	16	47	−13.0
March	$59 + i$	16	75	−2.4
April	$90 + i$	15	105	9.4
May	$120 + i$	15	135	18.8
June	$151 + i$	11	162	23.1
July	$181 + i$	17	198	21.2
August	$212 + i$	16	228	13.5
September	$243 + i$	15	258	2.2
October	$273 + i$	15	288	−9.6
November	$304 + i$	14	318	−18.9
December	$334 + i$	10	344	−23.0

$$R_b = \frac{(1 - \cos^2\delta\sin^2\omega)^{1/2}}{\cos\phi\cos\delta\cos\omega + \sin\phi\sin\delta} = \frac{\cos\theta}{\cos\theta_z}$$

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

$$\cos\theta = \sin\delta\sin\phi\cos\beta - \sin\delta\cos\phi\sin\beta\cos\gamma + \cos\delta\cos\phi\cos\beta\cos\omega + \cos\delta\sin\phi\sin\beta\cos\gamma\cos\omega + \cos\delta\sin\beta\sin\gamma\sin\omega$$

$$N = \tfrac{2}{15}\cos^{-1}(-\tan\phi\tan\delta)$$

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$$\gamma_S = \text{sign}(\omega)\left|\cos^{-1}\left(\frac{\cos\theta_z \sin\phi - \sin\delta}{\sin\theta_z \cos\phi}\right)\right|$$

$$\frac{I_d}{I} = \begin{cases} 1.0 - 0.09k_T & \text{for } k_T \le 0.22 \\ 0.9511 - 0.1604k_T + 4.388k_T^2 - 16.638k_T^3 + 12.336k_T^4 & \text{for } 0.22 < k_T \le 0.80 \\ 0.165 & \text{for } k_T > 0.8 \end{cases}$$

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

$$\frac{\overline{H}_T}{\overline{H}} = \left(1 - \frac{\overline{H}_d}{\overline{H}}\right)\overline{R}_b + \frac{\overline{H}_d}{\overline{H}}\left(\frac{1+\cos\beta}{2}\right) + \rho_g\left(\frac{1-\cos\beta}{2}\right)$$

For $\omega_s \le 81.4^\circ$ and $0.3 \le \overline{K}_T \le 0.8$

$$\frac{\overline{H}_d}{\overline{H}} = 1.391 - 3.560\overline{K}_T + 4.189\overline{K}_T^2 - 2.137\overline{K}_T^3$$

for $\omega_s > 81.4^\circ$ and $0.3 \le \overline{K}_T \le 0.8$

$$\frac{\overline{H}_d}{\overline{H}} = 1.311 - 3.022\overline{K}_T + 3.427\overline{K}_T^2 - 1.821\overline{K}_T^3$$

where $\overline{K_T} = \overline{H}/\overline{H_O}$

$$r_t = \frac{\pi}{24}(a + b\cos\omega)\frac{\cos\omega - \cos\omega_s}{\sin\omega_s - \frac{\pi\omega_s}{180}\cos\omega_s}$$

$$a = 0.409 + 0.5016\sin(\omega_s - 60)$$

$$b = 0.6609 - 0.4767\sin(\omega_s - 60)$$

$$r_t = \frac{I}{H} \qquad A_i = \frac{I_b}{I_o} \qquad f = \sqrt{\frac{I_b}{I}} \qquad k_T = \frac{I}{I_o}$$

$$I_T = (I_b + I_d A_i)R_b + I_d(1 - A_i)\left(\frac{1+\cos\beta}{2}\right)\left[1 + f\sin^3\left(\frac{\beta}{2}\right)\right] + I\rho_g\left(\frac{1-\cos\beta}{2}\right)$$

$$\overline{R}_b = \frac{\cos(\phi-\beta)\cos\delta\sin\omega_s' + (\pi/180)\omega_s'\sin(\phi-\beta)\sin\delta}{\cos\phi\cos\delta\sin\omega_s + (\pi/180)\omega_s\sin\phi\sin\delta}$$

$$\omega_s' = \min\begin{bmatrix}\cos^{-1}(-\tan\phi\tan\delta) \\ \cos^{-1}(-\tan(\phi-\beta)\tan\delta)\end{bmatrix}$$

$$\text{Nu} = \frac{hL}{k} \qquad \text{Ra} = \frac{g\beta'\Delta T L^3}{\nu\alpha} \qquad \text{Pr} = \frac{\nu}{\alpha}$$

$$\text{Nu} = 1 + 1.44\left[1 - \frac{1708(\sin 1.8\beta)^{1.6}}{\text{Ra}\cos\beta}\right]\left[1 - \frac{1708}{\text{Ra}\cos\beta}\right]^+ + \left[\left(\frac{\text{Ra}\cos\beta}{5830}\right)^{1/3} - 1\right]^+$$