20.5.3.4 Daily irradiation

The most accurate way of calculating $G_{dm}(\beta, \alpha)$ from $G_{dm}(0)$ is, first, to calculate the hourly horizontal irradiation components $G_{hm}(0)$, $D_{hm}(0)$ and $B_{hm}(0)$; second, to transpose them to the inclined surface $G_{hm}(\beta, \alpha)$, $D_{hm}(\beta, \alpha)$ and $B_{hm}(\beta, \alpha)$; and, finally, to integrate during the day.

Such a procedure, summarised in Figure 20.16, allows us to account for the anisotropic properties of diffuse radiation, and leads to good results whatever the orientation of the inclined surface. However, it is laborious to apply and a computer must be used. It is interesting to mention that, for the case of surfaces tilted to the equator ($\alpha = 0$), frequently encountered in photovoltaic applications, if the diffuse radiation is taken to be isotropic, the following expression may be applied

$$G_d(\beta, 0) = B_d(0) \times RB + D_d(0)\frac{1 + \cos\beta}{2} + \rho G_d(0)\frac{1 - \cos\beta}{2} \tag{20.39}$$

where the factor RB represents the ratio between the daily direct irradiations on an inclined surface and on an horizontal surface, and may be approximated by setting it equal to the corresponding ratio between daily extraterrestrial irradiations on similar surfaces. Hence, RB is given as follows:

$$RB = \frac{\omega_{SS}\dfrac{\pi}{180}[\text{sign}(\phi)]\sin\delta\sin(|\phi| - \beta) + \cos\delta\cos(|\phi| - \beta)\sin\omega_{SS}}{\omega_S\dfrac{\pi}{180}\sin\delta\sin\phi + \cos\delta\cos\phi\sin\omega_S} \tag{20.40}$$

where ω_{SS} is the sunrise angle on the inclined surface, which is given by

$$\omega_{SS} = \max[\omega_S, -\arccos(-[\text{sign}(\phi)]\tan\delta\tan(abs(\phi) - \beta))] \tag{20.41}$$

It is interesting to observe that for the equinox days, $\delta = 0 \Rightarrow \omega_S = \omega_{SS}$ and equation (20.40) becomes $RB = \cos[abs(\phi) - \beta]/\cos\phi$.

Example: Estimate the average daily irradiation in January at Changchun–China ($\phi = 43.8^\circ$) over a fixed surface facing south and tilted at an angle $\beta = 50^\circ$ with respect to the horizontal, knowing that the mean value of the global horizontal irradiation is $G_{dm}(0) = 1861$ Wh/m^2 and the ground reflection $\rho = 0.2$. The solution is as follows:

January $\Rightarrow d_n = 17; \delta = -20.92^\circ$

$\phi = 43.8^\circ \Rightarrow \omega_S = -68.50$ and $B_{0d}(0) = 3586\ \text{Wh/m}^2 \Rightarrow K_{Tm} = 0.519$

$\Rightarrow F_{Dm} = 0.414$

$D_{dm}(0) = 770\ \text{Wh/m}^2$; $B_{dm}(0) = 1091\ \text{Wh/m}^2$

$\arccos(-\tan\delta\tan(\phi - \beta)) = -92.38^\circ \Rightarrow \omega_{SS} = -68.5^\circ \Rightarrow RB = 2.741$