tilted towards the equator, that is, to $\alpha \neq 0$, and also to dirty surfaces. E. Caamaño [44] has proposed the following solution:

$$\frac{G_{\text{effdy}}(\beta, \alpha)}{G_{\text{dy}}(\beta_{\text{opt}})} = g_1(\beta - \beta_{\text{opt}})^2 + g_2(\beta - \beta_{\text{opt}}) + g_3 \tag{20.52}$$

where

$$g_i = g_{i1} \cdot |\alpha|^2 + g_{i2} \cdot |\alpha| + g_{i3}; i = 1, 2, 3 \tag{20.53}$$

being the values of the coefficients as show in Table 20.6, for medium dirty surfaces. The sub-index "eff" in the left term of equation (20.52) indicates that the dirt effect on the relative normal transmittance is also being included, in order to facilitate the direct application of the equation to real cases.

Let us continue with the example of Sapporo-Japan, by calculating the effective irradiation available on the following surfaces:

1. Optimally oriented, $\alpha = 0$, and optimally tilted, $\beta = \beta_{\text{opt}}$
   Equation (20.53), $\alpha = 0 \Rightarrow g_i = g_{i3}$
   Equation (20.52), $\beta = \beta_{\text{opt}} \Rightarrow G_{\text{effdy}}(\beta_{\text{opt}}) = 0.9314\ G_{\text{dy}}(\beta = \beta_{\text{opt}}) = 3517$ Wh/m^2
   Note that the total losses due to the optical effects of the angle of incidence ($\approx$7%) are larger than pure normal transmittance losses ($\approx$3%)
2. Tilted 20° with respect to the horizontal, $\beta = 20°$, and oriented 30° towards the west, $\alpha = 30° \Rightarrow g_1 = -1.032 \times 10^{-4}$; $g_2 = 1.509 \times 10^{-4}$; $g_3 = 0.9057$
   $\beta - \beta_{\text{opt}} = -13.37° \Rightarrow G_{\text{effdy}}(20, 30) = 0.8853 \cdot G_{\text{dy}}(\beta_{\text{opt}}) = 3343$ Wh/m^2
   It is worth mentioning that a similar calculation, but without considering the angular losses, would lead to $G_{\text{dy}}(20, 30) = 0.936 \cdot G_{\text{dy}}(\beta_{\text{opt}}) = 3533$ Wh/m^2
3. A vertical facade, $\beta = 90°$, oriented towards the south-east, $\alpha = -45°$.
   $\alpha = -45° \Rightarrow g_1 = -0.885 \times 10^{-4}$; $g_2 = -2.065 \times 10^{-4}$; $g_3 = 0.8761$
   $\beta - \beta_{\text{opt}} = 56.63° \Rightarrow G_{\text{effdy}}(90, -45) = 0.5806 \cdot G_{\text{dy}}(\beta_{\text{opt}}) = 2192$ Wh/m^2

It is opportune to mention again the relatively weak sensitivity of the annual capture of energy to the inclination angle. A value of 0.2% loss for each degree of deviation from the optimum value is a rough approximation. This is true to an even greater extent in the case of azimuthal orientation, where only a 0.08% loss occurs for each degree of deviation from the south. This means that many existing surfaces (roofs, car parks etc.) are suitable for PV modules integration, even if their orientation differs considerably from

Table 20.6 Coefficients used to solve equation (20.52). Values are given for the representative case of medium dirtiness degree ($T_{\text{dirt}}(0)/T_{\text{clean}}(0) = 0.97$)

Coefficients	$T_{\text{dirt}}(0)/T_{\text{clean}}(0) = 0.97$		
	$i = 1$	$i = 2$	$i = 3$
g_{1i}	8×10^{-9}	3.8×10^{-7}	-1.218×10^{-4}
g_{2i}	-4.27×10^{-7}	8.2×10^{-6}	2.892×10^{-4}
g_{3i}	-2.5×10^{-5}	-1.034×10^{-4}	0.9314