modifying the equation (20.68). Thus

$$I_{SC} = \frac{I^*_{SC}}{G^*}(B_{eff} \cdot f_B + D_{eff} \cdot f_D + R_{eff} \cdot f_R) \tag{20.76}$$

where f_B, f_D and f_R obeys to the general form

$$f = c \cdot \exp[a(K_T - 0.74) + b(AM - 1.5)] \tag{20.77}$$

and a, b and c are empirically adjusted factors, for each module type and for each radiation component. Note that 0.74 and 1.5 are just the values of the atmospheric parameters corresponding to the STC. Table 20.7 shows the recommended values of these parameters for crystalline, c-Si, and amorphous a-Si modules. The usefulness of this table can be extended to other PV materials, by linear interpolation on the energy band gap, E_g, between E_g(c-Si) = 1.12 eV and E_g(a-Si) = 1.7 eV. For example, E_g(a-SiGe) = 1.4 eV ⇒ estimated value of c is equal to 0.8.

Spectral effects used to be small on a yearly basis. Spectral losses with respect to STC are typically below 2% with semiconductors with broad spectral sensitivity, and below 4% for the others. However, on an hourly basis, spectral effects up to 8% can be encountered.

The PV module cell temperature is a function of the physical variables of the PV cell material, the module and its configuration, the surrounding environment and the weather conditions. It results from the balance of energy inputs and outputs through radiation, convection, conduction and power generation. Today, the more widely extended model, based on the *NOCT* concept and described by equations (20.70 and 20.71), lump the contributions together in an overall heat-loss coefficient, resulting in a liner relationship between module temperature and irradiance under steady-state conditions. This implies accepting that the heat transfer process between the solar cell and the ambience is essentially dominated by the conduction through the encapsulating materials, and neglecting the wind effects on convection. This model is simple to use and requires only standard available input information, which are undeniable advantages for the PV designer. But it can lead to significant errors in cell temperature estimation for non-steady-state conditions [62] (observed thermal time constant of PV modules is about 7 minutes), and for high wind speeds. That has stimulated several authors to develop new thermal models for PV systems, based not only on irradiance but also on wind speed. For example, Sandia

Table 20.7 Coefficient for spectral response modelling, for c-Si and a-Si modules

	B		D		R	
	c-Si	a-Si	c-Si	a-Si	c-Si	a-Si
c	1.029	1.024	0.764	0.840	0.970	0.989
a	−3.13E-01	−2.22E-01	−8.82E-01	−7.28E-01	−2.44E-01	−2.19E-01
b	5.24E-03	9.20E-03	−2.04E-02	−1.83E-02	1.29E-02	1.79E-02