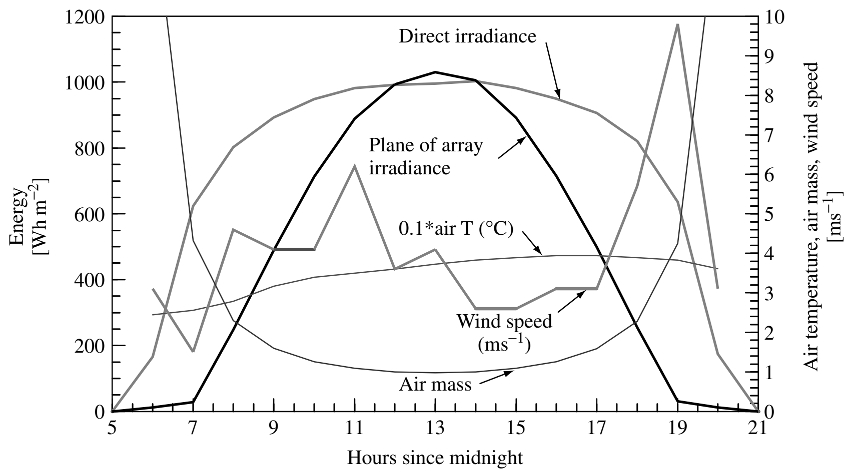

Figure 16.3 Meteorological conditions for the hot-sunny reference day [46–49]

various operating conditions [3, 4, 52–54]. This method has been used to compare commercial modules, highlighting the different dependencies on light level and temperature. Figure 16.4 illustrates the comparative ratings of selected modules for various locations in the United States [52] and Europe [53]. The results in Figure 16.4 indicate that the annual PV efficiency is 2 to 20% less than the efficiency under SRC (25°C, 1000 Wm^{-2}, and the global reference spectrum). The annual PV efficiency is total PV energy divided by the total energy deposited on a south-facing surface tilted to the latitude of the site. Spectral effects were ignored in Figure 16.4 with the global reference spectrum in Table 16.2 used for all calculations, so only temperature and total irradiance effects are included. The solar cell was modeled as described in Chapter 3 with a double exponential with series resistance and shunt resistance to model the performance as a function of total irradiance and temperature. Current state-of-the-art modules may be less sensitive to temperature and irradiance variations because of smaller temperature coefficients, series resistance, dark current, and a larger shunt resistance. The deviation of the annual efficiency from the efficiency under SRC would have been less if two-axis tracking were assumed. However, most flat-plate systems do not employ two-axis tracking. The spectral model developed by Nann was coupled with a PV model to compare the performance of a variety of PV technologies [4]. The PV model used a double exponential with series and shunt resistances to fit to the highest-efficiency cells made at the time of each technology. The environmental conditions include time, date, global-horizontal irradiance, direct-normal irradiance, diffuse irradiance, plane-of-array irradiance, ambient temperature, wind speed, and relative humidity. The results of the study were similar to those summarized in Figure 16.4 and References [52, 53]. The spectral model confirmed that the spectral sensitivity of Si, CdTe, $CuInSe_2$, and GaAs technologies on the annual energy production is +1% to −3%. The results also show that the efficiency of single- and multijunction amorphous silicon is ~10% less in winter months solely from spectral effects [4].