should be at the minimum possible temperature which limits the possible applications of combined systems to situations where thermal energy is needed at low temperatures.

An energy balance on a unit area of module which is cooled by losses to the surroundings can be written as[4]

$$(\tau\alpha)G_T = \eta_c G_T + U_L\,(T_c - T_a) \tag{23.3.1}$$

where $(\tau\alpha)$ is the effective transmittance-absorptance product that when multiplied by the incident radiation yields the energy that is absorbed and η_c is the efficiency of the module in converting incident radiation into electrical energy. This efficiency will vary from zero to the maximum module efficiency depending on how close to the maximum power point the module is operating. The loss coefficient U_L will include losses by convection and radiation from top and bottom and by conduction through any mounting framework that may be present, all to the ambient temperature T_a.

The nominal operating cell temperature (NOCT) is defined as the cell or module temperature that is reached when the cells are mounted in their normal way at a solar radiation level of 800 W/m^2, a wind speed of 1 m/s, an ambient temperature of 20°C, and no-load operation (i.e., with $\eta_c = 0$). The mounting has a strong impact on the NOCT so care must be exercised in using the NOCT if the cells are not mounted in the same manner as they are tested. Measurements of the cell temperature, ambient temperature, and solar radiation can be used in Equation 23.3.1 at NOCT conditions:

$$(\tau\alpha)G_{T,NOCT} = U_{L,NOCT}\,(T_{NOCT} - T_{a,NOCT}) \tag{23.3.2}$$

The cell temperature at any ambient temperature is then found from

$$\frac{T_c - T_a}{T_{NOCT} - T_{a,NOCT}} = \frac{G_T}{G_{NOCT}}\frac{U_{L,NOCT}}{U_L}\left[1 - \frac{\eta_c}{(\tau\alpha)}\right] \tag{23.3.3}$$

The $(\tau\alpha)$ in the last term of Equation 23.3.3 is not generally known, but an estimate of 0.9 can be used without serious error since the term $\eta_c/(\tau\alpha)$ is small compared to unity. It is clear that Equation 23.3.3 does not account for the variation in cell temperature with wind speed unless the ratio of the two loss coefficients is known. One approximation is to replace the ratio by the ratio of Equation 3.15.2 at NOCT and actual operating conditions:

$$\frac{T_c - T_a}{T_{NOCT} - T_{a,NOCT}} = \frac{G_T}{G_{NOCT}}\frac{9.5}{(5.7 + 3.8V)}\left[1 - \frac{\eta_c}{(\tau\alpha)}\right] \tag{23.3.4}$$

where V is the local wind speed in meters per second. In design practice the local wind speed is seldom known with any certainty. If the actual mounting is not the same as used in the NOCT test, then estimates given by Equation 23.3.3 or 23.3.4 will not be correct.

Other approaches to determining the operating cell temperature have been proposed by Sandia (King et al., 2004) and NIST (Davis et al., 2001). In both cases additional

[4] These energy balances can also be written for an hour in terms of I_T.