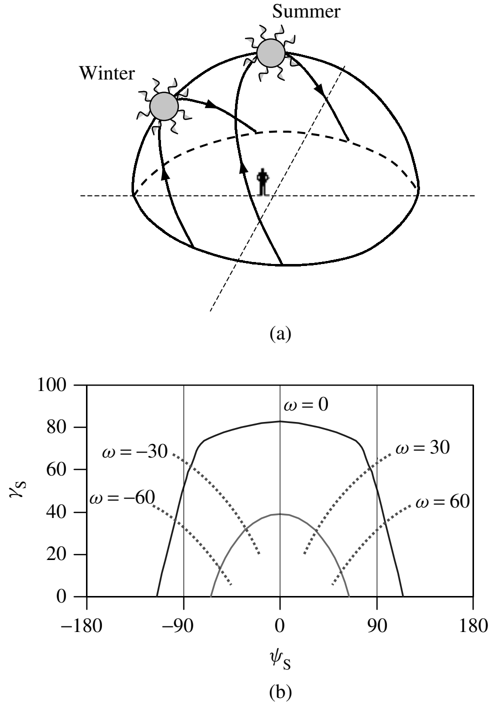

Figure 20.6 (a) Sun's trajectory corresponding to a winter and to a summer day represented over the celestial sphere. (b) The solar altitude γ_S is plotted against the solar azimuth ψ_S. The solar time ω is also shown

complement plus the declination

$$\omega = 0 \Rightarrow \gamma_S = \frac{\pi}{2} - \phi + \delta \tag{20.8}$$

It should be noted that equation (20.5) is indeterminate for $\gamma_S = \pi/2$ and for $\phi = \pi/2$. In the first case, the sun is just on the vertical, so that ψ_S is meaningless. In the second, the sun's position is given by $\gamma_S = \delta$ and $\psi_S = \omega$.

It should now be said that equations (20.1–20.3 and 20.6) derive from considering the angular velocity of the Earth through its elliptic orbit as constant, which is sufficiently accurate for most PV engineering applications. In particular, for all designs involving flat-plate PV modules, typical accuracy is about 1°. However, if desired, more accurate expressions are obtained when taking into account that the well-known Kepler's second law governs this angular velocity [2].

Another word of caution is necessary here. All the above-presented equations refer to a baseline year composed of 365 days, while the time length of the real year is 365 days, 5 h, 48 min and 45.9 s. As is well known, the difference is compensated by adding a day in the leap years. For most PV engineering applications, the same number corresponding to the precedent may be associated to this additional day, that is, $d_n = 59$ for both 28th and 29th of February. However, for some demanding applications, such as