APPENDIX A

1. **General Solar Position Calculations :**

First, the fractional year (γ) is calculated, in radians.

$$\gamma = \frac{2\pi}{365} * \left(day_{of_{year}} - 1 + \frac{hour - 12}{24} \right)$$

From γ we can estimate the equation of time (in minutes) and the solar declination angle (in radian).

$$eqtime = 229.18 * (0.000075 + 0.001868 \cos\gamma - 0.032077 \sin\gamma - 0.014615 \cos 2\gamma - 0.040849 \sin 2\gamma)$$

$$decl = 0.006918 - 0.399912 \cos\gamma + 0.070257 \sin\gamma - 0.006758 \cos 2\gamma + 0.000907 \sin 2\gamma - 0.002697 \cos 3\gamma + 0.00148 \sin 3\gamma$$

Next, the true solar time is calculated in the following two equations. First the time offset is found, in minutes, and then the true solar time, in minutes.

$$time\_offset = eqtime - 4 * longitude + 60 * timezone$$

where eqtime is in minutes, longitude is in degrees, timezone is in hours from UTC (Mountain Standard Time = +7 hours).

$$tst = hr * 60 + mn + \frac{sc}{60} + time\_offset$$

where hr is the hour (0 - 23), mn is the minute (0 - 60), sc is the second (0 - 60).

The solar hour angle, in degrees, is:

$$ha = (tst/4) - 180$$

The solar zenith angle (∅) can then be found from the following equation:

$$\cos\emptyset = \sin(lat)\sin(decl) + \cos(lat)\cos(decl)\cos(ha)$$

And the solar azimuth (θ, clockwise from north) is:

$$\cos(180 - \theta) = -\frac{\sin(lat)\cos\emptyset - \sin(decl)}{\cos(lat)\sin(\emptyset)}$$

2. **Sunrise/Sunset Calculations:**

For the special case of sunrise or sunset, the zenith is set to 90.833° (the approximate correction for atmospheric refraction at sunrise and sunset), and the hour angle becomes:

$$ha = \pm arc\cos\left(\frac{\cos(90.83)}{\cos(lat)\cos(decl)} - \tan(lat)\tan(decl)\right)$$

where the positive number corresponds to sunrise, negative to sunset.

Then the UTC time of sunrise (or sunset) in minutes is:

$$sunrise = 720 + 4(longitude - ha) - eqtime$$

where longitude and hour angle are in degrees and the equation of time is in minutes. Solar noon for a given location is found from the longitude (in degrees) and the equation of time (in minutes):

$$snoon = 720 + 4 * longitude - eqtime$$