Chapter 6:

SOLAR GEOMETRY

Full credit for this chapter to Prof. Leonard Bachman of the University of Houston

"SOLAR GEOMETRY AS A DETERMINING FACTOR OF HEAT GAIN, SHADING AND THE POTENTIAL OF DAYLIGHT PENETRATION..."

"Declination" refers to the tilt of the earth's axis measured from perpendicular to the sun's rays. This angle is 0 degrees at the spring and autumn equinox. Maximum declination is reached at the summer (23.45 deg.) and winter (-23.45 deg.) solstice.

"Air Mass" is the effective thickness of the atmospheric path of sunlight relative to the shortest possible path. An air mass of 2.0, for example, is twice as long (thick) as the direct path. When the sun travels through higher air masses , less solar energy reaches the surface of the earth. This is a primary cause of seasonal weather. Beyond an air mass of 5.0, little sun will be received. Air Mass = 1 / sin(solar altitude angle)

"Equation of Time" (EOT) is a variable that adjusts for the ellipicity of the earth's orbit and non-uniform solar time.

"Solar Noon" occurs when the sun is at its mid point and highest angle of its daily path across the sky. The position of the sun relative to the horizon at this time is called "True South'.

"Magnetic Deviation" accounts for the difference between magnetic north and true north. This varies with location.

"Solar Time" is the measure of time which a sundial would read at any particular location. This is different from "clock' or "standard' time due mostly to conventions of time zones and Daylight Savings.

Two angles of general interest to architects are the AZIMUTH and ALTITUDE angles. These angles express the polar coordinates of the sun's position relative to a location on the earth's surface and provide general ideas about availability of solar energy and shading strategies at a particular time of year and day.

"Solar Azimuth" is the bearing of the sun from true south. At solar noon, the sun is at true south and the solar azimuth angle is defined as 0. Morning angles are measured as negative.

"Solar Altitude" is the bearing of the sun above the horizon. At sunrise and sunset, the solar altitude angle is 0. At solar noon, the sun reaches its highest point (greatest altitude). For locations within the tropics (between the Tropic of Cancer and the Tropic of Capricorn at 23.45 deg N. Latitude and 23.45 deg S. Latitude respectively) the sun will sometimes reach a 90 deg altitude angle. At that time, the air mass is 1.0. The altitude angle is a function of latitude and declination of the earth as well as hour of day. For solar noon we can generalize the solar altitude angle in respect to latitude and declination as follows:

Summer Solstice (around June 21) at solar noon:

$$\text{Altitude} = (90^o - \text{latitude}) + 23.45^o$$

Winter Solstice (around December 21) at solar noon:

$$\text{Altitude} = (90^o - \text{latitude}) - 23.45^o$$

Spring/Fall Equinox (around March 21 and September 21) at solar noon:

$$\text{Altitude} = (90^o - \text{latitude})$$

Window Angles: Usually, architects are concerned about solar position in relation to the position of a window or solar collector. Without a good idea of the geometry involved, it is not possible to reliably design a fixed shading device or optimize exposure.

"Window Azimuth" is much like the solar azimuth. But where solar azimuth is concerned with the bearing of the sun from true south, the window azimuth measures the bearing of the sun on the horizon from normal (perpendicular in plan) to the window. Before the sun's rays are normal to the window, the angle is expressed in negative degrees. Afterwards, the angles are positive.

"Profile Angle" is the vertical angle of the sun measured in section cut normal (perpendicular) to the window in question. When the window azimuth angle is 0, the profile angle is equal to the solar altitude angle; otherwise the profile angle is greater because it is visually foreshortened by the oblique viewing angle (turn a 45 deg triangle away from a flat elevation and it becomes progressively steeper until it reaches 90 degrees.

"Incidence Angle" is measured between the angle of the sun's direct rays and a line normal (perpendicular in all directions) to the surface of the window. At high angles of incidence, the path length of solar energy through glazing becomes very long and more energy is reflected and absorbed. Thus the angle of incidence has an effect on the shading coefficient and visible light transmittance of windows and skylights.

PROJECTIONS AND CHARTS

If the path of the sun is projected on to a vertical plane at the imaginary horizon line, we get a rectangular grid map of solar azimuth (horizontal axis) and solar altitude (vertical axis). This easy to read format was popularized by Bennet and is noted as the Bennet Sun Angle Chart. It is useful for simple information about solar position.

If we project the sky dome on t o the ground plans to get a horizontal plane map, the result is a polar coordinate grid showing azimuth as radiating lines from the center and altitude as distance from the center. The path of the sun across the sky is projected in arcs across the ground projection relative to the center as the imaginary location.

Both charts are useful as solar calendars and can be colour coded to indicate temperature correlations to solar position. This relationship is useful when designing shading devices and passive solar collector strategies. The polar coordinate horizontal projection is more useful for architectural applications since it incorporates an overlay for looking at solar geometry relative to windows at different orientations (surface azimuth angle, profile or section angle, and incidence angle).

Both of the charts save a great deal of trigonometric calculation in dealing with the complex geometries of sun:earth:window as they all move relative to each other.

<u>SOLAR TIME</u>

For reasons of convention, we adopt a standard time for each time zone in the world. Since the world is 360 degrees around and there are 24 hours in one rotation, each time zone covers about 15 degrees of longitude. A sun dial however, would tell a different time for each and every location within the time zone because it is dependent on the exact position of the sun. When we plan for solar access or shading, it is important to remember that the sun does not follow the conventions of time zones or daylight savings time. The difference between local standard time and solar time is partially a matter of distance from the standard meridian longitude for the time zone and partly a consideration of the obliqueness and ellipticity of the earth's orbit around the sun. Finally, if daylight savings is also in effect ("spring forward, fall back"- lasting from late April to late October) one hour needs to be subtracted from standard time.

For the longitude correction we note that 15 degrees of longitude accounts for one hour or 60 minutes of time. Each degree of longitude our location is away from the standard meridian therefore, will account for four minutes of error between clock and solar time. For the orbit correction, we need to look at a chart of the Equation of Time (EOT). The correction factor is a matter of the date of year. These two correction factors can account for as much as an hour and twenty-two minutes of difference between clock and solar time. Since we are planning to respond to the actual position of the sun we must make this correction first.

Solar Time = Clock Time + EOT + 4(M_{st} - M_{loc}) - 60 min. Daylight Savings

note: all terms in minutes

where:

- Solar Time is the time a sundial would indicate
- Clock Time is the conventional time for that time zone
- EOT is the correction in minutes for the earth's orbit
- M_{st} is the local standard meridian of longitude, always a multiple of 15^{o} and always smaller than the local longitude.
- M_{loc} is the local longitude.
- 60 min. is the correction for daylight savings when in effect (late April to late October)
- The constant '4' is the number of minutes of variation from solar time for each degree of longitude from the standard meridian

MAGNETIC DEVIATION

Compass directions indicate the direction of the magnetic north pole. The deviation between magnetic and true north will vary with location. Easterly deviations mean that true east is some number of degrees to the east of magnetic north. 11 north is given as magnetic, then orientation for solar access and shading must be corrected accordingly. Using the profile overlay protractor for a window which faces magnetic north means that the normal to the window line would have to be rotated counterclockwise by the magnitude of the deviation. This correction holds for any window orientation on a site with an easterly deviation- rotate the Normal To The Window arrow counterclockwise that number of degrees. For any magnetic orientation with a westerly deviation, rotate the protractor overlay clockwise that number of degrees.

IMPORTANCE OF CORRECTION FACTORS

Clock time error can be up to 2 hours from solar time. This might result in something up to a 30^{o} error in predicting the sun's position. Magnetic deviation in the U.S. can be more than 20^{o} east or west. Compounding these two errors makes the actual position of the sun unpredictable. If a structure is incorrectly oriented, its passive solar gain and shading strategies will be compromised and once built, very difficult to correct.

INCIDENCE ANGLE SHADING

At high angles of incidence, where the sun's rays are almost parallel to the window surface (at glazing angles), glass becomes more reflective. At incidence angles of 80^{o}, both single and double pane glazings (clear plate glass) become about 50% reflective. This geometry occurs when profile angles are very high, window azimuth angles are high, or both. This will reduce solar radiation transmitted through the glass by an equal percentage. Some other problems like interior glare or reflected glare from the facade to the exterior may occur.

AIR MASS SHADING

As a function of solar altitude, the air mass extinction becomes critical at about air mass 5.0. This relates to a solar altitude of 12 degrees above the horizon or less. At these low altitudes, the sun is more of a glare problem than heat gain. This notion works against a building which tries to collect low winter sun. Shading devices should allow for the fact that incidence and air mass shading will eliminate some periods of the year from consideration but may still require shielding from glare.

DIFFUSE SOLAR ENERGY

Shading devices are usually configured to provide agains direct beam sunlight and from the brightest part of the sky on cloudy days. Some scattered (diffuse) energy will still arrive at the window. For a fully shaded window, we usually consider the incident solar energy to still equal that of a expose window on a shaded north elevation. The actual insolation received for a fully shaded window is a function of how much sky the window 'sees' and how reflective the foreground landscape is.

RELATION OF INCIDENCE ANGLE TO GLASS REFLECTANCE:

Incidence Angle	% Reflectance

	Single Pane	*Double Pane*
0	2	6
10	3	6
20	4	6
30	5	7
40	6	9
50	7	10
60	9	18
70	18	30
80	38	57
90	100	100