

Designing with the Pilkington Sun Angle Calculator

In 1951, Libbey-Owens-Ford introduced the first Sun Angle Calculator, to provide a relatively simple method of determining solar geometry variables for architectural design. The Sun Angle Calculator proved to be a quick and accurate tool and has been used extensively by academics, researchers, and design professionals for the past 50 years. The Society of Building Science Educators (SBSE) has recompiled the sun angle calculator package as a service to the architectural and engineering professions. The Libbey-Owens-Ford Company was acquired in 1986 by the largest global glass manufacturer, Pilkington, and is now referred to as Pilkington North America (PNA).

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The Sun Angle Calculator

The sun has influenced architectural design since primitive times. In the sixth century, the Greek philosopher Xenophanes wrote:

"In houses with a south aspect, the sun's rays penetrate into the porticoes in winter, but in the summer the path of the sun is right over our heads and above the roof, so that there is shade. If, then, this is the best arrangement, we should build the south side loftier to get the winter sun, and the north side lower to keep out the cold winds."

This principle is still true today and is becoming more important with the emphasis on curtailing energy consumption.

To meet human needs for natural light and outside views, buildings are designed with large window openings, making proper orientation and sun control very important. Solar radiation affects air conditioning capacity and solar energy can supplement the heat source in winter. Thus it is increasingly important to know and understand the sun's effect on the design and engineering of a building. Paramount in this is knowledge of the sun's apparent position.

The seasonal positions of the sun are universally known in general terms. It is directly over the equator about March 21, the vernal equinox, and thereafter it appears farther north each day until it reaches its zenith above the Tropic of Cancer about June 21 (the summer solstice in northern latitudes). Then the sun appears a little more southerly each day, rising above the Equator about September 21 (the autumnal equinox) and reaching its most southerly point over the Tropic of Capricorn about December 21 (winter solstice).

This general information is insufficient to determine the sun's effect on a specific structure in a particular location. To know how the rays will strike a building and how far the rays will penetrate through the opening; to shade certain areas and irradiate others; to utilize the sun for supplementary heating; to effectively use daylighting to reduce the use of artificial lighting; to know the effect of solar energy on air conditioning capacity and operation; we must have the following information:

1. The Angle of the Sun above the horizon.
2. The Bearing (Azimuth) of the Sun, or its direction.
3. The Angle of Incidence of the Sun relative to the surface being considered.

These must be known for a particular surface, no matter what its orientation, for at least several hours of each day studied.

Because time-consuming trigonometric methods are needed for calculating, a quick method of obtaining solar angular values was necessary. But such a method must be applicable to all latitudes within the United States and give all necessary values for all possible time and orientation conditions.

The Sun Angle Calculator is the result. It was developed by Libbey-Owens-Ford Company with the help of architects, engineers and Aeronautical Services Incorporated, a firm long experienced with navigation instruments. Actual use has proven its quickness and accuracy.

Glossary Of Terms

True Altitude -- The angle between the rays of the sun and a horizontal plane.

Angle of Incidence -- The angle between the sun's rays and face of the building.

Bearing (Azimuth) -- The angle of the sun from True South. True South, rather than True North, is used because southern orientation is the one to be considered in northern latitudes.

Normal to Window -- A line perpendicular to the plane of the window.

Profile Angle -- The angle between Normal to Window and the rays of the sun perpendicular to the window plane. Profile Angle must be determined in order to compute position and dimensions of shading devices.

Overhang -- A roof extension or other horizontal device above a window to intercept the rays of the sun, to provide protection from the elements or for aesthetics.

Lateral Control-- A vertical projection from a building to provide protection from the elements.

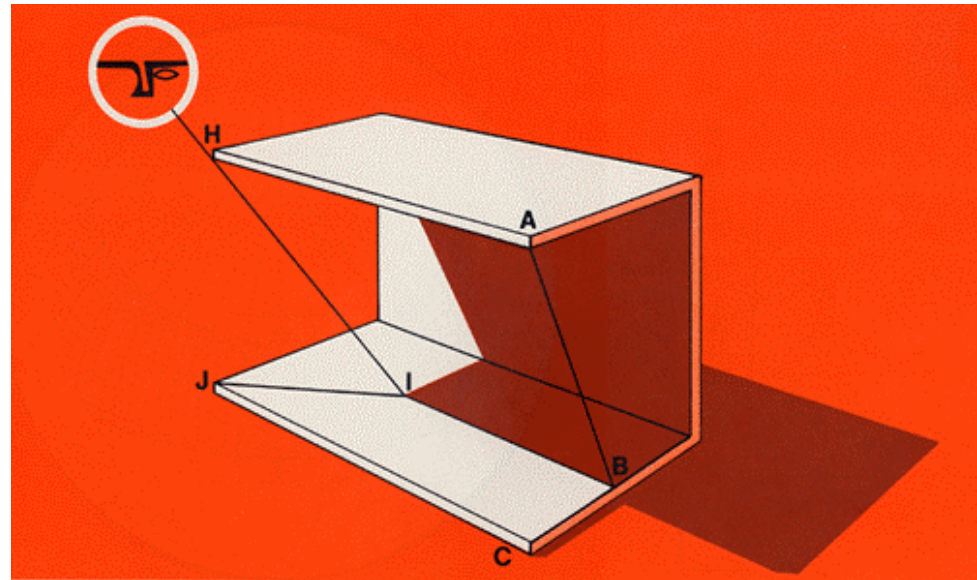
Shading Device -- A device positioned to intercept the rays of the sun. Some examples are roof overhangs, vertical fins, Venetian blinds and draperies.

Sun Time -- Hours based on the Position of the Sun. Solar noon is the instant the sun reaches its maximum altitude for that day. The bearing of the sun at this moment is True South.

Position of the Sun -- The true altitude and bearing of the sun at the geographic location being studied.

True South (North) -- Direction based on the geographic north and south poles.

Magnetic South (North) -- Direction based on the magnetic north pole.



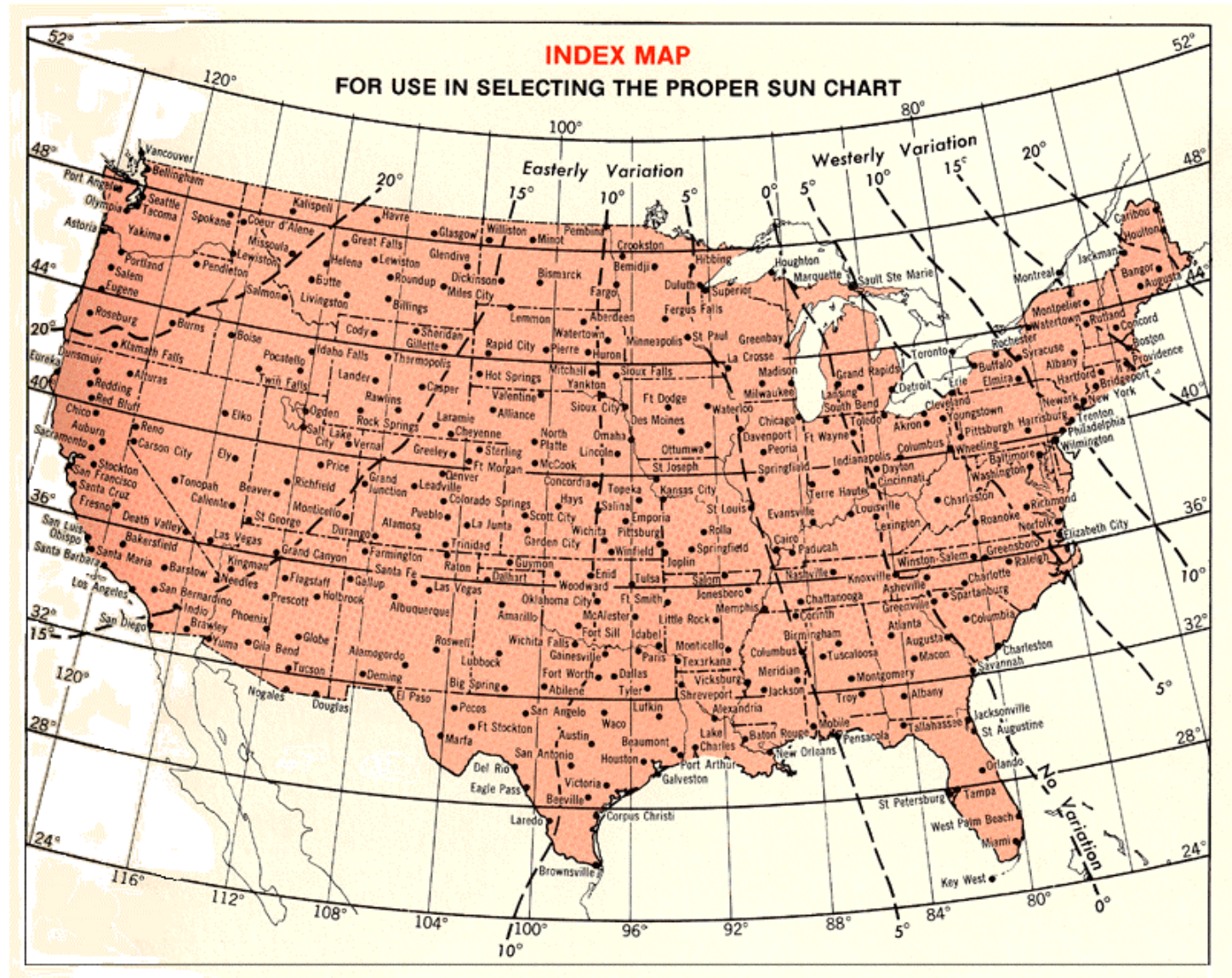
The Glossary defines True Altitude as the angle between the sun's rays and the horizon and Profile Angle as the angle between Normal to Window and the rays of the sun perpendicular on the window plane.

The drawing above may help to visualize these angles and their differences. Angle H I J is True Altitude. H A is the horizontal plane and I B is the horizontal axis in the plane of the window. A B C is the Profile Angle.

Elements of the Sun Angle Calculator

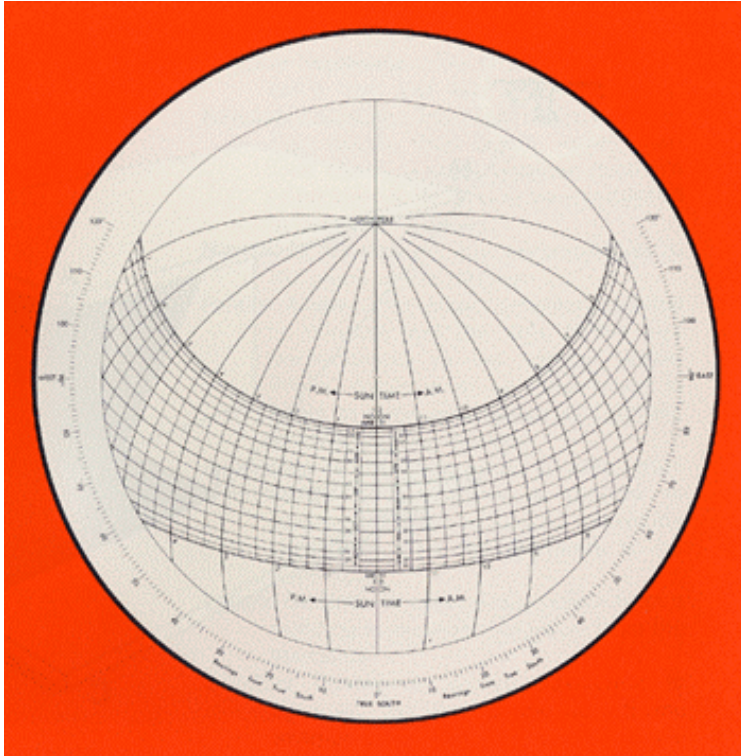
1. Index Map

Use the map inside back cover to determine the latitude of the location under study. If more exact information is necessary, especially for locations not shown on the map, consult a standard atlas. The broken lines are lines of magnetic variation, in case a magnetic compass has been used in preliminary calculations. The actual building orientation and calculation of the sun's position should be based on True South (North) as established by survey.



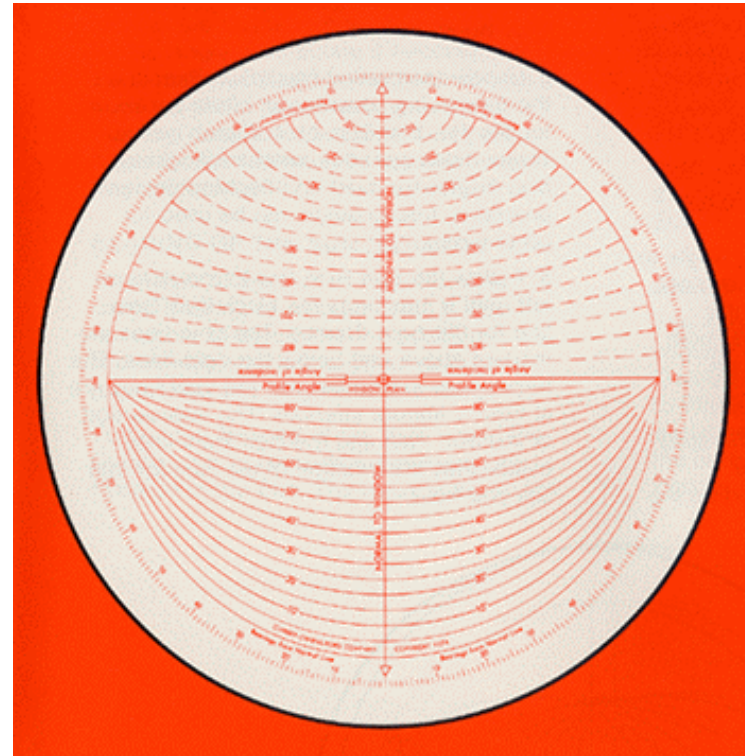
2. Sun Chart

There is a Sun Chart for each four degrees of North latitude from 24 deg to 52 deg. The Charts are printed in black on both sides of the board. The curved lines represent the Position of the Sun on the earth's surface, as seen from above, at that latitude and date. The lines radiating from the North Pole represent Sun Time, with the light lines positioned at twenty minute intervals.



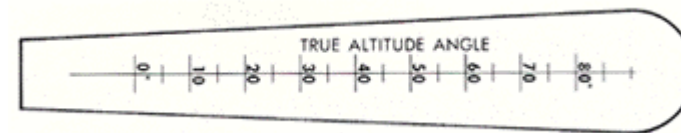
3. Red Transparent Overlay

The circular overlay is applied to all Sun Charts. In the center is a plan view showing the window under study. That part of the Overlay with the solid red lines is used to determine the Profile Angles. That part with the broken red lines is used to find the Angles of Incidence.



4. Cursor

The wedge-shaped Cursor is used for reading the Bearing of the Sun from True South and from Normal to the Window where it intersects the scales along the perimeter of the Sun Chart and Overlay. Its own scale is used to read the True Altitude of the Sun.



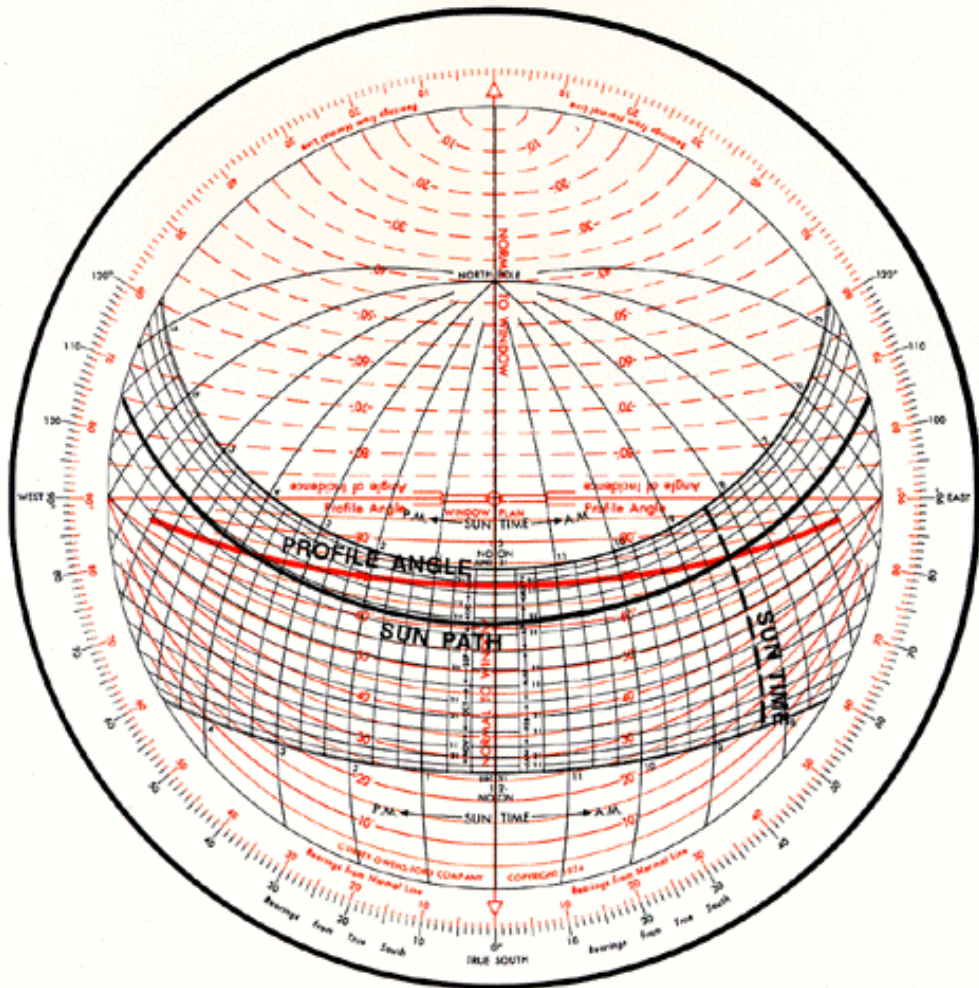
USING THE SUN ANGLE CALCULATOR

Find the latitude of the structure under consideration by using the map inside the back cover. Disassemble the Calculator, and select the Sun Chart nearest that latitude. Place this on top. Add the red Overlay and Cursor and reassemble.

Determining the Profile Angle

It is necessary to know the Profile Angle to establish the position and dimensions of overhangs and also to determine the penetration of the sun's rays into a room or the length of a shadow cast by an opaque object.

1. Rotate red Overlay to line up the solid line, "Normal to Window," with the orientation of the window indicated on the black peripheral scale, "Bearings from True South."
2. Locate the curved black Sun Path line for the date being considered. Lines are shown for the 1st, 11th and 21st of each month. These dates are adequate for calculating Sun Angles for most architectural design problems. Interpolation can be used for other dates.
3. Follow the Sun Path line to the right or left until it intersects the black Sun Time line for the hour desired. The time lines are marked above and below the date lines. The heavy lines are hours, and the light lines are at twenty minute intervals. The intersection of the Sun Path and the Sun Time lines establishes the Position of the Sun for that day and hour.
4. The curved red line on the Overlay nearest the Position of the Sun is the Profile Angle. Interpolate if necessary. If the location in question lies between the latitudes of the Sun Charts and more exacting data is desired, find the Profile Angle for the higher and the lower latitude and interpolate.



Bearing of the Sun (Azimuth)

The Angle of the Sun to True South is called Bearing or Azimuth. This is also necessary to determine the position and dimensions of fins, other vertical projections and lengths of overhangs.

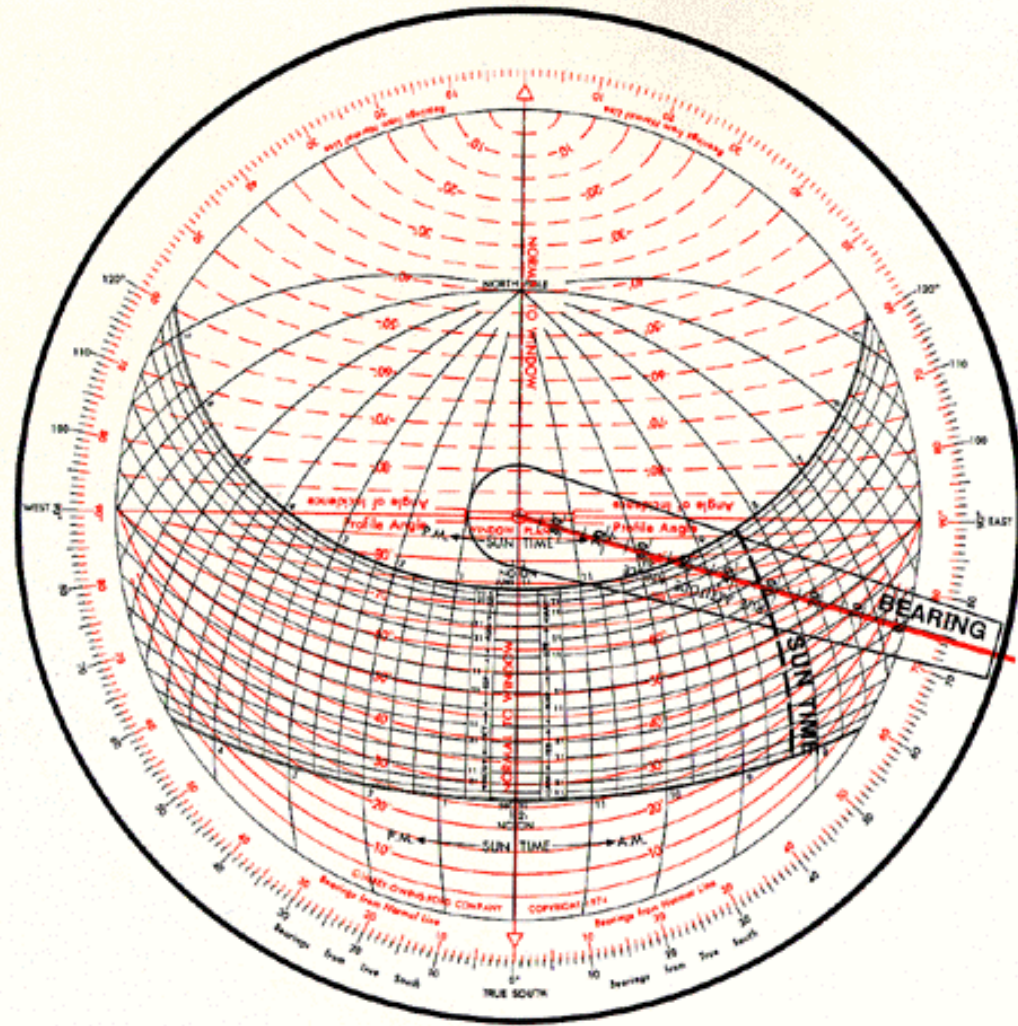
To find the Bearing of the Sun, rotate the Cursor until its centerline intersects the Position of the Sun. The black scale on the periphery of the Sun Chart indicates the Bearing from True South and, on the Overlay, the red scale gives the Bearing from Normal.

True Altitude

True Altitude is read on the Cursor where the center line crosses the Position of the Sun.

Angle of Incidence

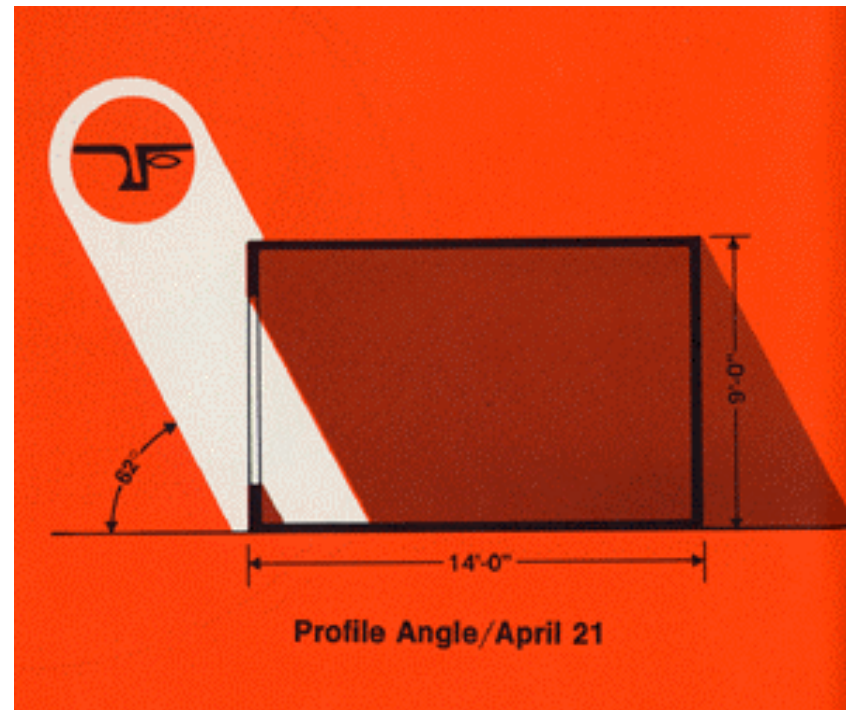
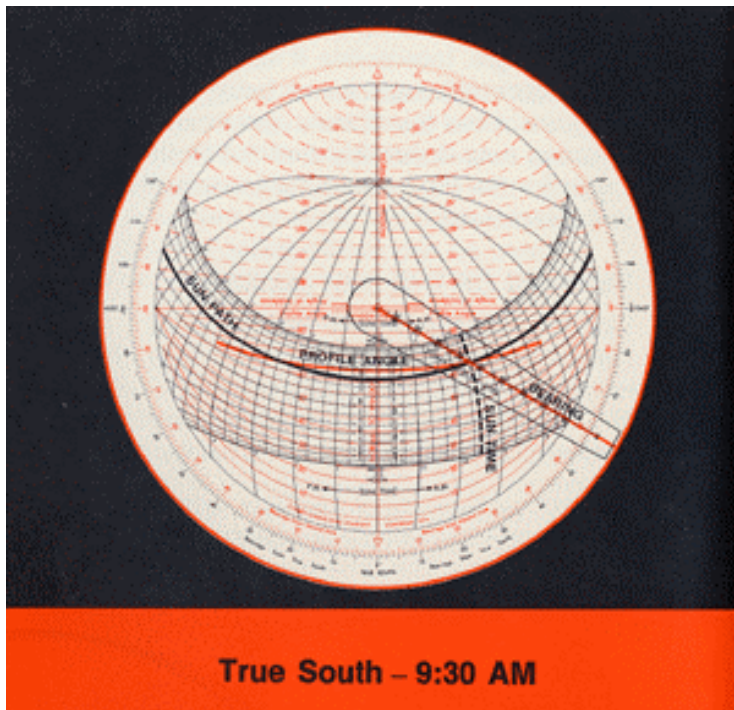
The Angle of Incidence of the sun to a window is determined by rotating the Overlay 180° to the broken red line "Normal to Window" and to the same reading on the peripheral scale. The Angle of Incidence is the broken red line coinciding with the Position of the Sun.



Using the Sun Angle Calculator -- Example A

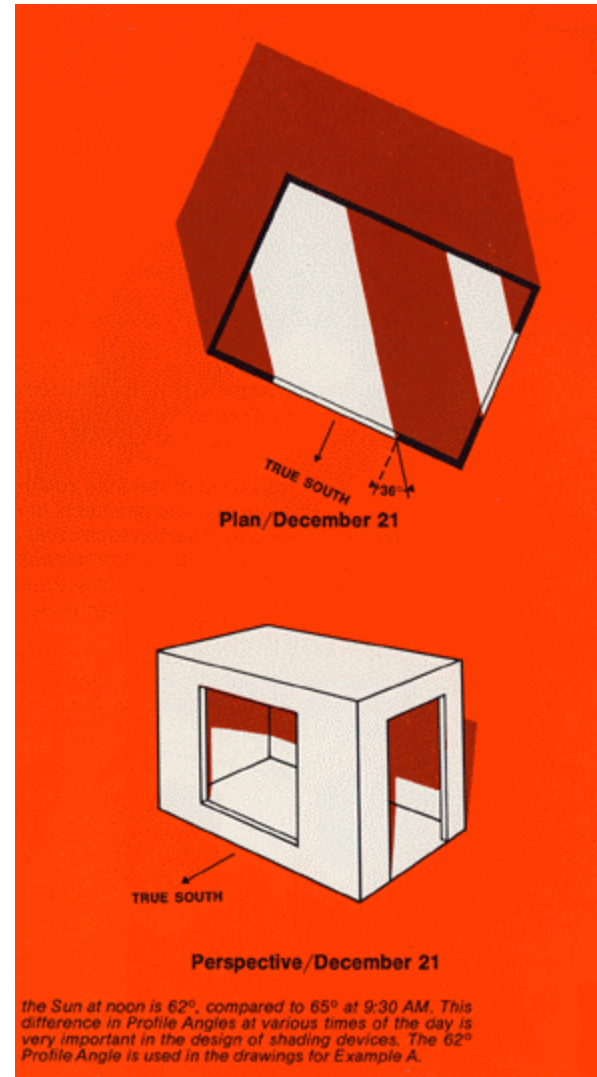
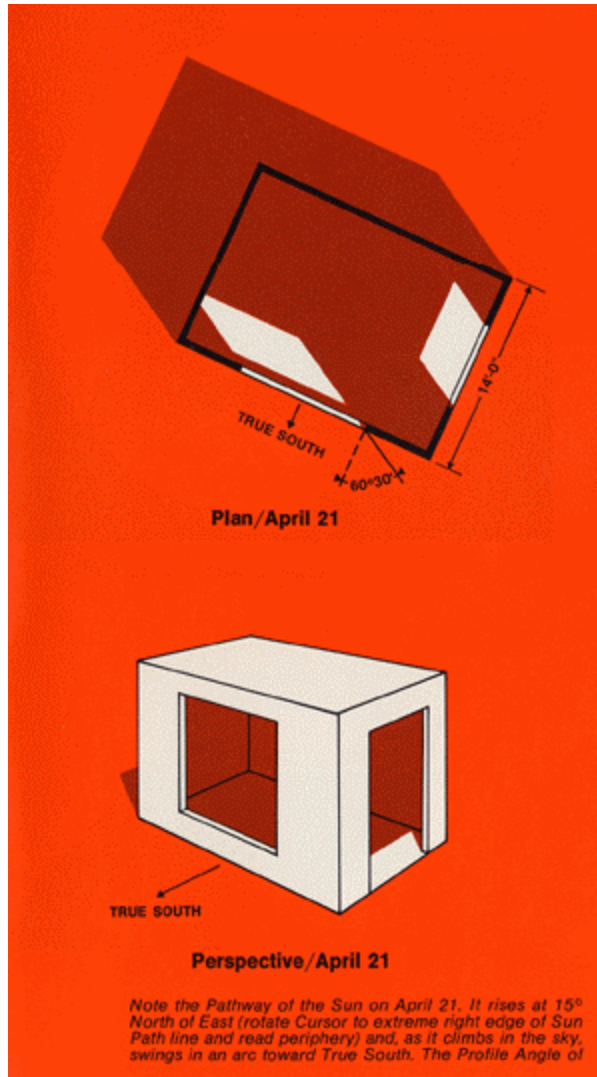
Building located in Columbus, Ohio at 40 deg North latitude, with windows facing True South. Time is 9:30 AM on April 21 and December 21. Find the Profile Angle, Bearing of the Sun and True Altitude.

1. Select 40 deg Sun Chart, place on top, add red Overlay and Cursor. Line up solid Normal to Window line with True South on Sun Chart.
2. Locate April 21 on the curved black Sun Path line and follow across until it intersects the Sun Time line for 9:30 AM. This is the Position of the Sun for that instant.
3. The curved red line intersecting the Position of the Sun is the Profile Angle for that time and date. The reading is 65 deg.
4. To find the Bearing of the Sun, rotate the Cursor until its center line intersects the Position of the Sun. The black scale on the periphery of the Sun Chart indicates the Bearing from True South for April 21 at 9:30 AM is 60 deg 30 min East of True South.
5. True Altitude is read on the Cursor where it intersects the Position of the Sun. True Altitude is 47 deg.



Repeat these same steps for the readings on December 21.

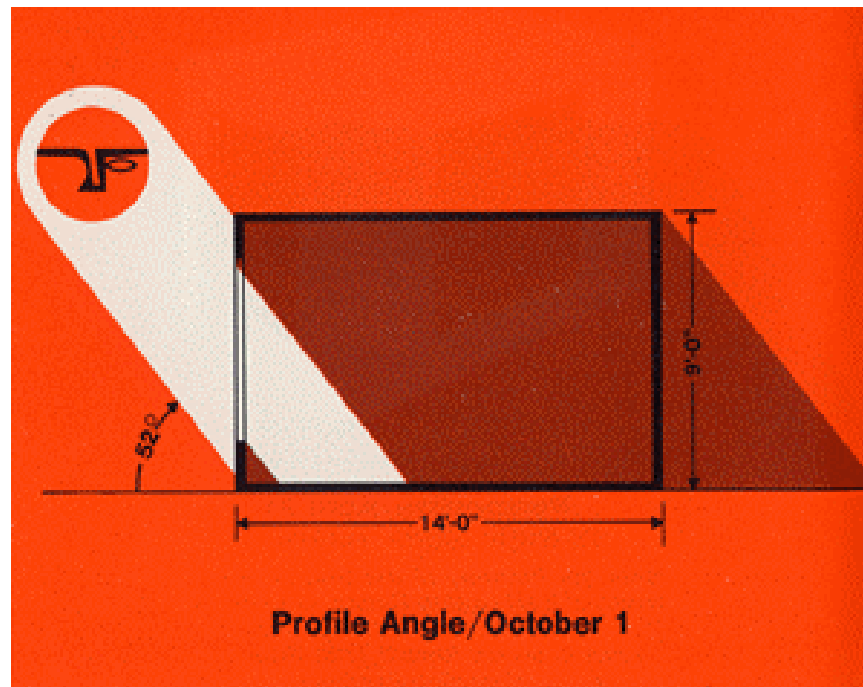
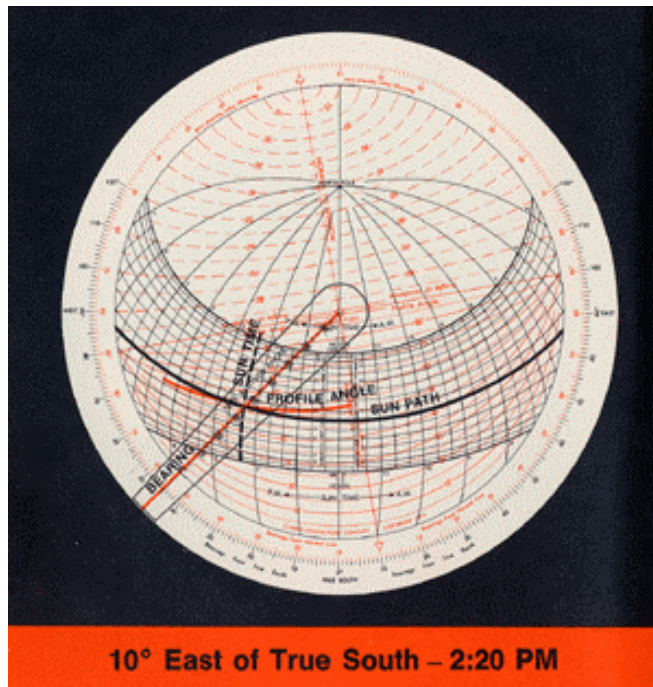
By transmitting this information to scaled sectional and plan drawings, it is possible to determine the proper length and width of an overhang to completely shade the window during the warm months from April 21 until August 21, and let in more and more sun until maximum solar penetration is reached on December 21, when the sun is at its most southerly position.

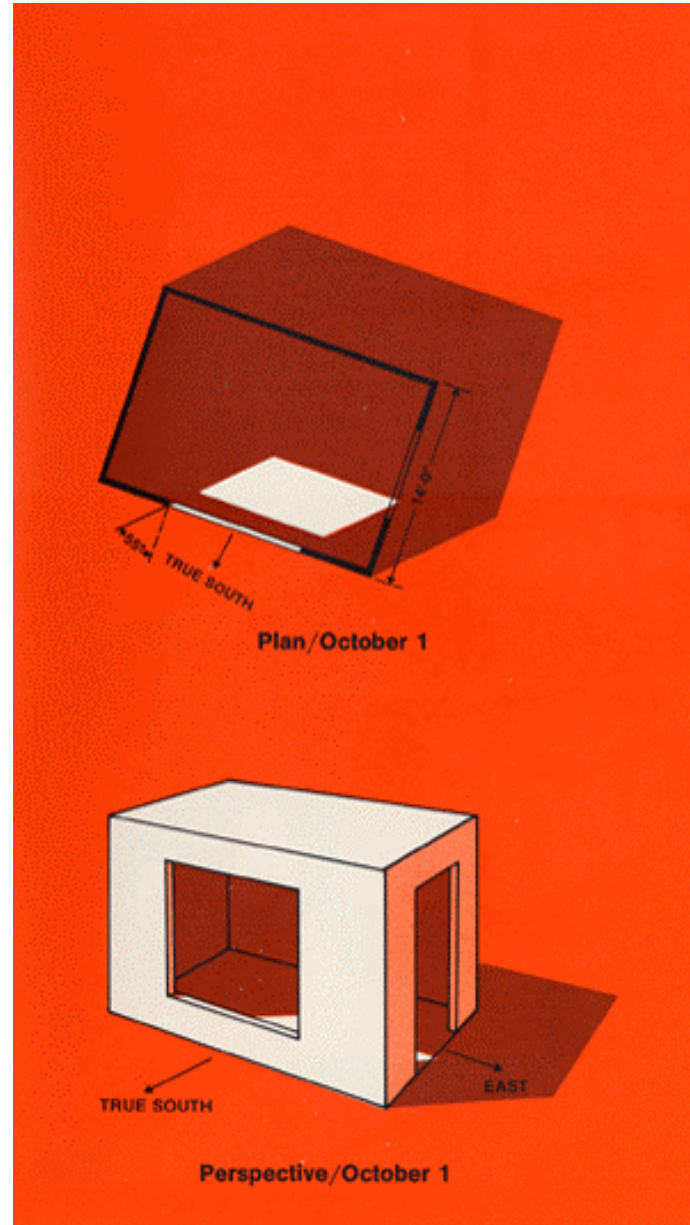
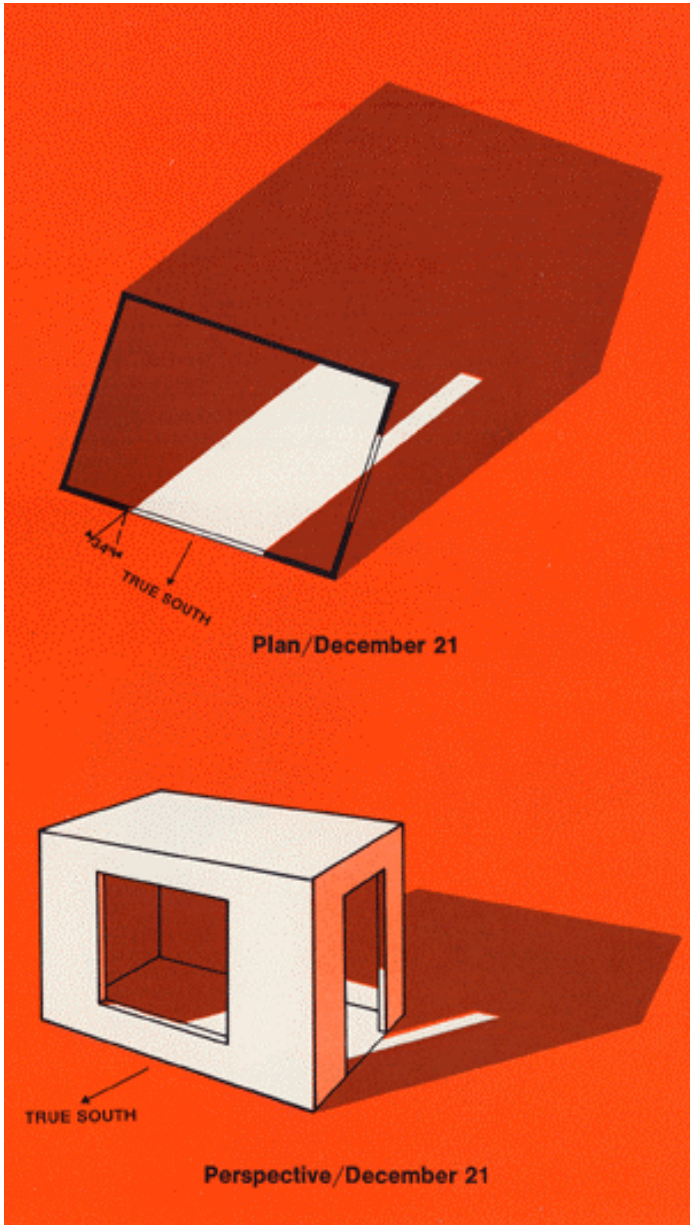


Using the Sun Angle Calculator -- Example B

Building located at 40 deg North Latitude, with window facing 10 deg East of True South. Time is 2:20 PM on October 1. Find the Profile Angle, Bearing of the Sun and True Altitude.

1. Rotate red Overlay until Normal to Window line points to 10 deg East of True South on the periphery of the Sun Chart.
2. Locate October 1 on curved black Sun Path line and follow across until it intersects the Sun Time line for 2:20 PM. This is the Position of the Sun for that instant.
3. The Profile Angle is the corresponding red line on the Overlay. By interpolation it reads 52 deg for October 1 at 2:20 PM.
4. To find the Bearing of the Sun, rotate the Cursor until its center line intersects the Position of the Sun. The corresponding Bearing from True South on the periphery is 45 deg West of True South, and the Bearing from Normal, on the adjacent red scale, is 55 deg.
5. True Altitude is read on the Cursor where it intersects the Position of the Sun. True Altitude is 36 deg.





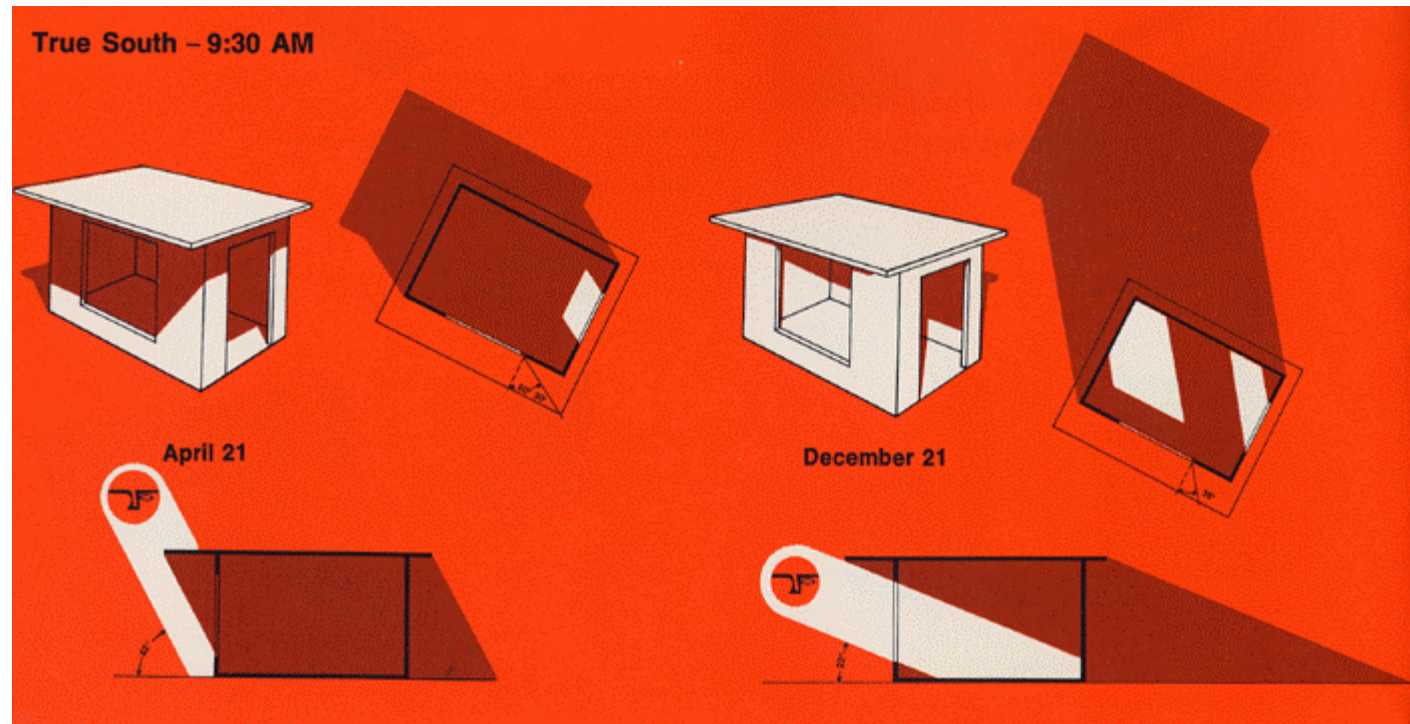
Location And Dimensions Of Sun Control Devices -- Overhangs

One method used to control the amount of sun coming through a window is the overhang. This is most effective for windows facing south or nearly so. But, its efficiency depends on placement and dimensions.

It is necessary to know the Profile Angles of the Sun on many specific dates and hours to figure the width of the overhang necessary to screen out the sun during the warm months and yet allow it to enter during the cold months.

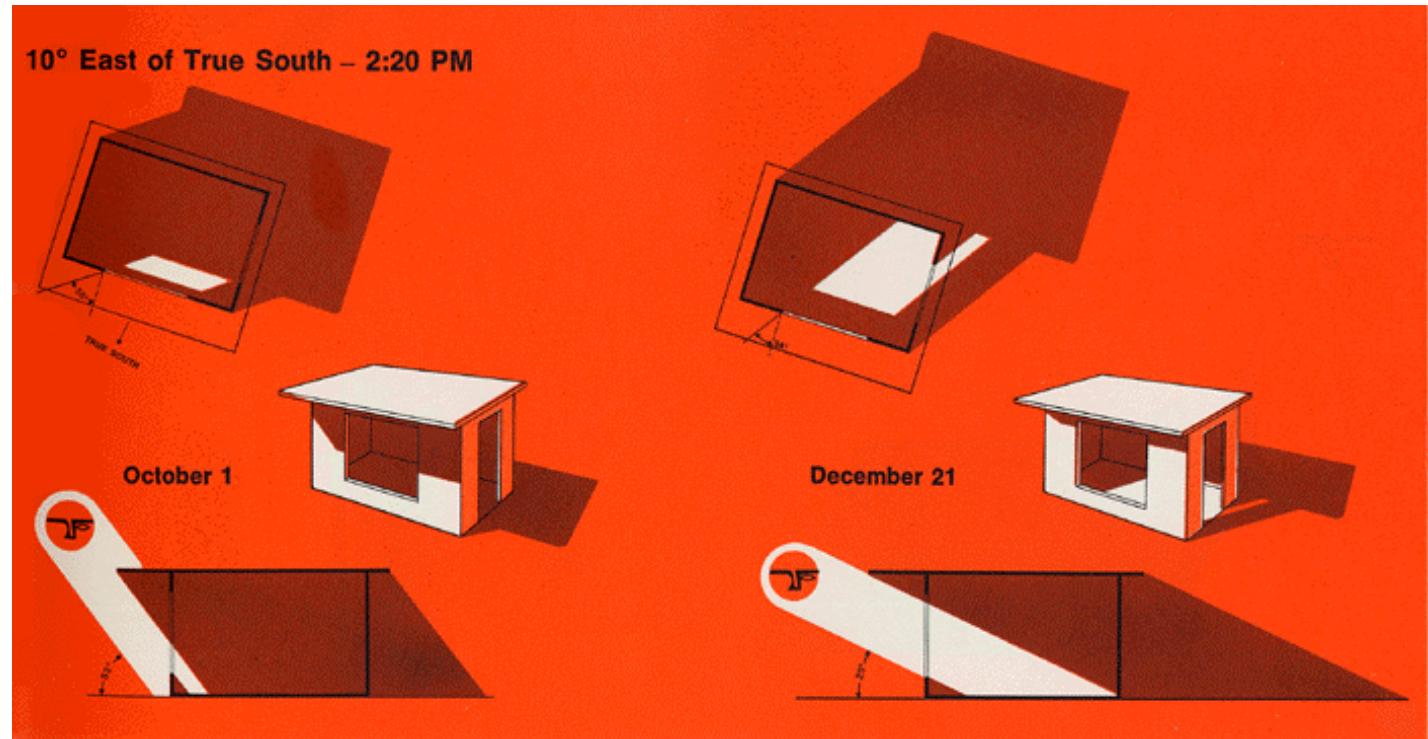
Once determined, the Profile Angle can be applied to a scaled vertical section drawing to determine the exact width of the overhang. The calculations in Example A show the Profile Angle is 62 deg.

The introduction said the sun is directly over the Equator on March 21 and appears a little higher in the sky each day until it reaches its maximum height on June 21. Then it appears a little lower in the sky each day, rising again above the Equator about September 21. Thus, the overhang calculated in Example A will provide shade from April 21 to August 21. After that, the shadow line will gradually move up until maximum sunlight enters the opening about December 21, when the sun appears to be the most southerly.



By constructing Profile Angles for various Positions of the Sun, the depth of penetration can be determined to help establish the desired overhang.

Whenever an overhang is designed using a Profile Angle coinciding with or below the Sun Path Line on the Calculator (further from the pivot point), it will completely shade the window. Conversely, an overhang designed to a Profile Angle above the Sun Path line will not be wide enough to completely shade the window.



In Example B, the Profile Angle of the Sun at 2:20 PM on October 1 is 52 deg. This is above the Sun Path Line before 2:20 PM so the 52 deg Profile Angle will only completely shade the window after 2:20 PM.

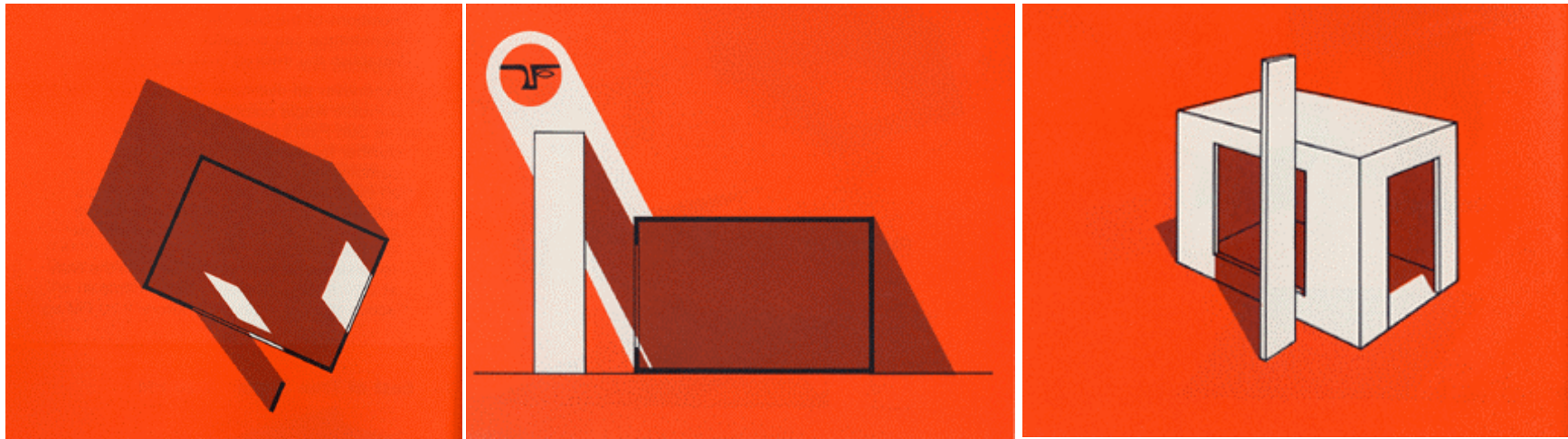
The correct length of an overhang also must be considered. Otherwise, the sun can penetrate under the ends of the overhang.

The Angle of the Sun's Bearing is used to correct this situation. By drawing a plan of the window and overhang and projecting the Bearing Angle from True South, from the edge of the window, the length of the overhang can be determined. By using 60 deg 30 min, the Bearing Angle of the Sun for April 21 at 9:30 AM, and projecting this from a perpendicular to the window, the length of the overhang is figured.

Location and Dimensions of Sun Control Devices -- Lateral Control

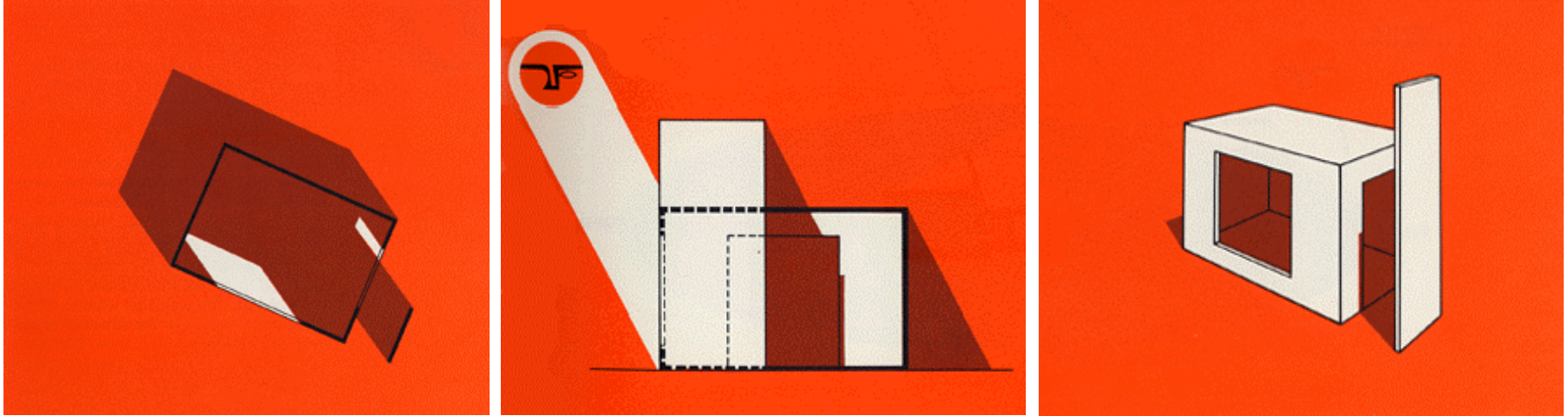
If the overhang seems excessive or doesn't provide sufficient shade, a lateral control situated between the Position of the Sun and the area to be shaded may be the answer. Lateral controls take many forms -- vertical fins projecting from a building, screens, trellises, trees and shrubbery.

The horizontal dimension of a lateral control and its orientation to the area being shaded is governed by the Bearing of the Sun at its earliest and latest positions during the time period in question. The Bearing angles should be plotted on a scaled plan for each side of the window opening.



The height of the lateral control is determined by finding the Profile Angle of the Sun at its highest position for the period being considered.

The examples shown so far are for windows Normal to True South. The same methods, however, work for other orientations. Here is the plan of a window facing True East. The Bearing angles of the Sun at the hours under consideration are projected from the surface of the Shading Device.



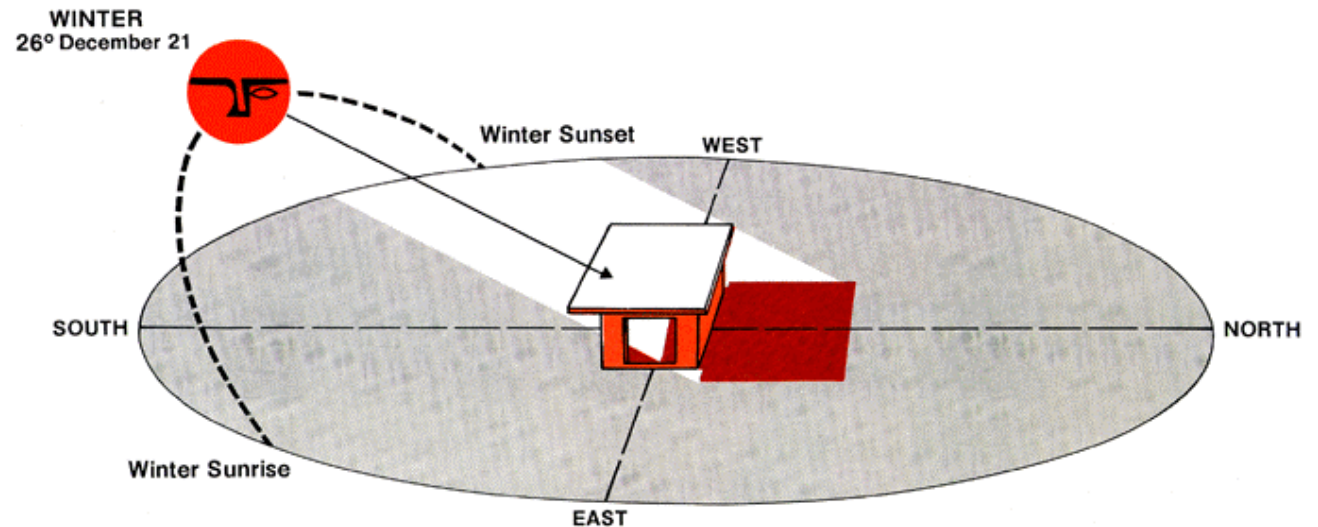
The Principle Of Solar Orientation

The History of Architecture, said Le Corbusier, the eminent French architect, is a history of the struggle for light, the struggle for the window. For more than a thousand years men have striven for windows of the greatest possible size, against the limitations of construction methods and building materials and, when these were surmounted, against reactionary design influences. Eventually the window was triumphant; it won recognition not merely as an opening in a wall but as a transparent part of the wall itself.

In the 1930's, as a consequence of this victory, houses with virtually an entire wall of glass began to dot the landscape, oriented to accept from nature its abundant gifts of light, the welcome warmth of the winter sun, the view, the sense of oneness with the out-of-doors.

In our crisp, compartmentalized age, prone as it is to put a tag on everything, these houses, heated by the sun's rays, were tagged "solar houses."

Few architectural developments have kindled the interest of designers like the Solar House. In essence, this is a building oriented and designed to admit a minimum amount of direct sun rays in summer and a maximum amount of solar heat during the winter. This is usually accomplished through large window openings and strategically placed overhangs or other shading devices. The windows are shaded in the summer, when the sun is high in the sky; and the direct rays of the sun admitted during the winter season, when the sun is low in the sky. Sun control is easier to accomplish where the window faces True South, although successful Solar Houses can be built with the window orientation slightly east or west of True South. Solar Heat Gain will be greater in the morning if the window faces east of True South; and, obviously, if the window is oriented west of True South, more gain will occur in the afternoon. Interestingly, the width of the overhang increases surprisingly with each degree of orientation away from True South.

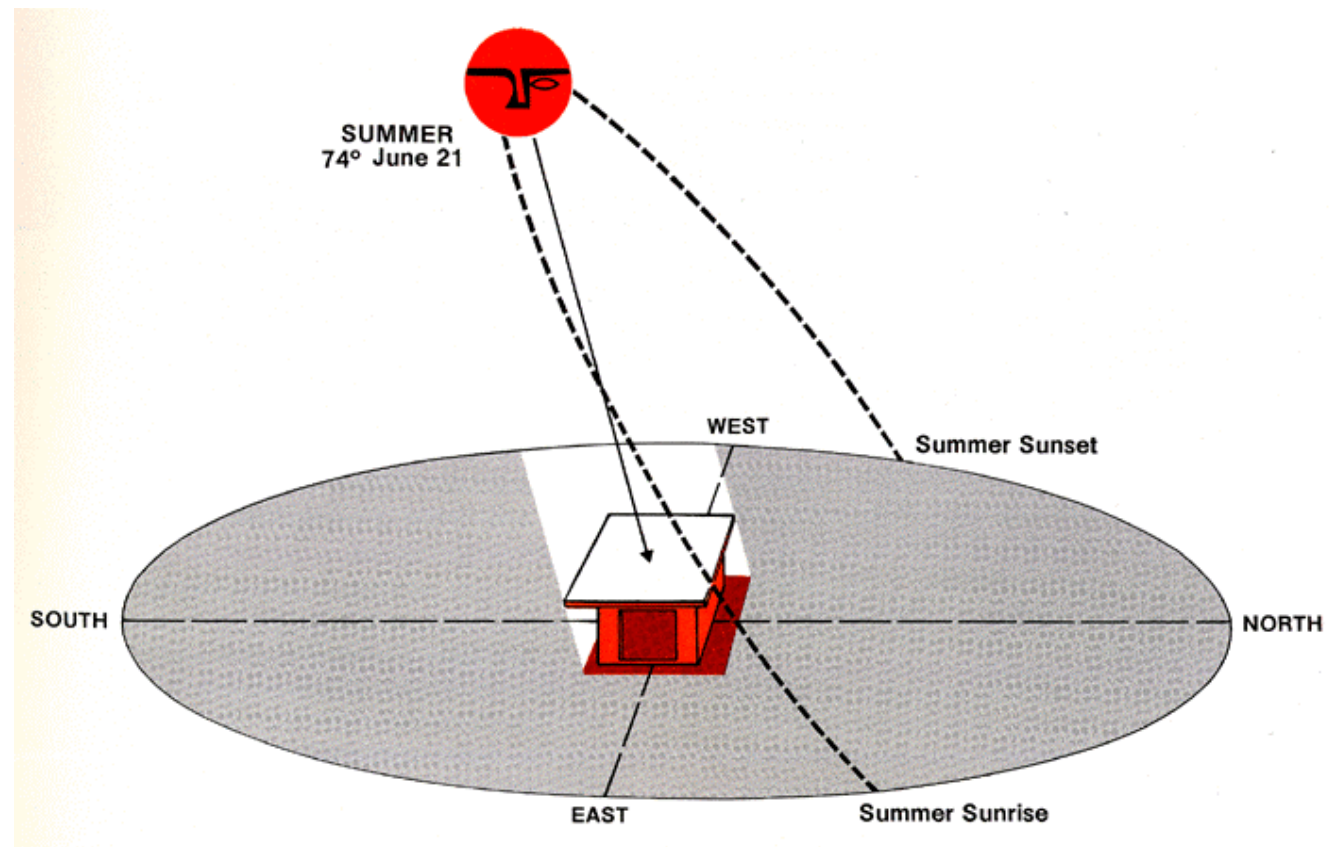


Shading devices may be adjustable to accommodate the seasonal Position of the Sun. Awnings do an excellent job, as do trellises intertwined with deciduous vines that are in full leaf during the summer and bare of foliage during the winter.

Regardless of the type of shading device, dimensions and location are determined by using the Sun Angle Calculator to find the Profile Angle and Bearings of the Sun for a number of dates and hours. The dates vary with locality: in warmer regions, it may be desirable to exclude all Solar Heat after April 1; in more northerly latitudes, this exclusion might not be wanted until after May 21. In any case remember that the seasonal movements of the sun impose certain inflexible limitations. The Date Line on the Calculator shows this at a glance. If April 1 is used as a "cut-off," the sun will be in the same position on September 11, after which more and more solar heat will enter each day. Correspondingly July 21 is the last day of total shade when exclusion begins May 21.

Besides selecting design dates, it is usually necessary to determine the Position of the Sun for several different hours on each date to find the Bearing of the Sun, which is needed to establish adequate overhangs or locate and dimension lateral shading devices.

A home properly oriented to receive the sun's heat in winter and shield it in summer not only will be more comfortable, but in most cases it also can be heated and cooled more economically.



The Importance of Daylight

Natural daylight is an abundant source of effective lighting. With shortages and increasing costs of available manufactured energy, the importance of daylighting in building design is being viewed with new emphasis.

It has been estimated that twenty percent of the electricity now consumed for lighting offices, factories and homes can be saved by using the more efficient light sources, luminaires and design technology that are now available.

In considering ways to redesign an office to reduce its energy requirements while retaining the aesthetic and psychological advantages provided by natural daylight, one solution is to use a high performance glass in the window wall area so that artificial light, which not only consumes energy in supplying illumination but adds very substantially to the air conditioning load, may be turned off.

High performance glass includes coated glass products which reflect solar heat and glare and tinted glass products which absorb heat energy.

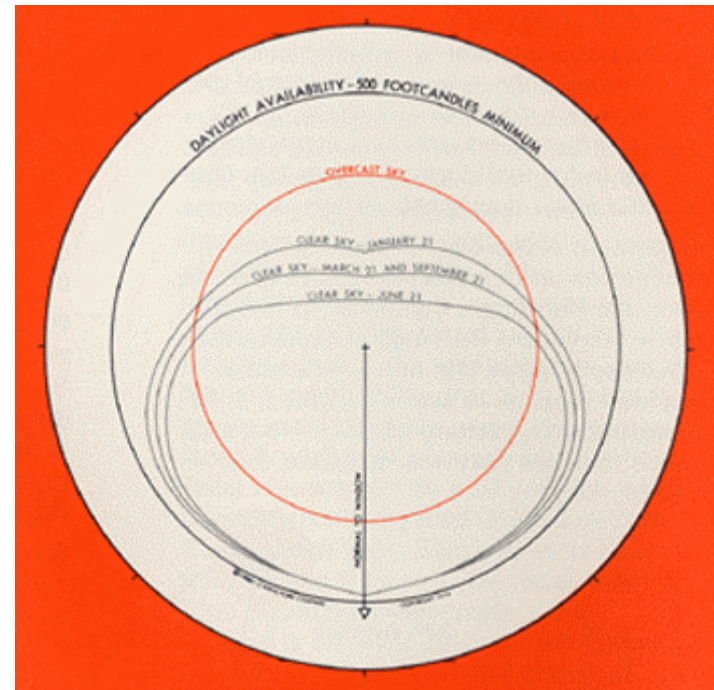
On overcast days the natural illumination on a vertical surface is about 500 footcandles. On clear days the level varies with the geometric relationship between the surface and the Position of the Sun and may be as high as 1500 footcandles. A detailed study of Daylight Availability can be made by using the manual, **Predicting Daylight as Interior Illumination**. This manual, used in conjunction with the Sun Angle Calculator, predicts daylighting levels for any building location.

A preliminary study of the feasibility of using daylight can be made by determining the periods during which the daylighting levels will exceed 500 footcandles.

With this minimum level and the use of low-light transmitting glasses, daylighting becomes a practical and economic source of lighting. This preliminary study can be made using the overlay designated Daylight Availability. For all days and hours within the areas indicated on the overlay, the daylighting level will be greater than 500 footcandles.

Example: For a window facing south in a building in Columbus, Ohio determine what hours the illumination will exceed 500 footcandles for January 21, March 21 and June 21. (Columbus is at 40 deg north latitude.)

Solution: Using the "Daylight Availability" overlay, position the arrow at True South. All areas within the red circle will have daylight illumination in excess of 500 footcandles on overcast days. The daylight level within the blue lines will exceed this amount on clear days. The Daylight Availability Chart determines when these levels are adequate.



Daylight Availability Chart

Date	Overcast Sky	Clear Sky
January 21	None	8:00 AM to 4:00 PM
March 21	8:40 AM to 3:20 PM	7:20 AM to 4:40 PM
June 21	7:20 AM to 4:40 PM	7:40 AM to 4:20 PM

The Relation Between Solar And Standard Time

Standard Time is the conventional time for the zone containing the geographical location under consideration. It is measured in hours, minutes and seconds. The intervals are the same throughout the day and the year.

Sun Time is measured by the varying Positions of the Sun above the earth. It is also expressed in hours, minutes and seconds but the length of the Solar Day will vary by seconds. The accumulative effect of these seconds causes the hours of the Solar Day to shift periodically over a range of 30 minutes. Thus Standard Noon can occur 15 minutes earlier or later during the year than Sun Noon. Also Sun Time varies with the longitude within the time zone while Standard Time is uniform throughout.

The following equation converts Standard Time to Sun Time or vice versa:

$$\text{SuT} = \text{StT} + \text{ET} + 4 (\text{SM}-\text{L})$$

SuT -- Sun Time (hours and minutes)

StT -- Standard Time (hours and minutes)

ET -- Equation of Time, the factor for the non-uniformity of Sun Time (minutes)-- see chart 1

4 -- Number of minutes required for the sun to pass over one degree of longitude

SM -- Standard Meridian (longitude) for the local time zone (see chart 2)

L -- Longitude of location

Chart 1: Equation of Time

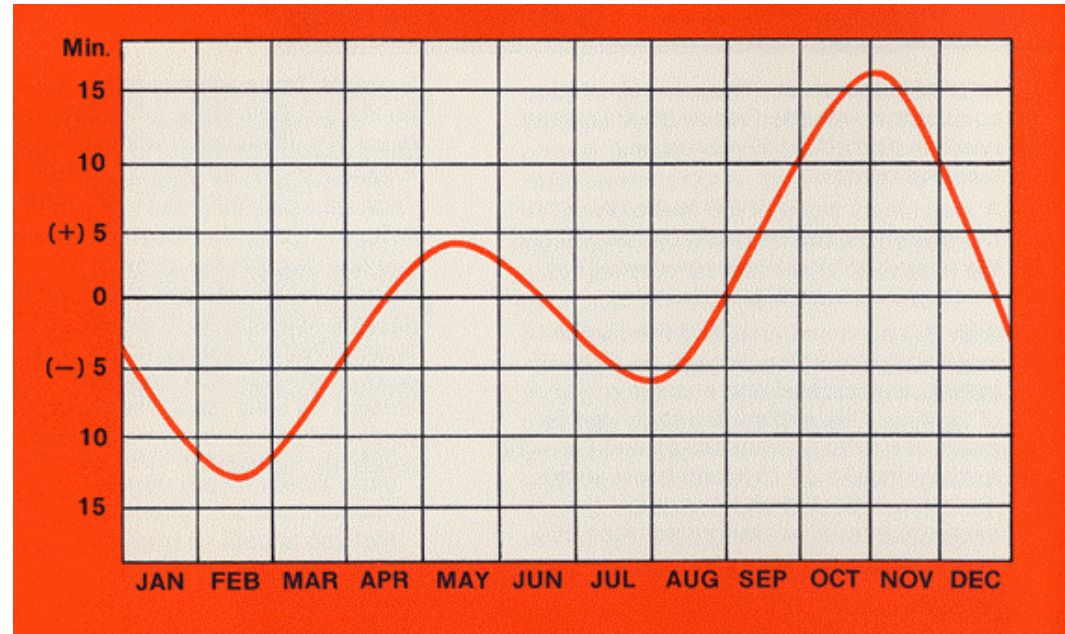


Chart 2: Standard Meridians of Time Zones

Zone	Position	Standard Meridian (Longitude)
+4	Atlantic	60 deg W
+5	Eastern	75 deg W
+6	Central	90 deg W
+7	Mountain	105 deg W
+8	Pacific	120 deg W

Solar Heat Gains

Solar heat gain has been defined in general terms as, "transmitted and absorbed solar energy." A building that is effectively designed to limit heat loss and gain may cost less to build, equip and maintain and can reduce initial and life-cycle ownership costs.

According to the 1972 **ASHRAE Handbook of Fundamentals**, "The ability of glazing materials to transmit solar radiation depends upon the wave length of the radiation, the chemical composition and thickness of the material and the incident angle." Proper solar orientation and thermal design can minimize a "greenhouse effect," in buildings, a phenomenon when solar radiation which enters through a window area is emitted as long wave radiation and cannot be transmitted outward, trapping the solar heat within.

Heat gain, or loss, through fenestration areas (any light-transmitting opening in a building wall or roof) is affected by many environmental factors. These include solar radiation, intensity and Angle of Incidence, outdoor-indoor temperature differential, and velocity and direction of air flow across the exterior and interior fenestration surfaces.

Heat gains related to various glass types for all hours and times of the year, and latitudes encompassing the 48 contiguous states and the populated areas of Canada, are included in the Heat Gain Calculator.

The Heat Gain Calculator does not consider the effects of shading in reducing solar heat gains. For buildings with significant shading from overhangs, vertical projections, and other shading devices, the solar heat gain and attendant cooling requirements may be much less than they would have been without the shading. The amount of shading provided during various times of the year can be determined using the Sun Angle Calculator in the procedures outlined earlier.

In the Heat Gain Calculator, values of Solar Heat Gain Factors are listed for all times of the year for most daylight hours. The Solar Heat Gain Factor is the transmitted and absorbed solar energy for double strength clear glass with no shade.

Magnetic Variation

The magnetic compass points to magnetic north rather than true north. In most localities magnetic north does not coincide with true north but is toward the east ("easterly variation") or toward the west ("westerly variation") from it

The heavy broken lines on this map connect points of equal magnetic variation, and present a generalized picture of magnetic variation in the United States. Due to "local attraction" it may be quite different in your locality. For more exact information consult your local surveyor.

