ARCH 140

Architecture 140 Energy and Environmental Management
College of Environmental Design, UC Berkeley

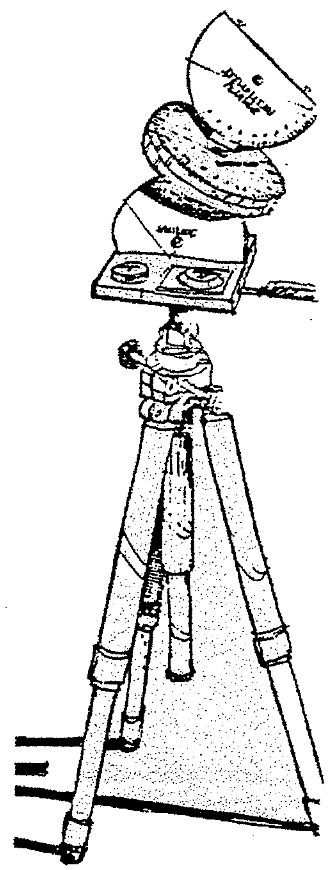
READING 20

SOLAR TRANSIT

The skilled analysis of a proposed building site and subsequent decisions related to its utilization are major components in the architectural design process. This process involves the careful consideration of a range of site factors including access to the heat and light of the sun. The sun can exercise considerable influence on the character of a proposed building site. Beyond an obvious consideration of solar radiation as a potential energy source, the sun has strong impact on the microclimate of a landform. Decisions in siting will determine the quality of natural light available to a building, the character of surrounding exterior spaces and the visual modelling of the building mass itself. An architect must include an understanding of the sun's dynamic behavior in his repertoire of special talents.

The sun crosses the sky with regular and predictable motions. Its apparent movement (the earth moves, the sun doesn't) is caused by the earth's daily rotation. The sun's position in the sky will also vary with the latitude of the observer and seasonal changes in the earth's tilt relative to the sun. There are many tools available to the architect for examining the apparent motions of the sun. Solar position for a given time and location can be determined by equations (**ASHRAE Handbook of Fundamentals**, Ch. 26) or graphic sunpath diagrams (Olgyay and Mazria). These graphic tools are particularly appropriate for architects.

One example of a sunpath diagram is presented by Ed Mazria in **The Passive Solar Energy Book.** A sunpath diagram is a two-dimensional plot of the skyvault over which lines representing the sun's path are superimposed. In Mazria's system, the sun's position is defined by its **altitude** (degrees above the horizon) and its **azimuth** (bearing in degrees from due south). This rectilinear plot is but one of several systems for plotting the sun's path.



The Solar Transit is an unique instrument which can be usec to determine solar access at a site by modelling the seasonal path of the sun across the site and locating horizon obstructions.

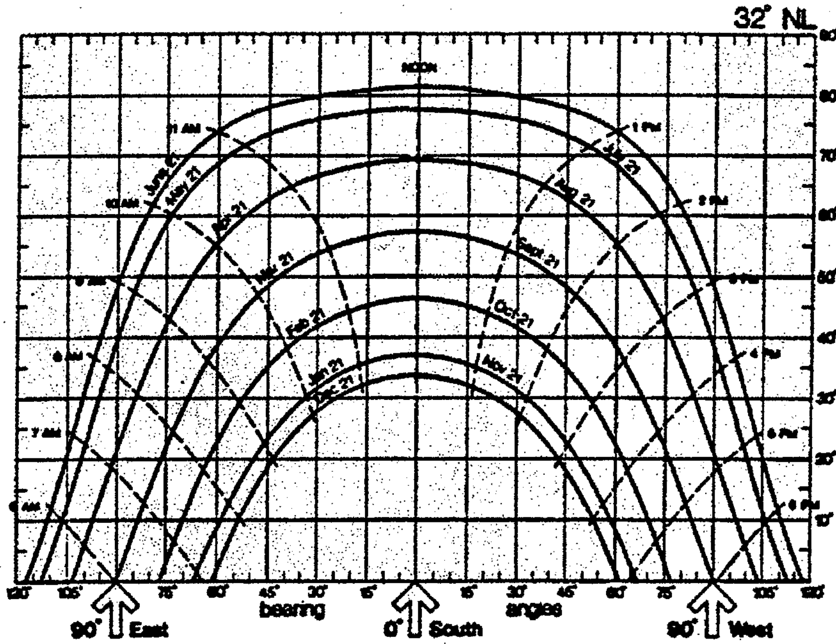


Figure 1. A typical Mazria style sunpath diagram for 32°N latitude. Each latitude has a specific sunpath diagram.

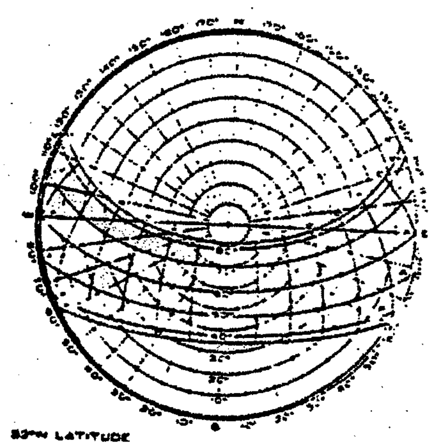


Figure 2. Sunpath diagrams are available in other formats. For instance, this equidistant polar projection is used by Olgyay in **Design with Climate.** (Refer to Reading 12)

The sunpath diagram can be used, in conjunction with site data and overlays, to provide a wealth of information about solar patterns at your site. These include:

- data on the sun's position at any time.
- the quantity of radiation that will strike a given surface under clear sky conditions (diffuse and direct).
- performance data on specific shading device applications.
- the extent of shading at a specific location from surrounding site obstacles (trees, buildings, etc.).

The reader is referred to **The Passive Solar Energy Book** (Chapter: The Tools) for an excellent description of the sunpath diagram and its application.

In this laboratory exercise you will construct a simple transit designed for the analysis of a site's solar access. The Solar Transit may be used in two different modes. In the first mode, it can be used as a conventional transit to measure the bearing (azimuth) and height (altitude) of shading obstacles at the site. This information can be combined with a sunpath diagram to yield a concise summary of year's shading at the surveyed point.

In its second mode of operation, the Solar Transit will point to the sun's position in the sky for any time or season of interest to the user. It will tell the user when, and for how long, portions of a site will be shaded. The instrument provides an immediate, on-site visualization of solar movements. For instance, an architect visiting a site in midsummer can evaluate alternative locations for solar collection components. For each location, the Solar Transit can define the sun's winter path. If the sun's path lies behind neighboring trees or buildings, this site will be shaded during the winter and will therefore be a poor site for solar collection. If this particular location must be used, the Solar Transit can identify the obstructions that must be pruned or removed to provide solar access. Site evaluations can be made for solar collectors, passive windows, exterior spaces and even vegetable gardens. The instrument is useful for the assessment of summertime solar impact as well.

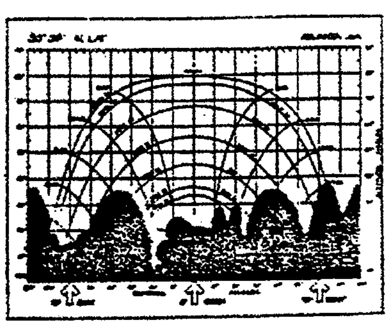
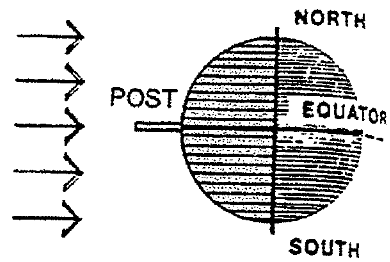


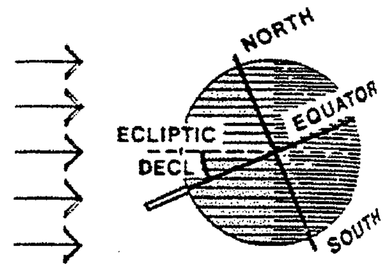
Figure 3. An example of a sunpath diagram with horizon shading data plotted.

1. Before detailing the construction of the Solar Transit, a brief description of the earth's relationship with the sun is in order. Imagine that a post is located at the earth's equator, is_perpendicular to the earth's surface (vertical) and is parallel to the equatorial plane of the earth. The rays of the sun will be parallel to this post at two times during the year: solar noon on the equinoxes (March 21 and September 21). On an equinox, the earth's axis is perpendicular to the sun's rays.



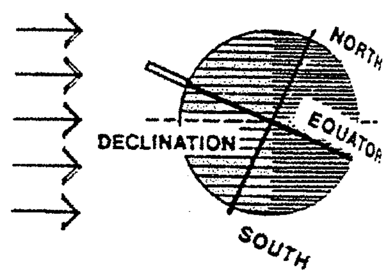
EQUINOX

2. On days other than the equinox, the earth's axis is tilted relative to the sun. This tilt is labelled **declination** and is defined as the angle between the earth's equatorial plane and our plane of orbit around the sun (the ecliptic). At the vernal equinox (March 21), declination is 0°. During spring, the Northern Hemisphere tilts progressively toward the sun until a maximum declination of +23.45° is reached on the summer solstice (June 21). During this period, the sun will appear higher in the sky and will rise and set further to the north.



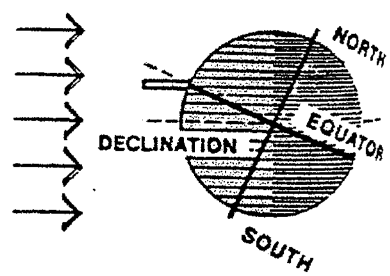
SUMMER SOLSTICE

3. Following the summer solstice, the Northern Hemisphere will begin to tilt away from the sun. This trend will continue through the autumnal equinox (September 21) until the Northern Hemisphere reaches a maximum tilt away from the sun on the winter solstice (December 21) of -23.45°.

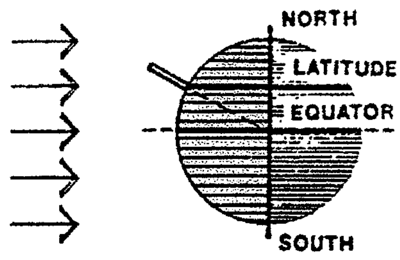


WINTER SOLSTICE

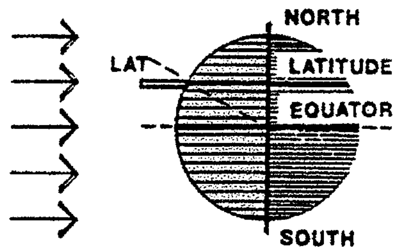
4. To keep the imaginary post at the earth's equator parallel to the sun's rays at solar noon it must be tilted. The tilt must be equal to the declination angle. Following the tilt, the pole will be parallel to the ecliptic. Adjustments to compensate for declination are always indexed to the ecliptic.



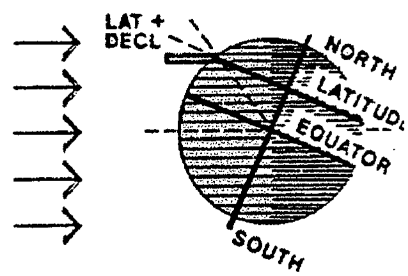
Imagine now that the post is located at another latitude, for instance, Atlanta at 33.5°N on the equinox. If the post remains perpendicular to the earth's surface then the sun's rays will not be parallel to the post at solar noon on either equinox.



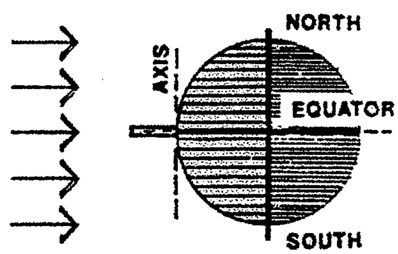
6. If the post was tilted 33.5° (equal to the latitude) toward the south, it would now be parallel to the equatorial plane of the earth. The sun's radiation will now be parallel to the post at solar noon on the equinox. Adjustments for latitude are always indexed to the earth's equatorial plane.



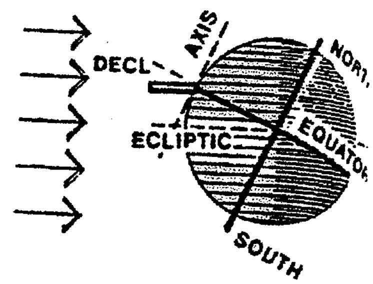
7. At solar noon, declination can simply be subtracted from the latitude to establish the tilt required to restore our post parallel to the sun's rays. For hours other than solar noon, the combination of declination and latitude becomes a trickier problem. Declination is indexed to the ecliptic and latitude is indexed to the earth's equatorial plane; the two are separated by a rotating adjustment for time.



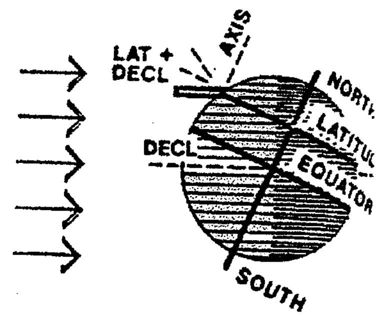
8. Consider again the post located to the earth's equator on the equinox. If the post were mounted on a device which would allow the post to follow the sun, the post could always face the apparent position of the sun. This can only occur if the post's axis of rotation is parallel to the north-south axis of the earth. The post would rotate at the same angular velocity that the earth rotates; 360° in 24 hours or 15° per hour. Adjustments for time are always indexed to rotation around the earth's north-south axis.



9. Remaining at the equator with our rotating post as the seasons change, the earth will tilt relative to the ecliptic. This requires a tilt of the post equal to the declination if the sun's rays are to remain parallel. It is important to note that this adjustment is made relative to the earth's equatorial plane and that the post must continue to rotate on the earth's north-south axis for hourly adjustments.



10. Bringing it all together, the following adjustments are necessary if the post is to remain parallel to the sun's rays. First, the pole must be mounted on a device capable of tilting, rotating, then tilting again. The first required adjustment is a tilt from vertical toward the south equal to the latitude. The device's axis of rotation is now parallel to the earth's north-south axis. The device must now be rotated 15° west of south for each hour since solar noon. Finally the post must be tilted toward or away from the ecliptic by an angle equal to the declination. Following these adjustments for latitude, hour and declination, the post will remain parallel to the sun's rays.



The previous section reviewed the somewhat confusing adjustments required to keep a post parallel to the sun's rays. Remember that adjustments for latitude, hour and declination are all that is required to track the sun's path through the sky. This lab now addresses the construction of the Solar Transit, a tool to do just that job. The Solar Transit can be built using scrap materials and a couple of dollars in parts. The following section will provide construction details. As you use this device in the exercise, and in studio, you will notice that your intuitive feel for the sun's position is becoming more accurate. This is perhaps the greatest benefit of the exercise.

MATERIALS AND EQUIPMENT

Materials:

1. (1) Parts drawings, cut as indicated.
2. (1) Hardwood (well-dried) 7 1/4" x 36" x 1/2" tk.
3. (3) Stove bolts, 1/4 - 20 x 1 1/2"
4 (3) Wing nuts, 1/4 - 20.
5. (3) Washers, 1/4"
6. (1) Scout type magnetic compass
7. (1) Bull's eye bubble level
8. (5) Brads, 3/4"
9. (4) Wood screws, #8 - 1 1/4"
10. (1) Threaded insert, 1/4 - 20
11. (1) Can of contact or rubber cement
12. (1) 5 minute epoxy resin.

Optional:

13. (1) Can of wood filler
14. (1) Can spray paint
15. (1) Clear wood finish

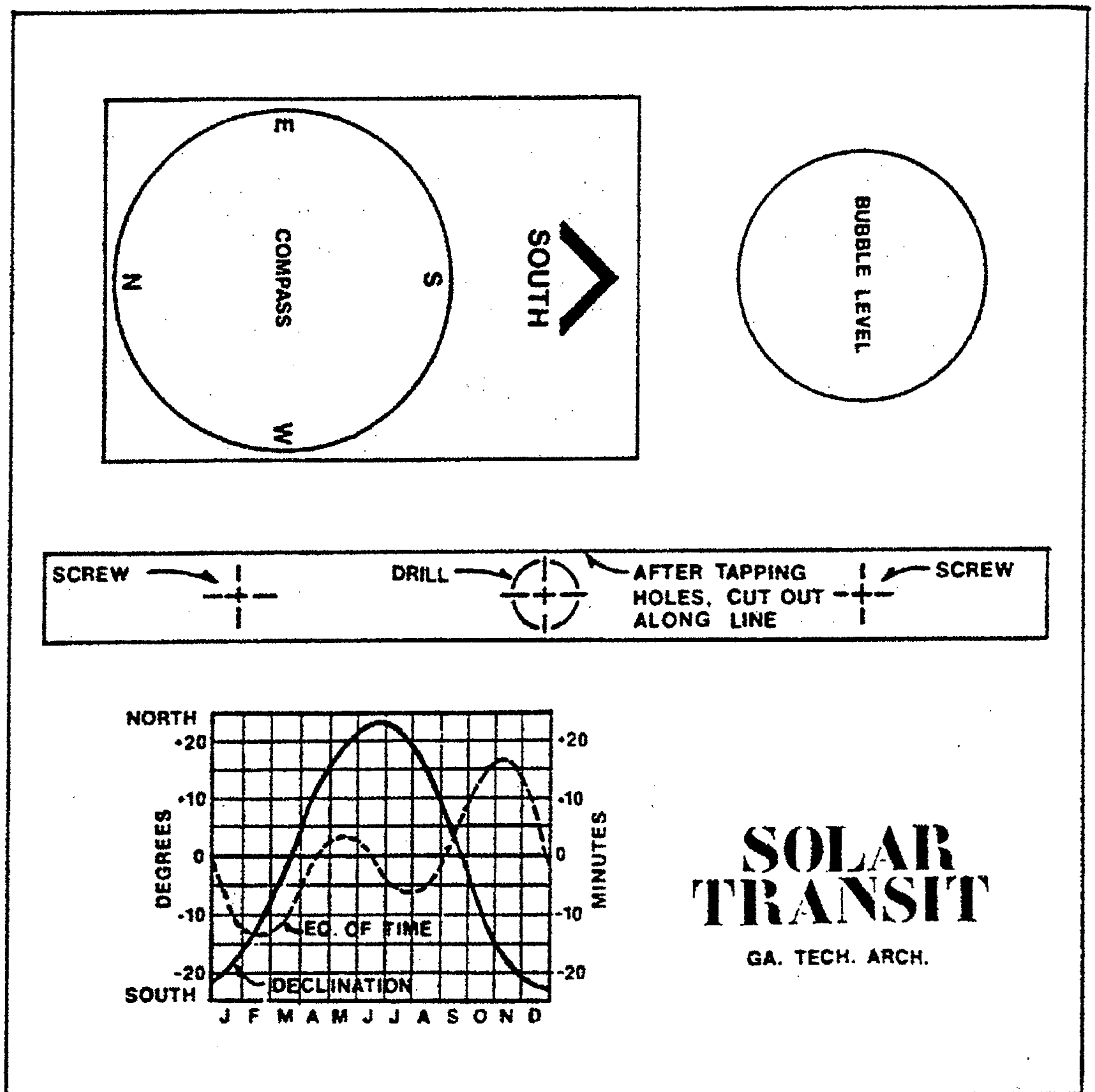
Equipment:

1. Sabre saw
2. Electric drill
3. 1/4" drill bit
4. Pilot bit for #8 screw
5. 3/8" drill bit
6. Sandpaper
7. Rasp
8. Square
9. Aluminum foil
10. Spatula
11. Screwdriver
12. Light Hammer
13. Camera Tripod

PROCEDURE

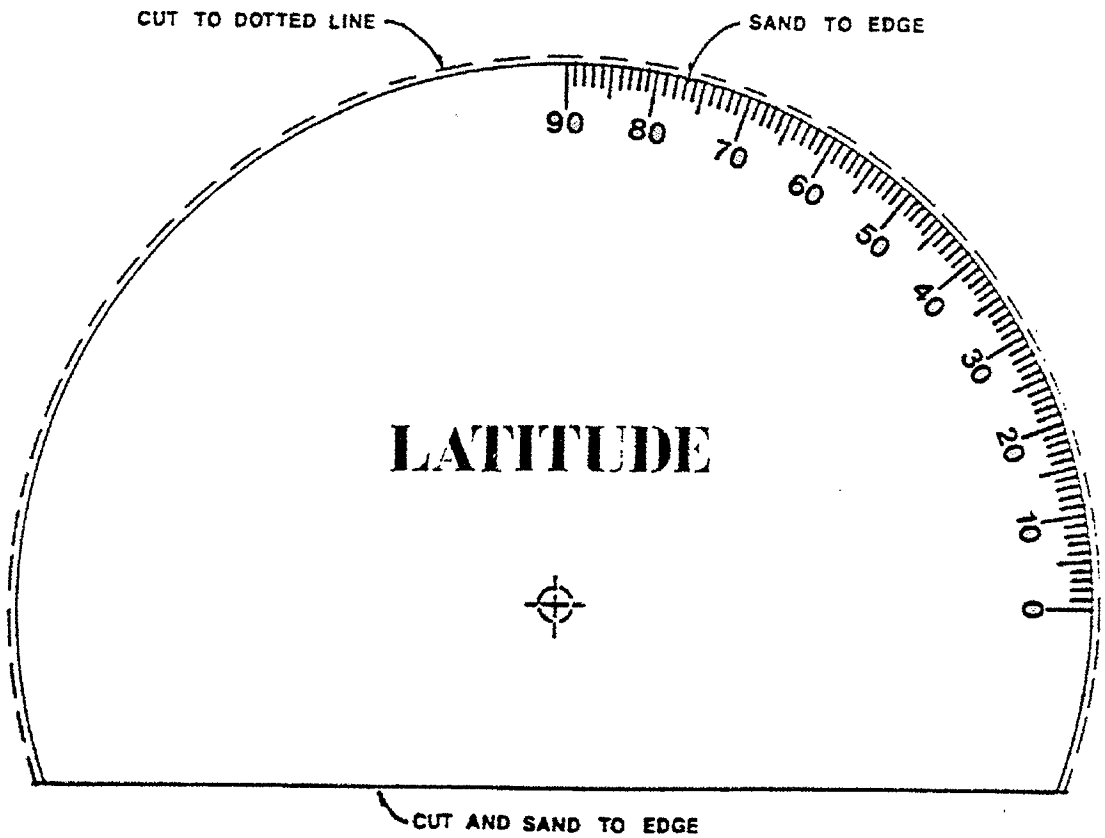
CONSTRUCTION TEMPLATES:

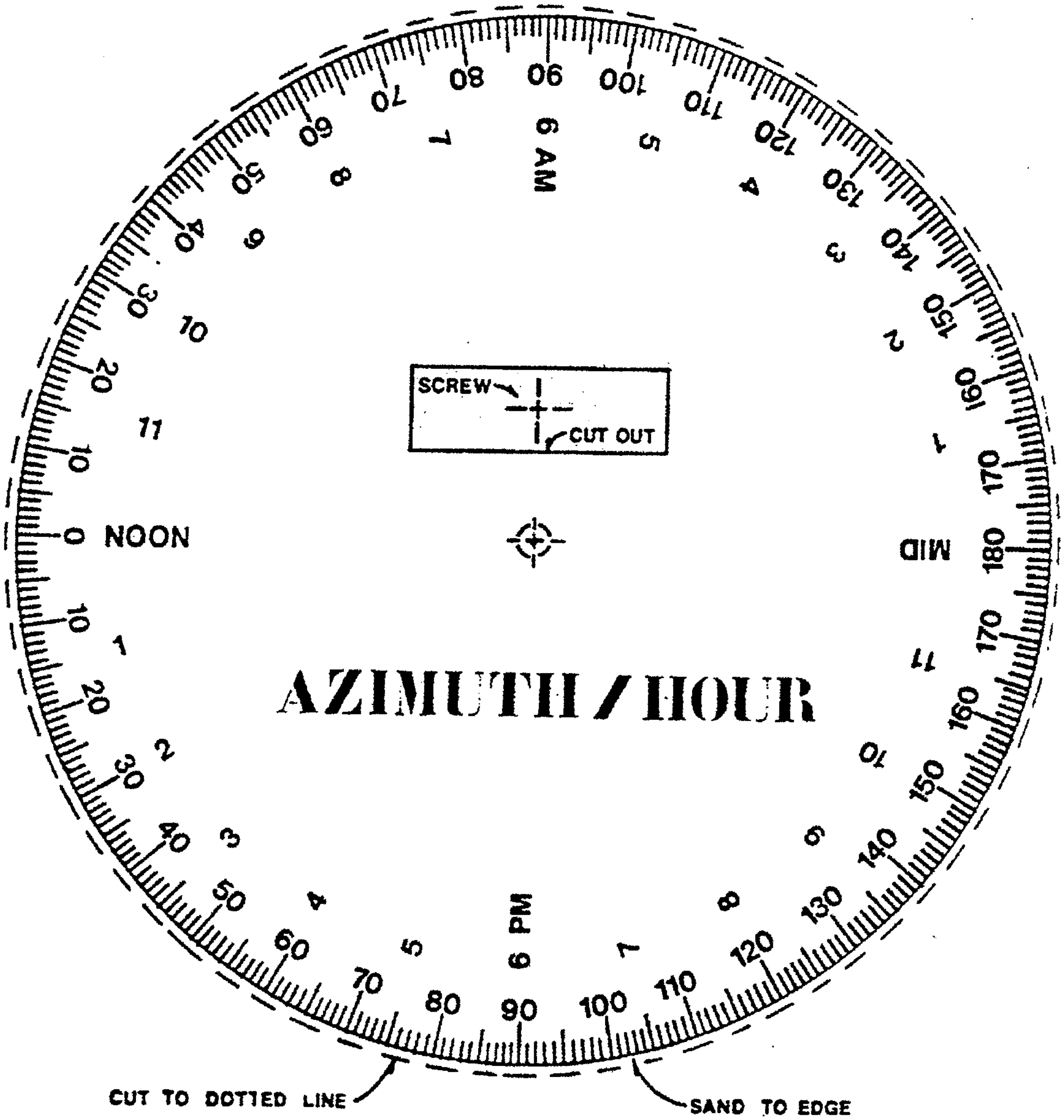
The drawings on this and the following pages are full size construction templates for the Solar Transit. They will be cut out and glued to wood blocks for construction.

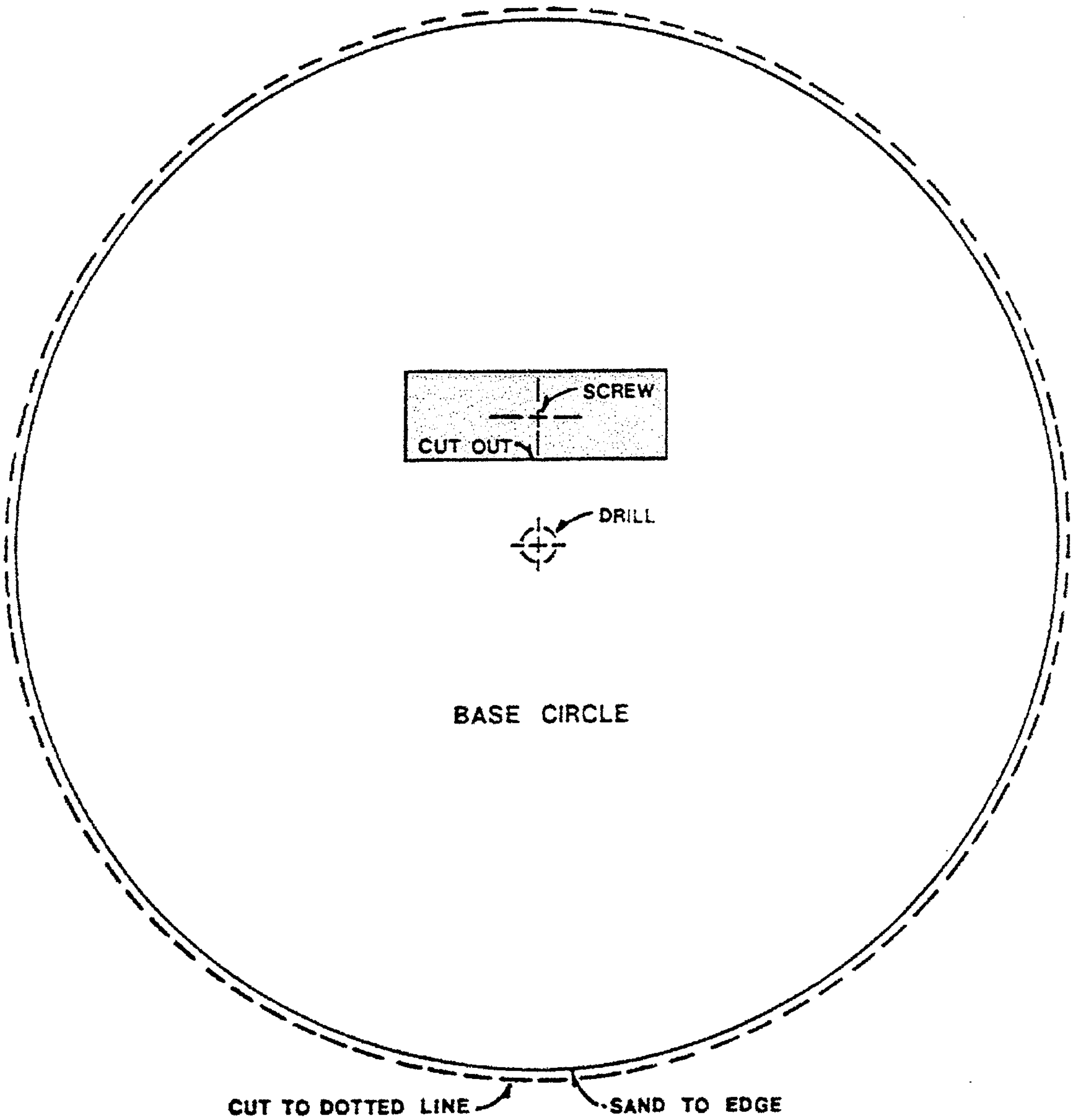


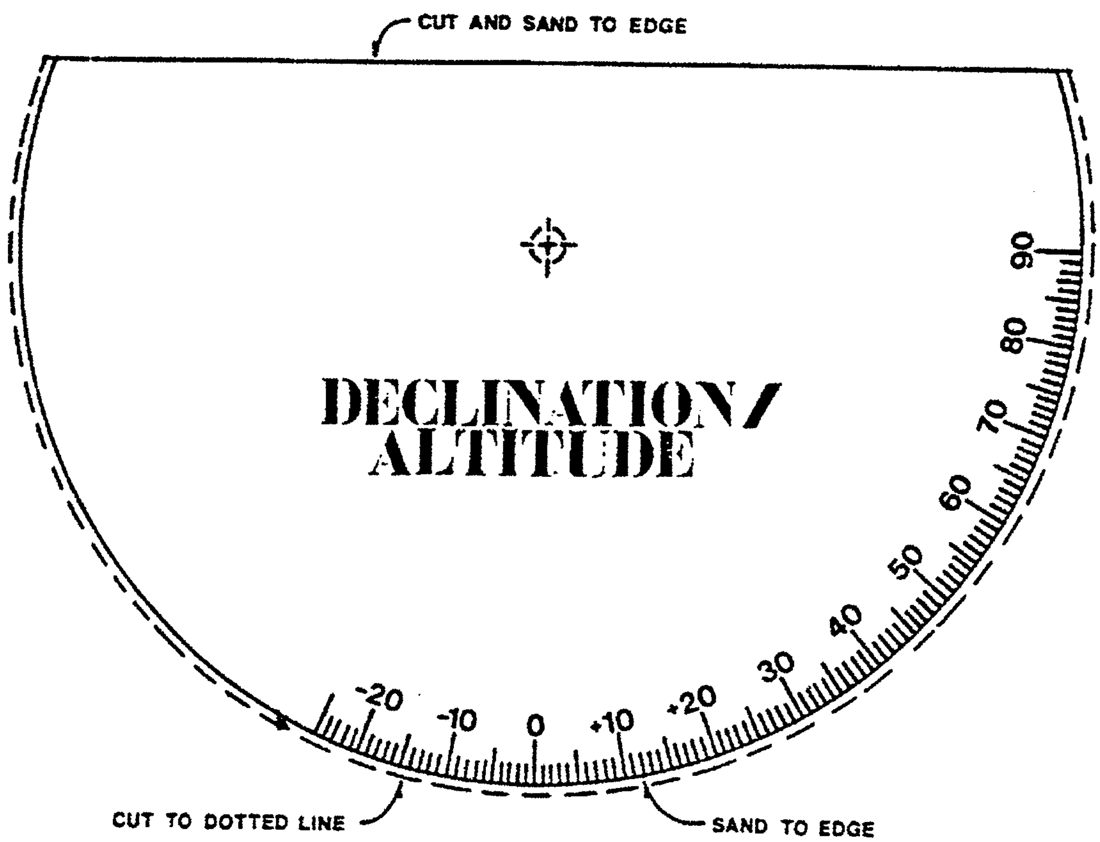
CUT AND SAND TO EDGE

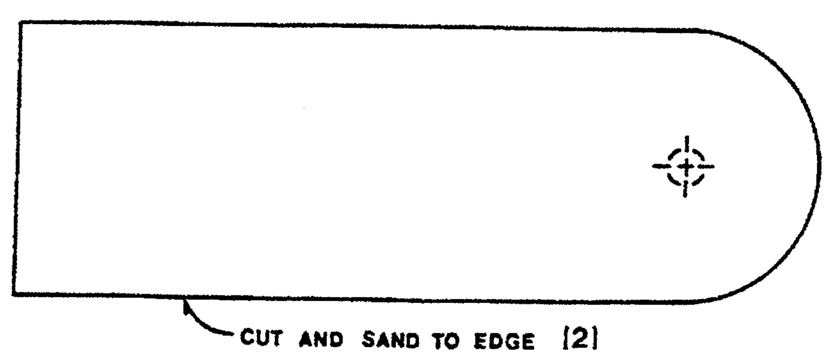
Check the protractors on the following pages to verify their accuracy. Some photocopying techniques are not dimensionally stable and distorted copies can result. If necessary, accurate templates ~~can~~ can be redrawn on cardstock.




SCREW
CUT OUT
6 AM
NOON
MID
AZIMUTH / HOUR
6 PM
CUT TO DOTTED LINE
SAND TO EDGE


SCREW
CUT OUT
DRILL
BASE CIRCLE
CUT TO DOTTED LINE
SAND TO EDGE


CUT AND SAND TO EDGE
90
80
70
60
50
40
30
DECLINATION/
ALTITUDE
-20
-10
0
+10
+20
CUT TO DOTTED LINE
SAND TO EDGE


CUT AND SAND TO EDGE (2)

SOLAR TRANSIT CONSTRUCTION:

1. Apply contact cement to the backside of the construction templates for the Solar Transit; allow the cement to dry briefly.

2. Apply contact cement to an area of the approximate size of the Solar Transit components on the 1/2" tk. hardwood; allow the cement to dry briefly.

3. Carefully place the construction templates on the cement areas of the hardwood; the bond between the paper and wood should now be permanent.

4. With a sabre saw, cut the components to the cut lines indicated on the drawings.

5. With a rasp and sandpaper, finish the outer edges of the components. The straight edge portions of the declination and latitude semicircles should be as straight and square as possible. The alignment should be checked with a square; the flat edge should be perpendicular to a line from the circle's center to the outer angle (0° or 90°) of each.

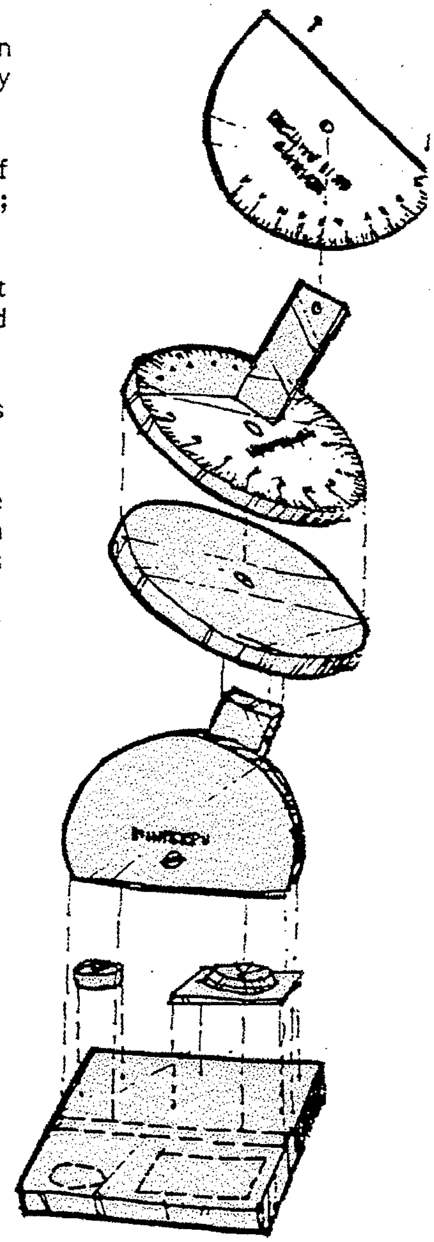
6. With a 1/4" bit, drill the holes indicated at the pivot points of each component. The two complete circles should be drilled together for good alignment.

7. Cut two each 4½" lengths of 1/2" x 1 1/2" wood. Finish one end of each to a semicircle. Drill one 1/4" hole in each at the center of the rounded end. The other end should remain square and true.

8. Using a 3/8" drill bit, tap a hole at the center rear of the Solar Transit base for the 1/4 - 20 threaded insert. Install the insert.

9. With a pilot bit for #8 screws, tap the locations marked "screw." Screws will be inserted from the back side of the components into the latitude semicircle and the square ends of the 1/2" x 1 1/2" wood members.

10. (Optional) Apply finish to components for the desired quality.



Exploded view of solar transit

11. Mix the epoxy resin on aluminum foil per instructions on tubes; apply resin to the latitude semicircle along the bottom edge. Position the flat edge of the semicircle on the square transit base as indicated. The latitude scale should face the compass position.

12. Mechanically fasten the latitude semicircle to the transit base with two wood screws as indicated. Take care to keep the latitude semicircle perpendicular to the square base.

13. Apply resin to the flat end of one 1/2" x 1 1/2" and position on the Azimuth/Hour circle as indicated; this member must be square to the circle's surface, secure with a wood screw.

14. Repeat step 13 with the base circle.

15. Apply resin to the bottom surfaces of the compass and level, position compass and level on transit base as indicated, press firmly on each and allow resin to harden.

16. Join the Azimuth/Hour circle and the base circle with a bolt, wing nut and washer. Note:several layers of paper between the circles will serve as a clutch when the transit is used.

17. Join the circle assembly to the clear side of the latitude semicircle with a bolt, wing nut and washer. The wing nut is positioned on the outside of the 1/2" x 1 1/2" component.

18. Locate a brad on the centerline of the 1/2" x 1 1/2" component at the latitude semi circle; the brad will serve as an angle indicator for latitude adjustment.

19. Repeat steps 17 and 18 with the declination semicircle.

20. On the flat edge of the declination semicircle, place two brads 4" apart. The brads must be centered on the board's thickness and must be inserted to the same depth. The brads will serve as the sighting mechanism of the transit.

21. On the edge of the base circle, place a brad at the southmost end. This brad may be bent up to serve as an indicator for the Azimuth/Hour scale.

ANALYSIS SUGGESTIONS

Congratulations, you have now constructed the Solar Transit. Before you rush outside to see if it works you should know about two additional adjustments; corrections for solar time and magnetic deviation. Each of these corrections is discussed thoroughly in Mazria's **The Passive Solar Energy Book** and a brief summary is provided below:

Corrections for Solar Time:

The hour scale on the Solar Transit reads in solar time which is defined by the occurrance of noon when the sun is due south. Local clock time can differ from solar time by few minutes up to an hour and more. The following equation can be used to convert local time to solar time:

$$\text{Solar time} = \text{Local time} + E + 4(L_{st} - L_{loc})$$

where: E = equation of time in minutes (a graph providing these values is located on the base of the Solar Transit).

L_{st} = the standard time longitude line from your local time zone.

L_{loc} = longitude of your location.

Corrections for Magnetic Deviation

An ordinary compass will point to the magnetic north pole rather than the true north pole. This error can be corrected if you know the amount of magnetic deviation for your area. The isogonic chart provides the magnetic deviation for locations throughout the United States. The values on this chart represent the angle and direction of the error. For instance in New York the variation is 10°W which means the compass is pointing 10° west of true north.

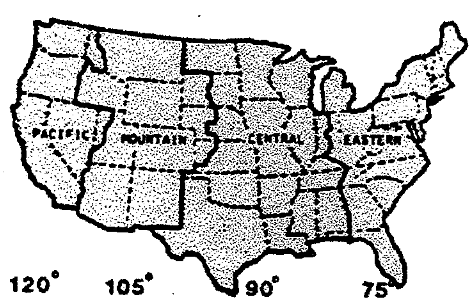


Figure 4. Time Zones for the Continental United States.

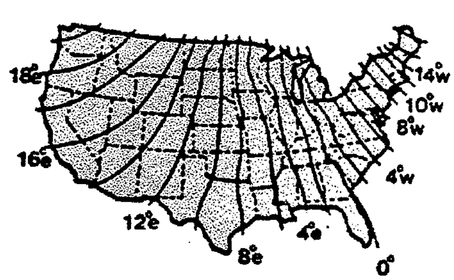


Figure 5. Isogonic Chart for the Continental United States.

Following the construction of your instrument, you may wish to check its accuracy. This can be accomplished by using it to check the sun's current position. Use the following procedure when the sun is out and shining.

Check Procedure for Solar Transit:

1. Mount the Solar Transit on a tripod and place it outdoors.

2. Refer to the isogonic map of the United States and find the magnetic deviation for you area. Using the Solar Transit's compass, and correcting for magnetic deviation, orient the Solar Transit base to face due South.

3. Using the circular bubble level, adjust the Solar Transit so that its base is parallel to the ground plane.

4. Adjust the latitude semicircle to indicate your latitude (remember, the angles on this scale will be on the north side of the semicircle).

5. Calculate the correct solar time and set the hour scale to this value. Remember to adjust for daylight savings time if it is in effect.

6. Adjust the declination scale to the correct value for your date of observation. A graph with values for declination (in degrees) is located on the base of the Solar Transit.

7. The two sighting pins on the Solar Transit should now be in line with the sun. If your transit is not aligned review the procedure again.

CAUTION: DO NOT LOOK DIRECTLY AT THE SUN!

Eye damage can occur by looking directly at the sun even if the observer is wearing sun glasses. Alternately, a piece of white paper can be positioned behind the rear index; the instrument will be aligned with the sun when the shadows of the two indices (brads) appear as one on the paper.

Now that you have verified that the Solar Transit can locate the sun's position the instrument may be used in its conventional modes. In its first mode of operation, the Solar Transit is used much like a conventional transit to measure the bearing and height ~~of~~ horizon obstructions. The following procedure applies:

Horizon Survey Procedure:

1. Mount the Solar Transit at eye height on a tripod at the point of observation. Level the device using the bubble level and orient the base toward due south (remember to adjust for magnetic deviation).

2. Adjust the angle of the latitude semicircle to 90° and tighten securely.

3. For each horizon obstruction, adjust the azimuth and altitude circles until the pointers align on the top of the obstruction. Record discrete corners or points of the obstruction by designating their altitude and azimuth bearing.

This horizon survey should include all obstructions between 120°E of S and 120°W of S. The interval of your observations will depend on the nature of your site. A 10° increment in azimuth is suggested as a minimum starting point. The data from this horizon survey may be drawn directly on a sunpath diagram as described in **The Passive Solar Energy Book.**

The final mode of operation for the Solar Transit is its use to visually track the sun's path through the sky. This may be accomplished by following the procedure below:

Sun Path-Tracking Procedure:

1. Mount the Solar Transit on a tripod and position at the survey location.

2. Orient the Solar Transit base due south (correcting for magnetic deviation) and level the base using the bubble level.

3. Adjust the latitude semicircle to read your latitude.

4. Adjust the declination semicircle to read the month in which you are interested (declination values in degrees are found on a graph at the base of the instrument).

5. Sighting along the two indices (brads) on the declination semicircle, the path of the sun for the month selected may be followed by rotating the hour circle from east to west.

6. Repeat the procedure for other months as desired.

The Solar Transit can be a valuable tool in the investigation of a site's solar access. The ability to visualize and quantify the patterns of solar penetration will allow more sensitive siting decisions and reduce errors in collector placement. One final note on the use of the Solar Transit. The survey information that it provides is point specific. In other words, the shading patterns from one set of readings can not necessarily be assumed representative of the entire site. It is recommended that the device be used to evaluate several areas within a given building site. Experience will help you decide how many locations should be surveyed in each site evaluation.

REFERENCES

1. Ashrae, **Handbook of Fundamentals** (New York: Ashrae,1977), p. 26.2 - 26.9.

2. Clark, Robert S., Shadows at the Site: Solar Access Measurement (**Solar** Age, Vol. 4, No. 10, Oct. 1980), pp. 12-15.

3. Mazria, Edward, **The Passive Solar Energy Book** (Emmans, Pa.: Rodale Press, 1979), pp. 267-308.

4. Olgyay, Victor, **Design with Climate** (Princeton, N.J.: Princeton University Press, 1963), pp. 32-42.