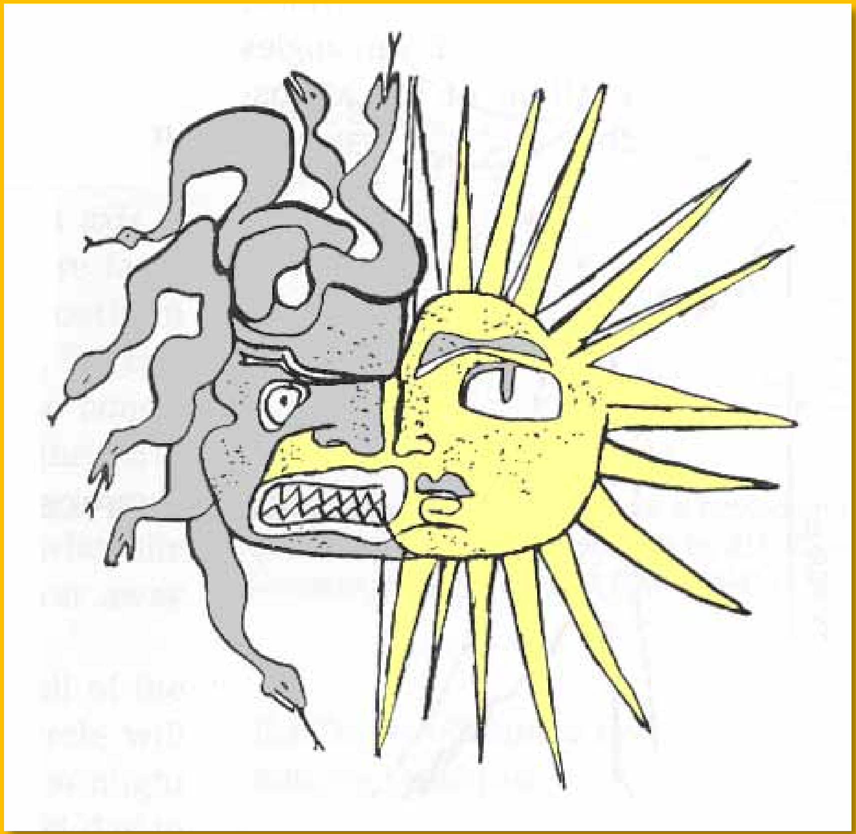
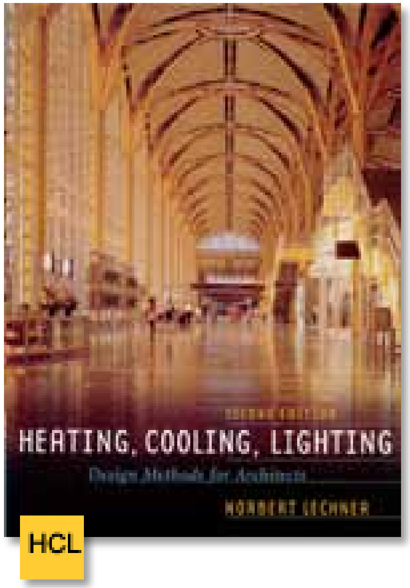
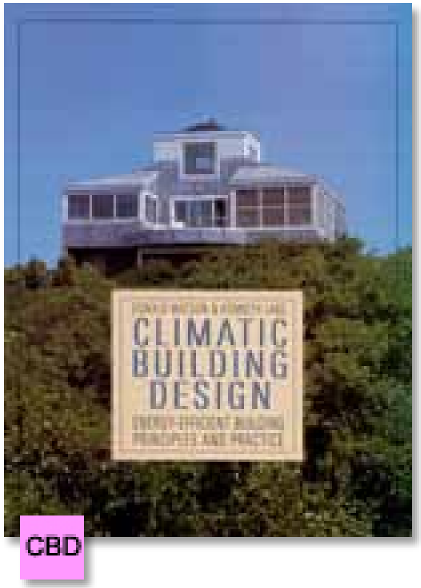
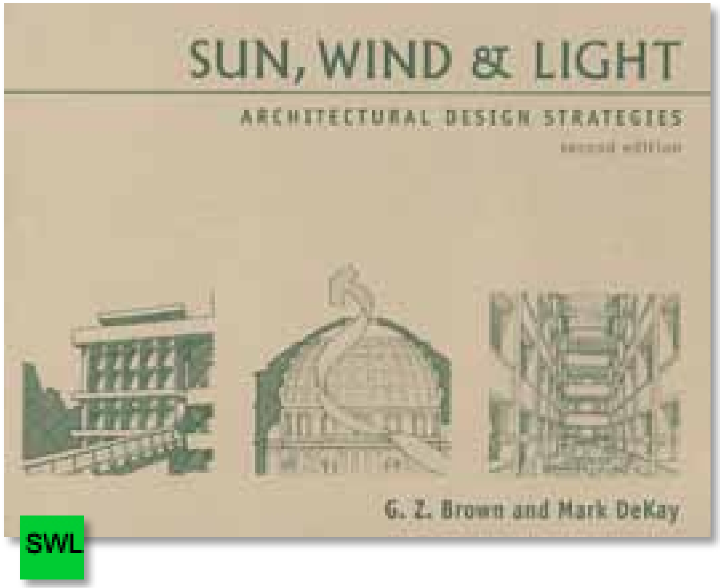
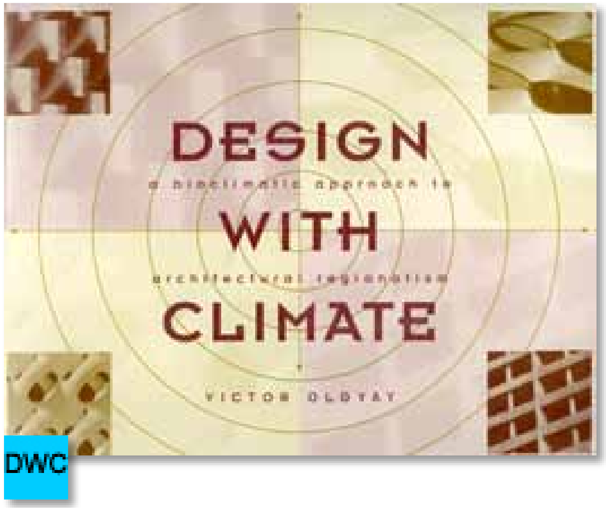
Arch 125: Intro to Environmental Design
SOLAR GEOMETRY

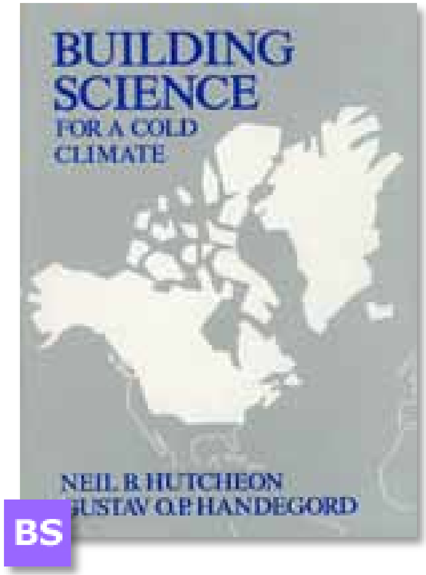










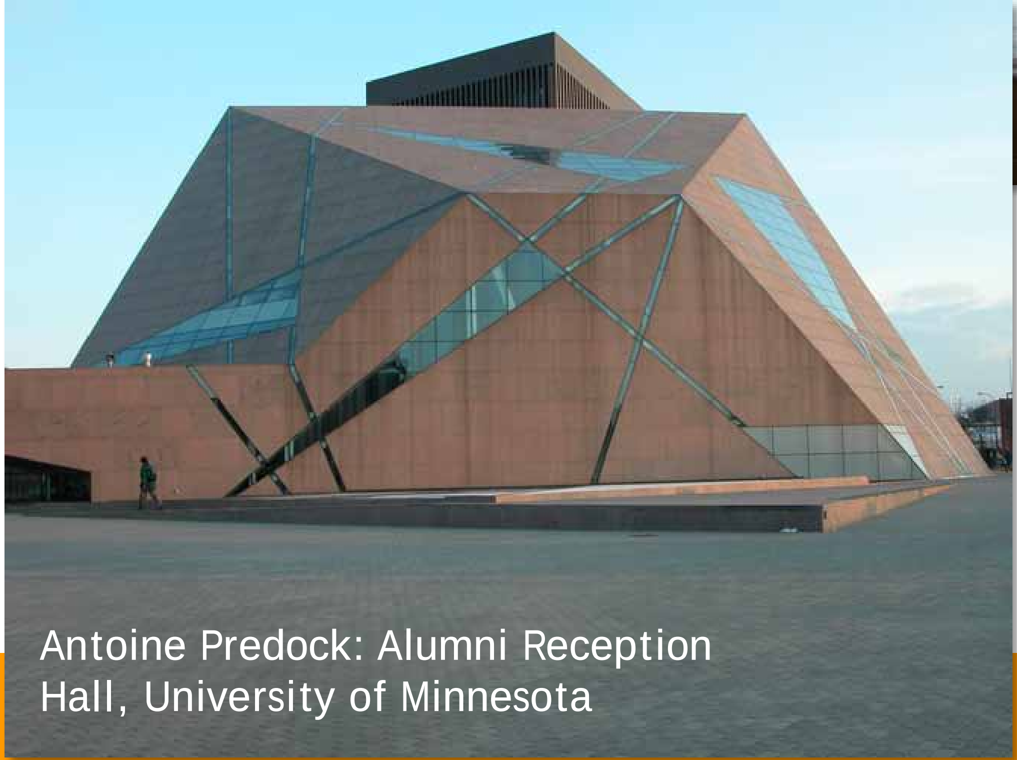


Texts used in the preparation of this presentation.

There are large numbers of buildings that treat windows as patterning devices, and that do not take advantage of the sun in *obvious* ways.

In fact, the windows at the right ARE Morse Code.

…time of day affects windows…



Antoine Predock: Alumni Reception Hall, University of Minnesota

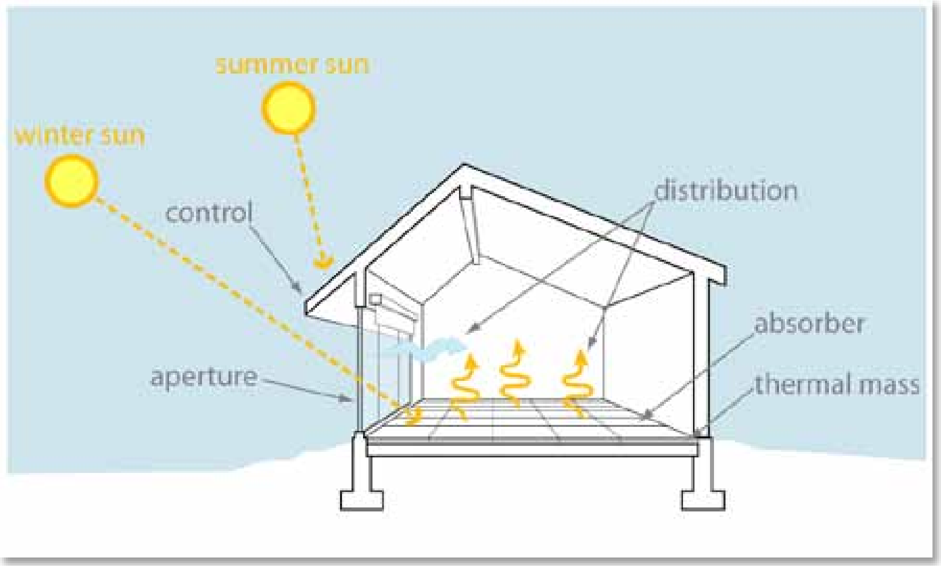
In studying Solar Geometry we are going to figure out how to use the sun’s natural path in summer vs. winter to provide FREE heat in the Winter, and to reduce required COOLING in the summer.

Differentiating Passive vs. Active Design

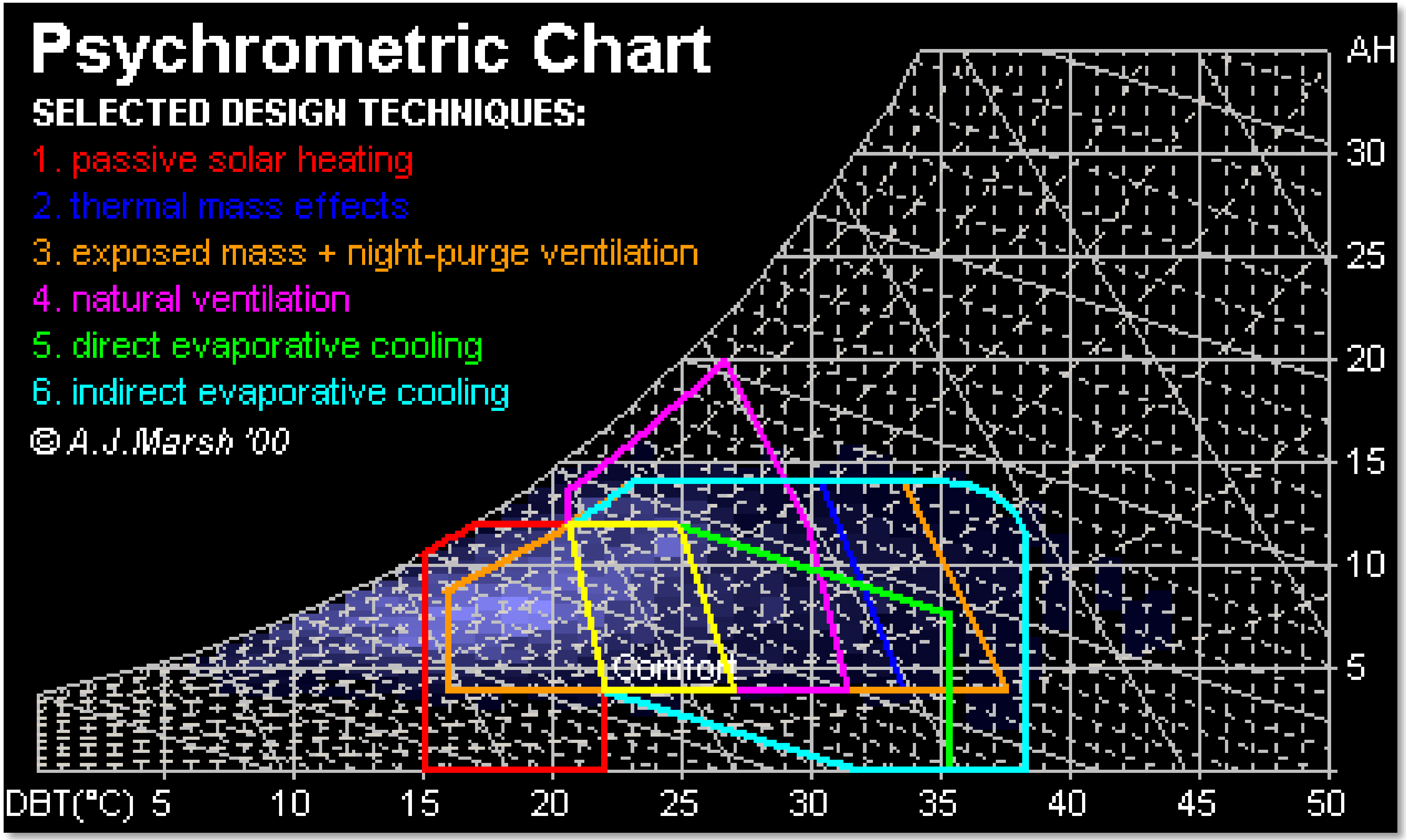
Passive design results when a building is created and simply works “on its own”. The plan, section, materials selections and siting create a positive energy flow through the building and “save energy”.

Active design uses equipment to modify the state of the building, create energy and comfort; ie. Fans, pumps, etc.

Passive buildings require active users (to open and shut windows and blinds...)

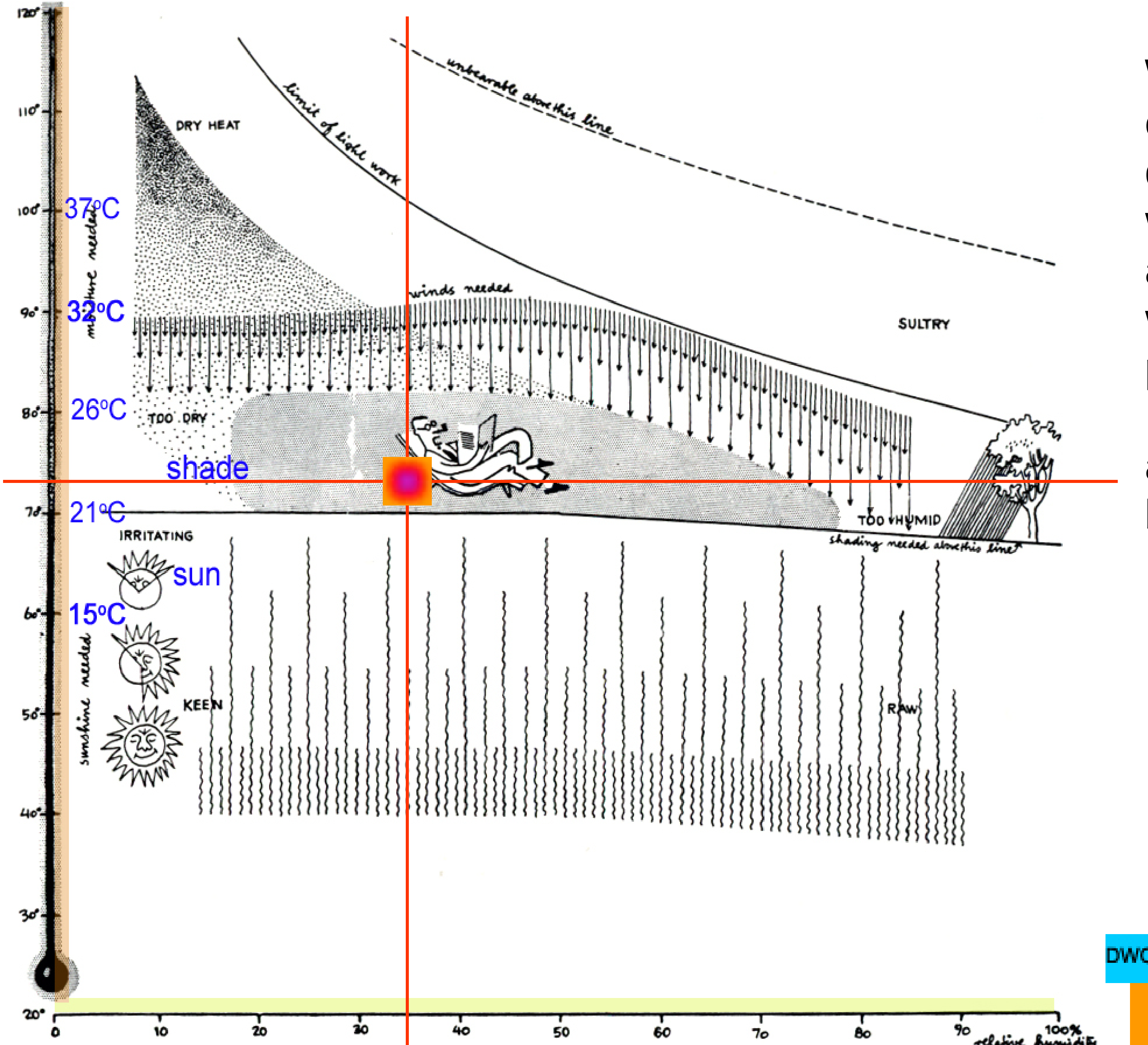


6 main strategy modes for PASSIVE design



GO TO PSYCHROMETRIC CHART TUTORIAL!

tboake.com/sustain_casestudies/PsyChart.html



46. Schematic bioclimatic index.

We use this chart to determine when we DO and DO NOT want sun penetration in and around our buildings.

Why Solar Geometry?

Understanding solar geometry is essential in order to:

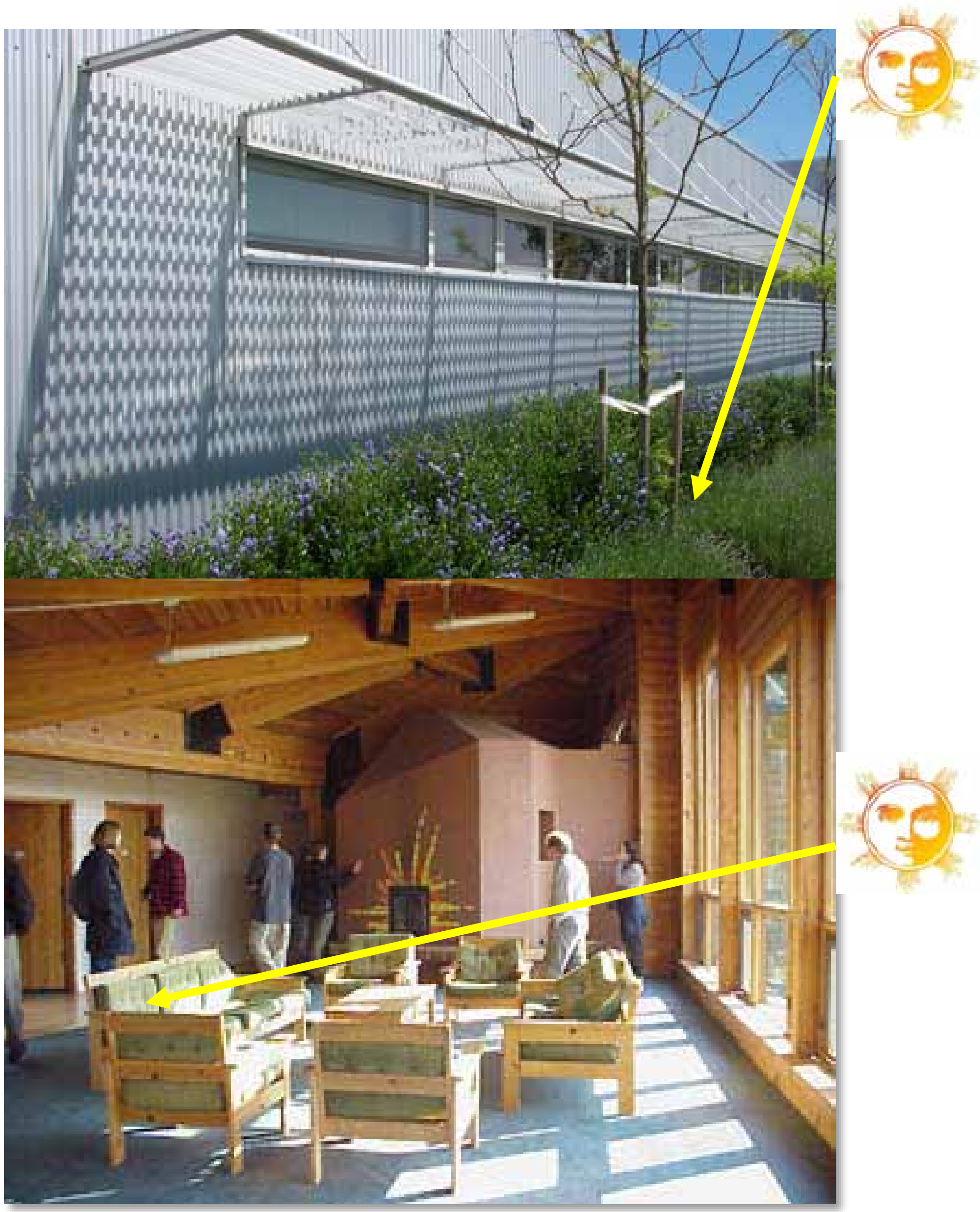
• do passive building design (for heating and cooling)

• orient buildings properly

• understand seasonal changes in the building and its surroundings

• design shading devices

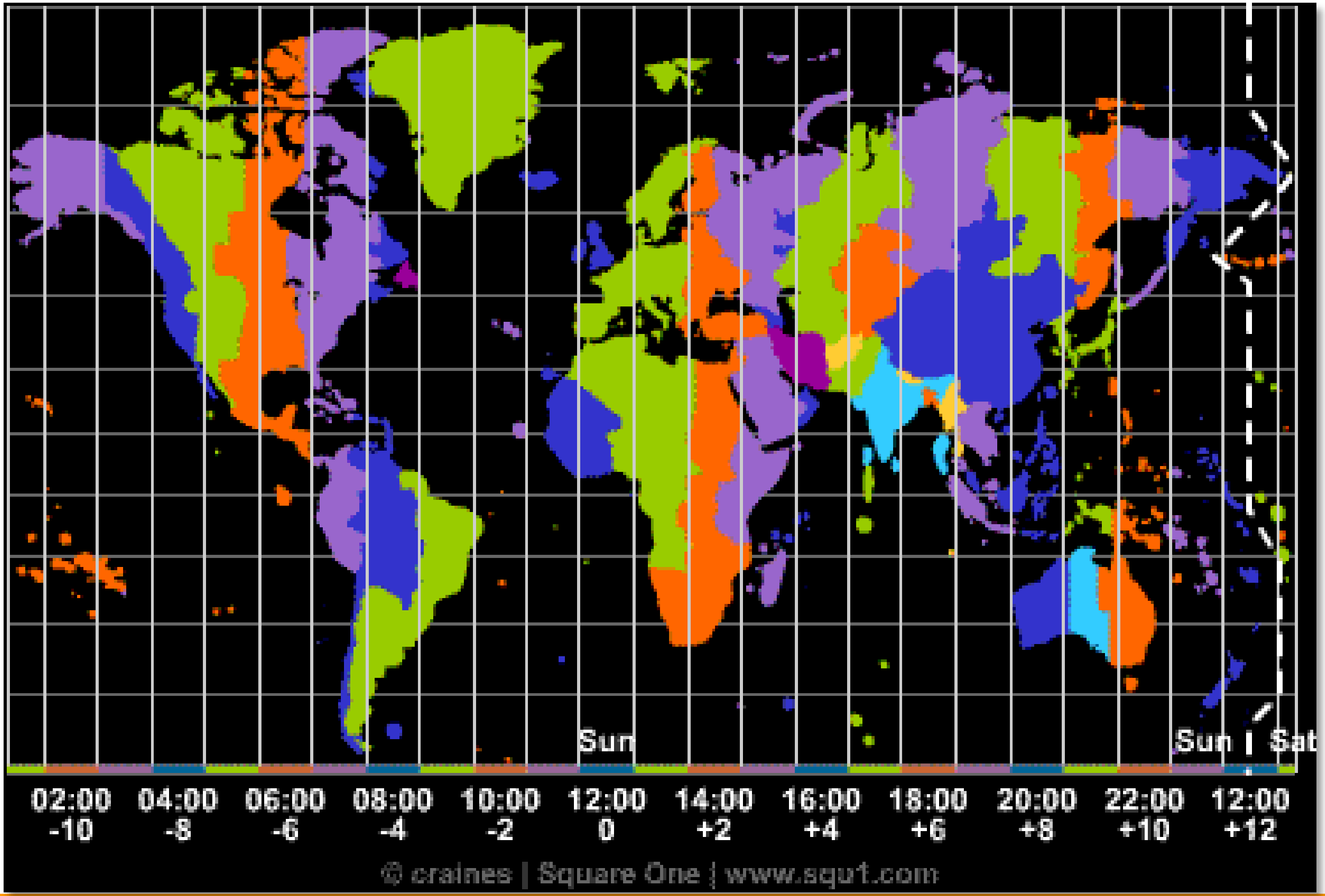
• use the sun to animate our architecture



Solar geometry works for us because the sun is naturally HIGH in the summer, making it easy to block the sun with shading devices.

And it is naturally LOW in Winter, allowing the sun to penetrate below our shading devices and enter the building - with FREE heat.

The time zone is important as it affects “solar noon”. All charts are based on solar noon not the “hour noon”. Easiest way to find solar noon for your location is to note the sunrise and sunset times (in the paper/net) and solar noon is halfway inbetween.



Detailed weather data is available online at:
http://www.weatheroffice.ec.gc.ca/city/pages/on-150_metric_e.html

For example: for Collingwood, Ontario for Sunday, Jan 22, 2006

Sunrise 7:50, Sunset 17:15, Moonrise 0:44, Moonset 11:12

So… solar noon is halfway between 7:50 and 17:15, so

4:10 + 5:15 = 9:25 / 2 = 4:42.5 (4 hours 42.5 minutes),
so at 42.5 minutes after 12 noon.

Toronto was 7:44 and 17:14

For Toronto Sunrise was 7:44 and Sunset was 17:14, so solar noon is 4:16 + 5:14 = 9:30/2 = 4:45, so at 45 minutes past noon.

Latitude and longitude will affect this timing!

Toronto is latitude 43º 40’ and longitude 79º 24’

Montreal is in the same time zone but is located at latitude 45º 30’ longitude 73º 35’, and its sunrise 7:26 and 16:46, so solar noon is 4:34 + 4:46 = 8:80 or 9:20/2 = 4:40, so at 40 minutes past 12 noon.

We can also see that Toronto gets 9 hours and 30 minutes of daylight and Montreal, being 2º further north gets only 9 hours and 20 minutes of daylight. The change in longitude means that dawn is earlier as is dusk.

The rotation of the earth about the sun affects the amount of solar radiation we receive at varying times of the year.

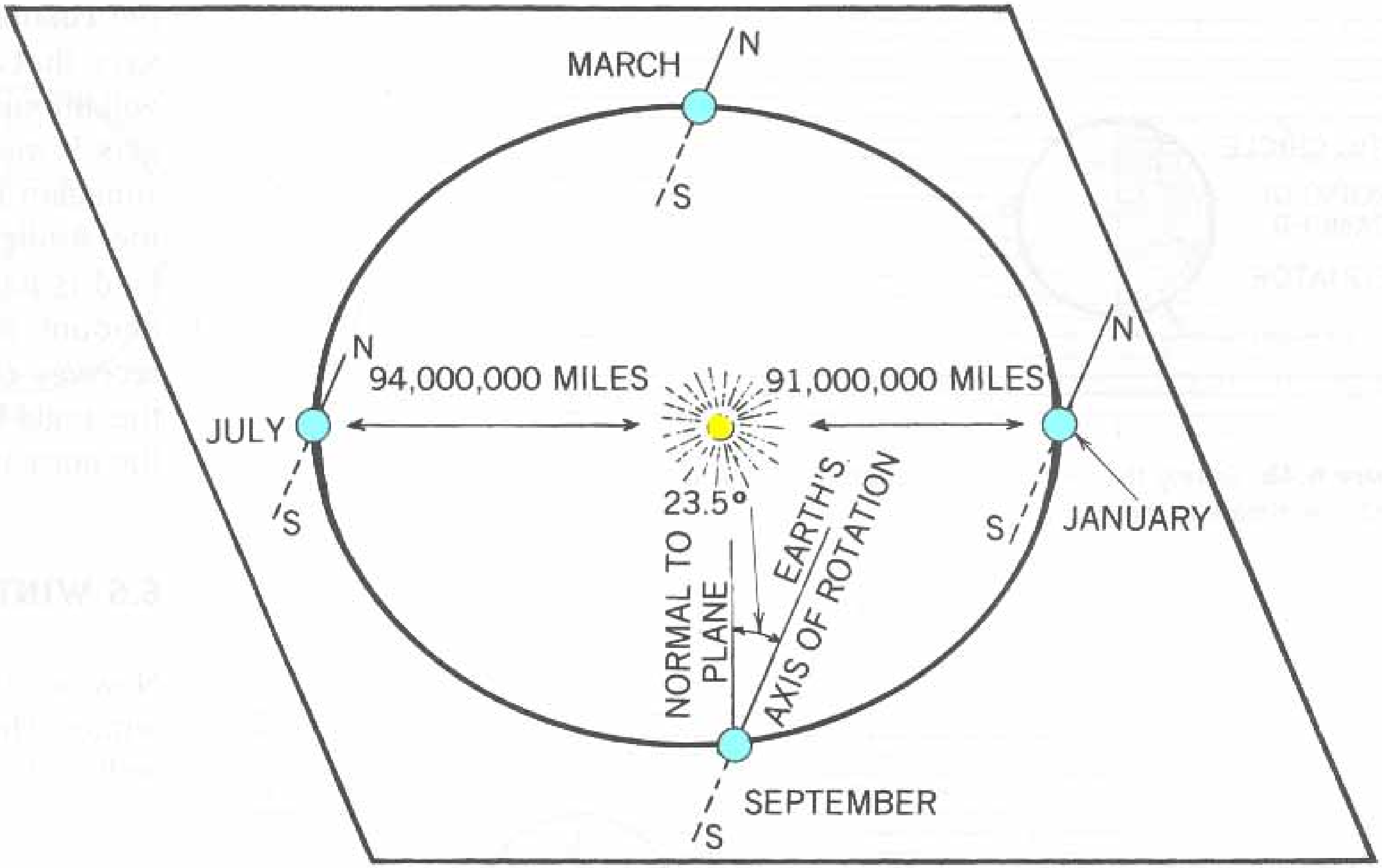
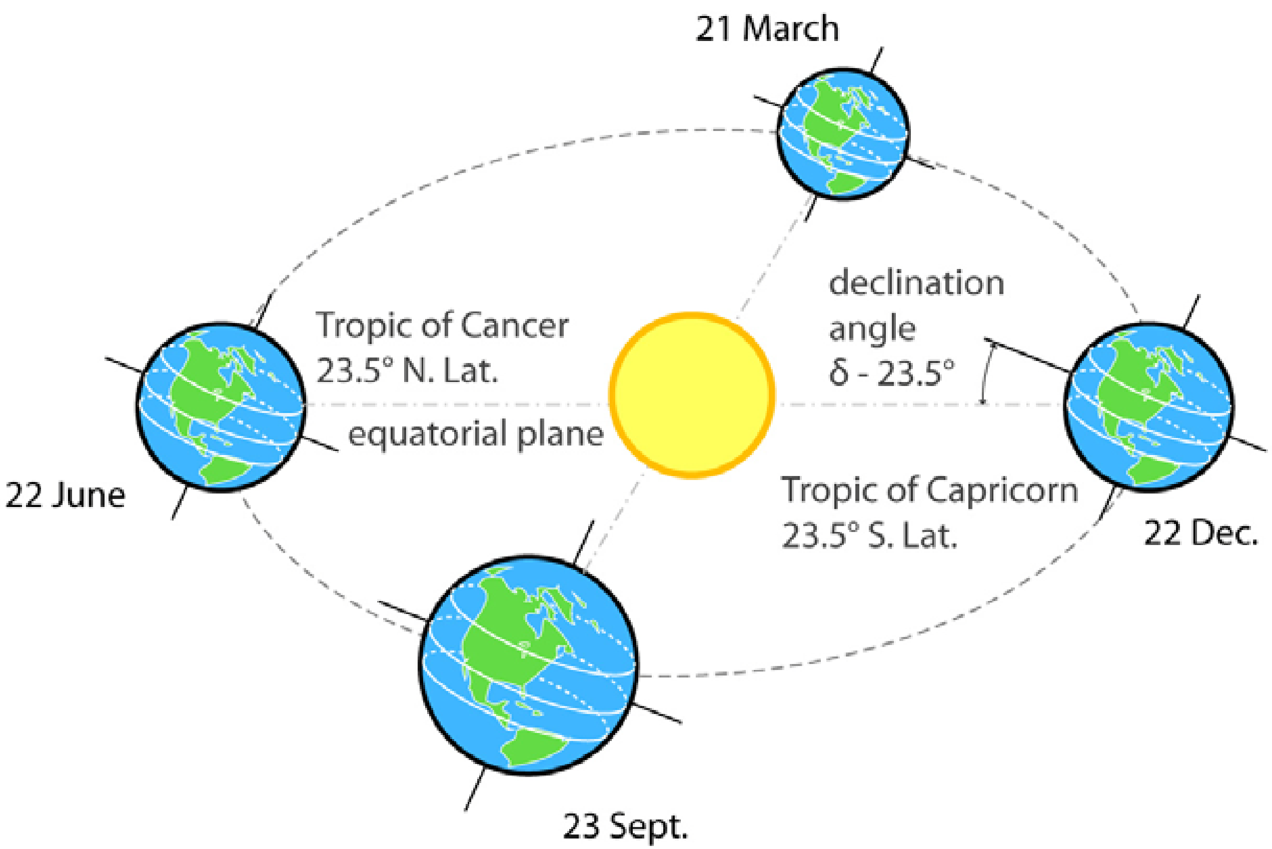


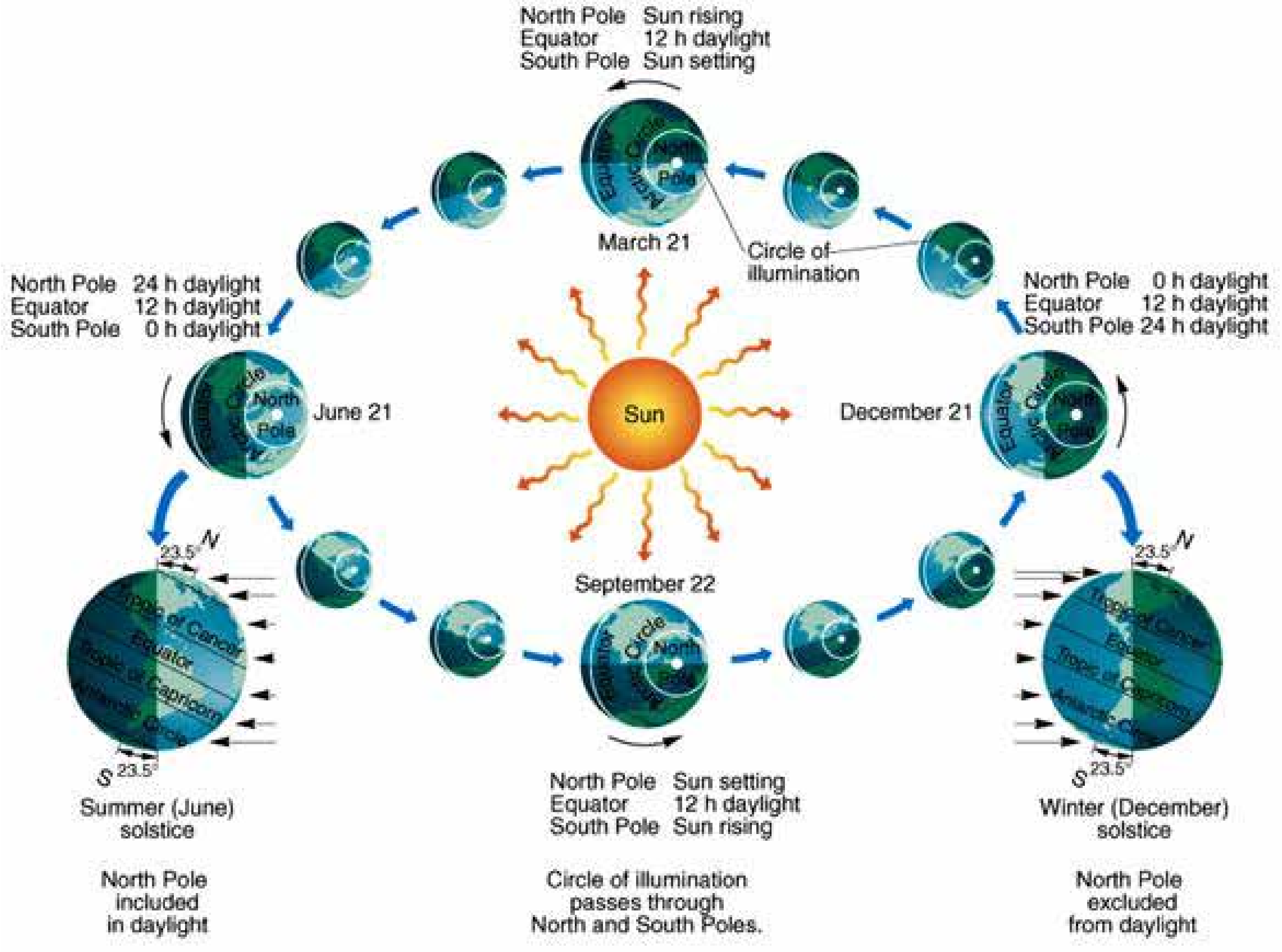
Figure 6.3 The earth's axis of rotation is tilted to the plane of the elliptical orbit.

HCL

Solar Position

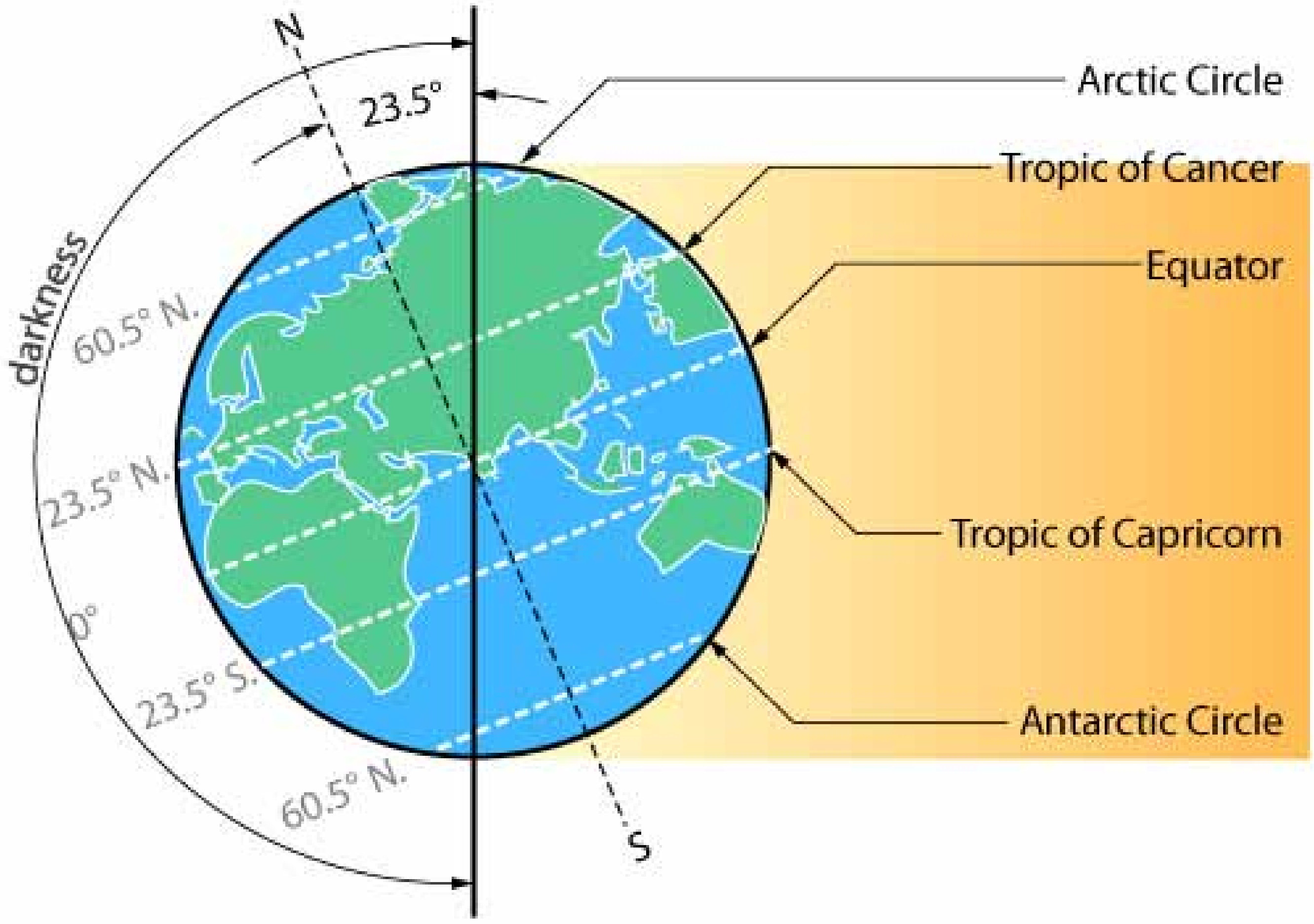


Earth's motion around the sun.



North Pole Sun rising
Equator 12 h daylight
South Pole Sun setting
March 21
Circle of illumination
North Pole 24 h daylight
Equator 12 h daylight
South Pole 0 h daylight
June 21
Sun
December 21
North Pole 0 h daylight
Equator 12 h daylight
South Pole 24 h daylight
September 22
North Pole Sun setting
Equator 12 h daylight
South Pole Sun rising
Summer (June) solstice
Winter (December) solstice
North Pole included in daylight
Circle of illumination passes through North and South Poles.
North Pole excluded from daylight
Tropic of Cancer
Equator
Tropic of Capricorn
Antarctic Circle
Arctic Circle
North Pole
23.5°
N
S

Solar Position



Earth relative to sun at winter solstice.

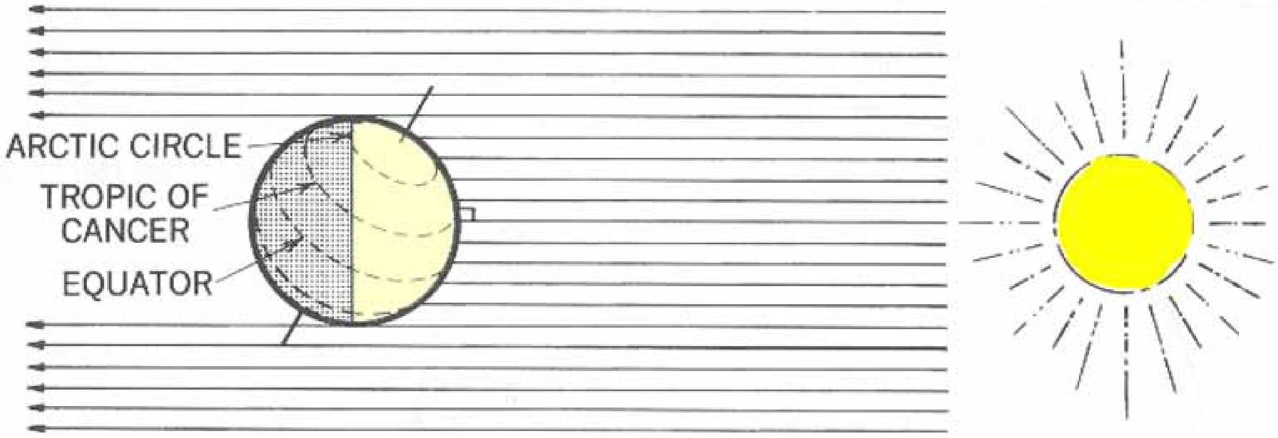


Figure 6.4b During the summer solstice (June 21), the sun is directly overhead on the Tropic of Cancer.

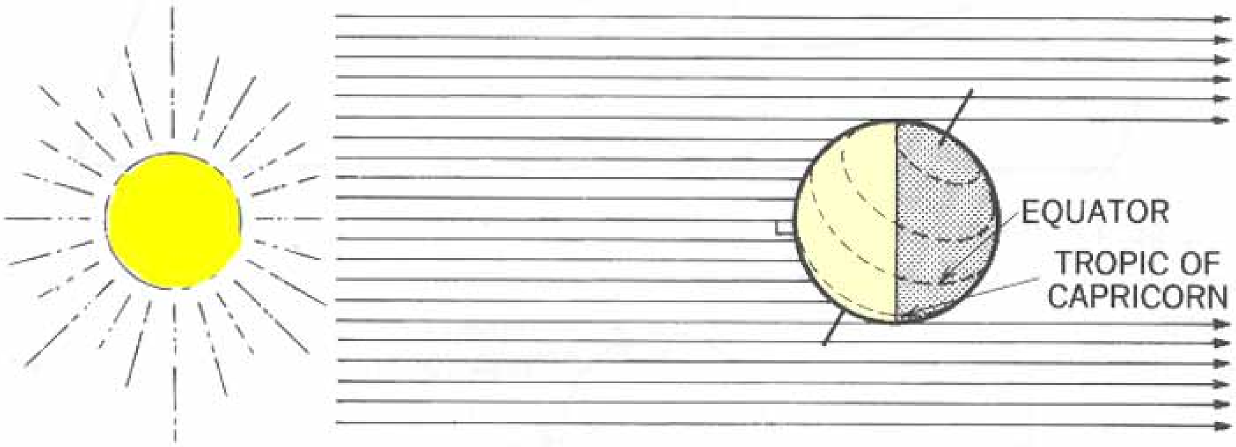
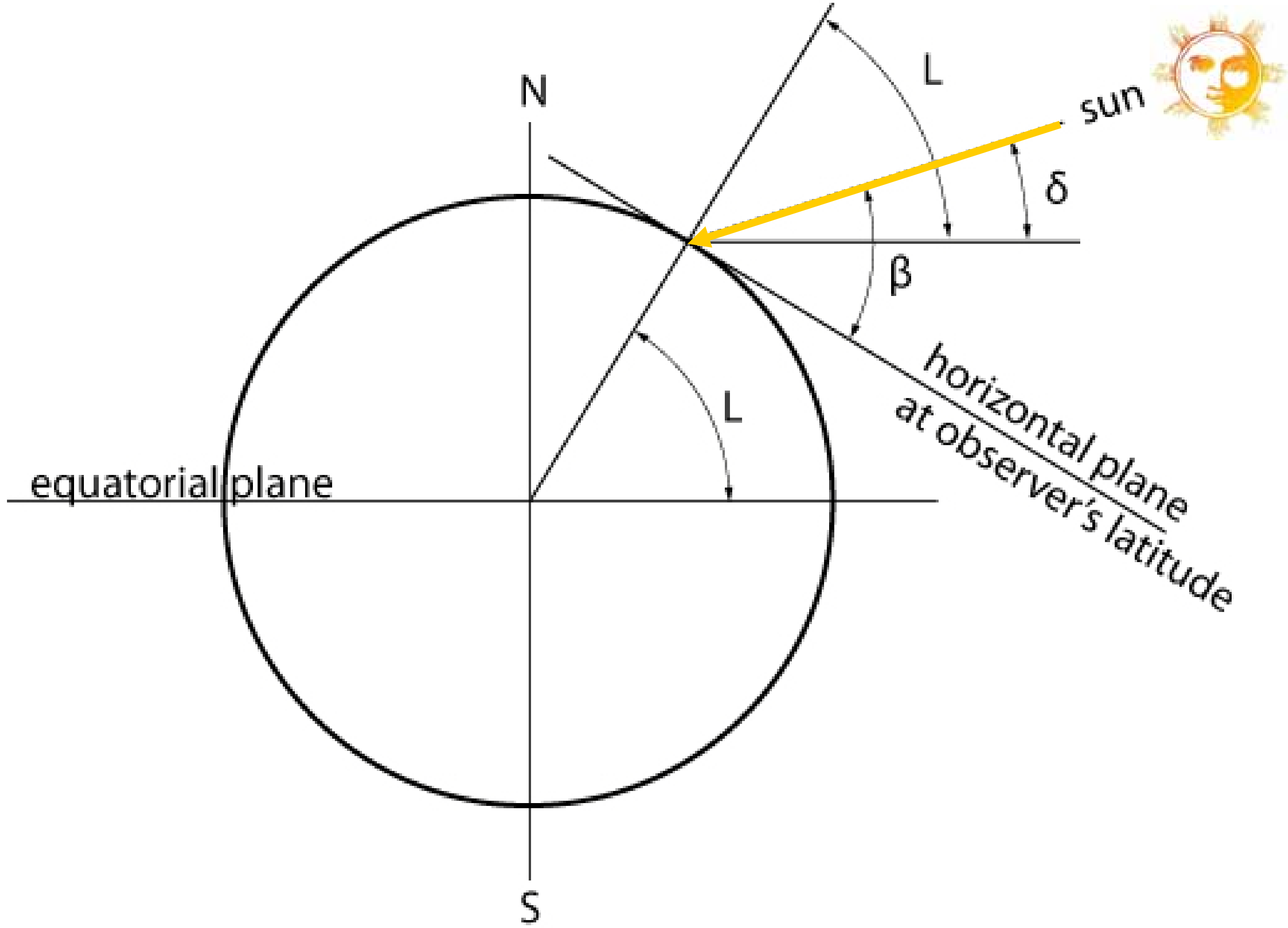


Figure 6.4c During the winter solstice (December 21), the sun is directly overhead on the Tropic of Capricorn.



Relation between declination, altitude angle, and latitude.

Solar Position

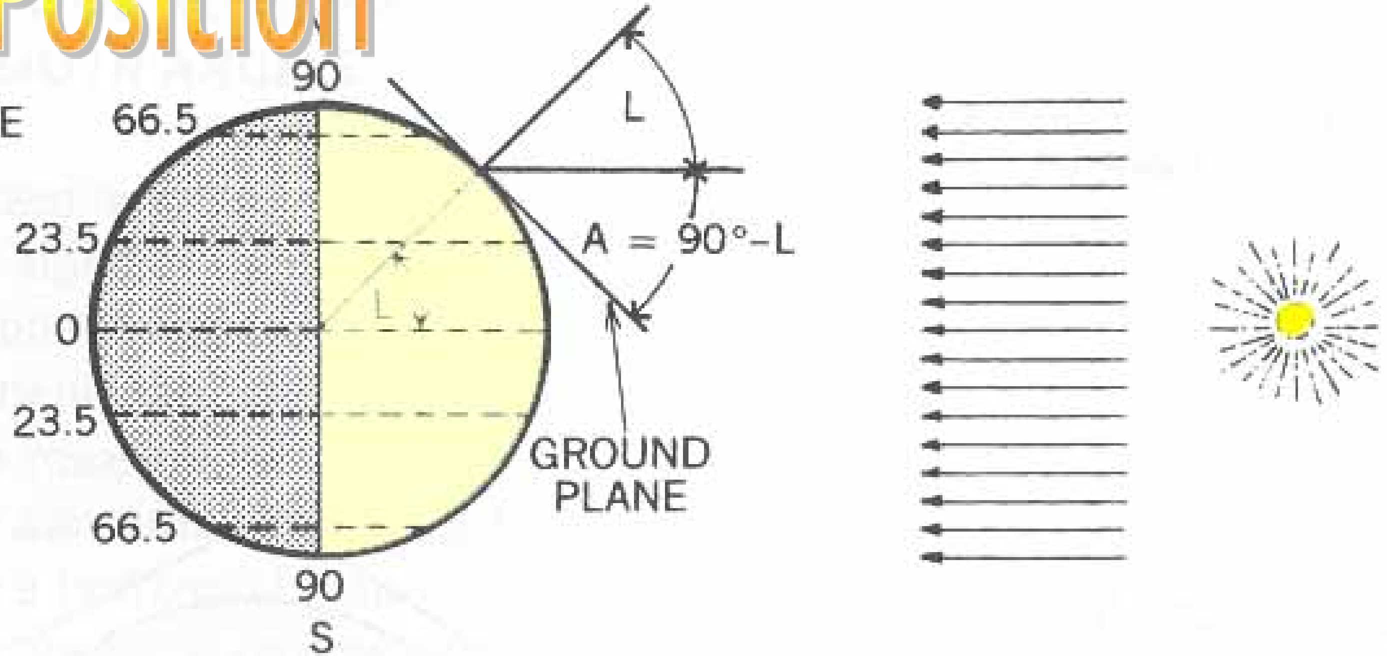
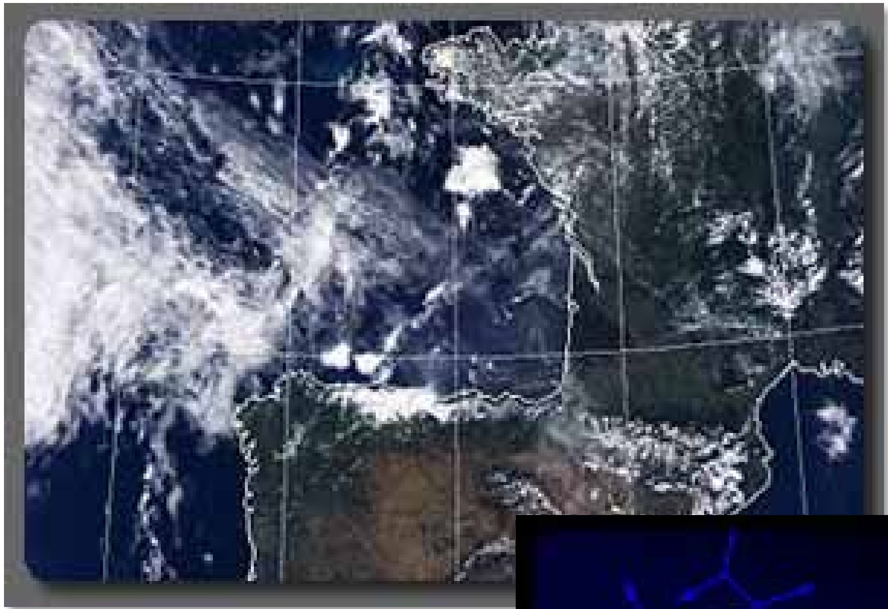


Figure 6.5a On the equinox, the sun's altitude (A) at solar noon at any place on earth is equal to 90 degrees minus the latitude (L).

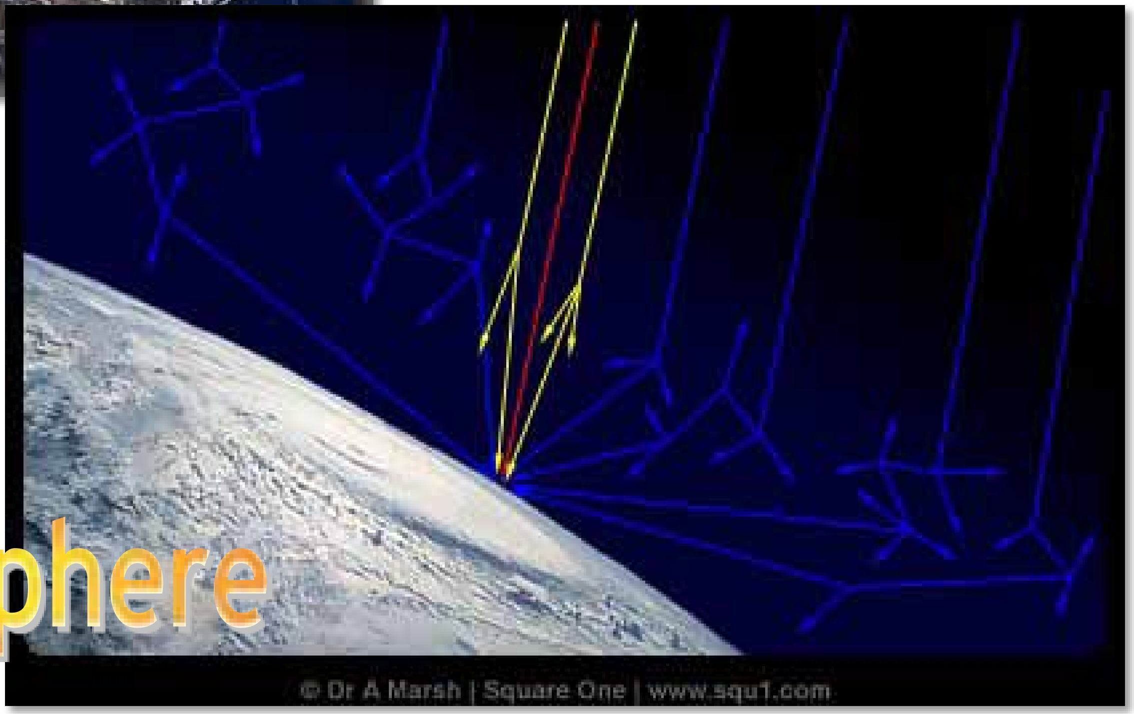
HCL

The vertical angle at which the sun's rays strike the earth is called the 'altitude angle', and is a function of latitude, time of year and time of day. The simplest situation occurs at 12 noon on the equinox, when the sun's rays are perpendicular to the earth at equator. Altitude Angle = 90^{o} - Latitude

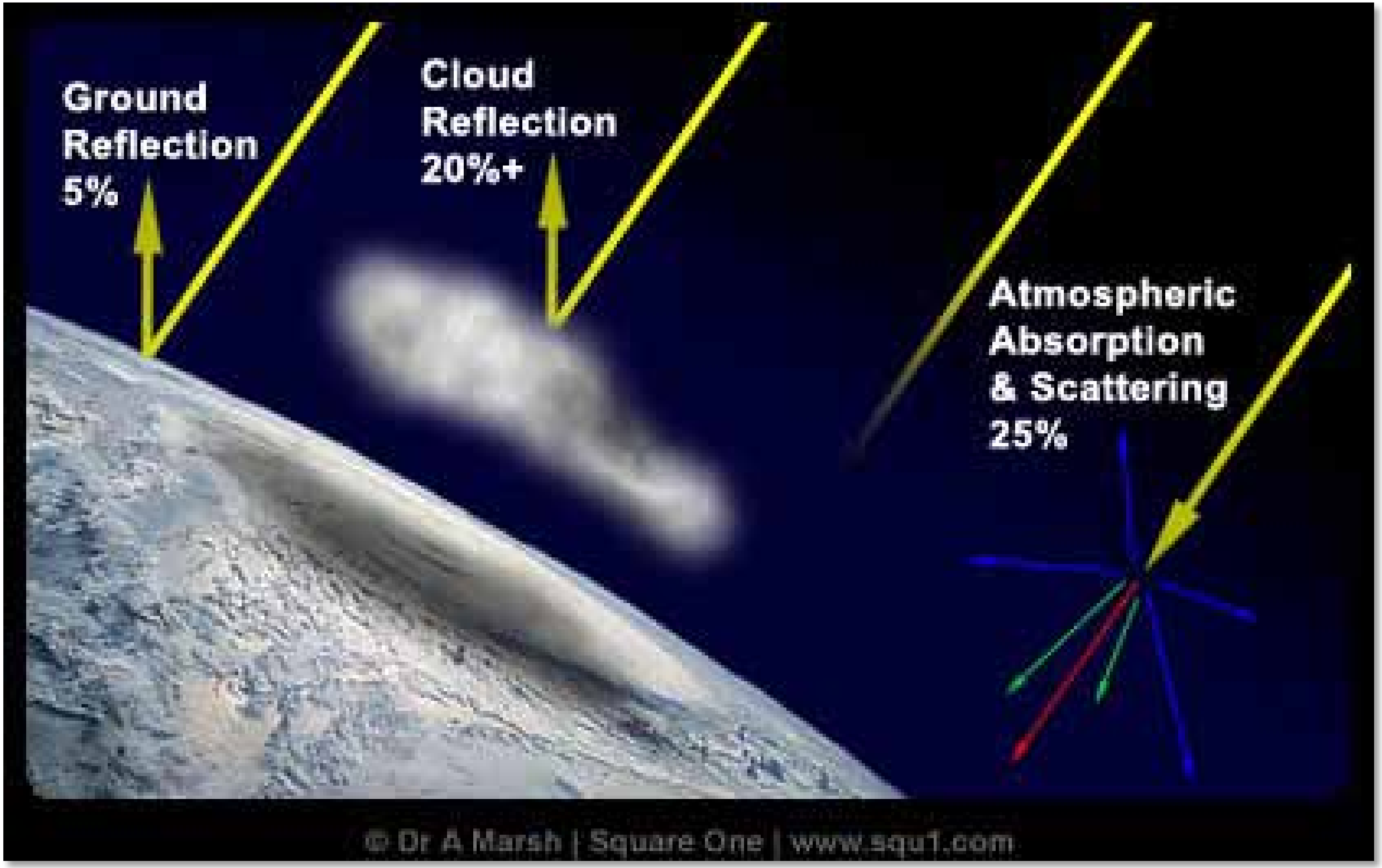
The Atmosphere

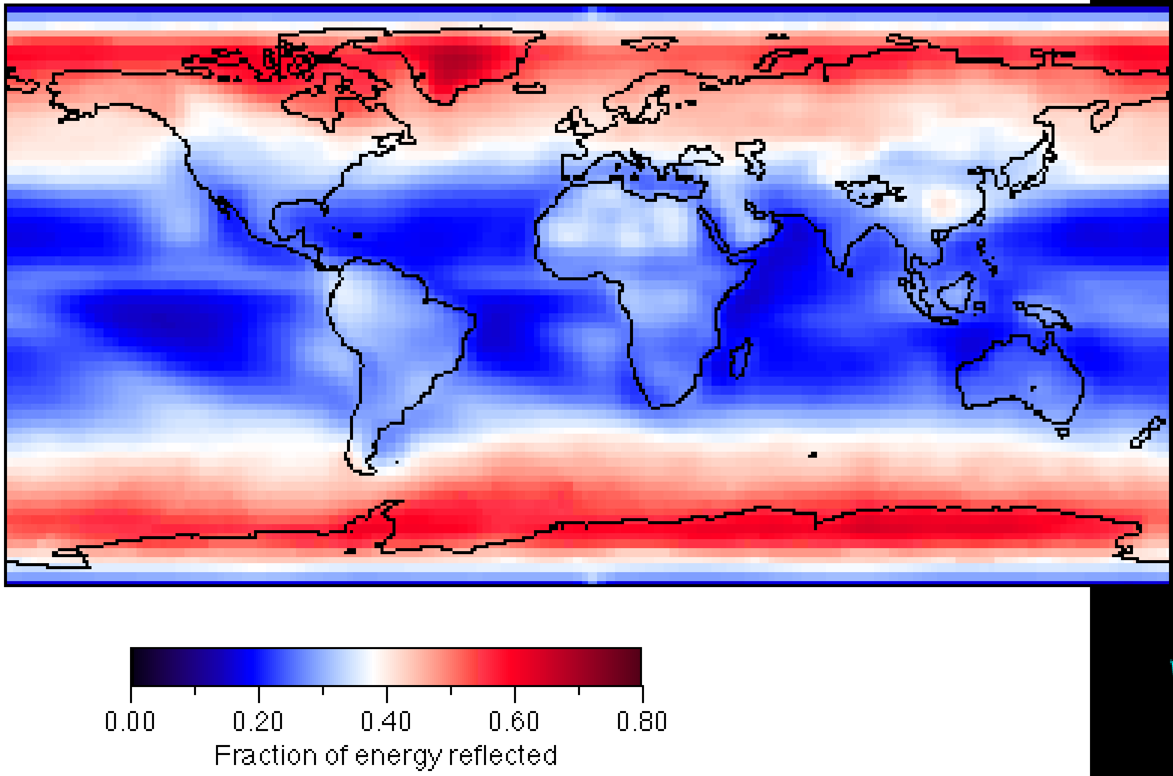


The exact nature of the solar radiation we receive is a function of our atmosphere.

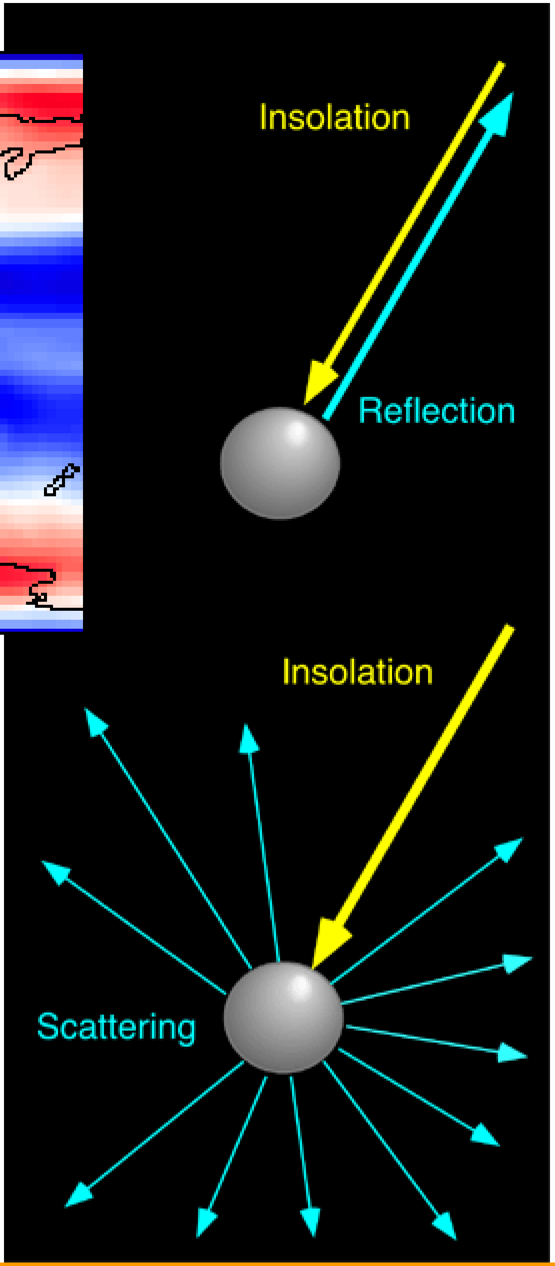


The Atmosphere





Not all solar radiation is absorbed by the earth - much is reflected and scattered. The image of the earth above shows more is collected where the sun passes through the atmosphere with less travel distance. It is also a function of cloud cover.



Part of the reason for the decrease in intensity in WINTER is the amount of radiation that is absorbed by the atmosphere during the longer trip through it by oblique rays.

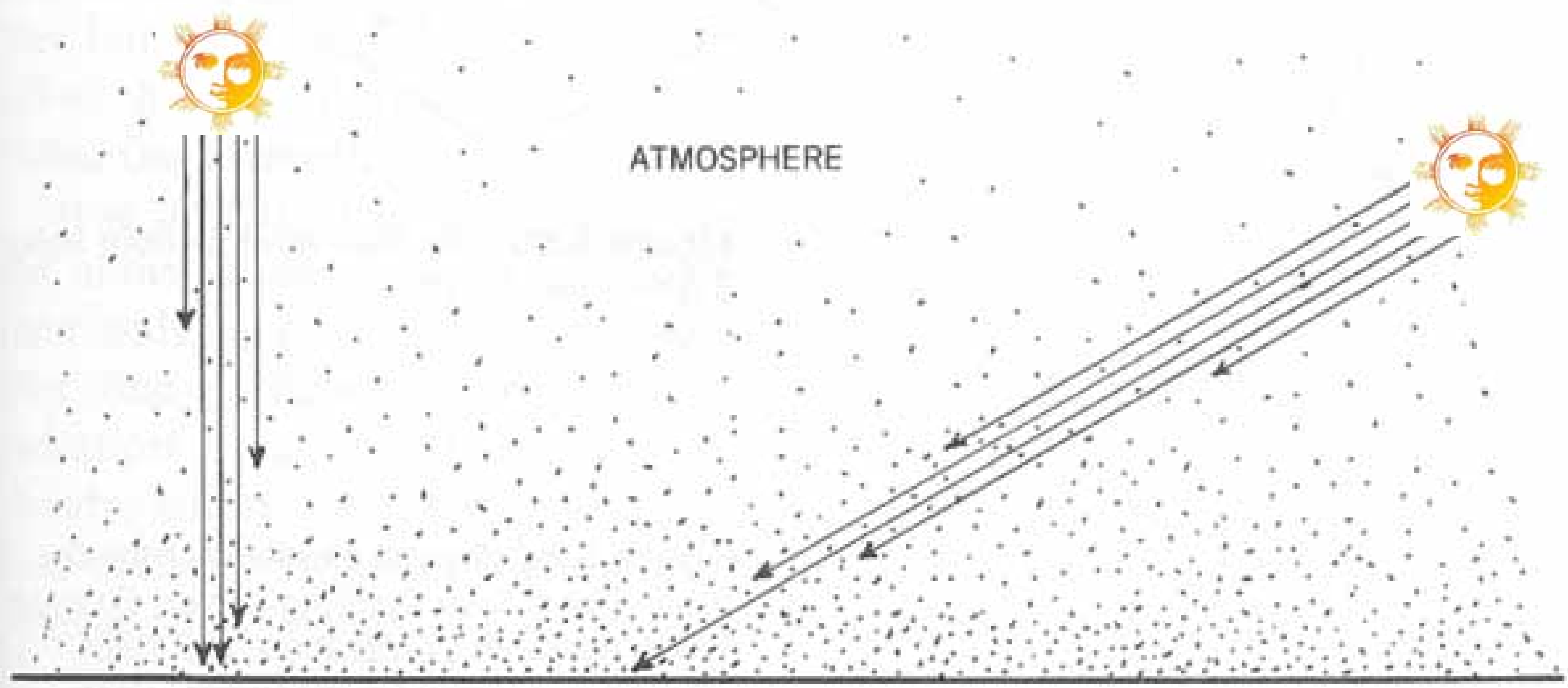


Figure 6.5b The altitude angle determines how much of the solar radiation will be absorbed by the atmosphere.

HCL

At low angles the sun's rays pass through more of the atmosphere – resulting in radiation reaching the surface being weaker –

i.e.: sunset

The angle the sun's rays make with the earth's surface also affects solar radiation levels. When the angle is oblique, the rays are less intense.

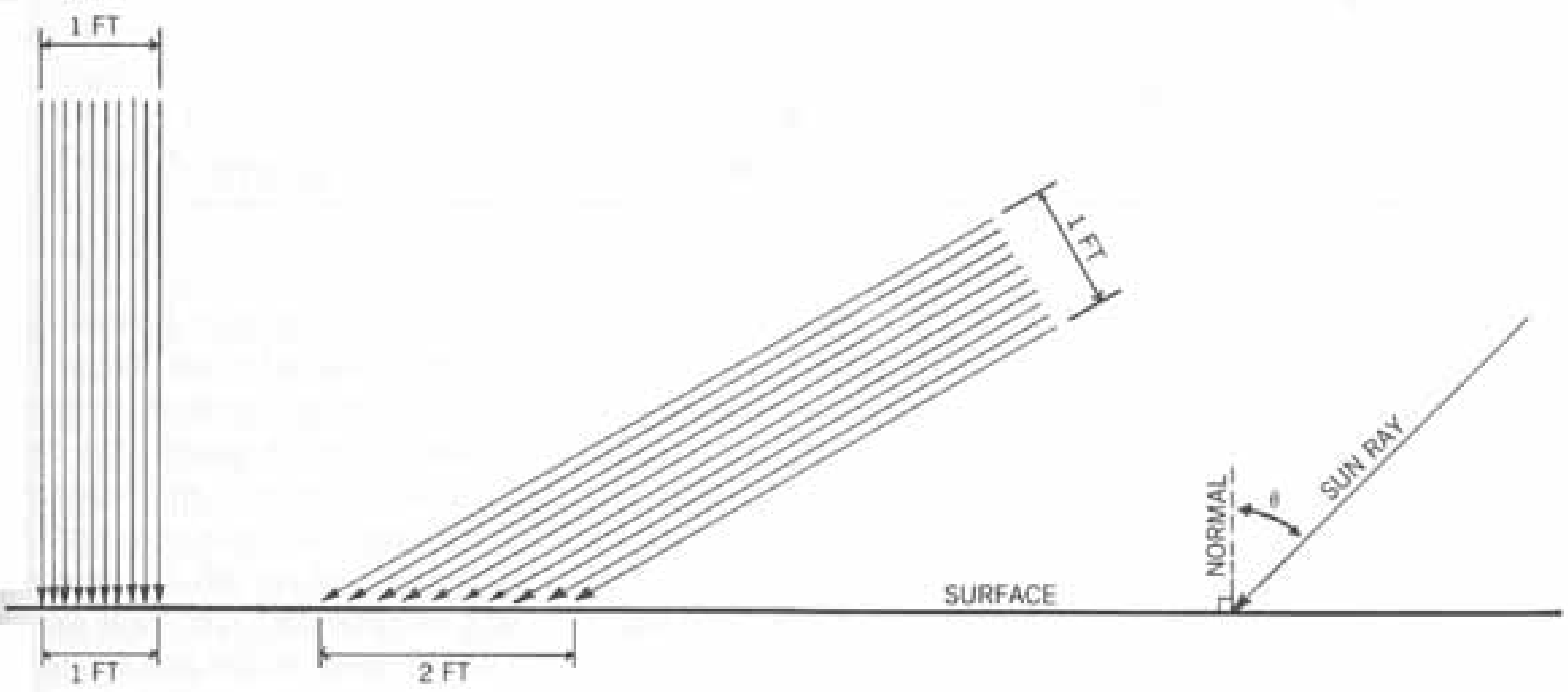


Figure 6.5c The cosine law states that the amount of radiation received by a surface decreases as the angle with the normal increases.

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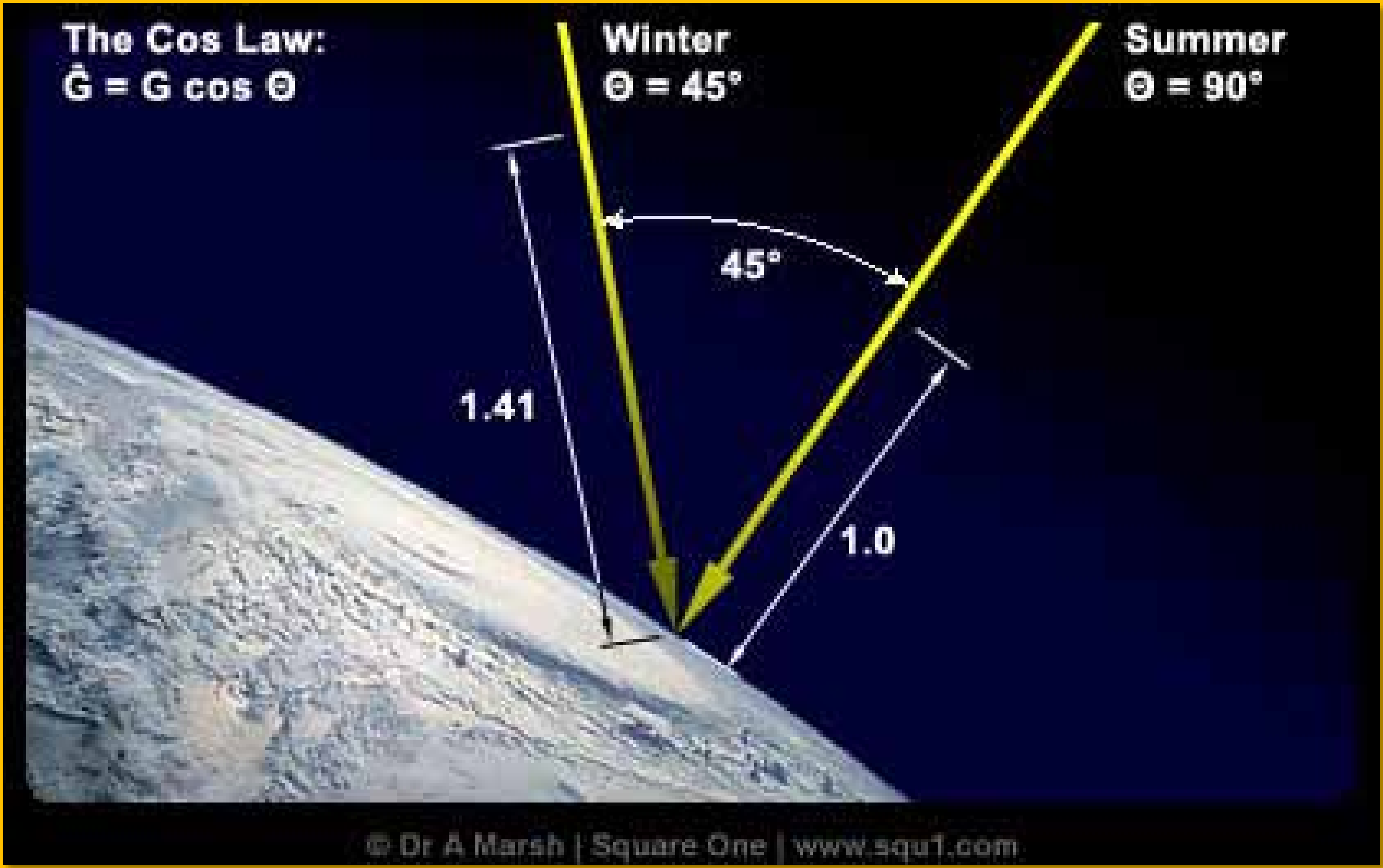
The Cos Law:
Ĝ = G cos Θ
Winter
Θ = 45°
Summer
Θ = 90°
45°
1.41
1.0
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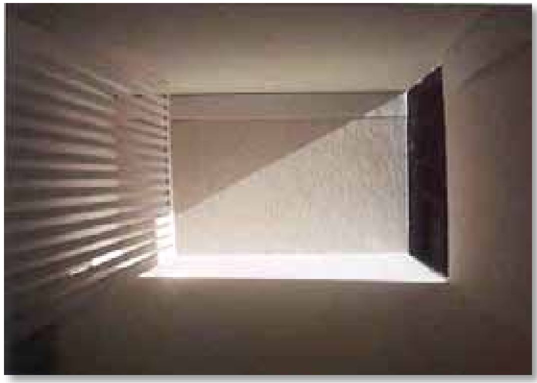
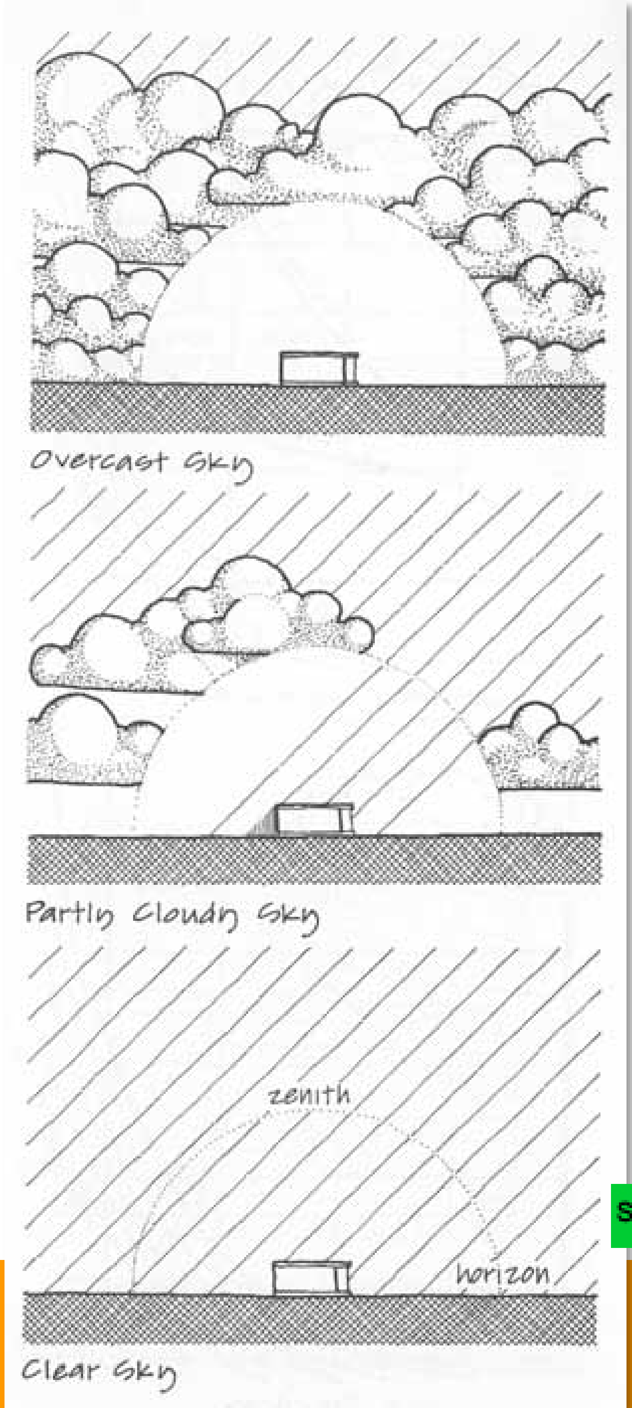
The precise condition of the sky is taken into account when determining the amount of solar radiation that is received by a building. *The clearer the sky, the more energy received.*

diffuse



direct



SWL

When it is cloudy the rays are diffused and even less radiation reaches the earth's surface. Shadows are less severe and light is more even.

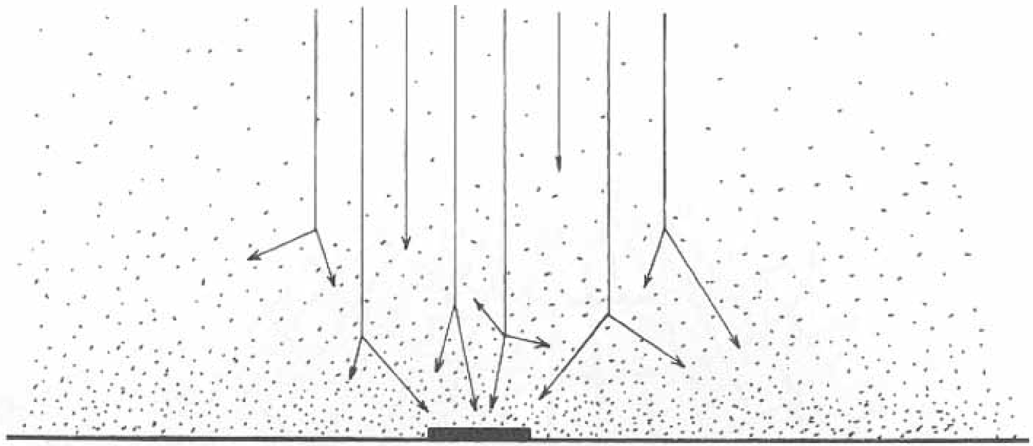
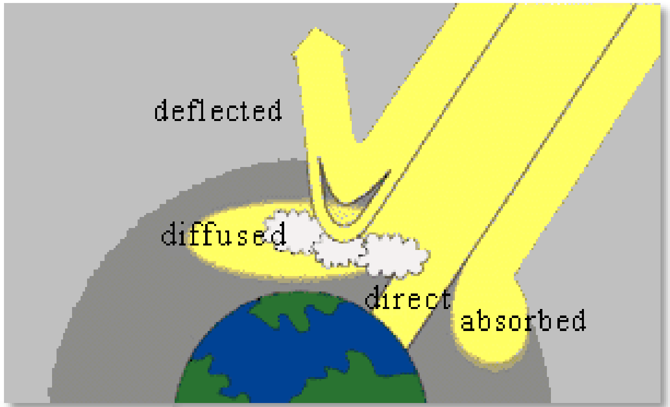


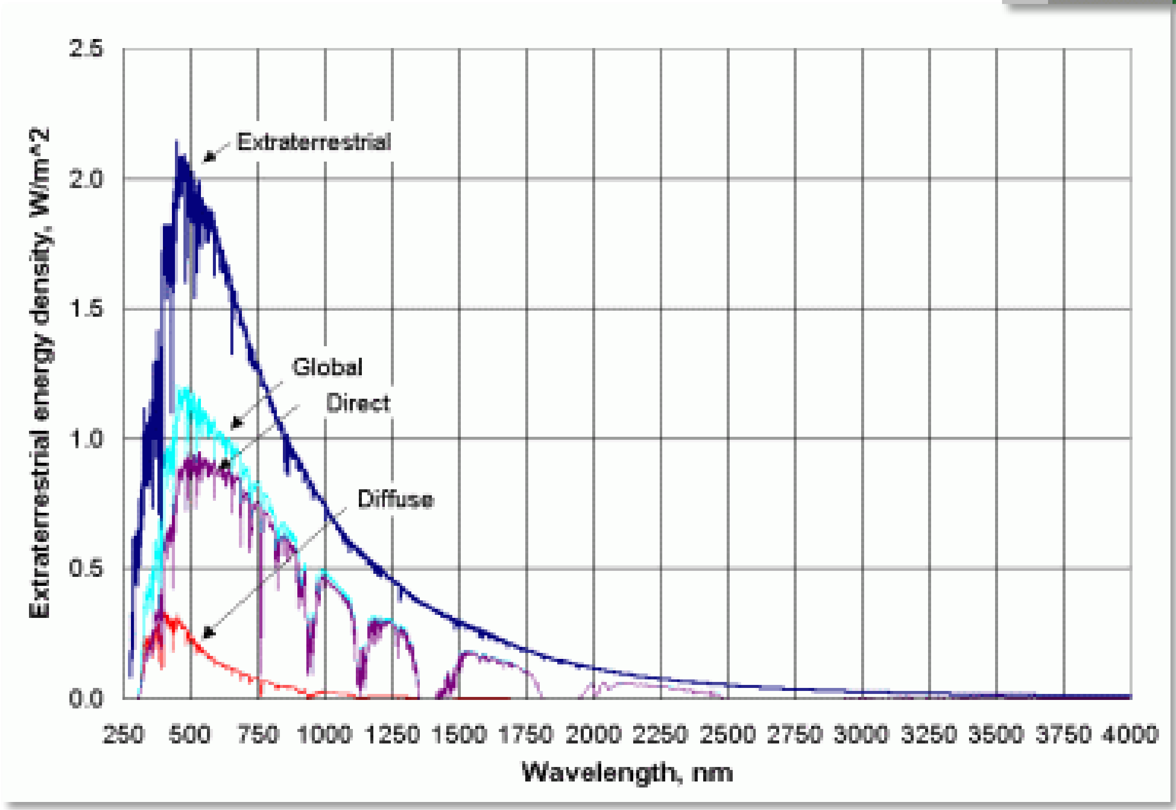
Figure 6.9b Diffuse radiation.

So even within the same space, the **microclimate** will change due to solar conditions from one day to the next.

The diffuse light on the cloudy day more evenly illuminates all faces of the building, leaving no faces in dark shadow.

The wavelength of the light is also affected by its “clarity” and source.





Reasons for Winter

The temperature of the air, and land is primarily a result of the amount of solar radiation absorbed by land.

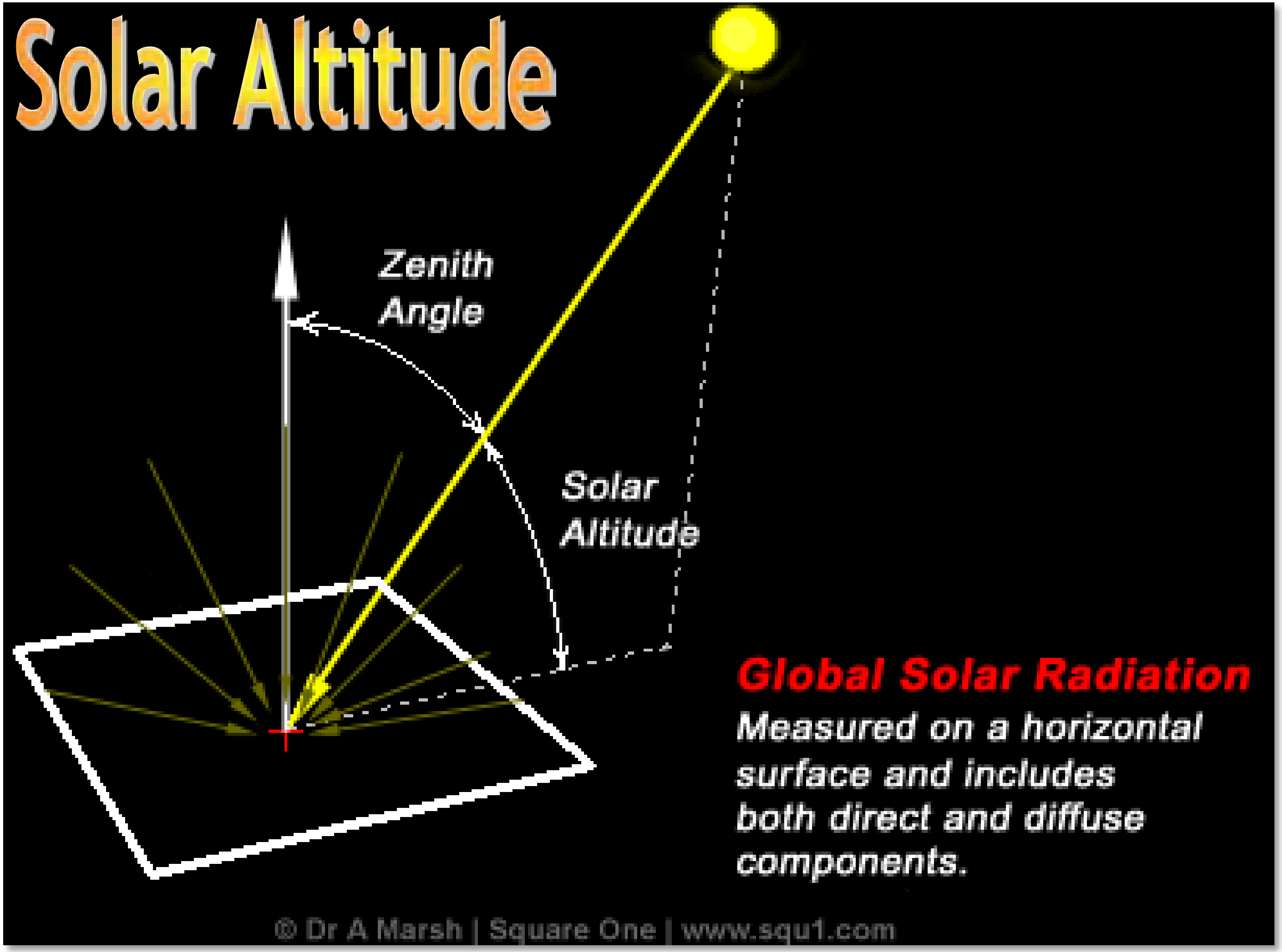
Reasons for less radiation are:

1. Far fewer hours of daylight (6 hrs less at 40 degrees latitude on December 21st than June 21st)
2. Reduced solar radiation due to cosine law.
3. Lower sun angles increase amount of atmosphere the sun must pass through to get here

Solar "Attitude"

Copernicus is credited with establishing that the earth orbits around the sun –

However for the purposes of building design let's again assume that the sun revolves around the earth, or at least that the sun revolves around the building site in question.


Solar Altitude
Zenith Angle
Solar Altitude
Global Solar Radiation
Measured on a horizontal surface and includes both direct and diffuse components.
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Solar Altitude

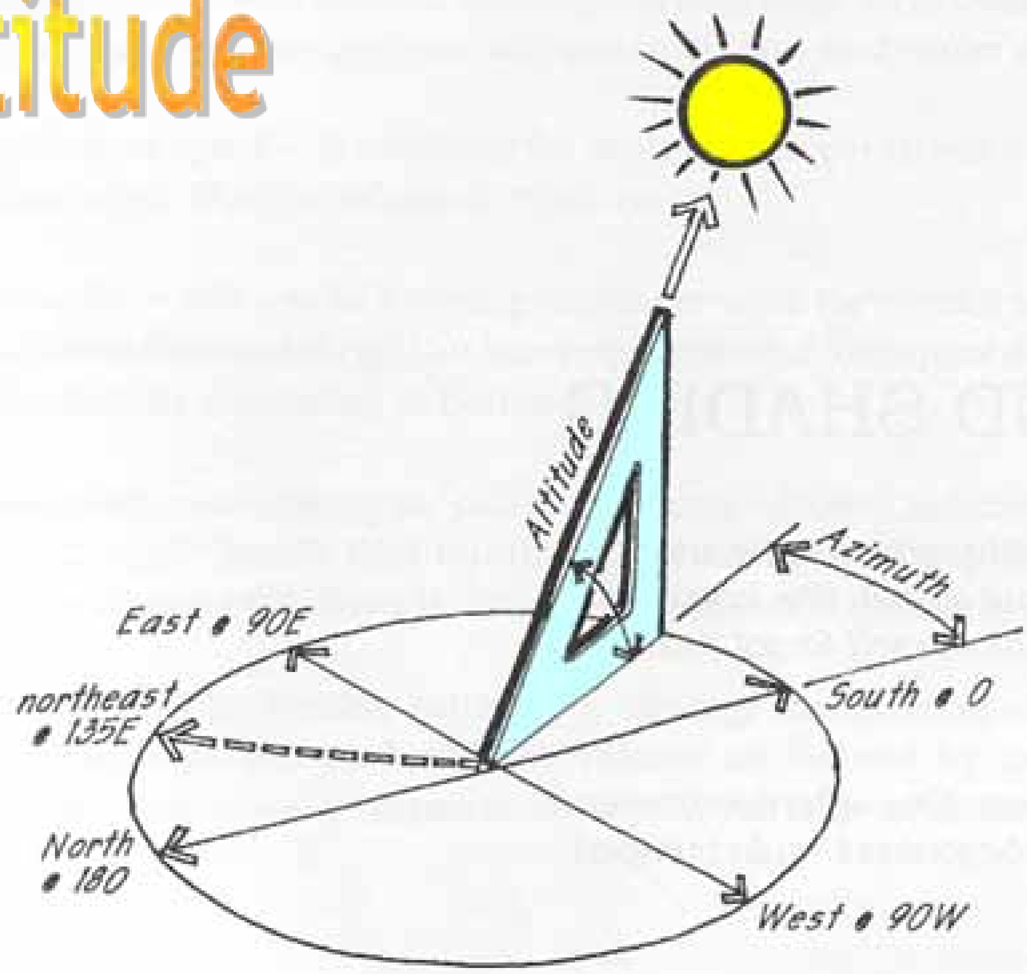
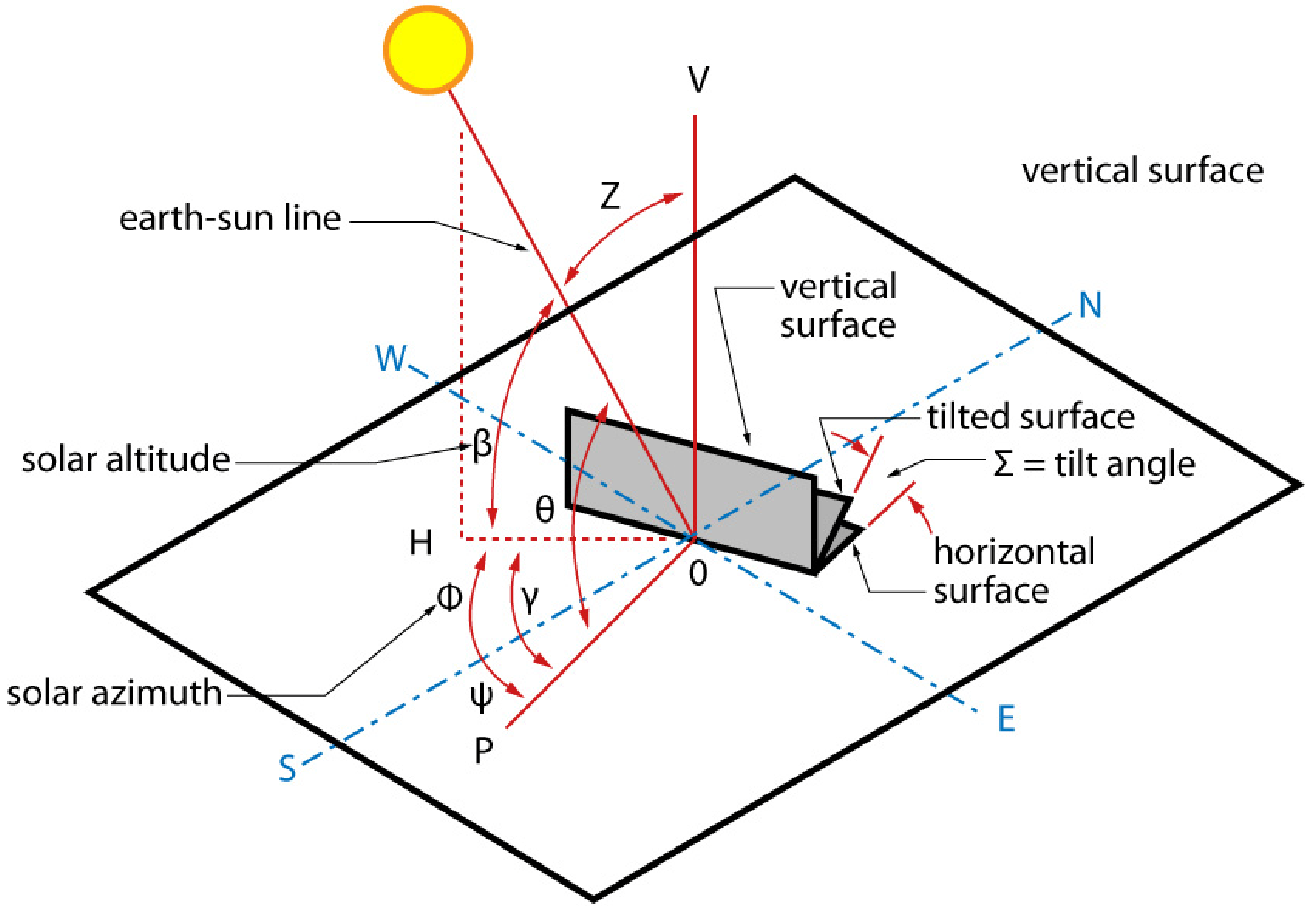
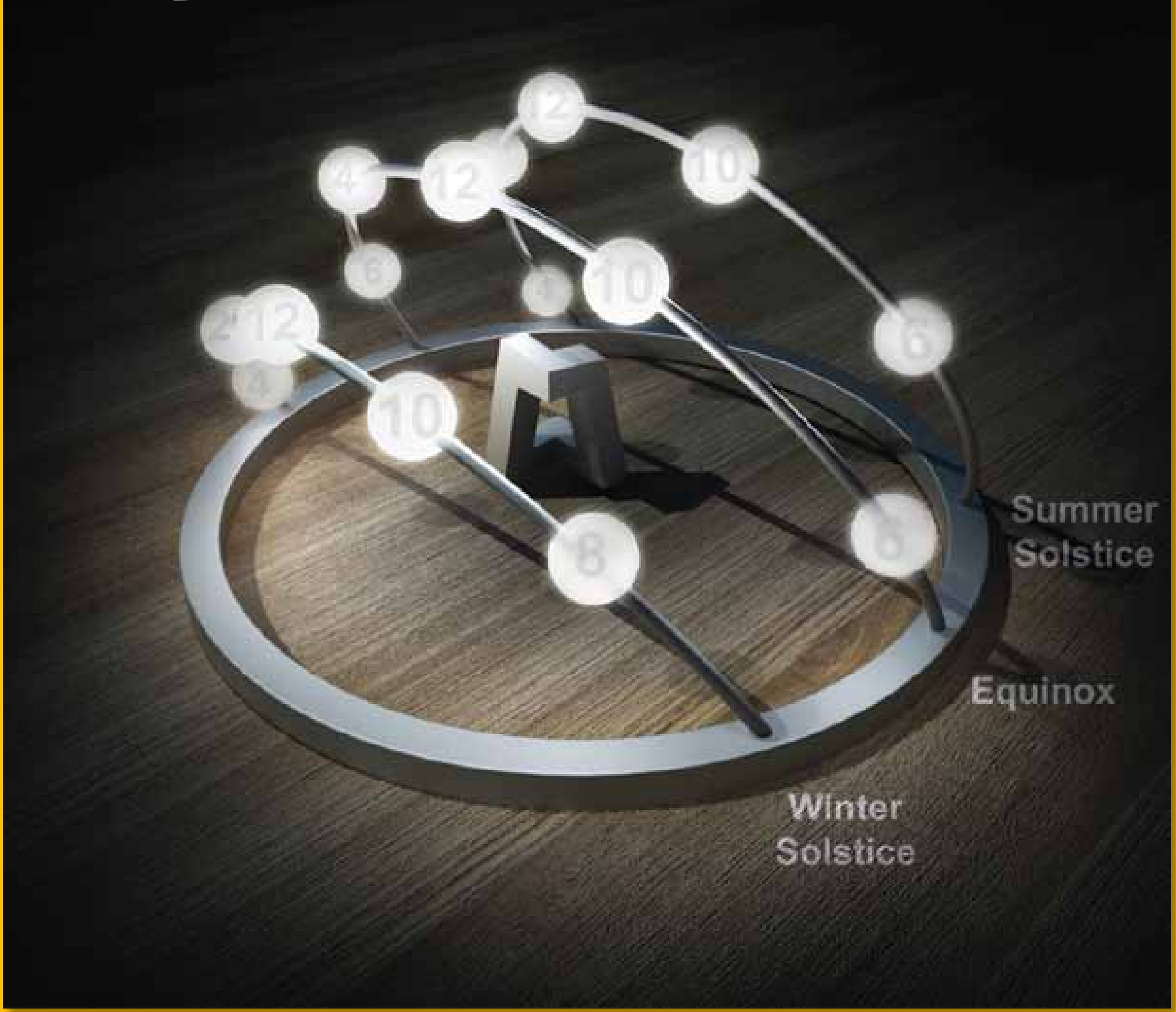


Figure 5.1: Solar azimuth and altitude angles. *Azimuth* angles are measured in each direction from south (for example, northeast = 135° E). *Altitude* angles are measured vertically from the horizon. *(Reproduced from Moore, 1985, by permission.)*

HCL


vertical surface
V
Z
earth-sun line
vertical
surface
N
W
tilted surface
Σ = tilt angle
solar altitude
β
θ
H
0
horizontal
surface
Φ
γ
solar azimuth
ψ
E
S
P

Sky Dome


12
10
4
12
10
6
6
2
12
10
4
6
8
Summer Solstice
Equinox
Winter Solstice

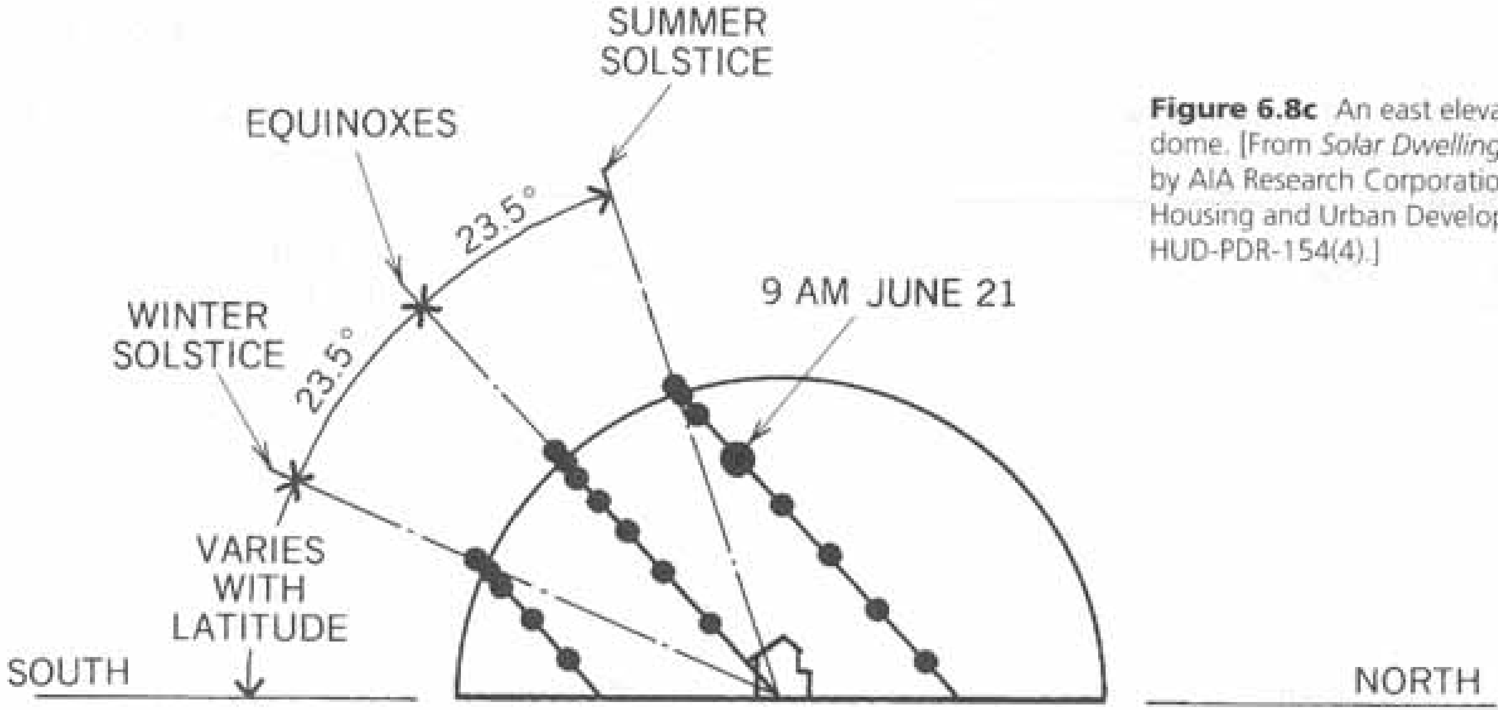


Figure 6.8c An east elevation of the sky dome. [From *Solar Dwelling Design Concepts* by AIA Research Corporation. U.S. Dept. Housing and Urban Development, 1976. HUD-PDR-154(4).]

HCL

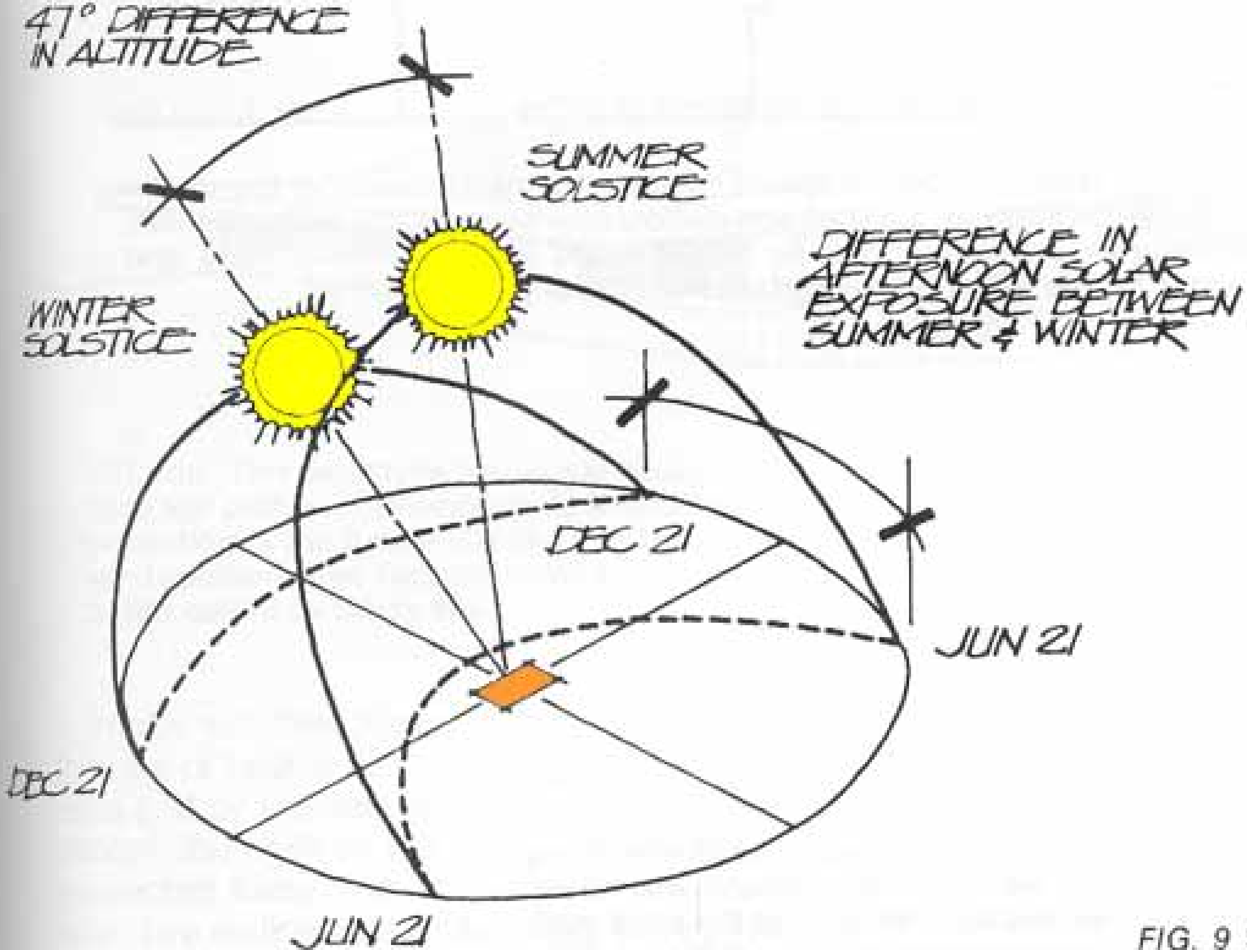


FIG. 9 Sunpath diagram illustrates that the only meaningful orientation for winter sun exposure is south. In summer, east and west exposures are the worst villains for overheating.

CBD

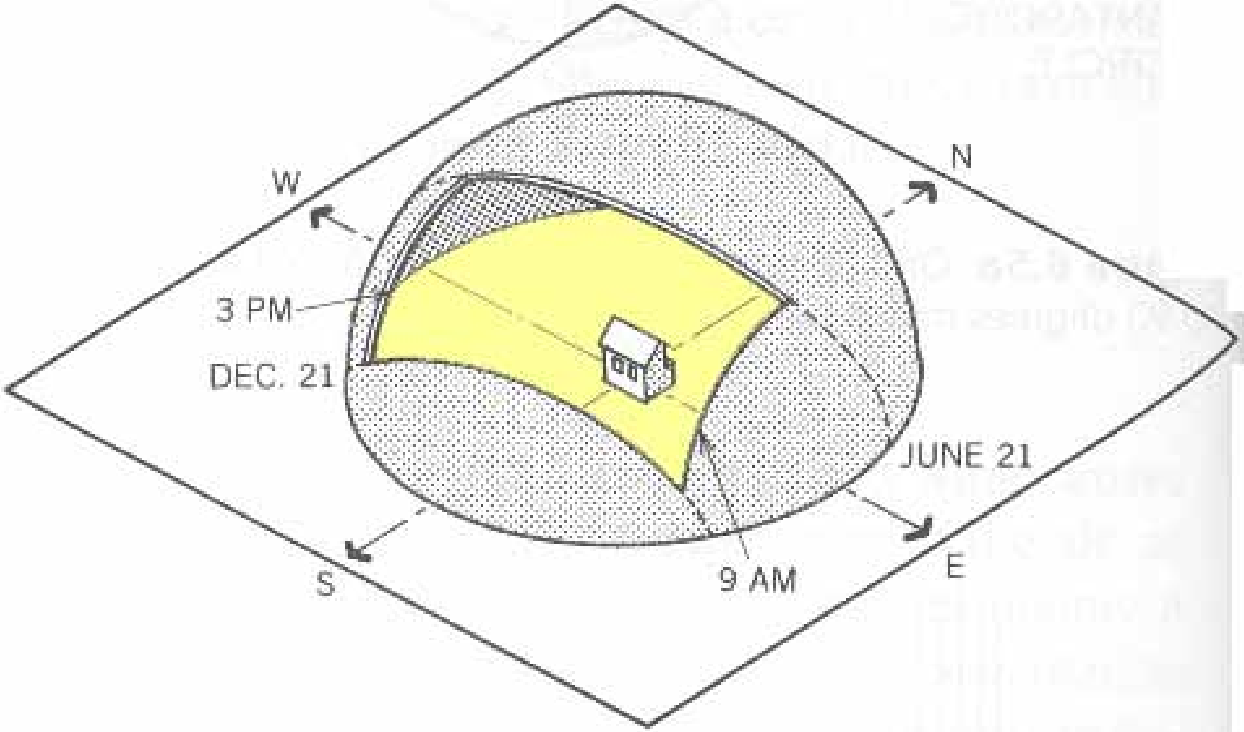
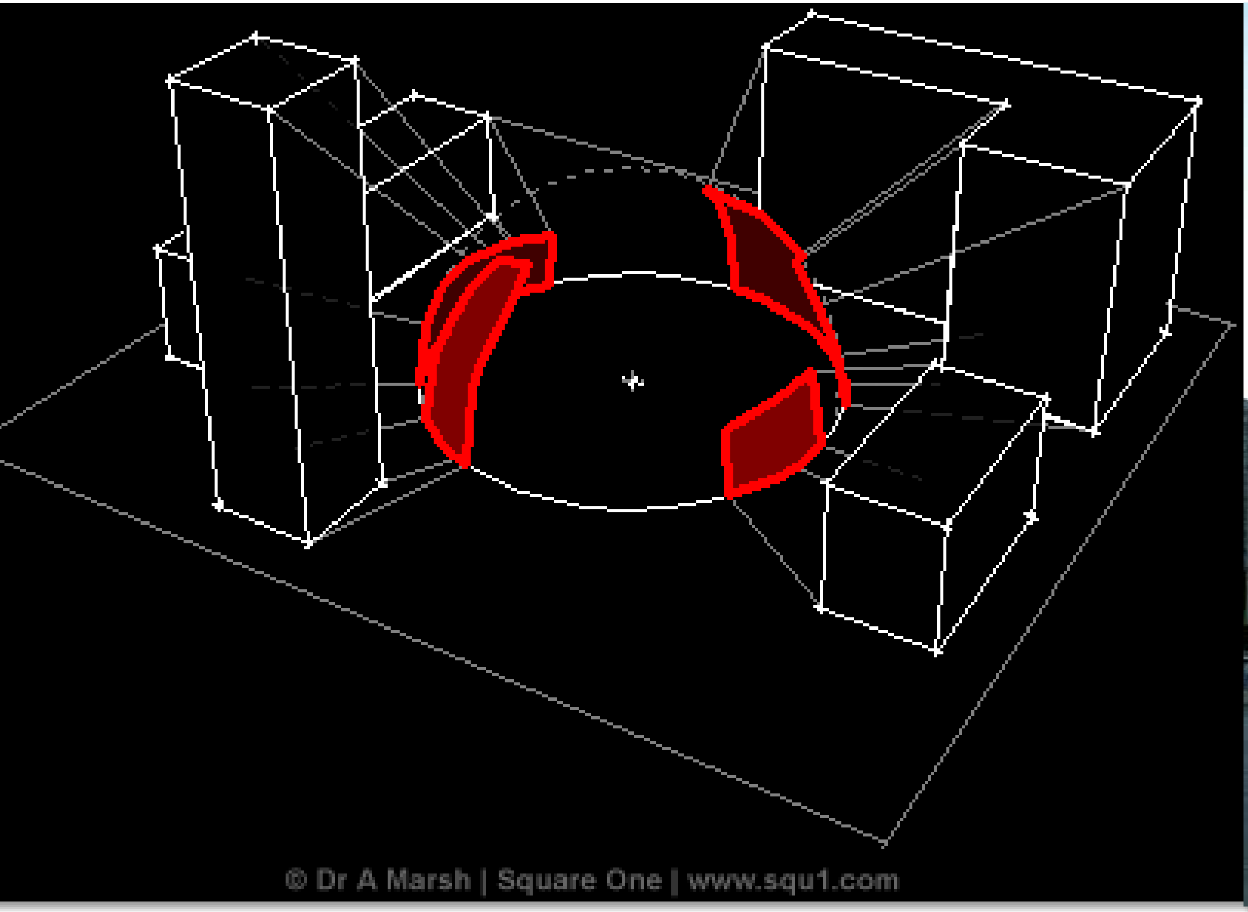


Figure 6.8b The solar window from about 9 A.M. to about 3 P.M.

HCL

- Space Heating - lower half of solar window, mostly desired in winter only
- Domestic Hot Water Heating - all year round

Surrounding buildings affect the view from the site to the sky.



As well as cast shadows on the site.

Derivation of Sun Path Diagrams

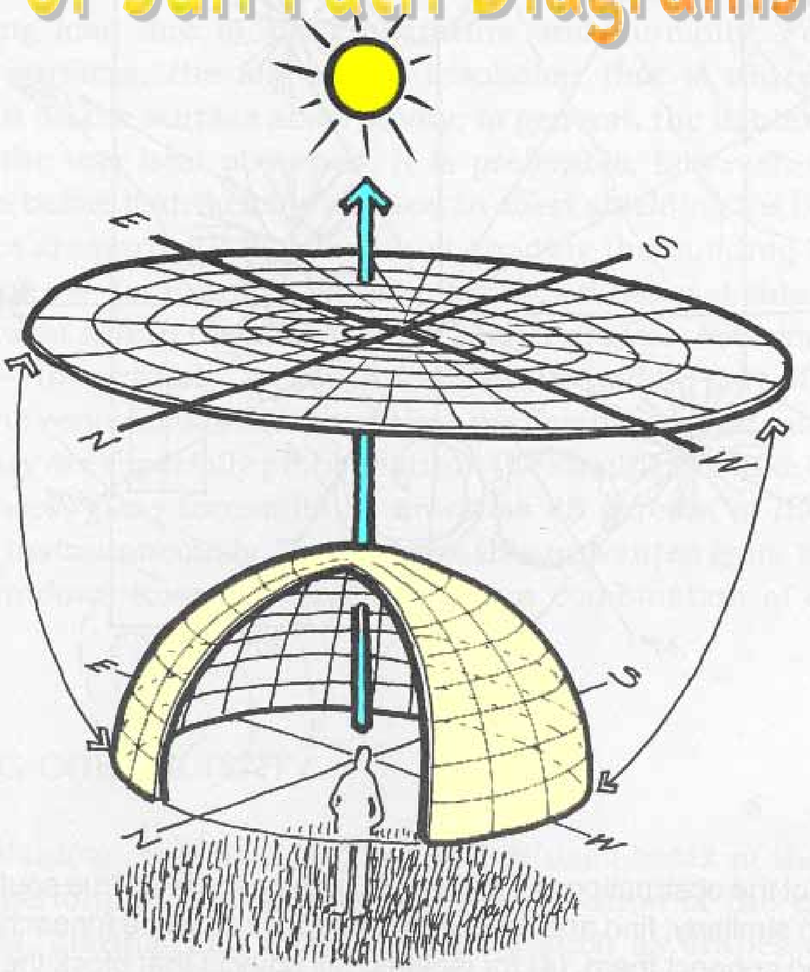


Figure 5.8: Sky dome, with equidistant plan projection showing azimuth and altitude coordinates. *(Reproduced from Moore, 1985, by permission.)*

HCL

Horizontal Projection Sun Path Diagram

Vertical Projection Sun Path Diagram

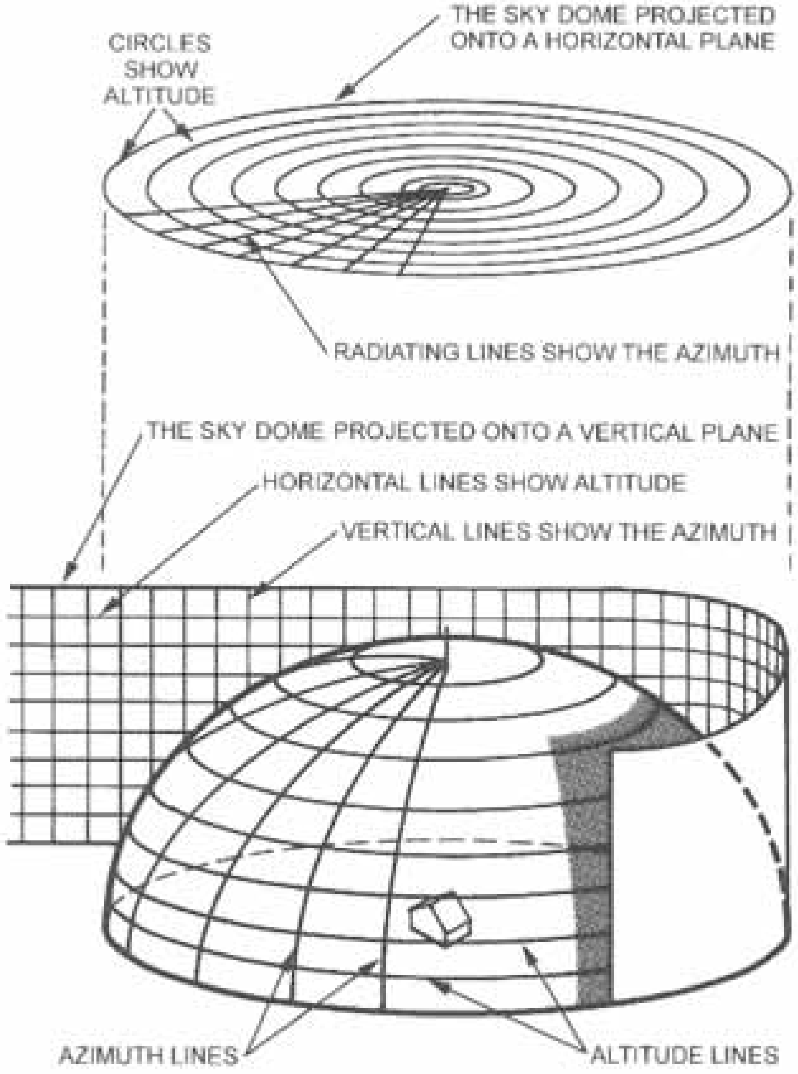


Figure 6.11a Derivation of the horizontal and vertical sun path diagrams.

HCL

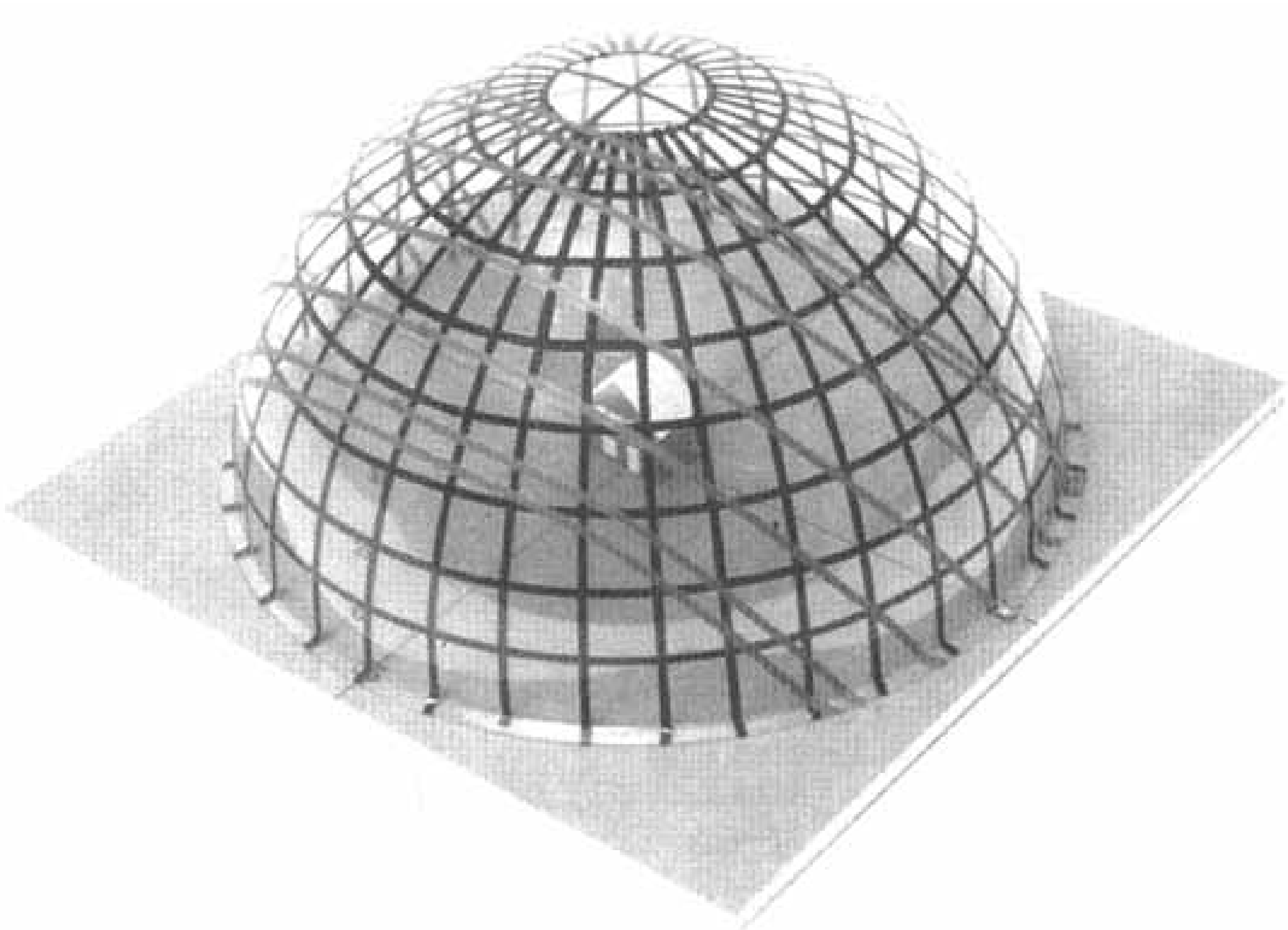


Figure 6.11b A model of the sky dome. The sun paths for the 21st day of each month are shown. Only seven paths are needed for twelve months because of symmetry (i.e., May 21 is the same path as July 21.

HCL

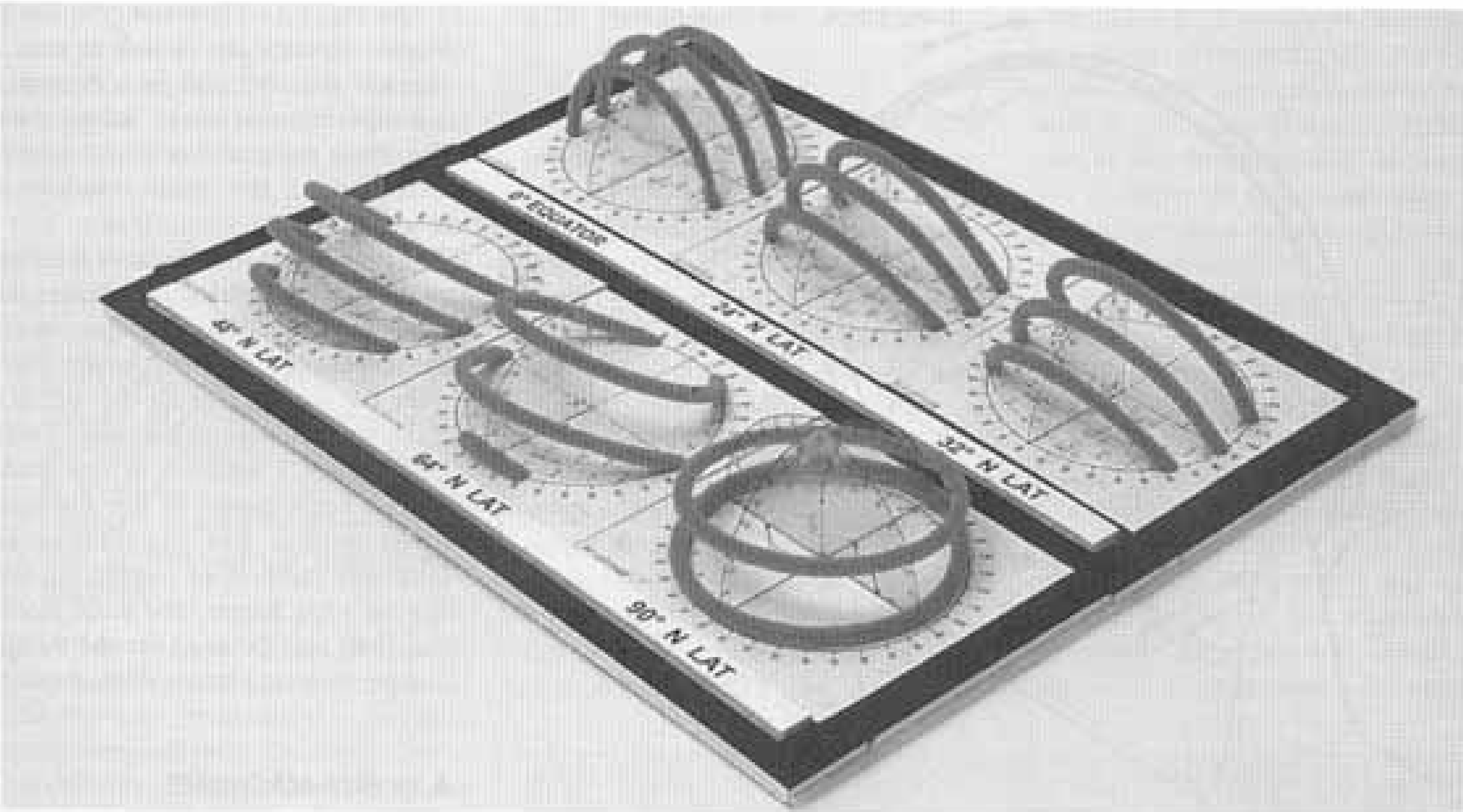
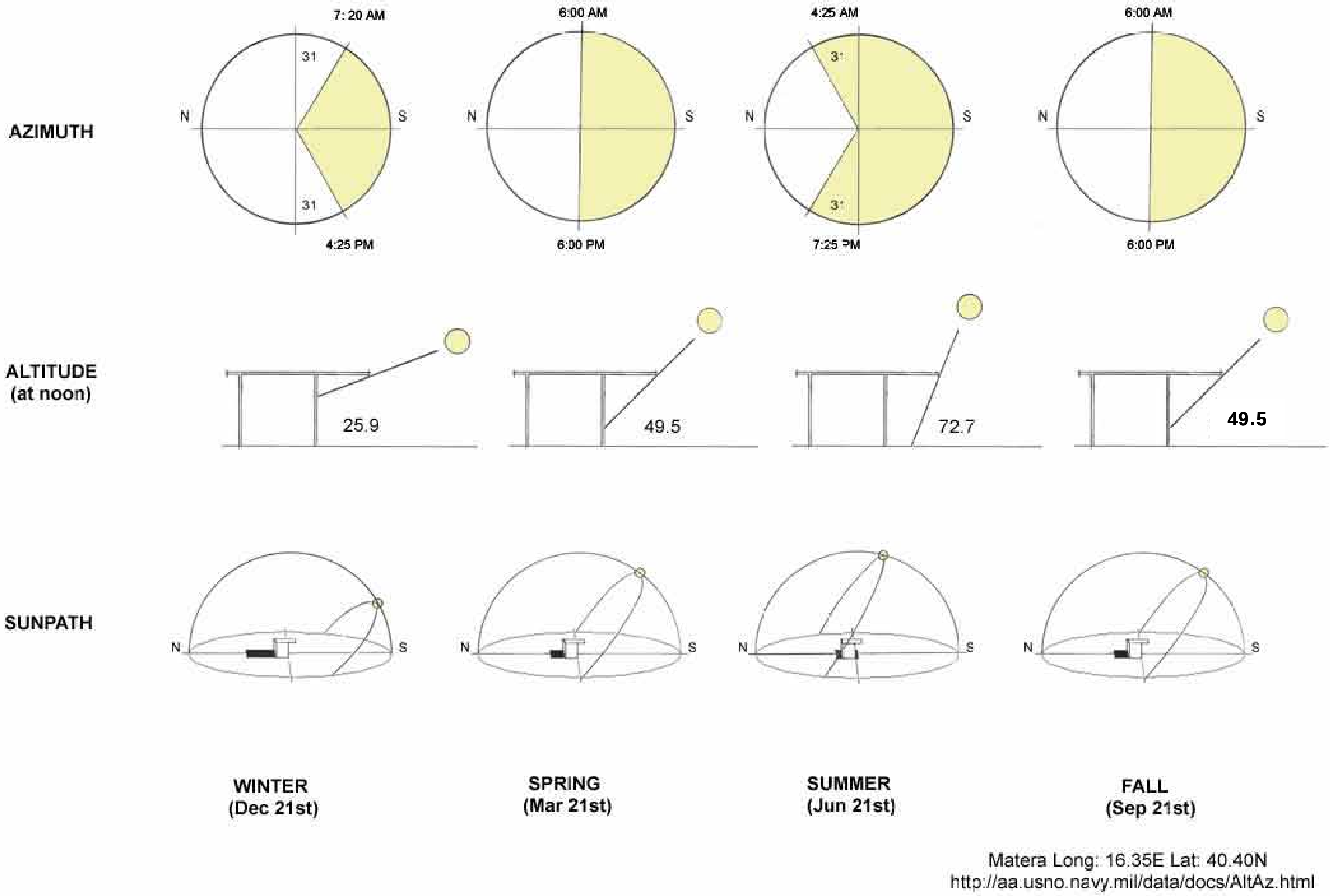
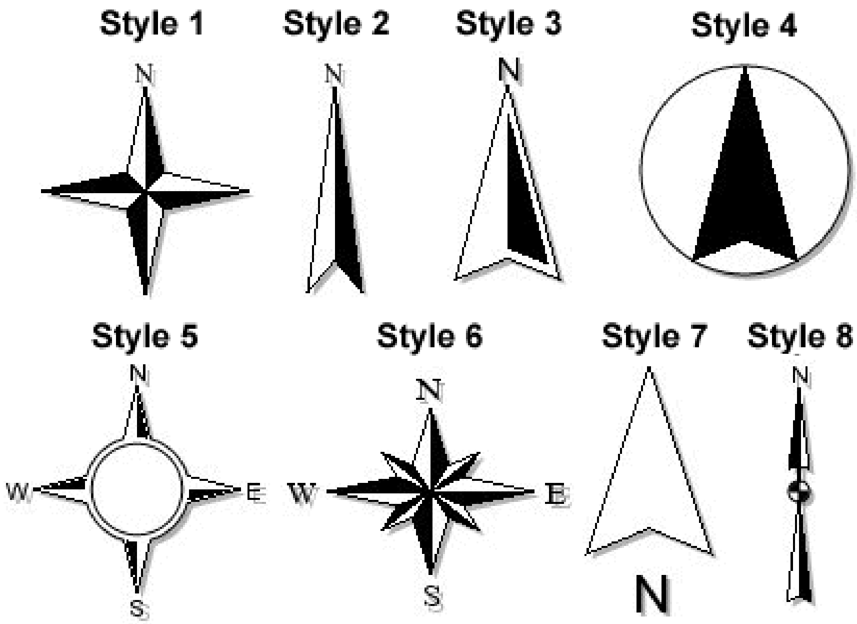


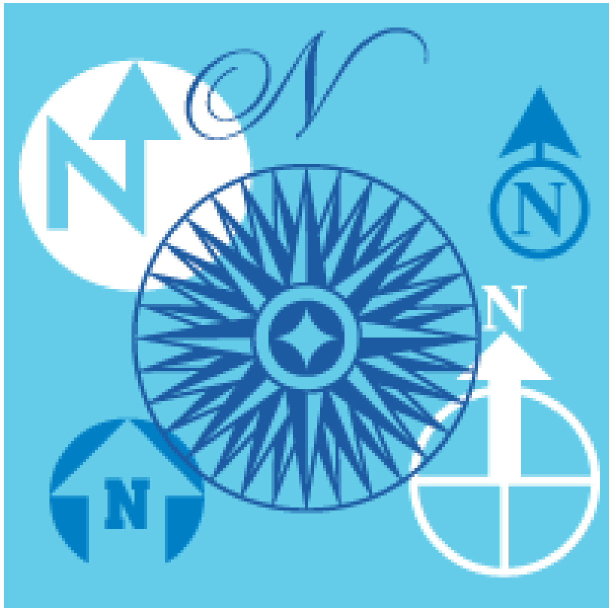
Figure 6.13 A comparison of various sun-path models. Note especially the sun paths for the Equator, Tropic of Cancer, Arctic Circle, and North Pole.

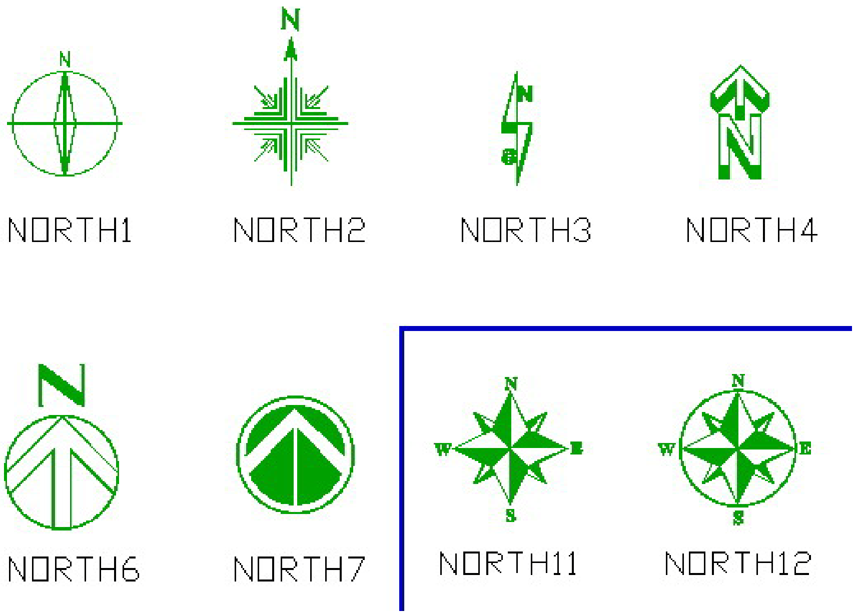
HCL



You should be able to construct this set of diagrams for *any site* you are working on.

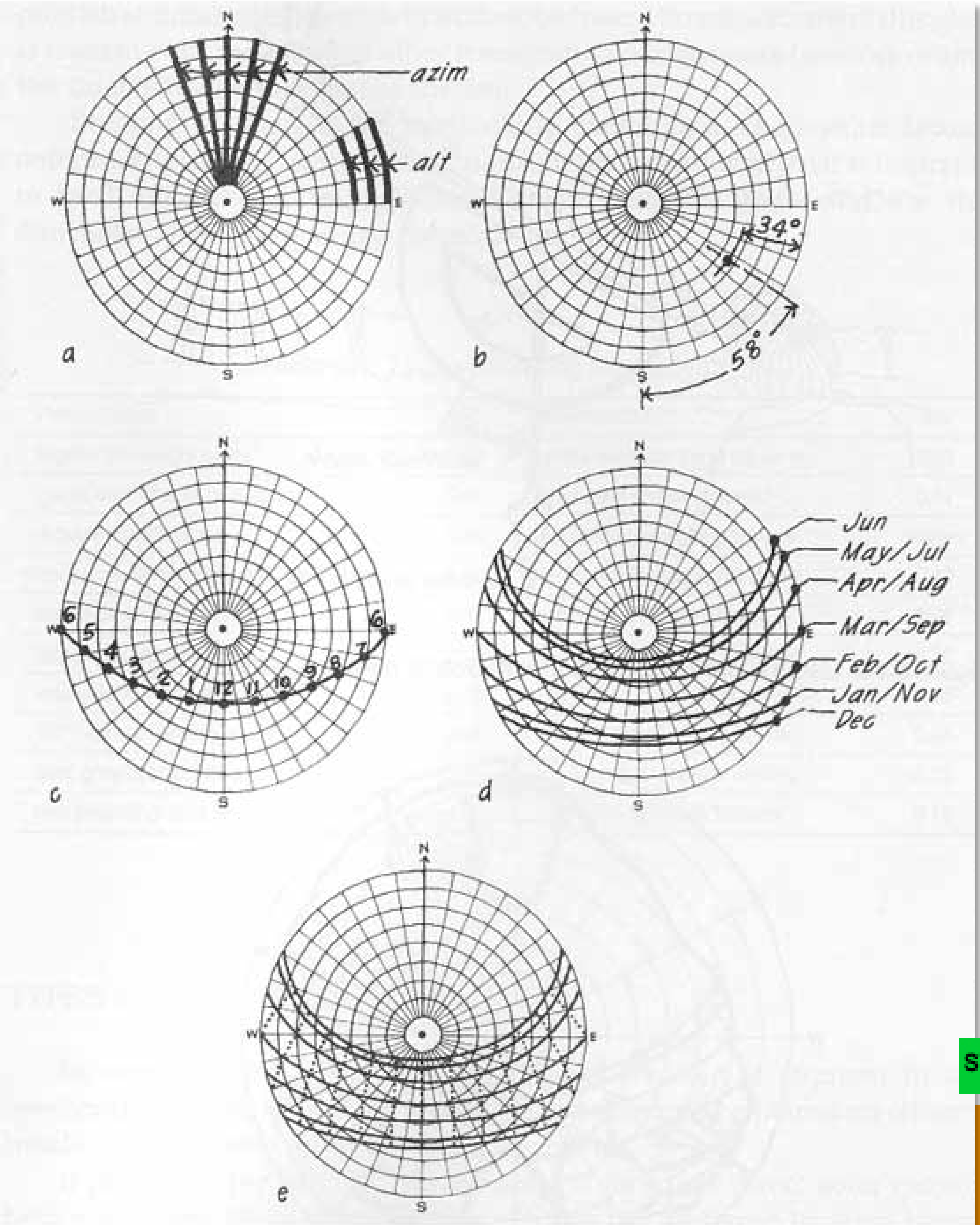






Designing for solar conditions requires that you are aware of the orientation of the site. If you don't have one of these on your plan *from the beginning*, then, *you are not aware.*

Sun Path Diagrams



These are "aerial plan views" of the skydome.

Notice that the sun is symmetrical about the solstices, so we get the same lines for the spring and fall months.

SWL

Horizontal Projection Sun Path Diagram

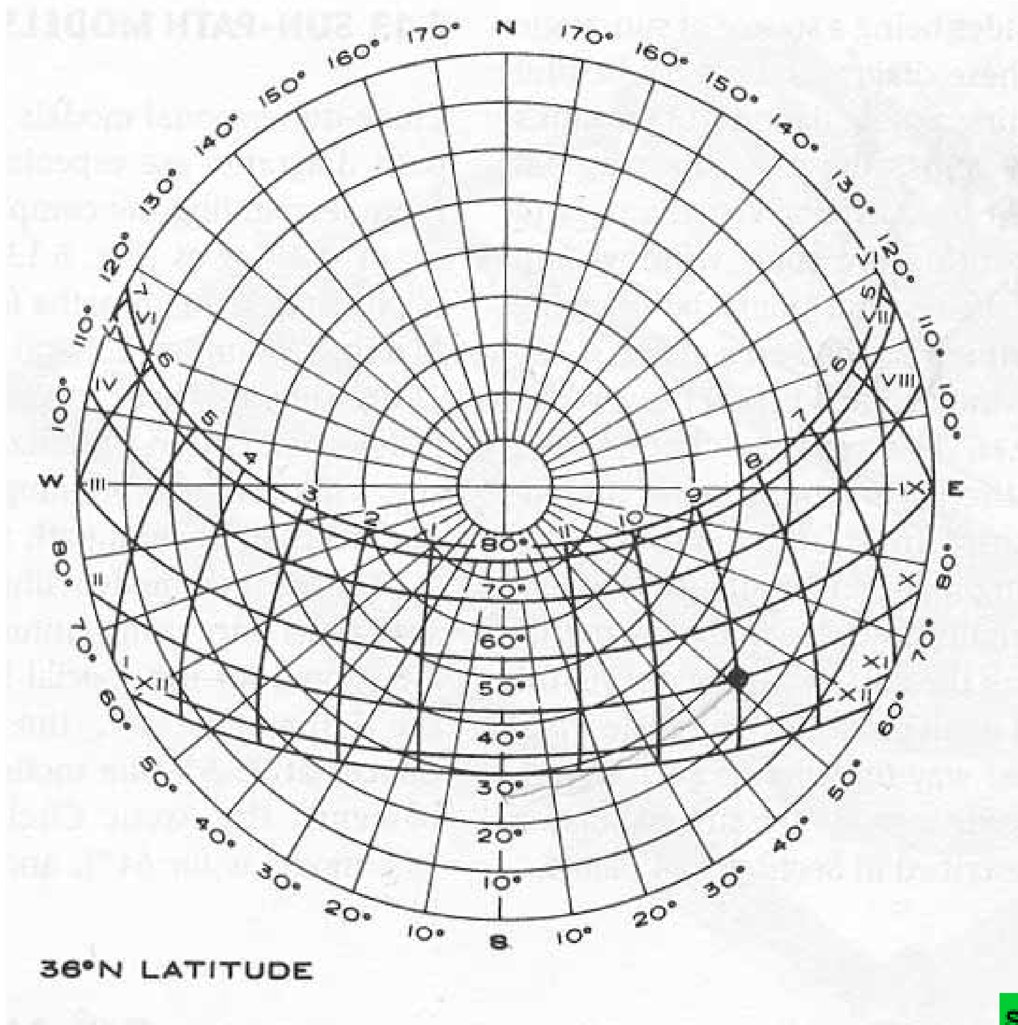
Example: Find the altitude and azimuth of the sun in Memphis, Tennessee, on February 21 at 9 A.M.

Step 1. From a map of the United States, find the latitude of Memphis. Since it is at about 35 degrees latitude, use the sun-path diagram for 36 degrees north latitude (found in Appendix A and Fig. 6.11c).

Step 2. On this sun-path diagram, find the intersection of the sun path for February 21 (curve II) and the 9 A.M. line. This represents the location of the sun. The intersection is circled in Fig. 6.11c.

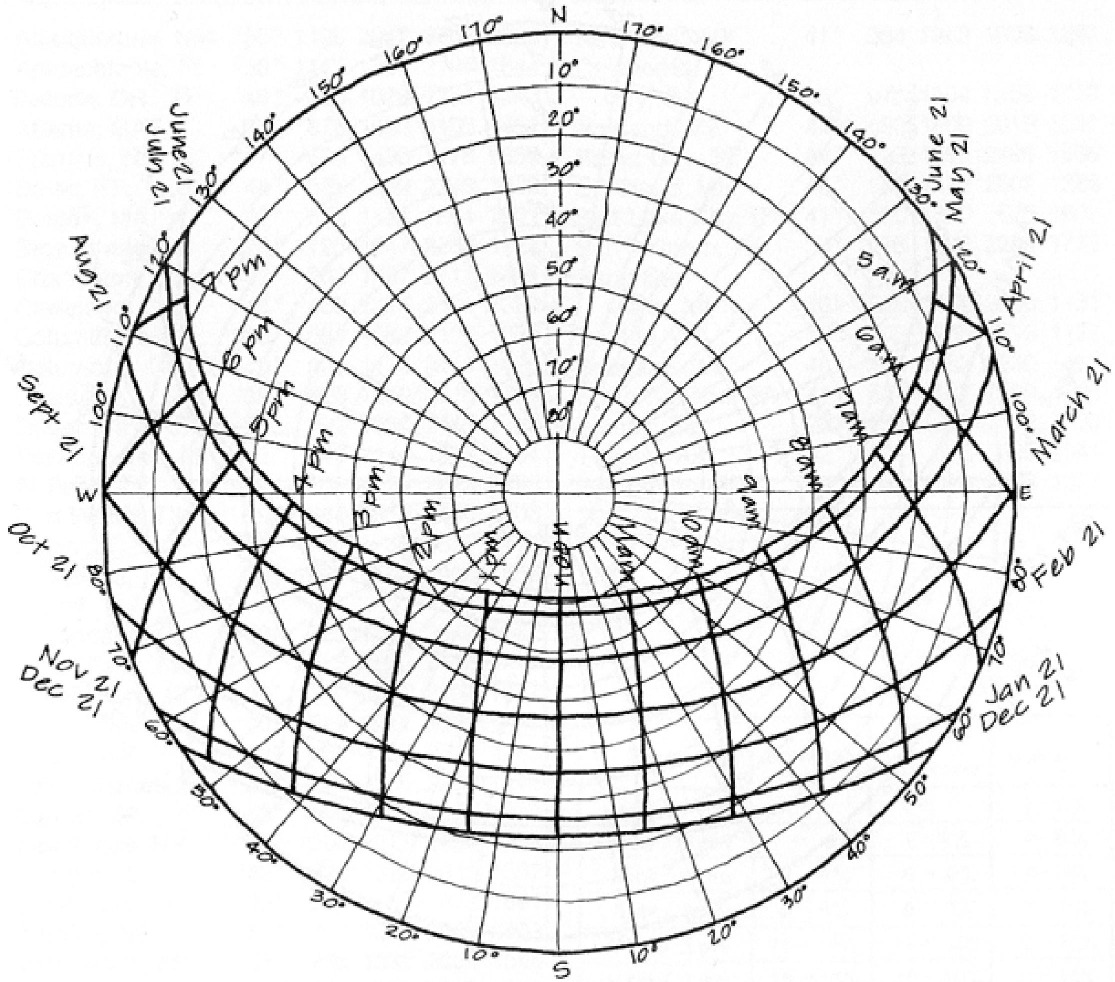
Step 3. From the concentric circles, the altitude is found to be about 27 degrees.

Step 4. From the radial lines, the azimuth is found to be about 51 degrees east of south.



SWL

These diagrams always use “solar noon” as 12:00. You need to look at the local time conditions to see how this aligns to the actual time.

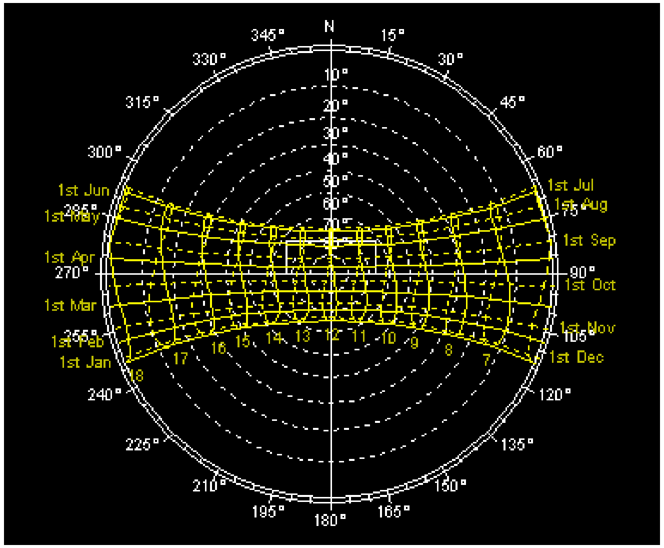


Sun Path Diagram 44° North Latitude

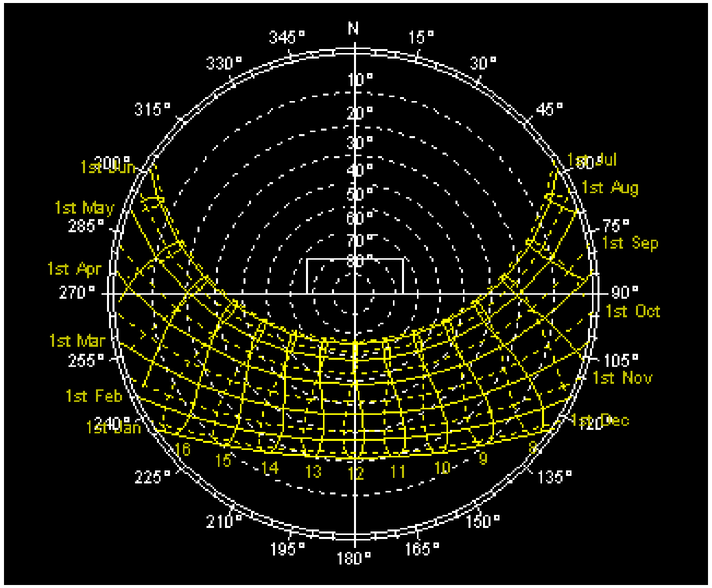
SWL

Toronto Latitude: 43° 40‘ North

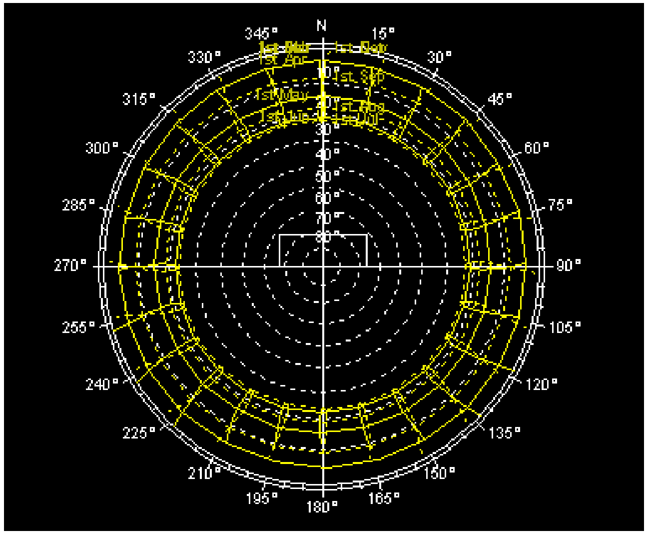
Kitchener Latitude: 43° 27‘ North



Equator



45 degrees N



North Pole

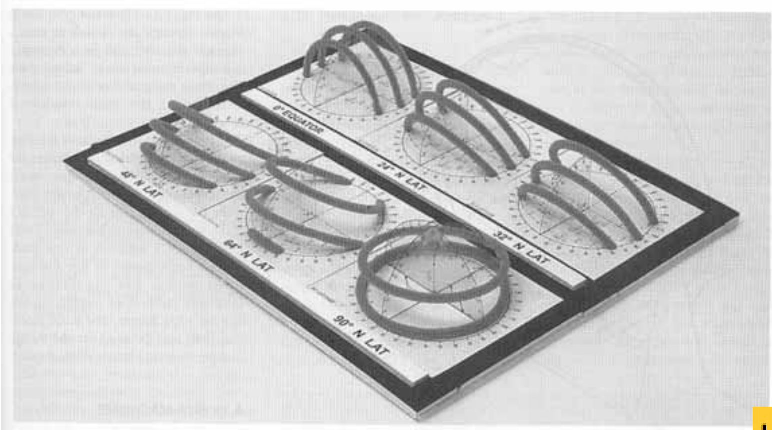


Figure 6.13 A comparison of various sun-path models. Note especially the sun paths for the Equator, Tropic of Cancer, Arctic Circle, and North Pole.

HCL

Vertical Projection Sun Path Diagram

Example: Find the altitude and azimuth of a sun ray in Albuquerque, New Mexico, on March 21 at 3 P.M.

Step 1. From Appendix B, choose the sun-path diagram that is within 2 degrees of the place in question. Since Albuquerque is at 35°N latitude, use the sun path for 36°N.

Step 2. Find the intersection of the curves for March 21 and 3 P.M. (see circle in Fig. 6.12a).

Step 3. From the horizontal scale, the azimuth is found to be about 59° *west* of south.

Step 4. From the vertical scale, the altitude is found to be about 34° above the horizontal.

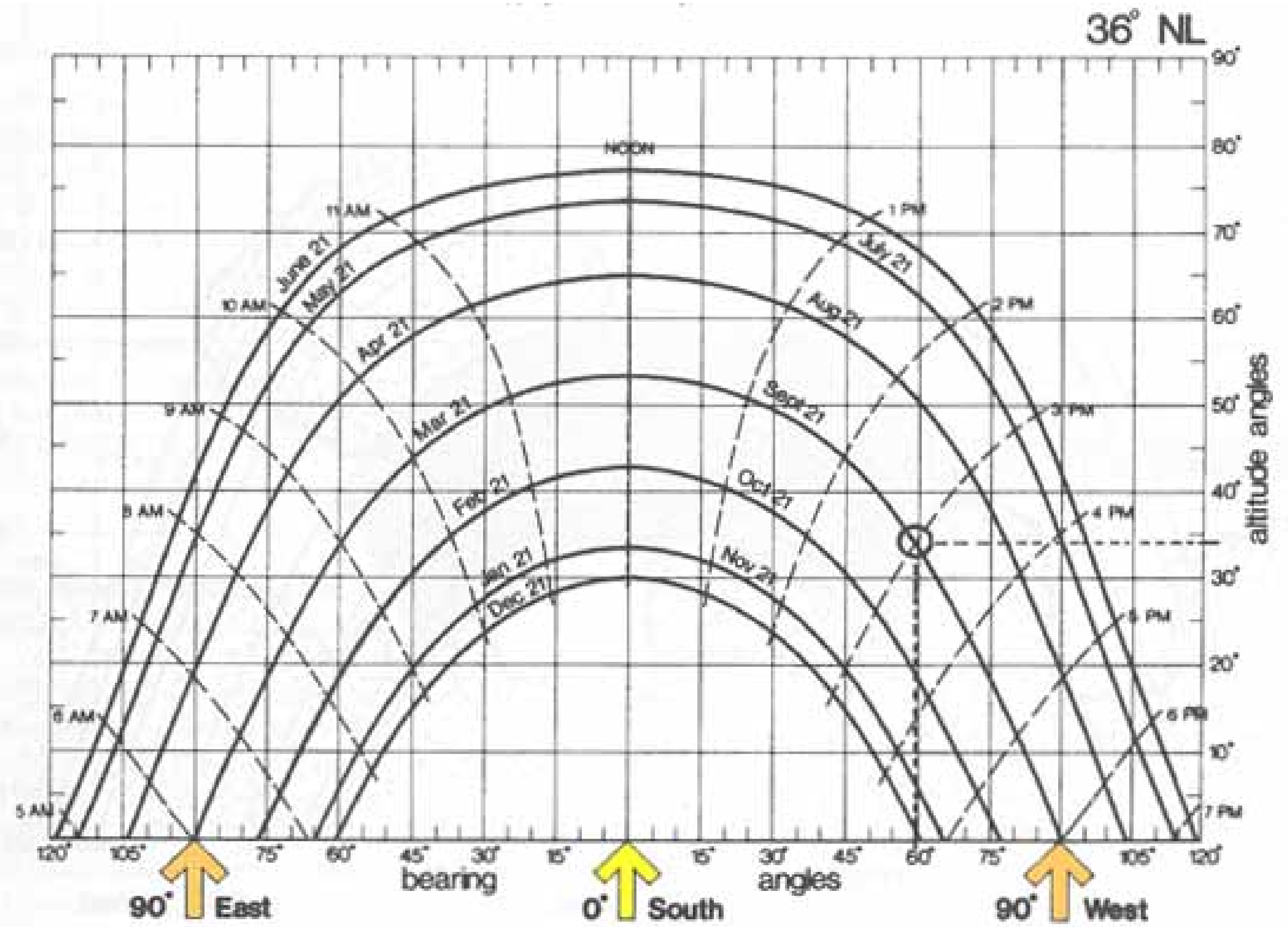


Figure 6.12a Vertical sun path diagram. A complete set of these diagrams is found in Appendix B. (Reprinted from *The Passive Solar Energy Book*, copyright E. Mazria, 1979, by permission.)

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We use this tool to understand how surrounding buildings and trees will shade our site at various times of the year.

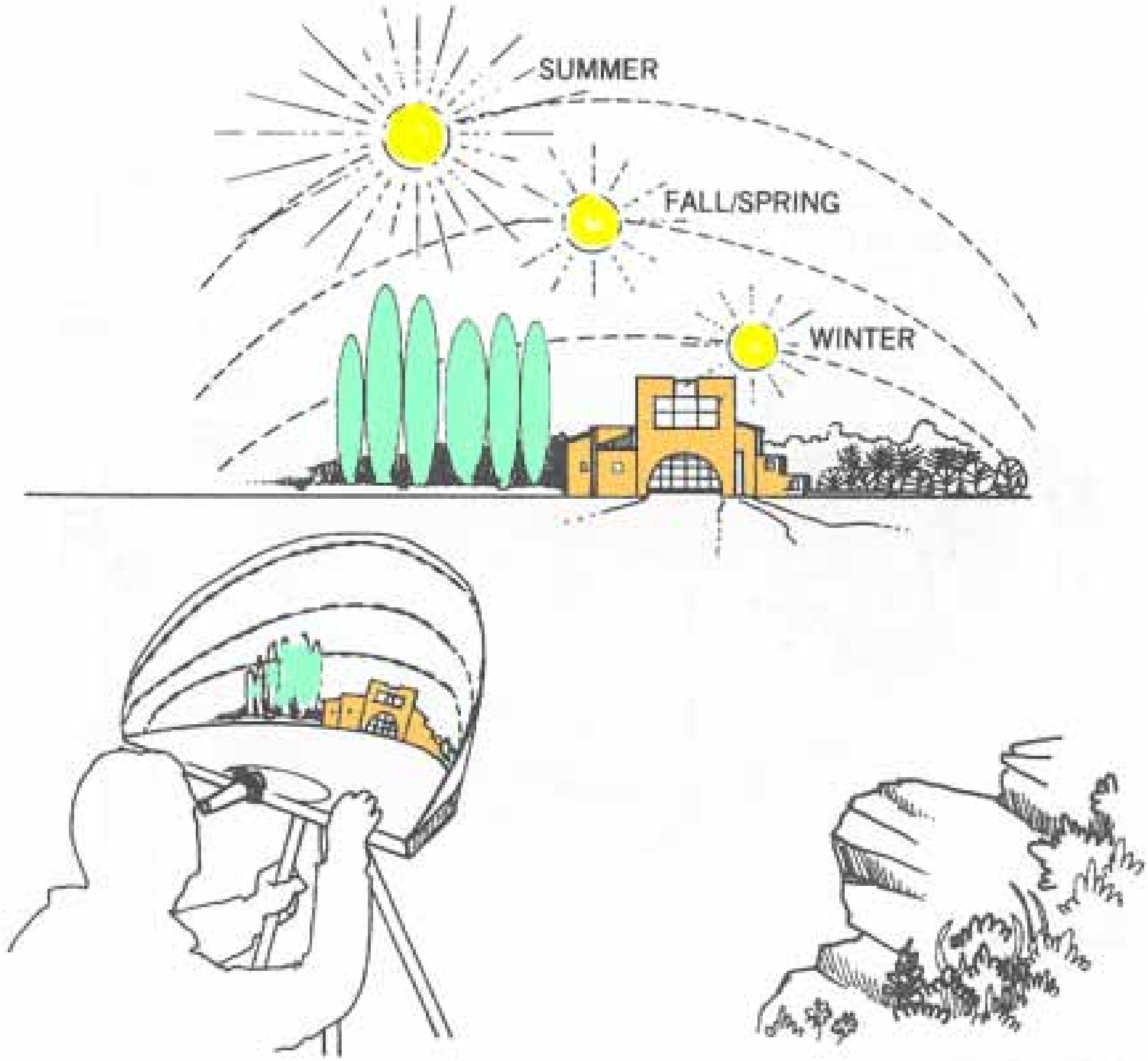

Figure 6.14 The sun-path diagram used as part of a solar site-evaluation tool.

HCL

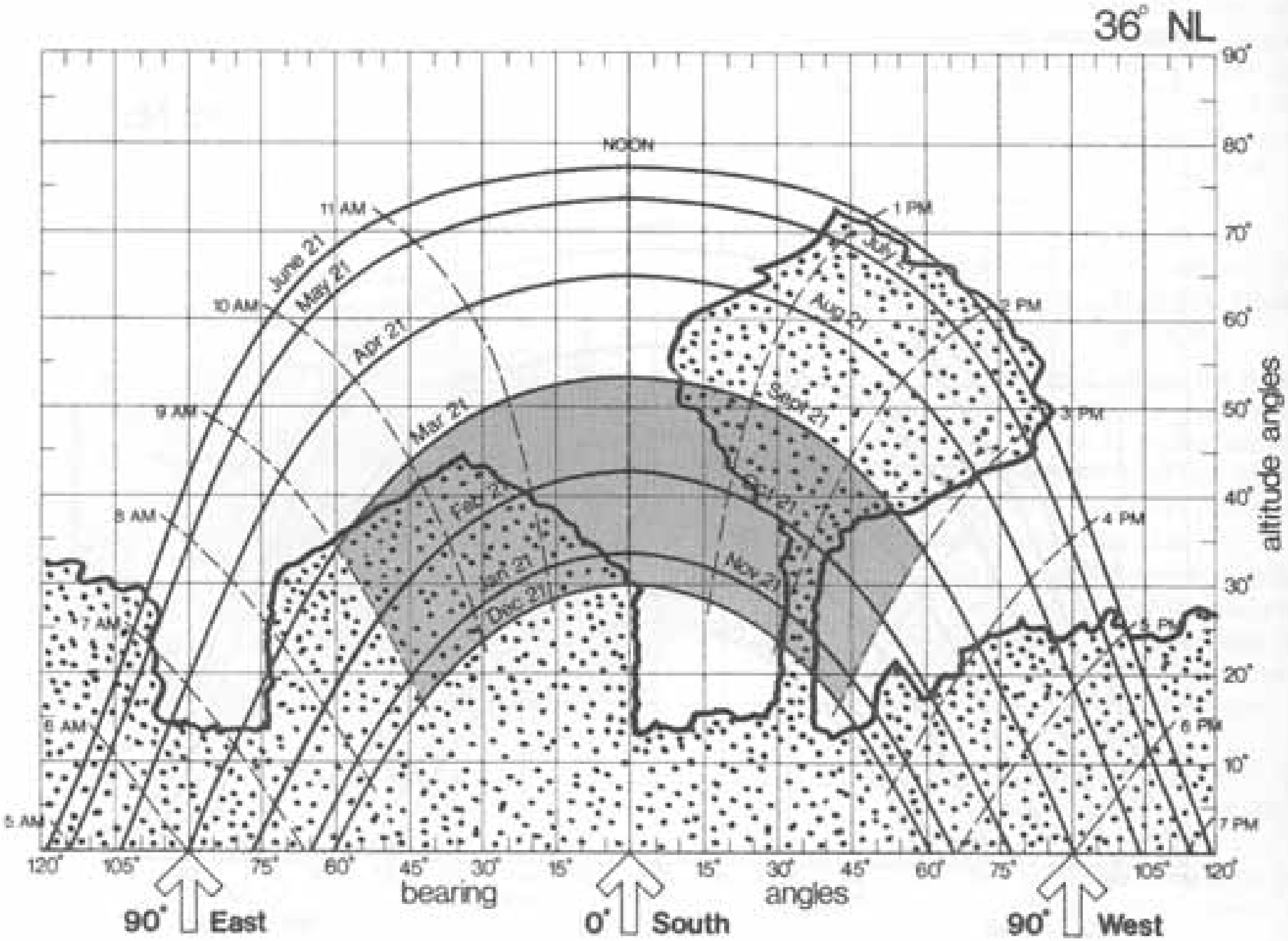

Figure 6.12b The winter solar window and silhouette of surrounding objects are shown on this vertical sun path diagram. The silhouette of a specific location was hand-drawn by means of a site-evaluator tool described in Section 6.14. (Sun path diagram from *The Passive Solar Energy Book*, copyright E. Mazria, 1979, reprinted by permission.)

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Sundials

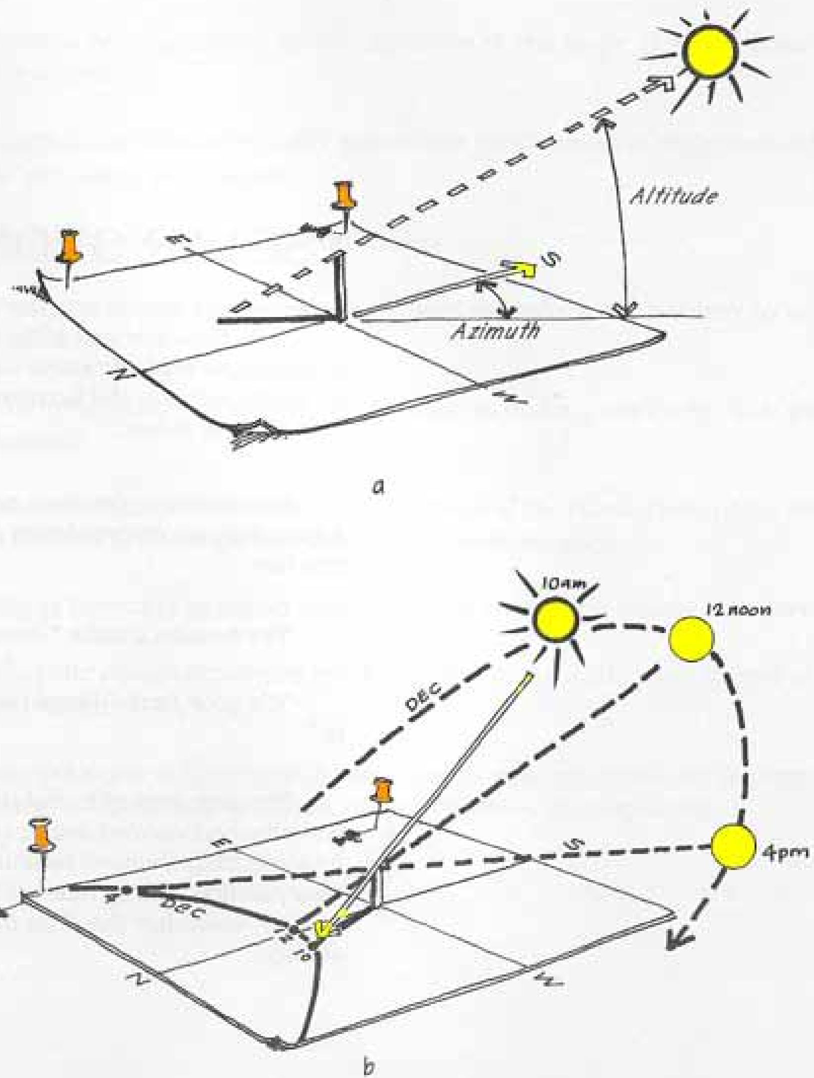

Figure 5.2: (a) Shadow location on a sundial at 2 p.m. December 21, and (b) shadow path for December 21, 40° N latitude. *(Reproduced from Moore, 1985, by permission.)*

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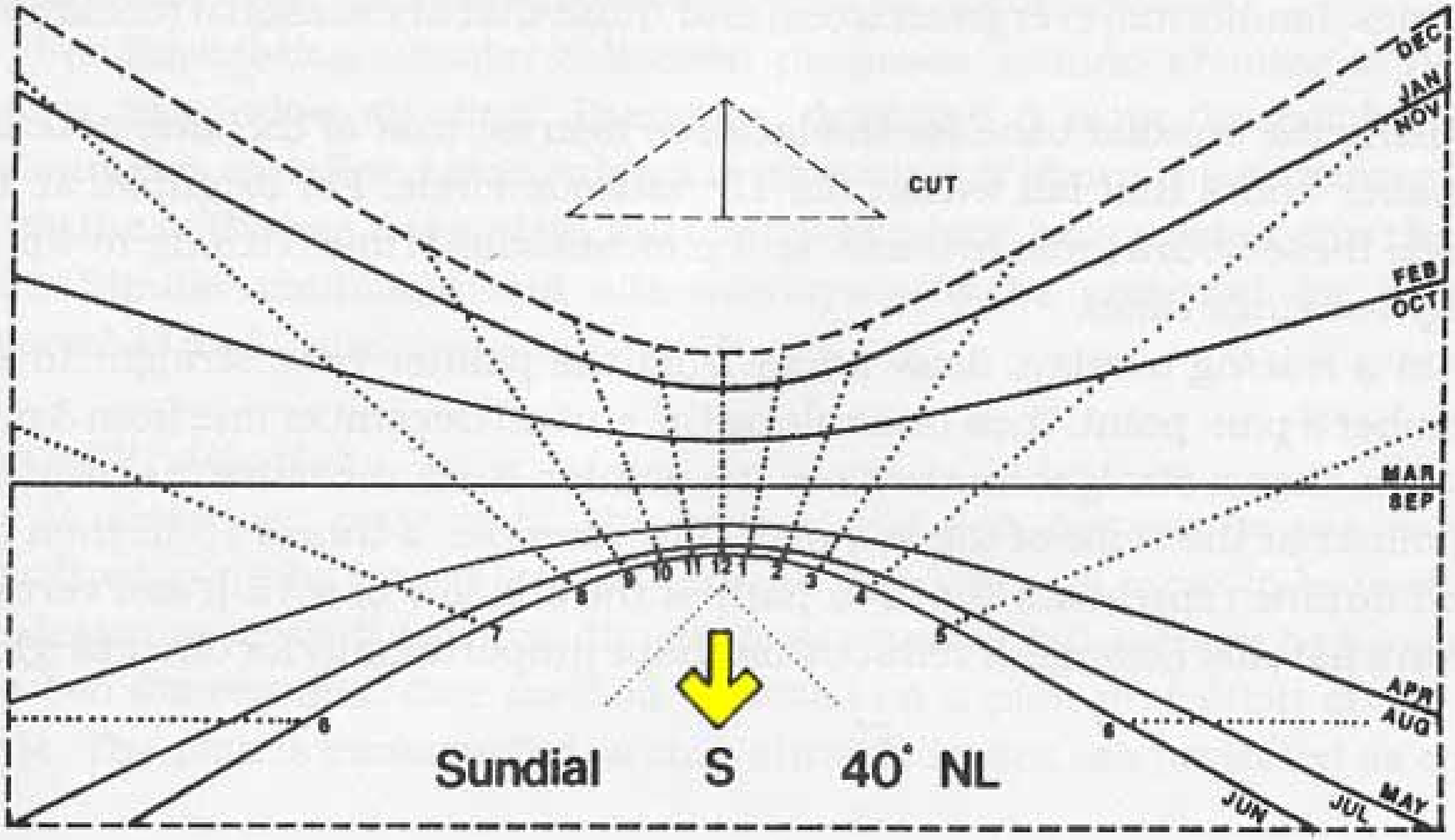


Figure 5.3: Completed sundial for 40° N. latitude. *(Reproduced from Moore, 1985, by permission.)*

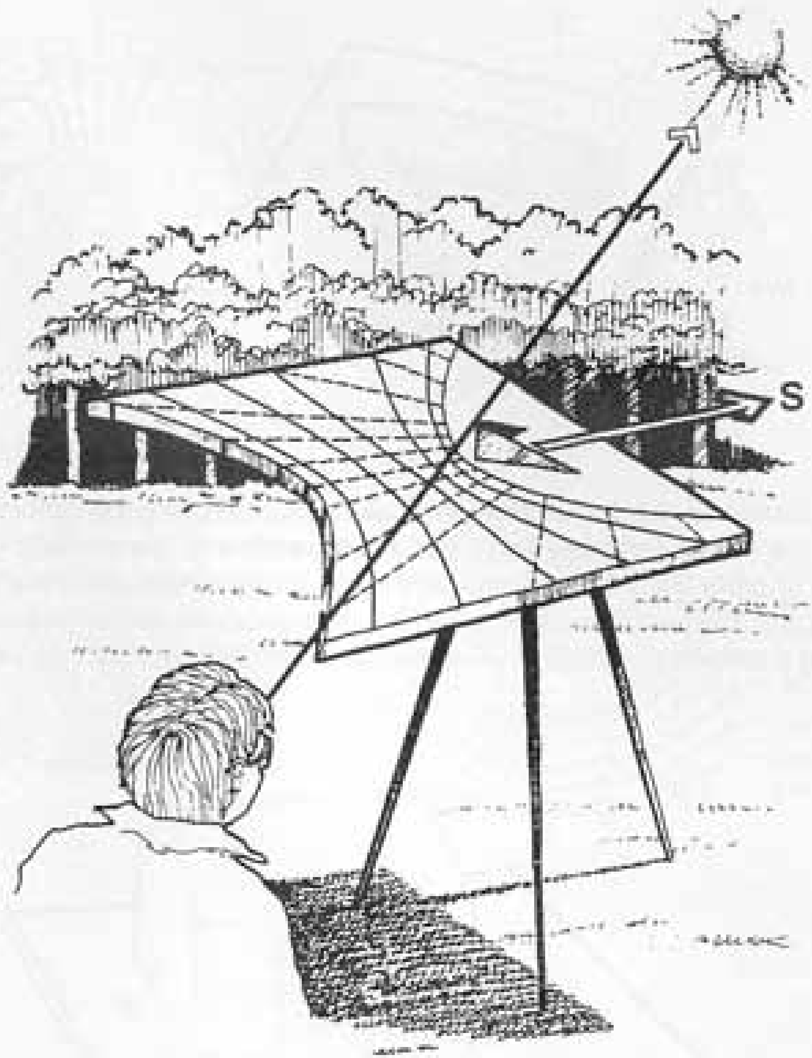
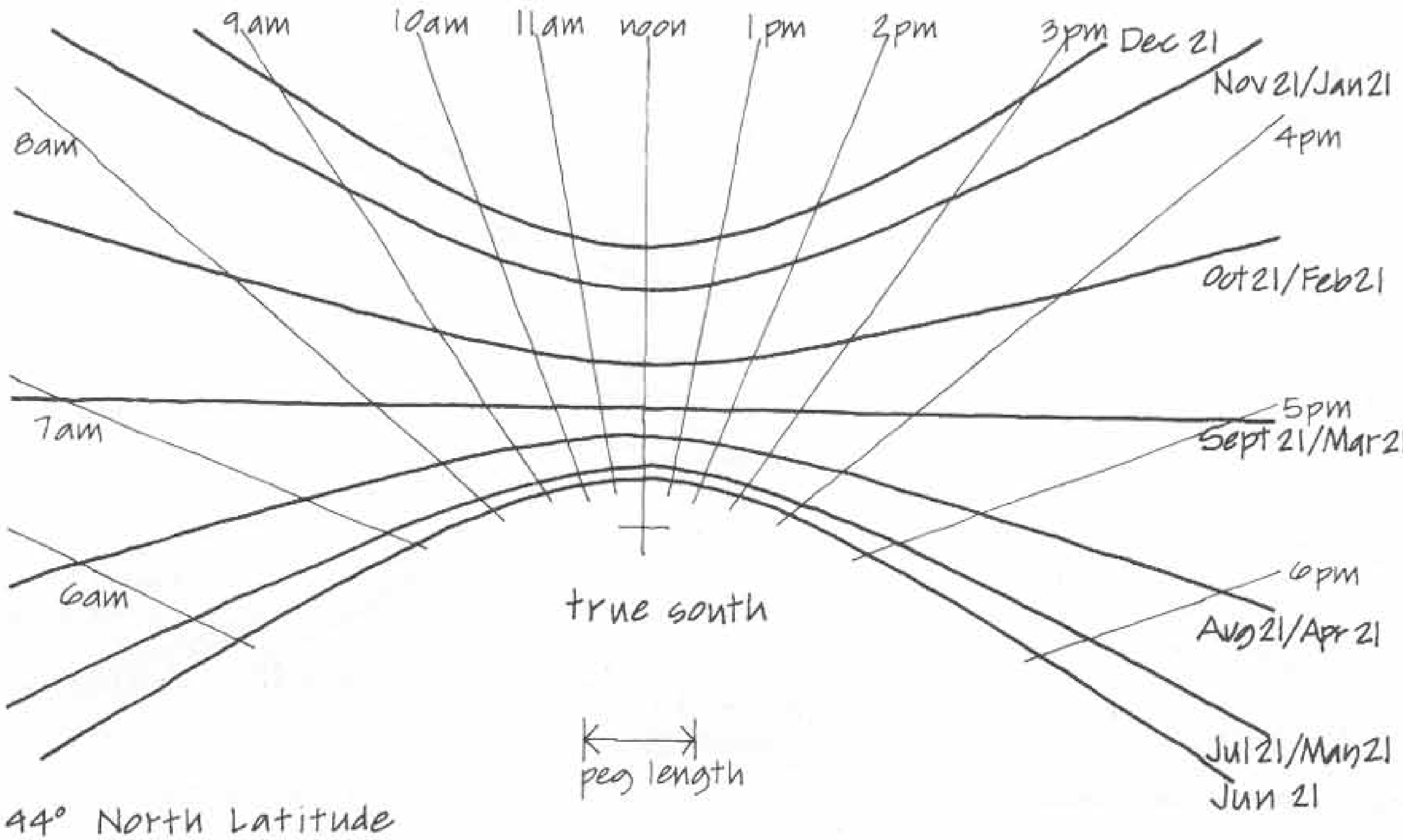


Figure 5.4: Use of sundial for preliminary obstruction survey. The sundial is level and oriented south. Sight from below from north edge, over pointer, to December sun location. *(Reproduced from Moore, 1985, by permission.)*

HCL


9am
10am
11am
noon
1pm
2pm
3pm
Dec 21
Nov21/Jan21
4pm
8am
Oct21/Feb21
5pm
Sept 21/Mar21
7am
6am
6pm
true south
Aug21/Apr21
peg length
Jul21/May21
Jun 21
44° North Latitude

SWL

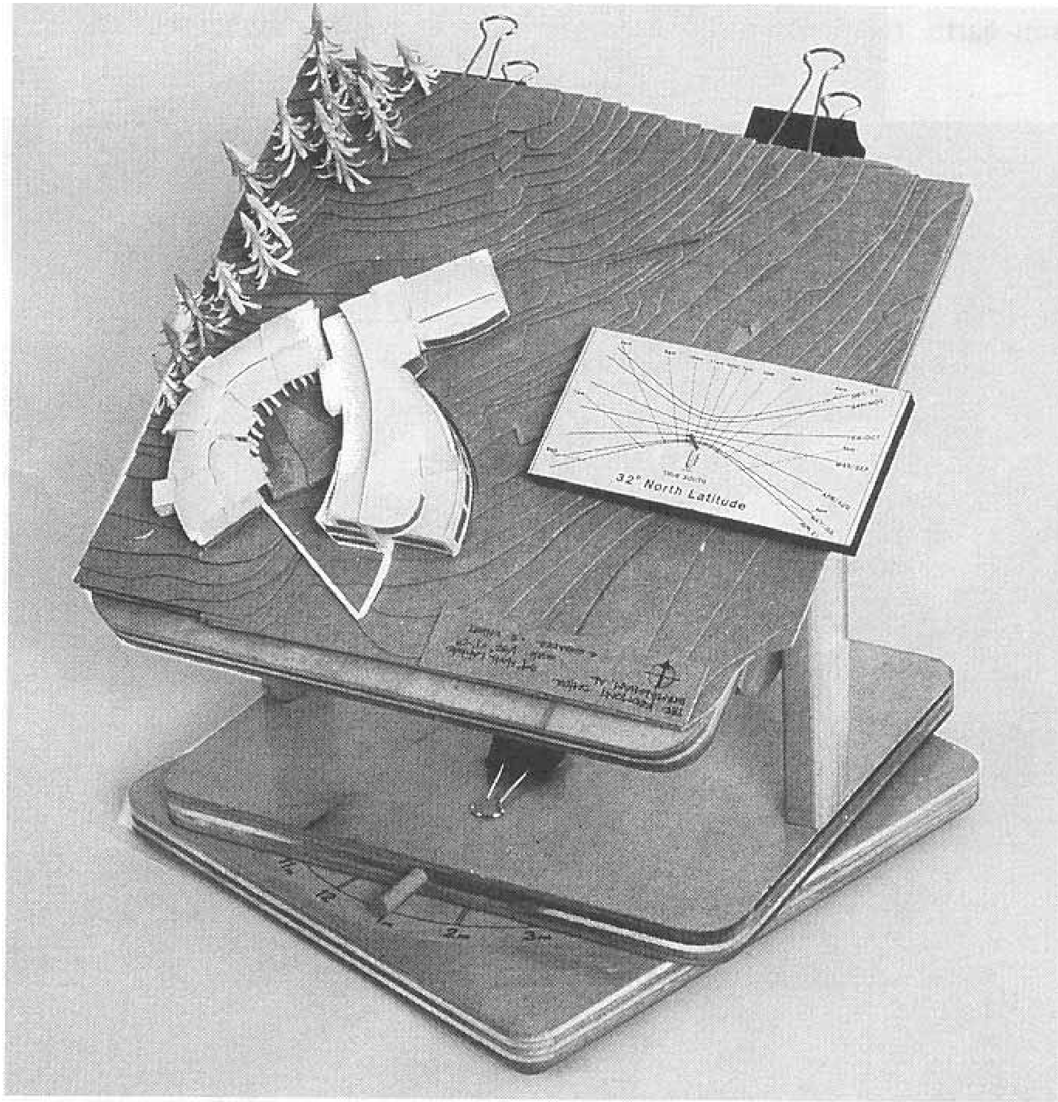
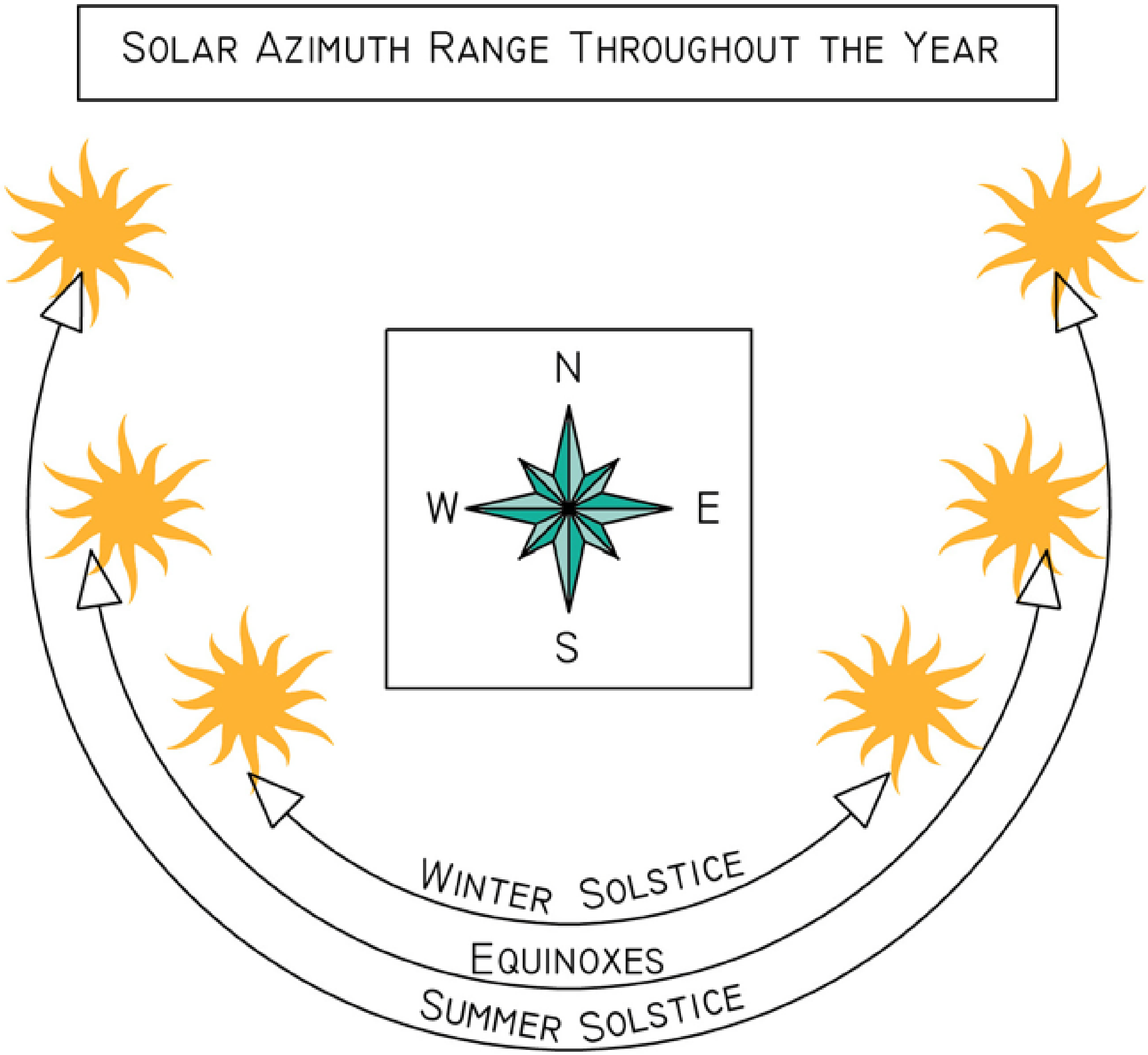


Figure 6.16 Sundials can be used to test models either under sunlight or an artificial light source.

HCL


SOLAR AZIMUTH RANGE THROUGHOUT THE YEAR
N
W
E
S
WINTER SOLSTICE
EQUINOXES
SUMMER SOLSTICE

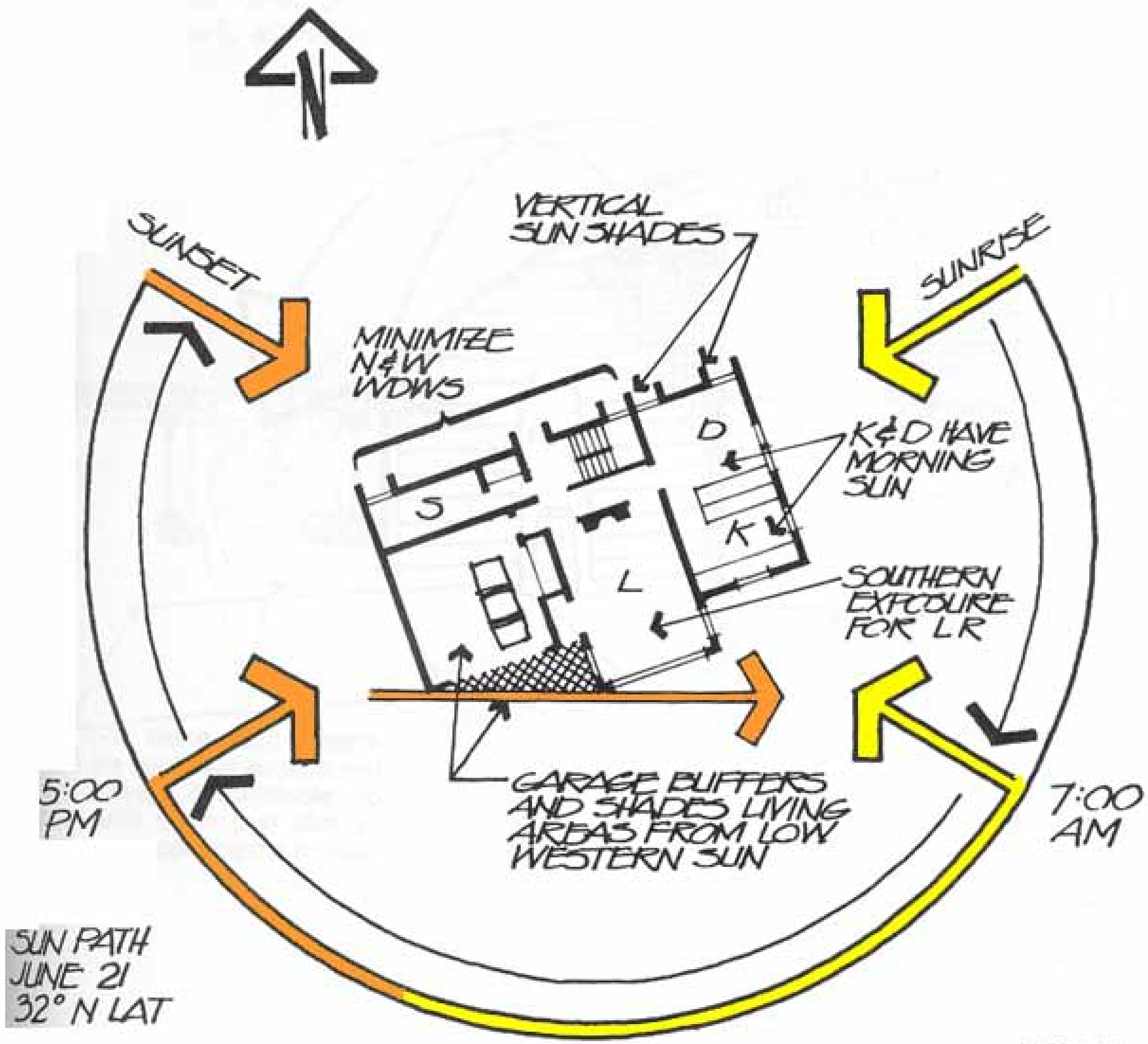


FIG. 21a

We begin to make key layout decisions based upon exposure to sun for heat and light.

CBD

We begin to make key layout decisions based upon exposure to sun for heat and light.

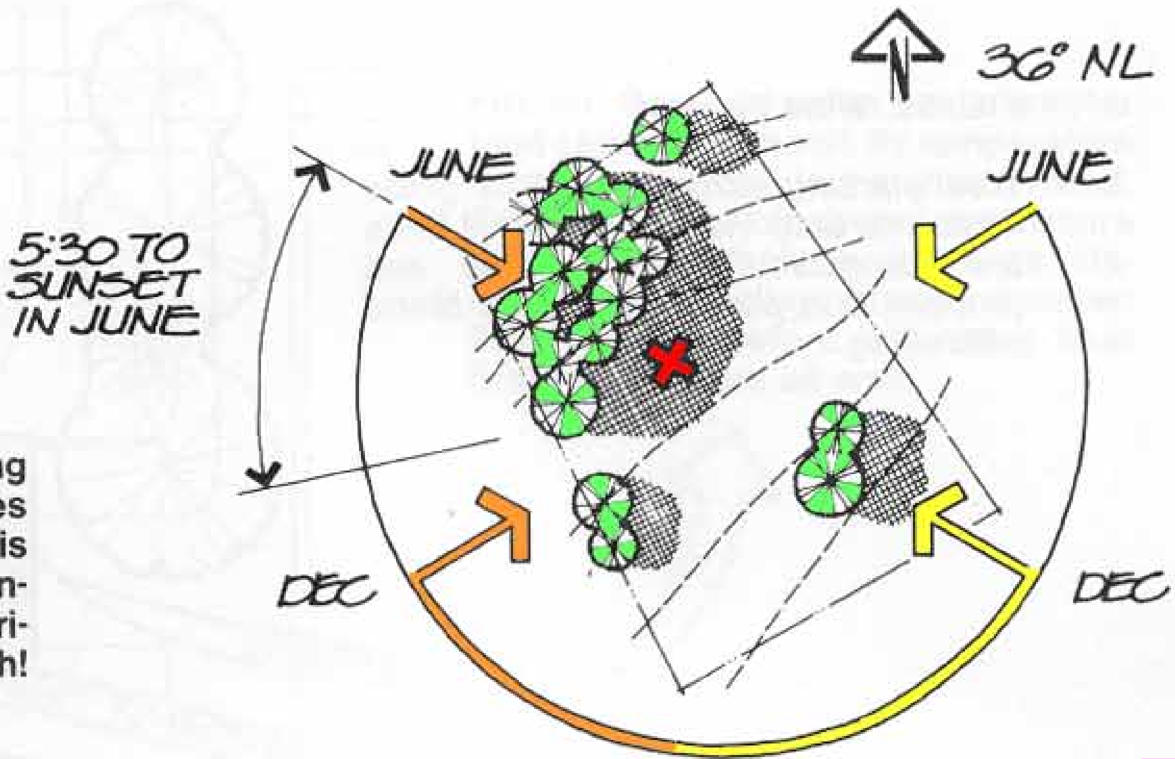
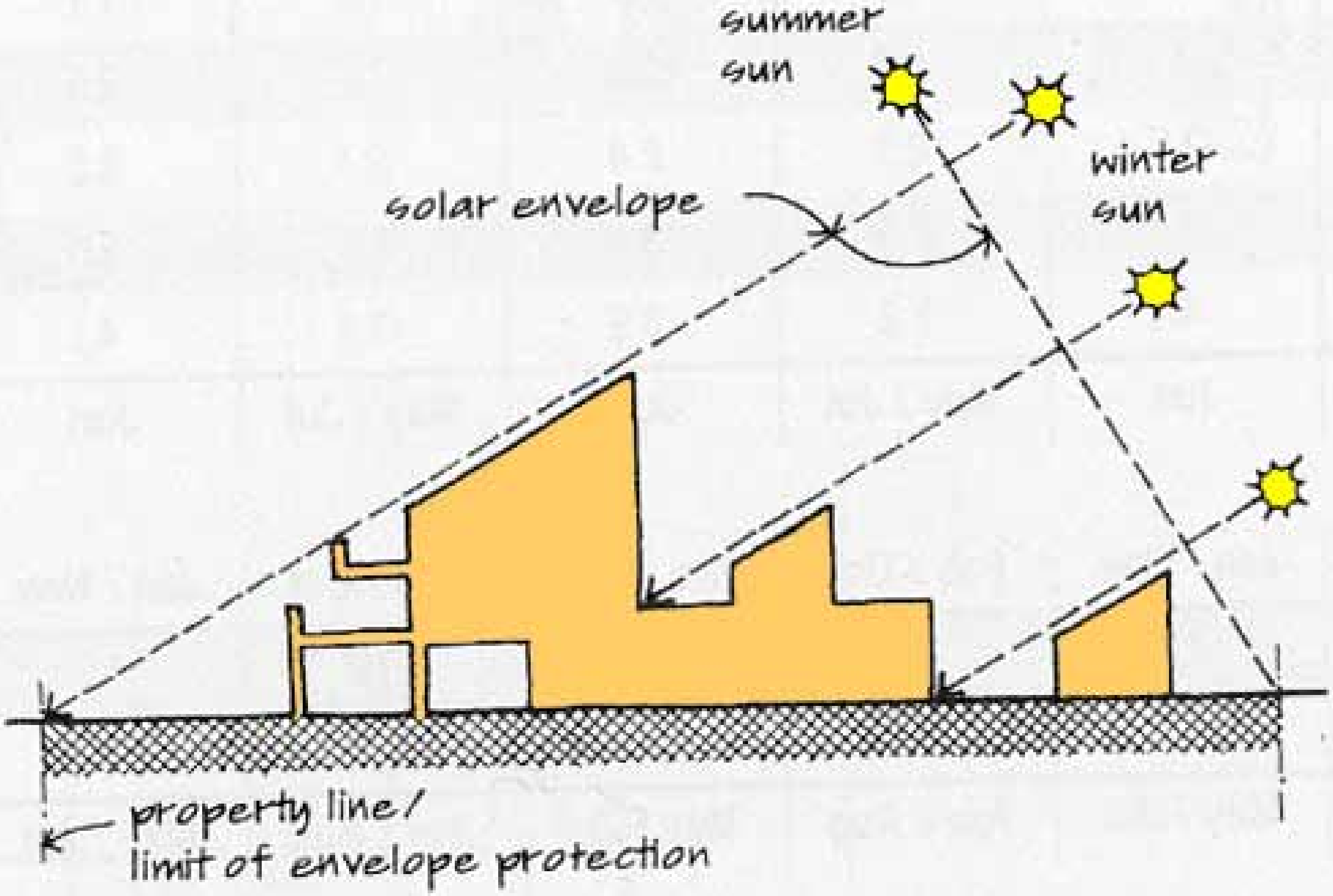


FIG. 4a "X" marks the spot for existing on-site sun protection. Look for sites shrouded by trees on west side. In this example, trees are on upslope, enhancing their shading ability. Don't sacrifice winter southern exposure, though!

CBD



Solar Collection Within the Solar Envelope

SWL

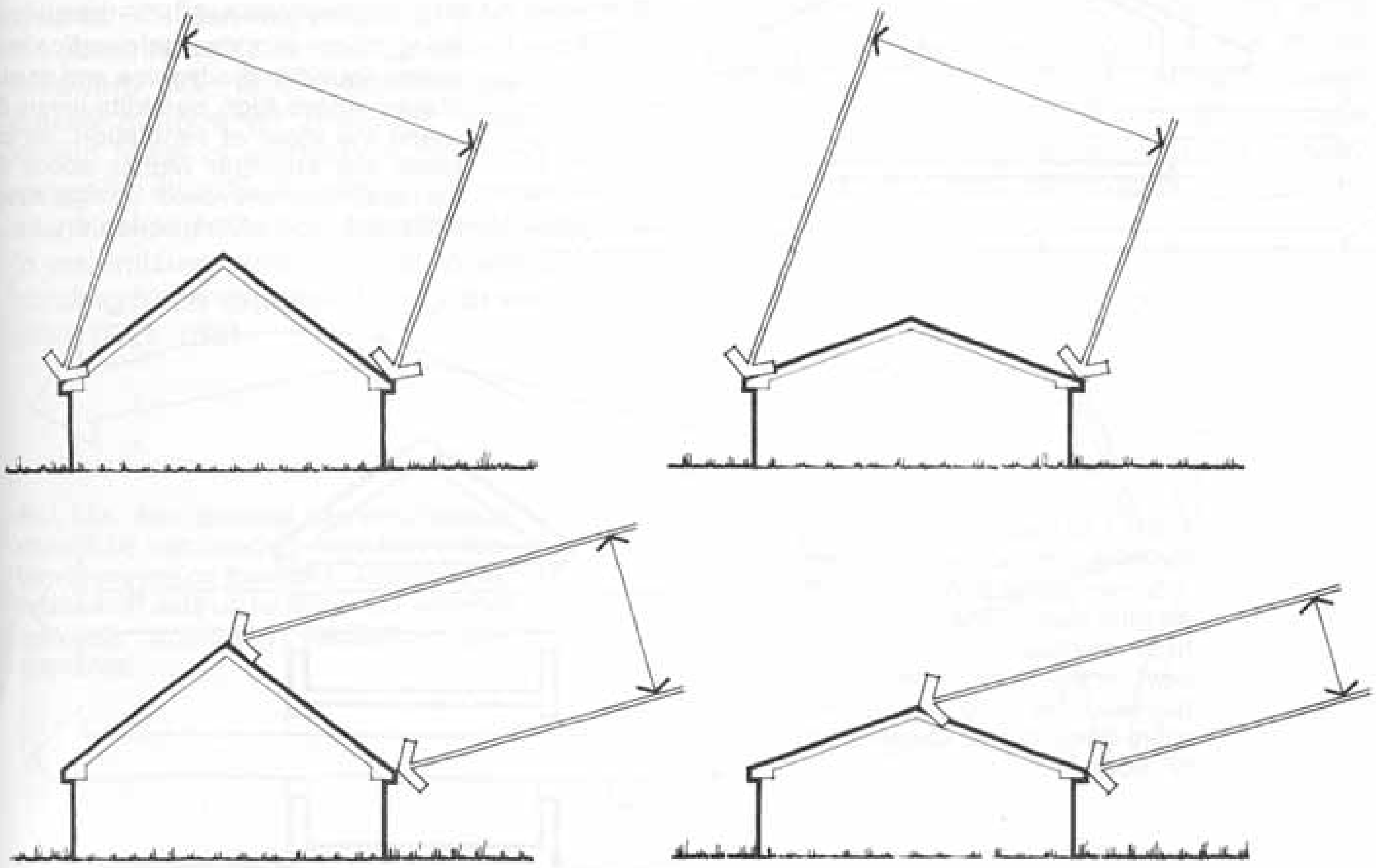


FIG. 12c. **Roof shape has little effect on mid-day gain when sun is high.**

HCL

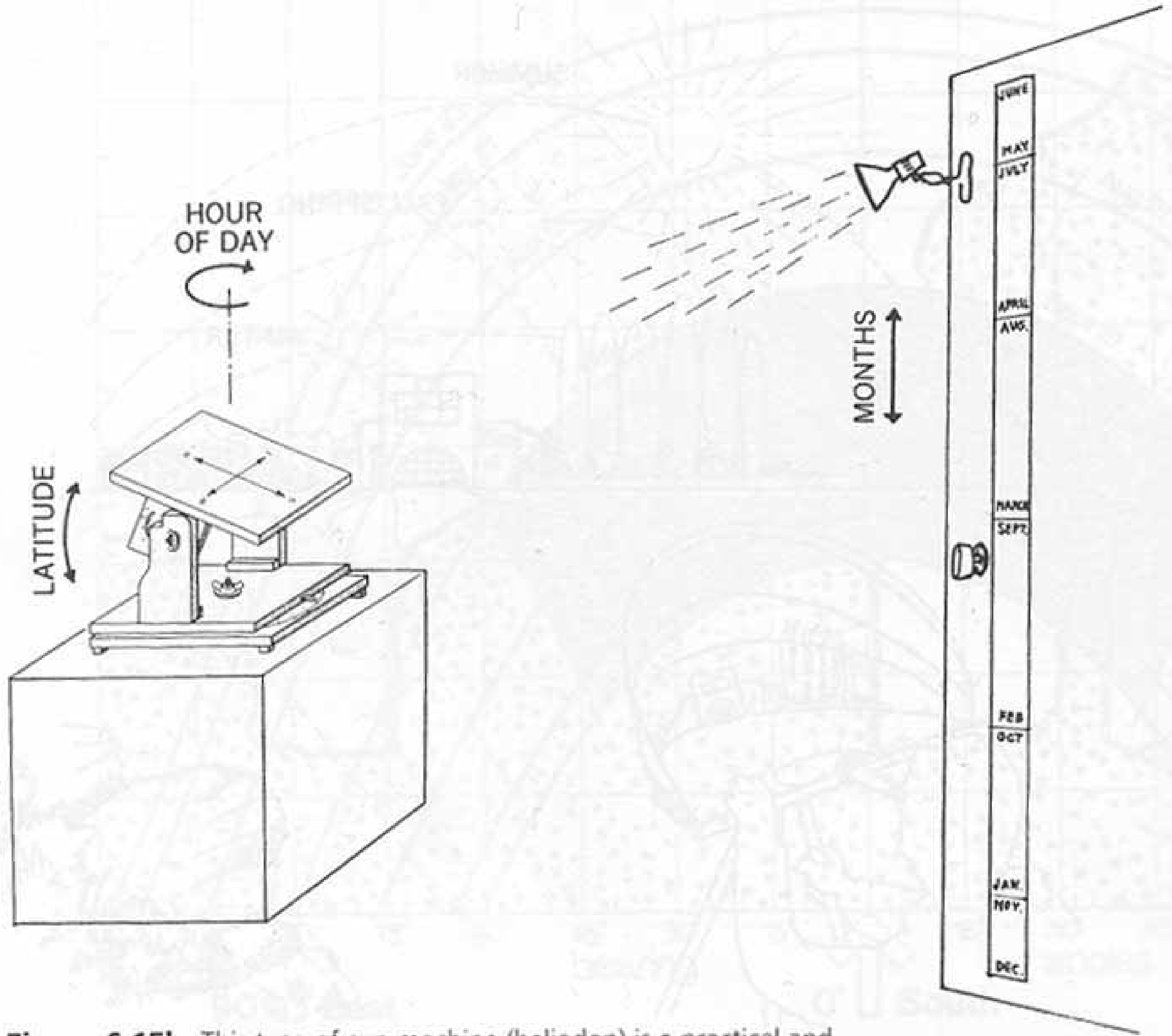


Figure 6.15b This type of sun machine (heliodon) is a practical and appropriate tool for every design studio.

HCL