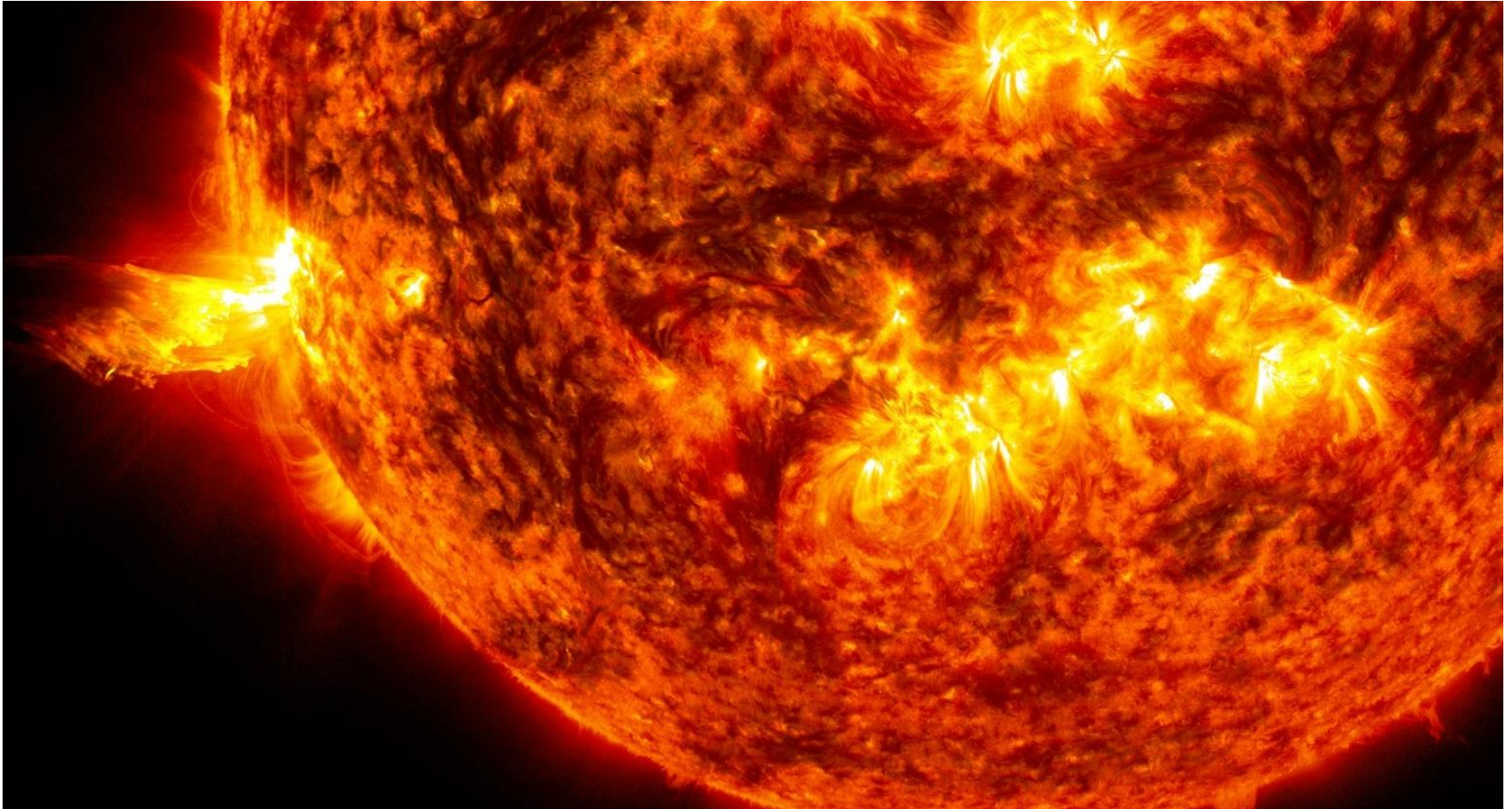


Lecture ٩: Solar Geometry

((It is the mission of modern architecture to concern itself with the sun)) Le Corbusier, from a letter to Sert.

A building cannot be energy efficient if it is not solar responsive.

Orientation is the most valuable energy-saving strategy.



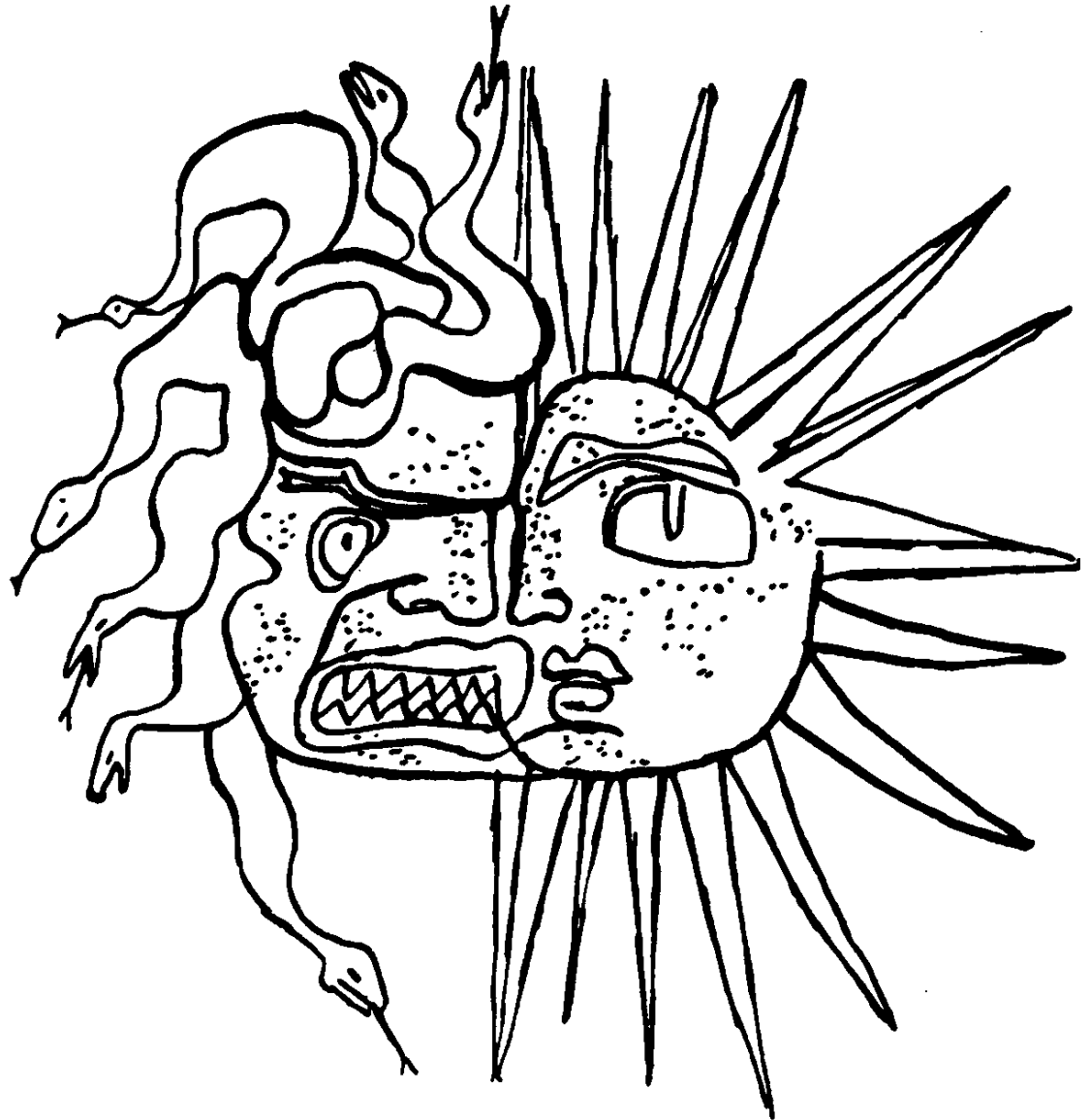
Introduction

The looming crisis of global warming must persuade us to reconsider our relationships with nature and technology. There is a deepening conviction that progress will come mainly from technology that is in harmony with nature. The fast-growing interest in sustainable or green design illustrates this shift in attitude.

In architecture, this point of view is represented by buildings that let the sun shine in during the winter and are shaded from the sun in the summer.

This approach to architecture requires that the designer have a good understanding of the natural world.

Central to this understanding is the relationship of the sun to the earth.



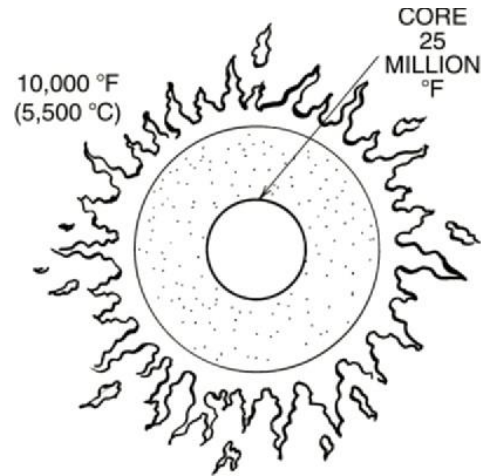
Part of the year the sun is our friend, and part of the year it is our enemy. (Drawing by Le Corbusier)

The Sun

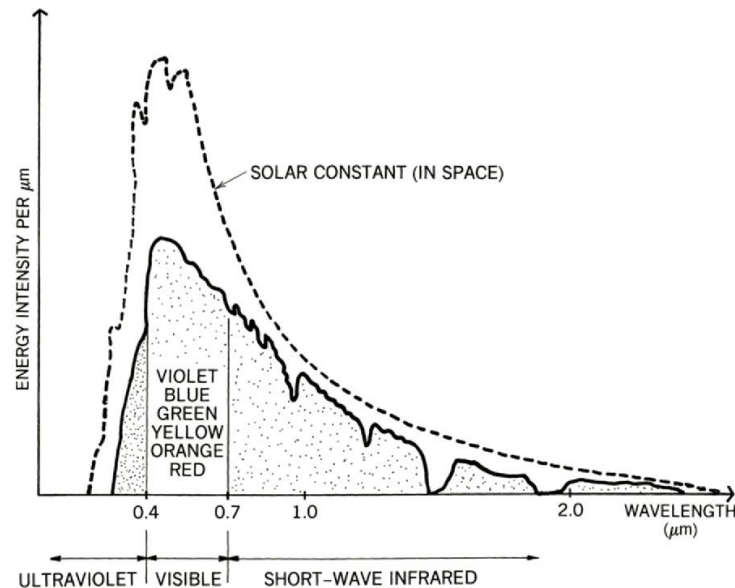
Solar radiation is the kind of radiation that a body having a temperature of about 10,000°F (5,500°C) emits.

The amount and composition of solar radiation reaching the outer edge of the earth's atmosphere are quite unvarying and are called the solar constant.

The amount and composition of the radiation reaching the earth's surface, however, vary widely with sun angles, elevation, and the composition of the atmosphere



The surface temperature of the sun determines the type of radiation emitted.



The solar spectrum at the earth's surface consists of about 47 percent visible, 48 percent short-wave infrared, and about 5 percent ultraviolet radiation.

Elliptical Orbit

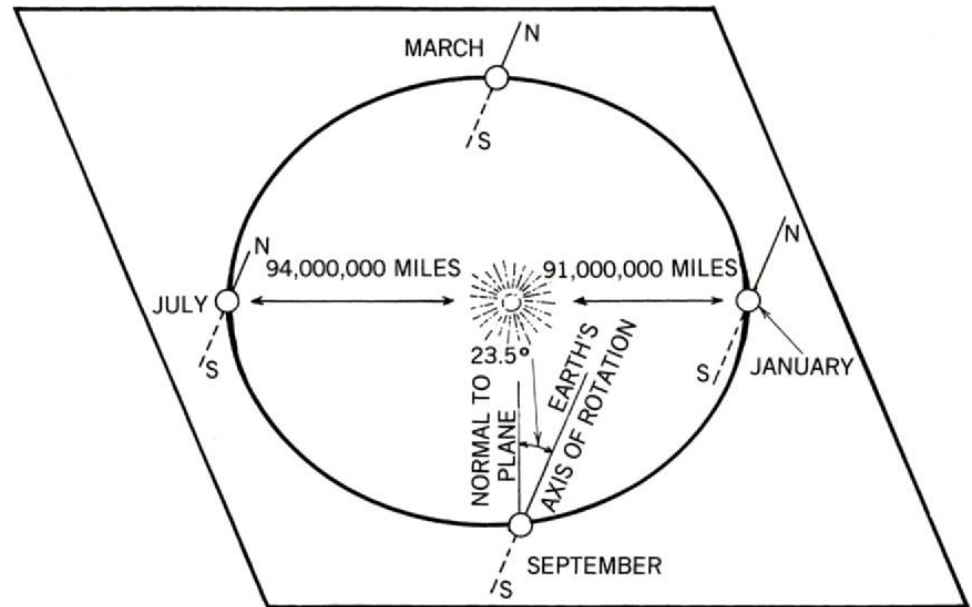
The orbit of the earth is not a circle but an ellipse, so that the distance between the earth and the sun varies as the earth revolves around the sun.

The distance varies about 3.3 percent, and this results in a small annual variation in the intensity of solar radiation.

Since the sun is very far away and since it lies in the plane of the earth's orbit, solar radiation striking the earth is always parallel to this plane.

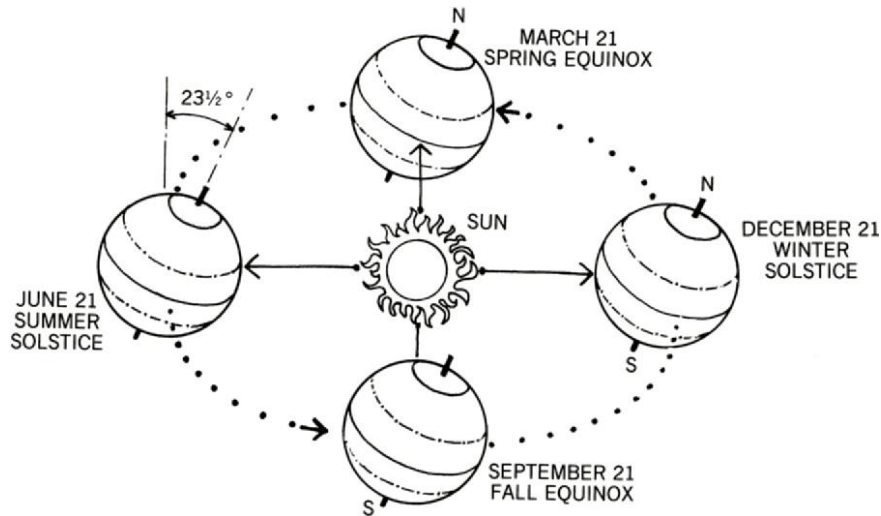
While the earth revolves around the sun, it also spins around its own north-south axis. Because this axis is not perpendicular to the orbital plane but is tilted 23.5° off the normal to this plane, and because the orientation in space of this axis of rotation remains fixed as the earth revolves around the sun, the angle at which the sun's rays hit the earth continuously changes throughout the year.

This tilt of 23.5° is the cause of the seasons and has major implications for solar design.

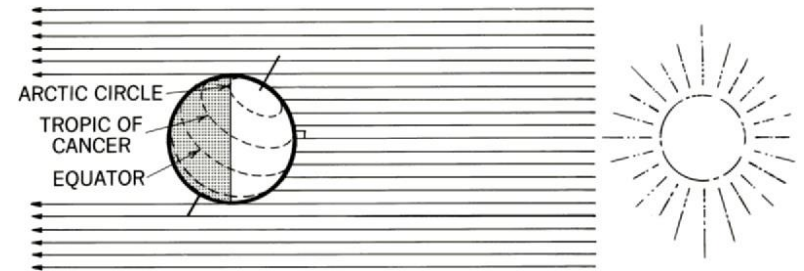


The earth's axis of rotation is tilted to the plane of the elliptical orbit. The distance to the sun is 3,000,000 mi (4,800,000 km) closer in January than in July.

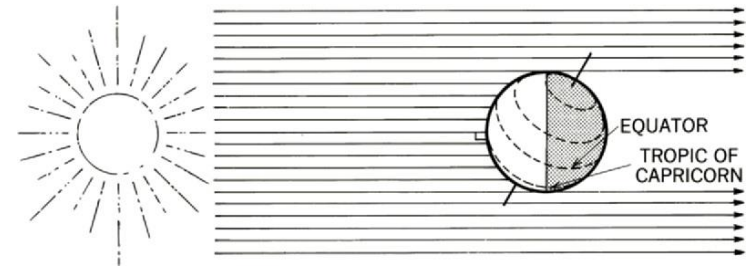
Tilt Of The Earth's Axis



*The seasons are a consequence of the tilt of the earth's axis of rotation.
(From Solar Dwelling Design Concepts by AIA Research Corporation, U.S. Dept.
Housing and Urban Development, 1976.*



During the summer solstice (June 21), the sun is directly overhead on the Tropic of Cancer, which is 23.5° N latitude.

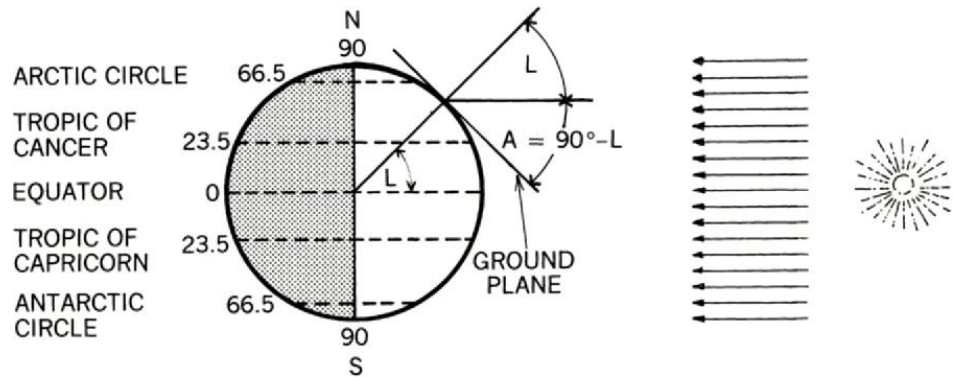


During the winter solstice (December 21), the sun is directly overhead on the Tropic of Capricorn, which is 23.5° S latitude.

Consequences Of The Altitude Angle

The vertical angle at which the sun's rays strike the earth is called the altitude angle and is a function of the latitude, time of year, and time of day.

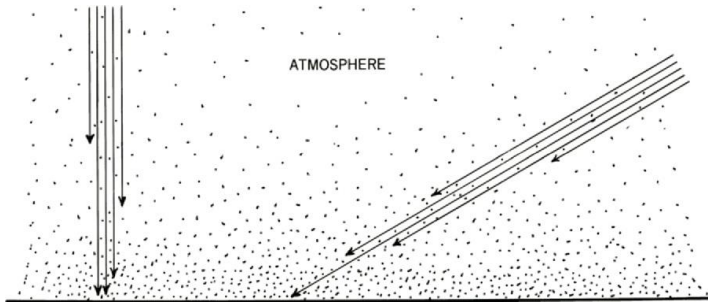
To find the altitude angle of the sun at any latitude, draw the ground plane tangent to the earth at that latitude. By simple geometric principles, it can be shown that the altitude angle is equal to 90° minus the latitude. There are two important consequences of this altitude angle on climate and the seasons.



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

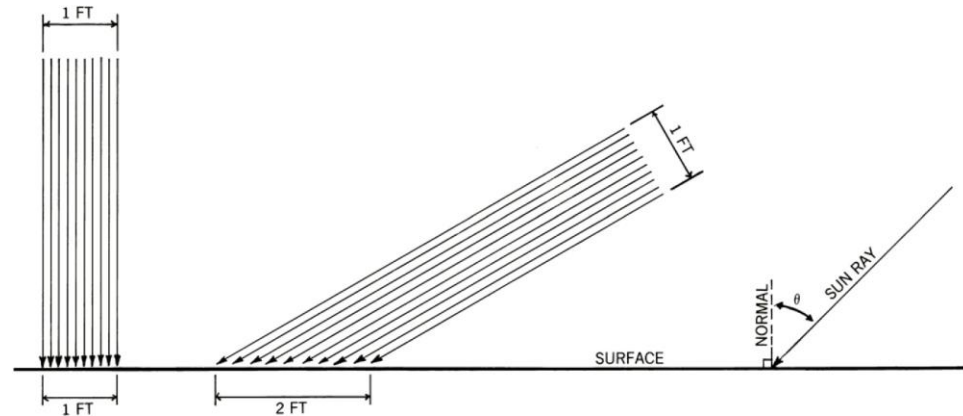
Consequences Of The Altitude Angle

The first effect of the altitude angle is illustrated by Figure, which indicates that at low angles the sun's rays pass through more of the atmosphere. Consequently, the radiation reaching the surface will be weaker and more modified in composition. The extreme case occurs at sunset, when the radiation is red and weak enough to be looked at. This is because of the selective absorption, reflection, and refraction of solar radiation in the atmosphere.



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

The second effect of the altitude angle is illustrated in the diagram of the cosine law. This law says that a given beam of sunlight will illuminate a larger area as the sun gets lower in the sky. As the given sunbeam is spread over larger areas, the sunlight on each square unit of land naturally gets weaker. The amount of sunlight that a surface receives changes with the cosine of the angle between the sun's rays and the normal to the surface.



Each square foot (m2) of land receives only half the solar heating. Thus, as the altitude angle decreases, so does the heating of the land.

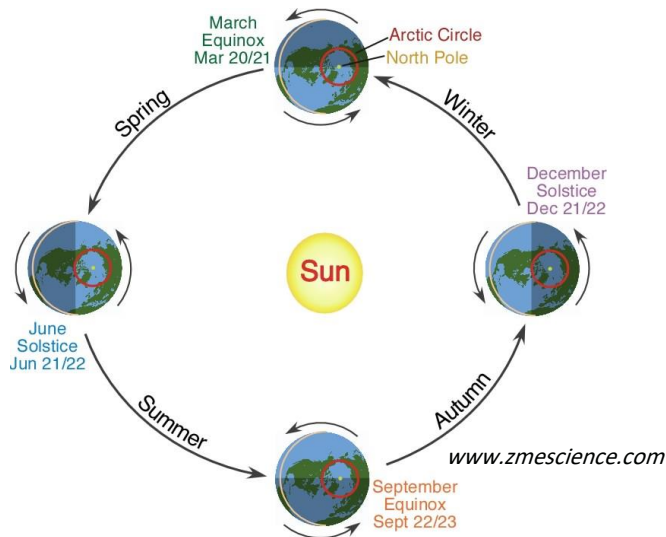
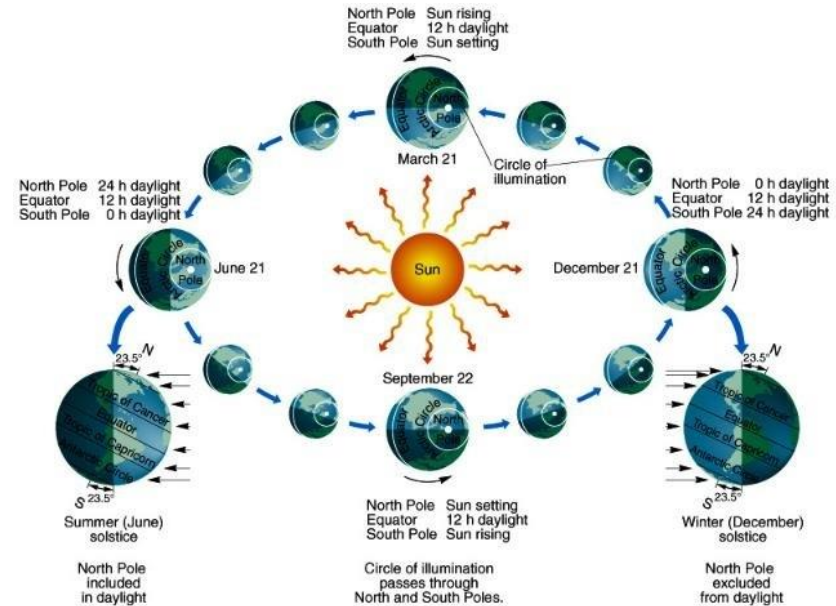
Winter

What causes winter??

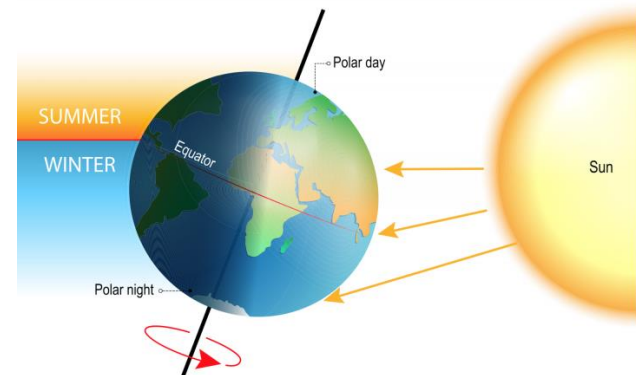
The temperature of the air, as well as that of the land, is mainly a result of the amount of solar radiation absorbed by the land. The air is mainly heated or cooled by its contact with the earth. The reasons for less radiation falling on the ground in the winter follow.

1. Most important is the fact that there are far fewer hours of daylight in the winter.
2. The second reason for reduced heating of the earth is the cosine law.

Lastly, the lower sun angles increase the amount of atmosphere the sun must pass through and, therefore, there is again less radiation reaching each square foot (square meter) of land.

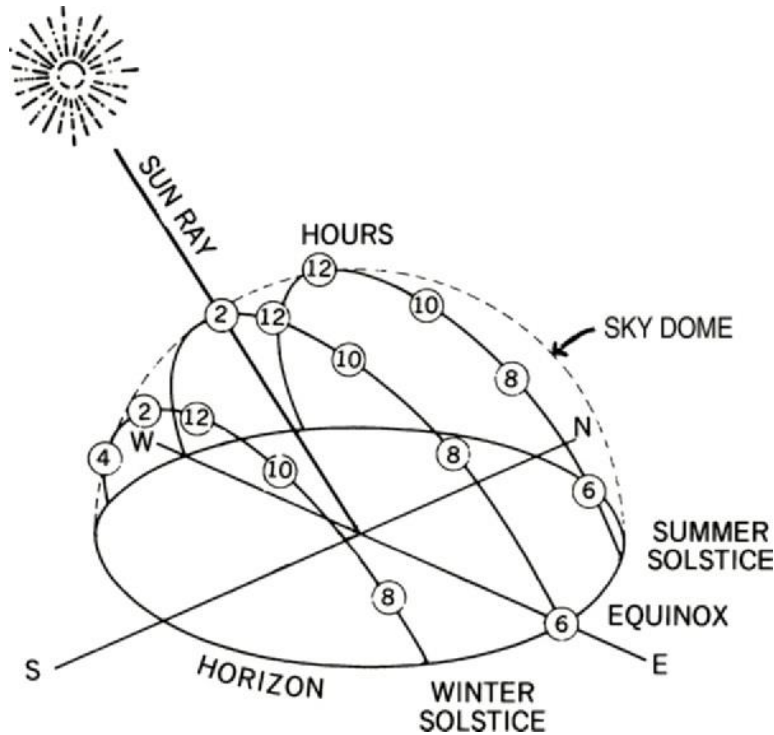


EARTH'S SEASONS

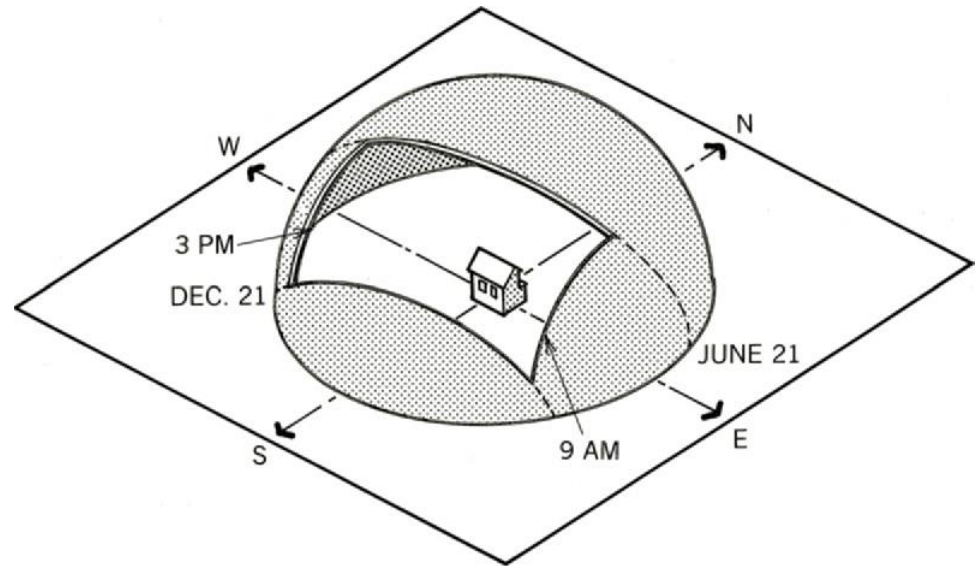


The Sky Dome

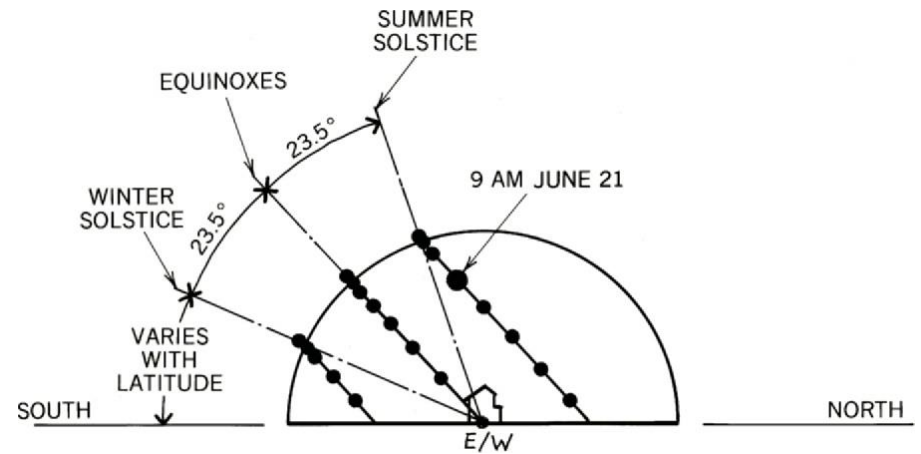
When all the points for one day are connected, we get a line on the sky dome called the sun path for that day. Figure 6.8a shows the highest sun path of the year (summer solstice), the lowest sun path (winter solstice), and the middle sun paths (equinoxes).



The sky dome and the three sun paths of June 21, September/March 21, and December 21 are shown



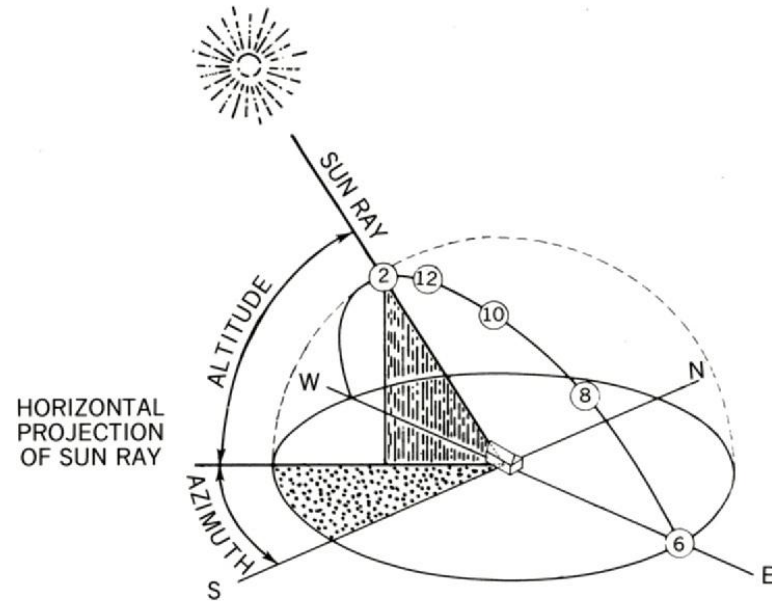
The part of the sky dome between the December 21 and June 21 sun paths is called the solar window. Most radiation in the winter is received between 9 a.m. and 3 p.m.



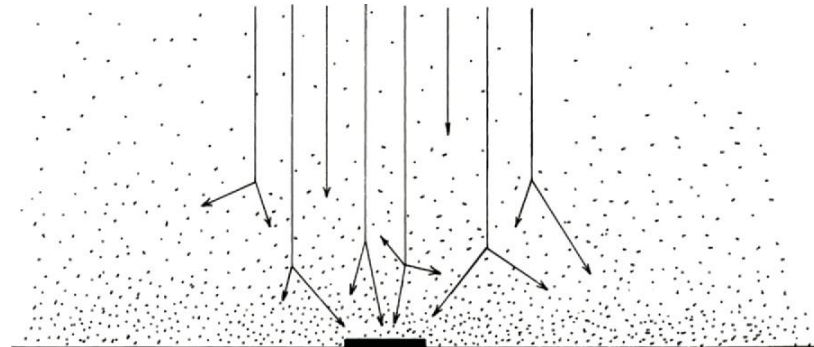
An east elevation of the sky dome is shown. The east-west axis is the point at the center of the sky dome. It is also where the sun rises and sets on the equinoxes.

Determining Altitude And Azimuth Angles

By far the easiest way to work with the compound angle of sunrays is to use component angles. The most useful components are the altitude angle, which is measured in a vertical plane, and the azimuth angle, which is measured in a horizontal plane.



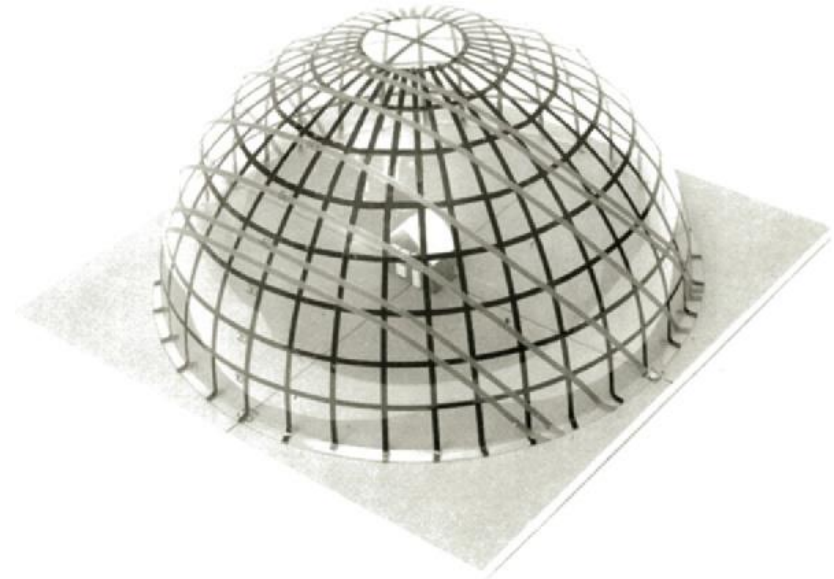
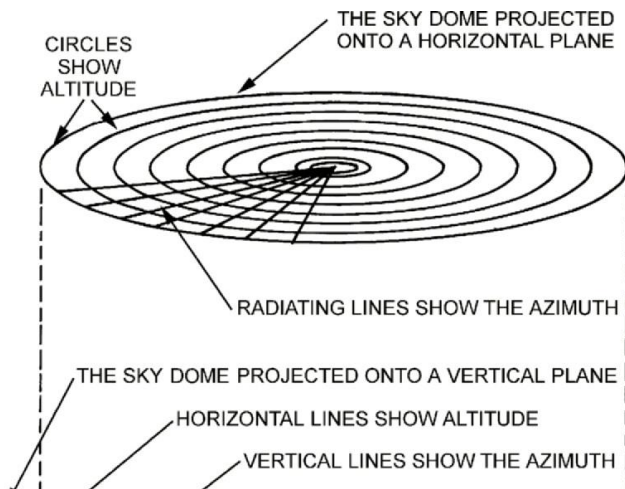
Definition of altitude and azimuth angles.



Diffuse radiation.

Horizontal Sun-path Diagrams

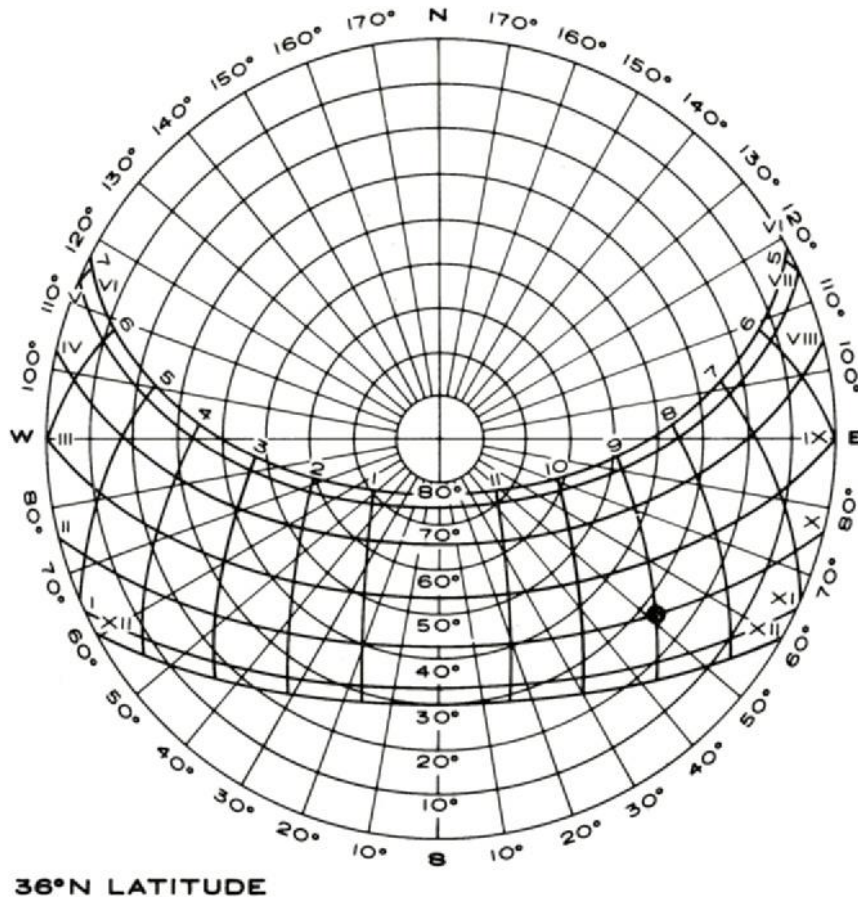
Although altitude and azimuth angles can be readily obtained from tables, it is more informative to obtain the information from sun-path diagrams



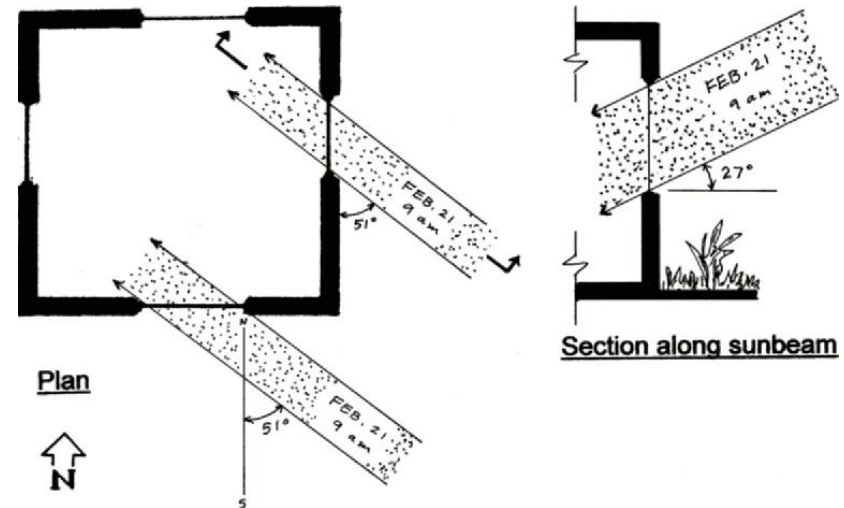
A model of the sky dome. The sun paths for the twentyfirst day of each month are shown. Only seven paths are needed for twelve months because of symmetry

Derivation of the horizontal and vertical sun-path diagrams.

Horizontal Sun-path Diagrams



The azimuth angle measured from a north–south line is used to draw the sunbeam in plan. The altitude angle is used to draw the sunbeam in section. To prevent graphical distortion, the section is cut along the sunbeam, as can be seen from the section marks on the east window in plan.

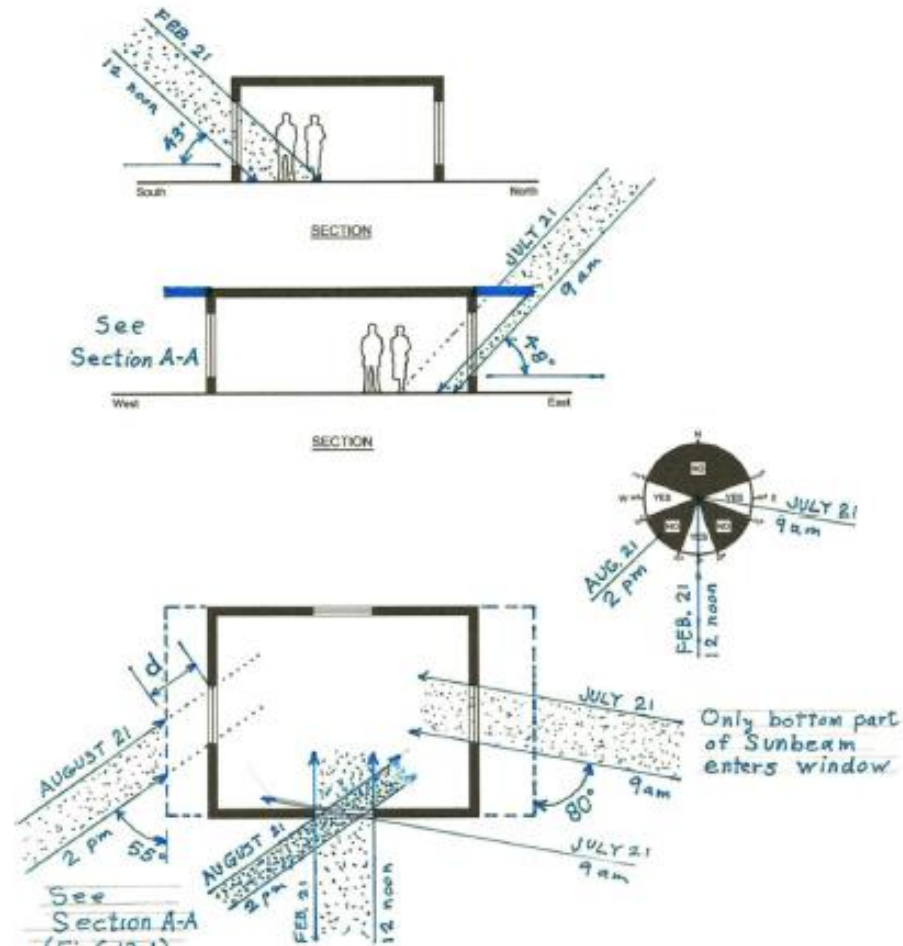


Horizontal sun-path diagram

Drawing Sunbeams

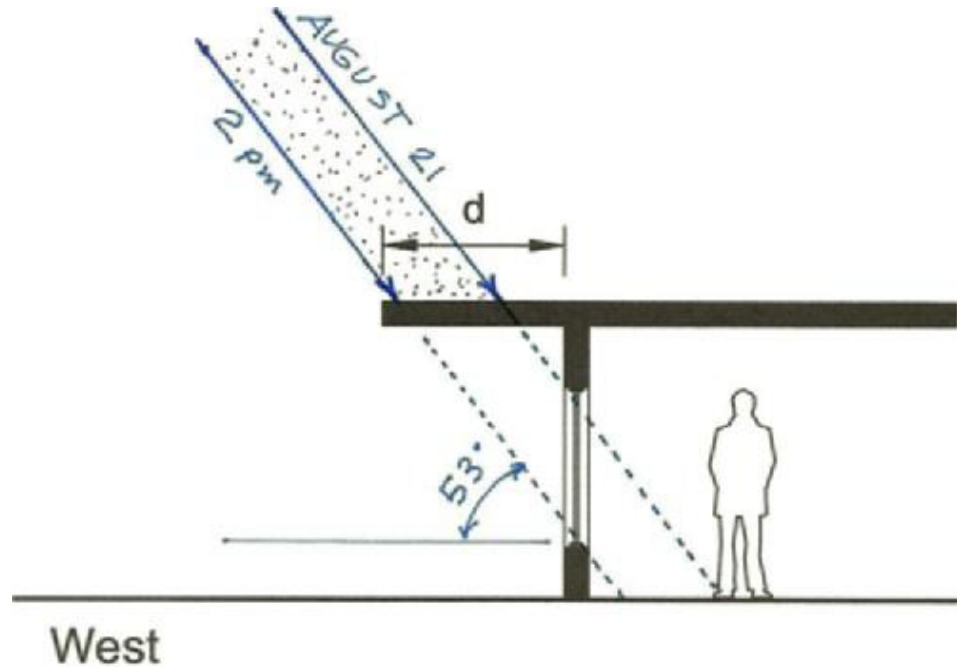
Month	Hour	Altitude	Azimuth
FEBRUARY 21	12 noon	43°	0°
JULY 21	9 am	48°	80° E of S
AUGUST 21	2 pm	53°	85° W of S

All sunbeams are shown on plan, but only those in the "yes" zone of the key plan can be shown in the appropriate section. From the section it is possible to determine which sunbeams are blocked by an overhang and which are not. Since the July 21, 2 p.m., sunbeam is more than 20 degrees out of the east-west section, a special section cut along the azimuth must be used, as shown in Fig. Because that section shows that the sunbeam is blocked, the sunbeam is shown in plan ending at the edge of the west overhang.



Drawing Sunbeams

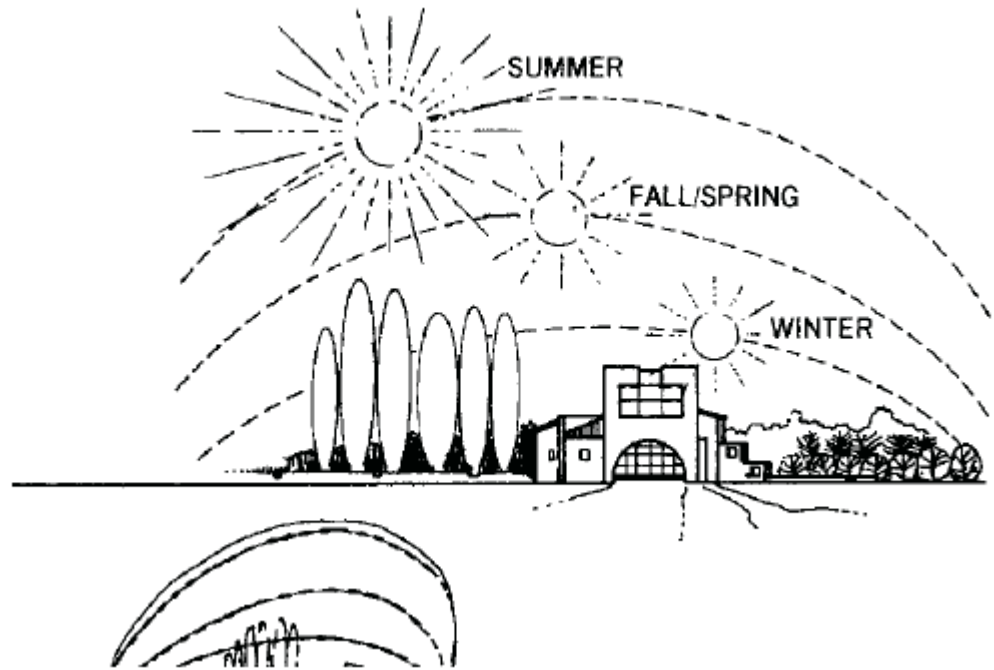
When important sunbeams are more than 20° out of the plane of standard sections, special sections must be cut parallel to those sunbeams to get accurate results. In this special section the apparent overhang length is "d," as also indicated in the plan.



SECTION A-A

SUN-PATH MODELS

Various sun-path models are shown to illustrate how sun angles vary with latitude. In each case, the highest sun path is for June 21, the middle for March/September 21, and the lowest for December 21. Thus, the sun paths for all other months would be located between the highest and lowest sun paths.



References

Norbert Lechner-Heating, Cooling, Lighting_
Sustainable Design Methods for Architects-
Wiley (2014)

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