Chapter Seven

Daylight Design Principles

In these times of genuine concern about the shortage, cost and pollution penalty associated with most fossil fuel sources of energy we are becoming increasingly aware of those forms of natural energy that can be readily utilized without the need for any modification. Among these, daylight, should be counted as one of the most generous gifts of nature.

Although the sun is the primary source of daylight, the atmosphere surrounding the earth diffuses its light and therefore the whole sky becomes a secondary source of light. For several reasons direct sunlight is not normally considered to be a suitable source of daylight in buildings. First, it is very intense, ranging from 6,000 to 12,000 footcandles, and therefore cannot be used directly for task illumination. Second, it is so much brighter than the ambient environmental luminance (i.e., Adaptation Level), both inside and external to buildings, that it can easily become a source of severe glare (i.e., Disability Glare). Third, it is associated with considerable heat energy and although this may be desirable for the heating of building spaces by natural means, it is an undesirable characteristic in respect to lighting. Accordingly, daylight design is not based on direct sunlight but on secondary light from the sky, which is defined as a luminous hemisphere with the observer's horizon plane as its base.

However, this does not mean that direct sunlight should necessarily be completely excluded from building interiors. Carefully controlled beams of sunlight can add a highly desirable degree of movement, directional highlighting, variety, and excitement to a space. This is particularly true for corridors and similar circulation spaces, where the occupants are mostly transitory and not engaged in detailed visual tasks. Even in spaces where the occupants are seated in relatively fixed locations undertaking reading and writing tasks, movable window shades and blinds may provide sufficient control for the intermittent penetration of direct sunlight.

7.1 Variability of Daylight

It is an important characteristic of daylight illumination that it varies constantly during each day and from day to day. The horizontal illumination on a photoelectric cell exposed on the roof of a building but shaded from direct sunlight can vary widely depending not only on the time of day but also on the degree of cloud cover (if any). A clear sky will be brightest near the sun, and since the sun moves from sunrise to sunset the brightness distribution of the sky will change correspondingly. On the other hand, in the north-western part of Europe the sky is mostly covered by clouds and therefore the overcast sky becomes the principal source of daylight. The influence of dispersed clouds in the sky can be readily seen in the typical daily illumination curves shown in Figure 7.1. The upper curve depicts the hourly distribution of light that we would expect on a clear day with perhaps a few isolated cloud whisks producing minor fluctuations. However, the situation will be quite different as soon as major cloud formations appear in the sky. The lower curve of Figure 7.1 indicates the significant variations in daylight availability that will occur abruptly as soon as a large cloud either hides the sun or the bright blue sky. In a few seconds the available daylight might be reduced by as much as 30% to 50%.

What is also clearly seen in Figure 7.1 is that apart from the influence of clouds the daily daylight distribution follows a slightly skewed Normal Distribution Curve[1]. The reducing illumination levels in the afternoon occur at a slightly slower rate than the progressively increasing illumination levels during the morning hours.

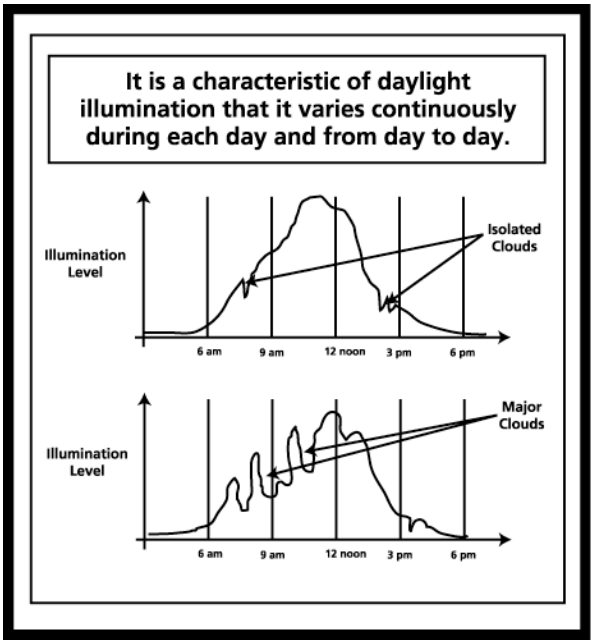

Figure 7.1: Variability of daylight

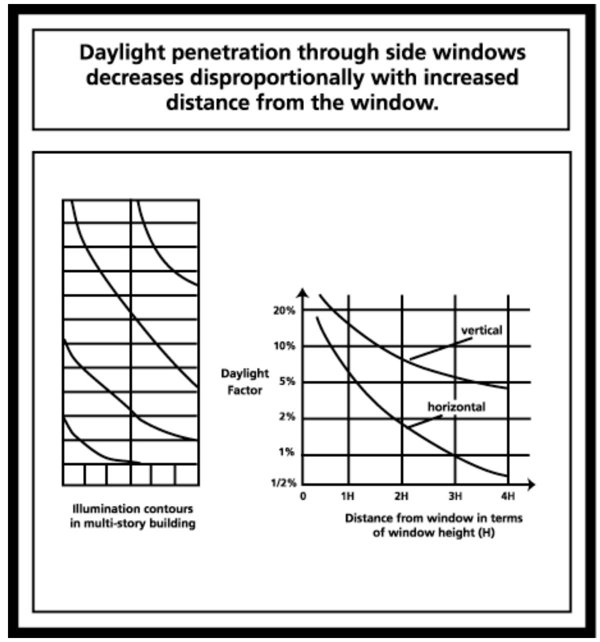

Figure 7.2: Daylight penetration constraints

Since daylight is largely unpredictable it was argued in the US, prior to the recognition of an increasing energy shortage and cost in the early 1970s, that the internal building environment should be lit artificially to ensure good seeing conditions at all times. At the same time, it was also recognized that apart from any energy conservation considerations the characteristic variability of daylight may be desirable on psychological grounds.

Whether or not it is possible to light a building adequately by daylight will depend on the circumstances, although for a normal high-rise, city building the answer is normally in the negative. In these buildings lighting conditions are likely to be poor on the lower floors (Figure 7.2) and in deep rooms. The reduction in daylight as we move further away from the window is by no means linear. For example, as shown by the graph in Figure 7.2, the difference in illumination level on a horizontal surface at points that are one and two window head-heights distant from a side window may be more than 60%.

[1] The Normal Distribution Curve is a statistical measure of the degree of variation within a related set (i.e., population) of data. A steep curve indicates that most of the data values are clustered around the mean (i.e., average) value, which is located at the center of the curve, while a flatter curve indicates a wider distribution. The precise distribution characteristics of any particular population can be calculated mathematically as Standard Deviations from the mean. Setting the area under the Normal Distribution Curve to be equal to 1 (i.e., 100% of the population), the mean plus or minus one Standard Deviation represents 68% of the population and the mean plus or minus 2 Standard Deviations represents 94% of the population. Mathematical adjustments are made in calculating the Standard Deviations of Normal Distribution Curves that are slightly skewed, such as in the case of the typical daily daylight distribution shown in Figure 7.1 above.

7.2 Quality of Daylight and Color

As discussed previously in Chapter 6, we often speak of light in terms of the *visible spectrum*, indicating that light consists of a number of wavelengths of electromagnetic radiation. These wavelengths range in color from violet through indigo, blue, green, yellow and orange to red. If all of these wavelengths are present then we perceive colorless light. However, should the same light beam fall unto a surface that absorbs some wavelengths more than others, then this surface will appear colored to the observer. In other words, the color of a surface is governed by the selective absorption properties of that surface. Some surfaces reflect all wavelengths in the visible spectrum equally and will therefore appear white, grey, or black (i.e., colorless) to the observer.

The electromagnetic spectrum of daylight varies with the condition of the sky and the direct influence of the sun. The bright blue color of a clear sky is in stark contrast to the grayish appearance of an overcast sky. Direct sunlight, on the other hand, is much warmer in appearance than either a clear or overcast sky. The color spectrum of any light source, whether natural or artificial, is often expressed in terms of its *color temperature*[2], which defines the distribution of electromagnetic wavelengths emitted by the light source. In other words, as explained in the footnote below, color temperature is a measure of the color composition of a light source and has nothing whatsoever to do with the operating temperature of the light source.

Through our eyes we perceive color as light and therefore evaluate its properties subjectively. The fact that adjectives are used to describe different colors emphasizes the difficulty of attempting to specify color in technical terms. Although the description 'apple-green' does not represent the precise specification of a particular color it nevertheless conveys a more meaningful picture than 'Munsell 5GY'. It might be argued that since light is contained within a narrow band of the electromagnetic spectrum it follows that color can be accurately specified by wavelength. However, wavelength does not take into account the brightness or luminance of the light source and the purity or saturation (i.e., the extent of dilution with white light) of the color. For the complete specification of a color we require values for the following three color characteristics:

1. The dominant wavelength, referred to as the *hue* of the color.
2. The luminance or brightness, referred to as the *value* of the color.
3. The degree of saturation or *chroma* of the color.

Over the years a number of different methods of color specification have been developed to meet different requirements. For colored surfaces it is normal practice to specify the color in relationship to its appearance or rendition under a specified light source. Such a system was devised by Albert Munsell (1858-1918), an American artist, in 1915. The Munsell Color Atlas applies to colored surfaces only. Each color is specified in terms of:

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[2] Contrary to its name *color temperature* is not related to the operating temperature of a light source. Instead, it is related to the spectral distribution of radiation that is emitted by a full radiator (i.e., Black Body) when it is heated to different temperatures. These temperatures are measured in degrees Kelvin (ºK) and referred to as color temperatures. Accordingly, the spectral distribution of an overcast sky is approximately equivalent to the spectral distribution of a Black Body heated to 6,400 ºK. Similarly, the color temperature of direct sunlight and a clear blue sky are approximately 5,500 ºK and 11,500 ºK, respectively.

Value, which is a measure of the degree of dilution with white. The range between black (0) and white (10) includes nine grades of gray. Accordingly, if a colored pigment is mixed with a neutral base the *value* from 0 to 10 will indicate the whiteness of the base.

Hue describes the actual color, such as red, yellow, and so on, of the surface. For each *hue* there is an example of increasing purity.

Chroma measures the intensity or saturation of the color. The *hue circle* contains the *hues* at maximum *chroma*.

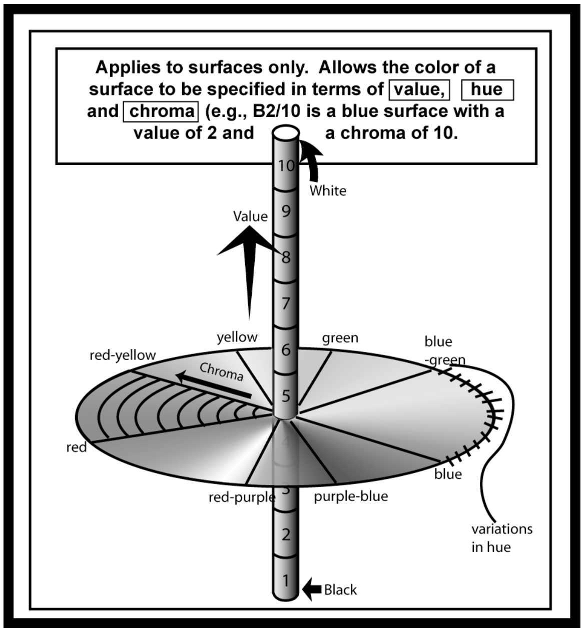

Figure 7.3: The Munsell Color Atlas

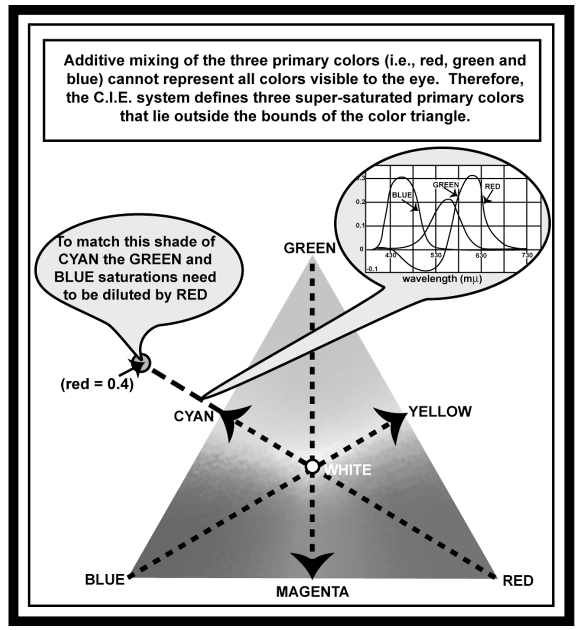

Figure 7.4: The CIE color notation

By reference to Figure 7.3, a color specified as ‘R5/2’ is a red with a *value* of 5 and a *chroma* of 2, while ‘R3/2’ would be a darker red and ‘R5/l0’ would be a much stronger red. Although the Munsell system cannot be applied to light sources, it conveniently provides an approximate indication of the percentage light reflectance of a surface based on the *value* of the color.

approximate light reflectance = [color *value* x (color *value* - 1)]% …….. (7.1)

Accordingly, ‘R5/2’, ‘R4/2’ and ‘R3/2’ have light reflectances of approximately 20%, 12% and 6%, respectively.

In 1931 the Commission Internationale de l'Eclairage (CIE) agreed upon a system of color notation to provide a common basis for all color measuring instruments. The system is based on the color-matching characteristics of the average eye. To establish adequate subjective test data a number of observers were asked to make a series of color matches using a colorimeter. A colorimeter (Figure 7.5) is very similar to the photometer described in Section 7.4. However, whereas the photometer requires the observer to match two patches of light, colorimeters are used to match two patches of color. While one part of a divided surface is illuminated by the source of light under investigation, the other part of the surface is exposed simultaneously to three standard sources. One source is red, the other blue and the third green. By adjusting the relative intensities of these colored light sources, the observer is able to match the two light patches until they look exactly alike.

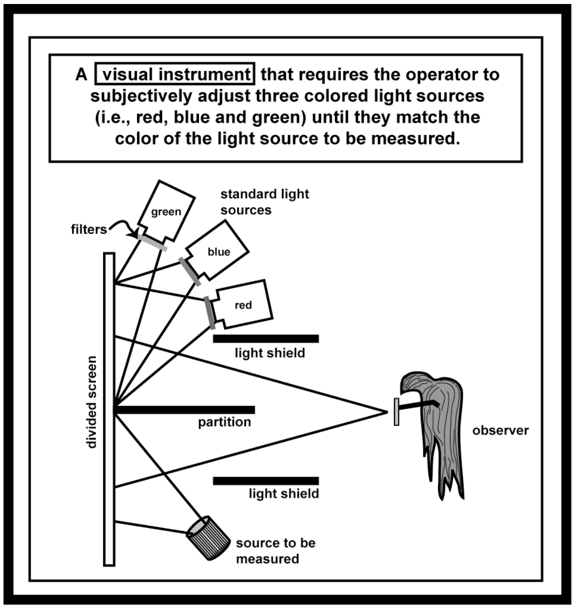

Figure 7.5: Colorimeter

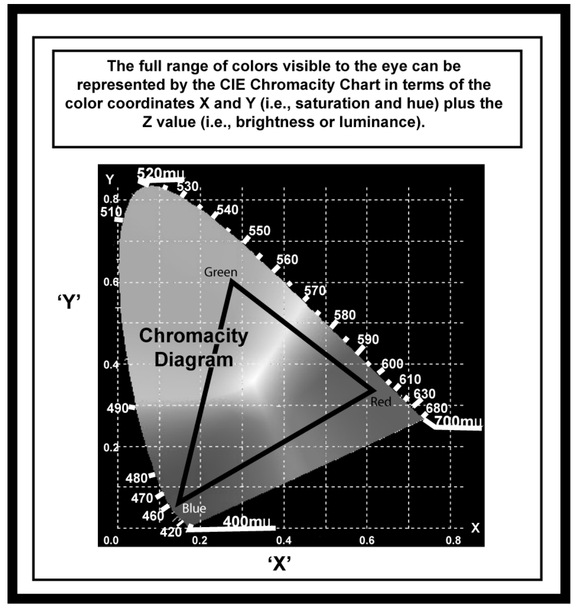

Figure 7.6: CIE Chromacity Diagram

While this seems quite straightforward, there are in fact two complicating factors that require further explanation. The first of these deals with the notion that two identical visual stimuli may have different color spectrums. In the above colorimeter example, even though the two colored light patches may look alike they are highly unlikely to have the same spectral composition. Even the same observer could produce matching colored light patches with different spectral compositions for the same source patch. In other words, different spectral compositions can produce identical color stimuli as perceived by the eyes. This phenomenon is referred to as *metamerism* and forms the basis of all color reproduction techniques.

The second factor is demonstrated in Figure 7.4, which shows the color triangle formed by the three primary colors: red; green; and, blue. Let us assume that each of the primary colors is produced by a white light source fitted with a filter appropriate to its color. Further, the intensity of each of the light sources is adjusted so that it reduces uniformly to zero at the opposite boundary of the triangle. The sides of the triangle represent the greatest saturation that can be produced by the primary color lights for each of the color hues. For example, the cyan hue located in the center of the left side of the triangle is composed of 50% green plus 50% blue plus 0% red. However, the human eye can identify saturations of cyan that lie outside the boundary of the triangle. These shades of cyan can be produced only by diluting the saturation levels of green and blue with red. Therefore, the particular shade of cyan shown by the point outside the left edge of the triangle in Figure 7.4 will require the subtraction of red from the other two primary colors (i.e., green and blue). In other words, not all of the colors that can be perceived by the human eye can be created by the simple addition of the three primary colors within the color triangle.[3]

[3] Since computer monitors rely on an additive mixture of the three primary colors (and are therefore commonly referred to as RGB monitors) they cannot accurately represent many of the colors in the

Based on a large number of subjective tests using the colorimeter technique the CIE *chromaticity diagram* shown in Figure 7.6 has been produced. It avoids the problem of negative values through the adoption of three super-saturated primary colors. This allows any color within the chromaticity diagram to be specified as a mixture of these three notional primary colors (i.e., X, Y and Z)[4]. The actual values of X, Y and Z that uniquely describe a particular visually perceivable hue are referred to as the *tristimulus* values. It follows that different combinations of light waves that result in the same set of tristimulus will be indistinguishable by the human eye.

7.3 How Much Daylight is Available?

Due to variability, lack of control, and the difficulty of achieving high illumination levels in local areas, daylight alone cannot normally provide satisfactory illumination levels for tasks involving higher degrees of visual acuity. Generally speaking, it will therefore be the function of daylight to provide general illumination levels compatible with the task to be performed in the building environment, on the understanding that artificial light sources will be available to provide local task illumination if and when required.

However, the concept of adequate lighting incorporates more than just sufficient light. Obviously, the visual field must be free from glare and the light must come from the correct direction. Accordingly, the major daylighting concern is how to admit sufficient light for comfortable vision, without the presence of glare. This problem is a very complex one, not only due to the variation in brightness of the sky but also due to the necessity for the designer to balance natural lighting with heat insulation and the capital and operating costs of artificial light installations.

The amount of light received inside a building must be related to the light available externally, to form a reasonable basis for daylight design. There are essentially two common measures of the natural light available from the sky, namely:

1. The *uniform brightness sky*, which applies to the dry, sunny regions of the world where a clear atmosphere is prevalent. In such regions the clear blue sky has a fairly even brightness distribution over most of the sky except for the sun and its immediate surround (Figure 7.7). This local area, which moves from east to west each day at the rate of approximately 15° per hour, is about 10 times as bright as the remainder of the sky. The following empirical relationship has been proposed for the outdoor illumination (E_H) on a horizontal surface from the sun and the whole *clear sky*:

$$\mathbf{E_H = A\,[1750 \times (\sin(a))^{0.5}] + B\,[13200 \times \sin(a) \times 10^{-0.1m}]\ \ fc} \quad \ldots\ldots\ldots\ldots\ldots \quad \mathbf{(7.2)}$$

where: a = altitude of the sun

m = air mass (or cosec(a))

chromaticity diagram. The black-line triangle shown in Figure 7.6 provides an indication of the restricted color range that applies to an average RGB monitor.

[4] The CIE super-saturated primary colors do not actually exist. In other words, they are notional mathematical constructs that lie outside the boundaries of the chromaticity diagram. Constructed as a right-angled triangle, which circumscribes the chromaticity diagram, the two sides of the triangle that form the 90° angle also represent the 'x' and 'y' axes of the CIE chromaticity diagram.

$10^{-0.1m}$ = transmission factor of atmosphere

In equation 7.2 the first term represents the contribution to the total illumination (E) provided by the sky, and the second term represents the contribution provided by the sun. The substitution of appropriate values for the constants *A* and *B* allows equation 7.2 to be adapted to different sky conditions (i.e., conditions other than *clear sky* conditions), as follows:

A = 0.89 and B = 0.35 for: thin film of clouds

A = 0.54 and B = 0.26 for: clouded sky

A = 1.02 and B = 0.08 for: light white clouds and clear sun

For a *clouded sky* the values of *0.46* for *A* and *0.26* for *B* allow equation 7.2 to be contracted to the much simpler form (sun altitude *a* measured in degrees):

$$E_H = 52(a) \quad (7.3)$$

Krochmann (1963) proposed a slightly more elaborate empirical relationship to account for the influence of the sun under overcast sky conditions:

$$E_H = 30 + [1950 \times \sin(a)] \quad (7.4)$$

Taking into account these various proposals, it has been suggested (Lynes 1968) that the illumination (E_H) on a horizontal surface out of doors should be based on the following relationships:

temperate climates where overcast skies predominate: equation 7.4

hot dry climates where clear skies predominate: equation 7.2

temperate climates generally: equation 7.3[5]

The horizontal illumination values (E_H) obtained by equations 7.2 and 7.4 are not very different, however, equation 7.3 produces increasingly larger values for higher sun altitudes as shown below.

Sun Altitude	Clear Sky (7.2)	Overcast Sky (7.4)	Mean Sky (7.3)
10°	500 fc	370 fc	530 fc
20°	750 fc	700 fc	1,060 fc
30°	900 fc	1,005 fc	1,590 fc
40°	1,100 fc	1,280 fc	2,120 fc
50°	1,200 fc	1,520 fc	2,640 fc
60°	1,300 fc	1,720 fc	3,180 fc
70°	1,380 fc	1,860 fc	3,710 fc
80°	1,450 fc	1,950 fc	4,240 fc

It may appear surprising that the *mean sky* illumination exceeds the illumination for both cloudless and overcast conditions. The reason is that the brightest

[5] Actually, a slightly modified form of equation 7.3 (i.e., *53(a)* instead of *52(a)*) was suggested. However, the difference between *53(a)* and *52(a)* is barely 2%.

portions of the sky are usually the sunlit edges of white clouds, which would not normally exist under *clear sky* and *overcast sky* conditions.

2. The *standard overcast sky*, which applies to maritime, cloudy, temperate regions where the sky is mostly overcast. This sky condition was internationally standardized by the Commission Internationale de L'Eclairage (CIE) in 1955. While it is not of uniform brightness, its luminance is symmetrically distributed from the zenith to be about one third less bright at the horizon (Figure 7.8).

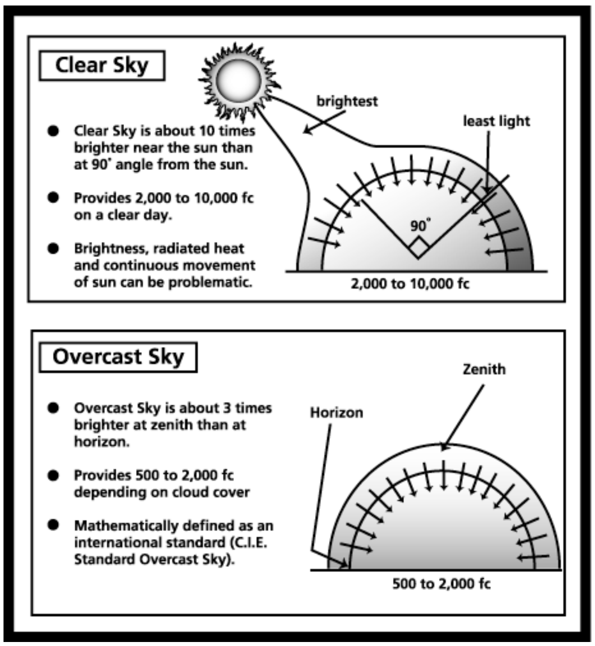

Figure 7.7: Idealized sky conditions

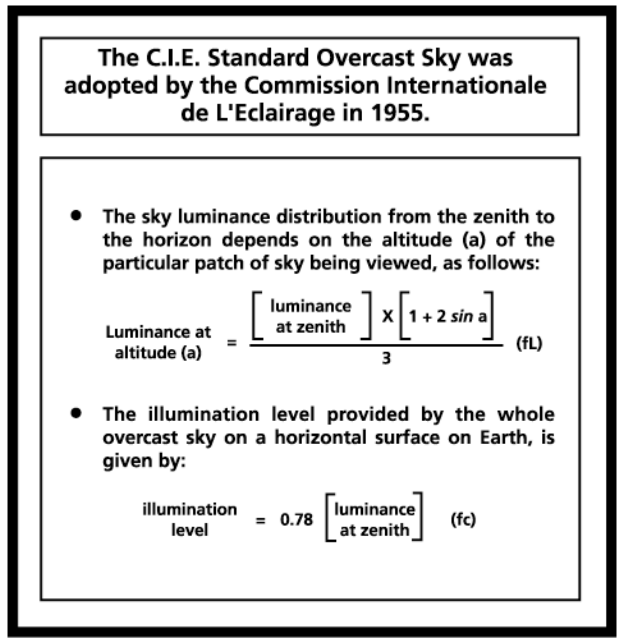

Figure 7.8: CIE standard overcast sky

The natural light available at any point in the building environment must be based on a particular value of the external illumination. Due to the continuous variation of daylight, it is necessary to resort to a statistical analysis and determine probability curves relating to the external illumination levels available for portions of the working day. This information, based on continuous measurements of daylight levels over a number of years, is now available for most major cities. It is common practice to assume that the daylight should be adequate for the greater part of the normal working day (i.e., 8 am to 4 pm) and this is normally considered to be around 85% of daytime working hours.

The CIE Standard Overcast Sky increases in brightness from the horizon to the zenith, so that the luminance at the zenith is about three times that at the horizon. The actual gradation of luminance from zenith to horizon is expressed by the equation:

$$\mathbf{L_a = L_z / (1 + 2 \sin(a))} \quad \ldots\ldots \quad \mathbf{(7.5)}$$

where: L_a = luminance at an altitude of a^o above the horizon

L_z = luminance at the zenith

Thus at the horizon, where the altitude is zero (i.e., $a^o = 0$ and therefore $\sin(a) = 1$):

$$\mathbf{L_0 = L_z / 3} \quad \ldots\ldots \quad \mathbf{(7.6)}$$

It has been found in practice that although the total illumination provided by an overcast sky in different parts of the world may vary widely, the luminance distribution given by equation 7.5 is reasonably constant. Also, the author has found based on a large number of measurements of daylight conditions in actual buildings undertaken by architecture students at Cal Poly, San Luis Obispo, that even in the clear sky conditions prevalent in the California Central Coast region the CIE Standard Overcast Sky correlated better with actual lighting conditions than the Uniform Brightness Sky.[6]

To ensure adequate natural light inside buildings it is the usual procedure to design on the basis of an assumed overcast sky. Any point in a room that is remote from windows will be directly in line with a section of the sky near the horizon, and will therefore receive least light when the sky is clouded.

7.4 Measurement of Daylight

There are two basic types of instruments used to measure light, namely visual and photoelectric meters. Visual instruments of photometry, such as the photometer shown in Figure 7.9, rely on the subjective comparison of two patches of light, one of which can be controlled to match the other. Normally the standard light source and the light source to be measured enter the central chamber of the photometer from opposite directions, illuminating the two surfaces of a central dividing partition. The observer is able to see both of these illuminated surfaces simultaneously through mirrors and adjust the distance of the standard light source from the partition until the two patches of light match in brightness.

The use of a photometer is not recommended for building designers who are only from time to time involved in the measurement of light levels. Proper application of this kind of visual instrument requires skill and experience. The difficulties encountered in the design of the required control luminance patch, the constant need for calibration, and individual differences in sensitivity to light of different wavelengths, may lead to unreliable readings in unskilled hands.

Photoelectric cells convert light into electricity and therefore measure the current or voltage generated by the incident light radiation. By far the most common choice for both daylight and artificial light measurements is the selenium photoelectric cell or light meter (Figure 7.10) in which incident light is converted directly into electrical energy without the need for an additional, external source of electricity. The selenium cell consists simply of a crystalline selenium plate sandwiched between a metal plate acting as cathode and a metal contact ring anode. This assembly is normally encased in a non-conductive housing and soldered rather than clamped, to avoid damage to the sensitive selenium plate. Unfortunately, selenium cells tend to *drift*, due to a decrease in response during the first few minutes of exposure to light.

[6] Over a period of several years (1973-1978) small groups of students were required to undertake a class assignment in which they chose any interior space on campus, measured actual light levels at nine equidistant points within the space at approximately 9 am, 12 noon and 4 pm on successive days, and then compared these measurements with predicted values generated by a computer program. The computer program was capable of calculating two sets of illumination levels at user-specified grid intersection points. One set was based on a Uniform Brightness Sky and the other set was based on the CIE Standard Overcast Sky. Except for spaces with windows facing due west, the calculated values that were based on overcast sky conditions invariably correlated significantly better with the actual measurements than the estimates that were based on uniform clear sky conditions.

Accordingly, readings should not be recorded until the cell has been illuminated for about ten minutes.

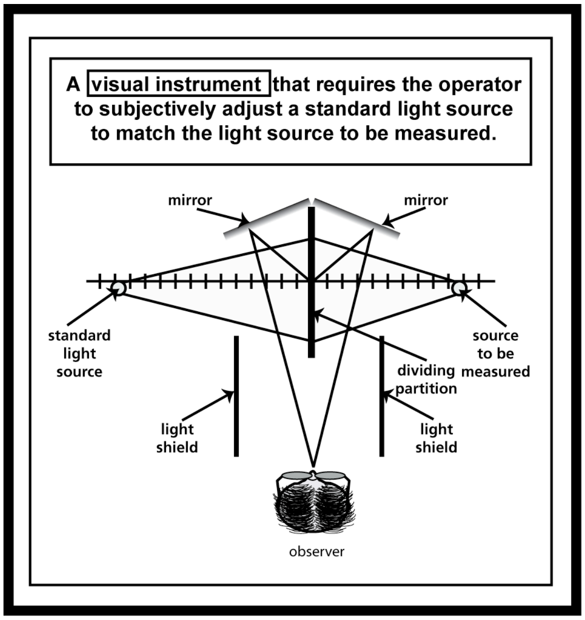

Figure 7.9: Photometer

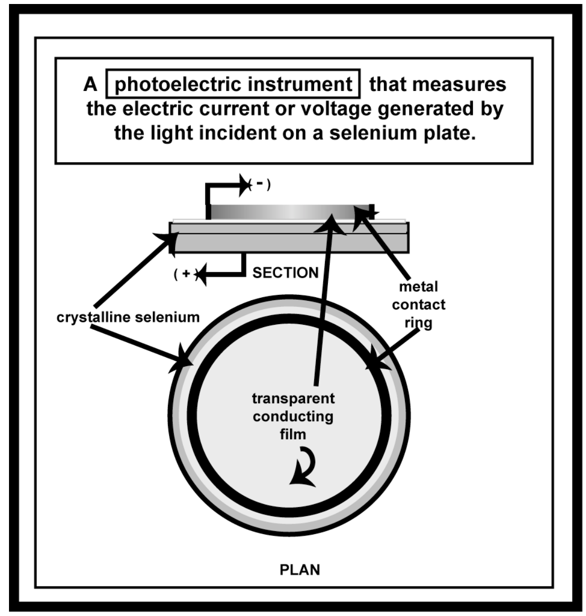

Figure 7.10: Photoelectric light meter

7.5 Model Analysis

Before the availability of computers, model analysis was a very popular method for exploring the daylight design of buildings. A scale model can be constructed rather inexpensively and fairly quickly out of cardboard. Therefore, even today with the availability of sophisticated computer programs that can render the lighting conditions of building interiors, model analysis is still considered a useful design tool for at least the subjective investigation of the proposed lighting conditions of interior spaces.

It has been proven conclusively that the distribution of illumination inside a scale model is identical with that found in a full-size building, provided that the absorption of all surfaces in the model is precisely that of the original building and the luminance of all sources is accurately reproduced. Accordingly, scale models of buildings may be exposed either to the luminance of the outdoor sky or more conveniently to an electrically controlled artificial sky dome.

An *artificial sky dome* of the type shown in Figure 7.11 consists of a reflecting enclosure lit by a series of electric lamps, which may be adjusted to simulate any particular outdoor illumination level. An alternative to the artificial sky dome is a square box lined with flat mirrors, referred to as a *mirror box artificial sky* (Figure 7.12). The roof of the mirror sky consists of an opal acrylic sheet illuminated from above by a carefully distributed set of fluorescent lamps. Three principal criteria govern the design of either type of artificial sky:

1. A luminous overhead surface to represent the sky. It is desirable for the luminous distribution of this surface to be adjustable.
2. A ground surface of known reflectance.

3. A correctly located horizon in relationship to the model. In the case of the artificial sky dome the model is placed in the center under the dome and therefore the boundary of the dome on the base platform satisfies the horizon criterion. For the mirror box artificial sky, the mirrors that line the internal walls produce an infinite number of inter-reflections, which ensure that the image of the horizon is always at the eye-level of the observer inside the box (and at an infinite distance from the observer).

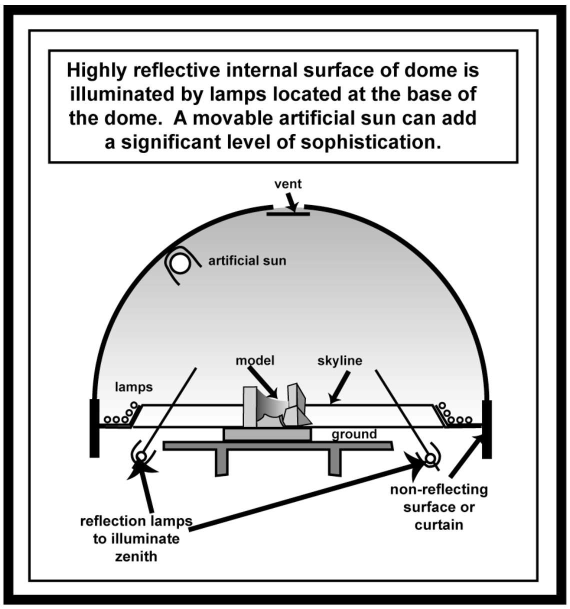

Figure 7.11: Artificial Sky Dome

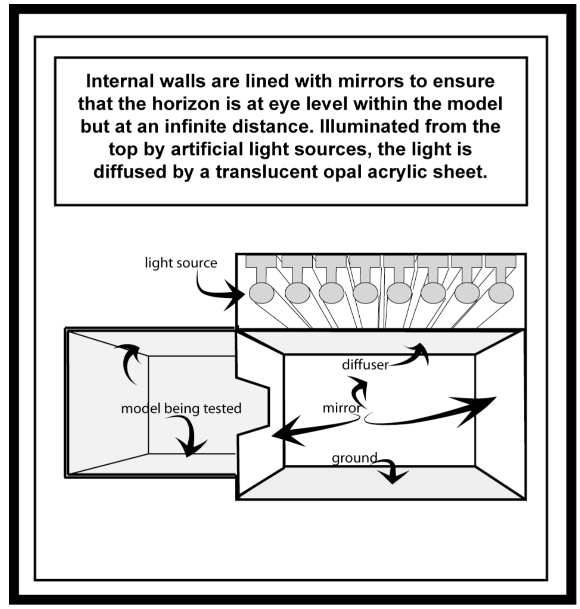

Figure 7.12: Mirror Box Artificial Sky

In the dome-shaped artificial sky the white and highly reflective internal surface of the dome is illuminated from below by a series of lamps. Normally these lamps are positioned around the internal perimeter of the dome on moveable panels. Slight changes in the luminance distribution of the dome surface may be obtained by tilting the perimeter light panels vertically. However, the upper limit of illumination that may be achieved is severely limited due to problems of heat dissipation and ventilation. Although this is not necessarily a significant disadvantage when concerned with the measurement of *daylight factors* (see Section 7.6), it does prevent the use of this type of artificial sky for subjective studies of glare and visual comfort conditions. For these explorations the mirror box artificial sky is more useful, because it is capable of producing much higher levels of illumination.

7.6 The Daylight Factor Concept

The amount of daylight available outdoors varies hour by hour due to the movement of the sun, and sometimes even minute by minute under intermittent cloud conditions. If, in addition, we take into account that our eyes measure brightness differences and not absolute illumination levels, then it really does not make sense to design the daylight conditions inside a building in terms of specific illumination levels. An alternative and more useful approach is to determine the proportion of the ambient external daylight that should be available at particular locations inside a given building space. These considerations led to the acceptance of the concept of a *daylight* *factor*, which expresses the daylight available inside a building as a percentage of the daylight concurrently available out of doors. Specifically, the Daylight Factor assumes that the daylight available from the sky may be measured by the total illumination (E_H) received on a horizontal plane from the whole sky (Figure 7.13). Therefore, the Daylight Factor (DF) is given by:

DF = [(indoor illumination at a point) / (external illumination from sky)] x 100 %

If E_P is the illumination at a point indoors and E_H is the simultaneous external illumination from the whole sky, then:

$$\mathbf{DF = 100\,[\,E_P / E_H\,]\ (\%)} \quad \ldots\ldots \quad \mathbf{(7.7)}$$

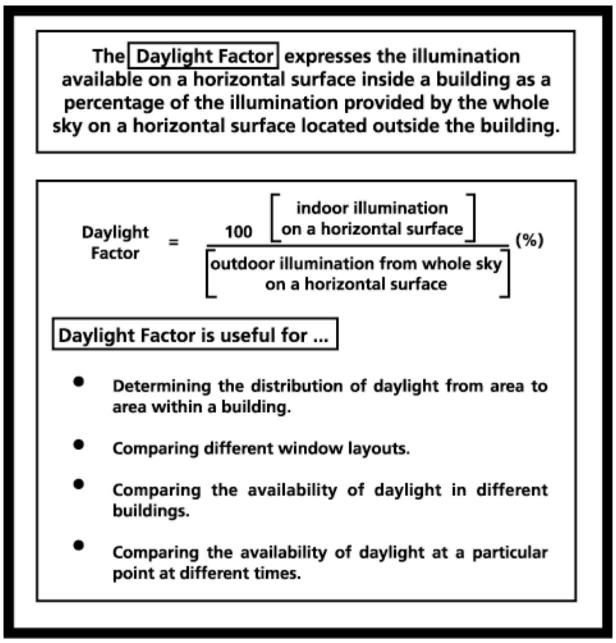

Figure 7.13: The Daylight Factor concept

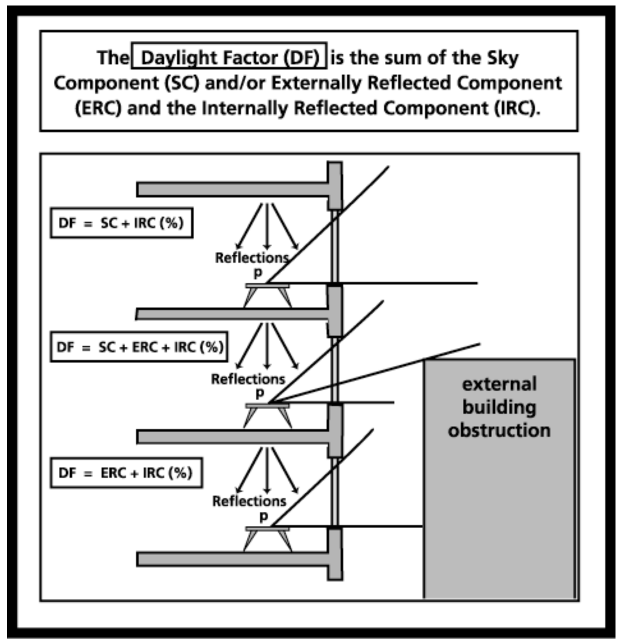

Figure 7.14: Daylight Factor components

As a guide to the amount of natural light available in the interior spaces of a building, the Daylight Factor has the advantage of relative constancy. Although there may be wide fluctuations in the outdoor illumination level, the ratio of outdoor to indoor illumination will remain constant as long as the distribution of sky luminance remains static. Unfortunately, due to direct sunshine or isolated clouds the distribution of sky luminance will vary in practice. Nevertheless, the Daylight Factor remains a very useful and popular method for investigating:

- The distribution of daylight from area to area within a building.
- The comparison of various window layouts.
- The comparison of the availability of daylight in different buildings.
- The comparison of measurements taken at different times in the same or different building spaces.

The determination of the Daylight Factor at a particular point in a space is normally undertaken in three stages, although in the case of an open site this can be reduced to two stages. First, we calculate the direct light from the sky, referred to as the *sky component.* This is followed by the calculation of the *externally reflected component*. However, this component exists only if external obstructions such as buildings are visible through the window. On the other hand, if external obstructions block out the entire view of the sky then there will be no *sky component*. Finally, the many inter-reflections that will occur among the surface in the space is calculated as an *internally reflected component*. This component is always present because it will be produced by either the Sky Component or the Externally Reflected Component or both. Accordingly, as shown in Figure 7.14, the total Daylight Factor at any point inside a building will incorporate up to three components:

1. The Sky Component (SC) due to light received directly at the point under consideration from that section of the sky that is visible through the window.
2. The Externally Reflected Component (ERC) due to light reflected from external objects such as buildings, visible through the window.
3. The Internally Reflected Component (IRC) due to light received by reflection from surfaces within the building.

While the Externally Reflected Component will not occur in the case of an open site, it is also true that in the case of densely grouped high-rise buildings in urban areas the Sky Component may not occur on the lower floors, particularly at points remote from windows.

Sky Component (SC): For an idealized uniform sky and unglazed openings the Sky Component is equal to a measure of the luminance of a uniformly bright sky, referred to as the *sky factor*. Although the Sky Factor has little direct practical value since sky luminance is not uniform, it can be calculated very accurately and has therefore considerable application in the settling of legal disputes.

For purposes of building design, the Sky Component takes into account both a non-uniform sky luminance and transmission losses in the window glazing. In the case of predominantly clear sky conditions, it can be calculated by adjusting the idealized, numerical value of the Sky Factor for variations in sky luminance (R_L) and the transmission loss of clear glass (T_G), as follows:

$$\textbf{SC} = \textbf{(Sky Factor)} \times R_L \times T_G \ (\%) \quad \ldots\ldots \quad \textbf{(7.8)}$$

Alternatively, R_L may also be described as the sky brightness ratio. In this case it is defined as the average brightness of the section of the sky seen through the window, divided by the average brightness of the whole sky. The Sky Factor therefore takes into account the brightness of the altitude of the sky visible through the window. Sky luminance factors (R_L) for average altitude angles of portions of the sky visible through a window are given below.

Altitude Angle	R_L	Altitude Angle	R_L
0°	0.50	50°	1.09
10°	0.58	60°	1.17
20°	0.72	70°	1.24
30°	0.86	80°	1.27
40°	0.98	90°	1.28

The transmission loss (T_G) for clear glass is about 10% at normal angles. However, this percentage will increase at high incident angles and adjustments will have to be made in those special cases. The following light transmission ranges for common types of glass used in buildings are normally applied in Daylight Factor calculations:

Glass Type	Light Transmission
clear glass (single glazed units)	90 to 92%
clear glass (double glazed units)	56 to 76%
clear plate and tempered glass	90 to 92%
heat absorbing glass	40 to 75%
glare reducing glass	12 to 68%
low-E glass (double glazed units)	70 to 73%
low-E glass (triple glazed units)	55 to 64%
glass blocks	81 to 85%
frosted glass	63 to 76%
patterned glass	52 to 92%

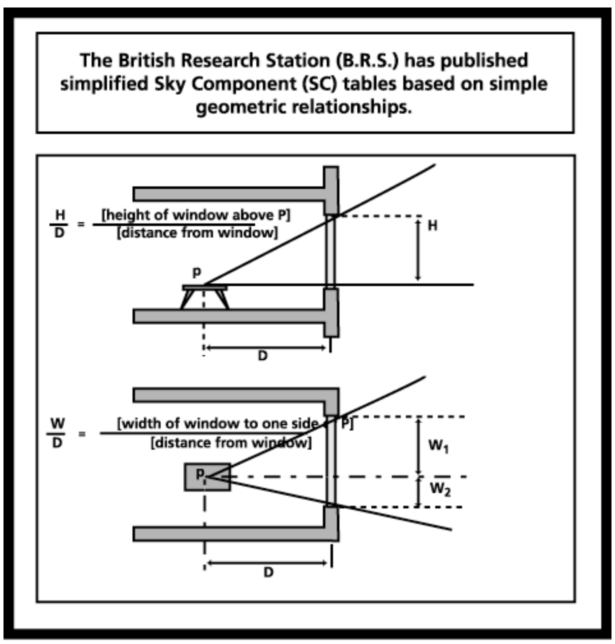

Figure 7.15: BRS Sky Factor Table parameters

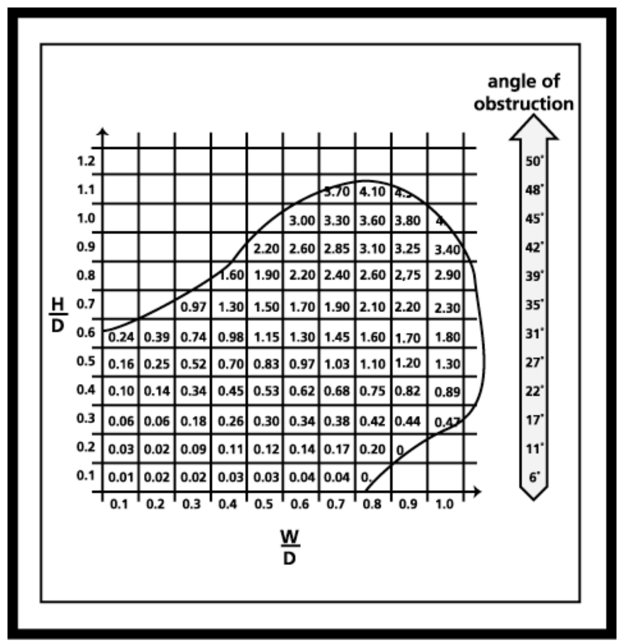

Figure 7.16: BRS Sky Factor Table excerpt

The British Research Station (BRS) has published a very convenient set of Sky Component (SC) tables (Table 7.1 and Figures 7.15 and 7.16) for the CIE Standard Overcast Sky that is based on simple geometric ratios. These ratios take into account the geometry of a side window in respect to its distance, height and horizontal displacement from the point (P) at which the Daylight Factor is to be determined.

H / D = [window head height above 'P'] / [distance of 'P' from window] ……. (7.9)

W / D = [window width to one side of 'P'] / [distance of 'P' from window] …... (7.10)

The distance (D) of point (P) from the window is measured as the perpendicular distance from the window wall.

Table 7.1: The BRS Sky Component (SC) tables for the CIE Standard Overcast Sky

H/D															Angle of Obstruction
∞	1.3	2.5	3.7	4.9	6.9	8.4	9.6	10.7	11.6	12.2	12.6	13.0	14.2	15.0	**90°**
5.0	1.2	2.4	3.7	4.8	6.8	8.3	9.4	10.5	11.1	11.7	12.3	12.7	13.7	14.2	**79°**
4.0	1.2	2.4	3.6	4.7	6.7	8.2	9.2	10.3	10.9	11.4	12.0	12.4	13.3	13.7	**76°**
3.5	1.2	2.4	3.6	4.6	6.6	8.0	9.0	10.1	10.6	11.1	11.8	12.2	12.9	12.9	**74°**
3.0	1.2	2.3	3.5	4.5	6.4	7.8	8.7	9.8	10.2	10.7	11.3	11.7	12.4	12.7	**72°**
2.8	1.1	2.3	3.4	4.5	6.3	7.6	8.6	9.6	10.0	10.5	11.1	11.4	12.0	12.3	**70°**
2.6	1.1	2.2	3.4	4.4	6.2	7.5	8.4	9.3	9.8	10.2	10.8	11.1	11.7	11.9	**69°**
2.4	1.1	2.2	3.3	4.3	6.0	7.3	8.1	9.1	9.5	10.0	10.4	10.7	11.2	11.5	**67°**
2.2	1.1	2.1	3.2	4.1	5.8	7.0	7.9	8.7	9.1	9.6	10.0	10.2	10.7	10.9	**66°**
2.0	1.0	2.0	3.1	4.0	5.6	6.7	7.5	8.3	8.7	9.1	9.5	9.7	10.0	10.3	**63°**
1.9	1.0	2.0	3.0	3.9	5.4	6.5	7.3	8.1	8.5	8.8	9.2	9.4	9.7	9.9	**62°**
1.8	0.97	1.9	2.9	3.8	5.3	6.3	7.1	7.8	8.2	8.5	8.8	9.0	9.3	9.5	**61°**
1.7	0.94	1.8	2.8	3.6	5.1	6.1	6.8	7.5	7.8	8.2	8.5	8.6	8.9	9.1	**60°**
1.6	0.90	1.7	2.7	3.5	4.9	5.8	6.5	7.2	7.5	7.8	8.1	8.2	8.5	8.6	**58°**
1.5	0.86	1.6	2.6	3.3	4.6	5.6	6.2	6.8	7.1	7.4	7.6	7.8	8.0	8.1	**56°**
1.4	0.82	1.5	2.4	3.2	4.4	5.2	5.9	6.4	6.7	7.0	7.2	7.3	7.5	7.6	**54°**
1.3	0.77	1.4	2.3	2.9	4.1	4.9	5.5	5.9	6.2	6.4	6.6	6.7	6.9	7.0	**52°**
1.2	0.71	1.3	2.1	2.7	3.8	4.5	5.0	5.4	5.7	5.9	6.0	6.1	6.2	6.3	**50°**
1.1	0.65	1.1	1.9	2.5	3.4	4.1	4.6	4.9	5.1	5.3	5.4	5.4	5.6	5.7	**48°**
1.0	0.57	0.99	1.7	2.2	3.0	3.6	4.0	4.3	4.5	4.6	4.7	4.7	4.8	5.0	**45°**
0.9	0.50	0.83	1.5	1.9	2.6	3.1	3.4	3.7	3.8	3.9	4.0	4.0	4.1	4.2	**42°**
0.8	0.42	0.68	1.2	1.6	2.2	2.6	2.9	3.1	3.2	3.3	3.3	3.3	3.4	3.4	**39°**
0.7	0.33	0.53	0.97	1.3	1.7	2.1	2.3	2.5	2.5	2.6	2.6	2.6	2.7	2.8	**35°**
0.6	0.24	0.39	0.74	0.98	1.3	1.6	1.8	1.9	1.9	2.0	2.0	2.0	2.1	2.1	**31°**
0.5	0.16	0.25	0.52	0.70	0.97	1.10	1.3	1.4	1.4	1.4	1.4	1.5	1.5	1.5	**27°**
0.4	0.10	0.14	0.34	0.45	0.62	0.75	0.89	0.92	0.95	0.95	0.96	0.96	0.97	0.98	**22°**
0.3	0.06	0.06	0.18	0.26	0.34	0.42	0.47	0.49	0.50	0.50	0.51	0.51	0.52	0.53	**17°**
0.2	0.03	0.02	0.09	0.11	0.14	0.20	0.21	0.22	0.22	0.22	0.22	0.23	0.23	0.24	**11°**
0.1	0.01	0.02	0.02	0.03	0.04	0.05	0.05	0.06	0.06	0.06	0.06	0.07	0.07	0.08	**6°**
0	**0.1**	**0.2**	**0.3**	**0.4**	**0.6**	**0.8**	**1.0**	**1.2**	**1.4**	**1.6**	**1.8**	**2.0**	**3.0**	∞	**0°**

Ratio W/D = Width of Window to one Side of Normal / Distance from Window

(Ratio H/D = Height of Window Head above Working Plane / Distance From Window)

Four different cases of the application of the BRS Sky Component (SC) table are shown in Figures 7.17 to 7.20 below. Case (1) in Figure 7.17 is the simplest case in which point (P) is at window sill height and located symmetrically on the center line of the window. Therefore, *H* is equal to the height of the head of the window above sill level (i.e., 6FT), while the perpendicular distance between point (P) and the window wall *D* is 8FT. Since the total width of the window is 15FT and point (P) is located exactly opposite the center of the window, *W* is 7.5FT. Accordingly the ratios *H/D* and *W/D* are equal to *0.75* and *0.94*, respectively. By extrapolating between *H/D* ratios of *0.7* and *0.8* in Table 7.1, these ratios generate a Sky Component (SC) of approximately 2.5%. However, that accounts for the daylight provided by only half of the window. Since point (P) is located on the center line of the window the daylight provided by the entire window will be twice the value obtained for either side, or *5%* in this case.

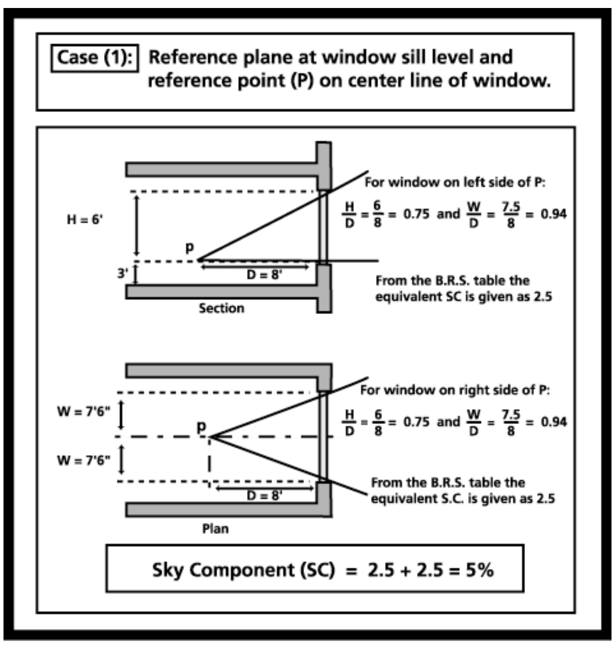

Figure 7.17: Case (1) – Reference point at window sill level

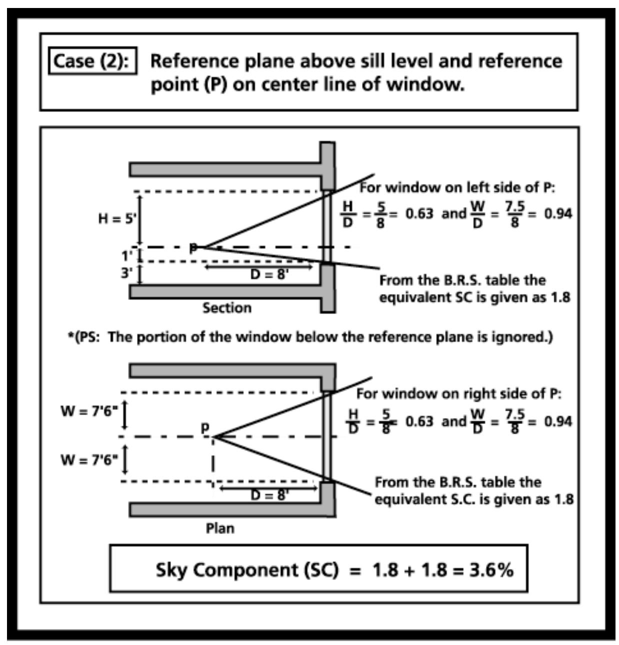

Figure 7.18: Case (2) – Reference Point above window sill level

In case (2), shown in Figure 7.18, point (P) is still on the center line of the window but 1FT above sill level. This changes the *H/D* ratio to *5/8* or *0.63*, while the *W/D* ratio remains at *0.94*. The portion of the window below the plane of point (P) is typically ignored because an observer stationed at point (P) would normally not be able to see any portion of the sky through that lower portion of the window.[7]

[7] While this is certainly true for the Sky Component (SC), there may be instances when a highly reflective surface at ground level outside the window (e.g., water or the shiny roof surface of a neighboring building that is located just below the window sill level) may reflect light through the lower

Case (3) in Figure 7.19 illustrates a situation where point (P) is located below the window sill. The determination of the Sky Component (SC) in this case requires us to proceed in two stages. First, we calculate the H_1/D ratio for a hypothetical window that extends from the actual window head down to the plane of point (P). In other words, we temporarily assume that the window sill is located at the same height above floor level as point (P). Then we calculate the H_2/D ratio for the portion of the hypothetical window that extends from the actual window sill down to the plane of point (P). The true Sky Component (SC) is found by subtracting the SC given by Table 7.1 for the H_2/D ratio from the SC given by Table 7.1 for the H_1/D ratio (i.e., 3.9% - 0.1% = 3.8%). Again, since point (P) lies on the center line of the window, this SC value is doubled to account for the two sides of the window (i.e., 3.8% + 3.8% = 7.6%).

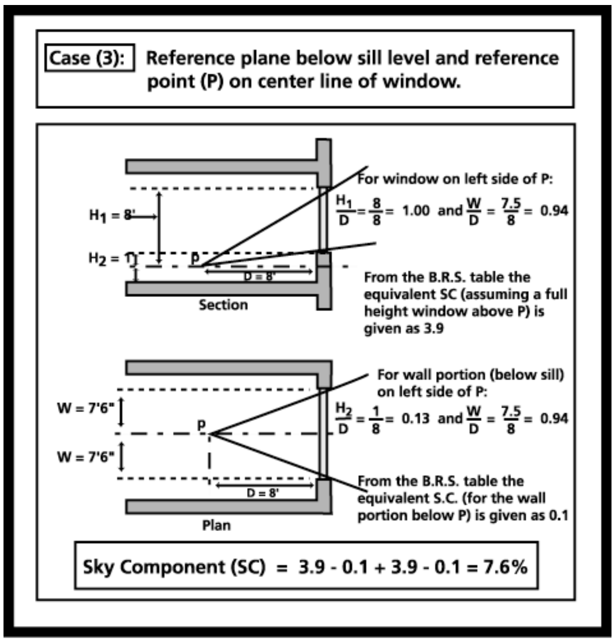

Figure 7.19: Case (3) – Reference point below window sill level

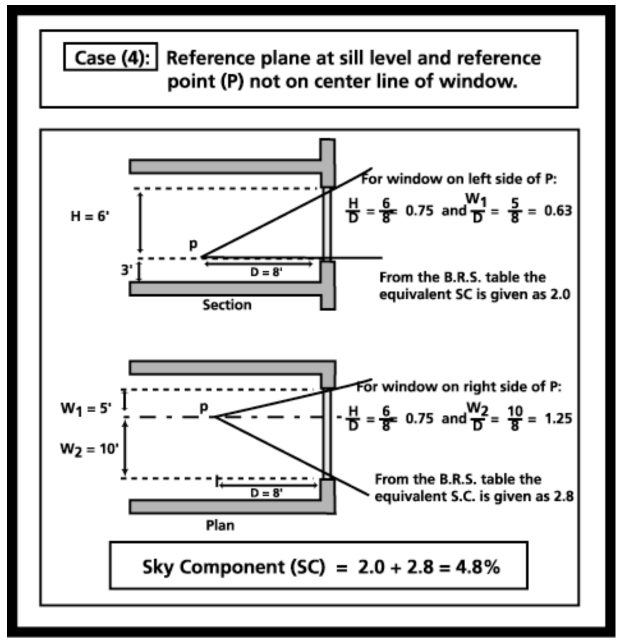

Figure 7.20: Case (4) – Reference Point not on center line of window

Case (4) shown in Figure 7.20 is actually more typical than the other three cases because the point at which the Sky Component (SC) is to be determined is seldom on the center line of a window. Under these circumstances the SC value has to be calculated separately for each side of the window. In Figure 7.20, with point (P) at window sill height, the H/D ratio for either side of the window is *6/8* or *0.75*. The W_1/D ratio is *5/8* or *0.63*, since the width of the window extending from the perpendicular line that point (P) subtends to the window to the left side of point (P) is 5FT. From Table 7.1 we extrapolate the SC value for this portion of the window to be approximately 2.0.

However, the width of the portion of the window on the right side of the perpendicular line between point (P) and the window is 10FT. Therefore, the W_2/D ratio for this portion of the window is *10/8* or *1.25*. Using this ratio together with the H/D ratio of *0.75* (which applies to both sides of the window) to look up Table 7.1, we obtain a SC value of approximately *2.8*. Therefore, the Sky Component (SC) for case (4) is 4.8% (i.e., 2.0% + 2.8%).

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part of the window. In this rather unusual case the portion below the window sill level would not be ignored, but calculated as an Externally Reflected Component (ERC). As we will see later in this section, the ERC is calculated as a Sky Component with reduced luminance (i.e., normally 20%).

In a more extreme case where the location of the window is so far to one side of point (P) that the perpendicular line subtended by point (P) to the window wall does not lie within the width of the window, the Sky Component (SC) is also calculated in two steps. For example, let us assume that the window in Figure 7.20 (i.e., case (4)) is replaced with a much narrower 4FT wide window located 6FT to the right of point (P). In other words, the perpendicular line from point (P) to the window wall is now 6FT to the left of the window. Relative to point (P), the Sky Component (SC) of this window is calculated by subtracting the SC value of a hypothetical window that extends from the perpendicular subtended by point (P) to the left side of the actual window to another hypothetical window that extends from the same perpendicular to the right side of the actual window. The first W_1/D ratio is *6/8* or *0.75* and the second W_2/D ratio is *10/8* or *1.25*. With a *H/D* ratio of *6/8* or *0.75*, which applies to both of these hypothetical window configurations, the SC values (from Table 7.1) are approximately 2.2 and 2.9, respectively. Therefore, the Sky Component (SC) of this 4FT wide window is 0.7% (i.e., 2.9% - 2.2%). The low SC value is due to the fact that the window is located far to the right of point (P) and therefore provides little daylight exposure to point (P).

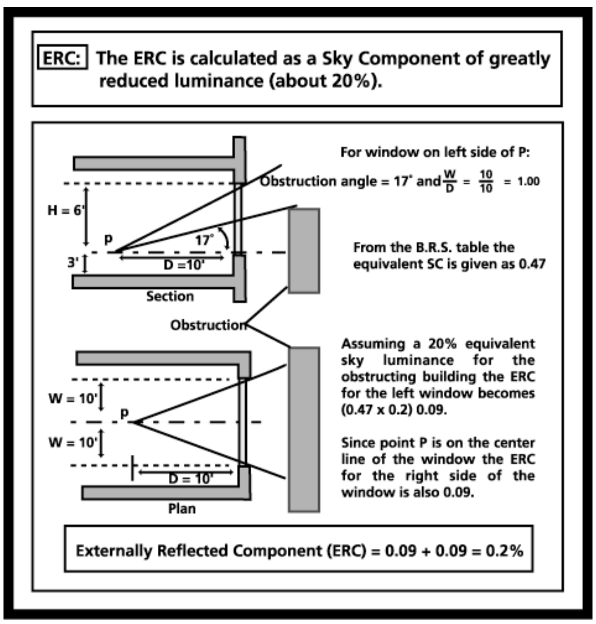

Figure 7.21: Externally Reflected Component

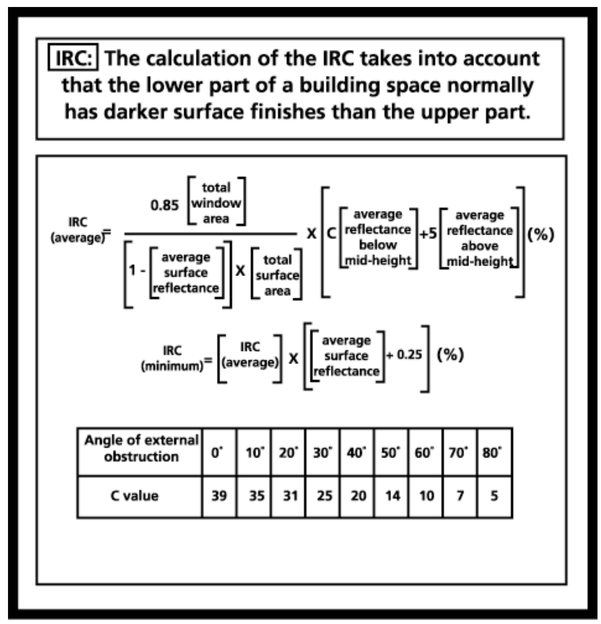

Figure 7.22: Internally Reflected Component

Externally Reflected Component (ERC): Part of the view through the window may be obstructed by buildings that are visible because they reflect light toward the observer. Therefore, they may be treated as a secondary sky of much lower luminance. In practice, since a precise calculation is difficult, the luminance of the obstructed portion of the sky is assumed to be between 10% and 20% of the sky component unadjusted for variations in sky luminance.

$$\textbf{ERC} = \textbf{(Sky Factor)} \times B_R \ (\%) \quad \ldots\ldots \quad (7.11)$$

where: ERC = Externally Reflected Component

B_R = ratio of brightness of obstruction to average brightness of sky (usually 0.2)

For the window configuration shown in Figure 7.21 (i.e., *W/D = 10/10* or *1*.0) and an angle of obstruction of 17°, the SC value provided by Table 7.1 is 0.47. If the luminance of the visible surface of the obstructing building is 20% of the luminance of the sky (i.e., B_R is equal to 0.2), then this SC value is adjusted to 0.09 (i.e., 0.47 x 0.2). Since point (P) is located on the center line of the window, the Sky Component (SC) is equal to the sum of the SC values for each portion of the window, namely 0.2% (i.e., 0.09% + 0.09% = 0.2%).

Internally Reflected Component (IRC): The calculation of the effect of the internal reflections is very much complicated by the differences in reflection factors of the normally dull floor and light-colored ceiling and walls. It is unfortunate that since the highest quality daylight is directed downward from the sky, it will be first reflected by the floor, the lower sections of the walls, and the work plane. Lesser quality daylight that is reflected into a room from external obstructions is directed upward and will therefore be reflected for a second time by the typically more brightly colored ceiling and upper sections of the walls. This suggests that the Internally Reflected Component (IRC) is likely to be a small fraction of the total Daylight Factor when there is a substantial Sky Component (SC). In fact, in practice it has been found that under those conditions the IRC value is seldom greater than 10% of the Daylight Factor. In situations where the SC value is relatively small the contribution of the IRC will be proportionally greater, although the overall Daylight Factor will be much smaller.

Although a number of calculation techniques had been developed in the past, these were largely replaced by a simplified method for estimating the average (IRC_{AVE}) and minimum (IRC_{MIN}) values of the Internally Reflected Component proposed by the British Research Station (BRS) in 1954 (Hopkinson et al. 1966). This method draws a distinction between the reflectivity of the surfaces of the upper and lower portions of a room as follows:

$$\mathbf{IRC_{AVE} = 0.85 \times A_G / [A_S (1 - R_T)] \;\; \times \;\; [C (R_{FW}) + 5 (R_{CW})] \;\; (\%)} \quad \ldots\ldots\ldots\ldots\ldots \quad \mathbf{(7.12)}$$

where: IRC_{AVE} = average Internally Reflected Component
A_G = total window area
A_S = total area of walls, floor and ceiling
R_T = average reflectance of all surfaces
C = factor dependent on angle of obstruction (see Figure 7.22)
R_{FW} = average reflectance of floor and walls below mid-height
R_{CW} = average reflectance of ceiling and walls above mid-height

The minimum Internally Reflected Component (IRC_{MIN}) is then derived as a function of the relative reflectivity of the internal surfaces of the space under consideration.

$$\mathbf{IRC_{MIN} = IRC_{AVE} [R_T + 0.25] \;\; (\%)} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad \mathbf{(7.13)}$$

As an example of the calculation of both the average and minimum Internally Reflected Component we will consider a room that is 10FT wide, 20FT long and 8FT high. It has a complete window wall at one end (i.e., 10FT by 8FT) and no windows in the other three walls.

Step (1): Calculate the total area of walls, floor and ceiling (A_S):

ceiling area = 200SF (i.e., 10 x 20 = 200)
floor area = 200SF (i.e., 10 x 20 = 200)
wall area = 480SF (i.e., 2(10 x 8) + 2(20 x 8) = 480)
total surface area = 880SF (i.e., 200 + 200 + 480 = 880)

Step (2): Calculate the total window area (A_G):

total window area = 80SF (i.e., 10 x 8 = 80)

Step (3): Calculate the average reflectance of all surfaces (R_T), if:

solid wall reflectance = 40% (i.e., 400 x 0.4 = 160)
ceiling reflectance = 80% (i.e., 200 x 0.8 = 160)
floor reflectance = 20% (i.e., 200 x 0.2 = 40)
window glass reflectance = 10% (i.e., 80 x 0.1 = 8)
average surface reflectance = 0.42 (i.e., [160 + 160 + 40 + 8] / 880)

Step (4): Calculate the average reflectances below and above mid-height:

reflectance below mid-height = 0.28 (i.e., [80 + 40 + 4] / 440)
reflectance above mid-height = 0.55 (i.e., [80 + 160 + 4] / 440)

Step (5): Calculate the average Internally Reflected Component (IRC_{AVE}):

IRC_{AVE} = [0.85 x 80] / [(1-0.42) x 880] x [(39 x 0.28) + (5 x 0.55)]
= **1.8%**

Step (6): Calculate the minimum Internally Reflected Component (IRC_{MIN}):

IRC_{MIN} = [1.8 x (0.42 + 0.25)]
= **1.2%**

The individual values calculated for the three components (i.e., SC, ERC, and IRC) are summated and then adjusted for a further loss in light transmission due to deposits of dust and grime on the window glazing. The allowance to be made for dirty windows depends on the locality and the cleaning cycle. The following typical correction factors may be applied:

Locality	Occupancy	Factor
Outer suburban area	clean	0.9
	dirty	0.7
Built-up residential area	clean	0.8
	dirty	0.6
Built-up industrial area	clean	0.7
	dirty	0.5

While the BRS Sky Component tables (Table 7.1) take into account the light transmission loss through normal window glass, an additional adjustment will be necessary in the case of special glass with greatly reduced light transmission properties (e.g., heat absorbing glass or low-E glass in triple glazed units). Finally, if gross window dimensions were used in the calculation of *H/D* and *W/D* ratios for the determination of SC and ERC values then these values should be modified to allow for the area taken up by the window frame. The typical *frame* factors shown in Figure 7.23 should be applied with caution. The proportion of frame area to total window area is not only dependent on the frame material as suggested in Figure 7.23, but also on the overall size of the window. For example, in the case of large fixed windows the proportional area of the window frame may be negligible.

The calculated Daylight Factor must be adjusted for glazing, window frames and dirty windows. (The B.R.S. table takes into account the light transmission loss of normal window glass.)

Glass

Glass Type	Factor
Heat Absorbing glass	0.7
Glass blocks	0.9
Wired glass	0.9
Frosted glass`	0.8
Double glazed windows	0.8

Frame

Window Frame Material	Factor
Wood (openable windows)	0.65
Wood (fixed windows)	0.75
Steel window frames	0.85
Aluminum window frames	0.80

Dirt

Locality	Occupancy	Factor
Rural suburban	clean	0.9
	dirty	0.7
Urban residential	clean	0.8
	dirty	0.6
Industrial area	clean	0.7
	dirty	0.5

Figure 7.23: Daylight Factor adjustments

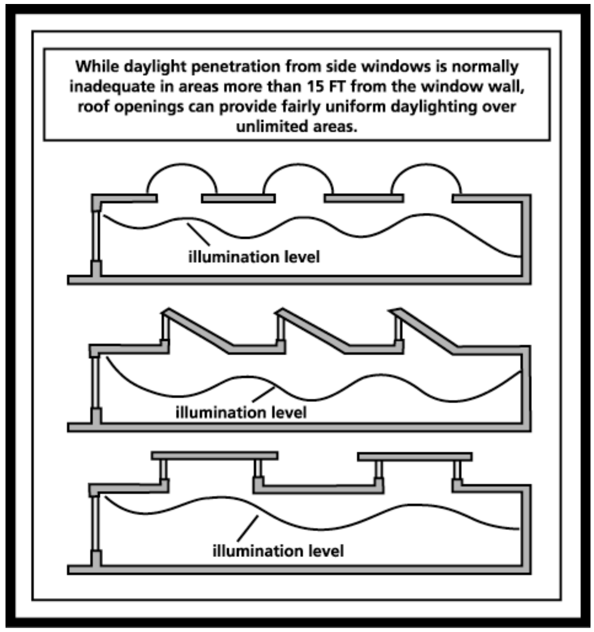

Figure 7.24: Roof lighting variations

7.7 Glare from Daylight

Direct, reflected and diffuse sunlight are the most common causes of glare from windows. In these cases, the contrast between the luminance of the window and the surrounding surfaces may be sufficiently pronounced to produce conditions varying from noticeable visual stress to disability glare and the impairment of vision. Basically, there are four possible remedies available to ameliorate such glare conditions:

1. Raising the level of illumination in the vicinity of the windows by means of supplementary, artificial lighting installations. While this remedy is often used in regions where overcast skies are prevalent, it tends to be uneconomical in regions where clear sky conditions are predominant. In the latter case the amount of artificial light that is required to mitigate the glare condition may not be compatible with the energy conservation objectives of the design solution.
2. Blocking direct sunlight or reducing the section of the sky visible through the windows by means of blinds, curtains, fins, louvers, or canopies. In the Northern Hemisphere this is a relatively simple matter if the main windows face south (or north in the Southern Hemisphere). On the other hand, east and west elevations may require adjustable vertical sun-shading devices, which tend to be expensive in respect to both initial acquisition cost and maintenance requirements.

3. The use of roof lights. As shown in Figure 7.24, various configurations with and without the provision of sun shading are available. The principal limitation of roof lights is that they are applicable only to single story buildings (or the top floor of multi-story buildings).
4. The use of special anti-glare or low transmission glass in combination with light-colored interior surfaces, especially on the window wall, to increase the luminance of the building environment. It should be noted, however, that the application of low transmission glass will result in a substantial reduction in the amount of natural light available inside the building, while the contrast in brightness between the window and surrounding surfaces is little affected. Further, it is well to remember that one of the main functions of a window is to provide a view. Depending on the exterior brightness and light transmission, these special glasses will, at times, behave like mirrors and therefore interfere with the transparency of the window.

7.8 Questions Relating to Chapter 7

Answers to the following multiple-choice questions with references to the appropriate text (by page number) may be found at the back of the book.

1. **Which of the following is not a correct characteristic of daylight?**
   - A. It is fairly constant for the greater part of the working day.
   - B. It follows a "Normal Distribution" curve.
   - C. It is visible.
   - D. It changes constantly.
   - E. All of the above are correct characteristics of daylight.

2. **Whether or not it is possible to light a building adequately by daylight will depend on the circumstances. In multi-story, city buildings, lighting conditions are likely to be poorest:**
   - A. On the higher floors, since these are unlikely to receive extra light by reflection from neighboring buildings.
   - B. On lower floors and in deep rooms.
   - C. On the southern side due to external sunshading devices.
   - D. On the higher floors if walls and ceiling are painted in dark shades.
   - E. None of the above are correct.

3. **Which of the following measures of the natural light available externally forms the basis of the "Daylight Factor" concept:**
   - A. The luminance or brightness of a section of sky seen through a window.
   - B. Direct sunlight.

C. The total illumination received from half the sky on the vertical plane of the window.

D. The total illumination received on a horizontal plane from the whole sky out-of-doors.

E. None of the above (i.e., A, B, C, D) are correct.

4. **Daylight design is based on the following source of light:**

   A. The sun

   B. Ultra-violet radiation

   C. The sky

   D. Infra-red radiation

   E. None of the above (i.e., A, B, C, D) are correct.

5. **The visible spectrum of electromagnetic radiation or light as we perceive it, occupies a narrow band that extends from approximately:**

   A. 400 to 700 microns

   B. 4,000 to 7,000 millimicrons

   C. 40 to 700 microns

   D. 400 to 7,000 millimicrons

   E. 400 to 700 millimicrons

6. **The natural light available at any point in the building environment must be based on a particular value of the external illumination. Due to the continuous variation of daylight, it is necessary to resort to:**

   A. An experimental analysis.

   B. A statistical analysis.

   C. A random analysis.

   D. A subjective procedure.

   E. None of the above (i.e., A, B, C, D) are correct.

7. **The external illumination available on a rainy overcast weekday for 80% of working hours in California is likely to be at least:**

   A. 400 fc.

   B. 3,000 fc.

   C. 2,000 fc

   D. 800 fc

   E. 1,500 fc

8. **If the external illumination available in a Mexican town for 90% of working hours is <u>2,400 lm/sq. ft</u>., then the external illumination available for 80% of working hours is likely to be:**

A. 2,700 fc
B. 2,000 fc
C. 1,000 fc
D. 5,000 fc
E. None of the above (i.e., A, B, C, D) are correct.

9. **The assumption that the daylight available from the sky must be measured by the total illumination received on a horizontal plane from the sky leads to the concept of the Daylight Factor (DF), which may be expressed as:**

A. DF = 100 [indoor illumination at a point] / [external illumination from whole sky]
B. DF = 100 [average indoor illumination] / [average outdoor illumination]
C. DF = 100 [indoor illumination at a point] / [external illumination from half the sky]
D. DF = 100 [indoor illumination at a point] / [luminance of sky seen through window]
E. None of the above (i.e., A, B, C, D) are correct.

10. **The Daylight Factor provides a convenient method for studying:**

1. The distribution of daylight from area to area within a building.
2. Comparison of various window layouts.
3. Comparison of the availability of daylight in different buildings.
4. Comparison of daylight measurements taken at different times.
5. Adequacy in direct numerical terms of daylight in any building.

Which of the above statements (if any) is <u>not</u> correct:

A. Statements 2 and 5 are incorrect.
B. Statements 1, 2, 3 and 4 are incorrect.
C. Statement 5 is incorrect
D. All statements (i.e., A, B and C) are correct.
E. All statements (i.e., A, B, C and D) are incorrect.

11. **The light transmission loss for clear glass is about <u>X%</u> at normal angles. This value will _____ at high incident angles.**

A. 10%; missing word is DECREASE.
B. 20%; missing word is DECREASE.
C. 10%; missing word is INCREASE.
D. 30%; missing word is INCREASE.

12. **The light transmission loss through heat-absorbing glass is likely to be:**

A. 30%
B. The same as that for glass blocks.
C. 10%
D. Slightly more than that for clear glass.

E. None of the above (i.e., A, B, C, D) are correct.

13. **Photoelectric cells are commonly used for the measurement of light. They eliminate many of the difficulties encountered in visual light meters, for the following reason:**

    A. They are much smaller and more rugged than visual light meters.
    B. They convert incident light directly into electrical energy.
    C. They do not require an additional external source of electricity.
    D. Photoelectric cells rely on the subjective comparison of two patches of light, one of which can be controlled to match the other.
    E. None of the above (i.e., A, B, C, D) are correct.

14. **A clear sky is about 'X' times brighter near the sun than at a 90° angle from the sun. What is the approximate value of 'X"?**

    A. 2
    B. 4
    C. 10
    D. 20
    E. None of the above (i.e., A, B, C and D) are correct.

15. **A complete specification of color must include values for the following three characteristics:**

    A. wavelength, brightness, and saturation
    B. hue, value, and chroma
    C. wavelength, luminance, and purity
    D. All of the above (i.e., A, B and C) are correct.
    E. None of the above (i.e., A, B, C and D) are correct.

16. **Which of the following explanations of *metamerism* is correct?**

    A. *Metamerism* refers to the ability of the human eyes to judge color differences.
    B. *Metamerism* refers to the ability of a person to match a colored light patch with different spectral compositions.
    C. *Metamerism* refers to the ability of the human eyes to perceive colors under a wide range of luminances.
    D. All of the above explanations (i.e., A, B and C) are correct.
    E. None of the above (i.e., A, B, C and D) are correct.