Translation

- When illuminance data are not available, radiation data can be converted to illuminance values (weather data file usually contains radiation data)

Total radiation, sun and sky = 119 lm/W

Diffuse (sky) radiation only ~= 14 lm/W

Direct solar radiation only ~= 105 lm/W

Therefore, a surface receiving a total radiation of 750 W/m^2 is illuminated to

$$E = 750\ \text{W}\ (119\ \text{lm/W}) = 89{,}250\ \text{lux, or } 8272\ \text{fc}$$

Illuminance

- Overcast
  - Horizontal: Fig.10.23
  - Vertical: Fig.10.23
- Clear sky
  - Horizontal: Fig.10.24
    - Direct sun
    - Sky component
  - Vertical: Fig.10.26
    - Sun only, no sky contribution, year-long: Fig.10.26 (a)
    - Summer sky, no sun contribution: Fig.10.26 (b)
    - Sky during various seasons, no sun contribution: Fig.10.26 (c)

Partly cloudy sky

- Difficult to express the sky luminance mathematically because of its infinite variability of conditions
- However, statistical data on cloud cover are available from observations at many weather stations, and these data are used for a partly cloudy sky model and hour-by-hour building energy analysis programs.
- The illuminance from a partly cloudy sky is higher than that from a clear sky by 10-15% because of the additional reflected sunlight from cloud edges.

Daylight Factor (DF)

- Primarily intended for overcast skies
- Defined as the ratio of indoor illuminance to available outdoor illuminance
- Used as a means of
  - (1) setting criteria
  - (2) determining the effectiveness of a daylighting design

Daylight Factor (DF)

- Developed in England, Scandinavia (overcast sky dominant)
- Defined as:
  - DF = indoor daylight illuminance / E_H
    - Variations in daylight inside correspond to variations outside (DF remains the same)
- The overcast sky in the DF method represents minimum exterior illumination.
  - Large window areas in overcast sky design locales can be a severe glare source in clear sky.
  - Because under clear or partly cloudy sky conditions the daylight factor at a given point also varies continuously, the concept of DF is useless for a calculation tool for absolute daylight values.

Why sDA and ASE?

- Because daylight factor does not take into consideration location, climate, and building orientation.
- Spatial Daylight Autonomy (sDA) and Annual Sun Exposure (ASE) together provide more accurate performance predictions over the entire year.
- These metrics are used in the USGBC LEED v4 certification and the AIA Committee on the Environment's Top Ten Honor Award submission requirements.

sDA & ASE

- sDA: the percentage of regularly occupied floor area receiving at least 300 lux for at least 50% of the annual occupied hours.
  - This metric describes how much of the building receives sufficient daylight.
- ASE: the percentage of floor area that receives at least 1000 lux for at least 250 occupied hours per year.
  - The ASE metric describes how much of space receives too much direct sunlight, which can cause visual discomfort (glare) or increase cooling loads (Reinhart, et al., 2006; IESNA Daylight Metrics Committee, 2012; Van DenWymelenberg and Mahic, 2016; and Sefaira.com)

sDA & ASE

- sDA and ASE are the first IES-adopted, annual daylighting performance metric.
- known as climate-based daylight metrics or dynamic-daylight metrics.
- now incorporated in common lighting analysis and design software packages, such as Diva-for-Rhino, OpenStudio, Radiance, Daysim.
- These two metrics are important in that they are necessary for earning all LEED v4 daylighting credit points. (https://www.usgbc.org/credits/healthcare/v4-draft/eqc-0).

sDA

- sDA value >= 75: indicates a space in which daylighting is "preferred" by occupants; that is, occupants would be able to work comfortably there without the use of any electric lights, and find the daylight levels to be sufficient.
- 55<=sDA<75: indicates a space in which daylighting is "nominally accepted" by occupants. Lighting designers, therefore, should aim to achieve sDA values of 75 percent or higher in regularly occupied spaces, such as an open-plan office or classroom, and at least 55 percent in areas where some daylight is important.

ASE

- Lighting Measurement-83 (LM-83, IES-approved method) provides preliminary guidance for recommended ASE limits, cautioning that spaces with ASE values exceeding 10 percent will likely result in visual discomfort. LEED v4 suggests that ($ASE_{1000,250}$) of no more than 10% should be achieved (https://www.usgbc.org/credits/healthcare/v4-draft/eqc-0).

Daylight components in DF

- Sky component (SC)
- Externally reflected Component (ERC)
- Internally reflected Components (IRC_1 + IRC_2)

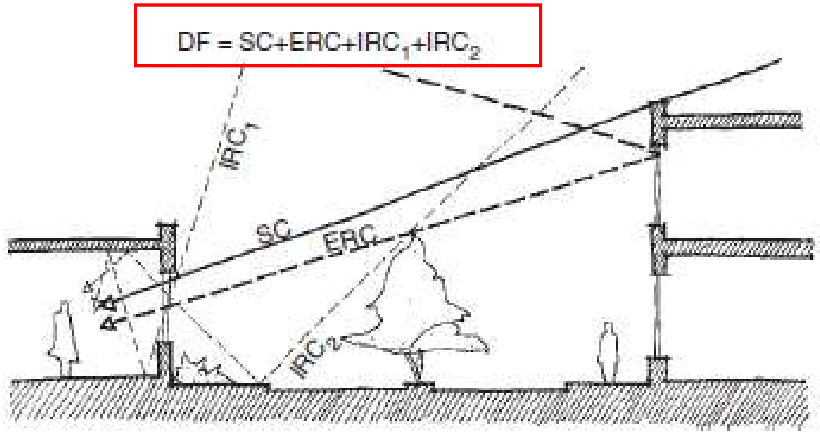


Fig. 10.27 Total daylight factor (DF) is composed of the SC, ERC, and IRC. The IRC, in turn, is subdivided into reflected sky light and reflected ground light components. Note that surfaces deep in the room are illuminated with re-reflected light. (Drawing by Erik Winter.)

1. Direct calculation is extremely complex (not difficult)
2. The DF calculation for each point needs individual calculation!!

Any change in parameters, such as window dimensions or height above the working plane, ceiling height, surface reflectance, ground reflection, and obstructions, alters the curves (Fig.10.29) and requires recalculation and replotting. The job is very tedious and time-consuming.

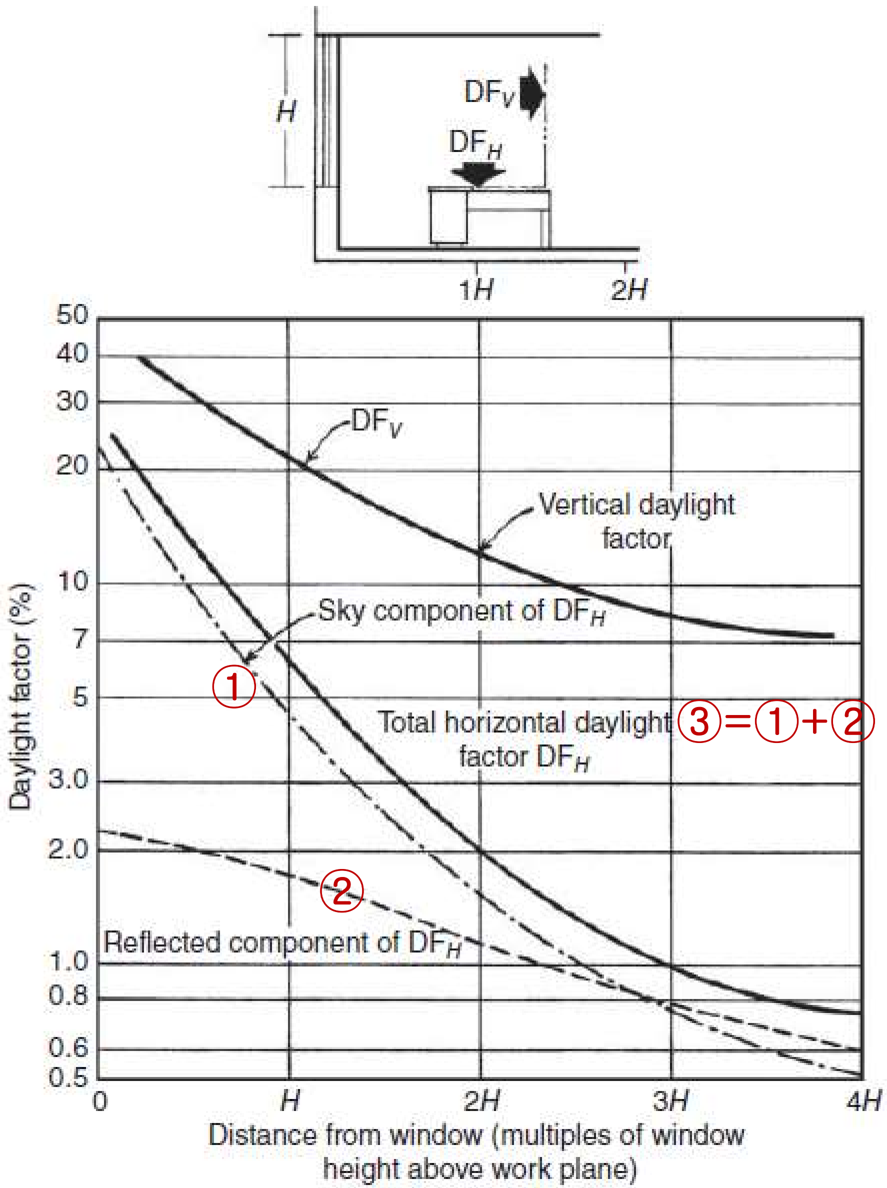


Fig. 10.29 *Typical daylight factor curves for horizontal (DFH) and vertical (DFV) illuminance for a room with large windows on one side only. Note that the SC represents almost the entire DF near the window, but its proportion reduces at greater depths. There, interreflected light constitutes 50% of the available daylight.*

Fig 10.29 Typical daylight factor curves

Guidelines for preliminary daylighting design

For a window-wall:
A 15ft wide zone can be daylit sufficiently for office tasks.

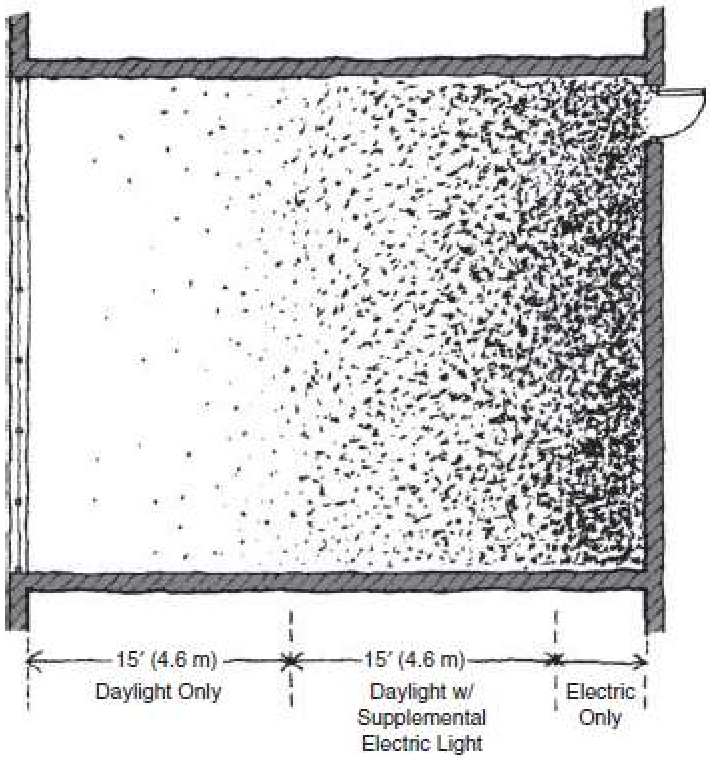


Fig. 10.31 *Plan shows the 15/30 guideline, which assumes that sufficient daylight will be delivered to the desk plane at a 15-ft (4.6-m) distance from the window wall. The 15- to 30-ft (4.6- to 9.1-m) daylight zone will need supplementary electric lighting, and the zone beyond 30 ft (9.1 m) will receive virtually no daylight. (Drawn by Jonathan Meendering and Ayush Vaidya; © Walter Grondzik; all rights reserved.)*

(2) The 15/30 guideline

For window width = ½ wall width:
There will be sufficient workplane illuminance from a window up to a distance of 2.5H, assuming clear glazing, overcast skies, no major obstructions

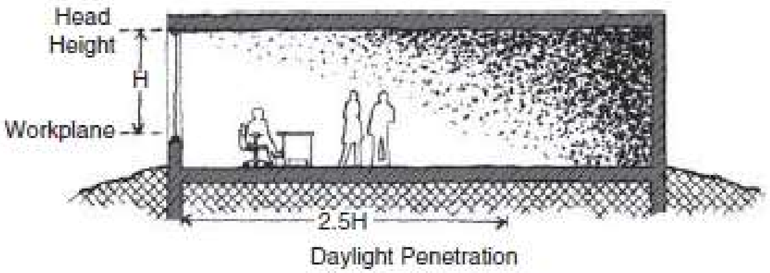


Fig. 10.30 *Section shows the 2.5H guideline, which assumes that sufficient daylight for the desk plane will be delivered at a depth 2.5 times the height of the window above the desk plane. (Drawn by Jonathan Meendering and Ayush Vaidya; © Walter Grondzik; all rights reserved.)*

(1) The 2.5H guideline

Daylighting design analysis methods

- Use of simplifications, such as standard curves, tabular data, or the CIE method (Section 10.12(a))
- Use of a library of graphic light distribution plots with varying parameters (GDDM) (Section 10.12(b))
- Use of less laborious manual calculation: the lumen method or the IESNA method (Section 10.12(c))
- Use of computer simulation software: DIVA for Rhino

But, remember that this is "analysis" rather than "design"; that is, calculating daylight given the openings, not vice versa.

Daylighting design analysis methods

- Manual methods: inexpensive, limited to simple spatial geometries
  - (a) CIE method
  - (b) Graphic Daylighting Design Method (GDDM)
  - (c) IESNA method
- Computer simulation: expertise, cost, training
- Physical models

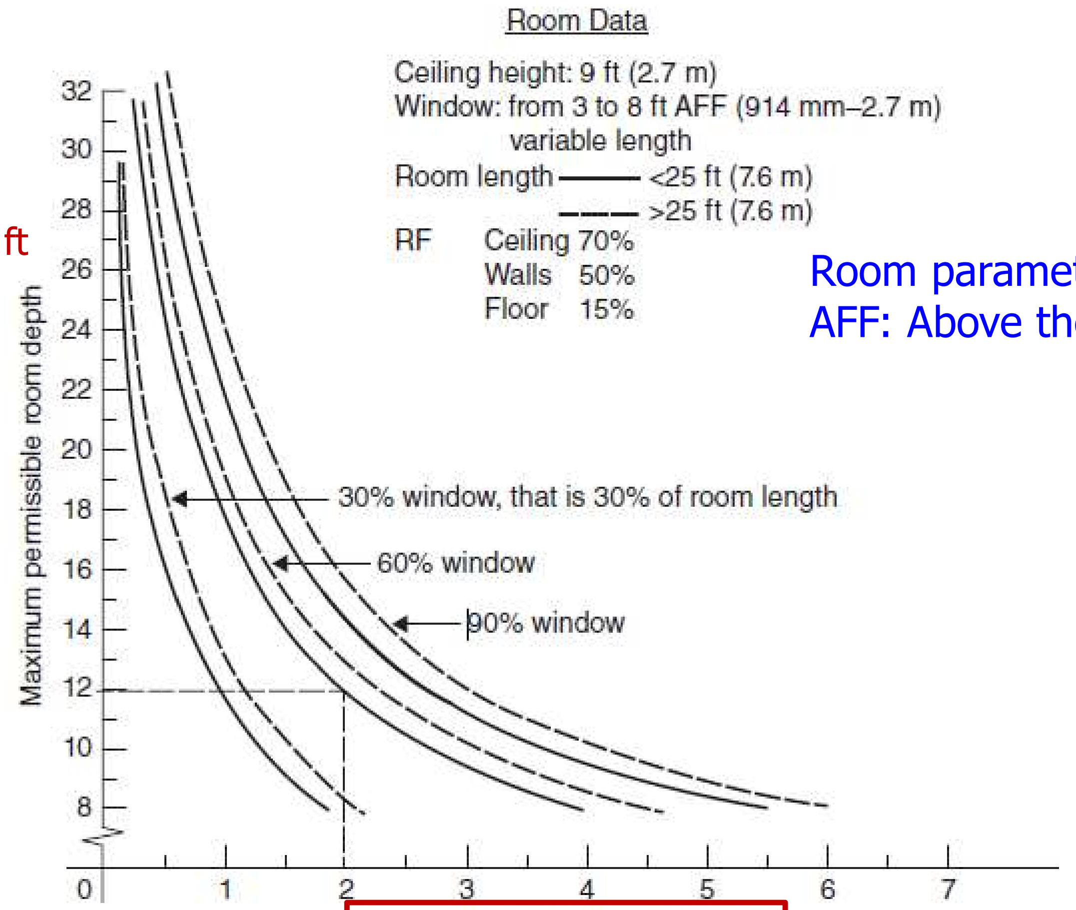
CIE system usable in two modes

- Mode 1: given complete architectural dimensional data, find interior illuminance (Example 10.1)
- Mode 2: given incomplete architectural dimensional data and required interior illuminance, find maximum room depth and/or other room proportions that satisfy the illuminance requirement (Fig.10.32)

Daylight Analysis: CIE method (Mode 2)

- CIE method: simple, rapid, straightforward, reasonably accurate
- Based on Daylight Factor (DF)

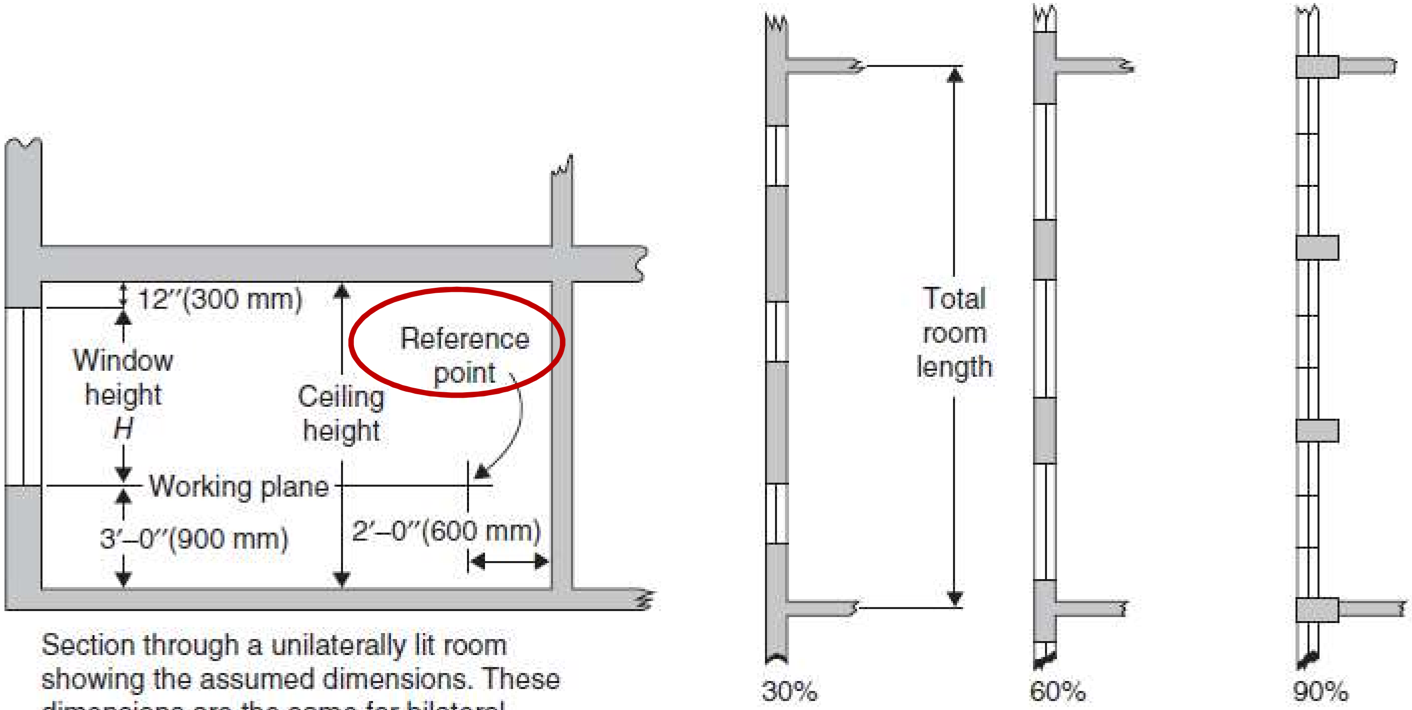
Unit: ft



Room parameters: See Fig.10.33
AFF: Above the Finish Floor

Fig. 10.32 *Maximum room depth that will maintain a minimum daylight factor is proportional to window size. Thus, for a room less than 25 ft (7.6 m) long with a 5-ft- (1.5-m)-high window for 60% of the room's length, the depth cannot exceed 12 ft (3.7 m) if 2% DF is to be maintained at a point 2 ft (61 cm) from the rear wall. (From Daylight Design Diagrams, 1963.)*

Room parameters



Section through a unilaterally lit room showing the assumed dimensions. These dimensions are the same for bilateral lighting except that the reference point is midway between the window walls.

(*a*)

Plane of window walls showing window width expressed as a percentage of total room length.

(*b*)

Fig. 10.33 *Sketches indicating the parameters of the CIE calculation system. (a) A vertical section through a room with dimensional data relevant to this system. Note that the sill height has been selected to coincide with a working plane at 900 mm (3 ft). The height of the working plane usually varies between 760 and 910 mm (30 and 36 in.), the former being more common in North America, the latter in Europe. A lower sill contributes only ground-reflected light at the working plane. Where the window sill is significantly above the working plane (i.e., short windows high on a wall), this analysis system is inapplicable. (b) Calculation size (length) of windows with respect to overall room length. (From* Daylight, International Recommendations for the Calculation of Natural Daylight*, 1970, Commission Internationale de l'Eclairage; reproduced with permission.)*

EXAMPLE 10.1 An example of the CIE method in Mode 1 uses a classroom in a single-story Seattle elementary school, 25 ft (7.6 m) long, 18 ft (5.5 m) deep, and with a 9.5-ft (3-m) ceiling. It receives daylight unilaterally from windows totaling 18 ft (5.5 m) in length (see the room sketch in Fig. 10.34). Window glazing is wired glass having a transmittance of 80%. The school is situated in a dense residential area. Determine the portion of the year during which tasks requiring a minimum illuminance of 14 fc (150 lux) can be carried out by daylight throughout the room. Also, determine what illuminance levels can be maintained for 85% of daylight hours and at what distances from the window. (Note that 14 fc [150 lux] corresponds to a DF of 2% applied to an E_H of 70 fc [7500 lux].)

Calculation. The latitude of Seattle is 47.6°N. The design condition for Seattle is solid overcast sky for 85% of the hours between 9:00 a.m. and 5:00 p.m. From Fig. 10.35, the minimum unobstructed horizontal illuminance E_H during these hours is 67 fc (7200 lux).

Refer to room parameters: Fig.10.34

STEP 1. Determine the room depth in terms of window height. Window height H is 5 ft (1.5 m) (see Fig. 10.34). In plan, the room depth is expressed as multiples of window height above sill level:

$$\frac{\text{18-ft depth}}{\text{5-ft window height}} = 3.6H$$

STEP 2. Determine window coverage. This variable is expressed as a percentage of the total room length based upon the width of the glazing used in the room. It is assumed that the window head is 12 in. (305 mm) below the ceiling. This distance was selected as the representation of best practice "without being unduly optimistic."

$$\frac{3 \times 6\ \text{ft}}{25\ \text{ft}} = 72\%$$

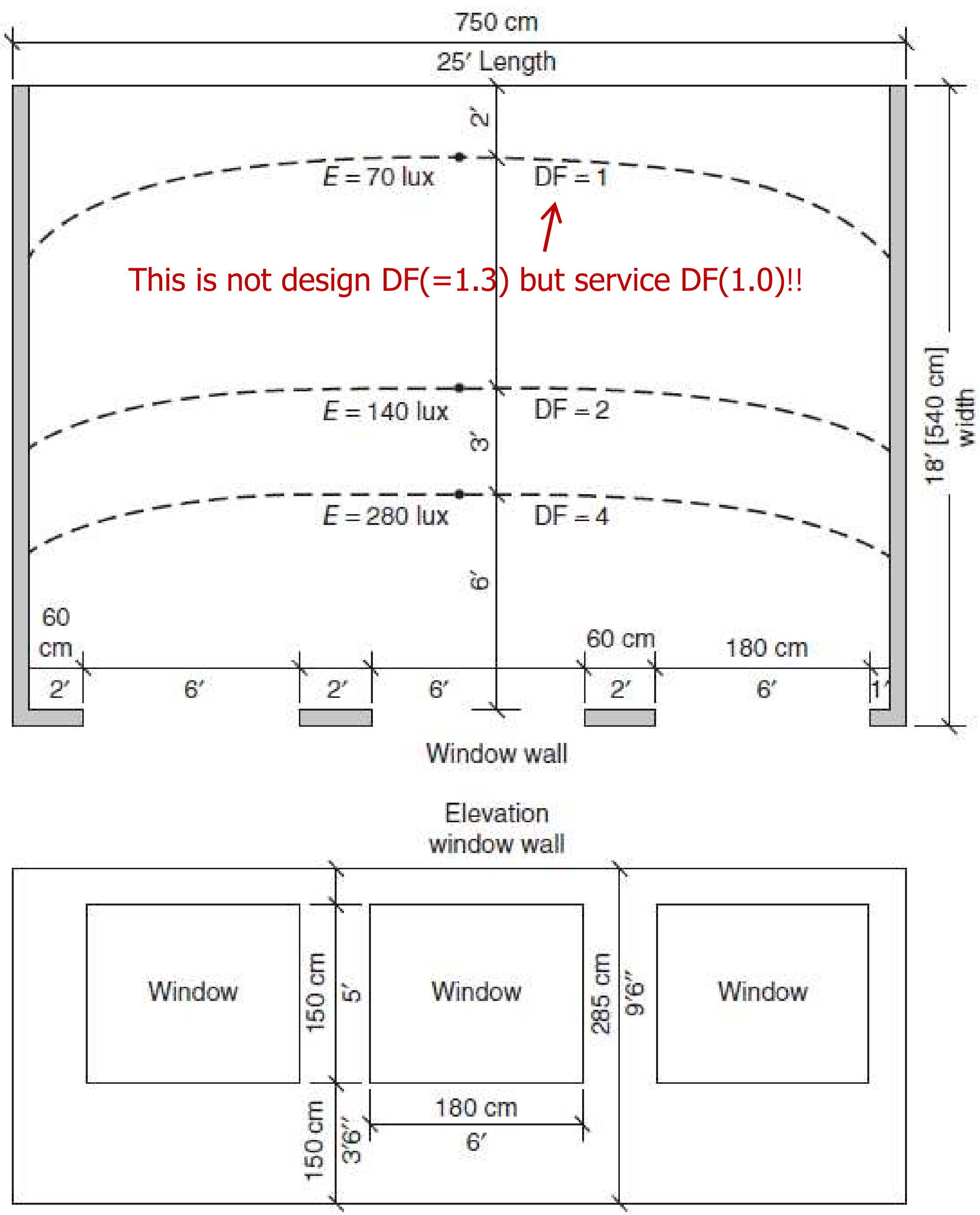


Fig. 10.34 *Plan and window wall elevation of the Seattle classroom calculation example using the CIE method. The three daylight contours are estimated based upon the calculated center point. They represent the levels maintained for 85% of daylight hours. Levels twice as high are maintained for 60% of the daylight hours.*

STEP 3. Determine the design daylight factor and the service daylight factor. The design daylight factor is calculated at a point 2 ft (0.6 m) from the wall opposite the window—on the window centerline. This represents the minimum daylight factor that will occur in a room of a given depth (lower values that will occur closer to the wall and/or off the centerline being discounted). From Fig. 10.36, for a room length of 25 ft (7.6 m), ceiling height 9.5 ft (2.9 m), window coverage 72%:

$$\text{design daylight factor at } 3.6H = 1.3$$

The service daylight factor takes into account correction factors such as glazing transmission and dirt accumulation. The service daylight factor is a product of the design daylight factor and correction factors.

$$DF_{\text{service}} = DF_{\text{design}} \times \text{correction factors}$$

Correction factors from Table 10.6 and Fig. 10.37 are:

Glass transmission 0.95
Glass cleanliness 0.8

Therefore:

$$DF_{\text{service}} = 1.3 \times 0.95 \times 0.8 \approx 1.0$$

No obstruction assumed in this example !!

Note that the terms "design" and "service" as used in this method have meanings that are not necessarily consistent with normal design practice. Design daylight factor typically would include the effects of building components such as glazing—and would often be described as "initial" daylight factor. Service daylight factor would often be called "maintained" daylight factor and include those effects that would reduce daylight illuminance over time (such as dirt on glazings or reductions in surface reflectances). Maintained daylight factor must equal or exceed the designer's daylight factor criterion for the system to be successful in the long run.

Given:
- Room length: 7.5m (25’)
– Percentage of windows: 72%
– Ceiling height: 3m
– Interpolated between 60% & 90%
(See Fig.10.34 for room parameters)

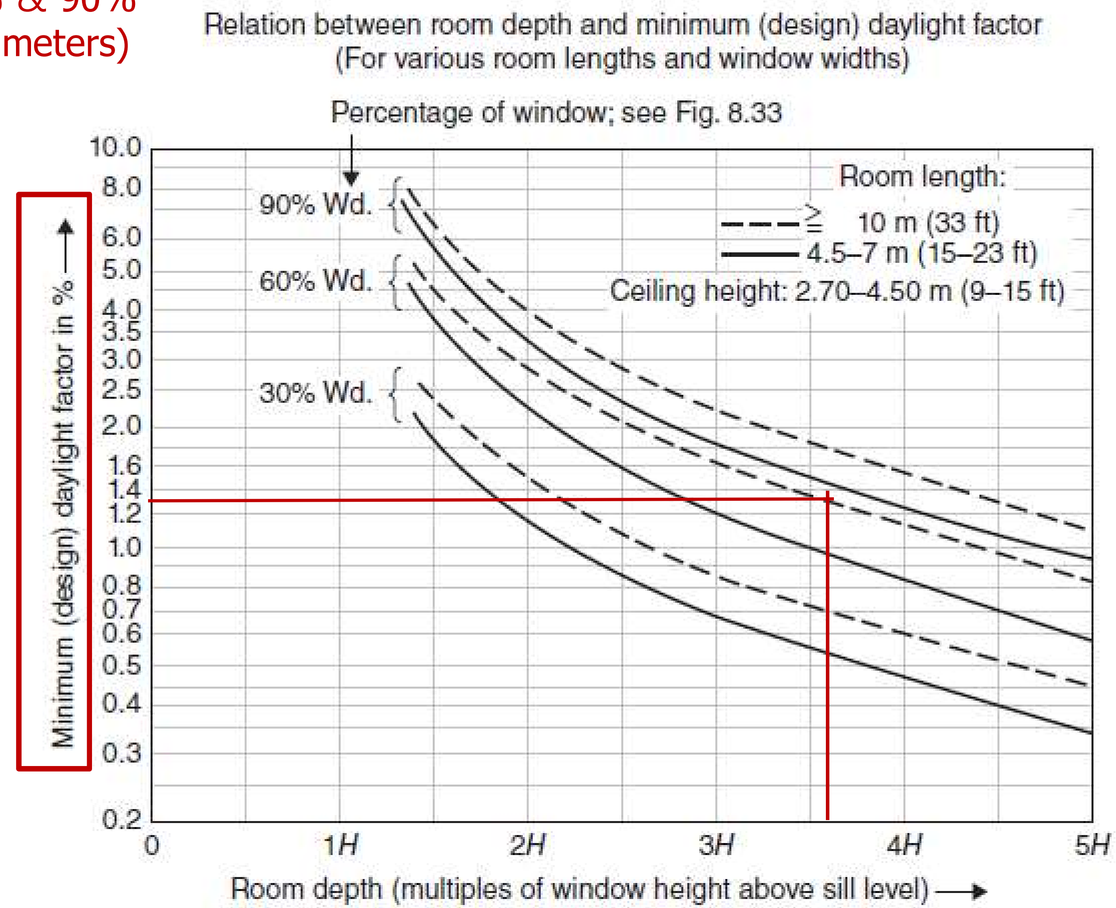


Fig. 10.36 *Basic design diagram that relates minimum daylight factor to room depth. Inasmuch as room depth is expressed in terms of window height, the curves effectively relate minimum daylight factor (2 ft [610 mm] from the back wall) to room proportion. (From* Daylight: International Recommendations for the Calculation of Natural Daylight, *1970, Commission Internationale de l'Eclairage; reproduced with permission.)*

TABLE 10.6 Correction Factors to Be Used in CIE Daylight Calculations

A. CORRECTION FACTOR TO ACCOUNT FOR GLASS TRANSMITTANCE	
Diffuse Transmittance of Glass (%)	**Correction Factor**
80	0.95
70	0.80
60	0.70
50	0.60
40	0.45
30	0.35

B. CORRECTION FACTORS TO ACCOUNT FOR DIRT ACCUMULATION ON GLASS				
		Angle of Slope (Measured to the Horizontal)		
Locality	**Class of Industry**	**90–75°**	**60–45°**	**30–0°**
Country or outer-suburban area	Clean	0.9	0.85	0.8
	Dirty	0.7	0.6	0.55
Built-up residential area	Clean	0.8	0.75	0.7
	Dirty	0.6	0.5	0.4
Built-up industrial area	Clean	0.7	0.6	0.55
	Dirty	0.5	0.35	0.25

C. PERCENTAGES TO USE WHEN FIGURE 10.35 CURVES ARE APPLIED TO PERIODS OTHER THAN 09.00–17.00						
Curve in Figure 10.35	**95%**	**90%**	**85%**	**80%**	**70%**	**60%**
Alternative period			Percentage of alternative period			
07.00–15.00	95	90	85	80	70	60
08.00–16.00	100	100	95	85	70	60
07.00–17.00	95	85	75	65	55	45
06.00–18.00	75	70	65	60	50	40

Source: Daylight: International Recommendations for the Calculation of Natural Daylight (CIE, 1970).

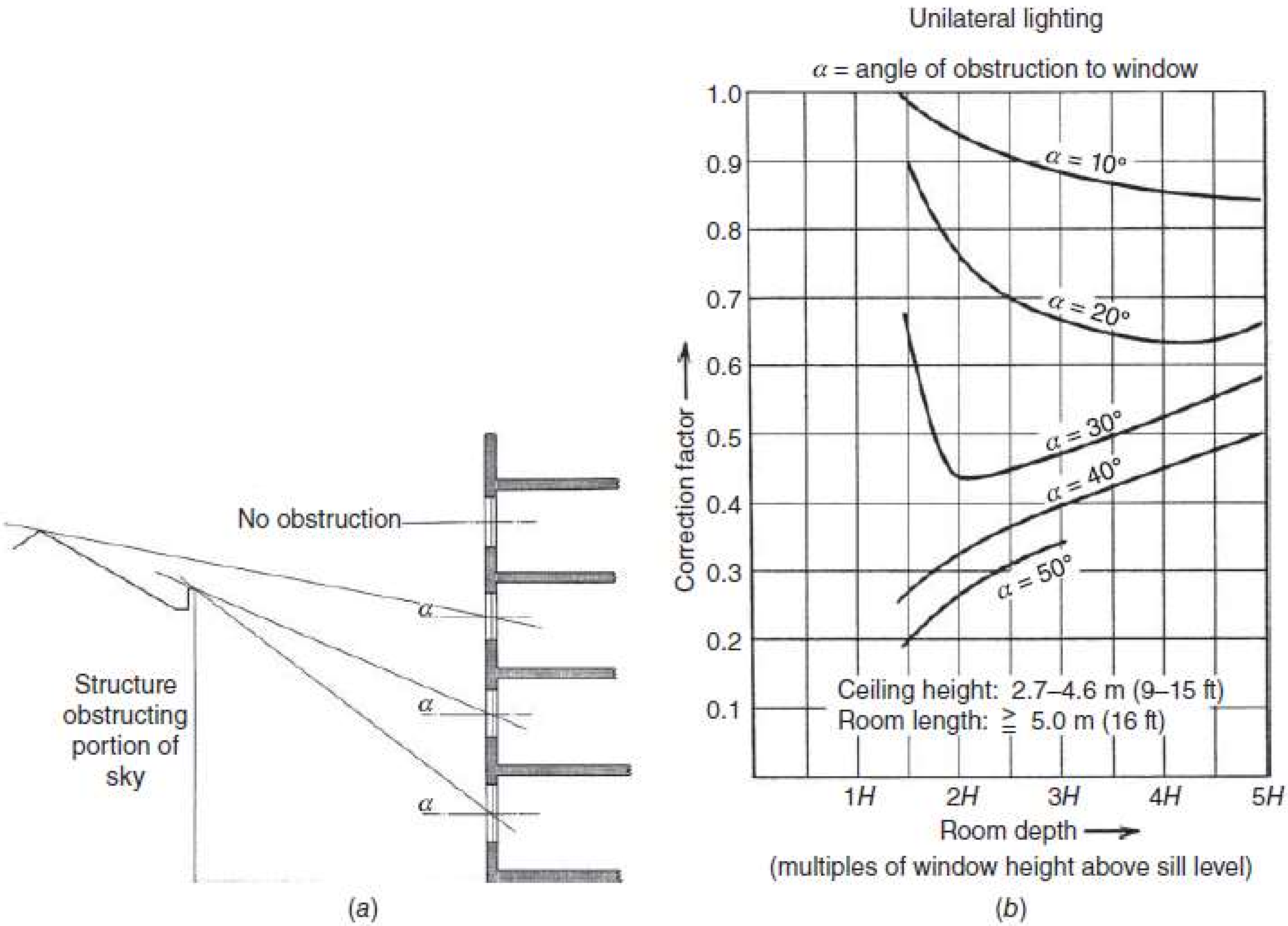


Fig. 10.37 *(a) Angle of obstruction α of an external object. (b) Correlation factors to account for the influence of external obstructions on the minimum daylight factor. (From* Daylight, International Recommendations for the Calculation of Natural Daylight, *1970, Commission Internationale de l'Eclairage; reproduced with permission.)*

STEP 4. Determine the required exterior illuminance. Use the service daylight factor in Equation 10.4 to obtain required exterior illuminance.

$$E_H\text{, required exterior illuminance} = \frac{\text{required interior illuminance}}{DF_{service}} \quad (10.4)$$

$$E_H = \frac{150 \text{ lux min}}{1.0} \times 100 = 15{,}000 \text{ lux}$$

STEP 5. Obtain the percentage of hours between 9:00 a.m. and 5:00 p.m. during which the required illuminance is maintained. From Fig. 10.35 with the given conditions (roughly 48°N latitude, exterior illuminance 15,000 lux [1500 fc]), an illuminance of 150 lux (15 fc) will be maintained for less than 60% of the hours between 09:00 a.m. and 5:00 p.m. (for time periods other than this, see Table 10.6C). The level that is maintained for 85% of the hours is:

$$E_{min} = 7200 \text{ lux} \times 0.01 \text{ (a DF of 1.0)} = 72 \text{ lux}$$

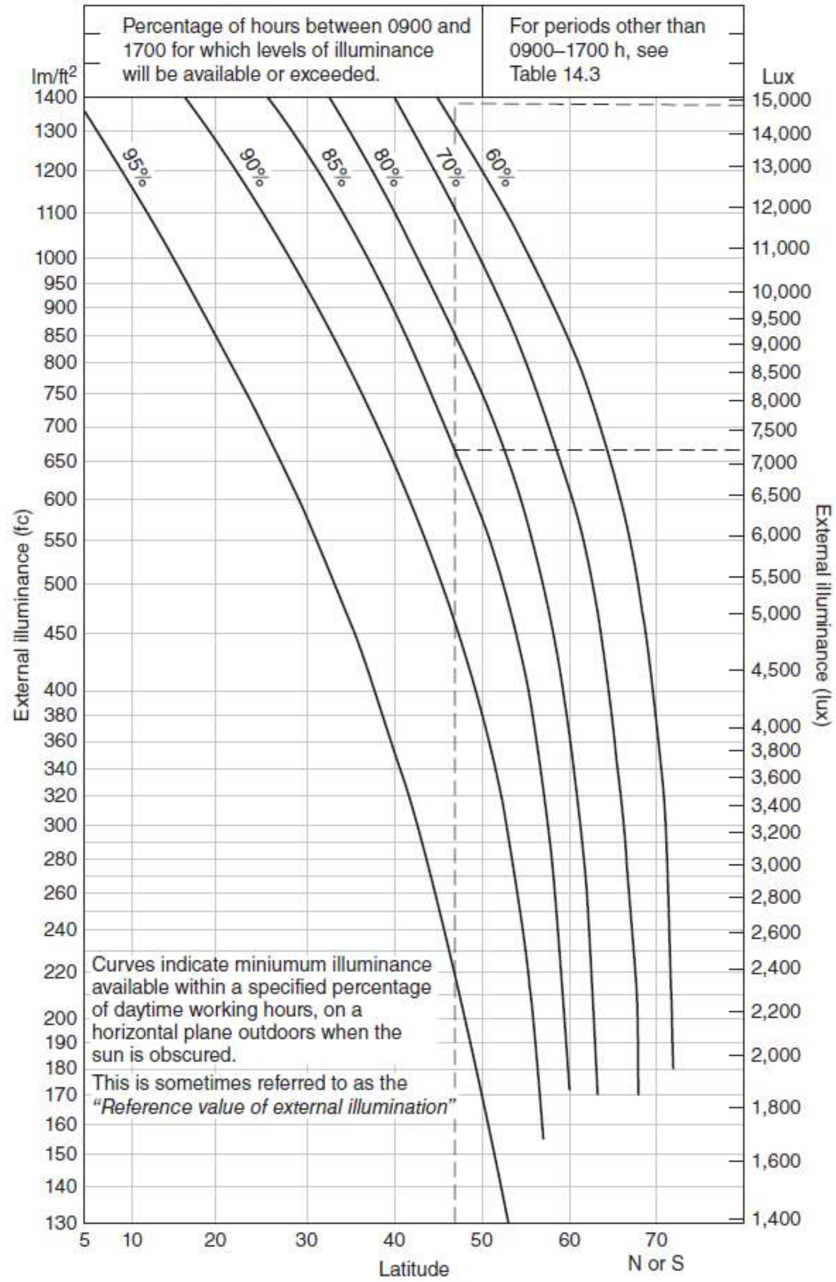


Fig. 10.35 Minimum maintained external illuminance as a function of latitude for a given percentage of the normal working day. (From Daylight: International Recommendations for the Calculation of Natural Daylight, 1970, Commission Internationale de l'Eclairage; reproduced with permission.)

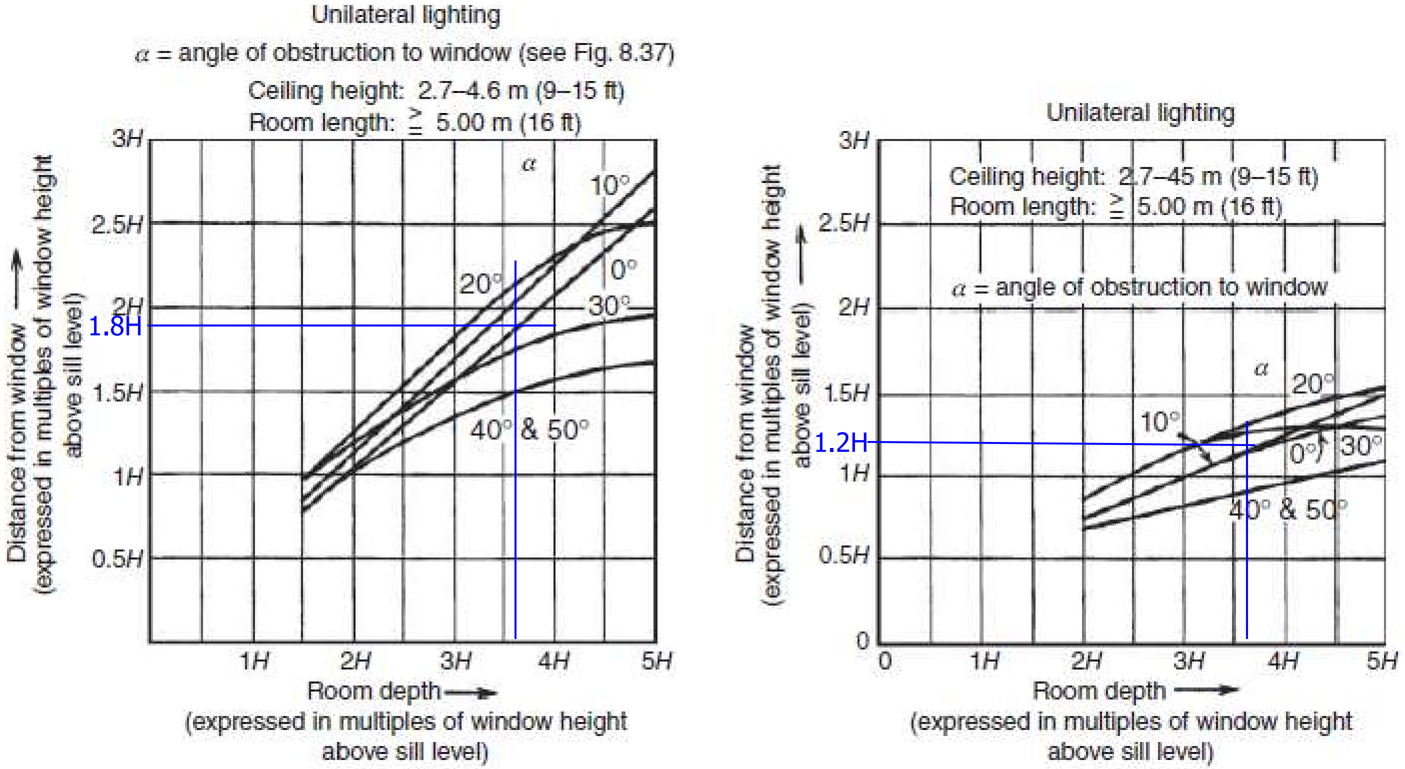
STEP 6. Determine the locations in the room that will receive adequate illuminance. Figure 10.38 shows the distance from the window at which the daylight factor is twice or four times the minimum. Using Fig. 10.38a, the room depth from Step 1 is 3.6*H*. This point intersects with the $\alpha = 0°$ angle of obstruction line at a 1.8*H* distance (1.8 × 5 ft = 9 ft [2.7 m]) from the window, resulting in a doubling of the daylight factor.

$$7200 \text{ lux} \times 0.02 \text{ (a DF of 2.0)} = 144 \text{ lux}$$

Using Fig. 10.38b, the room depth from Step 1 is 3.6*H*. This point intersects with the $\alpha = 0°$ angle of obstruction line at a 1.2*H* distance (1.2 × 5 ft = 6 ft [1.8 m]) from the window, resulting in a quadrupling of the daylight factor quadruples.

$$7200 \text{ lux} \times 0.04 \text{ (a DF of 4.0)} = 288 \text{ lux}$$

See Fig.10.34: solution



(a) Twice the minimum DF

(b) Four times the minimum DF

Fig. 10.38 *(a) Distance from the window at which the daylight factor is twice the minimum daylight factor. (b) Distance from the window at which the daylight factor is four times the minimum daylight factor. (From* Daylight: International Recommendations for the Calculation of Natural Daylight, *1970, Commission Internationale de l'Eclairage; reproduced with permission.)*

Advantages: CIE method

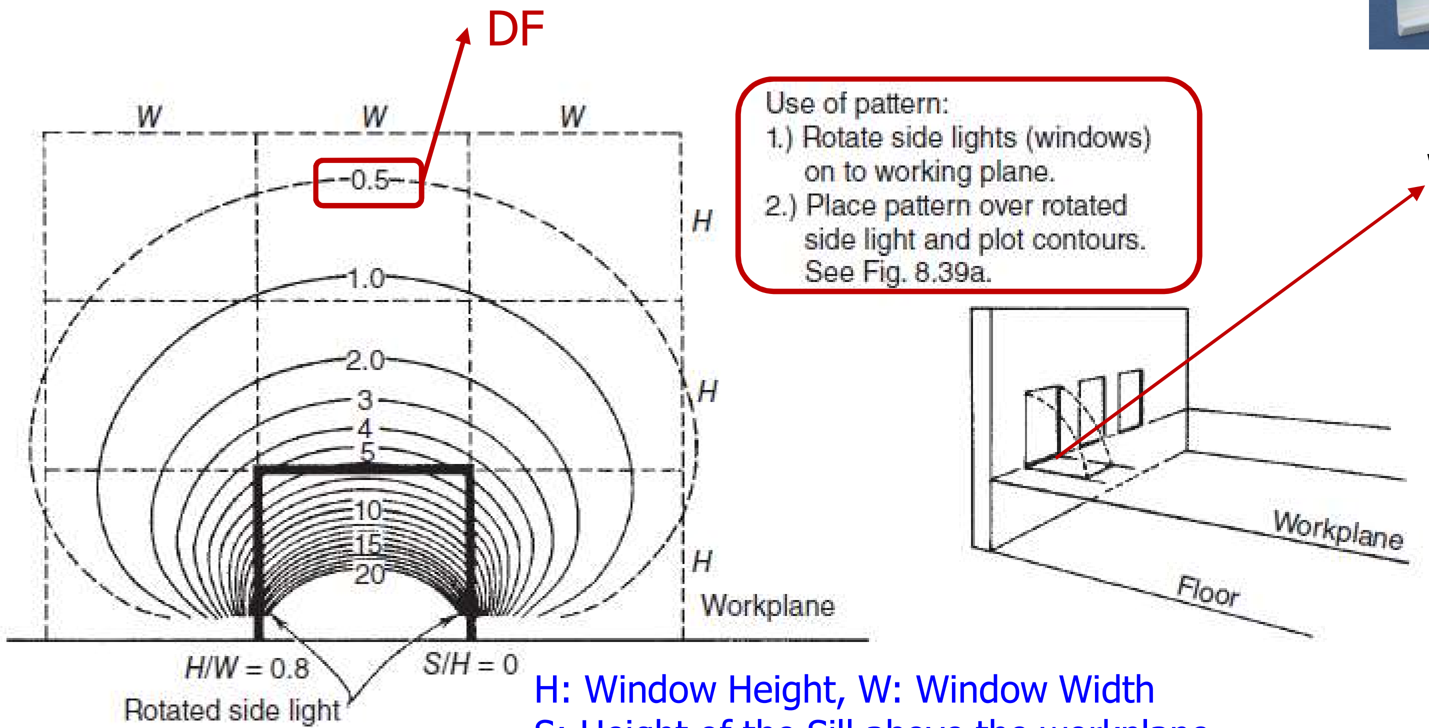
- Consideration of obstructions, reflections, and interior reflections.
- Applicability to a very wide range of side and top fenestration designs
- Establishment of required room proportions is architecturally more useful than solving for specific dimensions

Limitations: CIE method

- inapplicable to clear and sun conditions (remember that CIE is based on the DF method!!)
- inapplicable to other than rectangular rooms
- unusable with sun-shading or high reflectance ground
- Results give points of minimum, twice minimum, and four times minimum daylight only. Other points must be interpolated or extrapolated.
- Windows proportions and position in a wall are fixed.

Graphic Daylighting Design Method (GDDM)

- DF contour under the overcast sky developed by M.S. Millet & J.R. Bedrick (1980)



H: Window Height, W: Window Width
S: Height of the Sill above the workplane

Fig. 10.40 *Typical isolux contour map for a window with a height-to-width ratio of 0.8 and a sill at the working plane elevation. Numbers represent the SC of daylight factors for an overcast sky condition. The rectangles are the window outlines rotated (projected) onto the working plane. See insert. (From Millet and Bedrick, 1980, p. 191.)*

Remarks

- Authors used a simulation tool (UWLIGHT) to develop daylight distribution patterns
- Advantages:
  - DF contours are more meaningful to a lighting designer than is numerical output
- Limitations:
  - Requires a library of more than 200 patterns
  - Practically not applicable to clear-sky conditions due to the size of the library

EXAMPLE 10.2 Figure 10.40 shows a typical isolux pattern for a window whose *H/W* ratio is 0.8 and whose sill is at the work plane. This particular window pattern was selected because it corresponds to the window in the previous example, Fig. 10.34, enabling graphical comparison.

Calculation. Employing the GDDM method with the dimensions of the Seattle classroom used in the last section:

STEP 1. Determine the window proportion.

Referring to Fig. 10.34, the window proportion is

$$\frac{H}{W} = \frac{5}{6} = 0.83$$

STEP 2. Select the appropriate window pattern. In this case, Fig. 10.40 (selected from a library of isolux patterns developed by Millet and Bedrick) is the closest pattern to match the example. $S/H = 0$ indicates that the pattern begins at the window wall, as shown.

STEP 3. Develop an isolux pattern for each window of the space. On a plan of the room, trace the isolux pattern for each window (Fig. 10.39a). The patterns overlap because the windows are close together. Where contours meet, the daylight factors of the contours are added together, producing values for the new combined contours. The combined contours and their daylight factors are shown in Fig. 10.39b.

STEP 4. Make corrections to the isolux pattern. The value of the combined contours is corrected to account for internally reflected components of daylight plus light reduction due to glazing. The final contours are shown in Fig. 10.39c. Note that this diagram gives the designer a much more complete picture of the daylight contours than do the results of the CIE method. For the purpose of comparison, the three calculated daylight factors from the CIE method are shown in Fig. 10.39c. ■

The contours were corrected to account for light reduction. The isolux pattern is not design DF, but service DF!!

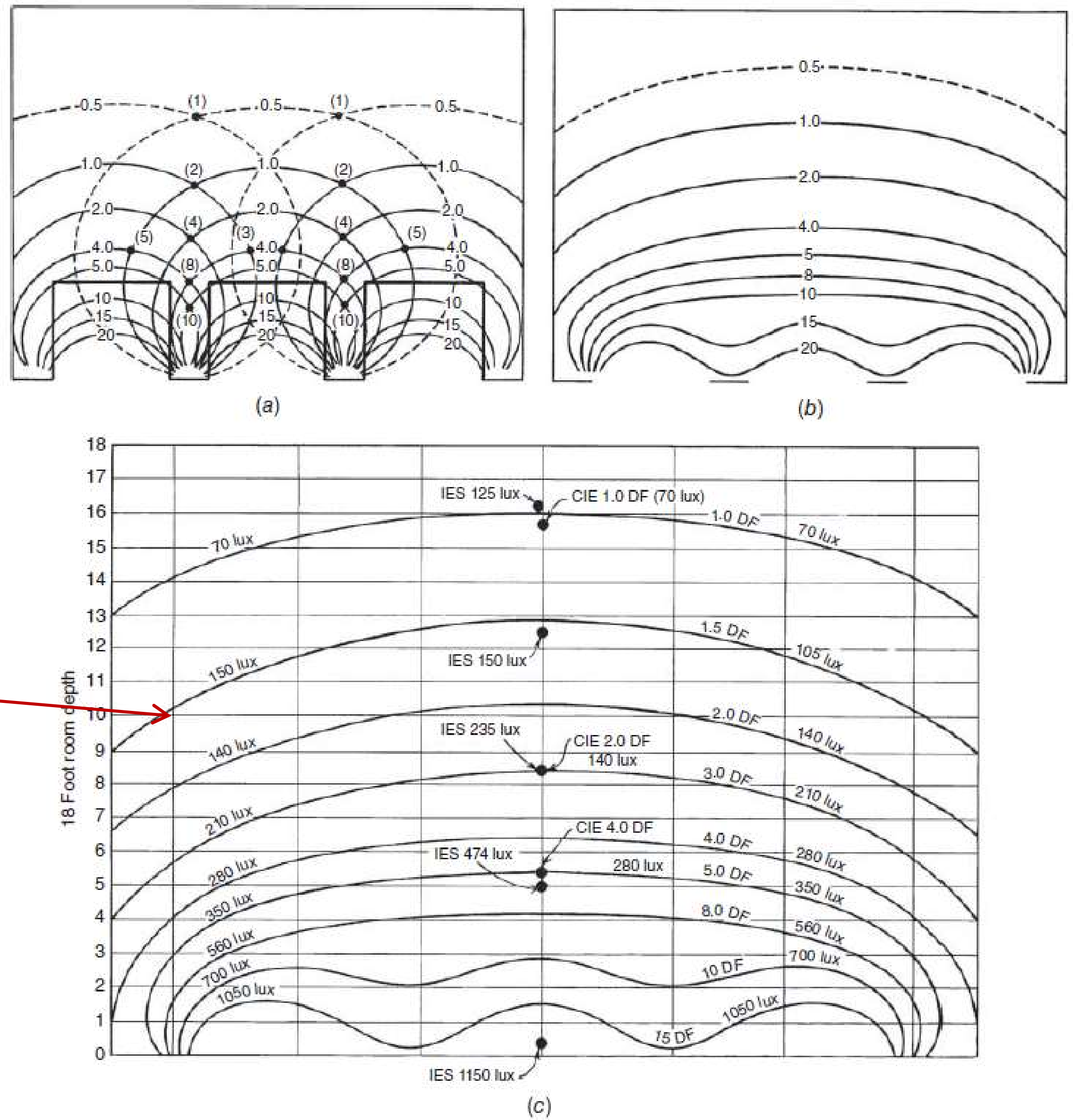


Fig. 10.39 (a) Daylight contours for each window of Fig. 10.34 are plotted on the floor plan of the room being studied. Numbers in parentheses are combined SC values. (b) The isolux contours of (a) are combined to form new isolux contours that represent the total SC of daylight within the room. (c) The final isolux contours are calculated, including correction factors (accounting for internally reflected components of daylight plus light reduction due to glazing). The numbers represent daylight factors. Note the variance between these contours and the points calculated by the CIE method. The five design points calculated by the IESNA method are also shown. A comparison of the results on the room centerline (a location where comparison of all methods is possible); agreement is within engineering accuracy (see text discussion).

IESNA Lumen method

- Calculate daylight illumination levels at five predetermined points
- Account for
  - all types of sky conditions (clear + overcast)
  - reflected daylight from ground
- Limitations
  - cannot accommodate direct sunlight
  - cavity reflectances (Fig.10.41) are fixed: 70%, 50 %, 30%)
  - Calculates only five points in a room
  - This is an 'analysis' tool, not a 'design' tool.

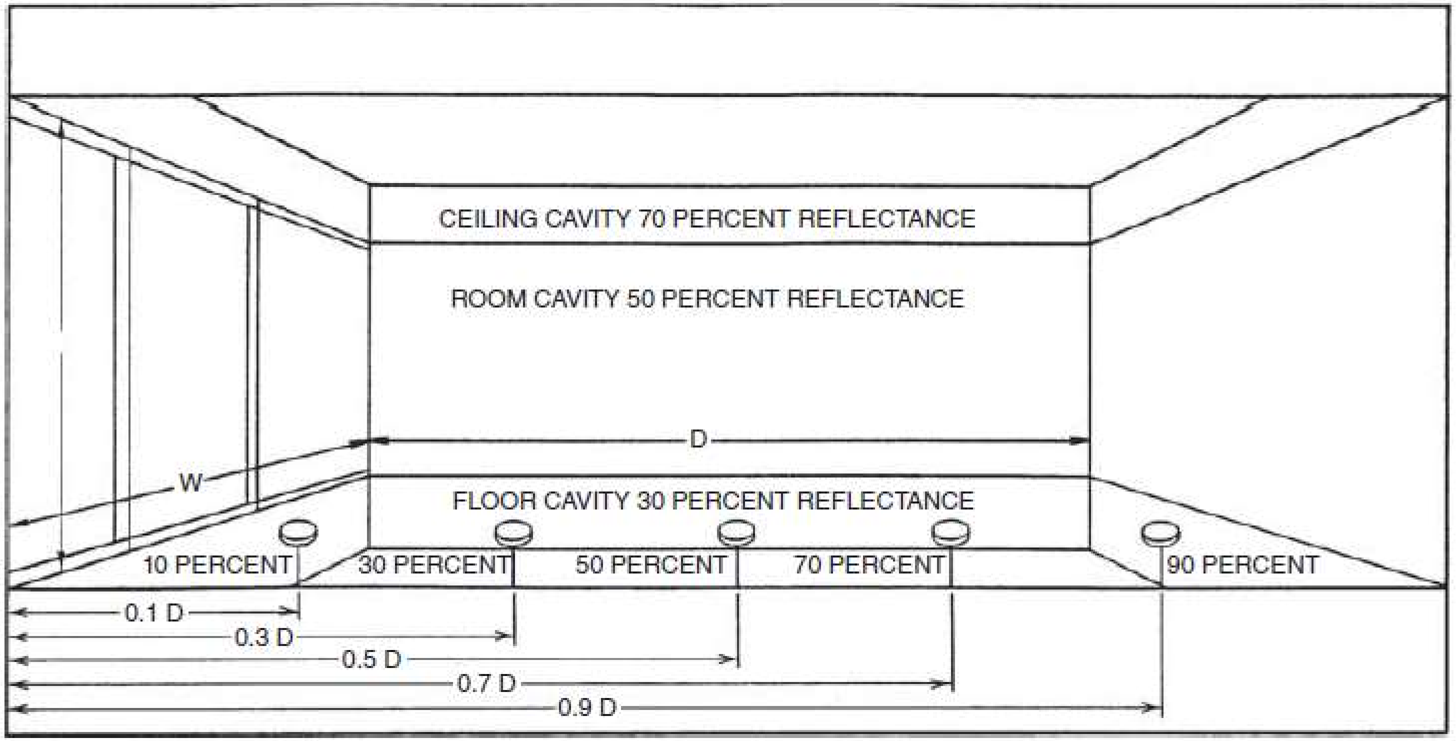


Fig. 10.41 *Standard conditions in a room for daylighting calculations: sidelighting. (IESNA, Recommended Practice for the Lumen Method of Daylight Calculations, RP-23–89.)*

Calculation procedure

- Step 1: determine the vertical and horizontal illuminances
  - For overcast: Fig.10.23 (horizontal, vertical)
  - For clear sky: Fig 10.24 (horizontal) and Fig.10.26 (vertical)
    - Fig.10.26(a): sun, year-long
    - Fig.10.26(b): sky, summer
    - Fig.10.26(c): sky, various seasons

Calculation procedure

- Step 2: Determine the net transmittance (τ) of window
  - $\tau = T * R_a * LLF$
    - T: glass transmittance (Table 10.8 or from manufacturer)
    - R_a : net-to-gross window area ratio representing mullions and glazing bars
    - LLF: Light-Loss factor (Table 10.9) to account for location

TABLE 10.8 Transmittance Data for Glass and Plastic Materials

Material	Approximate Transmittance (%)
Polished plate/float glass	80–90
Sheet glass	85–91
Heat-absorbing plate glass	70–80
Heat-absorbing sheet glass	70–85
Tinted polished plate	40–50
Figure glass	70–90
Corrugated glass	80–85
Glass block	60–80
Clear plastic sheet	80–92
Tinted plastic sheet	9–42
Colorless patterned plastic	80–90
White translucent plastic	10–80
Glass-fiber-reinforced plastic	5–80
Double glazed—two lights clear glass	77
Tinted plus clear	37–45
Reflective glass[a]	5–60

Source: IES Recommended Practice for the Lumen Method of Daylight Calculations, RP-23–1989; reprinted with permission.

[a]Includes single glass, double-glazed units, and laminated assemblies. Consult manufacturer's material for specific values.

TABLE 10.9 Typical Light Loss Factors for Daylighting Design

	Light Loss Factor Glazing Position		
Location	Vertical	Sloped	Horizontal
Clean areas	0.9	0.8	0.7
Industrial areas	0.8	0.7	0.6
Very dirty areas	0.7	0.6	0.5

Source: IES Recommended Practice for the Lumen Method of Daylight Calculations, RP-23–1989; reprinted with permission.

TABLE 10.10 Reflectances of Building Materials and Outside Surfaces

Material	Reflectance (%)
Aluminum	85
Asphalt (free from dirt)	7
Bluestone, sandstone	18
Brick	
Light buff	48
Dark buff	40
Dark red glazed	30
Red	15
Yellow ochre	25
White	75
Cement	27
Chromium	65
Concrete	55
Copper	40
Earth (moist cultivated)	7
Granolite pavement	17
Glass	
Clear	7
Reflective	20–30
Tinted	7
Grass (dark green)	6
Gravel	13
Granite	40
Marble (white)	45
Macadam	18
Marble	45
Paint (white)	
New	75
Old	55
Plaster	
Smooth	80
Rough	40
Stippled	40
Slate (dark clay)	8
Snow	
New	74
Old	64
Vegetation (mean)	25

Source: Values compiled from Lam (1986), Stein and Reynolds (1992), and the Lighting Design Lab (© 2005; used with permission).

Calculation procedure

- Step 3: Select coefficients of utilization from Table C.21 to C.26
  - Table C.21 to C.25: sky component (CU_k)
  - Table C.26: ground component (CU_g)
- Step 4: calculate daylight interior illuminance at five reference points (0.1D, 0.3D, 0.5D, 0.7D, 0.9D)
  - $E_i = \tau\ (E_{xvk} * CU_k + E_{xvg} * CU_g)$
    - $E_{xvg} = RF_g * E_{xHk} / 2$

EXAMPLE 10.3 To again use the Seattle classroom as an example, here are the conditions of the problem:

Location: Seattle, Washington

Latitude: 47.6°N

Room: 25 ft (7.6 m) long, 18 ft (5.5 m) deep, with a 9.5-ft (3-m) ceiling

Window: height 5 ft (1.5 m) above a 30-in. (760-mm) working plane; total length, 18 ft (5.5 m)

Transmittance: 85%; net glass area 92%

Ground reflectance: Not previously specified. Assume an extensive area of mixed grass, asphalt, and concrete walkways, with an average overall reflectance of 20% (see Table 10.10). For a more accurate calculation of reflectance, see the method described in the *IES Recommended Practice for the Calculation of Daylight Availability* (IESNA, 1994).

Calculation. Illuminance E_i will be found at the five points shown in Fig. 10.41 for a spring day and a winter day at 10:00 a.m. and 2:00 p.m. Assume that the sky is overcast so that a direct comparison with other methods can be made. Reflectances are assumed to be 70% for the ceiling, 50% for the wall, and 30% for the floor to correspond to the IESNA method standard conditions.

STEP 1. Determine the vertical and horizontal illuminance on the exterior of the window.

Using the solar altitude for the spring and winter day (Table D.1, solar data), the vertical and horizontal illuminances can be found from Fig. 10.23. Calculate E_{xhk}, the half-sky illuminance (a vertical window sees only half of the sky). The results are compiled in Table 10.7.

Vertical illuminance from the ground is:

$$E_{xvg} = RF_g \times \frac{E_{xHk}}{2} \qquad (10.5)$$

$$\text{Dec. 21}: E_{xvg} = \overset{0.2}{RF_g} \times \frac{E_{xHk}}{2} = 0.\cancel{2}1\ (5380) = \overset{538}{\cancel{1076}} \text{ lux}$$

$$\text{Mar. 21}: E_{xvg} = 0.\cancel{2}1\ (13{,}340) = \overset{1,334}{\cancel{2670}} \text{ lux}$$

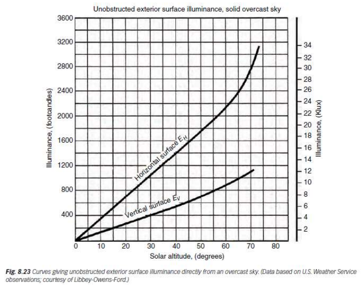


Fig.10.23

2.5 times

one half

TABLE 10.7 Vertical and Horizontal Illuminance Values for Spring and Winter, Seattle, Washington

Solar Altitude (Appendix D.1)	Vertical Window Illuminance, E_{xvk} (Fig. 10.23)	Horizontal Illuminance from Full Sky, E_{xHk} (Fig. 10.23)	Horizontal Illuminance from Half Sky, E_{xhk}
Dec. 21: 14°	200 fc (2150 lux)	500 fc (5380 lux)	250 fc (2690 lux)
Mar. 21: 36°	500 fc (5380 lux)	1,240 fc (13,340 lux)	620 fc (6670 lux)

D.1 SOLAR ALTITUDE AND AZIMUTH DATA FOR 30, 34, 38, 42, 44, AND 48°N LATITUDES

TABLE D.1 Typical Solar Altitude and Azimuth Data as a Function of Date and Time of Day

			Solar Time[a]						
Latitude (°N)		**Date**	**AM: 6 PM: 6**	**7 5**	**8 4**	**9 3**	**10 2**	**11 1**	**Noon**
30	Altitude	June 21	12	24	37	50	63	75	83
		Mar–Sept 21	—	13	26	38	49	57	60
		Dec 21	—	—	12	21	29	35	37
	Azimuth	June 21	111	104	99	92	84	67	0
		Mar–Sept 21	90	83	74	64	49	28	0
		Dec 21	—	60	54	44	32	17	0
34	Altitude	June 21	13	25	37	50	62	74	79
		Mar–Sept 21	—	12	25	36	46	53	56
		Dec 21	—	—	9	18	26	31	33
	Azimuth	June 21	110	103	95	90	78	58	0
		Mar–Sept 21	90	82	72	61	46	26	0
		Dec 21	—	—	54	43	30	16	0
38	Altitude	June 21	14	26	37	49	61	71	75
		Mar–Sept 21	—	12	23	34	43	50	52
		Dec 21	—	—	7	16	23	27	28
	Azimuth	June 21	109	101	90	83	70	46	0
		Mar–Sept 21	90	81	71	58	43	24	0
		Dec 21	—	—	54	43	30	16	0
42	Altitude	June 21	16	26	38	49	60	68	71
		Mar–Sept 21	—	11	22	32	40	46	48
		Dec 21	—	—	4	13	19	23	25
	Azimuth	June 21	108	99	89	78	63	39	0
		Mar–Sept 21	90	80	69	56	41	22	0
		Dec 21	—	—	53	42	29	15	0
46	Altitude	June 21	17	27	37	48	57	65	67
		Mar–Sept 21	—	10	20	30	37	42	44
		Dec 21	—	—	2	10	15	20	21
	Azimuth	June 21	107	97	88	74	58	34	0
		Mar–Sept 21	90	79	67	54	39	21	0
		Dec 21	—	—	52	41	28	14	0
48	Altitude	June 21	17	27	37	47	56	63	65
		Mar–Sept 21	—	10	20	29	$\boxed{36}$	40	42
		Dec 21	—	—	1	8	$\boxed{14}$	17	19
	Azimuth	June 21	106	95	85	72	55	31	0
		Mar–Sept 21	90	79	67	53	38	20	0
		Dec 21	—	—	52	41	28	14	0

[a]Solar time and clock time do not usually coincide. They are related by the equation of time (see Section 6.2).

STEP 2. Determine net transmittance of the window. A number of factors affect the transmittance of light through glazing. The net transmittance is the product of the glazing transmittance (Table 10.8) and a light loss factor (Table 10.9), which represents the cleanliness of the window. The net transmittance should also account for the net glazing area (i.e., gross window area less mullions, glazing bars, and so on) and any other factor (such as insect screens) that would reduce actual transmittance.

Glass transmittance is 85% (Table 10.8), light loss factor is 0.9 (Table 10.9), and the net glass area is given as 92%. The net transmittance (τ) of the window is a product of these factors:

$$\tau = (0.85)(0.9)(0.92) = 0.70$$

given, Table 10.9, given

STEP 3. Select coefficients of utilization for the five calculation locations (10%, 30%, 50%, 70%, and 90%) from Tables C.21–C.26 on the basis of room dimensions and the portion of the sky seen by the window. The SC seen by the window is determined by the ratio of vertical to horizontal illuminance at the window.

$$\text{SC } E_{xvk}/E_{xhk} : \text{(from Table } \cancel{8.7}\text{)} \quad 10.7$$

$$\text{Dec. 21} : 2150/2690 = 0.8$$

$$\text{Mar. 21} : 5380/6670 = 0.8$$

The E_{xvk}/E_{xhk} value corresponds most closely to the E_{xvk}/E_{xhk} value of Table C.21. Use the following values to find the coefficients of utilization, CU_k:

$$\frac{\text{room depth}}{\text{window height}} = 18/5 = 3.6$$

use 4.0 (first column variable)

Window width * # of windows = 6′X3 =18′

$$\frac{\boxed{\text{window length}}}{\text{window height}} = 18/5 = 3.6$$

use 4.0 (first row variable)

The ground component vertical illuminance (E_{xvg}) is the product of the ground reflectance (Table 10.10) and half of the horizontal illuminance (Equation 10.5). The sky and ground component values are compiled in Table 10.11 for each of the five reference locations (from C.21 and C.26).

TABLE C.21 Coefficient of Utilization from Window without Blinds; Sky Component $E_{xvk}/E_{xhk} = 0.75$

Room Depth/ Window Height	Depth	*Window Width/Window Height* .5	1	2	3	4	6	8	Infinite
	10	.824	.864	.870	.873	.875	.879	.880	.883
	30	.547	.711	.777	.789	.793	.798	.799	.801
1	50	.355	.526	.635	.659	.666	.669	.670	.672
	70	.243	.386	.505	.538	.548	.544	.545	.547
	90	.185	.304	.418	.451	.464	.444	.446	.447
	10	.667	.781	.809	.812	.813	.815	.816	.824
	30	.269	.416	.519	.544	.551	.556	.557	.563
2	50	.122	.204	.287	.319	.331	.339	.341	.345
	70	.068	.116	.173	.201	.214	.223	.226	.229
	90	.050	.084	.127	.151	.164	.167	.171	.172
	10	.522	.681	.739	.746	.747	.749	.747	.766
	30	.139	.232	.320	.350	.360	.366	.364	.373
3	50	.053	.092	.139	.163	.174	.183	.182	.187
	70	.031	.053	.081	.097	.106	.116	.116	.119
	90	.025	.041	.061	.074	.082	.089	.090	.092
	10	.405	.576	.658	.670	.673	.675	.674	.707
	30	.075	.134	.197	.224	.235	.243	.243	.255
4	50	.028	.050	.078	.094	.104	.112	.114	.119
	70	.018	.031	.048	.059	.065	.073	.074	.078
	90	.016	.026	.040	.048	.053	.059	.061	.064
	10	.242	.392	.494	.516	.521	.524	.523	.588
	30	.027	.054	.086	.102	.111	.119	.120	.135
6	50	.011	.023	.036	.044	.049	.055	.056	.063
	70	.009	.018	.027	.032	.035	.040	.041	.046
	90	.008	.016	.023	.028	.031	.034	.035	.040
	10	.147	.257	.352	.380	.387	.391	.392	.482
	30	.012	.026	.043	.054	.060	.067	.070	.086
8	50	.006	.013	.021	.026	.029	.033	.035	.043
	70	.005	.011	.017	.021	.023	.026	.027	.034
	90	.004	.010	.015	.019	.021	.023	.025	.030
	10	.092	.168	.248	.275	.284	.290	.291	.395
	30	.006	.014	.026	.032	.036	.041	.044	.059
10	50	.003	.008	.014	.017	.019	.022	.024	.032
	70	.003	.007	.012	.014	.016	.018	.019	.026
	90	.003	.006	.011	.013	.015	.016	.017	.024

Source: IES RP-23-1989; reprinted with permission of Illuminating Engineering Society of North America.

TABLE C.22 Coefficient of Utilization from Window without Blinds; Sky Component $E_{xvk}/E_{xhk} = 1.00$

Room Depth/ Window Height	Depth	*Window Width/Window Height* .5	1	2	3	4	6	8	Infinite
	10	.671	.704	.711	.715	.717	.726	.726	.728
	30	.458	.595	.654	.668	.672	.682	.683	.685
1	50	.313	.462	.563	.589	.598	.607	.608	.610
	70	.227	.362	.478	.515	.527	.530	.532	.534
	90	.186	.306	.424	.465	.481	.468	.471	.472
	10	.545	.636	.658	.660	.661	.665	.666	.672
	30	.239	.367	.459	.484	.491	.499	.501	.506
2	50	.121	.203	.286	.320	.335	.348	.351	.355
	70	.074	.128	.192	.226	.243	.259	.264	.267
	90	.058	.101	.156	.188	.207	.215	.221	.223
	10	.431	.561	.607	.613	.614	.616	.615	.631
	30	.133	.223	.306	.337	.348	.357	.357	.366
3	50	.058	.103	.155	.183	.197	.211	.213	.218
	70	.037	.064	.098	.119	.132	.147	.150	.154
	90	.030	.051	.079	.098	.110	.122	.126	.129
	10	.339	.482	.549	.560	.563	.566	.565	.593
	30	.078	.139	.204	.234	.247	.258	.260	.272
4	50	.033	.060	.094	.114	.126	.139	.143	.150
	70	.022	.039	.061	.074	.083	.095	.099	.104
	90	.019	.032	.050	.061	.070	.080	.084	.089
	10	.211	.343	.433	.453	.458	.461	.461	.518
	30	.033	.065	.103	.123	.135	.145	.148	.167
6	50	.015	.029	.047	.057	.064	.073	.077	.086
	70	.011	.021	.033	.040	.045	.051	.054	.060
	90	.010	.019	.028	.034	.038	.044	.046	.052
	10	.135	.238	.326	.353	.362	.366	.367	.452
	30	.016	.034	.058	.072	.080	.090	.094	.116
8	50	.008	.017	.027	.034	.039	.045	.048	.059
	70	.006	.013	.021	.026	.028	.032	.035	.043
	90	.005	.012	.019	.023	.025	.029	.031	.038
	10	.090	.165	.244	.272	.283	.290	.291	.395
	30	.009	.020	.036	.045	.052	.060	.064	.087
10	50	.005	.010	.019	.023	.026	.030	.033	.044
	70	.004	.009	.015	.018	.020	.023	.025	.033
	90	.003	.008	.014	.016	.018	.020	.022	.030

Source: IES RP-23-1989; reprinted with permission of Illuminating Engineering Society of North America.

TABLE C.23 Coefficient of Utilization from Window without Blinds; Sky Component $E_{xvk}/E_{xhk} = 1.25$

Room Depth/ Window Height	Depth	Window Width/Window Height .5	1	2	3	4	6	8	Infinite
1	10	.578	.607	.614	.619	.621	.633	.634	.635
	30	.405	.525	.580	.594	.599	.612	.614	.615
	50	.287	.423	.519	.547	.556	.569	.571	.573
	70	.218	.347	.461	.501	.515	.522	.525	.526
	90	.186	.307	.428	.473	.491	.483	.486	.487
2	10	.472	.549	.566	.569	.570	.574	.575	.581
	30	.221	.337	.422	.447	.456	.465	.467	.472
	50	.120	.202	.285	.321	.337	.353	.357	.361
	70	.078	.136	.204	.242	.261	.281	.287	.290
	90	.064	.112	.174	.211	.233	.244	.251	.253
3	10	.377	.488	.527	.533	.534	.536	.536	.549
	30	.130	.217	.298	.329	.341	.352	.353	.362
	50	.062	.110	.165	.195	.211	.228	.231	.237
	70	.040	.070	.109	.132	.147	.166	.171	.175
	90	.033	.057	.090	.112	.127	.142	.148	.152
4	10	.300	.424	.484	.494	.497	.499	.499	.524
	30	.080	.143	.209	.240	.255	.267	.269	.283
	50	.036	.066	.104	.126	.140	.156	.160	.168
	70	.024	.043	.068	.083	.094	.109	.115	.120
	90	.021	.036	.056	.070	.080	.092	.099	.103
6	10	.193	.314	.395	.415	.420	.423	.423	.476
	30	.036	.071	.113	.136	.149	.161	.165	.186
	50	.017	.033	.053	.065	.074	.084	.089	.100
	70	.012	.024	.037	.045	.050	.058	.061	.069
	90	.011	.021	.031	.038	.043	.049	.053	.060
8	10	.128	.226	.310	.337	.346	.351	.352	.433
	30	.019	.039	.066	.082	.092	.104	.109	.134
	50	.009	.019	.031	.040	.045	.052	.056	.069
	70	.007	.015	.023	.029	.032	.037	.040	.049
	90	.006	.013	.021	.025	.028	.032	.035	.043
10	10	.088	.164	.241	.270	.282	.290	.291	.396
	30	.011	.024	.043	.054	.062	.071	.076	.103
	50	.005	.012	.022	.026	.030	.035	.038	.052
	70	.004	.010	.017	.020	.023	.026	.028	.038
	90	.004	.009	.016	.018	.020	.023	.025	.034

Source: IES RP-23-1989; reprinted with permission of Illuminating Engineering Society of North America.

TABLE C.24 Coefficient of Utilization from Window without Blinds; Sky Component $E_{xvk}/E_{xhk} = 1.50$

Room Depth/ Window Height	Depth	Window Width/Window Height .5	1	2	3	4	6	8	Infinite
1	10	.503	.528	.536	.541	.544	.557	.558	.559
	30	.359	.464	.514	.528	.534	.549	.550	.552
	50	.261	.384	.471	.499	.508	.524	.526	.527
	70	.204	.325	.432	.470	.485	.497	.499	.500
	90	.179	.295	.412	.456	.475	.474	.477	.478
2	10	.412	.477	.490	.492	.493	.498	.499	.505
	30	.201	.304	.379	.402	.410	.422	.424	.429
	50	.115	.192	.269	.304	.320	.339	.343	.347
	70	.078	.136	.204	.241	.261	.286	.292	.295
	90	.066	.117	.183	.221	.246	.262	.271	.273
3	10	.331	.426	.458	.461	.462	.465	.465	.477
	30	.121	.202	.275	.304	.316	.327	.329	.337
	50	.062	.109	.164	.193	.209	.228	.232	.238
	70	.041	.073	.114	.138	.154	.176	.183	.188
	90	.035	.062	.099	.123	.141	.159	.169	.173
4	10	.265	.372	.422	.430	.433	.435	.435	.456
	30	.077	.137	.199	.229	.243	.256	.259	.272
	50	.037	.069	.107	.130	.144	.161	.167	.175
	70	.026	.046	.073	.089	.101	.119	.126	.132
	90	.022	.039	.063	.078	.090	.106	.114	.120
6	10	.173	.281	.351	.368	.373	.375	.375	.422
	30	.037	.073	.115	.137	.151	.164	.168	.189
	50	.018	.036	.058	.071	.080	.092	.098	.110
	70	.013	.026	.040	.049	.056	.064	.069	.078
	90	.012	.023	.035	.043	.048	.057	.062	.070
8	10	.117	.207	.282	.305	.314	.319	.320	.393
	30	.020	.042	.071	.087	.098	.111	.116	.143
	50	.010	.021	.035	.044	.050	.058	.063	.078
	70	.007	.016	.026	.032	.036	.041	.045	.055
	90	.076	.014	.023	.028	.031	.036	.040	.049
10	10	.082	.153	.224	.250	.262	.269	.271	.368
	30	.012	.026	.047	.059	.068	.078	.084	.114
	50	.006	.014	.024	.030	.034	.040	.044	.060
	70	.005	.011	.019	.022	.025	.029	.032	.043
	90	.004	.010	.017	.020	.023	.026	.028	.038

Source: IES RP-23-1989; reprinted with permission of Illuminating Engineering Society of North America.

TABLE C.25 Coefficient of Utilization from Window without Blinds; Sky Component $E_{xvk}/E_{xhk} = 1.75$

Room Depth/ Window Height	Depth	Window Width/Window Height .5	1	2	3	4	6	8	Infinite
1	10	.435	.457	.465	.471	.474	.486	.488	.489
	30	.317	.407	.452	.466	.471	.486	.488	.489
	50	.234	.343	.422	.447	.456	.472	.475	.476
	70	.187	.297	.395	.430	.445	.458	.461	.462
	90	.168	.276	.384	.426	.444	.447	.450	.451
2	10	.357	.412	.422	.424	.424	.430	.431	.436
	30	.180	.271	.335	.356	.363	.375	.378	.381
	50	.106	.177	.246	.278	.293	.313	.318	.321
	70	.074	.130	.194	.229	.249	.274	.282	.284
	90	.065	.116	.181	.219	.244	.264	.273	.276
3	10	.288	.369	.394	.397	.397	.400	.401	.411
	30	.110	.183	.247	.272	.282	.294	.296	.304
	50	.058	.104	.154	.181	.196	.215	.221	.226
	70	.040	.072	.112	.136	.152	.176	.184	.188
	90	.035	.063	.101	.126	.144	.166	.177	.182
4	10	.232	.324	.365	.371	.373	.375	.375	.394
	30	.071	.127	.183	.209	.222	.235	.238	.250
	50	.036	.067	.104	.125	.139	.157	.163	.171
	70	.025	.046	.072	.089	.101	.119	.127	.134
	90	.022	.041	.065	.082	.095	.114	.124	.130
6	10	.153	.247	.307	.320	.324	.326	.327	.367
	30	.035	.070	.109	.130	.143	.155	.160	.180
	50	.018	.036	.058	.071	.080	.091	.098	.110
	70	.013	.026	.041	.051	.058	.067	.073	.082
	90	.012	.023	.037	.046	.052	.062	.069	.078
8	10	.104	.184	.249	.269	.276	.281	.282	.346
	30	.020	.042	.070	.086	.096	.109	.115	.141
	50	.010	.022	.036	.046	.052	.060	.066	.081
	70	.008	.017	.027	.033	.038	.044	.048	.059
	90	.007	.015	.024	.030	.034	.040	.044	.054
10	10	.074	.138	.201	.223	.233	.240	.242	.328
	30	.012	.027	.048	.059	.067	.078	.084	.114
	50	.006	.014	.026	.032	.036	.043	.047	.064
	70	.005	.011	.020	.024	.027	.031	.034	.046
	90	.004	.010	.018	.022	.024	.028	.031	.042

Source: IES RP-23-1989; reprinted with permission of Illuminating Engineering Society of North America.

TABLE C.26 Coefficient of Utilization from Window without Blinds; Ground Component

Room Depth/ Window Height	Depth	Window Width/Window Height .5	1	2	3	4	6	8	Infinite
1	10	.105	.137	.177	.197	.207	.208	.210	.211
	30	.116	.157	.203	.225	.235	.241	.243	.244
	50	.110	.165	.217	.241	.252	.267	.269	.270
	70	.101	.162	.217	.243	.253	.283	.285	.286
	90	.091	.146	.199	.230	.239	.290	.292	.293
2	10	.095	.124	.160	.178	.186	.186	.189	.191
	30	.082	.132	.179	.201	.212	.219	.222	.225
	50	.062	.113	.165	.189	.202	.214	.218	.220
	70	.051	.093	.141	.165	.179	.194	.198	.200
	90	.045	.079	.118	.140	.153	.179	.183	.185
3	10	.088	.120	.157	.175	.183	.185	.163	.167
	30	.059	.107	.154	.176	.187	.198	.193	.198
	50	.039	.074	.114	.134	.146	.157	.163	.170
	70	.031	.055	.085	.101	.111	.122	.127	.130
	90	.028	.047	.070	.083	.092	.107	.113	.115
4	10	.073	.113	.154	.174	.183	.187	.176	.184
	30	.040	.082	.127	.148	.159	.170	.177	.185
	50	.025	.049	.078	.094	.103	.113	.117	.123
	70	.020	.036	.054	.065	.071	.079	.083	.087
	90	.019	.032	.046	.054	.060	.069	.073	.076
6	10	.056	.106	.143	.164	.175	.184	.173	.194
	30	.021	.050	.081	.098	.107	.117	.123	.138
	50	.013	.027	.041	.049	.054	.060	.064	.072
	70	.011	.021	.029	.033	.035	.039	.041	.046
	90	.011	.020	.026	.030	.032	.035	.037	.042
8	10	.036	.082	.122	.143	.156	.166	.170	.208
	30	.011	.029	.050	.062	.070	.078	.082	.101
	50	.007	.016	.024	.028	.031	.035	.038	.046
	70	.006	.013	.018	.020	.021	.023	.025	.030
	90	.006	.013	.017	.019	.020	.022	.023	.028
10	10	.024	.061	.109	.120	.131	.144	.147	.200
	30	.006	.017	.034	.040	.046	.053	.056	.076
	50	.004	.010	.016	.018	.020	.023	.024	.033
	70	.004	.009	.013	.014	.015	.016	.016	.022
	90	.004	.009	.013	.013	.014	.015	.016	.021

Source: IES RP-23-1989; reprinted with permission of Illuminating Engineering Society of North America.

STEP 4. Calculate the illuminances for each of the five reference locations. (Table 10.12 tabulates the illuminance values from this calculation.) The basic equation for each location is:

$$E_i = \tau(E_{xvk} \times CU_k + E_{xvg} \times CU_g) \qquad (10.6)$$

where

E_i = interior illuminance at a specific reference point
τ = net transmittance of the window
E_{xvk} = exterior vertical illuminance at the window from half of the sky (an unobstructed vertical window sees only half of the sky)
E_{xvg} = exterior vertical illuminance at the window from the ground
CU_k = coefficient of utilization for sky light
CU_g = coefficient of utilization for ground light

TABLE 10.11 Coefficients of Utilization for Sky and Ground Components for Five Interior Locations

Location	CU_k (Sky)	CU_g (Ground)
10	0.673	0.183
30	0.235	0.159
50	0.104	0.103
70	0.065	0.071
90	0.053	0.060

TABLE 10.12 Illuminance Values for Winter and Spring in Seattle, Washington, at Five Reference Locations

Location	E_i Dec. 21, lux (fc)	E_i Mar. 21, lux (fc)
10	1151 (107)	2877 (267)
30	474 (44)	1182 (110)
50	234 (22)	585 (54)
70	151 (14)	378 (35)
90	125 (12)	312 (29)

Dec. 21 (overcast)

	τ	CU_k	E_{xvk}	CU_g	E_{xvg}	E_i
0.1D	0.704	0.673	2,150	0.183	538	1,088
0.3D	0.704	0.235	2,150	0.159	538	416
0.5D	0.704	0.104	2,150	0.103	538	196
0.7D	0.704	0.065	2,150	0.071	538	125
0.9D	0.704	0.053	2,150	0.06	538	103

Mar. 21 (overcast)

	τ	CU_k	E_{xvk}	CU_g	E_{xvg}	E_i
0.1D	0.704	0.673	5,380	0.183	1,334	2,720
0.3D	0.704	0.235	5,380	0.159	1,334	1,039
0.5D	0.704	0.104	5,380	0.103	1,334	490
0.7D	0.704	0.065	5,380	0.071	1,334	313
0.9D	0.704	0.053	5,380	0.06	1,334	257

Jun. 21 (clear)

	τ	CU_k	E_{xvk}	CU_g	E_{xvg}	E_i
0.1D	0.704	0.673	7,500	0.183	9,800	4,815
0.3D	0.704	0.235	7,500	0.159	9,800	2,337
0.5D	0.704	0.104	7,500	0.103	9,800	1,259
0.7D	0.704	0.065	7,500	0.071	9,800	833
0.9D	0.704	0.053	7,500	0.06	9,800	694

To demonstrate the use of the IESNA method for clear-sky conditions, we can work through a brief example where five IESNA point illuminances are calculated for the same Seattle classroom, on June 21 at 10:00 a.m. for clear-sky conditions. Assume that the window faces southwest (azimuth angle = 45° west of south).

Solar azimuth at 10:00 a.m. on June 21 at 48°N latitude is ~~56°~~ 55 (Table D.1). The bearing angle is therefore 45° + ~~56°~~ 55 or 101° 100 (i.e., no direct sunlight enters the window, which is a necessary condition of the IESNA clear-sky method). Solar altitude is ~~55°~~ 56

CALCULATION

STEP 1. Determine the horizontal illuminance (refer to Fig. 10.24):

Sun only:	80,000 lux (7432 fc)
Sky only:	18,000 lux (1672 fc) full sky
	9000 lux (836 fc) half sky (E_{xhk})

TABLE 10.13 Illuminance Values for Clear-Sky Conditions on June 21 at Five Reference Locations

Location	E_i June 21, lux (fc)
10	4674 (434)
30	2225 (207)
50	1188 (110)
70	784 (73)
90	652 (61)

Determine the vertical illuminance (refer to Fig. 10.26b):

At a solar altitude of 55° and a bearing angle of 100 101°, the E_{xvk} = 700 fc (7500 lux).

From Equation 10.5, vertical illuminance on the exterior of the window resulting from ground light is:

$$E_{xvg} = 0.2 \times \frac{80{,}000 + \cancel{9000}\ 18{,}000}{2} = \cancel{8900}\ 9{,}800 \text{ lux (827 fc)}$$

STEP 2. Determine net transmittance of the window:

$$\tau = 0.70, \text{ as previously}$$

STEP 3. Select the coefficients of utilization (as was previously done for overcast conditions):

$$\frac{E_{xvk}}{E_{xhk}} = \frac{7500}{9000} = 0.83$$

STEP 4. Calculate the illuminance, using Equation 10.6:

$$E_i = \tau\,(E_{xvk} \times CU_k + E_{xvg} \times E_{xvg} \times CU_g)$$

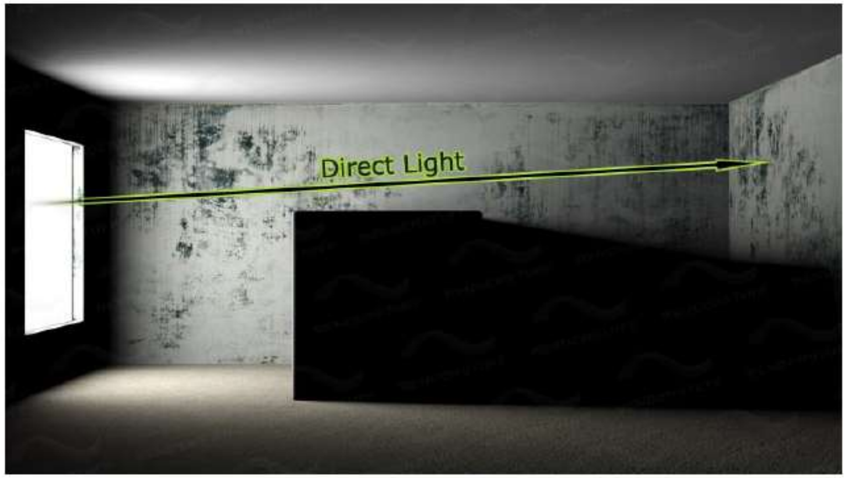
$$= 0.7\,(7500 \times CU_k + \cancel{8900}\ 9{,}800 \times CU_g)$$

Table 10.13 tabulates the illuminances at the five reference locations. ■

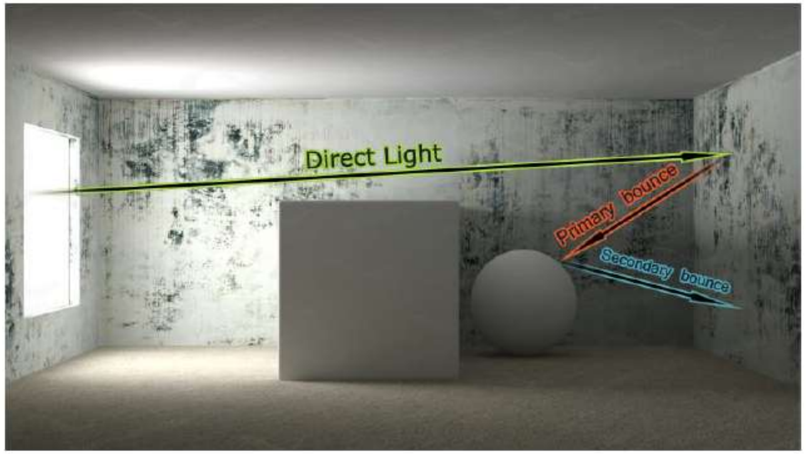
Daylighting simulation

- Rendering (photo-realistic image, local calculation) vs. simulation (scientific calculation, global calculation)
- Use of physical (mathematical) model (not use of computer)
- Advantages: accuracy, easy comparison (hourly, daily, per orientation, different sites), comparison of design alternatives
- Algorithm: Ray tracing vs. Radiosity

Global vs. local



Picture 4. An interior scene lighted with one directional light illuminating through window when global illumination is disabled. (Renderstuff.com 2013)



Picture 5. Interior scene lighted with one directional light illuminating through window when global illumination is enabled. The angles of reflection are not in scale. (Renderstuff.com 2013)

Picture 4: global illumination is disabled
Picture 5: global illumination is enabled

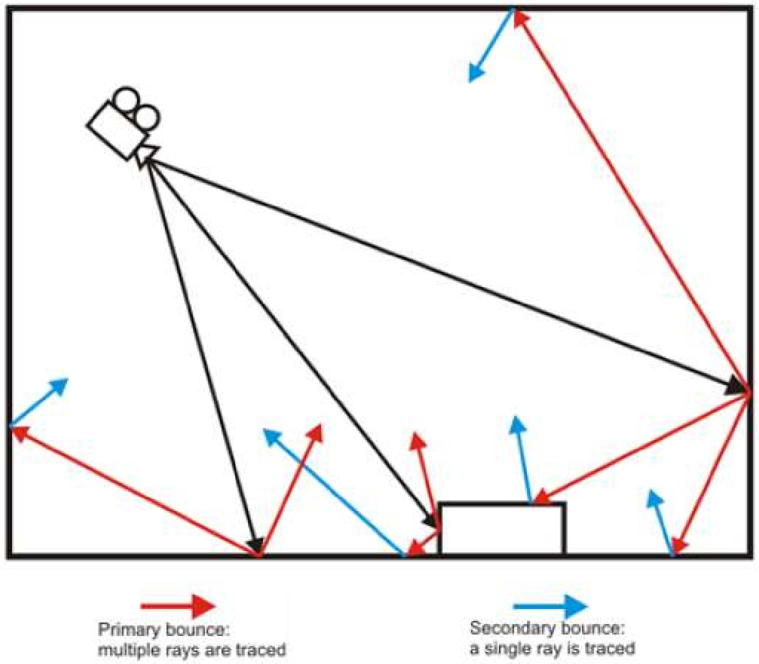


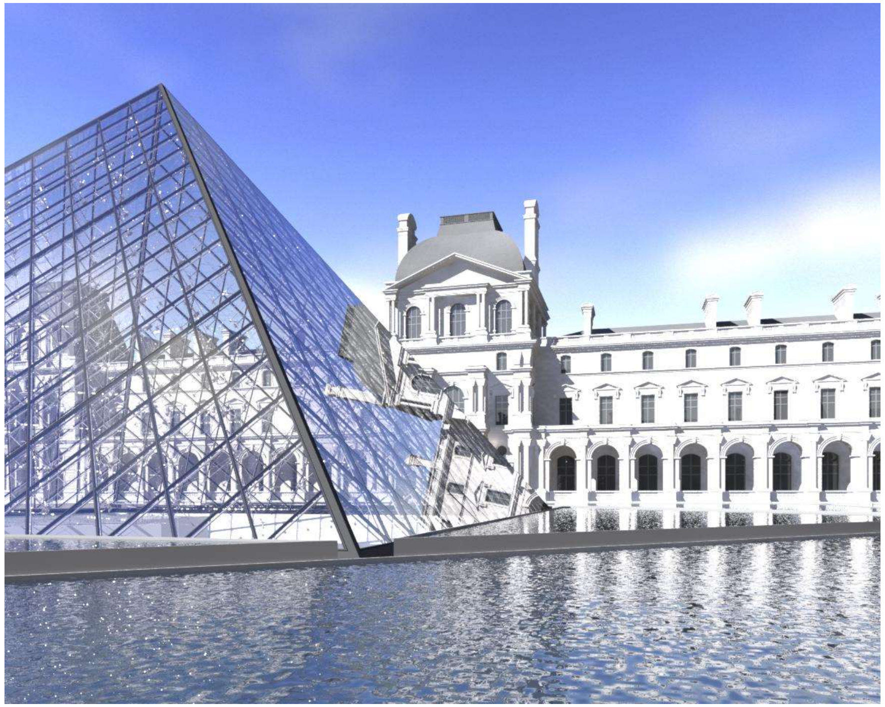
Image source: Antti Kämä, PHOTOREALISTIC LIGHTING AND RENDERING OF A SMALL APARTMENT INTERIOR

Lighting simulation tools

- Radiance: ray tracing
  - Desktop Radiance: http://radsite.lbl.gov/deskrad/dradHOME.html
  - Radiance (UNIX version): http://radsite.lbl.gov/
  - Radiance online: http://www.radiance-online.org/
- Lightscape 3.2 ended (Ray tracing + Radiosity) → Autodesk VIZ 2005
- Lumen Micro 2000 and lumen designer (widely used in lighting industry): http://www.lighting-technologies.com/ → http://www.ltioptics.com
- Relux: www.relux.biz
- Sefaira Autodesk Ecotect Analysis (http://usa.autodesk.com/ecotect-analysis/)
- Autodesk 3dsMax Design
- AGI32 (www.agi32.com/)
- DFcalc (http://archiphysics.com/programs/daylight/daylight.htm)
- Rhinoceros with DIVA plugin: www.rhino3d.com/

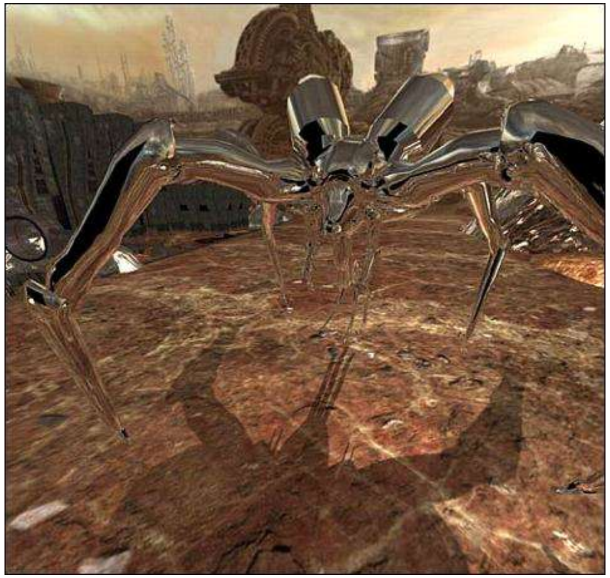
RADIANCE

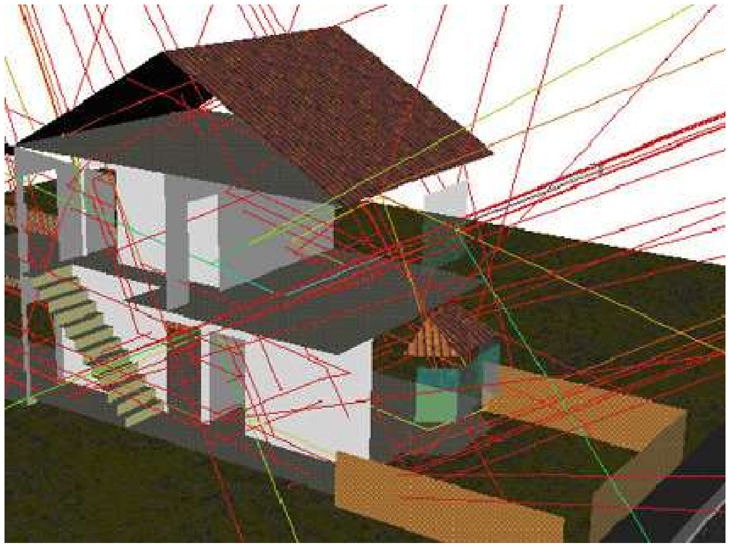
- Design tool to facilitate the design and analysis for daylighting and electric lighting
- Most sophisticated, especially for daylighting
- Runned with AutoCAD, now in DIVA
- http://radsite.lbl.gov/radiance/download.html



(from http://www.radiance-online.org)

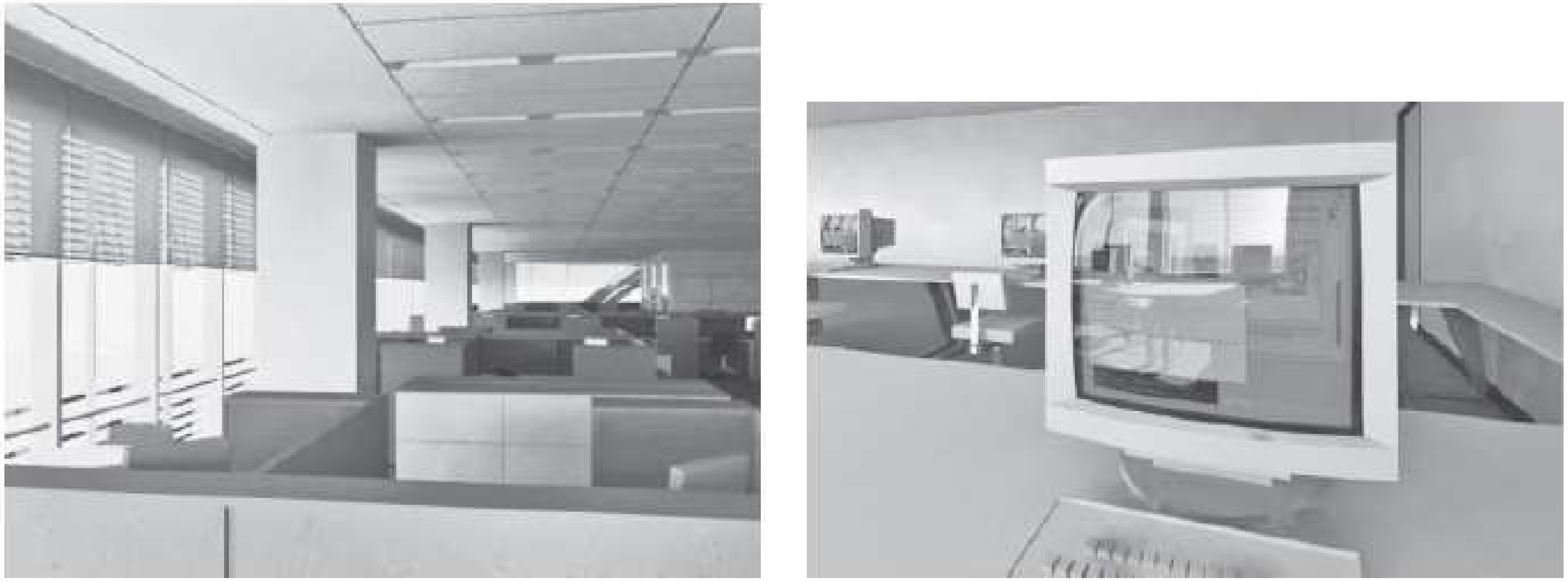
Ray tracing





Radiosity

Radiosity



(a) (b)

Fig. 10.42 *Renderings studies using Radiance. (a) Shading provided by the blinds at the* New York Times *building. (b) Veiling reflections on a computer monitor. (a: © Greg Ward and Judy Lai; b: by Chas Erlich, Lawrence Berkeley National Laboratory, used with permission.)*

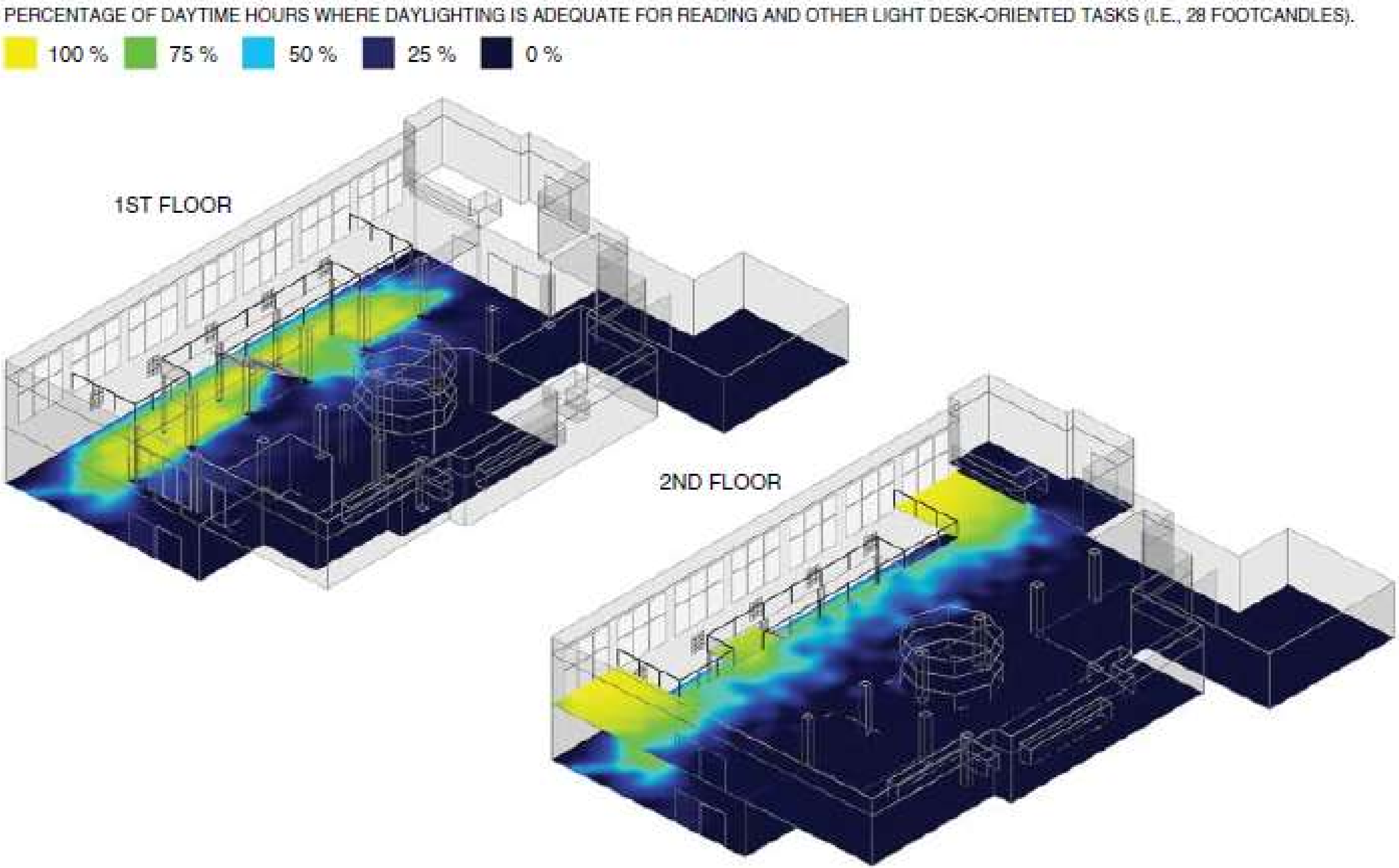


Fig. 10.43 *Schematic daylighting study using Sefaira depicts spatial daylight autonomy (sDA) for a renovation project in Indianapolis, Indiana. (Illustrations courtesy Daniel Overbey; © Browning Day Mullins Dierdorf.)*

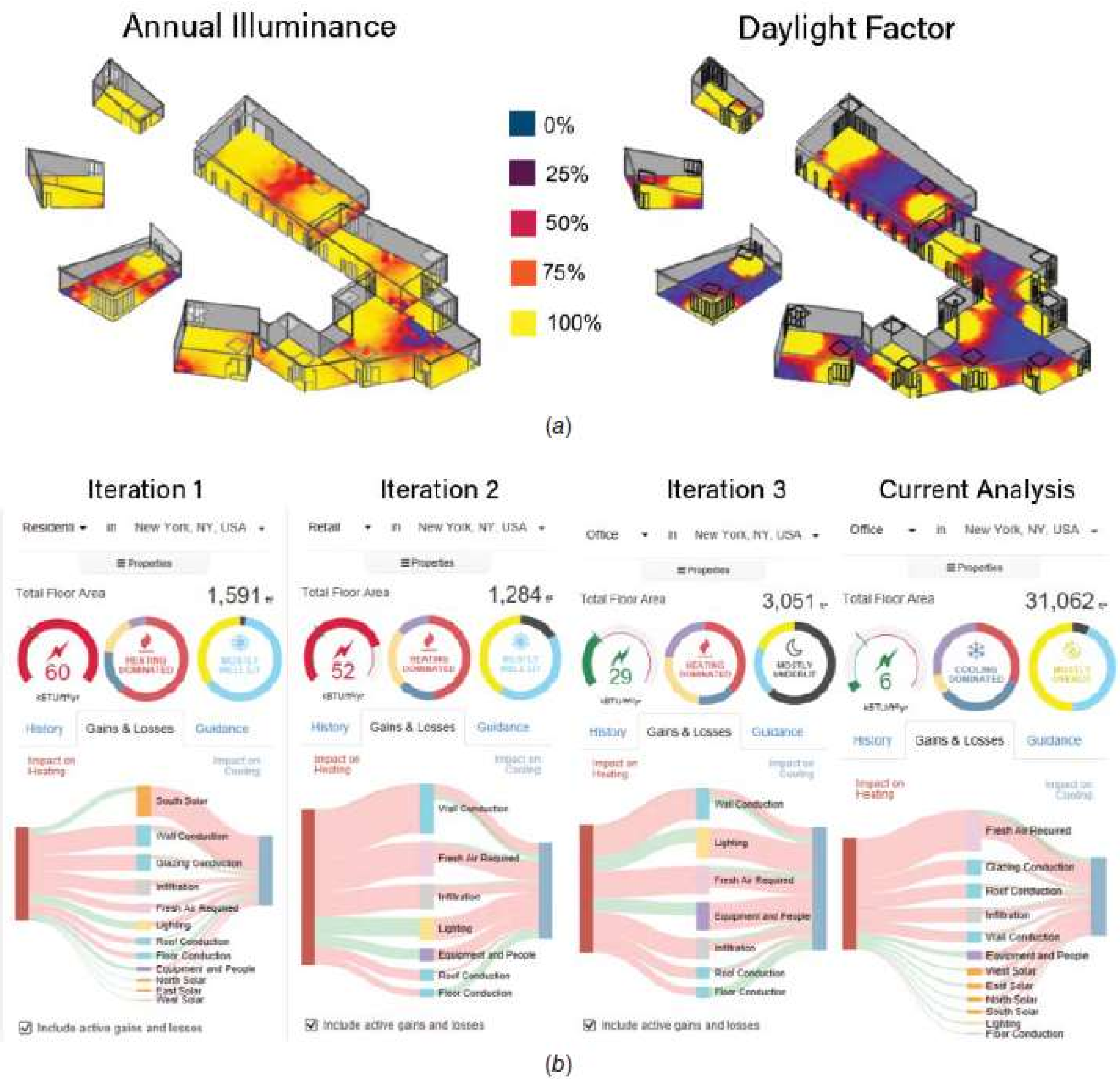


Fig. 10.44 *(a) Dynamic and diffuse daylighting analysis by targeting a range of illuminance levels for specific spaces and (b) estimating energy performance (EUI) for various parts of a studio program using Sefaira. (Illustrations by Megan York; used with permission.)*

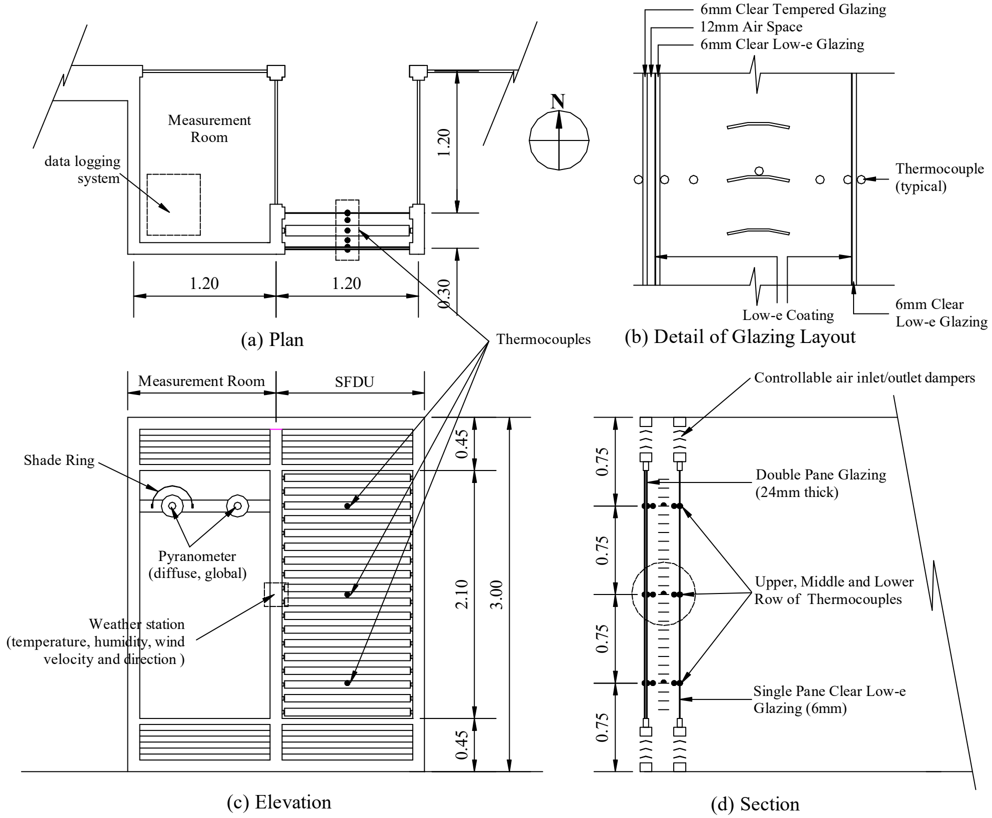
(*a*) (*b*)

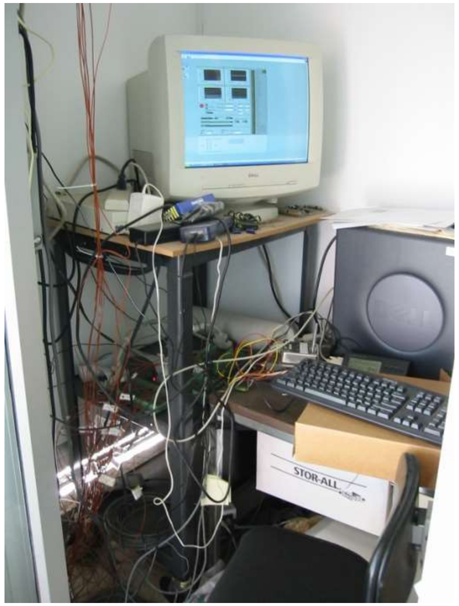
Fig. 10.45 *Renderings of daylight in a residence. (Images reproduced from Autodesk® VIZ Render 2004 software with permission of Autodesk, Inc.; all rights reserved.)*

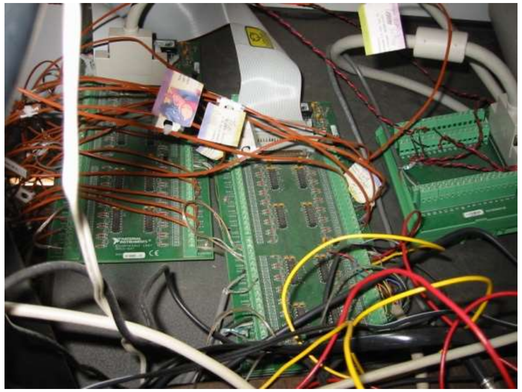
Fig. 10.46 *(a) Daylighting rendering for a middle school design in Las Vegas, Nevada and (b) corresponding photometric plan using AGi32. (Illustrations courtesy Daniel Overbey; © Tate Snyder Kimsey Architects.)*

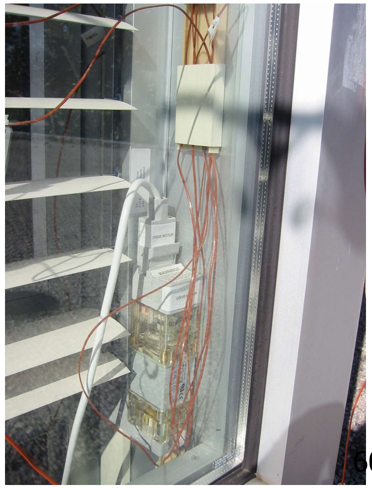
Test facility

The Smart Façade Demo Unit (SFDU)



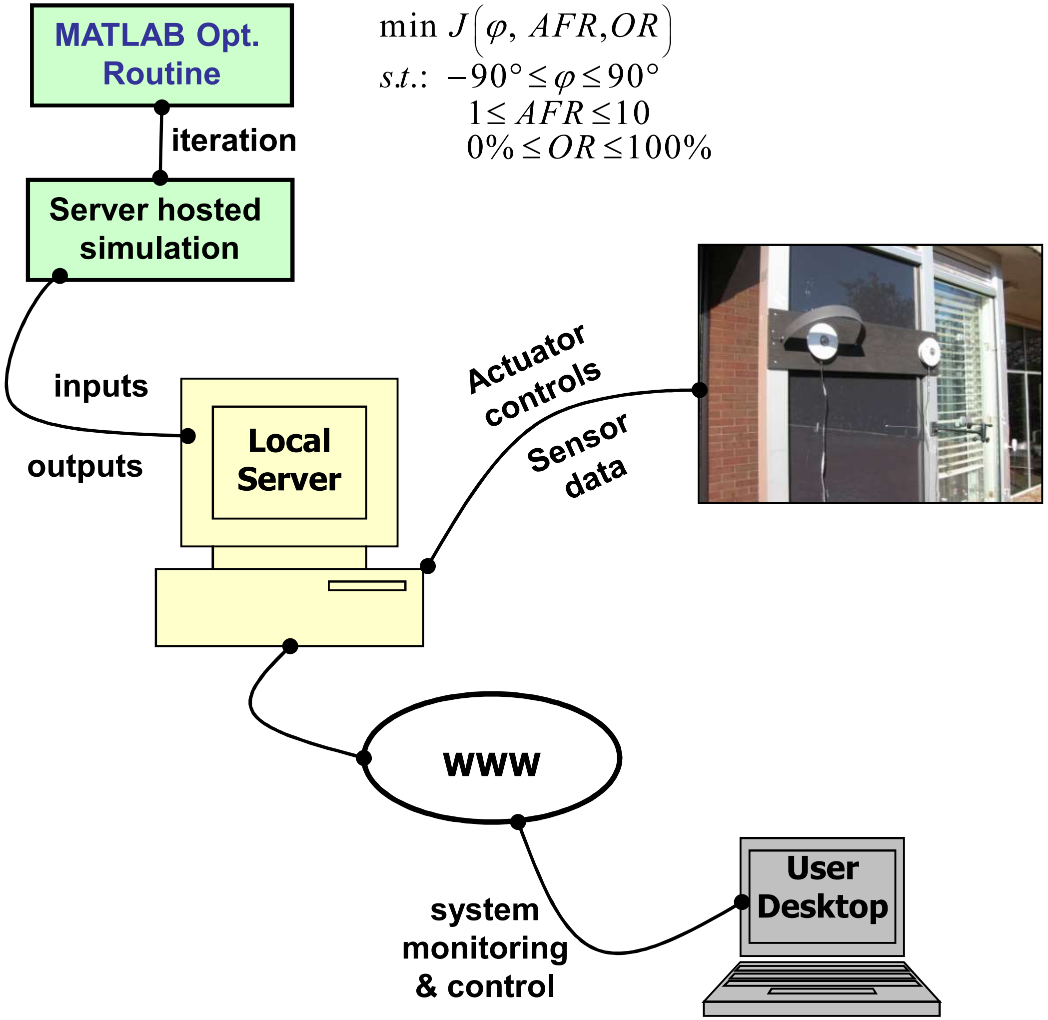


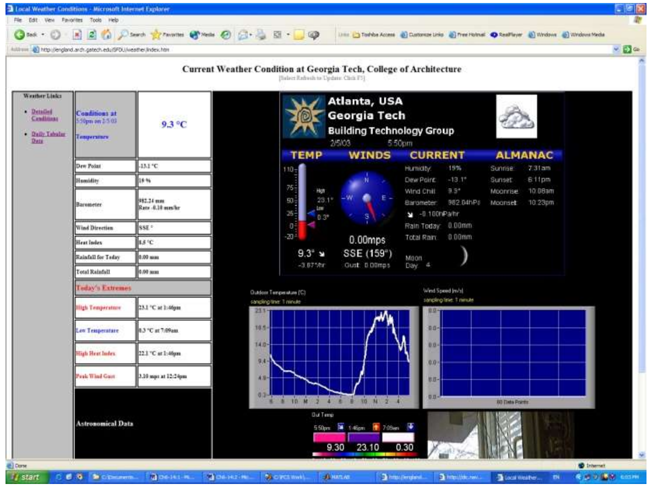


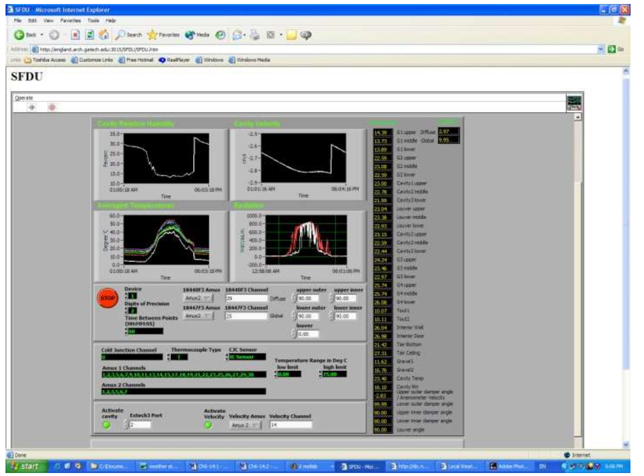


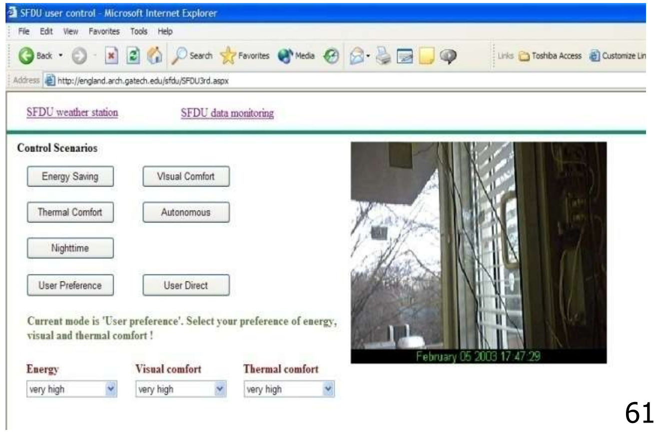
Architecture of
the smart façade demo unit

$$\min J(\varphi, AFR, OR)$$
$$s.t.: \; -90° \le \varphi \le 90°$$
$$1 \le AFR \le 10$$
$$0\% \le OR \le 100\%$$





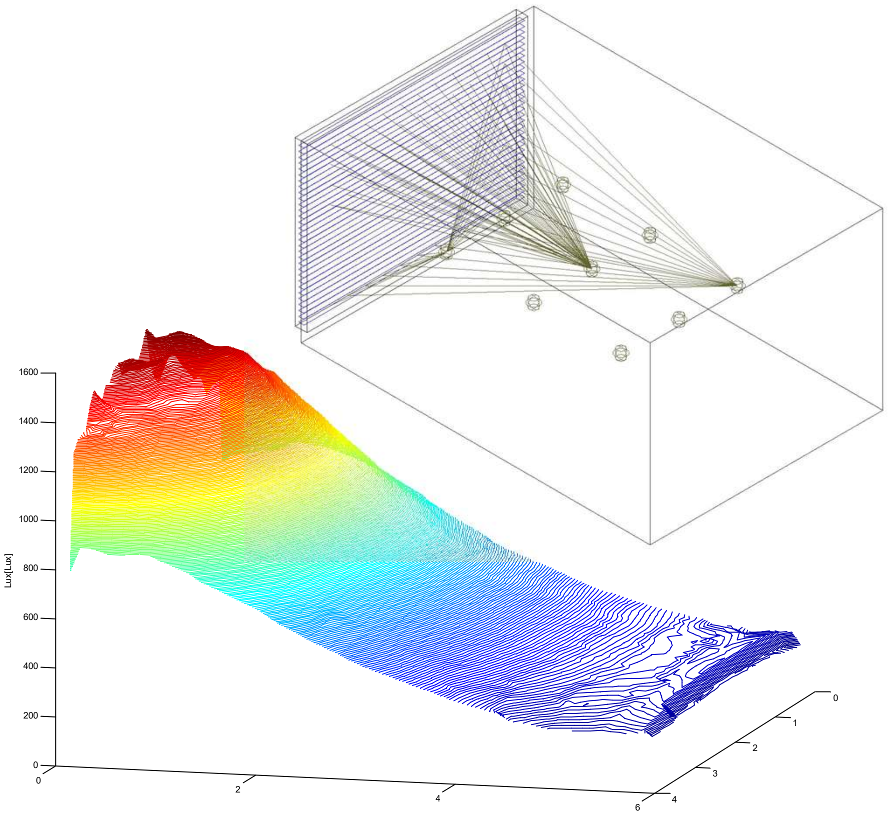




Daylighting simulation

- ✓ **Establish** a daylighting simulation model as a reference system
- ✓ Use RADIANCE pre simulations to **generate** an indoor daylight predictor
- ✓ Determine **an optimal louver slat angle** that meets specific visual comfort and daylighting autonomy

Desktop Radiance
Radiance User Interface for Windows



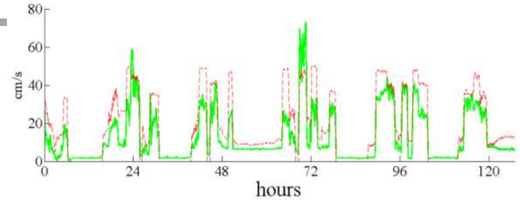
Daylit illuminance level in 3D contour

< simulation condition >
date: Dec. 22nd
time: 9:00 a.m.
sky condition: intermediate (CIE)
location: Atlanta, GA
louver slat angle: 40 °
< data analysis >
average illuminance: 405 lux
uniformity: 33.7%
luminance: 268 cd/m2
daylighting autonomy = 294 lux

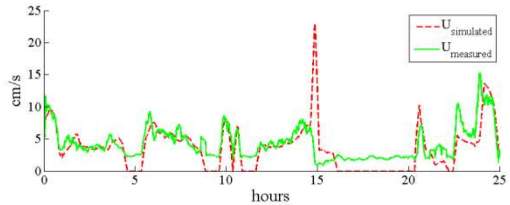
Smart double skins

Advanced daylighting control system, installed at the Sungkyunkwan University, Korea

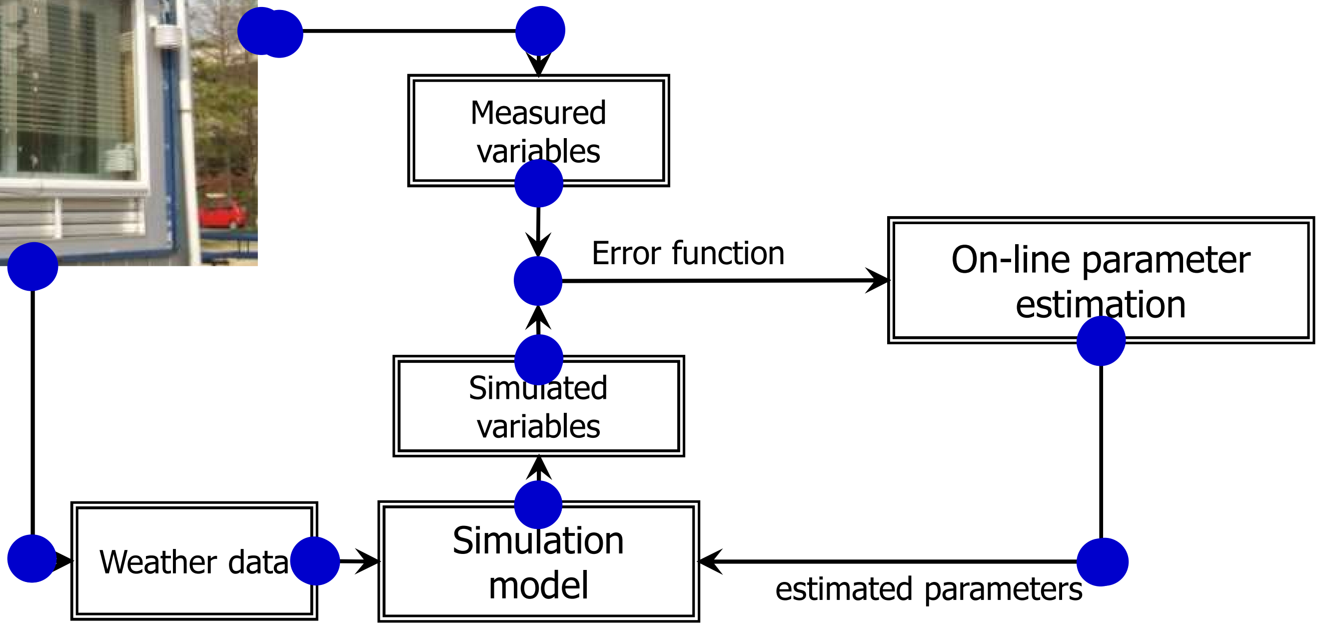
Self-calibrating simulation model



off-line parameter estimation



on-line parameter estimation



● : Data flow

Physical modeling

- Advantages
  - The opportunity for accurate daylight measurements and for qualitative evaluation
  - Easy construction (for most designers)
  - Crude models that can yield critical information
  - Easy comparisons of various schemes: e.g. interchangeable wall or ceiling elements
  - Realistic visualization for clients
  - 3 dimensional depiction
- Disadvantages
  - the need to expose them to the desired sky conditions. For example, waiting for suitable sky conditions in order to view a particular space under both overcast and clear sky conditions, or at different seasons of the year, or during different times of day, is not always practical.

Fig. 10.47 *The effectiveness of even a crude model for daylighting studies. (a) A faculty office served as an exercise for a daylighting study. (b) The scale model for this office was constructed of cardboard. Important reflecting surfaces such as desk surfaces and windowsills were carefully modeled. (c) A quick modification was made to the model so that the rear of the office would receive more light. All photos were taken on site at midday on an overcast day. (© Alison Kwok; all rights reserved.)*

(*a*)

(*b*)

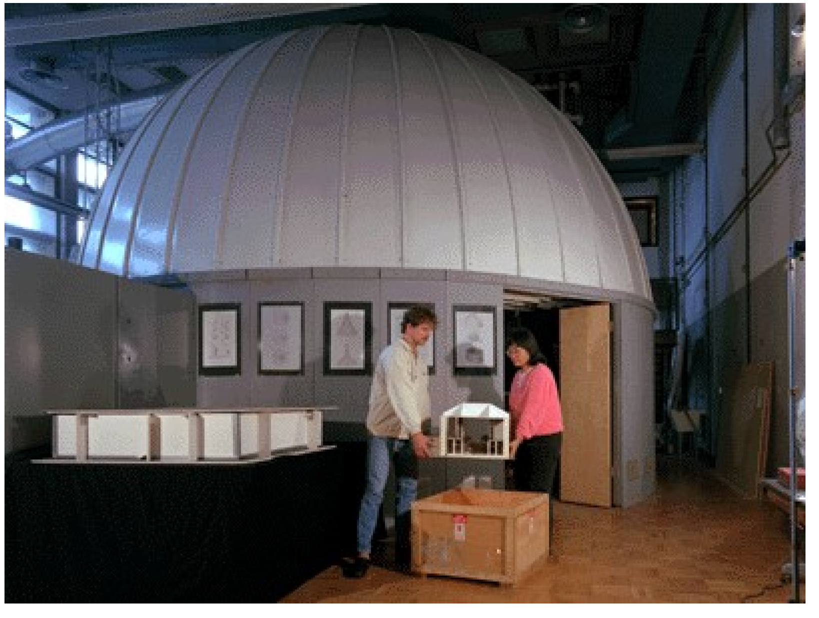
(*c*)

< Material> Constructing scale models is relatively simple, using corrugated cardboard, mat board, and colored paper—mounted on a base for ease of manipulation (Fig. 10.47).

< Modular > The model should be made modularly so that alternative design proposals can be interchanged. For example, to compare various skylight configurations, several replaceable roof configurations can be constructed.

< Size > Model size depends upon the size of photometers used to measure interior illuminance, the size of the space, and the need to accommodate a camera viewport. Considering ease of construction and visualization opportunities, bigger is usually better—although larger models are often preceded by smaller/cruder study models.

Sun simulator



Werner Osterhaus and Liliana Beltran prepare a scale model for tests in the sky simulator

In the facility's interior, Osterhaus and Beltran conduct performance tests of a shading device for a hotel atrium using the sun simulator, upper right

http://eetd.lbl.gov/newsletter/cbs_nl/nl4/skysimulator.html

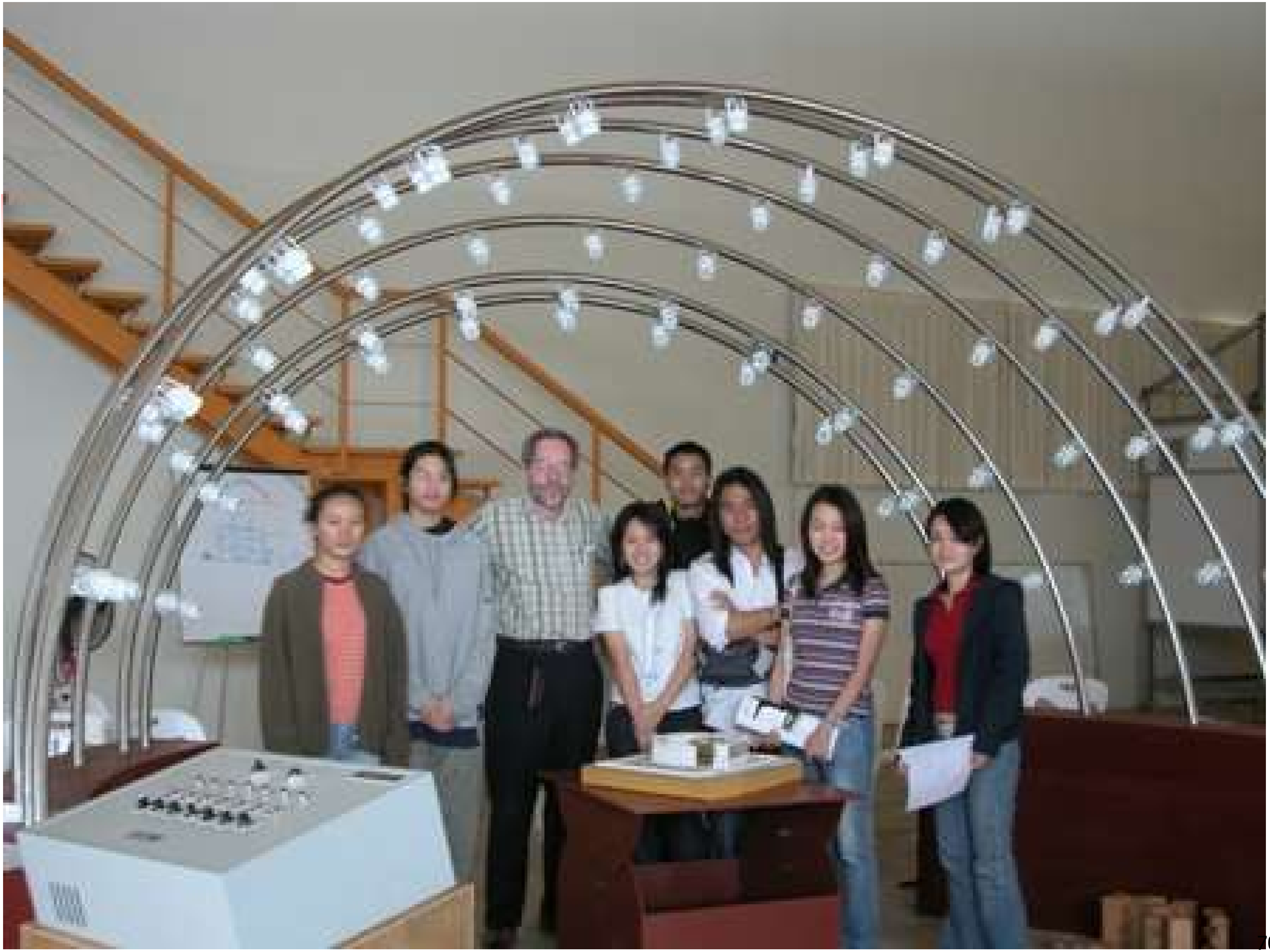


Fig. 10.54 *Daylit atrium is controlled by the structural timber baffles; use of absorptive material around voids in the atrium provides a good acoustical environment. (Photo by Nick Hufton; © Hufton & Crow; used with permission.)*