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A GRAPHICAL METHOD FOR DETERMINING INTERFLECTED DAYLIGHT IN CLEAR CLIMATES

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ABSTRACT

This report presents an extension of the daylight factor method of analysis that includes a graphical method for determining interflected light in clear climates. The interflected component of daylight, called the internal reflectance component (IRC), has been determined for overcast skies in research performed in the United Kingdom. The technique developed by the Building Research Establishment in the United Kingdom is based on determining an average IRC for a given room or space. Using a daylight availability model developed at SERI (1), we established a similar average IRC analysis technique for clear skies. The results of applying the SERI daylight availability model suggest that a critical element in determining the IRC under clear sky conditions is the ratio of global to diffuse (G/d) illuminance on a horizontal surface. This graphical technique for determining clear sky IRC values is expected to enhance the accuracy of daylighting system design by simplifying the format used in clear sky computation.

1. INTRODUCTION

The amount of daylight received in buildings can be expressed as the percentage ratio of indoor illuminance. This ratio is called the daylight factor (DF) and is computed as

$$DF\ (\%) = E_i/E_e \times 100\ , \qquad [1]$$

where

E_i = interior illuminance
E_e = exterior illuminance

This value depends on the sky conditions; the size, shape, and position of the aperture; and, in the case of clear skies, the location of the sun relative to the aperture.

Using the daylight factor method we can calculate the three components of the daylight reaching any reference point in a room:

- The sky component (SC)—the light received directly from the sky
- The external reflectance component (ERC)—light received after reflection from buildings and other external surfaces, including a direct view of the ground
- The internal reflectance component (IRC)—the light reflected from surfaces inside the room and an indirect view of the ground.

These components are calculated separately and added to determine the daylight factor:

$$DF\ (\%) = SC + ERC + IRC\ . \qquad [2]$$

Corrections for interior room maintenance, glazing material, dirt, and reductions for framing around the aperture can be added to Eq. 2 as follows:

$$DF = \left[SC + ERC + (M)(IRC)\right](D)(F)(G)\ , \qquad [3]$$

where

M = interior maintenance factor

D = dirt on glass factor

F = framing factor

G = glazing factor, for other than clear glass.

The average IRC is defined as the IRC at the midpoint of the room. This value is often used during the early stages of the building design process to predict daylight penetration into a building. The average IRC does not vary a great deal with respect to the view factor of an aperture from a specific station point in a room. Because it does not vary, graphical design aids can be used to determine the average IRC.

2. ESTIMATING INTERFLECTED LIGHT IN BUILDINGS

2.1 The BRS Interflection Formula

The Building Research Station (BRS) interflection formula was developed to estimate interflected light and can be determined from the equation:

$$IRC_{avg} = \frac{(T)(W)}{A(1 - R)} \left(C_1R_{fw} + C_2R_{cw}\right) \quad , [4]$$

where

T = transmission of the glazing in the visible spectrum

W = area of glazing

A = total area of the ceiling, floors, and walls including the glazing

R = average reflectance of the ceiling, walls, floor, and aperture

C_1 = aperture configuration factor equivalent due to the light incident on the aperture from above the horizontal at the midheight of the aperture

R_{fw} = average reflectance of the floor and those parts of the walls below the midheight of the aperture (excluding the aperture and aperture wall)

C_2 = aperture configuration factor equivalent due to light incident on the aperture from below the horizontal at the midheight of the aperture

R_{cw} = average reflectance of the ceiling and those parts of the walls above the midheight of the aperture (excluding the aperture and aperture wall).

The difference between clear and overcast conditions in the application of Eq. 4 lies in the configuration factors, which vary depending on the sky condition. C_1 and C_2 values for the BRS interflection equation are shown in Tables 1 and 2.

2.2 LBL Interflection Formula

Research at the Lawrence Berkeley Laboratories (LBL) (2) developed an equation, similar to Eq. 1, to compute an average internal reflectance component for clear sky conditions. However, because direct illuminance is contributing illumination to the ground, C_1 and C_2 are calculated differently than in the BRS interflection formula. The C_1 factors for a clear day are illustrated in Table 3.

Table 1. Aperature Configuration Factor Equivalent C_1 for Overcast Skies

Angle of Obstruction* (deg)	C_1
No obstruction	39
10	35
20	31
30	25
40	20
50	14
60	10
70	7
80	5

*Measured above the midheight of the aperture at the center of the room.

Table 2. Aperature Configuration Factor Equivalent C_2 for Overcast Skies

Average Ground Reflectivity (%)	C_2
10	5
20	10
30	15
40	20
50	25
60	30
70	35
80	40

Table 3. Aperture Configuration Factor Equivalent C_1 for Clear Skies

Solar Altitude (deg)	Aperture Azimuth with Respect to the Sun				
	0 deg	45 deg	90 deg	135 deg	180 deg
10	68	65	50	35	32
20	72	67	50	33	28
30	73	70	50	30	27
40	74	69	50	31	26
50	73	68	50	32	27
60	70	66	50	34	30
70	66	62	50	38	34
80	59	56	50	44	41
90	50	50	50	50	50

The C_2 coefficient is determined from the equation:

$$C_2 = \frac{(E_{DH,c} + E_{dH,c})(R_g)(F_g)}{E_{dh,c}} \times 100 \quad , \quad [5]$$

where

$E_{DH,c}$ = direct illuminance on a horizontal plane, clear sky

$E_{dH,c}$ = diffuse illuminance on a horizontal plane, clear sky

R_g = ground reflectivity

F_g = surface-to-ground configuration factor (0.5 for a vertical aperture and 1.0 for a horizontal aperture).

Because the direct plus the diffuse illuminance falling on a horizontal plane equals the total (global) illuminance $E_{GH,c}$ on a horizontal plane, Eq. 5 can be rewritten to reflect a global-to-diffuse ratio (G/d), an average ground reflectivity of 0.2 (20%), and a configuration factor of 0.5 for vertical surfaces:

$$\begin{aligned} C_2 &= (G/d)(0.2)(0.5)(100) \\ &= G/d \times 10 \quad . \end{aligned} \qquad [6]$$

3. Graphical Techniques to Determine the Average Internal Reflectance Component

3.1 BRS Nomograms

BRS nomograms offer a comprehensive method for computing the average IRC in spaces, although their precision is not as great as the equations from which they were derived. Because of their ease of use, the nomograms provide probably the most useful method of calculation for the majority of cases. A BRS nomogram is shown in Fig. 1.

3.2 SERI Clear-Sky Nomograms

The development of clear sky nomograms requires the establishment of local specific illuminance data to calculate the C_1 configuration factor using Eq. 6.

Since daylighting represents an instantaneous use of the available resource, the availability of daylight over the entire day (dawn to dusk) is not as critical as the availability during the operating schedule of the building. Some typical operating schedules, which we call standard work years, are shown in Table 4.

A review of daylighting availability data for 12 standard work years indicates that the G/d ratio for most locales falls between 4:1 and 7:1. Therefore, constructing an IRC nomogram based on 4:1 and 7:1 ratios allows us to calculate the clear sky IRC under varying conditions by interpolating between the scales to determine intermediate values.

The average IRC under a clear sky depends on the orientation of the aperture. Therefore, we have established five (0, 45, 90, 135, 180) clear-sky IRC nomograms for each 10 deg of solar altitude with the exception of a 90-deg angle, for which only one nomogram is needed. This results in a total of 41 nomograms. Figure 2 illustrates a sample nomogram for a solar altitude of 40 deg and an aperture azimuth of 0 deg from the sun.

To determine the IRC_{avg} with the clear sky nomogram, assume that the aperture to total surface area ratio (W:A) is 0.076, the average room reflectivity (R) is 42%, the G/d ratio is 5:1, and the aperture azimuth with respect to the sun is 0 deg for a solar altitude of 40 deg. Mark the W:A on the A scale and the R-value on the B scale. Draw a straight line between A and B, which will pass through the two (4:1 and 7:1) C scales as shown in Fig. 2. The IRC_{avg} from the 4:1 scale is 5.0%, and from the 7:1 scale, 6.5%. Using the straight line, interpolate between these values the IRC_{avg} when the G/d is 5:1, which would be 5.5%.

CONCLUSIONS

The SERI clear sky IRC nomograms provide the lighting designer a simple manual technique to determine the internal reflectance component. The nomograms can be used with the MIT clear sky protractors (3) to determine the daylight factor at any given reference point in a space.

This graphical technique for determining clear sky IRC values is expected to enhance the accuracy of daylighting system design by simplifying the format used in clear sky computations and thereby allowing the lighting design professional to analyze daylighting systems during the earliest phases of the building design process.

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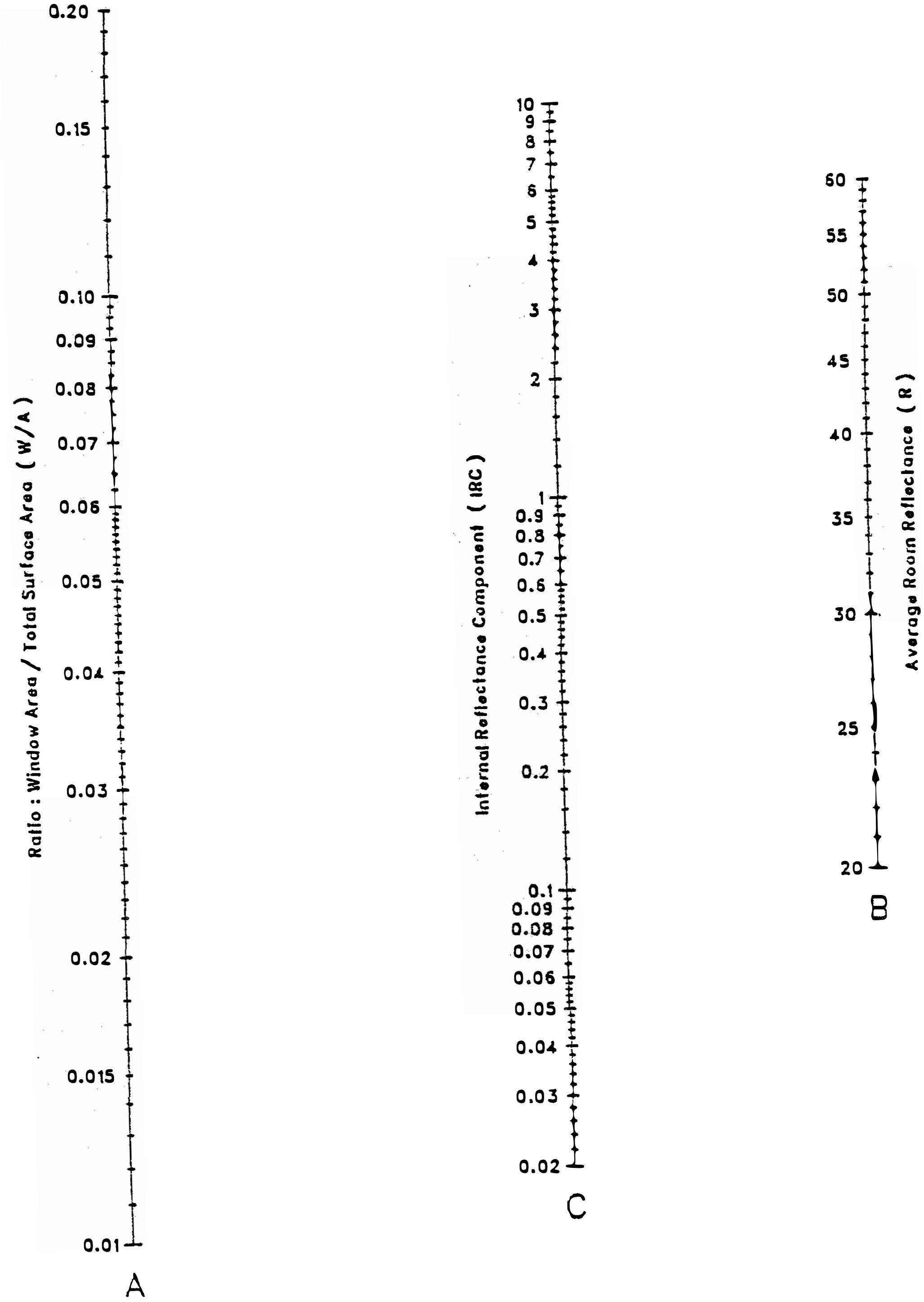

Figure 1. Nomogram for Figuring Average Internally Reflected Component of Daylight Factor

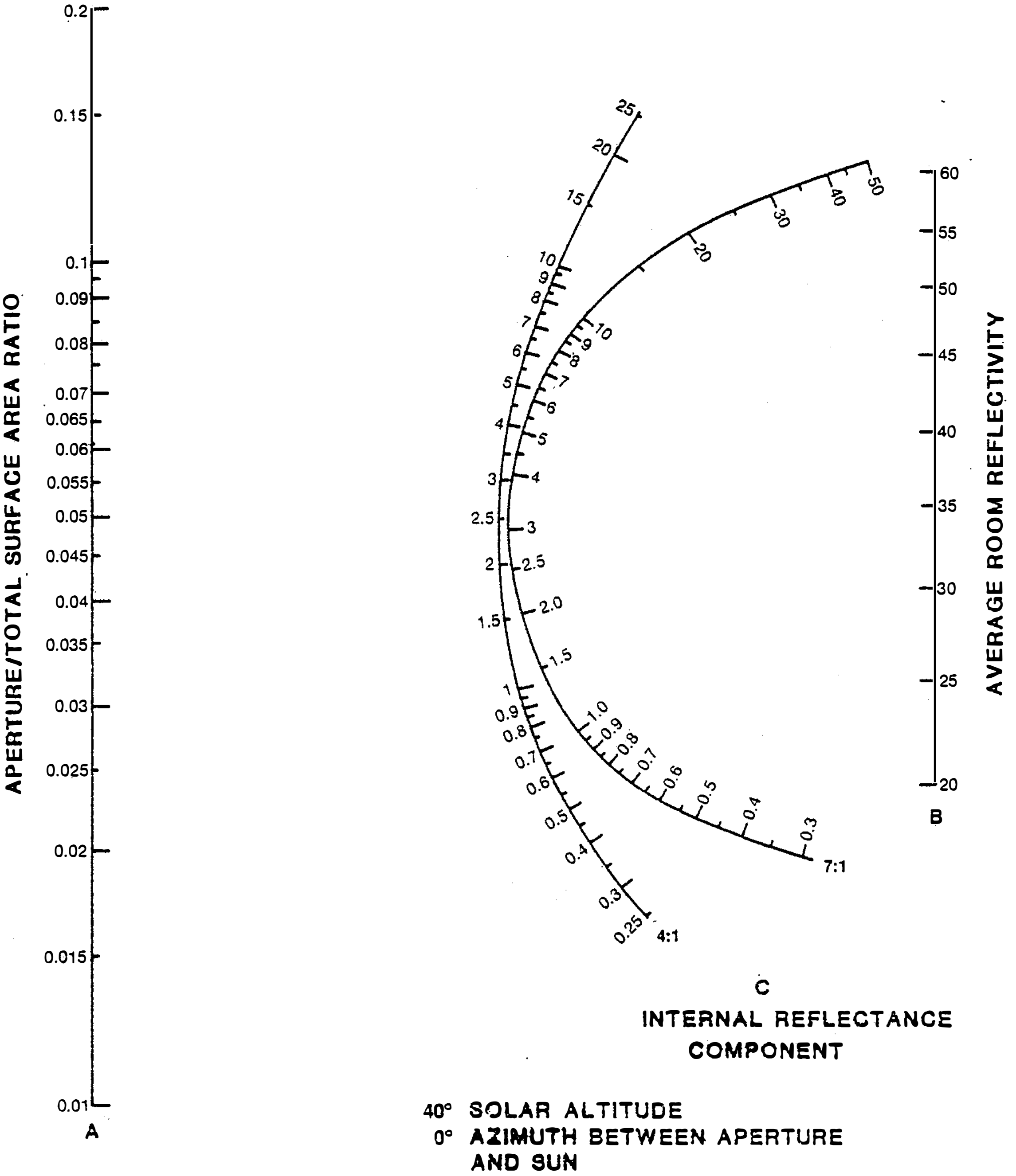

Figure 2. Sample of a Nomogram for Figuring Average Internally Reflected Component of Daylight Factor for Clear Skies

Table 4. Standard Work Years

0700-1600 hours	0800-1600 hours	0900-1600 hours
0700-1700 hours	0800-1700 hours	0900-1700 hours
0700-1800 hours	0800-1800 hours	0900-1800 hours
0700-1900 hours	0800-1900 hours	0900-1900 hours

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