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DEVELOPMENT OF REGRESSION EQUATIONS FOR A DAYLIGHT COEFFICIENT-OF-UTILIZATION MODEL

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ABSTRACT

When hourly energy simulation models are used to predict the performance of multi-zone buildings, they may be required to perform more than 2,000 daylight analyses in a single simulation. The traditional approach is to use a very fast computational model, which of necessity must be a very simple model. Coefficient of utilization models have been widely used as simple design tools but have been severely limited in their applicability to complex and realistic fenestration systems and building designs. This paper present a new coefficient of utilization (CU) model for daylighting that combines the ease of use of CU models with the ability to predict illuminance under a wide range of conditions. The model consists of seven regression equations normalized to exterior vertical surface illuminance. These equations describe daylight illuminance as a function of position in a room and are sensitive to all of the significant design variables. The equations are derived from parametric analysis using a mainframe daylighting computer model (SUPERLITE). We describe how these equations were developed and their physical and theoretical background. Comparisons between direct calculation and CU results for sample rooms are demonstrated.

INTRODUCTION

Daylighting is recognized as an important and useful strategy to reduce electric lighting consumption in commercial buildings. In order to optimize the architectural design and minimize energy costs for a project, it is essential to be able to predict annual lighting energy savings and overall energy effects that result from specific design solutions. Over the years, a variety of lighting design tools has been developed to assess interior daylight levels (1,2,3). However, to properly analyze the complex energy-related effects of daylighting, hour-by-hour energy simulation programs with integrated daylighting models had to be developed.

The development of an illuminance code for use in an hourly energy analysis model is a very difficult task, since the code will be used for each building zone for every daytime hour of the year. The code should be as versatile and flexible as possible to allow modeling of a wide variety of architectural design solutions under a range of exterior sun and sky conditions. Accuracy is a desirable attribute for these calculations, but an attribute that must be balanced by the need for adequate computational speed in order to reduce costs. These costs include not only computational time, but also time for the input requirements for the program and the educational investment necessary on the part of the user to effectively operate the program. Energy simulation tools with daylight illuminance models that enhance accuracy at the expense of computational cost are not likely to find extensive use in design practice.

The addition of a daylighting model to the DOE-2.1 energy analysis program was recently completed (4). The model is integrated into the hour-by-hour load calculation and is sensitive to a wide variety of climatic and building design parameters, while increasing the simulation cost only slightly. The daylight

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illuminance model itself operates as a pre-processor within the DOE-2 program, generating daylight factors for a variety of sun and sky conditions, which are then stored in the program. In the hour-by-hour computational loop, the program interpolates between daylight factors appropriate for the sun and sky characteristics of that hour.

While the overall daylighting package is thus flexible and responsive to realistic building operating conditions, the daylight illuminance calculation is limited to conventional window systems in simple room designs. Now that the overall daylighting model is functioning effectively, we have turned our attention to expanding the daylight illuminance model within DOE-2 to enable prediction of more complex and sophisticated architectural design strategies. The objective of this study is to develop a computationally efficient daylight illuminance model that combines adequate accuracy with the flexibility to model a wide variety of state-of-the-art daylighting design strategies. We expect that this illuminance model could also find many other uses as a stand-alone lighting design tool.

PROPOSED COEFFICIENTS OF UTILIZATION

The existing daylighting model in DOE-2 is an area-source model that calculates the direct illuminance at a task location from each element of the windows in a room; the indirect illuminance at a task location due to interreflections within the room is calculated using the split-flux method. This model works adequately for simple designs but is not readily extendable to more complex architectural designs. Very powerful daylight illuminance models, such as the SUPERLITE program, provide many of the desired capabilities (5). However, they are computationally too complex to use in an hour-by-hour program. Furthermore, even these models will not treat some complex sun shading devices adequately by direct computation.

An alternative calculation approach uses the lumen method, which is the basis for the daylight prediction technique recommended by the Illuminating Engineering Society (IES) (6,7). That approach utilizes a series of precalculated or premeasured coefficients that relate the illuminance at a task location to a normalized source of illuminance at the window location. Multiplying the appropriate coefficients by the window area, window transmittance, and exterior illuminance at the window provides the interior horizontal illuminance at the task location. The coefficients in the IES calculation procedure were developed from a series of extensive artificial sky model studies. A calculation based on the lumen method is very simple, but it becomes cumbersome because of the many tables of data required and because it is not readily extendable to design conditions other than those listed in the tables.

After examining advantages and disadvantages of a number of different approaches, we decided to use a modification of the lumen method. The computational speed of the lumen method calculation was highly desirable, but it would be necessary to develop a more extensive series of coefficients of utilization to make the method more broadly applicable.

Formulation of New Coefficients of Utilization

It is apparent that a unit of flux incident upon the window surface will make a different contribution to interior illuminance levels depending upon the spatial characteristics of the incident flux. Direct sunlight, clear sky conditions, overcast sky conditions, and ground-reflected light would all be expected to produce different illuminance patterns within the space, although for any one light source, the interior illuminance level would be expected to be a linear function of the exterior value.

A large number of design parameters will influence interior daylight illuminance levels. Aperture size, location in the wall, glazing transmittance properties, overhang or shading system effects, and other fenestration-related features will all influence transmitted flux. Room geometry, room reflectances, task location, and other interior design features will influence the distribution the transmitted flux in a space. We therefore decided to analyze the light flux at a particular task location in the space as the sum of light arriving through seven different pathways. Four exterior sources of light are possible: overcast sky diffuse light, clear sky diffuse light, ground-reflected light, and sunlight. The flux from each of these sources can either arrive directly at the task location or be interreflected one or more times in the room before arriving at the task location. The ground-reflected component is an exception, having no direct component but rather being entirely interreflected. There are thus seven illuminance components, each of which will have its own coefficient of utilization of daylight: a direct and an indirect term for overcast sky, clear sky, and sunlight; and a single indirect component for ground-reflected light.

There are several advantages to this formulation. First, all seven terms are additive so that the net result is simply the sum of the component contributions. Second, the direct component terms are primarily a function of fenestration properties, while the indirect terms are largely a function of interior design features. This formulation simplifies what would otherwise be an extremely complex interdependence of each of the coefficients on a very large number of design variables.

The coefficient is defined as the ratio of indoor illuminance component due to an outdoor illumination source (the sun, sky or ground) through a pathway (direct or indirect) to a corresponding reference outdoor illuminance level due to the source on the plane of the window of 100% transmittance. The general form of the coefficients can be expressed as follows:

$$C_{x-y} = \frac{E_{x-y}}{E_{n-x}} \tag{1}$$

where

E_{x-y} = Indoor illuminance due to source x through pathway y
E_{n-x} = Normal illuminance on the window plane due to source x

Thus, for a given window transmittance and outdoor conditions, an indoor illuminance component can be calculated as:

$$E_{x-y} = t_r \cdot E_{n-x} \cdot C_{x-y} \tag{2}$$

where

E_{x-y} = Indoor illuminance due to source x through pathway y
t_r = window transmittance
E_{n-x} = Normal illuminance on the window plane due to source x
C_{x-y} = coefficient of utilization for source x through pathway y

Basing the coefficient on exterior normal surface illuminance is originated by the first principal that indoor illuminance is a function of "the amount of light flux" through an opening. If one thus normalizes an indoor illuminance component by a factor that represents the light flux, the resulting coefficients will approach a constant value over a limited range. Fluctuation of the value in the range is due to factors that were not accounted for in the normalization, such as the sky luminance distribution patterns and interior surface reflectances. The calculation of light flux through an opening involves a series of multiplications of the normal illuminance by the area of glazing by its transmittance. For simplicity, we chose the unobstructed normal illuminances as normalization factors. Figure 1 and 2 show the CIE daylight factor, which is normalized by the horizontal illuminance, and our coefficients of utilization under a variety of sun position, respectively. Here for a given value of distance from the window, the variation of the coefficients with solar altitude is generally much smaller than the corresponding variation in the daylight factors, which implies that the regression of the coefficients of utilization equation can be further simplified.

DEVELOPMENT OF THE COEFFICIENTS OF UTILIZATION

The coefficient-of-utilization functions are developed in two different ways, depending on the complexity of the design.

1. For relatively standard room designs, the coefficient of utilization data are generated using an illuminance model such as SUPERLITE in a parametric series of tests covering the range of desired archi-

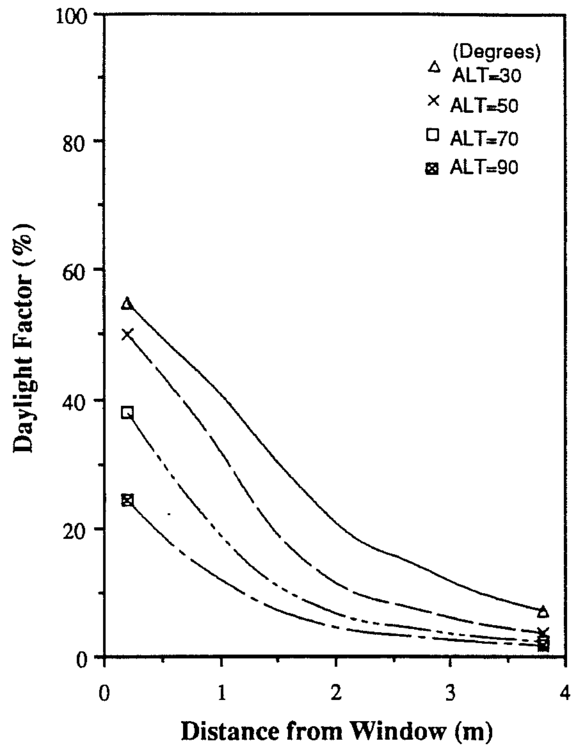


Figure 1. Daylight factors for various solar altitude angles. The solar azimuth angle was held constrant to 0 degrees for all cases.

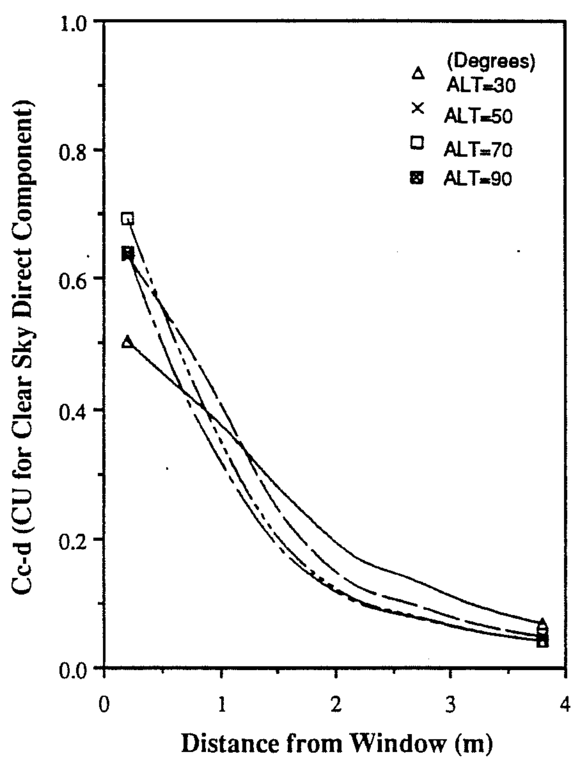


Figure 2. Coefficient of utilization for various solar altitude angles. The solar azimuth angle was held constant to 0 degrees for all cases.

tectural values. These results are then fit into regression equations, which then become the coefficient of utilization functions. The use of such equations as the coefficients of utilization allows us to estimate indoor illuminance levels over a wide range of the design variables included in the equations.

2. The coefficients of utilization for more complex architectural designs are developed using measurements from scale-model studies in a sky simulator. The data from these parametric tests are similarly reduced to a series of regression equations as a function of reference location and other limited parameters.

Procedure for Deriving the CU Regression Equations

Each of the seven coefficients is actually an equation that describes the contribution for that term as a function of depth of the room and any other key design variables. The derivation of each coefficient equation for both standard rooms and complex rooms follows a procedure of three major steps:

Step 1: Generation of Illuminance Component Data. The illuminances on reference locations are broken down into their components. For the overcast sky, indoor illuminance is broken down as:

$$E_o = E_{o-d} + E_{o-id} + E_g \quad (3)$$

where

E_o = total indoor illuminance from overcast sky
E_{o-d} = overcast sky direct component
E_{o-id} = overcast sky indirect component
E_g = ground component

For clear skies:

$$E_c = E_{c-d} + E_{c-id} + E_g + E_{s-d} + E_{s-id} \quad (4)$$

where

E_c = total indoor illuminance from clear sky
E_{c-d} = clear sky direct component
E_{c-id} = clear sky indirect component
E_g = ground component
E_{s-d} = sunlight direct component
E_{s-id} = sunlight indirect component

The normalization factor for each illuminance component is also calculated in this step.

Step 2: CU Data Generation. Each of the seven indoor illuminance components is normalized by dividing by its normalization factor (vertical illuminance from its illumination source). The resulting values are the coefficients of utilization for the components:

$$\begin{aligned} C_{o-d} &= E_{o-d}/E_{n-o} \\ C_{o-id} &= E_{o-id}/E_{n-o} \\ C_{c-d} &= E_{c-d}/E_{n-c} \\ C_{c-id} &= E_{c-id}/E_{n-c} \\ C_g &= E_g/E_{n-g} \\ C_{s-d} &= E_{s-d}/E_{n-s} \\ C_{s-id} &= E_{s-id}/E_{n-s} \end{aligned} \quad (5)$$

where En-g, En-o, En-c, and En-s are the normalization factors for the ground, overcast sky, clear sky, and sun components, respectively.

Step 3: Regression of Data. After calculating the coefficients, a series of coefficients are fitted into proper types of equational forms.

There are essentially two types of regression techniques: linear and nonlinear. The major difference between the techniques concerns the number of regression coefficients in a term. A linear regression technique allows only one coefficient per term, while a nonlinear regression model can employ one or more regression coefficients, which allows higher degree of freedom than a linear regression.

We, however, limited the use of the nonlinear regression technique only in generating the CU regression equations for complex rooms, but not for the standard room, because better regression results can be obtained by first deriving good regressions with a linear regression technique and later giving a greater degree of freedom using a nonlinear regression technique.

DERIVATION OF CU REGRESSION EQUATIONS FOR STANDARD ROOMS

Early in the project, the regression of the CU equations was attempted by entirely mathematical means. Seemingly related variables were thrown into the equations in the form of linear, quadratic, trigonometric, or combinations of those functions; however, it was soon realized that this is very difficult, if not impossible. We encountered uncertainty in designing equational forms to cope with increasing numbers of independent variables, which becomes even more problematic as the number of the variables increase. Furthermore, the derived regression equations that give reasonably good fit become prohibitively long. It is true that any illuminance distribution can be modeled using the sum of a series of functions; however, deriving regression equations through blind trial and error is grossly inefficient.

We thus turned our efforts to deriving principal equations based on their associated fundamental lighting mathematics. It was expected, and proved later experimentally, that this approach not only gives statistically better fits but also allows easy expansion of the regression equations for new independent variables.

The spatial distributions of direct components and indirect components of indoor illuminance are distinctively different. However, the direct components of the overcast sky and clear skies display similar distribution (Figure 3). Likewise, the indirect components from the overcast sky, clear skies, and the sun show similar distributions (Figure 4). The distribution of the ground components differs from other indirect components because the components take different pathway to the workplane from those indirect components. The distribution of the direct components from the sun is unique for several accounts: their distribution and magnitude are determined by solar and building geometries, and the magnitude is a delta or on-off function, i.e., in sunlit areas, the components have a constant value (on), while in shaded areas, zero (off).

Based on these preliminary analyses, the principal forms of the seven regression equations are divided into four groups: (1) direct components from the overcast sky and clear skies; (2) indirect components from the overcast sky, clear skies, a and sun; (3) ground components; and (4) direct components from the sun. The idea of grouping the equations is that once a principal equational form is established for the group, the equation for a specific member of the group can be derived with only minor modifications of the principal form.

Principal Equation 1: Direct Components from Skies

The amount of light directly reaching the workplane from the sky is a function of the solid angle of the windows, the cosine angle of incident light from the source to the workplane, and the luminance intensity of the light source, a window in this case. Recognizing this fundamental principal of light, we initially adapted the sky factor equation in the regression of direct components from the sky, represented as:

$$f_s = c\,[\tan^{-1}(\frac{w}{x}) - \frac{x}{\sqrt{h^2 + x^2}}\tan^{-1}(\frac{w}{\sqrt{h^2 + x^2}})] \qquad (6)$$

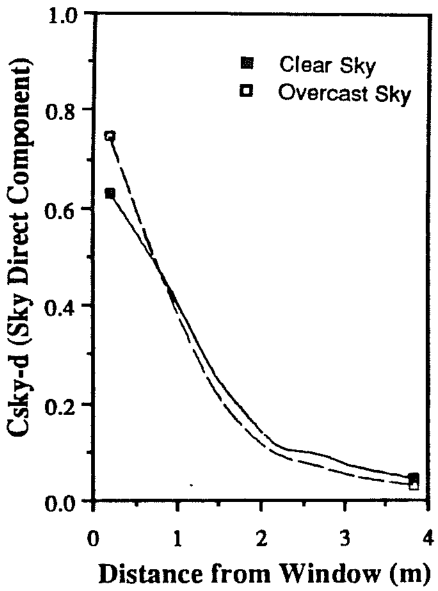


Figure 3. Coefficients of utilization for clerar sky and overcast sky direct components.

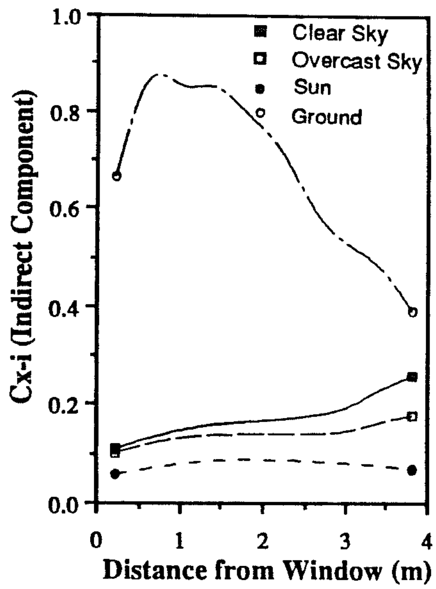


Figure 4. Coefficients of utilization for indirect components (clear sky, overcast sky, sun and ground).

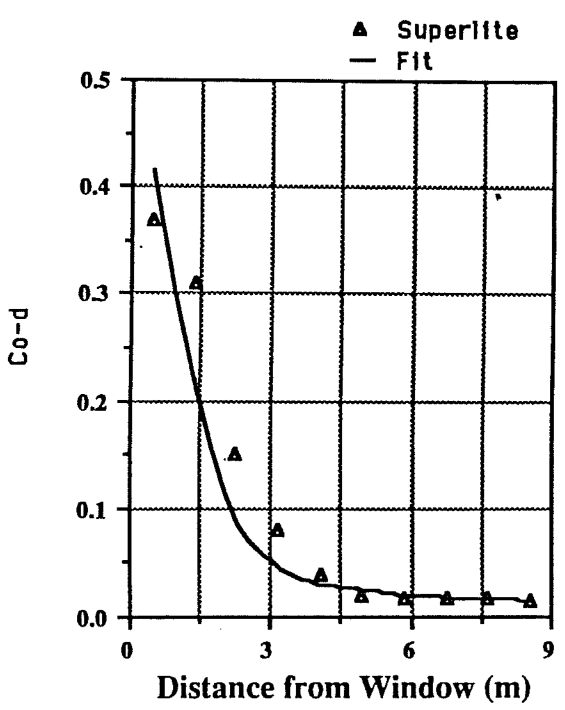


Figure 5. Sample regression of coefficient of utilization for direct components from the overcast sky (Co-d).

where

- f_s = sky factor
- w = window width
- h = window height
- x = distance from window
- c = constant

Equation 6 was originally derived for the uniform sky conditions and for the cases where the height of a reference point is the same as the sill height and the point must be located on the line normally projected from a corner of the window. The expansion of the equation to accommodate the cases where the window is located above the workplane has been carried out by incorporating two additional factors, which are designed to take into account the cosine law of illumination into the equation as:

$$C_d = \tan^{-1}\frac{ww}{x} \cdot (c_1 \cdot R_1 + c_2 \cdot R_2 + c_3 \cdot R_1 \cdot R_2) + c_4 \frac{x^2}{\sqrt{wh^2 + x^2}} \tan^{-1}\frac{ww}{\sqrt{wh^2 + x^2}} \cdot R_1^2 + c_5 \qquad (7)$$

where

ww	= window width
wh	= window height
x	= x coordinate of the location: distance from window
wd	= displacement of reference point measured from an end of window
c_1, c_2, c_3, c_4, and c_5	= regression coefficients

And R_1 and R_2 are defined as:

$$R_1 = \left[\frac{x^2 + (wd - ww/2 - y)^2 + (wh/2 + sh - z)^2}{(x^2 + (ww/2)^2 + (wh/2)^2}\right]^{1/2} \qquad (8)$$

$$R_2 = \frac{wh/2}{wh/2 + sh - z} \qquad (9)$$

where

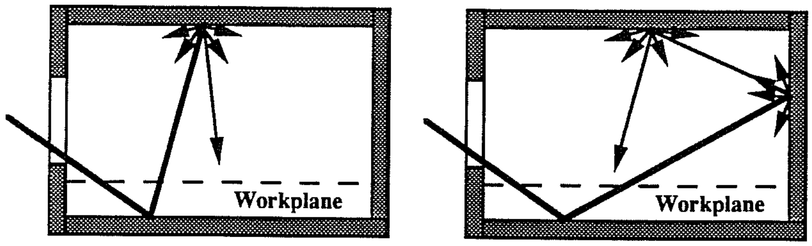
- sh = sill height
- y = y coordinate of the location: distance from wall
- z = z coordinate of the location: height above floor

This expanded form of regression equation was tested for the regression of the overcast sky direct components. Figure 5 demonstrates the sample regression results from the regression tests.

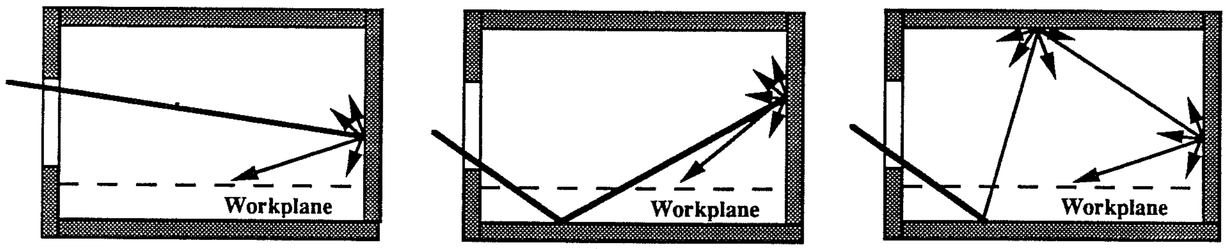
Principal Equation 2: Indirect Components

As in the case of the direct components, regression of the indirect components was initially attempted by entirely mathematical means and this approach was rejected for the same reasons. Instead, we attempted to derive a regression equation by tracing major paths of reflected flux reaching a workplane (see Figure 6). The equations for indirect components from all the light sources, including the sky, ground, and sun, were derived by considering the following phenomena of light flux exchange between surfaces:

1. The amount of flux reflected from a surface reaching a reference location depends on its view factor from the location and the luminance of the reflecting surfaces. The luminance of the surfaces, in turn, depends on surface reflectances and the illuminance falling on the surfaces.



a) Two major paths of reflected light from ceiling



b) Three major paths of reflected light from walls

Figure 6. Major paths of reflected fluxes reaching a workplane: a) two paths of reflected flux from the ceiling, and b) three paths of reflected flux from the walls.

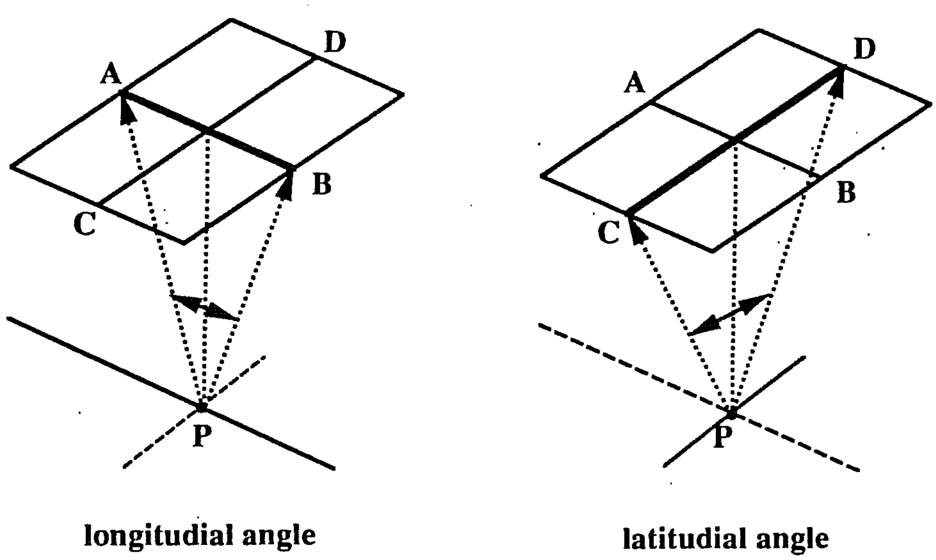


Figure 7. Two (longitudinal and latitudinal) angles for calculating a pseudo view factor.

2. After multiple reflections, final reflected flux arriving on a work plane comes from the visible parts of interior surfaces; for a typical upward-facing horizontal workplane, the ceiling is the single most importance surface, and the wall areas above the work plane also contribute significantly.

The consideration of these paths and attributes of reflected flux in the regression of indirect components was implemented through the following factors.

Pseudo View Factor. The view factor is the most important factor for quantifying the radiation flux exchange between an emitting surface and a receiving surface. The accurate calculation of the view factor requires a complex process of double area integrations over light-emitting surfaces and receiving surfaces. We thus devised a simple term that approximately accounts for the view factor. This term is basically a multiplication of two angles shown in Figure 7 as:

$$F = \theta_\alpha \cdot \theta_\beta / \pi^2 \tag{10}$$

where
θ_α = longitudinal angle
θ_β = latitudinal angle

Reflected Flux from a Ceiling to a Work Plane. Since the ceiling is not in direct line of sight from the sky, the flux emitted from the ceiling is reflected originally from walls, floor, and window. The flux reaching the ceiling from the floor, for example, can be approximated by the luminance of the floor and the ceiling's view factor to the floor. The luminance of the floor is, in turn, approximated by the floor's view factor to the window multiplied by its reflectance. Such reflected flux exchange can be represented as:

$$E_c = F_{p-c} \cdot L_c \tag{11}$$

where
E_c = reflected flux from the ceiling
F_{p-c} = pseudo view factor of the ceiling from a reference point
L_c = luminance of the ceiling

The luminance of the ceiling, L_c, can be approximated as:

$$L_c = r_c \cdot (F_{c-f} \cdot r_f \cdot F_{f-win} + F_{c-w} \cdot r_w \cdot F_{w-win}) \tag{12}$$

where
r_c = ceiling reflectance
F_{c-f} = pseudo view factor of floor from ceiling
r_f = floor reflectance
F_{f-win} = pseudo view factor of window from floor
F_{w-c} = pseudo view factor of wall from ceiling
r_w = wall reflectance
F_{w-win} = pseudo view factor of window from wall

In the above equation, the first term in the parenthesis represents the reflected flux from the floor and the second walls.

Reflected Flux from Walls to Work Plane. Similarly, the reflected flux from the walls that reaches a workplane can be approximated as:

$$E_w = F_{p-w} \cdot L_w \tag{13}$$

where

E_w = reflected flux from the walls
F_{p-w} = pseudo view factor of the walls from a reference point
L_w = luminance of walls

The luminance of the walls is approximated as:

$$L_w = r_w \cdot (F_{w-f} \cdot r_f \cdot F_{f-win} + F_{w-win}) \tag{14}$$

where

r_w = wall reflectance
F_{w-f} = pseudo view factor of floor from walls
r_f = floor reflectance
F_{w-win} = pseudo view factor of window from walls

In Equation 14, the first term in the parenthesis represents the portion of light flux falling on walls that comes from the floor, and the second, the portion from the window.

Finally, based on the relationships in Equations 11 and 13, the form of the principal regression equations for indirect components is represented as:

$$\begin{aligned} C_i = & F_{p-c} \cdot r_c \cdot (c_1 \cdot F_{c-f} \cdot r_f \cdot F_{f-win} + c_2 \cdot F_{c-w} \cdot r_w \cdot F_{w-win}) \\ & + F_{p-w} \cdot r_w \cdot (c_3 \cdot F_{w-f} \cdot r_f \cdot F_{f-win} + c_4 \cdot F_{w-win}) + c_5 \end{aligned} \tag{15}$$

where

C_i = CU for indirect components from skies and the sun
c_1, c_2, c_3, c_4, and c_5 = regression coefficients

Equation 15 was tested in regressing the CU data of a standard room under the overcast sky condition. Figure 8 shows sample regression results.

Principal Equation 3: Ground Component

The regression equation for the ground components has been developed by applying the same principal of path tracing as the indirect components from the skies and the sun. Here, it is considered that the flux originating from the ground that reaches a workplane takes different paths to a workplane from that originating from the sky or the sun. The regression equation for ground components is represented as:

$$\begin{aligned} C_g = & F_{p-c} \cdot r_c \cdot (c_1 \cdot F_{c-win} + c_2 \cdot r_w \cdot F_{w-win}) \\ & + (c_3 \cdot F_{p-w} \cdot r_w \cdot F_{w-win}) + c_4 \end{aligned} \tag{16}$$

where

C_g = coefficient for ground components
r_c = ceiling reflectance
r_f = wall reflectance
c_1, c_2, c_3, and c_4 = regression coefficients

We again tested Equation 16 in regressing the CU data of ground components from a standard room. Figure 9 displays very excellent agreements between CU data and the regression results using Equation 16.

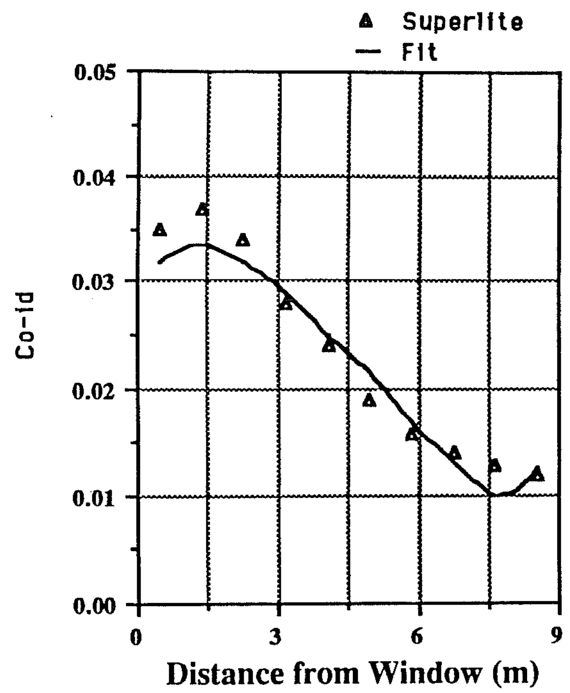


Figure 8. Sample regression of coefficients of utilization for the indirect componets from the overcast sky (Co-id).

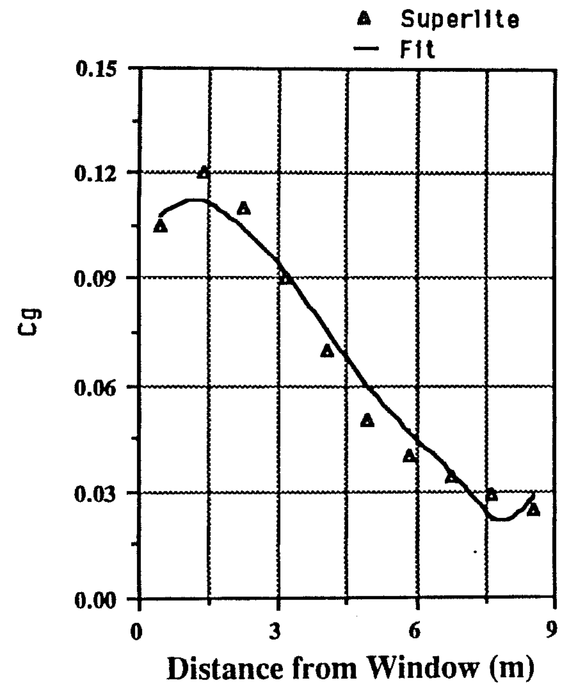


Figure 9. Sample regression coefficients of utilization for the ground-reflected components (Cg).

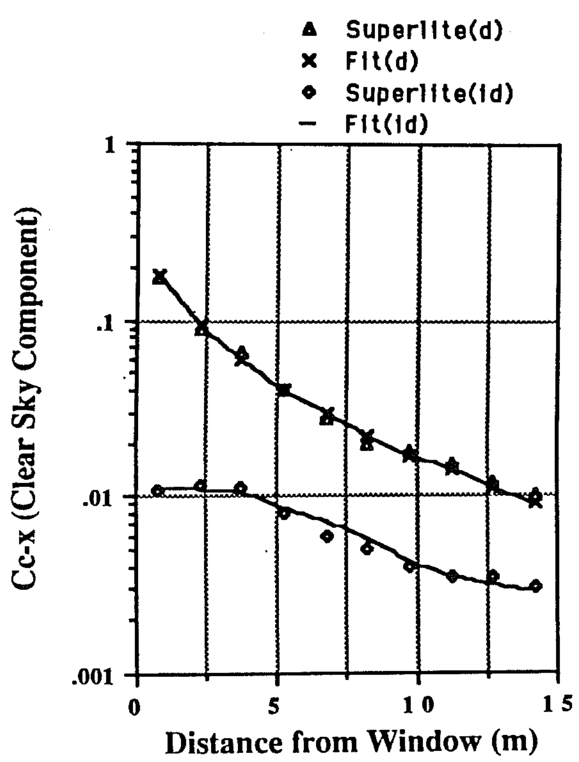


Figure 10. Coefficients of utilization of a room with a light shelf for direct and indirect components from the clear sky.

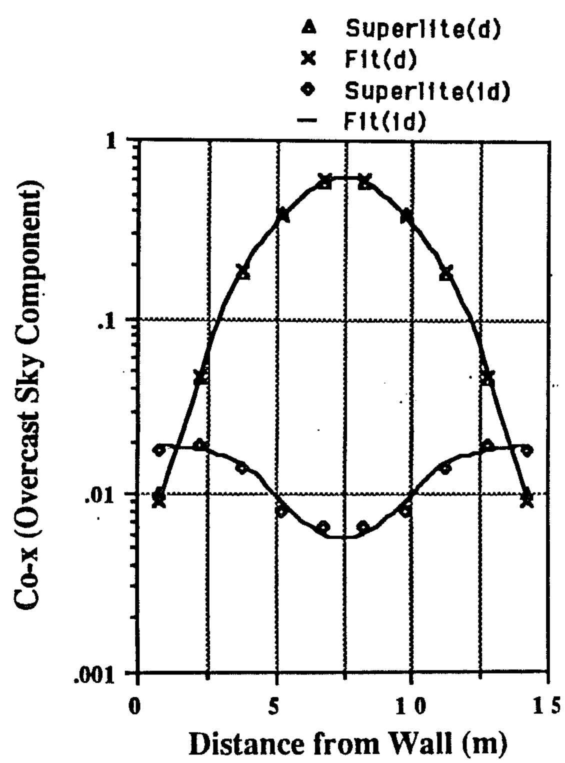


Figure 11. Coefficients of utilization of a room with a skylight for direct and indirect components from the overcast sky.

Principal Equation 4: Direct Component from the Sun

For the case of the clear sky, the direct component from the sun must be considered. This component depends entirely on the geometrical relationships between the sun, the window, and the location of interest and the optical properties of the window (transmittance). Therefore, the coefficient can be derived analytically as:

$$C_{s-d} = 1.018 \sin\alpha \;\; 1 + \cos\alpha \cdot \cos\beta (1 - \cos^2\alpha \cdot \cos^2\beta) \cdot \delta \qquad (17)$$

where

C_{s-d} = coefficient of the direct component from the sun
α = solar altitude angle
δ = 1, if reference location is exposed to direct sun; 0, otherwise

DERIVATION OF CU REGRESSION EQUATIONS FOR COMPLEX ROOMS

The coefficients for more complex architectural designs can be developed using measurements from systematic scale-model studies in a sky simulator. In this paper, however, the sample data for the coefficients were generated from SUPERLITE. The data from these parametric tests are reduced to regression equations. In contrast to the previous standard room case, the data are regressed as a function of only the distance from the window using a nonlinear regression technique.

To experiment with our approach, the regression tests on the CU data for two sample rooms with rather complex architectural design features, were carried out as below one with a light shelf, and another with a skylight.

Room with Light Shelf

Two forms of the regression equations for complex models were developed, one for direct components and another for indirect components. For the direct components from both overcast sky and clear sky, the CU data were fit in an exponential function as:

$$C_{x-d} = \exp(c_1 + c_2 \cdot x) \qquad (18)$$

where x is the distance between the window and a reference point.

For the indirect components, various equational forms were investigated, and the following form was chosen because it can flexibly model various cases of the indirect component:

$$C_{x-id} = x^{c_1} \cdot \exp(c_2 + c_3 \cdot x) \qquad (19)$$

These equational forms proved to be good for modeling various cases. The comparison of coefficients and their regression results are displayed in Figure 10.

Room with a Skylight

For a room with a skylight, slightly modified functional forms were adapted. Thus, for the direct components we can write:

$$C_{x-d} = \exp(c_1 - c_2 \cdot (x-d)^{2.0}) \qquad (20)$$

And for the indirect components:

$$C_{x-id} = c_1 - \exp(c_2 - c_3 \cdot (x-d)^{2.0}) \qquad (21)$$

where

x = distance form the south wall points to reference

d = constant

c_1, c_2 and c_3 = regression coefficients

Figure 11 indicates that we can fit the coefficients from a room of complex geometry with very good fits.

INTEGRATION OF ILLUMINATION MODELS

This coefficient-of-utilization model was designed to be used in the next version of the DOE-2 energy analysis program. The DOE-2 model will provide three pathways for the hourly illuminance calculation. First, if the room design is simple and the windows are not complex, the pre-processor will calculate the coefficient-of-utilization equations directly and then use those equations in the hourly loop in the program. Second, if the architectural design is more complex but standard (e.g., venetian blinds or light shelves), the coefficient-of-utilization equations will have been precalculated (or previously measured) for these devices and stored in a library in the program. The user then simply specifies the devices from within the library, with some interpolation allowed between similar device properties. Finally, if the user desires to model a unique architectural solution for which precalculated values are not available, instructions will be provided to develop the coefficient from the user's own model tests. These coefficient equations can then be loaded into the DOE-2 program and used directly as user-input values. In principal this approach provides great flexibility and versatility because it should be able to model virtually any design for which the basic performance data can be generated.

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