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Development of Atrium Daylighting Prediction: From an Algorithm to a Design Tool

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Introduction

Daylighting prediction tools in atria

The atrium has become a popular architectural feature in buildings. An atrium provides high marketing value, an environmentally controlled space, natural lighting, and shelter from rain, snow, and wind.[1,2] Daylighting represents one of the most aesthetic values of an atrium. However, today's atria are found in continuous need of artificial lighting, or are overlit with excessive solar gains.[3,4] This is due to a lack of daylighting prediction tools, which would allow designers to determine at the preliminary design stage the optimal transmittance for daylighting.

Most daylighting calculations do not work well for atrium buildings. The approaches for daylight modeling differ from one program to another, according to the program's level of sophistication, and in the degree to which daylight modeling is implemented into the thermal and solar gain simulations.[5] Although computer-based tools were developed for daylighting alternatives, the materials available to designers have not fundamentally changed. At present, the most popular method is the physical scale model. Artificial sky facilities are also available in many research and educational institutions.[6-8]

Previously validated atrium daylighting algorithm

A preliminary atrium daylighting algorithm was developed for clear and overcast sky conditions using physical modeling in an artificial sky. **Figure 1** shows the daylight factor (DF) at the center of the atrium floor as a function of the well index, and can be expressed as follows:[9]

$$\mathrm{DF(center)} = 117 \times \mathrm{T} \times e^{-.99}\ (\mathrm{WI}) \qquad (1)$$

where DF = daylight factor at the center of the atrium floor

T = transmittance of fenestration system

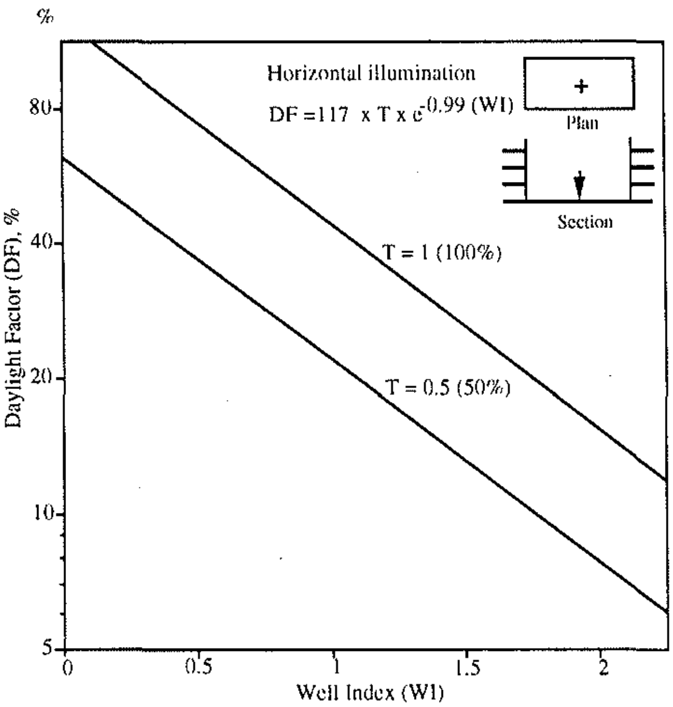

Figure 1—Daylight distribution (DF at the center) on top-lit atrium floor

$$\mathrm{WI} = \text{well index} = \frac{\text{height} \times (\text{length} + \text{width})}{2 \times \text{length} \times \text{width}} \qquad (2)$$

The algorithm in **Equation 1** was validated by measurements in several real, four-sided atria, up to eight stories high.[10] This algorithm applies to a four-sided atrium, and was developed only for planar walls with a fixed reflectance of 30 percent. Therefore, it does not take into account different wall configurations or reflectances. It is limited only to the prediction of the DF at the center of the floor, rather than an indicator of the overall daylight distribution. Finally, it is important to transform any daylighting algorithm into a design tool to be used at the preliminary stage of design.

Objectives

The objectives of this study are to extend the daylighting prediction algorithm to include atrium

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wall configuration and reflectance, and to determine the applications of the daylighting algorithm as a design tool for choosing optimal fenestration and wall configuration for daylighting.

Method

Procedure

Illuminance measurements were collected in physical scale models in a sky simulator. The scale of the foam core models was 1 to 24. Black foam core sheets were added to the perimeter of the physical models (around the adjacent spaces) to block the penetration of light from the sides of the atrium. The reflectance of the floor was 20 percent. View ports were used for the sensor probe and other types of evaluation. Illumination levels were collected using an illuminance data acquisition system, where each sensor has a unique calibration factor stored in the program disk.

Description of artificial sky

The daylighting experiment was performed in the sky simulator of Texas A&M University. The facility consists of a dome 8.5 m (28 ft) in diameter with a clear height of 3.7 m (12 ft). Interior lighting is provided by two separately switched perimeter bands of twin 122 cm (48 inch) power groove fluorescent lamps and four stations of two 38 cm (15 inch) long, high intensity discharge (HID) lamps, each individually controlled. The fluorescent lamps are fixed and the HID lamps rotate.[10]

Luminance distribution and sky conditions

Measurements were taken for clear sky with no sun and completely overcast sky. In order to develop rules of thumb that account for average annual sky illuminance (between clear with sun and completely overcast), only results with the clear-sky component are reported in this paper. The luminance distribution of the overcast sky followed the mathematical model of Moon-Spencer, which has been adopted by the CIE and is commonly used to represent an overcast sky.[11] For the clear sky with no sun the settings in the sky simulator were set according to the other widely accepted luminance distribution for clear sky, i.e., a horizontal luminance that is three times that of the zenith.[12] Sky conditions are defined according to the sky ratio method or the sky cover method.[11]

Atrium physical parameters

Variations for the atrium physical parameters included geometry, top glazing, and atrium walls. Illuminance measurements were collected in four four-sided atrium types: two-story linear atrium (well index of 0.5), two-story square atrium (well index of 0.75), four-story linear atrium (well index of 0.9), and four-story square atrium (well index of 1.35). **Figure 2** shows a schematic description of these generic atria. **Table 1** shows the section aspect ration (SAR), plan aspect ratio (PAR), and the well index of these atrium types.

Variations in the top glazing included configuration and projected area of the glazing. Two types of top glazing were investigated: horizontal and tilted south-facing (45 degrees). The top-glazing openings run along the length of the atrium. The widths of all atria were constant 12 m (40 ft) and were divided into eight parts, each 1.5 m (5 ft) wide. The area of the top glazing was varied by blocking one or more openings. This produced four areas of 38, 50, 75, and 100 percent of the total horizontal projected area. **Figure 3** shows the different alternatives for the south-facing top-glazing areas. By analogy, the same distribution was used for the horizontal glazing, using the same percentage.

Variations in the atrium walls included opaque-to-total area ratio and reflectance. Two different opaque-to-total area ratios were considered for each type of atria: 30 and 60 percent. **Figure 4** shows a sample distribution of these areas for the square atrium. The reflectance of the solid area was varied three times: 25, 40, and 90 percent.

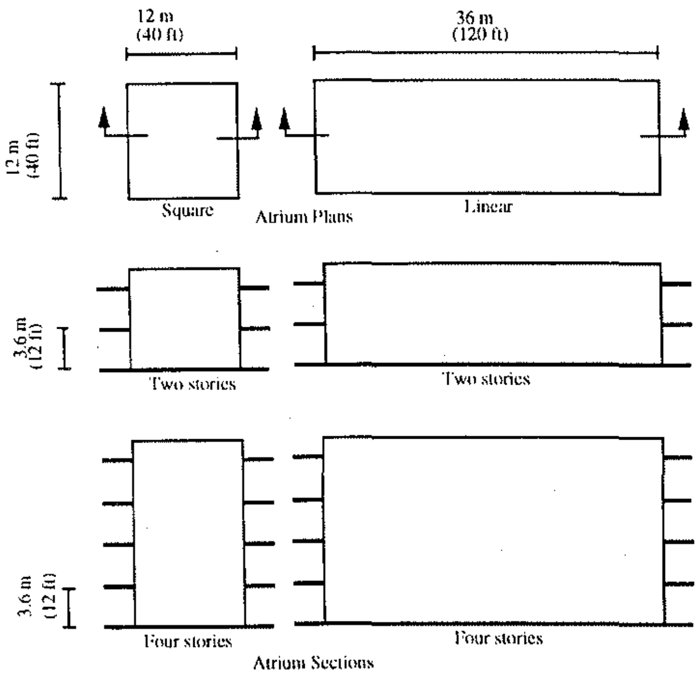

Figure 2—Dimensions of the generic shapes of atria for the daylighting experiment

Table 1—Dimension and proportion indexes of the four atria

Geometry	Number of stories	Height (m)	Width (m)	Length (m)	SAR index	PAR	Well
Square	2	9.1	12.2	12.2	0.75	1.0	0.75
	4	16.4	12.2	12.2	1.35	1.0	1.35
Linear	2	9.1	12.2	36.6	0.75	0.33	0.5
	4	14.4	12.2	36.6	1.35	0.33	0.9

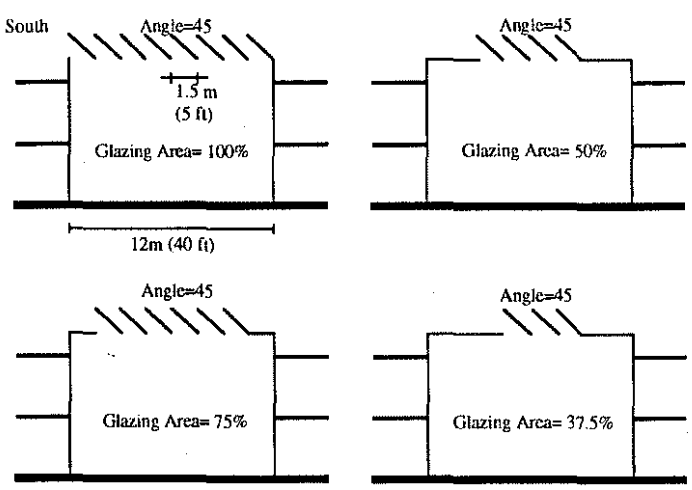

Figure 3—Different alternatives for the top-glazing area

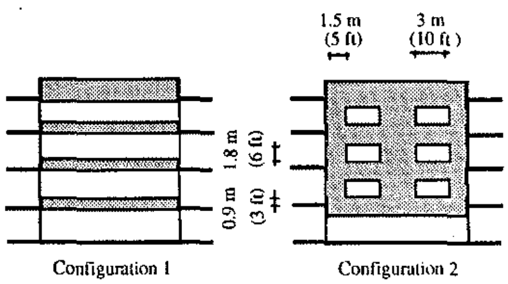

Figure 4—Schematic description of mass distributor for the square atria

Test points

Horizontal illuminance measurements were also taken in the physical models for the selected tests. Nine horizontal test points were selected through a grid of 6 by 6 m (20 by 20 ft) for the square atria and through a grid of 6 by 18 m (20 by 60 ft) for the linear atria. Horizontal measurements were taken at a workplane height of 0.75 m (2.5 ft) above the floor. Vertical measurements (i.e., on a vertical plane) were taken at the same workplane height but are not reported in this paper. The daylighting experiment included more than 120 tests. Each test included either 17 test points for the four-story atrium, or 13 for the two-story atrium.

Data analysis tools

The average DF at the atrium floor was used as the main index for results and analysis. The average DF at the atrium floor was the average of the DF's of all nine point measurements at the atrium floor. The transmittance of each top fenestration was calculated as the ratio of the average horizontal illumination measurement just below the top fenestration to the horizontal "outdoor" illumination (measured in the sky simulator). This transmittance, as described in the *IESNA Lighting Handbook* Eighth Edition, accounts for the overall configuration of each atrium cover component. It should not be confused with the transmittance of the glass or with the transmittance of the glazed area alone.

The variations in the atrium walls (i.e., the solid area and its reflectance) were combined as one index called the effective reflectance. The effective reflectance was calculated as an area-weighted value. **Table 2** shows the different values of the effective reflectance.

Results and discussion

Table 3 shows the value of the transmittance for the

Table 2—Calculated effective reflectance of the internal atrium walls (percent)

Type of atria	Solid area walls (percent)	Reflectance of solid area atria of the walls (percent)		
		25	40	90
Two-story square	60.0	21.0	not tested	not tested
	30.0	18.0	not tested	not tested
Four-story square	66.7	20.8	31.7	65.0
	27.8	17.8	22.0	35.0
Two-story linear	60.0	21.0	34.0	64.0
	30.0	18.0	not tested	not tested
Four-story linear	66.7	20.8	31.7	65.0
	27.8	17.8	not tested	not tested

Table 3—Measured overall transmittance for different top-fenestration types under diffuse sky (percent)

Top-glazing area (percentage of projected roof area)	Atrium type	Horizontal top glazing	Vertical south facing top glazing
100.0	Linear	85.0	30.0
	Square	86.0	29.0
50.0	Linear	not tested	18.0
	Square	not tested	19.0
37.5	Linear	37.0	15.0
	Square	36.0	14.0

different top-fenestration systems. The transmittance of the top fenestrations tested varied from 14.0 percent (tilted south-facing with an area 37.5 percent of the total projected roof area) to 86.0 percent (horizontal with an area 100 percent of the total projected roof area).

A comprehensive daylighting prediction algorithm was developed based on the data listed above, and on the previously validated algorithm of **Equation 1**. The latter daylighting prediction tool did not include any physical characteristics of the atrium walls, except to assume a fixed effective reflectance of 30 percent.

Average horizontal DF and transmittance—The average horizontal DF was plotted in **Figure 5** against the transmittance for given well index and effective reflectance for well indexes of 0.9 and 1.35 for four-story atria. For a given effective reflectance the average horizontal DF was linearly proportional to the transmittance. This was in agreement with the algorithm in **Equation 1**. Therefore, the average horizontal DF can be expressed as follows:

$$HDF = A \times T \tag{3}$$

where HDF = the average horizontal DF at the atrium floor, in percent

T = the top-fenestration system transmittance

A = a mathematical expression that is a function of the well index and the effective reflectance

The lowest R-square obtained with the linear regression was about 95 percent. As expected, the curves converge to zero: with a null transmittance there is no light penetration.

Average horizontal DF and effective reflectance—The average horizontal DF was not linearly proportional to the effective reflectance of the atrium walls. The best fit was obtained with exponential curves. The average horizontal DF was plotted against the effective reflectance of the atrium walls. **Figures 6** and **7** show

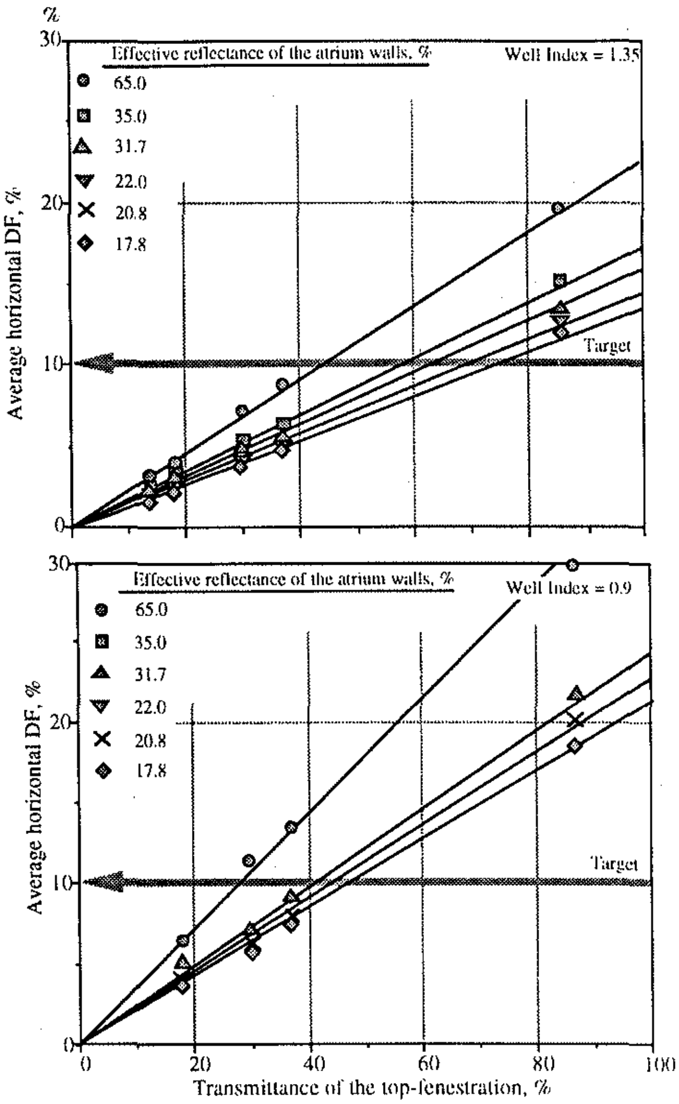

Figure 5—Average horizontal DF at the atrium floor as a function of the transmittance for different effective reflectance values

examples of these plots for well indexes of 1.35 and 0.9 respectively. Both figures show that data for each transmittance fit parallel exponential curves with an R-square of about 95 percent. This indicates that **Equation 3** can be transformed as follows:

$$HDF = B \times T \times e^{ER} \tag{4}$$

where ER = the effective reflectance of the atrium walls, including both the solid area and its reflectance

B = a mathematical expression that is a function of the well index

Average horizontal DF and the well index— **Equation 1** shows that the DF at the center is a function of the inverse of the exponential of the well index.[8] The average DF for the measured data verified this rela-

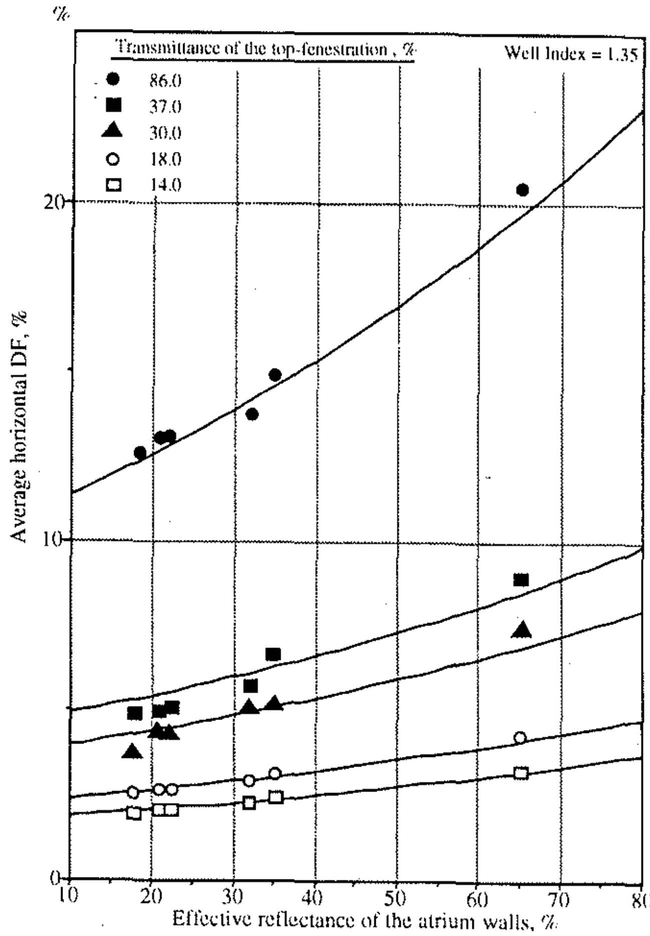

Figure 6—Curve fit of the average horizontal DF as a function of the effective reflectance in four-story square atria under clear diffuse sky

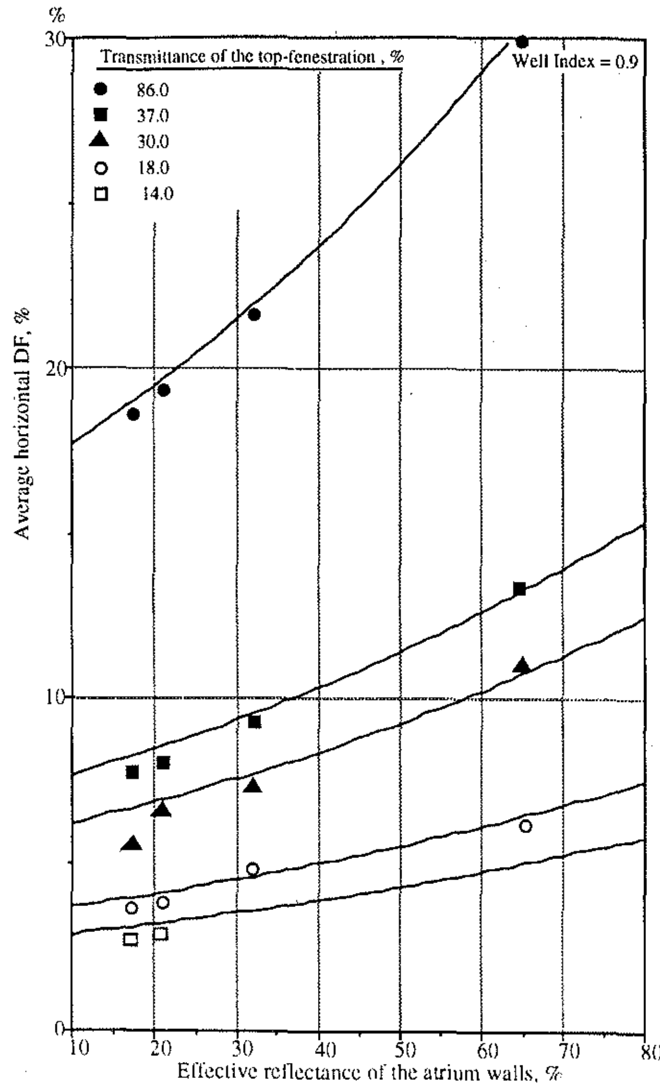

Figure 7—Curve fit of the average horizontal DF as a function of the effective reflectance in four-story linear atria under clear diffuse sky

tionship as well. **Figure 8** shows the average horizontal DF, in logarithmic scale, plotted against the well index as a function of the overall transmittance and effective reflectance. It shows that all average DF curves fit parallel lines and suggest that **Equation 4** can be transformed as follows:

$$HDF = C \times T \times e^{ER} \times e^{-WI} \quad (5)$$

where WI = the well index
C = a constant

The linear regression shown in **Figure 8**, defined the constant C as equal to 46.0. Therefore, the new daylighting algorithm can be expressed as follows:

$$HDF = 46 \times T \times e^{(-WI + ER)} \quad (6)$$

where HDF = the average horizontal DF on the atrium floor, in percent

T = the top-fenestration transmittance
ER = the effective reflectance of the atrium walls
WI = the well index of the atrium

Comparison with the previous algorithm

The validated algorithm in **Equation 1** was determined by a daylighting experiment with internal atrium walls simulated by a solid surface (no openings) with a nominal reflectance of 30 percent. The same material reflectance measured by the authors with a more accurate lightmeter was 34 percent. For a comparison between the previous and extended algorithms, it was essential to make some interpolations. First, the value of the effective reflectance simulated in the previous algorithm (34 percent) was substituted in **Equation 6**. Second, the average DF was

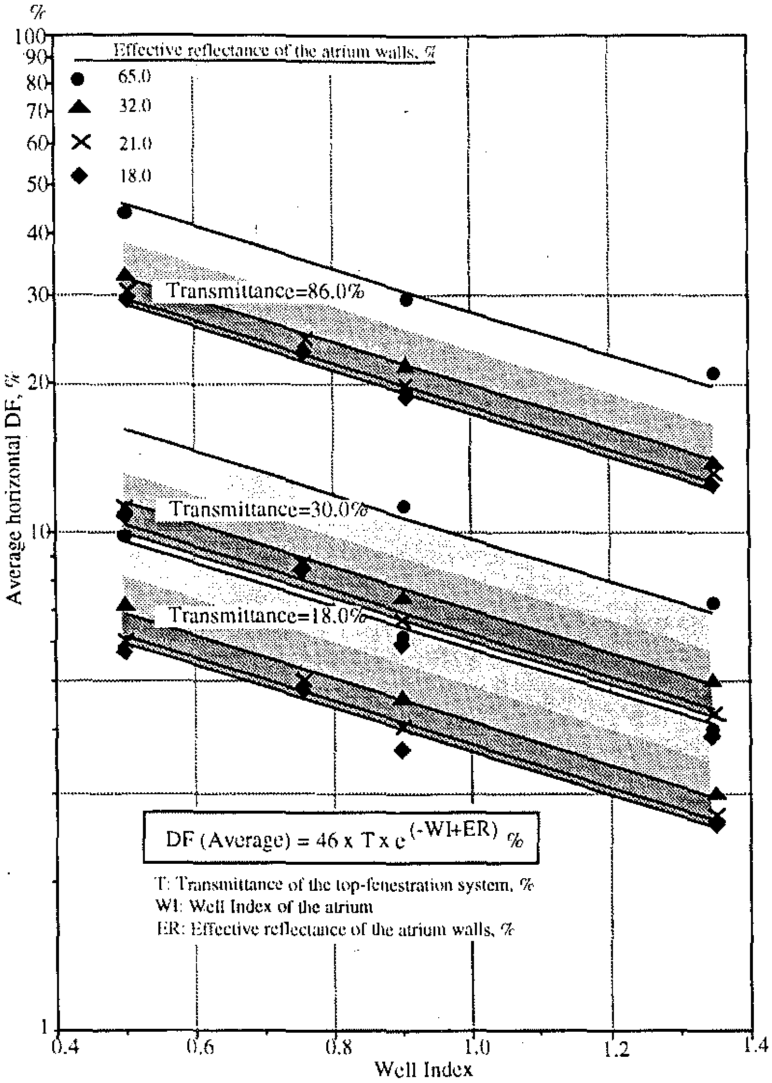

Figure 8—Daylighting prediction at the atrium floor under diffuse sky as a function of the well index, transmittance, and the effective reflectance of the atrium walls

substituted by the DF at the center, taking into account that the measured DF at the center was about 1.3 to 1.7 times that of the average. This estimation was based on measurements on the atrium floor, one of which was located at the center of the floor. This is because the previously validated algorithm was based on the DF at the center of the atrium floor rather the average. Therefore, the DF (at the center) in **Equation 6** would range between the two following equations:

$$DF(center) = 1.3 \times [46 \times T \times e^{(-WI+ER)}] = 87 \times T \times e^{-WI} \quad (7)$$

$$DF(center) = 1.7 \times [46 \times T \times e^{(-WI+ER)}] = 111 \times T \times e^{-WI} \quad (8)$$

The DF in **Equation 1** is slightly higher than that with the new algorithm. For a well index of 1 and an average transmittance of 50 percent, the DF at the center with the new algorithm would range between 16.0 and 20.4 percent, compared to 21.7 percent with the previous algorithm.

Discussion

The comparison between the two algorithms was based upon the effective reflectance of 34 percent. The algorithm that was restricted to the reflectance of 30 percent was developed using a single solid surface all over the atrium walls. However, data for the newly developed algorithm were collected in atria in which the walls of the first floor where glazing was simulated with a 15 percent reflectance. Therefore, reflected or direct light reaching the walls of the first floor is mostly absorbed, and only a slight amount is reflected onto the atrium floor. This explains to a great deal the small discrepancy between the two algorithms.

While the previous algorithm is a useful tool as a rule of thumb for daylighting prediction at the preliminary design stage, it does not take into account the relationship between the open and solid areas of the atrium walls. Logically, the first floor should have more openings since it receives the least amount of daylight and is the main connection between the atrium floor and occupied spaces. The newly developed algorithm was based upon two of the most common ratios of solid to open area of atrium walls. Furthermore, the DF at the center is greatly affected by not only the transmittance, but by the orientation of the top fenestration. The average DF is a much better evaluation tool because it reflects minimum, median, and maximum illumination levels at the atrium floor. It is important to note that the effect of the reflectance has been tested for diffuse light. The effect of reflectance on indoor illumination levels under diffuse light was reported lower than that under sunlight at high altitude.[3] Glazing can also contribute to specular light distribution.

Application

The algorithm developed in this study was represented into a graphical form to include the ratio of the top-fenestration transmittance to the solid fraction of atrium walls (R) (for a given reflectance) as a dimensionless index for daylighting prediction. First, R is more useful for design because it deals with dimensions of atrium physical parameters. Second, R defines the two major atrium physical parameters that affect the trade-off between daylighting and thermal performance. **Figures 9** and **10** show the average horizontal DF prediction at the atrium floor as a function of the ratio R for different reflectance values.

For daylighting prediction, the ratio has always

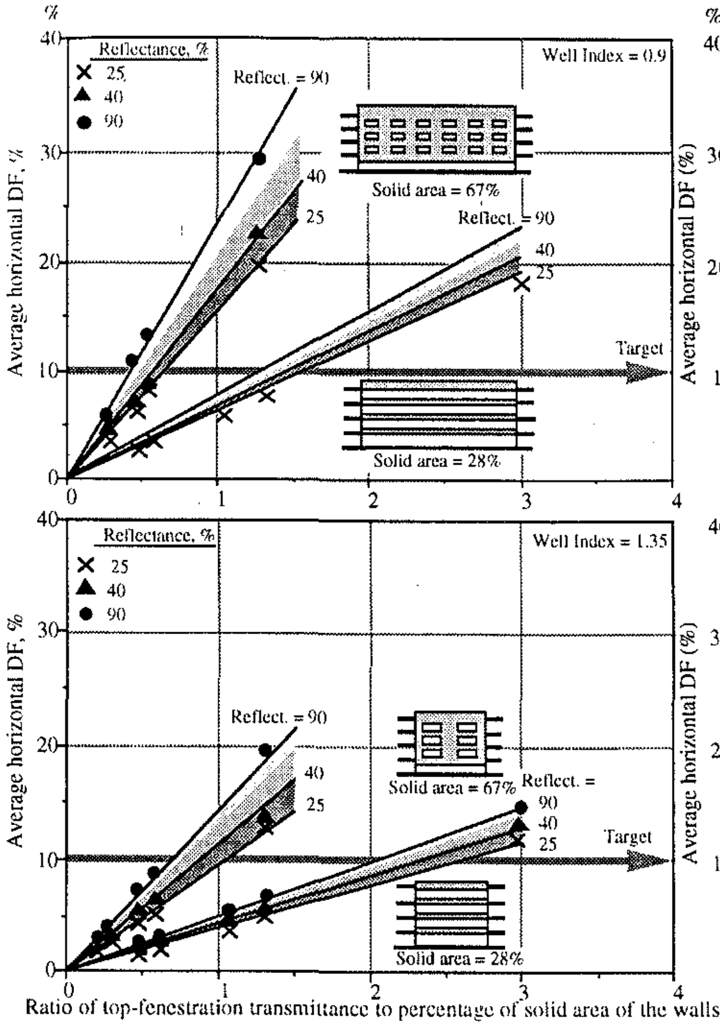

Figure 9—Daylighting prediction at the atrium floor of four-story, four-sided atria as a function of the ratio of transmittance to solid area of the atrium walls

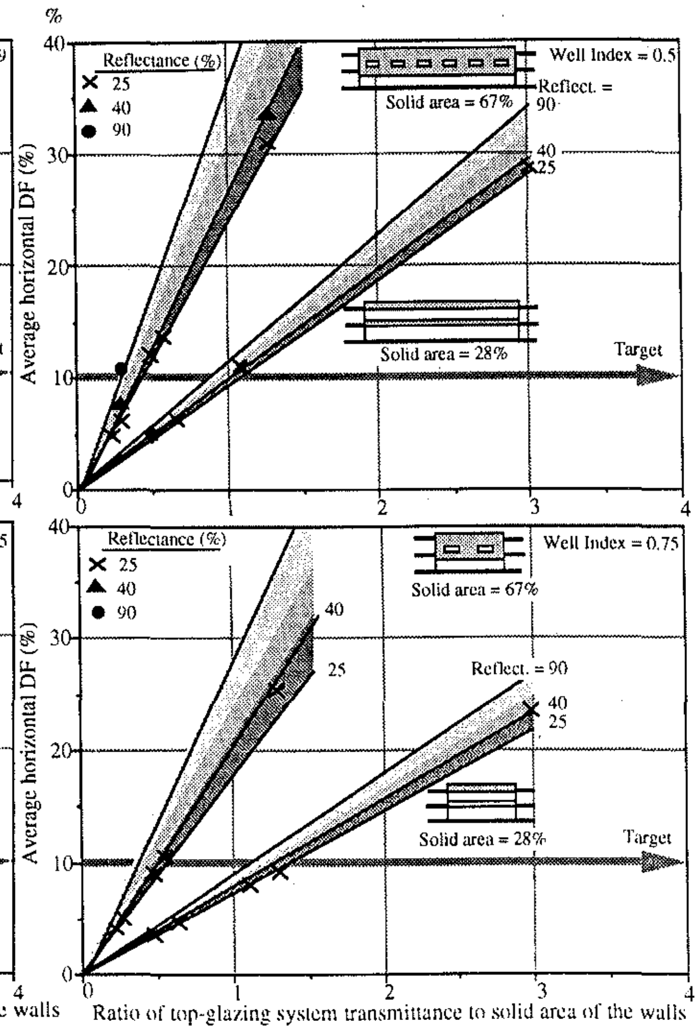

Figure 10—Daylighting prediction at the atrium floor of two-story, four-sided atria as a function of the ratio of transmittance to solid area of the atrium walls

been accompanied by the percentage of solid area on the atrium walls and its reflectance. For every R value, many combinations of transmittance and internal wall treatment can be fabricated to provide different values of average DF. The reader is invited to use the extended daylighting prediction algorithm in **Equation 6** to extrapolate any reflectance of solid wall area falling within the range of the values studied. These two wall treatments represent two common extreme designs. Furthermore, other R values falling within the range of variables studied can be extrapolated.

Optimal transmittance for daylighting

The algorithm also can be used to determine the optimal transmittance for effective daylighting. The optimal top-fenestration transmittance for effective daylighting cannot be defined independently of the reflective and surface characteristics of the internal walls. An increase of the area of the atrium walls provides more surfaces to reflect light downward.

Optimal top-fenestration transmittance for lighting criteria at the atrium floor can be derived from the algorithm as a function of solid wall area and its reflectance. These optimal combinations are shown in **Table 4**, and are based on minimum illuminance for plants of 1,000 lx (92 fc).[13] For a typical average outdoor horizontal illuminance of 10,870 lx (1000 fc), this typical example provides an average horizontal DF target of about 10 percent. **Table 4** can help designers choose their optimal design combinations of top fenestration and wall treatments to achieve target lighting criteria at the atrium floor. It is important to note that above the well index of 1, the lowest optimal transmittance is around 30 percent (e.g., transmittance of vertical, south-facing, top-glazing system with an area of 100 percent of total projected area). This

Table 4—Optimal top-fenestration transmittance for effective daylighting at the atrium floor under diffuse sky (percent)

Well Index	Percentage of solid area in the atrium walls					
	67			28		
	Reflectance (percent)			Reflectance (percent)		
	25	40	90	25	40	90
0.5	30	27	17	31	28	25
0.75	34	30	20	38	35	32
0.9	44	37	27	45	42	38
1.35	67	57	45	70	65	58

result agrees with daylighting measurements on the Dallas City Hall building, which has a vaulted vertical top-glazing facing north on the top of a linear atrium. This atrium, with a well index higher than 1, was in continuous need of artificial lighting despite side lighting at the first floor.

Conclusion and recommendations

The previously validated atrium daylighting prediction algorithm was extended to include wall treatment such as solid area and its reflectance. The algorithm can be used to define the optimal transmittance for daylighting as a function of the effective reflectance of the atrium walls. The algorithm was also transformed into a graphical design tool. The study applies to clear sky with no sun only due to the absence of an appropriate evaluation index for sunny conditions. However, this represents an average sky illuminance and can be considered an appropriate design tool. The study excludes other lighting effects associated with selection of the atrium physical parameters, such as daylighting distribution and lighting contribution on the atrium floor. The algorithm also needs to be tested for atria taller than those tested in this study.

The recommendations pertaining to the optimal combination of the components of the entire atrium perimeter cannot be stated without taking into account other architectural priorities such as glare, functional requirements, and so on. The first pertinent concern in daylighting an atrium is to determine the daylighting "task" of the space, i.e., whether the atrium daylighting role is restricted to the atrium floor only, the occupied spaces, or both. This basically determines the overall transmittance as well as the configuration of its walls. The second concern is to determine the light distribution targeted at the atrium floor and walls: uniform or light-and-shadow play. This should determine the desired configuration of the top fenestration and the amount of solid area on the walls and its reflectance. Finally, data and design tools in this study contribute to the design choices and sizing of the physical parameters in an atrium design.

There are several design options that compromise between daylight at the atrium floor and daylight contribution in the adjacent occupied spaces. The first option includes an uneven vertical distribution of the solid area in the atrium, the maximum proportion being at the top. Upper floors of atria need less openings because they receive more direct light. Furthermore, a solid area on the upper floors is likely to receive light that is either direct or has been reflected only a few times, thus increasing the amount of light reflected downward. This solution is more important for taller and narrower atria.

The second design solution would be to use reflective elements, such as fins and lightshelves, that would free the facades and still reflect light to the sides and the corners of the atrium floor. This would eventually increase the uniformity of light distribution at the atrium floor. These fins and lightshelves should be combined with solid area at the perimeter, otherwise their size would intervene with functional requirements of the atrium floor. The third choice would be to use stepped-down atria to allow lower floors to receive more direct light. This solution may be inappropriate because it increases the depth of lower floors.

Acknowledgments

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Discussion

I believe that your simplified tool provides useful preliminary design information on top-glazing system transmittance, atrium wall effective reflectance, and average daylight factor on the atrium floor. However, as you mention in your conclusion, there are numerous other factors, such as the adjacent space requirements, glare, and the very significant thermal impact, that must be taken into account. How does your tool best fit into the preliminary design stage with regard to these other design decisions? Is it really useful after choices related to these other decisions have been made?

Your scale model uses black foam core in place of glass in the atrium walls. How much impact on average illuminance at the atrium floor, will specularly reflective glass have?

I would be interested in hearing more details on the top-glazing systems modeled. Is the glazing diffusing or clear, and what is its visible transmittance? What is the configuration of the tilted south-facing system, is it sawtooth with opaque north-facing facades?

Last, is it really your premise that only the overall system's transmittance is significant, and that the specific configuration of the system is immaterial? If you are designing only for average sky illuminance (i.e., diffuse light), it would seem more appropriate in many climates to recommend north-facing glazing to reduce glare and solar heat gain from direct sunlight.

R. Hitchcock
Lawrence Berkeley Laboratory

I believe that in the development of a daylighting prediction tools even at early phases in the design process, direct sunlight should be considered. Direct sunlight is a very important component of daylighting and its interaction with the structure makes a great contribution to the qualitative and quantitative characteristics of the building. The sun is about five to seven times brighter than the sky; therefore it constitutes an important contribution to the illumination of an interior space, such as an atrium. The authors have simulated a 45-degree south-facing glazing with a 37–100 percent opening that allows sunlight in the atrium during several months of the year depending on the buildng location. This incoming sunlight increases the illumination in the atrium, but was not considered by the authors. In my opinion, the contribution of the sky as well as the sun should be included in this prediction tool.

The authors do not mention how they have validated their daylighting algorithms. I recommend that they compare their findings to results obtained with daylighting computer programs such as RADIANCE or SUPERLITE. To illustrate the usefulness of the authors' design tool, I ask them to present an example of how a designer can use such a tool in a real design situation.

I conclude by recommending to the authors the use of other reliable simulation tools that offer the advantage of modeling different sky distributions and sun positions so that annual daylight performance data can be assessed. I also recommend that they take into account the interaction of daylighting with other performance variables, such as thermal loads and occupants' comfort, and make the designers aware of the strong interactions among them and how they affect overall building performance.

L. Beltran
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Authors' response

To R. Hitchcock

As stated in the article, the study did not deal with the impact of atrium top glazing and atrium wall reflectance on glare and brightness ratios. Furthermore, glare in a promenade atria is a very difficult concept to define because these atria are usually designed to simulate an outdoor environment and, therefore, require high illuminance levels at the atrium floor. I've not yet found any literature related to glare problems in atria.

Even though the study did not deal with illuminance measurements in the adjacent spaces, the simplified daylighting algorithm and the resulting graphical tools take into account the ratio of openings to total area of the atrium wall and the reflectance of the walls. The simplified tool predicts the average horizontal illuminance at the atrium floor for two extreme, commonly encountered design scenarios with respect to the percentage (30 and 67) of openings in the atrium walls. The higher end would correspond to an atrium where a large daylighting contribution into the adjacent spaces is sought. In this case, the developed design tool would specify the reflectance needed to meet a given horizontal illuminance at the atrium floor, since a great portion of daylight in the atrium will be absorbed into the adjacent spaces. The design tool does not deal with the prediction of the daylighting contribution into the adjacent spaces.

The excessive thermal loads in an atrium, usually reported in the literature, are largely due to oversized fenestration, resulting in an overlighted atrium. The developed design tool not only can determine the optimal transmittance for a given illuminance at the atrium floor, but can provide more information on the contribution of wall reflectance in meeting this target. In other words, the configuration and the wall reflectance can play a role in reducing the required transmittance, thus providing potential for thermal load reduction.

The scale model did not use black foam core with a reflectance of 15 percent. The simulated glass in the fenestration system had a transmittance equal to 100 percent (there was no glass). We measured the transmittance of the overall fenestration system. In the case of the sawtooth configuration, the simulated glazing was vertical (i.e., no tilted glass).

The overall transmittance of the fenestration system is more useful at the preliminary design phase where it provides an overall quantitative daylighting performance of the system. The configuration of the atrium fenestration depends not only on the amount of daylighting sought both in the atrium and the adjacent spaces, but on the needed quality and location of light including direct sunlight, diffuse only light, and mostly reflected light. As for R. Hitchcock's recommendation for north-facing glazing in warm climates to reduce heat gain, we point out again that most promenade atria are designed to simulate outdoor conditions, and sunlight or reflected sunlight is important for the marketability of an atrium. This recommendation applies mainly in activities where direct sunlight is not recommended such as in a library.

To L. Beltran

The purpose of the study was to develop a design tool for daylight prediction under a diffuse sky. However, the study does not suggest that direct sunlight should be neglected in daylighting considerations, as suggested. Furthermore, the study recognizes that an atrium experiences very dim and overcast sky conditions, as well as very bright and sunny conditions, and the fenestration system must accommodate both. The daylighting prediction algorithm and graphical design tools were developed as rules of thumb for average sky conditions. The developed algorithm predicts the average horizontal illuminance at the atrium floor, and should be considered at the preliminary design stage. Computer programs such as RADIANCE and SUPERLITE can be used to examine more detailed aspects of daylighting such as illuminance distribution.

The algorithm was validated by comparison with the previously validated algorithm that was limited to only one effective wall reflectance (34 percent).

I have already addressed the applicability of the developed design toll in my response to R. Hitchcock. As an example, the paper provides information on the optimal transmittance that would meet illuminance requirements to keep plants healthy under a given outdoor horizontal illuminance of 10,870 lx (1,000 fc).

We have studied the problems of thermal loads and occupants' comfort that were suggested by L. Beltran. However, I did not address them here because, we feel, they are beyond the scope of *Journal of the IES*. Furthermore, we at the Institute for Research and Construction are conducting a long-term study on energy costs and indoor environmental aspects of atrium buildings (see also Atif, M.R. 1992. Daylighting and cooling of atrium buildings in warm climates: Impact of the top-fenestration and internal wall mass area. Ph.D. diss., Texas A&M University).