VALIDATION OF THE ALGORITHMS DEVELOPED FOR PRELIMINARY PREDICTION OF DAYLIGHT DISTRIBUTION IN A TOPLIGHTED ATRIUM

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ABSTRACT

Empirically based preliminary prediction algorithms were recently developed for different atrium types under various diffuse sky conditions. In the case of toplighted atriums, these algorithms were developed to predict light levels on the horizontal floor and on the vertical wall surfaces of the atrium. However, the actual building atriums measured to assess these algorithms in a full-scale setting were four stories high or lower.

This study presents an investigation of the validity of the developed algorithms using full-scale measurements in two four-sided toplighted atriums 11 and 14 stories high respectively. The measurements were made over several days in the two large atriums of the Anatole Hotel in Dallas, Texas. These data are compared with the algorithm predictions, and the usefulness of the prediction models is discussed.

INTRODUCTION

GENERAL STATEMENT OF THE PROBLEM

climate, thus providing a temperate and comfortable transition space. Moreover, besides the social and aesthetic advantages, atriums can be designed to accept natural light and distribute it to adjacent spaces. This use of natural light can reduce the electric load due to artificial lighting and the heat generated by such lighting. Therefore, the need to understand daylight distribution throughout an atrium space is essential to produce good designs.

Simplified daylight prediction algorithms for preliminary design of toplighted atriums under overcast and clear diffuse skies have been developed as part of a larger study (1-2). These algorithms were developed to predict light levels on the horizontal floor on the vertical wall surfaces of the atrium. However, the actual building atriums measured to assess these algorithms in a full-scale setting were not more than four stories high or lower.

SPECIFIC OBJECTIVES

The objectives of this investigation are as follows:

1. Examine daylight distribution in two case study atriums including analyses of the effective transmittance of each of the roof cover systems,
2. evaluate brightness ratios, glare potential, and provide subjective assessments of the overall quality of the daylighting provided, and
3. examine the degree of fit of daylight distribution data in the case study atriums under different sky conditions with the simplified preliminary prediction algorithms, and evaluate the usefulness of the algorithms.

This study is limited to two atriums in one building in Dallas, with measurements made at mid-day on two days in February and one day in April 1988. During the first period skies were overcast with no sun, and in April the sky was clear with sun, when clear diffuse measurements were made.

ALGORITHMS FOR PRELIMINARY DESIGN

Algorithms for daylight illumination and

algorithms were established using a series of generic scale models in a large sky simulator facility.(3) To examine the effectiveness of the predictive algorithms, measurements were made in eight Texas buildings(4) and computer simulations of those case studies were also developed.(5) In general, the algorithms have proved to be quite useful for the specific cases examined.

The specific algorithms to be further examined with case study comparisons in the present work are for tall atriums with toplighting only. Low level toplighted structures were previously examined for linear atriums.(1) The atrium daylight models are basically developed for diffuse sky condition, two atrium plan shapes, and two positions within each atrium for the noon time period. For the basic models, an open top condition (effective transmittance of atrium cover T_c=100%), interior reflectances of 30%, and simple rectilinear volumes are assumed. The Daylight Factor (Y) and Well Index (X) are the metrics which are related in each algorithm. The Well Index is defined as:

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$$X = \frac{\text{Well height (well width + well length)}}{2^* \text{ well width * well length}} \quad (1)$$

For overcast and clear diffuse sky conditions, on the atrium floor for square and rectilinear plans,

$$Y = T_c \; 117 \; e^{-0.99X} \quad (2)$$

on the atrium walls for square plans,

$$Y = T_c \; 44 \; e^{-0.99X} \quad (3)$$

and on the atrium walls for rectilinear plans,

$$Y = T_c \; 17 \; X^{-0.59} \quad (4)$$

DESCRIPTION OF 11- AND 14-STORY ATRIUMS

The hotel utilized for this case study contains two large toplighted four-sided atriums. They serve as sitting areas and circulation spaces around which are located meeting rooms and commercial spaces such as restaurants, bars, and retail shops. The older 14-story atrium shown in figure 1 is 177 ft (53m) high and has a 130 x 130 ft (39 x 39m) square base. The newer 11-story atrium shown in figure 2 is 140 ft (42m) high and has a 130 x 240 ft (39 x 72m) rectangular base. On most of the floors surrounding both atriums, corridors open to each atrium serve the hotel guest rooms and meeting rooms. The skylight system on the square 14-story atrium consists of a solar bronze tinted glass pyramid cut flat at the top with an opaque surfaced roof which is estimated to be about 200 ft (60m) high as shown on the cross-section on Figure 3; the corresponding plan is shown on figure 4. The skylight system over the 11-story rectangular atrium consists of two such pyramids separated by a low opaque flat roof surface at the center as shown on Figure 5; the corresponding plan is shown on figure 4.

The measured effective light transmissivity of the skylight system is 20.2% even though the glass manufacturer's data indicates a light transmissivity for the tinted glass of 52%. The difference between the two values is presumed to

Fig. 1 Photo of Square Atrium of 14-Story Building

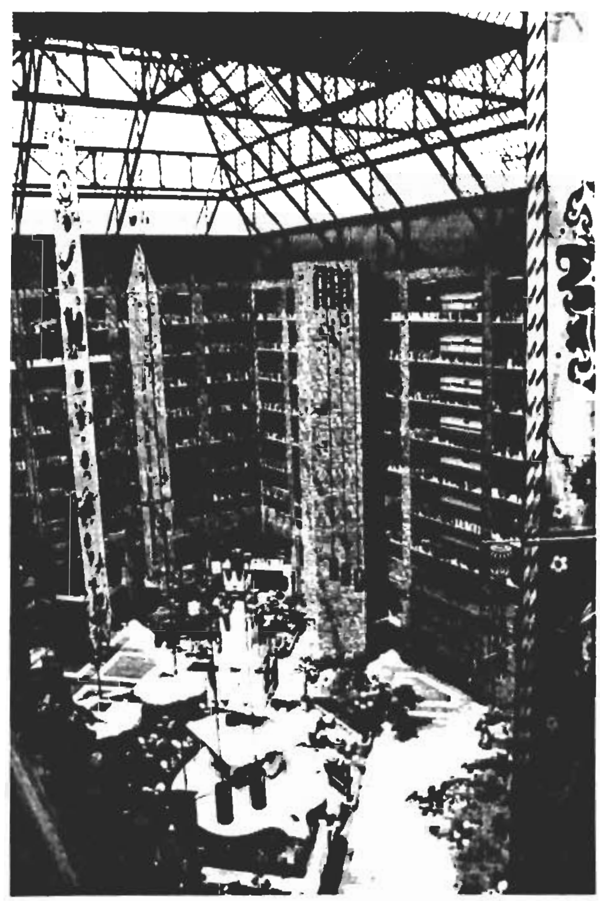

Fig. 2 Photo of Rectangular Atrium of 11-Story Building

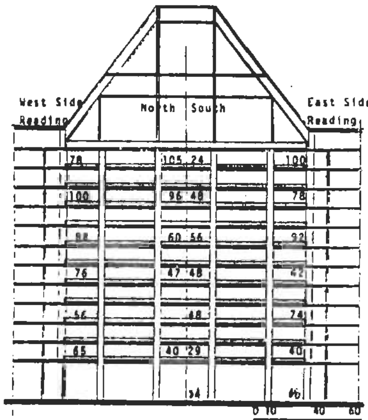

Fig. 3 Cross-Section of Square Atrium Looking North, Showing Illuminances Normal to Walls and Floor

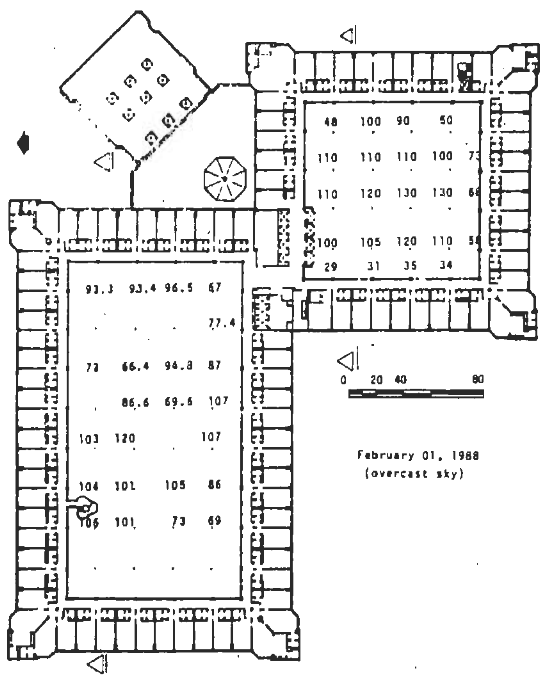

Fig. 4 Floor Plan of the Two Atriums with Illumination Readings Normal to the Floor

be due to the structural framing system as well as to the maintenance factor. In addition, for the rectangular atrium the low flat opaque roof at the center is believed to further reduce the effective transmittance even below the 20.2% value indicated.

The interior reflectances for both atriums were similar and are estimated to be about 25% for the light-colored marble flooring, about 5% for the inlaid brick flooring, 5% for the plants, and 16% for the surrounding brick-faced columns. The reflectance of the predominant horizontal

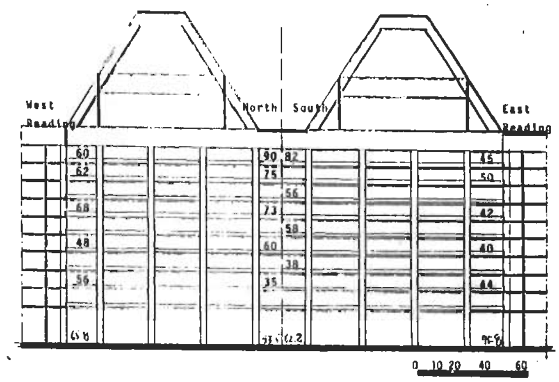

Fig. 5 Longitudinal Section of Rectangular Atrium Looking North, Showing Illuminances Normal to Walls and Floor

bands of wall material is about 30%, with the open-sided perimeter corridors reflecting very little light back into the atrium. The rectangular atrium contains a number of overhead daylight filtering features, including large trees, modular canvas canopies, a six-story aluminum sculpture, and five enormous hanging batik banners ranging from seven to eleven stories in height.

DATA COLLECTION AND ANALYSIS

The measurements of the illumination levels were taken on January 31, and February 1, around noon equinox time with an overcast sky and on the April 12 with a clear sky. A spot brightness and illuminance meter were used to measure the exterior illumination levels on these three days. The readings are reported in table 1. To estimate the average of exterior illumination levels, the median was considered for the readings taken on February 1, and April 12. However, due to the lack of a large number of readings taken on January 31, the mean average is assumed to be more appropriate since the median value was close to the maximum value for that particular set of readings.

On the two days with overcast skies the interior illumination readings were taken using two handheld illuminance meters with remote probe. The readings were taken to estimate the interior reflectances and the daylight distribution on every other floor on the median line of the four walls of both atriums. These readings are depicted in figures 3-5. The daylight factors for the overcast sky condition were computed using the data set of the measurements taken on February 1 when the median exterior illumination was 1742 footcandles.

On April 12 with a clear sky readings of the diffused daylight were taken using a simple pocket size illuminance meter. In the presence of many patches, diffused illumination was taken by shielding the photo cell of the light meter from the direct beams with an opaque piece of cardboard held at arm's length. The median

31 Jan 88 Overcast		1 Feb 88 Overcast		12 Apr 88 Clear w/o Sun	
Time	Illum. (fc)	Time	Illum. (fc)	Time	Illum. (fc)
2:00	2240	12:15	2630	12:15	1400
2:30	2170	12:30	2350	12:35	1425
2:45	1184	12:45	1900	12:50	1450
Mean = 1865		1:00	1567	1:20	1400
Median = 2170		1:15	1977	1:45	1400
		1:40	1170	Mean = 1415	
		1:47	1575	Median = 1425	
		1:55	1606		
		2:05	1742		
		Mean = 1835			
		Median = 1742			

Table 1. Exterior Illumination Readings

reading of the diffuse exterior illumination level was 1425 footcandles.

Errors are expected in the data because three different types of light meters were utilized and several people took the measurements. The difference in illumination readings are shown in table 2 which shows there is a strong correlation in the readings between the spot brightness illuminance meter and the illuminance meter with remote probes. The pocket size illuminance meter presents a difference in the readings that reaches up to 40% in indoor conditions.

COMPARISON WITH ALGORITHMS PREDICTIONS

The algorithms developed to predict daylight distribution in the center of a horizontal plane at different heights of a toplighted atrium as well as on the median line on the vertical walls show a mathematical relationship between the daylight factor and the well index. The daylight factors, being the percentage of interior illumination reading to the exterior horizontal reading have been plotted against the well indexes corresponding to the different points where the measurements were taken.

For the 14-story atrium, the prediction line was plotted taking into account a light transmissivity of 20.2% of the skylight system. On both overcast sky condition and diffused light on a clear day, the plotted data from the readings on vertical walls show a close relationship between the prediction line and the measured data as depicted in figures 6-7. A chi-square goodness-of-fit determines with at least a 95% accuracy, that there is no

Illuminance Meter w/ Remote Probe (fc lux)		Brightness-Illuminance Meter (fc lux)		Pocket Size Illuminance Meter (fc lux)	
28	(300)	24	(260)	42	(450)
55	(590)	49	(530)	135	(1450)
110	(1180)	96	(1030)	200	(2150)
420	(4520)	380	(4090)	750	(8070)
1300	(13990)	1150	(12370)	4000	(43040)
6000	(64560)	5340	(57460)	8000	(86080)
8600	(92540)	7500	(80700)	10000	(107600)

Table 2. Readings of Illumination Levels Under the Same Lighting Condition Using the 3 Light Meters (Source Ref. 4)

significant evidence that the data do not fit the prediction model. Similarly, the plotted data from the readings normal to the floor at the center of the 14-story atrium show a strong relationship between the prediction curve and the measured data as shown in figure 8. Even though the number of data is small, the chi-square goodness of fit show with a 95% accuracy that there is no evidence that the data do not fit the prediction model.

For the 11-story rectangular shape atrium, it has been mentioned previously that the light transmissivity of the skylight system may be much lower than 20.2% measured in the 14-story atrium. Its double pyramid skylight contains more opaque surfaces under which there are several objects hanging throughout the large atrium. It is believed that these two factors decrease the transmissivity of the skylight system significantly, perhaps to 15%. The plotted daylight factors for the vertical readings (figure 9) as well as horizontal readings (figure 8) show that the data do not fit the model with a light transmissivity of 20.2%, but there is a high level of confidence (95% at least) that there is no significant evidence of rejecting the model when the predicting curve has a 15% transmissivity.

Figure 8 indicates that the daylight factors measured at the center of the large rectangular base atrium are lower than those for the 14-story atrium. The measurements were taken in the center of the rectangular shape atrium between two modular canvas canopies and several trees. As a result the illumination level and the glare level were reduced considerably.

ASSESSMENT OF ALGORITHMS

The goodness-of-fit tests performed show the lack of evidence that the measured data do not

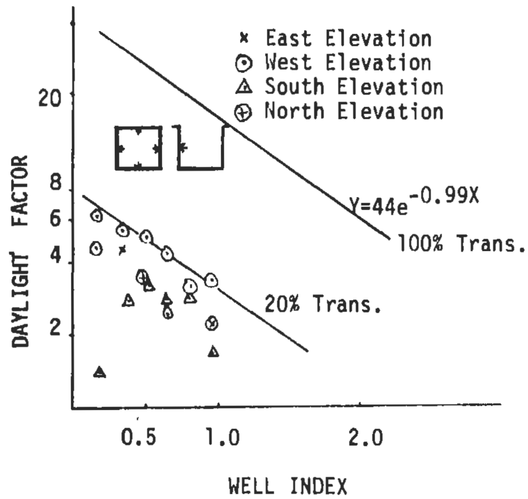

Fig. 6 Daylight Distribution Normal to the Wall of the 14 Story Toplighted Atrium Under Overcast Sky Conditions

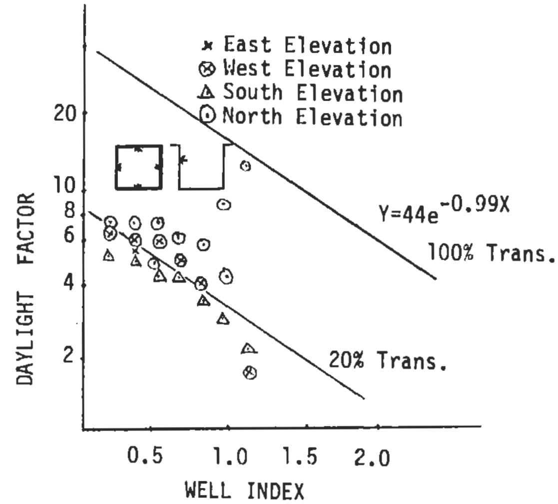

Fig. 7 Diffused Daylight Distribution Normal to the Wall of the 14 Story Toplighted Atrium Under Clear Sky Condition

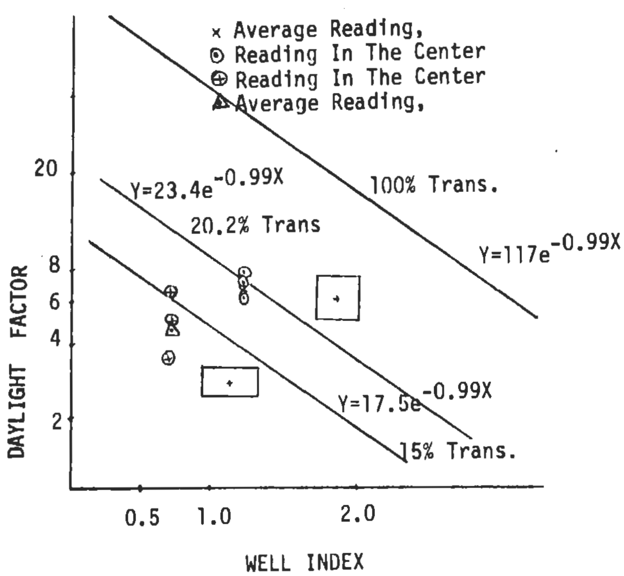

Fig. 8 Daylight Distribution Normal to the Floor at the Center of 14 and 11 Story Toplighted Atriums

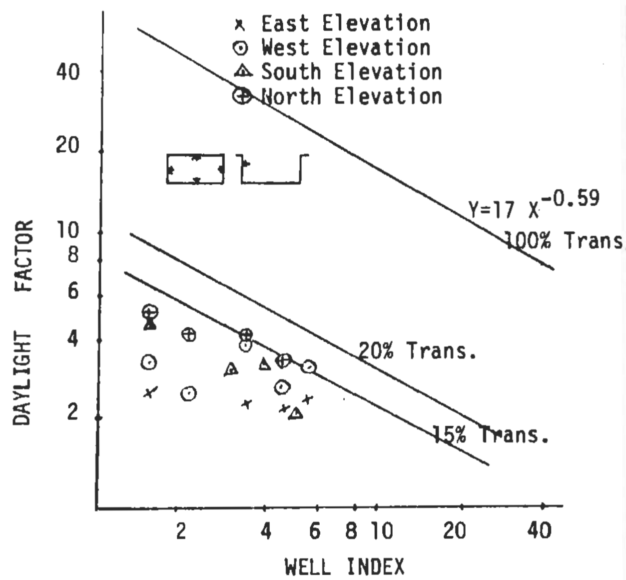

Fig. 9 Daylight Distribution Normal to the Wall of the 11 Story Toplighted Atrium Under Overcast Sky Conditions

fit the prediction curves. These algorithms were tested previously in a full scale 4-story buildings and in this project against 11- and 14-story atriums at the Anatole Hotel in Dallas. Both studies demonstrate the validity of the models.

Moreover, these models show that the fenestration system and the geometry of the toplighted atrium affect considerably the daylight distribution. On the other hand, other factors such as plants, hangings and dirt on the skylight system have the potential to affect the daylight distribution as well. However, even though they are not always easy to quantify, designers of such spaces should be aware of their potential effect. These algorithms have taken into account only the Well Index as the unique and primary variable in the atrium. There are other variables such as the interior reflectances, the skylight area and type which can affect the daylight distribution. Therefore, these algorithms need further developments.

ACKNOWLEDGEMENTS

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