ABSTRACT

The use of natural light (daylighting) in the atriums of office buildings is often done to supplement or eliminate the artificial lighting otherwise required. To the extent that the daylight can be effectively admits and then distributed, the dependence on artificial light is reduced, and energy is conserved.

This study involves two major Dallas Texas office buildings: Dallas City Hall (I. M. Pei and Partners) and Diamond Shamrock Corp. (Hawood E. Smith and Partners), both with linear type atriums (1). The fenestration type used at City Hall is a north-facing barrel vault system for direct light, while Diamond Shamrock uses a north-south pyramidal system which permits direct solar gain.

This paper compares the illumination levels of these two systems and the relative merits of each, as well as indicating the effectiveness of daylight distribution in both buildings. Also included in this study are data indicating some brightness ratios for each building and subjective responses to an informal survey.

INTRODUCTION

The intent of this study is to document the daylighting measurements of the two significant Dallas office buildings taken at noon on two successive Days in July (Sun. and Wed. July 8 and 9, 1986). Since there were nearly identical clear sky conditions, correlations should exist between the fenestration type and the intensity of daylight within the atrium, as well as the distribution of daylight into the perimeter offices. The relative significance of the reflectivities of the interior surfaces of each building's atrium will be examined. The impact of the direct solar illumination and heat gain of the Diamond Shamrock building as opposed to the diffuse light of the Dallas City Hall will also be compared. Another criterion to be considered in the evaluation of each facility is the large public building vs. the smaller private building and how this affects the fenestration type.

The present work is limited to an analysis of the atrium studies at the Dallas City Hall and the Diamond Shamrock Complex. It is also anticipated that a series of algorithms could be presented to evaluate new atrium designs and to study potential energy saving alterations to existing atriums. The specific objectives of this study include the comparison of actual daylight illumination levels in the atriums of two buildings, each with a different fenestration system (skylights). The results will be used to establish the effectiveness of each atrium at the distribution of daylight into perimeter office areas. The data and computer models have been adapted for predicting the distribution of daylight and heat gain of the Diamond Shamrock building as opposed to the diffuse light of the Dallas City Hall. The results of the comparison of these two systems indicates the high levels of illumination allowed by the pyramidal system along with significant solar gain (heat), while the diffuse north light of the barrel vault system provides no significant heat gain, yet admits lower levels of illumination.

The traditional method of daylight calculation has been to use data based on diffuse illumination. In the overcast sky, and equations based on the physics of light. This methodology is commonly called the Daylight Factor Method, and was developed by Mokhamsen (2). J. W. Griffith then developed calculation methods based on extensive studies of models under artificial sky which allowed predictions of a clear sky as well as a diffuse sky result (3). Recently these calculation methods have been adapted for predicting daylighting impacts on buildings, but a major shortcoming of these methods is that they are not directly applicable to the atrium studies at present.

The findings of this study represent a portion of a larger daylighting project conducted at Texas A&M University. The larger daylighting project was designed to evaluate a variety of atrium types by actual measurements as well as by scale model studies in a large sky simulator. The end result of this research is intended to be a series of design guidelines for the most efficient atrium geometry and fenestrations in given situations. It is also anticipated that a series of algorithms could be presented to evaluate new atrium designs and to study potential energy saving alterations to existing atriums.

The specific objectives of this study include the comparison of actual daylight illumination levels in the atria of two buildings, each with a different fenestration system (skylights). Also evaluated is the effectiveness of each atrium at the distribution of daylight into perimeter office areas. The energy load on the buildings will also be studied. The results of this work are primarily focused on the effectiveness of each atrium in distributing daylight well enough to have a positive impact on required electric lighting levels, and therefore to save energy.

DESCRIPTION OF PROJECT

The Dallas City Hall is a very large public office building with six stories, while the Diamond Shamrock Complex is a small two-story private office building located in nearby Las Colinas, Texas. Figure 1 shows the lobby plan of the atrium in City Hall which is some 225 ft. (68.6 m) long and about 25 ft. (7.6 m) wide. The atriums of office buildings are often designed to distribute daylight well enough to have a positive impact on required electric lighting levels, and therefore to save energy.
The atrium stair-steps wider at each level toward the skylights as is indicated in Figure 2. These parallel north-facing west- and south-facing clerestory skylights run the length of the atrium from east to west. The north and south sides of the atrium house city offices, while the east and west sides contain attached circulation areas and support facilities. The perimeter offices in this building are not directly exposed to the atrium, but are separated by means of large glass panels. This glazing reduces noise transmission into the perimeter offices, but also affects the transmission of daylight into the offices. The south side offices also have wide balconies for circulation passing east to west between them and the atrium. These could reflect some daylight into the offices. The south side offices, but they are carpeted, and have leafy green plants in planters on the railing. These high transmittance coupled with the glazing that separates the offices cuts down on daylight transmission into these offices.

The flow of the atrium is free of plants, furniture and general clutter, as it is primarily a circulation and queing area, and is carpeted. It might be assumed for a non-reflective atrium such as this, that daylighting levels six floors below the skylights would be significantly reduced by distance alone. This was not the case however, there still significant natural light found at the two lowest levels, but it was not primarily from the skylights but either from the 30 ft. (9.1 m) high north-facing windows at the lobby level. For this reason measurement data will be given but discounted somewhat for locations this deep in the atrium.

The Diamond Shamrock building is a relatively small office building in which the central atrium measures approximately 60 x 180 ft. (18.3 x 54.9 m). The skylight runs the full length of the atrium, and is made from two parallel hipped-section skylights. 'These could reflect some daylight into the offices. The south side offices, but they are carpeted, and have leafy green plants in planters on the railing. These high transmittance coupled with the glazing that separates the offices cuts down on daylight transmission into these offices.

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DATA ANALYSIS

EXTERIOR ILLUMINATION:

Unobstructed horizontal exterior illuminance was measured at noon on 8 July for the Dallas City Hall, and noon on 9 July for Diamond Shamrock. Two measurements were taken at each building location, a horizontal global reading and a diffuse reading, all of which were in clear sky conditions. The measurements were taken with a digital, hand-held Photometer (Litemate II), model 504 by Photo Research.

The global reading at City Hall was about 9,290 f.c. (99,960 lux) and the diffuse reading was 1,990 f.c. (21,410 lux). For comparison purposes, data were obtained from the Solar Energy Research Institute in Colorado which was gathered in nearby Waco, Texas (100 miles or 160 km). The SERI data indicates noon-time global readings of 9,300 f.c. (101,900 lux) and diffuse readings of 1,645 f.c. (17,710 lux) for a mid-July day. The SERI global/diffuse ratio at Waco was 4.6, while the City Hall data indicated a G/D ratio of 4.7. The Diamond Shamrock building from 9 July was 9,440 f.c. (global), 101,700 lux) and 2,180 f.c. (diffuse, 23,450 lux) resulting in a G/D ratio of 4.18.

The transmissivity of the north-facing semi-vaulted clerestory skylights at City Hall was determined by measuring natural illumination immediately below the skylight at the six floor balcony and expressing that as a percentage of the exterior horizontal diffuse illumination. The interior reading was 39 f.c., (0,010 lux) and is 4.3 percent of the exterior diffuse reading given above. Based on exterior global the transmissivity is about one percent. The transmissivity of diamond Shamrock was calculated in the same fashion using a reading obtained directly below the skylight at the six floor balcony. The interior reading was 2,200 f.c. (22,670 lux) expressed as a percentage of the exterior global reading; the actual system transmissivity is 23 percent. Possible explanations for the discrepancy of 9 percent between measured data and the calculated transmissivity is the percentage of daylight blocked by structure, interference of the floor or the glazing, or variances in the transmissivities from the manufacturers standards.

MATERIAL REFLECTANCES:

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<td>Glass</td>
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<td>Water</td>
<td>18</td>
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Actual Reflectances of Materials:

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<td>Concrete 39</td>
</tr>
<tr>
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</tr>
<tr>
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<tr>
<td>Wood 11</td>
<td>Wood 11</td>
</tr>
<tr>
<td>Water 18</td>
<td>Water 18</td>
</tr>
</tbody>
</table>

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INTERIOR ILLUMINATION LEVELS:

City Hall illumination decreases as a function of distance below the skylight (depth into the atrium) with the noted exception being the artificial light that diffused from the north-facing glass. Figures 1,4, and 5 indicate illumination levels in foot candles at similar locations on three levels: the lobby (second level), fourth and sixth levels.

The levels of illumination in unobstructed locations on the sixth level are nearly three times the readings at the same locations on the fourth level. Figure 2 is a section through the building at the center of the atrium which illustrates the change in illumination levels as the distance away from the skylight increases. Also indicated on the section at the skylight are spot brightness readings inside each vault. A comparison of Figure 2 with the northern vault, which is a result of having no reflecting surface to redirect the sunlight, shows an increase in foot candles. Daylight levels in Dallas City Hall perimeter offices on the north and south aides of the atrium (skylight) increases, as can be seen in Figure 3. This illustration indicates readings on both sides of the atrium and at both levels taken near the center of the building. The lobby floor in City Hall received a significant amount of good daylighting, averaging about 20 f.c. (215 lux) in the open areas, slightly less in obstructed areas, and significantly less at the ends and corners, which is evident in the readings shown in Figure 1. As previously noted, a significant amount of the light present at the lobby level is north light through the large lobby windows.

Typical readings in Diamond Shamrock indicate average levels of 20 (215 lux) to 50 foot candles (540 lux) in the common area at similar levels on the sixth level, and readings of up to 2000 foot candles (21,500 lux) in the direct sunlight, as can be seen in Figures 6 and 7. As previously noted, there was some spill over into the atrium. The broken skylight is evidence for circulation; but it was not bright enough to aid in task lighting in the perimeter offices, except to provide a pleasant glare-free environment. The circulation area at the sides and corners of the atrium were artificially lighted by necessity since the daylight did not satisfactorily light these areas. Also, user opposition was expressed about the glass which separated the working areas and offices at the lobby level from the atrium proper. Some users seemed self-conscious about the "fishbowl effect provided by the offices behind glass. Primarily, respondents dealt with the excessive glare through the building from exterior windows, and especially the large windows at the north side of the lobby. It was anticipated that this particular skylight type would admit only diffuse, north light and fill the atrium with enough daylight to spoil over into the office areas. The findings, however, showed negligible lighting levels at 10 feet (3 m) from the atrium which rendered additional measurements unnecessary (anticipated to go as deep as 20 feet (6 m) into the offices). Additionally, if
there had been useful levels of daylighting in the perimeter offices, no energy would have been saved due to the inflexibility of the lighting system design. Each office bay is on one lighting circuit and perimeter lights could not be dimmed independently of all the rest of the lights in that office bay without some lighting control modification. Diamond Shamrock user responses indicated an overwhelming acceptance of the pleasantness of the atrium space and the connection of the perimeter areas to it in an open plan fashion. There was significant daylight in the perimeter areas although not enough to work by because users indicated the need for task lighting at their individual work surfaces. The good view and importance of the view was held in high regard by most respondents. One employee even indicated the atrium as an amenity was a primary reason for taking her position there instead of elsewhere. There was concern by some for the heat or glare (which would affect the cost) as well. The smaller private corporation had been useful levels of daylighting transmitted about 25 percent of the exterior global illumination in comparison but allows direct sunlight penetration. This yields higher interior illumination levels than City Hall by as much as 300 foot candles, but the amount of direct solar reflection (heat gain) is still high. For example, if the skylight system were changed to admit diffuse north light only, the air conditioning load would be reduced by perhaps several magnitudes.

Material reflectances are very low in both buildings. If strategic surfaces were made more reflective, brightness and light distribution would be better, however glare would be likely to increase as well. Dallas City Hall gets no significant penetration of daylight into the perimeter offices. Partially due to the lack of sufficient lighting levels admitted to the atrium and the glazing separating each office from the atrium proper, Diamond Shamrock received a good penetration of daylight into the perimeter office areas. Although the light is not at levels satisfactory for working (50 f.c., 580 lux), the levels are enough to complement artificial light levels allowing them to be reduced and consequently, allowing lighting energy to be conserved.

North facing views which yielded brightness ratios in excess of the recommended comfort range. In every case at Diamond Shamrock however, the excessive brightnesses were a result of a direct line of sight at the skylight and not a problem. The excessive brightness of a direct line of sight at the skylight exceeded the 1:2 limit as well, but it too is a non-recurring view and may be discounted. The lobby glass at the north side of City Hall however, presented critical ratios for in excess of the comfort levels. The excessive brightness from those windows is an inconvenience to the whole lobby as well as the south side second floor offices and circulation balcony.

**STRATEGIES FOR IMPROVEMENT**

Dallas City Hall

- Improve adequacy of daylight through skylight system by increasing reflectivity of the interior of vaults and by directing more light into vaults from outside as shown in Figure 8.
- Selectively improve surface reflectances to help distribution of light within the atrium.
- If noise and security were no object, remove glazing at atrium/facility boundary to admit an amount of useful daylight transmitted into offices.

**Diamond Shamrock Building**

- Use a selective film with the skylight glazing which allows light without heat gain to reduce direct sun penetration yet allow daylight (reduce A.C. loads).
* Selectively change materials or surfaces to increase reflectivity and improve distribution of daylight into perimeter areas.
* Also, add vertical walls/baffles outside the skylight to block direct light into the atrium and increase the amount of diffuse light admitted by reflectivity. (Fig. 9).

**Future Work**

Daylighting measurements are being obtained in several buildings of three basic atrium types (linear, three-sided, and four-sided). Several types of lightshelf systems are being investigated as well. Extensive scale model tests of these same buildings will be conducted in the sky simulator at Texas A&M University. These tests in the 28 ft. diameter (8.5 m), 2 ft. (3.7 m) high dome facility will be conducted with various sun and sky conditions.

Following this testing, algorithms will be developed which will aid in the accurate prediction of daylighting and energy performance in atriums. These algorithms will be based on the physics of light and adjusted according to empirically derived coefficients from the scale model and the actual building studies. The algorithms can then be adjusted and simplified to act as a design tool for prediction at the conceptual and schematic design phases of the architectural design process.

**ACKNOWLEDGEMENT**

This particular study and the entire daylighting studies project is being supported by the National Science Foundation under Grant Number MSM 8504104. Also, thanks are extended to Dr. L. Boyer and L. Degelmann, P.E., for their help, guidance and contagious enthusiasm throughout this project.

**REFERENCES**

PARTIAL CROSS SECTION
FIGURE 2

CROSS SECTION
FIGURE 3

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NOTE: ALL READINGS IN FOOT CANDLES

DALLAS CITY HALL  FOURTH FLOOR PLAN

FIGURE 4

DALLAS CITY HALL  SIXTH FLOOR PLAN

FIGURE 5

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NOTE: ALL READINGS IN FOOT CANDLES

DIAMOND SHAMROCK
FIRST FLOOR PLAN

FIGURE 6

DIAMOND SHAMROCK
SECOND FLOOR PLAN

FIGURE 7

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In a case such as Dallas City Hall, it should be possible to increase building daylighting by making small modifications at the skylight. First, if a reflecting wall or surface is positioned to direct sunlight into the last vault, the total amount of daylight entering the building will increase. Next, to improve the distribution of daylight once it is admitted, the interior surfaces of the vaults could be finished with a more reflective surface such as white paint.

In a case where there is a direct gain fenestration type such as in the Diamond Shamrock facility, it would be desirable to reduce low angle direct sun (high glare) and to increase reflected light admitted (good quality daylight). This could possibly be accomplished as shown below, where baffle walls are erected to the sides of the skylight to block direct low angle sun, and to reflect daylight into the building to the “off” side. This could more evenly distribute light within the atrium at early and late times in the day, as well as possibly improve penetration of reflected light into the perimeter areas.