MEASUREMENTS AND COMPARISONS OF SUNLIGHTED AND NORTH-LIGHTED ATRIUMS ON TWO OFFICE BUILDINGS IN DALLAS, TEXAS

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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 admitted 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. (Harwood K. Smith and Partners), both with linear type atriums (1). The fenestration type used at City Hall is a north-facing barrel vault system for indirect 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 (Tue. 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 choice of the fenestration type.

Graphics and empirical data included indicate the effectiveness with which these two fenestration types distribute the daylight throughout the center of the buildings. 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 (daylight).

The traditional method of daylight calculation has been to use data based on diffuse illuminance 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 Hopkinson (2). J. W. Griffith then developed calculation methods based on extensive studies of models under an 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 that 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 atriums of two buildings, each with a different fenestration system (skylight). Also evaluated is the effectiveness of each atrium at the distribution of daylight into perimeter office areas. The effect of the fenestration type on the energy loads in the buildings will also be studied.

Next, tentative conclusions are drawn for each facility based on the relative effectiveness of the respective fenestration types as indicated by the field data. Additionally, suggestions are made regarding alterations to each installation which could make each one more effective at daylight distribution as well as maximizing energy savings.

The present work is limited to an analysis of the attributes and opportunities for improvement of the atrium in the subject buildings. Further, this work is primarily focused on the effectiveness of each atrium to distribute 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 an atrium of six stories, while the Diamond Shamrock Chemicals Division 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.

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The atrium stair-steps wider at each level towards the skylights as is indicated in Figure 2. Three parallel north-facing semi-vaulted 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 stacked 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 southside offices, but they are carpeted, and have leafy green plants in planters on the railing. These two treatments coupled with the glazing that separates the offices cuts down on daylight transmission into these offices.

The floor 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 was still significant natural light found at the two lowest levels, but it was not primarily from the skylights but rather 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 private office building in which the central atrium measures approximately 60 x 180 ft.(18.3 x 54.9 m), or about 10,800 sq.ft.(1000 sq. m.). The skylight runs the full length of the atrium, and is made from two parallel hipped-section skylights (fenestration type #12 according to Navvab and Selkowitz, (4)) and is illustrated in Figure 3. This type of skylight does allow direct sunlight; and consequently, the levels of natural illumination in the atrium are very high. However, as a result of the direct sun, the heat gain in the atrium is also high. In recognition of this fact, Diamond Shamrock has covered the skylight glazing with a polypropelene shading film which reduces light transmission by 60 percent. This film is in addition to the existing skylight glazing which cuts light transmission by 15-20 percent. This results in an over all transmissivity of 32 percent.

The atrium is surrounded on the east and west sides by perimeter offices which are completely exposed to the atrium in an open plan system as shown in Figures 6 and 7. The areas to the north and south of the atrium are primarily carpeted circulation space. The floor of the atrium itself is extensively landscaped with various types of plants and trees as well as with water, rocks, concrete, ceramic tile and carpet. Nearly all the materials in the atrium and perimeter offices are highly absorptive of light.

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 III), 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, Tx.(100 miles or 160 km). The SERI data indicates noontime global readings of 9,000 f.c.(96,880 lux) and diffuse readings of 1645 f.c. (17,710 lux) for a mid-July day. The SERI global/diffuse ratio at Waco was 5.4, while the City Hall data indicated a G/d ratio of 4.7. The Diamond Shamrock readings from 9 July were 9,440 f.c. global (101,570 lux) and 2,180 f.c. diffuse (23,450 lux) resulting in a G/d ratio of 4.18.

FENESTRATION SYSTEM TRANSMISSIVITY:

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 sixth floor balcony and expressing that as a percentage of the exterior horizontal diffuse illumination. The interior reading was 93.9 f.c. (1,010 lux) and is 4.7 percent of the exterior diffuse reading given above. Based on exterior global the transmissivity is about one percent. The transmissivity at Diamond Shamrock was calculated in the same fashion using a reading obtained directly below the skylight in the direct sun at the second floor balcony. The interior reading was 2,200 f.c. (23,670 lux) and 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 dirt or the glazing, or variances in the transmissivities from the manufacturers standards.

MATERIAL REFLECTANCES:

Measured reflectances of the primary materials in the Dallas City Hall and the materials in the Diamond Shamrock building can be found below.

ACTUAL REFLECTANCES OF MATERIALS (%)

Dallas City Hall		Diamond Shamrock	
Concrete	39	Concrete	22
Carpet	13	Carpet	22
Plants	9	Plants	6
Storage Box	33	Tile	11
Glass	15	Glass	27
		Rock	12
		White column	52
		White paint	72
		Wood	11
		Water	18

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 additional light at the lobby floor from the north-facing glass. Figures 1,4,and 5 indicate illumination levels in foot candles at similar spot locations on three floors: 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 comparatively low reading occurs in the northern vault, which is a result of having no reflecting surface to redirect the sunlight from the south.

Diamond Shamrock readings indicate a similar tendency to diminish as the distance from the daylight source (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 receives 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 60 foot candles (645 lux) in the diffuse or shaded locations, and readings of up to 2000 foot candles (21500 lux) in the direct sunlight, as can be seen in Figures 6 and 7. As in City Hall there was some diminishment in the ends (stacked circulation areas) and the corners.

Both buildings had adequate lighting for typical lobby usages 10 f.c. (107 lux), as recommended for circulation areas, and could do well using primarily daylight and supplementing lesser lit areas with artificial light.

Daylight levels in Dallas City Hall perimeter office areas fell far below the 50 foot candle (540 lux) levels required at a typical work surface. Figure 2 indicates the levels recorded in perimeter offices on the north and south sides of levels four and six. Even six inches (15 cm) inside the glass, the daylighting contribution was insignificant, and no reduction in artificial lighting could be made. As indicated previously, readings increase in proportion to the proximity of the reading location to the skylight. For this reason the sixth level perimeter office readings are higher than the fourth level counterparts.

Daylight levels penetrating about 10 feet (3 m) into the perimeter office areas of Diamond Shamrock were on the order of 10 to 20 f.c. (107 to 214 lux). Therefore, artificial lighting levels at the atrium perimeter could be significantly reduced. Figure 3 illustrates readings at both levels, on the east and west sides of the atrium, at the atrium edge, 10 ft. (3 m), and 20 ft. (6 m) into the perimeter office areas. These readings were taken at column lines and actually indicate lower illumination levels than were experienced in the center of bays where readings at 10 ft. reached 20 f.c. (210 lux), and at 20 ft. reached 14 f.c. (150 lux).

BRIGHTNESS RATIOS:

A brightness ratio indicates the relative brightnesses of the darkest spot in a field of view as compared to the brightest spot. It is also an indicator of excessive glare in a field of view. If the ratio of darkest to the brightest spot exceeds 1:20, then the view is considered to be too bright, and people have trouble adjusting to the range of brightnesses. Ratios below 1:20 are in accepted comfort ranges.

The brightness ratios taken in the Dallas City Hall fell almost exclusively within the comfortable range, with the only exceptions being a direct view of the skylight glass and the readings off the large lobby windows. These excessive readings were 1:25 and 1:94 respectively.

Diamond Shamrock had a number of ratios which exceeded the 1:20 comfort level, but every one involved looking directly at or towards the skylight or major structural elements and then to a relatively dark second surface. Views which were on the plane of the first or second levels had no ratios that exceeded the comfort limits.

SUBJECTIVE FINDINGS

The subjective findings about the daylighting in these two buildings are based on user/occupant responses to a survey completed the day of the measurements, as well as the personal appraisals of the investigators.

Dallas City Hall survey responses indicated a general acceptance of the atrium as an amenity, but few felt there was beneficial daylight as a result of the atrium. The investigators tend to agree that there was adequate light provided naturally for circulation; but it was not bright enough to aid in task lighting in the perimeter offices, except to provide a uniform glare-free environment. The circulation areas 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 atrium perimeter from the atrium proper. Some users seemed self conscious about the 'glass fishbowl' effect provided by the offices behind glass. Primarily, responses 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 spill over into the office areas. The findings, however, showed negligible lighting levels at 3 feet (1m) from the atrium which rendered additional measurements useless (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 modifications.

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 accompanied the early morning direct sun. And it was mentioned that on dark overcast days the atrium seemed dark itself and lost some of its charm.

Based on an understanding of the Texas climate for mid-July, it was anticipated that the Diamond Shamrock facility would be far too bright and very likely too warm. But, the previously described fenestration system kept the glare problem under control along with the highly absorptive atrium materials. And the temperature was quite pleasant, although probably at the expense of the air conditioning bill.

The lighting system is set up with strips of fluorescent lights running parallel to the long sides of the atrium. This allows for the artificial light to be turned down or off a bank at a time according to the daylight contribution at a given time. The lights are on a light sensitive circuit so they can automatically adjust themselves to suppliment the changing daylighting conditions. Therefore lighting energy is saved to the extent that the daylight suppliments the normal lighting levels.

One reason Diamond Shamrock can function with this type of fenestration is the relative size of the facility. City Hall would pay astronomical utility bills with taxpayers money if they allowed any direct sunlight inside. The private corporation can choose the benefit of added daylight and the amenity value of sun in the atrium, then do its best to deal with the expense (overhead) because it answers to itself. So, there seems to be a correlation between the cost of the operation of the atrium as an amenity and the choice of skylight type. It appears to be a decision based also on the relative size of the area under consideration (which would affect the cost) as well. The smaller private firm has the apparent option to use an ′energy hog′ system in an effort to maximize daylighting penetration, while the larger public facility has to consider the amount of, and source of payment of the utility bills.

FINDINGS AND COMPARISONS OF RESULTS

The exterior illumination levels of the City Hall and the Diamond Shamrock building are within 2 percent for the horizontal global measurements, and within 9 percent for the diffuse clear sky measurements. This insignificant difference allows direct comparison of the two projects without any adjustments to the measured data.

The City Hall skylights transmit too small a percentage of the exterior diffuse illumination: only 4.7 percent of the available diffuse sky illumination. The transmission based on available global (direct sun) exterior illumination, is only about 1 percent. The skylight at Diamond Shamrock transmits about 23 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 1900 foot candles, but the amount of direct solar radiation (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 receives 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.

Both facilities had 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 normal, level line of sight. City Hall had a view of their skylight exceed the 1:20 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, provided a ratio far in excess of the comfort level. The excessive glare 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 admittance of daylight through skylight system by increasing reflectivity of the inside 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/office boundary to aid in 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), 12 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.

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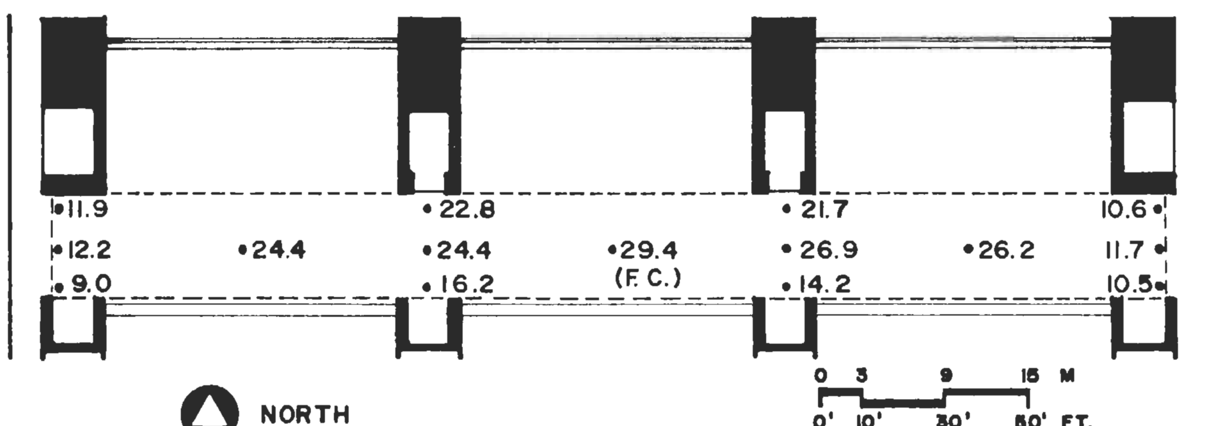
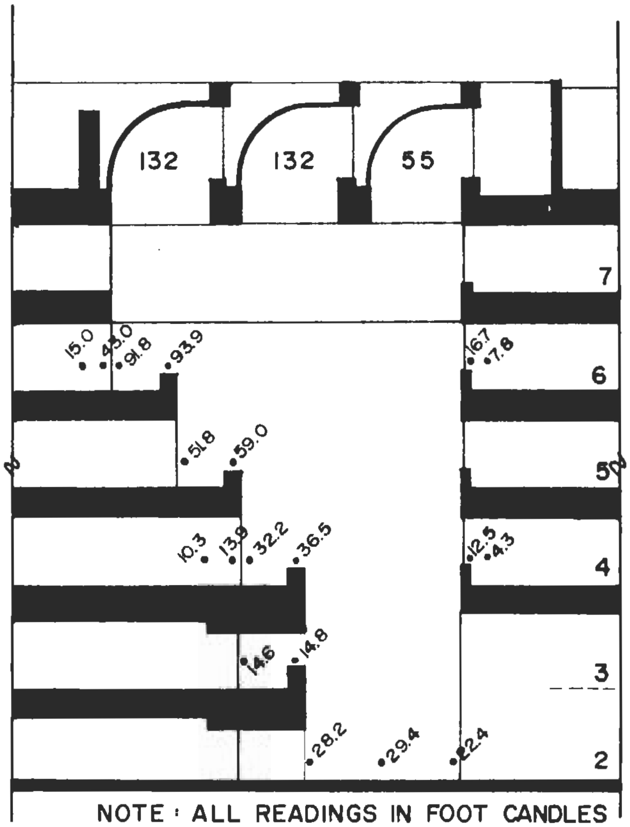
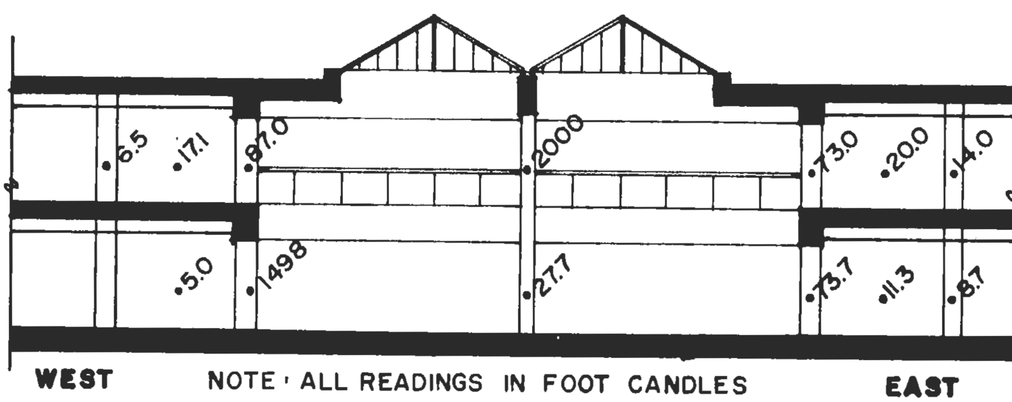


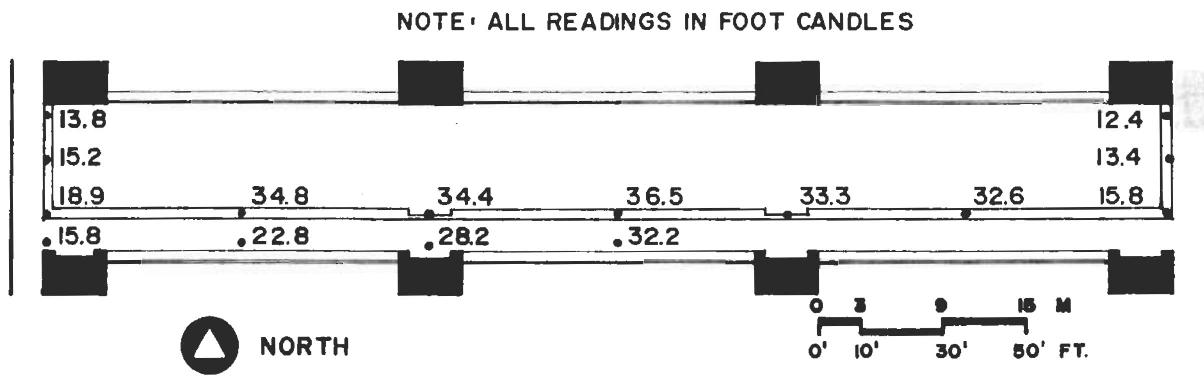
DALLAS CITY HALL LOBBY FLOOR PLAN
FIGURE 1



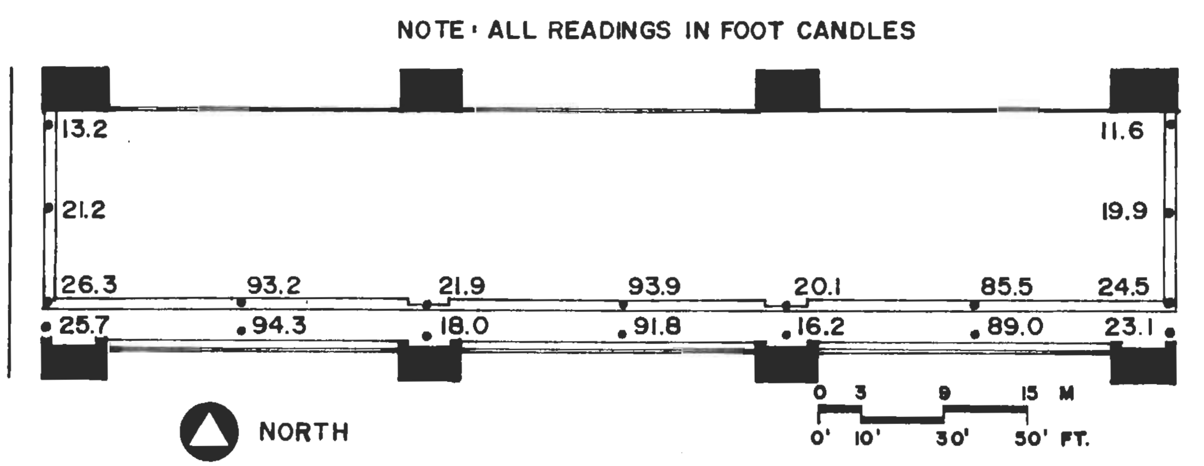
PARTIAL CROSS SECTION
FIGURE 2



CROSS SECTION
FIGURE 3



DALLAS CITY HALL FOURTH FLOOR PLAN
FIGURE 4



DALLAS CITY HALL SIXTH FLOOR PLAN
FIGURE 5