EVALUATION OF LIGHTSHELF DAYLIGHTING SYSTEMS FOR OFFICE BUILDINGS IN HOT CLIMATES

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ABSTRACT

This paper presents part of an on-going research project in the College of Architecture at Texas A&M University. This research investigates how lightshelf daylighting delivery systems can manipulate sunlight and daylight both in terms of thier light and heat by shading view apertures below the shelf to reduce solar heat gain and glare and by reflecting light deep into the space through the daylight aperture above the shelf. It also investigates how to provide view with good interior lighting in terms of light levels, distribution, and glare.

Evaluation of these systems are based on two different experiments. The first uses scale-models for daylighting evaluation. Methodology of the research is presented as well as results and evaluation for part of the first experiment. The second experiment will use computer program simulations for energy evaluation that include reducing lighting and cooling loads and shaving peak loads, especially, when used with selective low-e glazing for office buildings in hot climates.

INTRODUCTION

In office buildings, consumption of energy for artificial lighting alone is averaging 60% of the building's total consumption of electric energy [8,15]. Therefore, the reduction in the utilization of electrical lighting will, first, reduce the building's electrical lighting load and, second, reduce internal heat gain in the building which is generated from the use of electrical lighting "heat-of-light" . This heat gain reduction decreases the building's cooling load, especially in hot climates where the maximum cooling load is usually concurrent with maximum daylight availability. Moreover, this reduction in energy consumption will shave the peak demand during the key rate periods in these buildings and, therefore, additional saving in operating costs can be achieved. However, improper application of daylighting may offset these savings by producing one or more of the following: solar heat gain problems, excessive glare, and reduce view to the outdoors. Therefore, daylighting delivery systems should provide good illumination performance and good views of the outdoors without excessive glare as well as achieve acceptable energy performance.

Office buildings are often located in hot climates where solar radiation availability is enormous, and therefore are subjected to major heat gain, excessive brightness and discomfort glare problems. In such regions, the best design approaches that are utilized today to control these problems are using tiny windows, tinted glass and heavy shading devices that successfully exclude direct sunlight. However, these reduce the potential of achieving one of the main objectives for having a window, that is, view. In addition, unless these design approaches are modified, they tend to reduce the penetration of daylight, especially in interior spaces further away from the window, so much that artificial light is needed all day. Large office buildings which are internally load-dominated can shift the appropriate design strategy for the buildings to cooling, perhaps eliminating heating needs entirely. Therefore, this results in high operational cost due to the increase in consumption of electricity for using artificial lighting, and for using a bigger load to cool the added heat gain that is associated with the artificial lighting.

Daylight can replace electric lighting for most of the typical working day in most building types if the building is designed to allow daylight to reach most of the interior. However, daylighting is hard to achieve in most office buildings by simply applying windows around the perimeter of the building for side-lighting. Even when these windows are from wall to wall, this approach is unable to supply daylight to large portions of a building especially deeper into rear spaces away from the windows. In other words, daylight is badly distributed in these spaces, because the horizontal illuminance levels in the rear spaces are significantly low when compared to the ones in spaces near the window. In hot climates, this bad lighting distribution becomes more prominent when simple shading controls such as overhangs, horizontal or vertical blinds are added. Therefore, the benefit from daylight to reduce the use of electrical lighting is limited to a small area near the window. In addition, the luminance of internal surfaces of such spaces is excessively high (bright) near the window and low (dark) away from it. Therefore,

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there will be a potential of glare discomfort for occupants in such spaces when excessive brightness from the window comes into their field of view [1]. Moreover, the wide range in illuminance levels and luminance levels (uneven daylight distribution) is common with side-lighting in office buildings [4,5], however, it becomes worse with the presence of the partial height partitions that obstruct the daylight penetration coming from the windows.

There are different ways to deal with problems associated with side-lighting as presented above. One of the ways to approach this problem is to modify the wall fenestration by adding different kinds of design treatments that will enhance the performance of the daylighting delivery system (when referring to the daylighting delivery system, we are considering a fixed system that does not require mechanical or motorized equipment). These design treatments include lightshelf, lightscoop, fixed mirrored louvers, prismatic materials and holographic films as shown in **Figure 1**. In this study, the daylighting delivery system will be considered for side-lighting, shown in **Figure 1a**, and will consist of a wall fenestration with lightshelf as a design treatment.

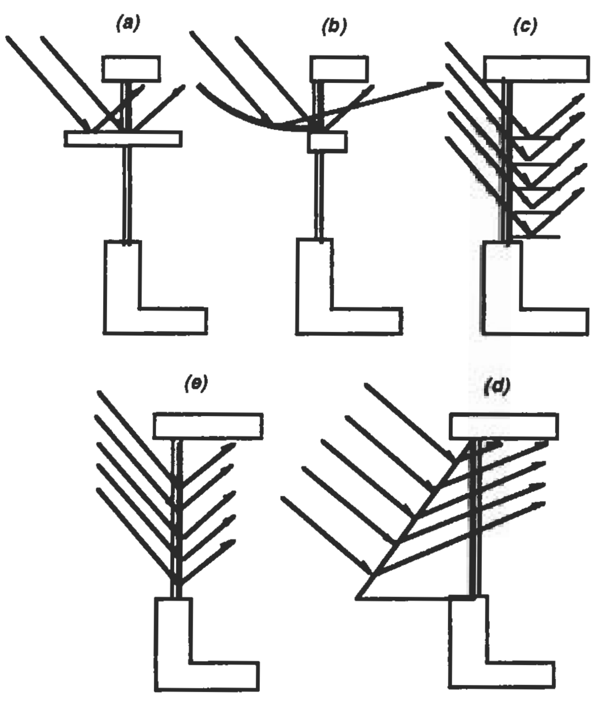

Figure 1. Daylighting delivery systems for side-lighting that consist of a wall fenestration with a fixed design treatment such as (a)lightshelf, (b)lightscoop, (c)prismatic panel, (d)holographic films and (e)fixed mirrored louvers.

The lightshelf configurations can be identified as: internal, external, and combined as shown in **Figure 2**. The combined lightshelf is intended to provide shade, shielding the occupants from the direct glare of the sky while reflecting sunlight and skylight off its surface onto the ceiling, and increasing the illuminance level at the rear of the space. Therefore, the objective of the lightshelf is to manipulate sunlight both in terms of its light and heat. If designed properly, a lightshelf should redirect sunlight or diffuse daylight onto the ceiling (based on the reflectance of the upside surface of lightshelf), enhancing lighting conditions in the space and improving the distribution of light and reducing glare [7].

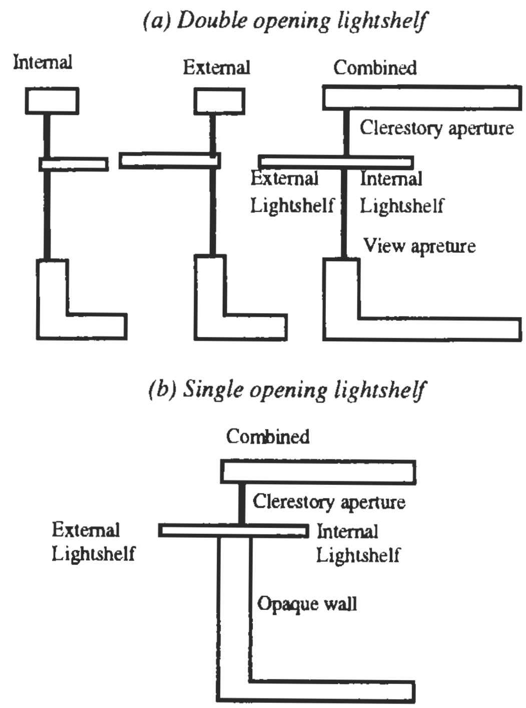

Figure 2. lightshelf configurations as part of a daylighting system.

OBJECTIVES

The objective of this study is to test and evaluate different daylighting delivery systems on the south wall of a deep office space, when compared with no or simple shading treatment such as when an overhang is added to the same wall, in terms of their ability to achieve the following:

1. Provide the recommended illuminance level of 46.5 fc (500 lx), especially at the rear of the space away from the glazing area [10].
2. Provide uniform light distribution.
3. Reduce Daylight Glare Discomfort in terms of Daylight Glare Index (DGI).

4. Reduce the total energy consumption of multi-story office buildings located in hot climates (these results are not presented in this paper).

METHODOLOGY

The method of accomplishing these objectives is by conducting two experiments. The first is related to the first three objectives mentioned above, and the second is related to the last objective mentioned above. This paper shows part of the results of on-going research in the College of Architecture at Texas A&M University. The results in this paper are related to the lighting evaluation experiment. However, results of the energy evaluation experiment are not included because the experiment has not yet been completed.

The lighting evaluation experiment is conducted using physical scale-models under the simulated sky dome [2] and simulated sun light. The office module represents a large office space in a large multi-story building. According to the Architects' Data, Second English Edition [9], an office plan of 24 ft and more which can accommodate at least five open plan workplaces is considered a deep office plan. Therefore, the selected office plan is 30 ft deep. The width of the plan is selected to be 30 ft as well to reduce the effect of the inter-reflection from the walls on the light sensors located inside the model. The height of the ceiling is 10.5 ft, and the scale of the model is 1 in.=1 ft. Most of the materials used for constructing the model were 1/16 inch cardboard. The finished surfaces of the model were selected to achieve the required surface reflectances and textures. The reflectance of ceiling, walls, floor, overhangs, interior lightshelves, and exterior lightshelves is 80%, 50%, 20%, 30%, 80%, and 80% upside surface and 30% downside surface, respectively.

The facade of the model (South elevation) is extended beyond one floor to include the lightshelf and the view aperture of the upper floor and the lightshelf and the clerestory aperture of the lower floor. All the glass is located on the south wall and its total area is 225 sq.ft (30 ft wide by 10.5 ft height). The orientation of the fenestration for the office space is due South. This orientation is recommended for a fenestration that utilizes lightshelves for maximum utilization of reflected sunlight and daylight into the room.

The model was constructed in a way to allow for five light sensors of the Illuminance Data Acquisition System IDAS which consists of eight photometric sensors and an analog-to-digital converter connected to the microcomputer. The sensors are placed along a median axis and positioned at distances of 0.1, 0.3, 0.5, 0.7, and 0.9 of depth of 30 in. These five sensors are labeled from 1 to 5, respectively. Additionally, two were placed along a transverse axis and positioned to the sides 3 inches from each wall. These two sensors were labeled 6 and 7 and mainly used for balancing the parallel rays of the sunlight source. All the sensors were positioned at the working plane height which is 30 inches above the floor as shown in **Figure 3**.

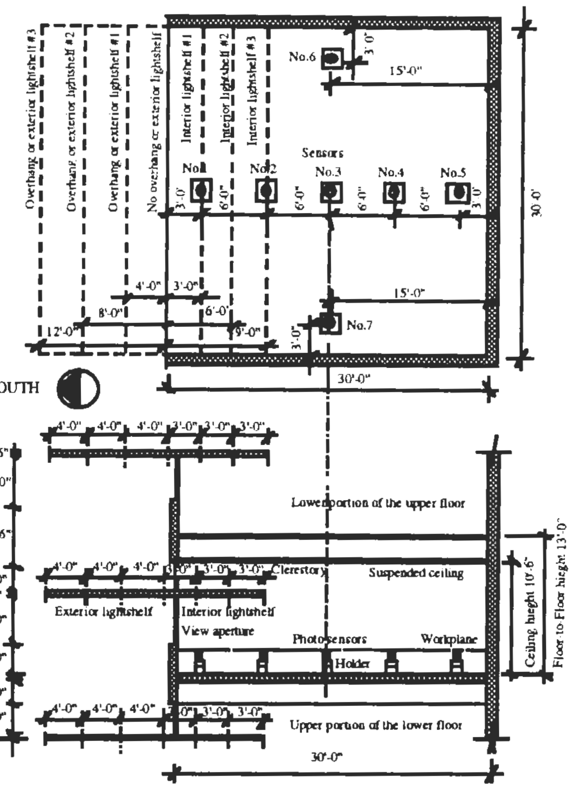

Figure 3. Section and floor plan of the physical scale model used in the lighting evaluation experiment.

A video-based luminance mapping system originally developed in 1983 to measure sky luminance distribution [16] has been modified in 1990 at Texas A&M University [13,14]. This system is used in this study along with a spot luminance meter (1/3°) to measure luminances that are used in the DGI calculation. It consists of video-based image-capture hardware and a series of customized digital image processing programs.

The solar altitude angles were determined for the model experiment to be 30°, 45°, 60° and 75° at noon. The results in this paper correspond to data collected for the solar altitude of 30° which represents low solar altitude angles. The experiment is performed for clear sky, and the direct sun measurements are done separately from the measurements for diffuse sky without sun. Therefore, there are four sets of cases in the experiment. Each set consists of 19 cases. It includes the base case (BC: (0)), and the base case with overhang sizes 4, 8, and 12 ft (OH1: (4), OH2: (8), and OH3: (12)). The set also includes three internal lightshelf, three external lightshelf, and nine combined lightshelf cases. A convension has been established for coding these cases is shown in **Table 4** that, for example, CL2: (8/6) means combined lightshelf with eight feet external lightshelf and six feet internal lightshelf.

Table 4. Tested cases and code names in the model experiment for different lightshelf depths.

Exterior lightshelf size (ft)	Interior lightshelf size (ft)			
	0	3	6	9
0	BC/OH	IL1: (0/3)	IL2: (0/6)	IL3: (0/9)
4	EL1: (4/0)	CL1: (4/3)	CL6: (4/6)	CL8: (4/9)
8	EL2: (8/0)	CL4: (8/3)	CL2: (8/6)	CL9: (8/9)
12	EL3:(12/0)	CL5:(12/3)	CL7:(12/6)	CL3:(12/9)

All measurements and calculations are repeatedly performed for the base case, the base case with the overhangs, and all the different alternative lightshelf cases which are specified above. Illuminance levels at the work plane inside the office, 2.5 ft above the floor, are measured using the IDAS where illuminance contribution of the direct sun is recorded separately from the illuminance contribution of clear sky without sun. Luminance intensities are measured using luminance distributions on the inside surfaces of the physical scale model using the video-based luminance mapping system and the spot luminance meter (1/3°). The measured luminances are taken for a viewing angle of a person looking directly at the aperture in a standing position at the rear of the office (scale model). This position represents the worst case for glare discomfort [11]. Then, the Daylight Glare Index (DGI) is calculated using the Cornell Formula [3] as shown in Equation (1) and then compared with glare discomfort criterion shown in **Table 5**.

$$DGI=10*\log_{10}\Sigma 0.48*(L_s^{1.6}*\Omega^{0.8}/(L+0.07*w^{0.5}*L_w)) \quad \text{Equation (1)}$$

where

L_w= luminance at aperture.

L_s= source luminance

L_b= background luminance

Ω and w= solid angles of the source with respect to the field of view.

Table 5. Glare Discomfort Criterion for Daylight Glare Index (DGI).

Glare Criterion	Daylight Glare Index
Just Imperceptible	16
	18
Just Acceptable	20
	22
Just Uncomfortable	24
	26
Just Intolerable	28

Source: Chauvel et al, 1982 [3].

The illuminance data obtained inside the physical model of the office space is converted into Daylight Factor (DF) for the data obtained under diffuse sky without direct sunlight and Sunlight Illuminance Ratio (SIR) for those obtained with only direct sunlight [12] by using the Equations (2,3).

$$DF=E_{ikh}/E_{okh} \quad \text{Equation (2)}$$

$$SIR=E_{iuh}/E_{ouh} \quad \text{Equation (3)}$$

where

E_{ikh}= indoor horizontal illuminance under diffuse sky

E_{okh}= outdoor horizontal illuminance under diffuse sky

E_{iuh}= indoor horizontal illuminance under direct sun

E_{ouh}= outdoor horizontal illuminance measured direct sun.

The impacts of DF and SIR are combined after using the daylight availability data [11] for a city to determine the E_{okh} and E_{ouh} (the city of El Paso, TX is used in this study to represent the hot climate). Then, Equations (4,5,6) are applied to get E_{ih}.

$$E_{ikh}=DF*E_{okh} \quad \text{Equation (4)}$$

$$E_{iuh}=SIR*E_{ouh} \quad \text{Equation (5)}$$

$$E_{ih}=E_{ikh}+E_{iuh} \quad \text{Equation (6)}$$

The E_{ih} data together with the light distribution and DGI analyses, are used to identify the optimum configuration of the south wall fenestration in terms of the interior luminous environment.

DISCUSSION OF RESULTS

In this study, the tested cases can be divided into two categories: 1) acceptable, 2) unacceptable. The acceptable cases are the ones that did not have sunlight patches on the work plane such as OH3, CL2, CL3, CL7, and CL9 (also referred to as selected cases). The rest of the cases are considered unacceptable since they have sunlight patches on the work plane, therefore, luminance ratio of the task to the immediate surrounding is more than 3:1 and/or the luminance ratio the task to the remote surrounding is more than 10:1 [6,10]. Hence, only the acceptable cases are evaluated for glare discomfort and the criteria used for this evaluation is the Daylight Glare Index (DGI).

The results in the tables and figures are presented in lux (lx) and kilo-lux (klx), and the conversion factor to footcandle (fc) is as follow: fc =0.093(lx)=93klx. Additionally, the letter "D" in the tables and figures refer to the depth of the office space in the direction normal to the aperture (which is the distance between the aperture and the back wall). The results of this study are based on the winter (21 December at noon) daylight availability data of El Paso, TX [11] where the Eokh=649 fc (6,980 lx) and Eouh=4,828 fc (51,910 lx).

The contribution to the indoor horizontal illuminances from the direct sun (Eiuh) is higher than the contribution from the diffuse sky (Eikh) for most of the cases as shown in **Tables 6,7,8,9**. This is due to, first, outdoor illuminance from the sun (Eouh) is more than seven times higher than outdoor illuminance from the diffuse sky (Eokh), and second, low solar altitude angle (altitude=30°) that allows more of sunlight penetration into space.

All the recorded total indoor horizontal illuminance (Eih) levels were higher than the target illuminance level of 46.5 fc (500 lx) except in case OH1, OH2, OH3, and CL9 as shown in **Table 10**. However, each group of same cases showed similar behavior (see **Figure 6**). The base case (BC) had the most sunlight patches on the work plane, and therefore it had the largest illuminance range (maximum-minimum) of 1,983 fc (21,335 lx) as shown in **Figure 4** and **Figure 5**. Shading a south aperture by adding an overhang to the base case, decreases the indoor horizontal illuminance levels (Eih) sharply as in the cases OH1, OH2, and OH3. However, when all the sun was blocked from entering the space in OH3 case, Eih levels were significantly decreased to only 0.03 (at depths of 9 ft into the space and away from the aperture) to 0.17 (at depths of 27 ft, close to the back wall) of those in the BC case as shown in **Figure 7**. Moreover, the OH3 case is the only one among the base wall) of those in the BC case as shown in **Figure 7**. Moreover, the OH3 case is the only one among the base and overhang cases that is considered acceptable in terms of luminance ratio, but Eih levels were below the target levels at depths of 9 ft and beyond.

All the combined lightshelf cases CL1 through CL9 provided better light distribution than the rest of the cases (base, overhang, interior and exterior lightshelf cases) as shown in **Figure 6**. However, the only acceptable cases in terms of illuminance ratio are CL2, CL3, CL7, and CL9. These cases have provided the target illuminance level in the space except for CL9 that had a low Eih level of 35 fc (377 lx) at a depth of up to 9 ft away from the aperture as shown in **Table 10** and **Figure 8**. In addition, these cases also provided the least illuminance range (Range=maximum Eih-minimum Eih) among all the cases as shown in **Figure 4** and **Figure 5**, because they are also the most uniform illuminance distribution among the rest as shown in **Figure 6** and **Figure 8** (except for OH3 that did not provide the target illuminance level at distance of 9 ft deep beyond). Among the cases CL2, CL3, and CL7, the least illuminance range is 227 fc (2,438 lx) that belongs to CL3 as shown in **Figure 5** which indicates that CL3 has provided the most uniform light distribution (also see **Figure 8**) . The average Eih level for each of these acceptable cases in the order of the highest to the lowest is CL7, CL2, and CL3 with values of 245 fc (2,633 lx), 208 fc (2241 lx), 282 fc (3035 lx), respectively.

The glare discomfort analysis is conducted only for those selected cases which are acceptable in terms of the luminance ratio. The Daylight Glare Index (DGI) for the acceptable cases are shown in **Table 11** and **Figure 9.** Based on these results and the discomfort glare criterion shown in **Table 5**, DGI for OH3 case is rated "Uncomfortable" to "Just Intolerable", however, CL2, CL3, CL7, and CL9 cases are rated "Acceptable" to "Just Uncomfortable" (see **Figure 9**).

Table 6. Daylight Factor (DF) for clear sky.

Case	3 ft (0.1D)	9 ft (0.3D)	15 ft (0.5D)	21 ft (0.7D)	27 ft (0.9D)
BC: (0)	24.9	12.0	5.2	3.5	2.6
OH1: (4)	15.9	7.1	3.6	2.6	2.2
OH2: (8)	9.6	5.0	2.8	2.2	2.0
OH3: (12)	6.3	3.9	2.5	2.0	1.8
IL1: (0/3)	20.4	9.3	5.5	3.3	2.2
IL2: (0/6)	19.0	6.6	3.4	2.7	2.1
IL3: (0/9)	19.3	4.9	3.4	2.3	2.1
EL1: (4/0)	16.5	13.2	5.8	3.3	2.3
EL2: (8/0)	13.2	12.4	5.4	3.6	2.6
EL3: (12/0)	14.7	13.6	5.9	3.3	2.3
CL1: (4/3)	8.4	8.7	5.3	3.2	2.2
CL2: (8/6)	3.4	5.5	3.9	3.4	2.5
CL3: (12/9)	3.6	2.7	3.2	2.3	2.0
CL4: (8/3)	5.6	8.4	5.2	3.6	2.7
CL5: (12/3)	5.9	8.3	5.4	3.0	2.3
CL6: (4/6)	6.1	5.7	3.7	2.8	2.2
CL7: (12/6)	3.9	5.3	3.6	2.8	2.0
CL8: (4/9)	5.9	3.0	3.4	2.3	2.1
CL9: (8/9)	2.9	2.7	3.2	2.6	2.4

Table 7. Solar Illuminance Ratio (SIR) for clear sky.

Case	3 ft (0.1D)	9 ft (0.3D)	15 ft (0.5D)	21 ft (0.7D)	27ft (0.9D)
BC: (0)	40.4	41.4	1.9	1.8	1.5
OH1: (4)	39.5	31.6	1.5	1.2	1.0
OH2: (8)	39.5	0.9	1.0	0.9	0.3
OH3: (12)	1.2	0.7	0.3	0.0	0.0
IL1: (0/3)	39.1	6.4	3.8	1.9	1.8
IL2: (0/6)	39.2	9.5	6.0	2.8	2.1
IL3: (0/9)	37.6	3.6	4.7	3.4	2.3
EL1: (4/0)	8.1	58.1	2.6	1.9	1.7
EL2: (8/0)	6.8	57.1	2.9	1.5	1.7
EL3: (12/0)	7.2	65.1	2.9	2.1	2.0
CL1: (4/3)	7.1	8.6	3.7	2.5	1.9
CL2: (8/6)	1.2	9.8	6.6	3.1	2.2
CL3: (12/9)	3.8	3.6	6.6	3.6	2.1
CL4: (8/3)	4.7	8.6	3.8	2.1	1.5
CL5: (12/3)	9.4	11.0	4.7	2.8	2.1
CL6: (4/6)	2.4	10.5	6.7	3.1	2.0
CL7: (12/6)	4.3	10.7	6.7	3.3	1.9
CL8: (4/9)	1.7	3.1	5.1	3.3	1.9
CL9: (8/9)	0.3	2.8	4.7	3.6	2.1

Table 8. Indoor horizontal illuminance on work plane for clear sky w/o direct sun (lx).

Case	3 ft (0.1D)	9 ft (0.3D)	15 ft (0.5D)	21 ft (0.7D)	27 ft (0.9D)
BC: (0)	1,737	835	361	242	183
OH1: (4)	1,112	495	255	184	153
OH2: (8)	671	346	197	155	137
OH3: (12)	441	271	172	139	128
IL1: (0/3)	1,426	649	385	229	151
IL2: (0/6)	1,328	459	234	190	147
IL3: (0/9)	1,349	344	234	161	144
EL1: (4/0)	1,154	924	404	229	163
EL2: (8/0)	923	869	377	251	179
EL3: (12/0)	1,023	948	413	227	158
CL1: (4/3)	587	605	372	222	156
CL2: (8/6)	239	385	273	235	175
CL3: (12/9)	251	187	221	158	139
CL4: (8/3)	393	586	365	251	187
CL5: (12/3)	413	579	377	211	158
CL6: (4/6)	429	401	261	197	154
CL7: (12/6)	270	368	251	194	141
CL8: (4/9)	411	211	234	161	147
CL9: (8/9)	205	189	223	179	169

Table 9. Indoor horizontal illuminance on work plane for clear sky w/sun at noon (lx).

Case	3 ft (0.1D)	9 ft (0.3D)	15 ft (0.5D)	21 ft (0.7D)	27 ft (0.9D)
BC: (0)	20,970	21,486	974	917	802
OH1: (4)	20,512	16,387	802	630	516
OH2: (8)	20,512	458	516	458	172
OH3: (12)	630	344	172	0	0
IL1: (0/3)	20,283	3,323	1,948	974	917
IL2: (0/6)	20,340	4,927	3,094	1,432	1,089
IL3: (0/9)	19,538	1,891	2,464	1,776	1,203
EL1: (4/0)	4,223	30,178	1,339	978	875
EL2: (8/0)	3,552	29,622	1,490	802	859
EL3: (12/0)	3,724	33,805	1,490	1,089	1,031
CL1: (4/3)	3,708	4,480	1,905	1,287	978
CL2: (8/6)	630	5,099	3,438	1,604	1,146
CL3: (12/9)	1,948	1,891	3,438	1,891	1,089
CL4: (8/3)	2,464	4,469	1,948	1,089	802
CL5: (12/3)	4,870	5,730	2,464	1,432	1,089
CL6: (4/6)	1,236	5,459	3,502	1,596	1,030
CL7: (12/6)	2,214	5,562	3,502	1,699	978
CL8: (4/9)	875	1,596	2,626	1,699	978
CL9: (8/9)	172	1,432	2,464	1,891	1,089

Table 10. Indoor horizontal illuminances on the work plane for clear sky w/direct sun (lx).

Case	3 ft (0.1D)	9 ft (0.3D)	15 ft (0.5D)	21 ft (0.7D)	27 ft (0.9D)
BC: (0)	22,708	22,321	1,335	1,158	985
OH1: (4)	21,624	16,882	1,057	815	669
OH2: (8)	21,183	804	712	614	309
OH3: (12)	1,071	615	344	139	128
IL1: (0/3)	21,709	3,972	2,333	1,203	1,068
IL2: (0/6)	21,668	5,386	3,328	1,623	1,235
IL3: (0/9)	20,886	2,235	2,698	1,937	1,348
EL1: (4/0)	5,376	31,102	1,743	1,208	1,038
EL2: (8/0)	4,476	30,491	1,867	1,053	1,038
EL3: (12/0)	4,748	34,752	1,902	1,316	1,189
CL1: (4/3)	4,295	5,086	2,277	1,510	1,134
CL2: (8/6)	869	5,485	3,711	1,839	1,321
CL3: (12/9)	2,199	2,078	3,659	2,049	1,228
CL4: (8/3)	2,857	5,055	2,313	1,339	989
CL5: (12/3)	5,283	6,309	2,841	1,643	1,247
CL6: (4/6)	1,665	5,860	3,763	1,794	1,184
CL7: (12/6)	2,484	5,930	3,752	1,893	1,120
CL8: (4/9)	1,286	1,807	2,860	1,860	1,125
CL9: (8/9)	377	1,621	2,686	2,069	1,257

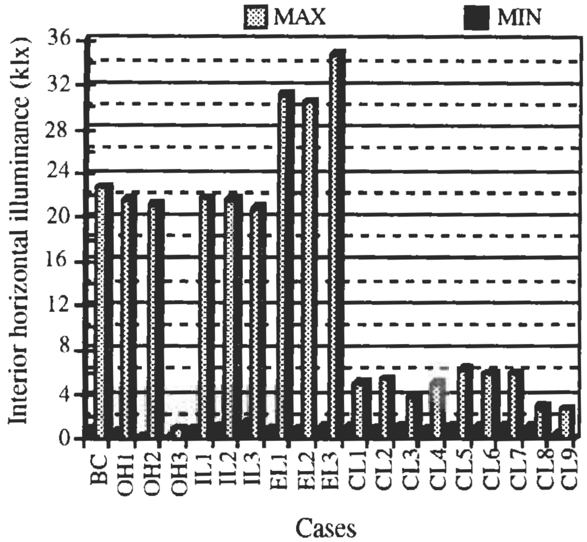

Figure 4. Minimum and maximum interior horizontal illuminance.

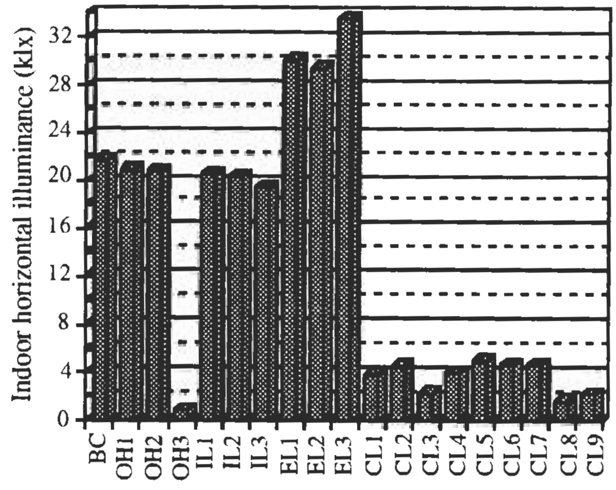

Figure 5. Range (Maximum-Minimum) of indoor horizontal illuminance for each case.

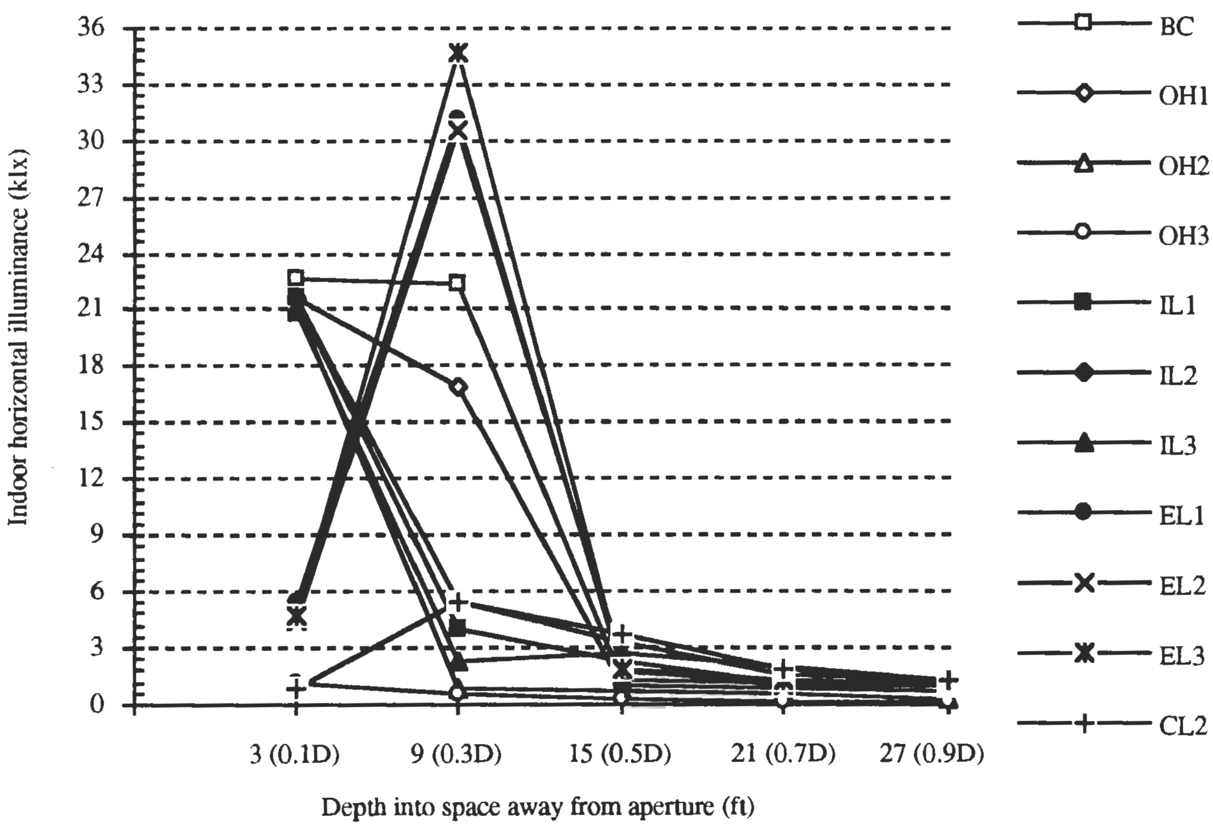

Figure 6. Illuminance levels and distribution for the base case, internal and external lightshelf cases, and an average combined lightshelf case.

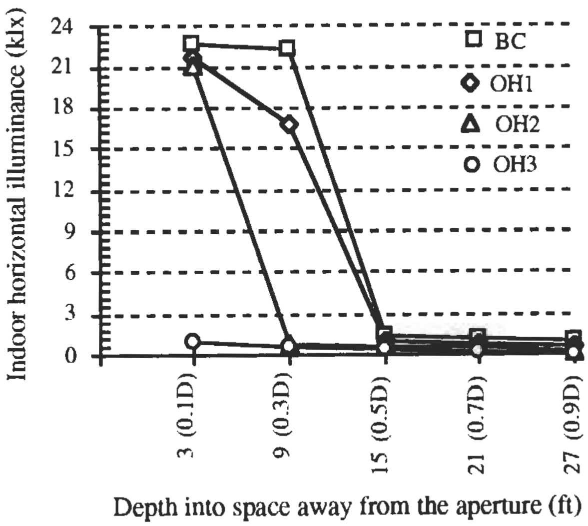

Figure 7. Illuminance levels and distribution for the base and the three overhang cases.

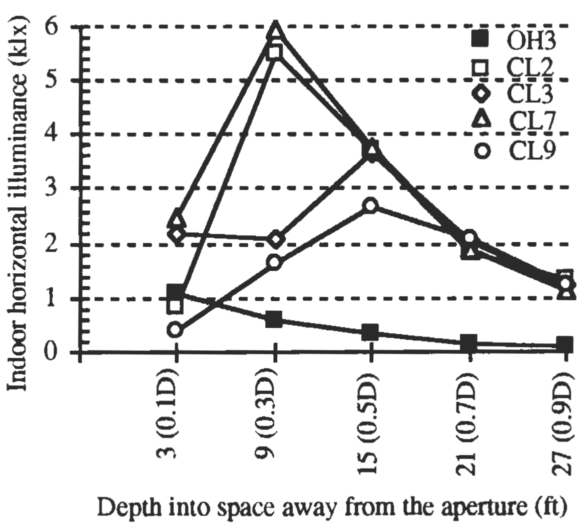

Figure 8. Illuminance levels and distribution for OH3 and the selected lightshelf cases.

Table 11. Daylight Glare Index (DGI) and variation in DGI for the selected cases with respect to OH3 case.

Case	DGI	DGI Variation	DGI Improvement (%)
OH3: (12)	18.0	0.0	0.0
CL2: (8/6)	17.6	-0.4	2.2
CL3: (12/9)	17.6	-0.4	2.2
CL7: (12/6)	17.7	-0.3	1.7
CL9: (8/9)	17.9	-0.1	0.6

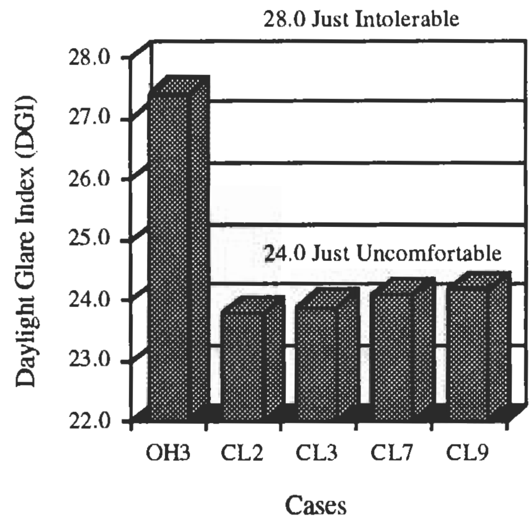

Figure 9. Daylight Glare Index (DGI) for selected cases.

CONCLUSION

The data from the model experiment for the daylighting evaluation in this paper is based on the low solar altitude angle of 30° and the below average outdoor daylight availability that represents winter season. This has played a major role on shaping the results of the experiment. In terms of adequate lighting levels, uniform distribution and reduction of glare discomfort, these results show that the best cases for the south aperture of a multi-story office buildings are the ones with combined lightshelf daylighting delivery system. Among these systems, the results also show that the best cases are those which have an exterior shelf depth of 2 to 3 times the height of the view aperture as well as an interior shelf depth of also 2 to 3 times the height of the daylight aperture. However, modifications to these results are expected when the rest of the model experiment for the daylighting evaluation is conducted for solar altitude angles of 45°, 60° and 75°. Furthermore, the energy analysis results of the research will be published in the near future.

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