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Evaluation of Light Shelf Performance Detected in Overcast Sky, on Different Latitudes, in Clear Sky, in Natural Lighting

Cüneyt KURTAY[1,♠], Okay ESEN[2]

[1] *Gazi University, Faculty of Architecture, Ankara, Turkey, kurtay@gazi.edu.tr*

[2] *Gazi University, Faculty of Architecture, Ankara, Turkey, okay.esen@gazi.edu.tr*

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ABSTRACT

The subject of this study is both determining the effect of location on earth and evaluating the effect of interior height to the position & dimension of light shelf used in natural lighting according to latitudes. After detecting the most suitable condition & dimension of light shelf for related latitude (0°) & interior height (300 cm) in CIE* standard overcast sky, the effects of the light shelf is evaluated in CIE standard clear sky on different directions in this paper. Calculations will be done for every determined latitudes and for different office heights. This study aims to guide the right light shelf application for different latitudes on earth.
*CIE = International Commission On Illumination

Keywords: *Light shelf, daylight simulation, CIE standard overcast sky, CIE standard clear sky, natural lighting*

1. INTRODUCTION

Light shelves are one of the improved daylight systems. Light shelves help to improve illuminance quantity within desired levels [1] and contribute energy saving by using daylight [2]. In addition to that, light shelves help to diminish environmental pollution caused by the fossil sourced energy usage & minimize psychological, physiological, visual discomforts caused by artificial lighting [3]. Correct application of light shelves provides homogenous distribution of exterior light into the room, convey daylight interiors & prevent glare by controlling the transfer of daylight, affect the quantity of interiors' illuminance.

The aim of this study is determining the effect of location on earth and evaluating the effect of room height to the position & dimension light shelf applied on a sample office unit with standard window dimension. After detecting the most suitable condition & dimension of light shelf for related latitude & room height in CIE standard overcast sky, the effects of the light shelf have been evaluated in CIE standard clear sky on different directions.

Some researches about daylight systems are summarized below:

"Improving the Daylighting Conditions of Existing Buildings: the benefits and limitations of integrating anidolic daylighting systems using the American classroom as a model" thesis by KLEINDIEST Sian A. aims to measure the effectiveness of anidolic lighting system applied in classrooms of an existing structure [4].

"Daylight in Facade Renewal: Using new metrics to inform the retrofitting of aging modern-era facade types" thesis by RICE Edward O. compares the effect of new daylight systems by integrating them into existing buildings in MIT campus area [5].

♠Corresponding author, e-mail: kurtay@gazi.edu.tr

"A Parametric Investigation of The Influence of Atrium Facades on the Daylight Performance Of Atrium Buildings" thesis by SAMANT Swinal aims to measure the daylight performance of atrium buildings [6].

"The Soralux Daylighting System: Passive Solar Illumination for Deep-Plan Building Spaces" thesis by THUOT Kevin W. aims to determine the effect of Soralux Daylight system for deep plan building spaces[7].

There is no research about the "Evaluation Of Light Shelf Performance Detected In Overcast Sky, On Different Latitudes, In Clear Sky, In Natural Lighting" is coincided in literature.

2. METHOD

Preparing suitable conditions and making calculations for the purpose of this study is the subject of this part (Figure 1).

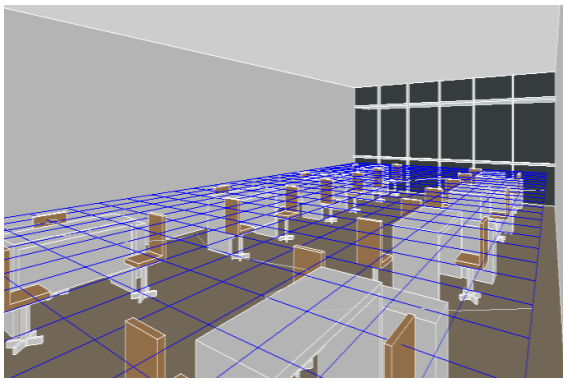


Figure 1. Sample Office, sensor placement on 75 cm height and light shelf on facade.

Although the calculations are done for 0° latitude in this paper. It is planned that calculations will be done for all 0, 15, 30, 45, 60, 75 latitudes. Outline about this study is as follows:

Determination of Design Sky Illuminance
Determination of sample Office Dimensions
Determination of materials and light reflection values for the sample Office
Determination of sensor placement
Determination of light shelf position-size and light shelf placement table
Sample Application

2.1. Determination of Design Sky Illuminance

Design sky illuminance (DSI) is the sky luminance level that is exceeded 85 percent of the time between the hours of 9 a.m. and 5 p.m. throughout the working year. This is a conservative design value for daylighting analysis [8]. Once the design sky illuminance has been determined for a particular site, the product of the daylight factor and the design sky illuminance approximates the illuminance that should be exceeded 85% of the working hours [9]. The design sky illuminance for London is 5000 lx and in a specific point of a sample room with %6 daylight factor is above 300 lx (5000lx x %6 = 300lx) for 85% of working hours between 9 a.m. and 5 p.m. in London.

Latitude is the main determinative of daylight illuminance. Some of the design sky illuminance values according to latitudes are as follows; London-52°-5000 lx, Hobart-43° -5500 lx, Sydney-33°-8000 lx, Brisbane-27°-10000 lx, Darwin-12°-15000 lx, Nairobi-1°-18000 lx[10]. Figure 2.a. represents the mentioned design sky illuminance values as a graphic

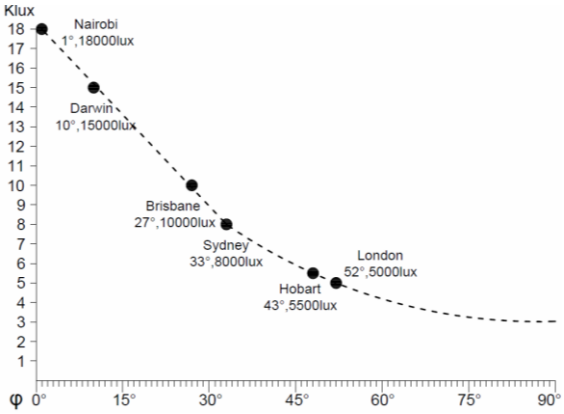


Figure 2.a. DSI values [10] as a graphic

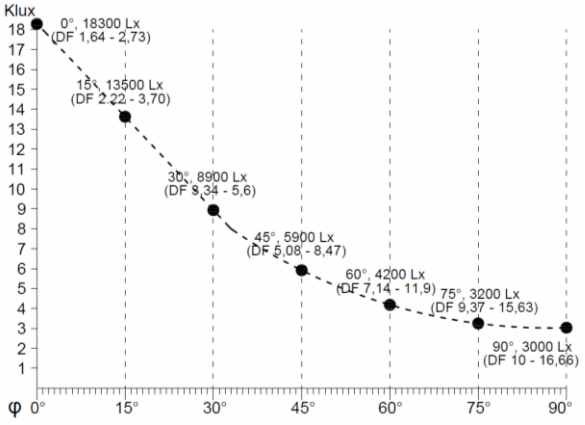


Figure 2.b. DSI values according to latitudes

Calculations will be done for all 0°, 15°, 30°, 45°, 60°, 75° latitudes at the end of the study. Design sky illuminance values about these latitudes are shown in figure 2.b. 500 lx illuminance level is recommended for writing, reading, data processing activities in offices by European Standard EN 12464-1 [11].The allowed illuminance differences are defined by illuminance uniformity. In the task area of an office, the illuminance uniformity (Uo) shall be not less than the minimum uniformity value of 0.60 according to EN 12464-1. So 300 – 500 lx interval has been determined as comfort illuminance interval for reading. DF values for desired

illuminance intervals according to the latitudes are shown in figure 2.b. 1,64-2,73 daylight factor interval (equals to 300-500 lux interval for 18300 lx) is used for 0° latitude related with this paper.

The maximum daylight illuminance value above 300 lx is limited to 900 lx to prevent glare as these levels exceed three times the recommended values [12].

2.2. Determination Of Sample Office Dimensions

High length/width ratio dimensioned office unit is needed to observe the distribution of daylight to interiors. Therefore; an office unit with 8 meter width, 14 meter length is planned. Sample office unit is chosen from mid, 6th level of 14 floor office building for the calculation. Sample office building without obstacles around it is shown in figure 3.

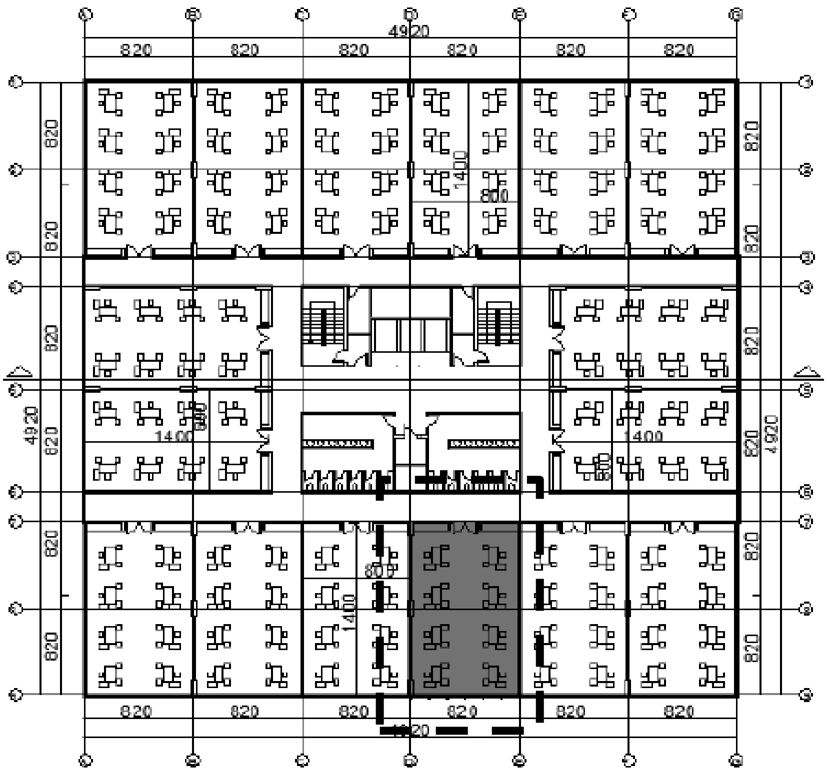


Figure 3. Typical Floor Plan

The selected typical office unit is seen above in figure 3.High length/width ratio dimensioned office unit is chosen for detecting the effect of light shelf about daylight distribution to interiors.

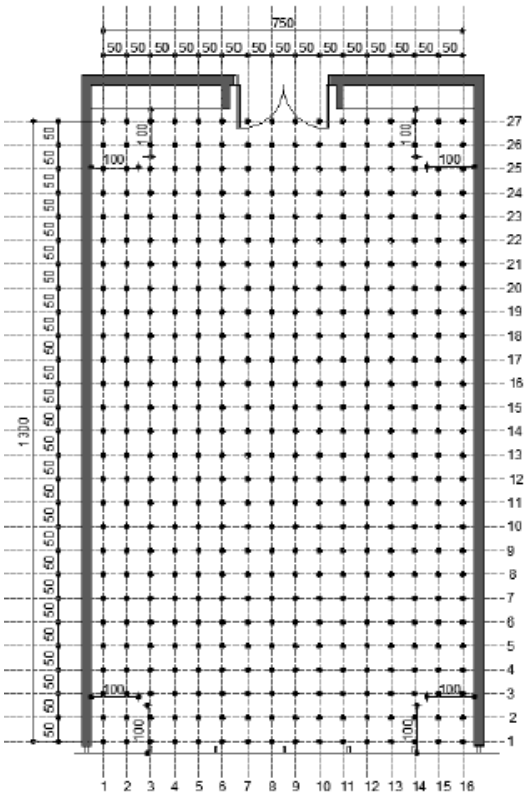
2.3. Determination Of Materials And Light Reflection Values For The Sample Office Unit

Most common materials for offices like aluminium profiles, double glazing facade systems are used in the sample office unit. Materials used in office furnishing and light reflectance (ρ) of these materials are; MDF desk, board (ρ: 0,7), wooden door (ρ: 0,7), aluminium seat construction (ρ: 0,75), fabric part of the seats (ρ: 0,4), carpet floor (ρ: 0,4), painting over gypsum board Wall (ρ: 0,7), gypsum board ceiling (ρ: 0,8), composite light shelf (ρ: 0,8), aluminium profile (ρ: 0,75), double glazing transmittance: 0,643. Materials used in exterior are; sidewalk (ρ: 0,75), greenery (ρ: 0,4) [13].

2.4. Determination Of Sensor Placement

Sensors used for calculating daylight illuminance differences according to the placement and size of light shelf are located at 75 cm task area above the floor [12]. The distance between grids have to be under 60 cm according to Leed v4.0 [14]. Sensor grid distance is determined as 50cm for providing continuity and calculation precision.

The total number of sensors used for calculation are 432 (Figure 4).



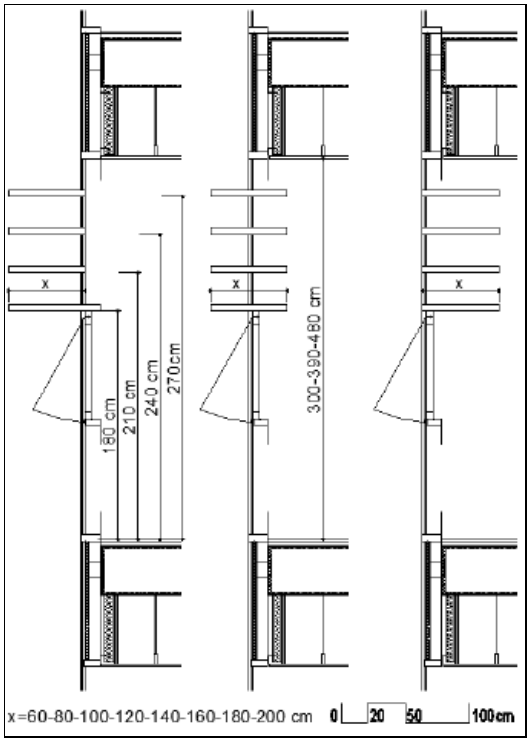


Figure 4. Sensor placement

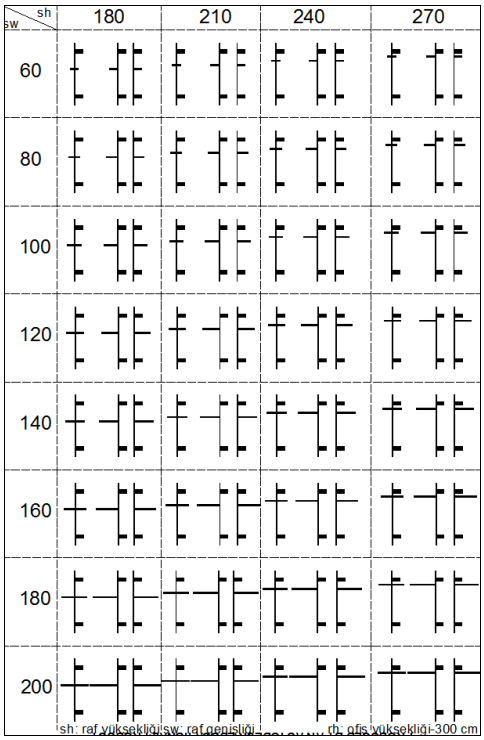


Figure 5. Placement variations for the 60 cm width light shelf on the left, light shelf placement variation table for the calculation on the right.

2.5. Determination Of Light Shelf Position-Size And Light Shelf Placement Table

Varying placement of 60 cm width light shelf is shown above (figure 5-on the left) to determine the daylight effectiveness as a sample. First light shelf is located exterior, 180 cm from the floor, above the eye level. Other light shelf variations are located exterior, centre and interior of the facade at 180, 210, 240, 270 cm height from the floor for 3 meter height office unit.

Light shelf placement table (Figure 5-on the right): Daylight sensor values are calculated for each exterior, centre and interior position of 60, 80, 100, 120, 140, 160, 180, 200 cm width & 180, 210, 240, 270 cm height light shelf for 0° (96 different variations for 3 meter Office height). Dimension of light shelf decreased by 10 cm for increasing the precision. (e.g.: Light shelf up-down to 10 cm, interior-exterior to 10 cm.) This process will be repeated for the 390 cm & 480 cm height offices by increasing light shelf level 30 cm.

2.6. Sample Application

Two different sky types are used for evaluating the effect of light shelf for comparison.

First one is the CIE standard overcast sky used for calculating the DF values for %85 of throughout the working year connected with design sky illuminance values and second one is the CIE standard clear sky used for evaluating the effect of 4 main directions

(North, South, East, West) and time according to the light shelf position & dimension that was determined in CIE standard overcast sky. It is planned that the calculations are done for mid time of the day (12: 00), at solstice time zone (21stJune and 21st December) for 4 main directions in CIE standard clear sky type. Time based measured weather data like IWEC (International Weather for Energy Calculations), CWEC (Canadian Weather for Energy Calculations) is used for CIE standard clear sky calculations [15].

The suitable light shelf size & position for 0° latitude and 3 metre height office unit is detected and analysed in this stage of study. The other variety of conditions will be continued within doctorate thesis.

DF interval is determined 1,64 – 2,73 on 0° latitude with 18300 lx design sky illuminance for 300-500 lx comfort daylight illuminance levels. Daylight illuminance values are evaluated within this interval. After calculating the effect of all light shelf varieties (mentioned in 2.5. part of this paper) for desired daylight factor interval on 0° latitude, exterior light shelf with 160 cm width & 240 cm above from the floor gives the best results. Daylight distribution to interiors with & without light shelf is seen in figure 6.

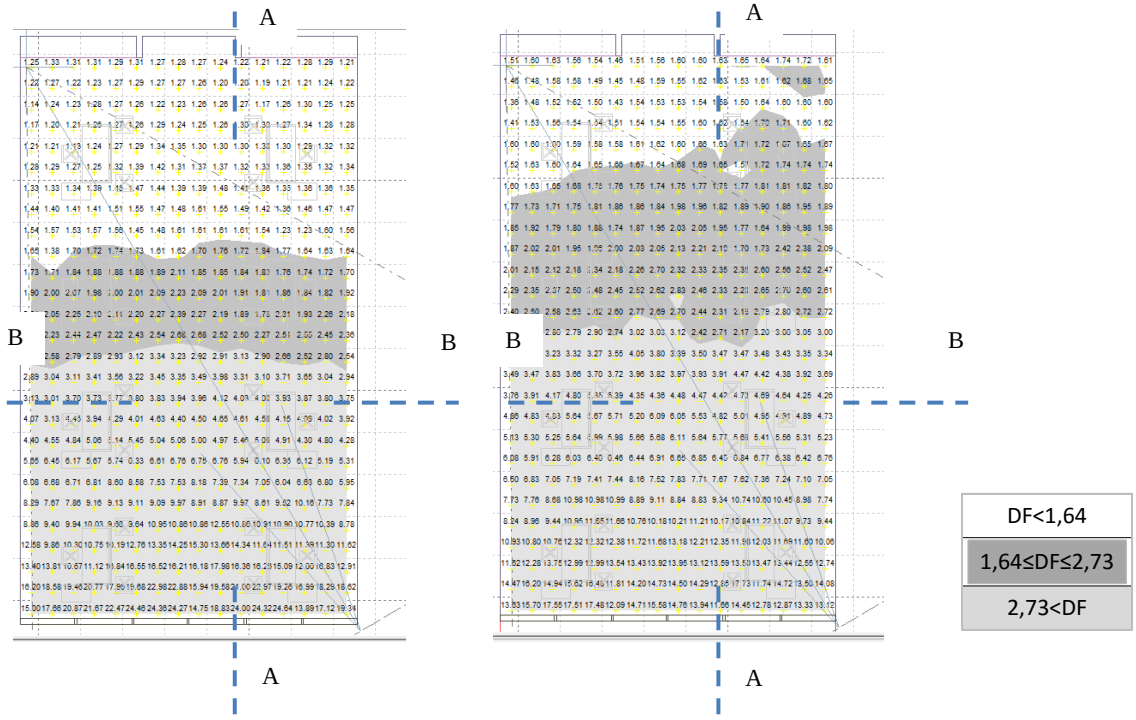


Figure 6. Distribution of daylight interiors with & without light shelf.

3. EVALUATION OF CONDITIONS WITH & WITHOUT LIGHT SHELF

Evaluating the comparison of sample office unit with and without light shelf is done in this part of the study. Comparison criteria's are as follows:

3.1. For The CIE Standard Overcast Sky

3.1.1. Comparison The Daylight Values, Distribution & Percentage Of Conditions With & Without Light Shelf

Table 1. Differences in percentage of sensor value intervals for with and without light shelf conditions on CIE standard overcast sky.

Position	**DF**	**Within(1,64≤DF≤2,73)**		**Above(1,64≤DF,max4,92)**	
	(from-to)	Sensor numbers	(%)	Sensor numbers	(%)
Without light shelf	1,64-2,73	81	18,75	147	34,03
With light shelf	1,64-2,73	136	31,48	205	47,45
The ratio of change	1,64-2,73	55	12,73	58	13,42

DF = Daylight Factor

432 sensors are placed above 75 cm from floor in modelled office unit for this calculation. The number and percentage of sensors for both with and without light shelf conditions are shown above (Table 1.) Daylight factor values between 1,64-2,73 represents the desired daylight illuminance intervals (300-500 lx) and daylight factor values above 1,64 represents the daylight illuminance values above 300 lx for sample office unit in this study. Maximum daylight illuminance value is limited to 900 lx (DF=4.92) to prevent glare. It is seen that there are 81 sensors without light shelf and 136 sensors with light shelf for desired daylight illuminance value intervals from the table. In addition to that the number of sensors above 300 lx are 147 without light shelf and 205 with light shelf. Numerical and percentage differences between conditions with and without light shelf are as seen Table 1 above.

Distribution of daylight factor values in A-A & B-B sections are shown below for the conditions with and without light shelf.

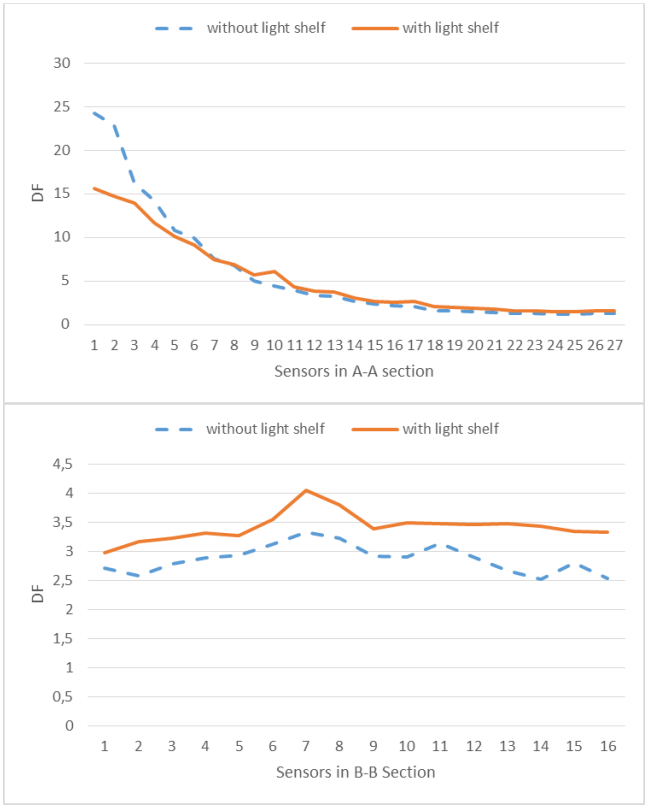


Figure 7. DF value distributions in A-A and B-B sections for with and without light shelf conditions.

However the daylight illuminance transitions from window to interiors are sharp without light shelf condition, the transitions become smoother with light shelf as shown in A-A section (Figure 7). It is seen from the A-A section(Figure 7) that light shelf contributes to the desired illuminance intervals, especially from the 14th sensor at window side. Moreover, light shelf helps both improving interior daylight levels and decreasing undesired low level daylight values deep side of the office. B-B section passes from 7,5 meter inner and parallel to the window surface. It is observed from the B-B section that daylight factor intervals are increased inner parts of the office unit by light shelf condition.

Volumetric distribution of daylight factor (DF) with and without light shelf condition is as seen below (Figure 8.) Perspectives are rendered by Radiance software.

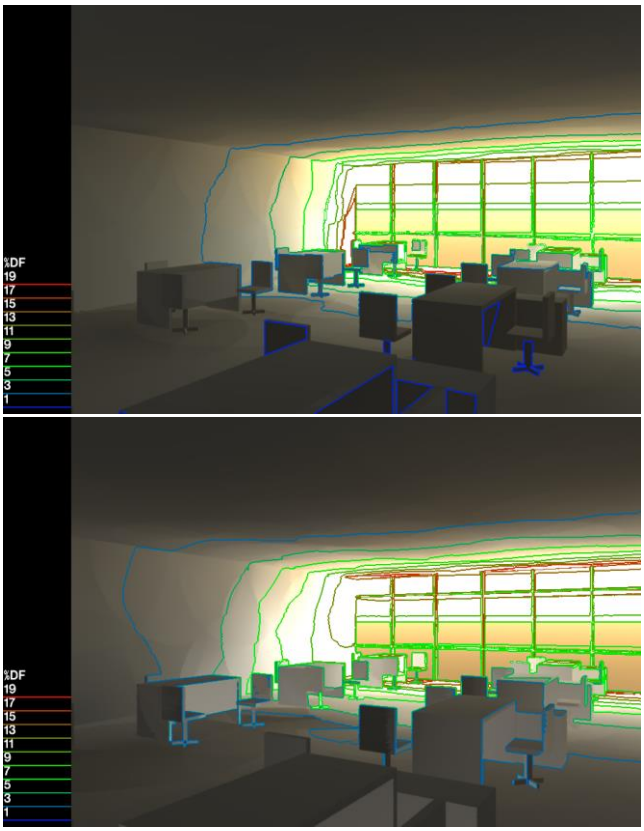


Figure 8. Volumetric distribution of DF with (right) and without (left) light shelf.

Volumetric distribution of daylight shows parallel condition as plan view. Although the daylight illuminance transitions are too sharp without light shelf condition, the transitions become smoother with light shelf from window to interiors.

3.1.2. Maximum Comfort Illuminance Levels According To Light Shelf Width

Table 2. Maximum comfort Illuminance levels according to the width of light shelf

		shelf height(cm)											
		180			210			240			270		
position		exterior	center	interior	exterior	center	interior	exterior	center	interior	exterior	center	interior
shelf width(cm)	60						X						
	80										X		
	100										X		
	120							X					
	140							X					
	160							X					
	180							X					
	200							X					

Table 2. indicates the optimum position and height of varying width of light shelves used in this study to provide the best daylight levels. e.g. The 100 cm wide light shelf may be used in sample office have to be positioned 270 cm height from the floor and exterior of the facade.

3.1.3. Maximum Comfort Luminance Levels According To Light Shelf Height

Table 3. Maximum comfort luminance levels according to light shelf height.

		shelf height(cm)											
		180			210			240			270		
position		exterior	center	interior	exterior	center	interior	exterior	center	interior	exterior	center	interior
shelf width(cm)	60						X						
	80												
	100												
	120												
	140		X								X		
	160							X					
	180												
	200												

Table 3. indicates the optimum position and width of varying height of light shelves used in this study to provide the best daylight levels. e.g. The 180 cm height, light shelf may be used in sample office have to be 140 cm wide and positioned center of the facade.

3.1.4. Maximum Comfort Illuminance Levels According To Centre Light Shelf Position

Table 4. Maximum comfort illuminance levels according to centre light shelf position.

		shelf height(cm)											
		180			210			240			270		
position		exterior	center	interior	exterior	center	interior	exterior	center	interior	exterior	center	interior
shelf width(cm)	60								X				
	80								X				
	100		X										
	120								X				
	140		X										
	160								X				
	180		X										
	200								X				

Table 4. indicates the optimum height and width of varying centre light shelf positions used in this study to provide the best daylight levels. e.g. The 120 cm wide, centre light shelf may be used in sample office have to be positioned 240 cm height from the floor.

3.1.5. Maximum Comfort Illuminance Levels According To Exterior Light Shelf Position

Table 5. Maximum comfort illuminance levels according to exterior light shelf position.

		shelf height(cm)											
		180			210			240			270		
position		exterior	center	interior	exterior	center	interior	exterior	center	interior	exterior	center	interior
shelf width(cm)	60	X											
	80										X		
	100										X		
	120							X					

	140							X					
	160							X					
	180							X					
	200							X					

Table 5. indicates the optimum height and width of varying exterior light shelf positions used in this study to provide the best daylight levels. e.g. The 160 cm wide, exterior light shelf may be used in sample office have to be positioned 240 cm height from the floor.

3.1.6. Maximum Comfort Illuminance Levels According To Interior Light Shelf Position

Table 6. Maximum comfort illuminance levels according to interior light shelf position.

		shelf height											
		180			210			240			270		
position		exterior	center	interior	exterior	center	interior	exterior	center	interior	exterior	center	interior
shelf width	60						X						
	80												X
	100									X			
	120									X			
	140												
	160						X						
	180						X						
	200			X									

Table 6. indicates the optimum height and width of varying interior light shelf positions used in this study to provide the best daylight levels. e.g. The 60 cm wide, interior light shelf may be used in sample office have to be positioned 210 cm height from the floor. The interior position of140 cm width light shelf is not suitable for this condition.

3.2. Comparison The Daylight Values, Distribution & Percentage Of Conditions With & Without Light Shelf For The CIE standard clear sky

The evaluation of constant light shelf size and position in CIE standard clear sky is the subject of this part. The position and size of light shelf that was determined by CIE standard overcast sky is used for the calculation.

Calculations are done for different office height varieties on related latitudes, 4 main directions (North, South, East, West), solstice time zone(21stJune and 21st December) and in the mid time of day(12:00) for both with and without light shelf conditions on the CIE standard clear sky. So, the distribution of daylight into the office in clear sky type can be determined for a year. The locations according to the latitudes are shown below (Table 7.)

Table 7. List of latitudes and locations used for calculations about this study.

Latitude(°)	**Location**
0	QUITO, ECUADOR
15	PANJIN, INDIA
30	SHANGAI, CHINA
45	MILANO, ITALY
60	WHITEHORSE, CANADA
75	RESOLUTE, CANADA

The distribution of daylight with and without light shelf is compared for Quito, Ecuador on 0° latitude (Table 7.), 300 cm office height in this part of study.

The sensor values for both with and without light shelf for these conditions in CIE standard clear sky are shown below (Table 8).

Table 8. Differences in percentage of sensor numbers connected with desired daylight factor values for with and without light shelf conditions on CIE standard clear sky

ho=300 CM hour= 12:00		**latitude**		**0°**					
		date		D:21.June			D:21.December		
		condition		Without lightshelf	With lightshelf	**change**	Without lightshelf	With lightshelf	**change**
direction	S	300 lx<d.i.<500 lx	Sensor no	81	122	41	119	128	9
			%	18,75	28,24	**9,49**	27,55	29,63	**2,08**
		300 lx< d.i. .(max 900lx)	Sensor no	146	203	57	193	190	-3
			%	33,80	46,99	**13,19**	44,68	43,98	**-0,69**
	E	300 lx<d.i.<500 lx	Sensor no	77	126	49	82	125	43
			%	17,82	29,17	**11,34**	18,98	28,94	**9,95**
		300 lx< d.i. .(max 900lx)	Sensor no	143	201	58	148	197	49
			%	33,10	46,53	**13,43**	34,26	45,60	**11,34**
	N	300 lx<d.i.<500 lx	Sensor no	115	111	-4	106	111	5
			%	26,62	25,69	**-0,93**	24,54	25,69	**1,16**
		300 lx< d.i. .(max 900lx)	Sensor no	185	181	-4	181	183	2
			%	42,82	41,90	**-0,93**	41,90	42,36	**0,46**
	W	300 lx<d.i.<500 lx	Sensor no	76	118	42	83	124	41
			%	17,59	27,31	**9,72**	19,21	28,70	**9,49**
		300 lx< d.i. .(max 900lx)	Sensor no	148	192	44	156	195	39
			%	34,26	44,44	**10,19**	36,11	45,14	**9,03**

Calculations are done for total 432 sensors in office unit. The number and percentage (%) of sensors with and without light shelf conditions for 4 main directions, 300 cm height office unit of 0° latitude are shown above (Table 8.). The daylight illuminance (d.i.) values are evaluated between desired 300-500 lx and above 300 lx. The Usage of table can be sampled as follows, the sensor number is 76 & sensor percentage is %17,59 without light shelf and sensor number is 118 & sensor percentage is %27,31 with light shelf and the difference between these two values are 42 & %9,72 between 300-500 lx, on west direction, at June21$^{st.}$

4. RESULTS AND RECOMMENDATIONS

The aim of this study is both determining the effect of location on earth and evaluating the effect of interior height to the position & dimension of light shelf used in natural lighting according to latitudes.

The effect of light shelf is evaluated for 0° latitude, 300 cm height sample office unit. First determinations of design sky illuminance (18300 lux for 0° latitude) , dimensions of office unit (8m x14m), materials and light reflection values of materials, placement of sensors (75cm from the floor) and placement of variety of light shelves about the calculation are identified. Secondly simulation is done in CIE standard overcast sky and it is determined that 240 cm height positioned, 160 cm width exterior light shelf is suitable for modelled office unit in these conditions.

The variety light shelf dimensions and placements are examined to achieve the best placement and dimensioning of light shelf. While calculations are in progress, it is determined that dissimilar light shelf dimensions are effective in different placement of shelves. These differences are summarized by tables in 3rd part of this paper (3.1.2. to 3.1.6.). In addition to that, the incorrect placement of light shelf diminishes desired daylight illuminance values instead of improving daylight quality.

In CIE standard overcast sky, it is determined that light shelf improves sensor numbers, that represents the desired daylight illuminance values (300lx - 500 lx), %12,73 contrary without light shelf condition from the calculations and light shelf increases sensor numbers %13,42 for the daylight illuminance values above 300 lx. Daylight illuminance values pass only the middle part of sample office unit without light shelf. The distribution of daylight illuminance values can be passed through the deep corners of the office room with light shelf. Moreover distribution of desired daylight illuminance levels and illuminance levels above 300 lux are increased with light shelf.

In CIE standard clear sky, the calculations are done for 4 main directions (North, South, East, West), solstice time zone (21stJune and 21st December) and in the mid time of day (12:00) for both with and without light shelf conditions. Desired daylight illuminance value interval changes %9,49 in South, %11,34 in East, %-0,93 in North, %9,72 in West on June 21st and %2,08 in South, %9,95 in East, %1,16 in North, %9,49 in West on December 21st with light shelf contrary to without light shelf. The effectiveness of light shelf according to directions from higher to lower are East, South, West and North within desired daylight illuminance value interval. Daylight illuminance values above 300 lx to 900 lx changes %13,19 in South, %13,43 in East, %-0,93 in North, %10,19 in West on June 21st and % -0,69 in South, % 11,39 in East, %0,46 in North, %9,03 in West on December 21st with light shelf contrary to without light shelf. The effectiveness of light shelf according to directions from higher to lower are East, West, South and North for above 300 lux daylight illuminance. Total percentage change connected with daylight illumination values are East, West South, and North respectively for 300 cm height office unit on 0° latitude in CIE standard clear sky.

This part of the study is done for 300 cm sample office unit of 0° latitude. The calculations will be done for 300 cm, 390 cm, 480 cm office height on 0°, 15°, 30°, 45°, 60°, 75° latitude to determine the effect of location and height of the office unit at the end of the work. This study continues within doctorate thesis scope.

CONFLICT OF INTEREST

No conflict of interest was declared by the authors.

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