Contemporary Engineering Sciences, Vol. 7, 2014, no. 21, 987 - 995
HIKARI Ltd, www.m-hikari.com
http://dx.doi.org/10.12988/ces.2014.49124

A Study on Optimal Variable of Light Shelf Based on the Gambrel Ceiling and Pyramid Ceiling for the Advanced Daylight Performance

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Abstract

Due to recent needs of studies on the energy issue, various studies regarding the light shelf which is a solution for lighting energy reduction are being carried out continuously. However, previous studies regarding the light shelf only focus on the performance evaluation according to simple variables of light shelf, so these studies cannot be used as preliminary data for light shelf design. Therefore, the purpose of this study is to carry out the simulation performance evaluation of light shelf according to the Light-Shelf, Gambrel Ceiling and Pyramid Ceiling which are special shape of space and to draw proper solutions. On the winter solstice, optimal light shelf dimensions were equally drawn to be 1.2m and less in width and 10˚ in angle, in consideration of lighting performance and uniformity factory, irrelevant of ceiling height, in the case of gambrel ceiling and pyramid ceiling.

Keywords: Light-Shelf, Gambrel Ceiling, Pyramid Ceiling

1 Introduction

Various studies proving the effectiveness of the light shelf which is one of solutions for the issue of increase in lighting energy consumed in buildings have been carried out in the aspect that it brings natural light from outside into indoors through the reflection. However, studies for finding a proper light shelf according to the shape of indoor space which is the physical characteristics are insufficient. Therefore, the purpose of this study is to find a proper light shelf for the shape of indoor space.

In this study, the shape of ceiling surface was limited in the aspect that the light shelf brings natural light into indoor space through the reflection on the ceiling surface, and especially, this study was carried out for the shape of Gambrel Ceiling and Pyramid Ceiling. Also, the range of study was limited to winter sols and Radiance, the illumination analysis and simulation program, was used for the performance evaluation.

2 Set up of Performance Evaluation of Light shelf for Gambrel Ceiling and Pyramid Ceiling

2.1 Setup of Inclined Ceiling and Light shelf

Table 1 includes contents regarding the setting of the Light shelf. And table 2 includes contents regarding the setting of the gambrel ceiling and pyramid ceiling. The spatial dimensions are 3m(width)*3m/6m(depth)*2.5m(height) in this research, and the research was conducted by restricting to the external shape of light shelf with the most excellent performance in terms of light shelf type[2].

Table 1. Setup of Gambrel Ceiling and Pyramid Ceiling

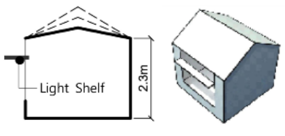
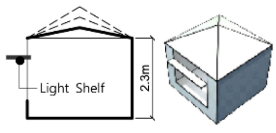
 Setup of Gambrel Ceiling	- The bent point of gambrel ceiling is generated at the intermediate point of the space, and maximum indoor ceiling height point is the bent point of the ceiling. - The shape of gambrel ceiling reflects light shelf's lighting performance evaluation by increasing maximum indoor spatial ceiling height to 2,600mm, 2,900mm and 3,200mm, based on 2,300mm of minimum indoor spatial ceiling height (lighting side, rear part of lighting window).
 Setup of Pyramid Ceiling	- The point of the highest height of pyramid ceiling is at the dead center in terms of plane. - The pyramid ceiling type reflects light shelf's lighting performance evaluation by increasing indoor spatial dead center's maximum ceiling height to 2,600mm, 2,900mm and 3,200mm, based on 2,300m of minimum indoor spatial ceiling height (lighting side and rear part).

Table 2. Setup of Light shelf

Reflectivity	Ceiling:74.99%, Wall:55%, Floor:25.1%		
Window Area Ratio / Glass Material	2.0m x 1.8m / Pair-glass with 12mm thickness, penetration ratio:80.82, clear colors		
Height	1.8m	Angle	0˚, 10˚, 20˚, 30˚
Width	0.3m, 0.6m	Reflectivity	85.77%

2.2 Position for Measurement of Illuminance for Performance Evaluation

The location of illuminance calculation is as shown in Figure 1, and the height is set as 0.75m above the floor based on related research. For the drawing of spatial depth meeting standard illuminance, 400lx, this research addressed Y2~Y5, which are directly affected by the light shelf in performance evaluation. Concerning uniformity factor, minimum illuminance and mean illuminance on all the illuminance sensor values from Y1 to Y6 were calculated[3].

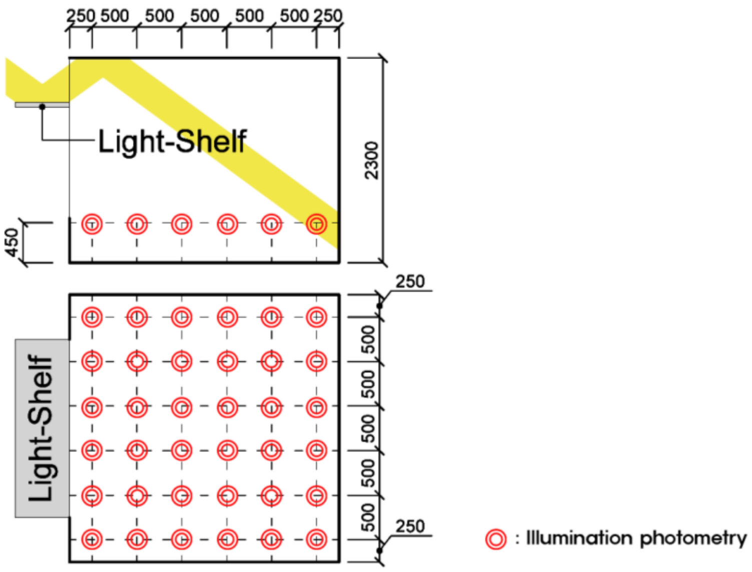


Figure 1. Illumination photometry for Light shelf's performance evaluation

3 Performance Evaluation of Light shelf for Gambrel Ceiling and Pyramid Ceiling

3.1 Performance Evaluation for Light Shelf

The methods to analyze light shelf performance evaluation, according to gambrel ceiling and pyramid ceiling, and to draw an optimal measure are presented below:

First, for the performance evaluation analysis and optimal measure drawing through gambrel ceiling and pyramid ceiling and light shelf variables, indoor illuminance values demonstrated by the set variables above were calculated. Also, this research drew spatial depth meeting standard illuminance, 400lx, upon visual work, targeting small objects, compared to general brightness. Based on the illuminance measuring location set above, this research conducted the lighting performance evaluation of light shelf by drawing mean indoor spatial illuminance and uniformity factor demonstrated by spatial type and light shelf variables.

Second, because the light shelf induces indoor light environment improvement by introducing external natural light deep inside through the reflection side of the light shelf- the reflection of indoor space ceiling, the type of ceiling, where the first reflection is conducted, is an important factor directly related to light shelf performance. This research drew the types of light introduction and reflection by ceiling type and light shelf variables, and used them as analysis data.

Third, this research defined indoor floor shadowed by the light shelf, namely, the part where natural light is introduced indoors by reflection out of the reflection plate area decided by awning area and light shelf width, as reflection area. For lighting performance analysis by spatial type and light shelf, awning area and reflection area were drawn. Since this research limited research scope to the type of gambrel ceiling and pyramid ceiling, no differences of awning area and reflection area are shown by the change in indoor spatial type. However, awning area difference is shown by light shelf variables. The awning area and reflection area created by light shelf are judged to be important factors, since they are related to indoor spatial uniformity factor and light amount introduced indoors. Therefore, this research drew the awning area, according to light shelf variables, and used it as the analysis data for light shelf performance evaluation.

3.2 Light Shelf performance evaluation based on the Gambrel Ceiling and Pyramid Ceiling during winter solstice

On the winter solstice, performance evaluation by the gambrel ceiling type and light shelf variables is as follows:

Firstly, on the winter solstice as shown in Table 3[1], the spatial depth meeting standard illuminance upon non-installation and installation of light shelf is demonstrated equally at 3m, irrelevant of ceiling height in terms of the gambrel ceiling type having 3m of spatial depth. Concerning the gambrel ceiling type having 6m of spatial depth, the spatial depth meeting standard illuminance upon non-installation and installation of light shelf is demonstrated equally at 5.75m, irrelevant of indoor ceiling heights, 2.45m, 2.6m and 2.75m. Upon installing light shelf at 2.45m, 2.6m and 2.75m of indoor ceiling heights, the spatial depth is demonstrated equally at 3.75m∼ 5.75m, according to changes in width and angle of the light shelf. Therefore, no efficiency in improving lighting performance is judged to be shown. In the case of gambrel ceiling, the increase of light shelf width is demonstrated appropriately, because spatial depth meeting standard illuminance decreases. But, the increase of light shelf angle increases the spatial depth meeting the standard illuminance, which is suitable for energy use reduction. Meanwhile, upon installing the gambrel ceiling and light shelf, there is no change in spatial depth meeting the standard illuminance, according to the change of spatial height. Secondly, on the winter solstice, when installing light shelf in the gambrel ceiling type space, mean indoor illuminance is demonstrated lower, compared to the case of non-installation of light shelf, which is judged to be the result of light shelf's awning. Thirdly, as demonstrated in Table 5[1], in the case of winter solstice and gambrel ceiling type space, the uniformity factor declines, due to increase in awning area, according to the increase of light shelf width. Also, the increase in light shelf angel decreases awning area, and thus, uniformity factory tends to diminish, which needs to be considered upon light shelf design. Fourthly, on the winter solstice, optimal light shelf dimensions taking into account energy reduction and uniformity factor, irrelevant of ceiling height, are 1,200mm and less in width and 10˚ in angle in the case of gambrel ceiling.

Table 3. Light shelf performance evaluation based on the Gambrel Ceiling during winter solstice

Depth : 3m										
		Ceiling height 2.45m			Ceiling height 2.6m			Ceiling height 2.75m		
Light Shelf		S.I. (m)	A.I. (lx)	U.F.	S.I. (m)	A.I. (lx)	U.F.	S.I. (m)	A.I. (lx)	U.F.
Width	Angle									
N		3.00	18408	0.054	3.00	18347	0.052	3.00	18281	0.049
0.3	0	3.00	15638	0.066	3.00	15556	0.062	3.00	15500	0.060
	10	3.00	15649	0.065	3.00	15569	0.061	3.00	15506	0.058
	20	3.00	18387	0.054	3.00	18316	0.051	3.00	18266	0.049
	30	3.00	18362	0.052	3.00	18309	0.050	3.00	18237	0.048
0.6	0	3.00	15579	0.068	3.00	15499	0.064	3.00	15420	0.059
	10	3.00	15610	0.066	3.00	15530	0.063	3.00	15468	0.059
	20	3.00	15624	0.064	3.00	15544	0.060	3.00	15483	0.057
	30	3.00	18340	0.052	3.00	18267	0.051	3.00	18216	0.048
Depth : 6m										
Width	Angle	Ceiling height 2.45m			Ceiling height 2.6m			Ceiling height 2.75m		
N		5.75	9482	0.039	5.75	9435	0.041	5.75	9400	0.042
0.3	0	5.75	8061	0.042	5.75	8015	0.044	5.75	7984	0.046
	10	5.75	7887	0.044	5.75	8041	0.047	5.75	8008	0.048
	20	5.75	9470	0.041	5.25	7967	0.043	5.75	9383	0.042
	30	5.75	9450	0.039	5.25	7931	0.043	5.75	9356	0.040
0.6	0	5.25	7998	0.042	5.25	7969	0.043	5.25	7925	0.042
	10	5.75	7856	0.043	5.75	7821	0.044	5.75	7964	0.045
	20	5.75	8063	0.046	5.75	8030	0.046	5.75	7989	0.046
	30	5.75	9420	0.037	5.75	9377	0.038	5.75	9347	0.035

N: Light shelf not installed, S.I.: Standard illuminance satisfaction degree(m), A.I.: Average illuminance, U.F.: Uniformity factor, [shaded box] : This indicates lower score than the value estimated with no Light shelf installed, Bold: Ceiling value of uniformity factor

On the winter solstice, performance evaluation by pyramid ceiling type and light shelf variables is as follows:

Firstly, in the case of the winter solstice as shown in Table 4, the spatial depth meeting standard illuminance upon non-installation and installation of light shelf is demonstrated equally at 3m, irrelevant of ceiling height in terms of the pyramid ceiling type having 3m of spatial depth. Therefore, no improvement in lighting performance through light shelf is judged to be shown. Concerning the pyramid ceiling type having 6m of spatial depth, the spatial depth meeting standard illuminance upon non-installation and installation of light shelf is demonstrated at 5.75m, irrelevant of indoor ceiling heights, 2.45m, 2.6m and 2.75m. Upon installing light shelf at 2.45m, 2.6m and 2.75m of indoor ceiling heights, the spatial depth is demonstrated equally at 4.25m∼ 5.75m, according to changes in width and angle of the light shelf. In the case of pyramid ceiling, the increase of light shelf width is demonstrated appropriately, because spatial depth meeting standard illuminance decreases. But, the increase of light shelf angle increases the spatial depth meeting the standard illuminance, which is suitable for energy use reduction.

Secondly, on the winter solstice, when installing light shelf in the pyramid ceiling type space, mean indoor illuminance tends to be lower, compared to non-installation of light shelf. However, high mean illuminance in the case of non-installation of light shelf is generated, according to the width and angle of light shelf. Thirdly, the uniformity factor drawn on the winter solstice and from the pyramid ceiling type space does not show any regularity, according to the width and angle of light shelf, which can be a factor to be careful upon light shelf design. On the winter solstice, the indoor ceiling height, 2.6m of uniformity factor, is demonstrated higher than the ceiling heights of 2.45m and 2.75m. Therefore, the results are different from those analyzed from other ceiling types. Fourthly, on the winter solstice, optimal light shelf dimensions taking into account energy reduction and uniformity factor, irrelevant of ceiling height, are 1.2m and less in width and 10˚ in angle in the case of pyramid ceiling.

Table 4. Light shelf performance evaluation based on the Pyramid Ceiling during winter solstice

Light Shelf Width	Light Shelf Angle	Ceiling height 2.45m S.I. (m)	Ceiling height 2.45m A.I. (lx)	Ceiling height 2.45m U.F.	Ceiling height 2.6m S.I. (m)	Ceiling height 2.6m A.I. (lx)	Ceiling height 2.6m U.F.	Ceiling height 2.75m S.I. (m)	Ceiling height 2.75m A.I. (lx)	Ceiling height 2.75m U.F.
Depth : 3m										
N		3.00	18454	0.056	3.00	18411	0.052	3.00	18363	0.052
0.3	0	3.00	15675	0.069	3.00	15653	0.067	3.00	15583	0.063
	10	3.00	15694	0.068	3.00	15636	0.064	3.00	15613	0.063
	20	3.00	18430	0.055	3.00	18405	0.054	3.00	18352	0.052
	30	3.00	18397	0.053	3.00	18371	0.053	3.00	18327	0.050
0.6	0	3.00	15610	0.071	3.00	15595	0.069	3.00	15519	0.062
	10	3.00	15650	0.066	3.00	15609	0.066	3.00	15565	0.063
	20	3.00	15674	0.066	3.00	15613	0.064	3.00	15571	0.062
	30	3.00	18377	0.054	3.00	18339	0.051	3.00	18286	0.051
Depth : 6m										
N		5.75	9291	0.041	5.75	9493	0.042	5.75	9469	0.043
0.3	0	5.75	8098	0.045	5.75	8078	0.046	5.75	8054	0.047
	10	5.75	8121	0.047	5.75	8097	0.048	5.75	8063	0.048
	20	5.75	9497	0.038	5.75	9469	0.040	5.75	9449	0.043
	30	5.75	9479	0.040	5.75	9458	0.041	5.75	9438	0.039
0.6	0	5.75	8034	0.043	5.75	8014	0.044	5.75	7996	0.039
	10	5.75	8042	0.044	5.75	8046	0.042	5.75	8020	0.046
	20	5.75	8063	0.045	5.75	8085	0.047	5.75	8051	0.044
	30	5.75	9420	0.039	5.75	9431	0.037	5.75	9400	0.039

N: Light shelf not installed, S.I.: Standard illuminance satisfaction degree(m),
A.I.: Average illuminance, U.F.: Uniformity factor,
: This indicates lower score than the value estimated with no Light shelf installed, Bold: Ceiling value of uniformity factor

Table 5. Shaded and Reflection area based on the Width and Angle of Light shelf during summer solstice

Light shelf Width(m)	Light shelf Angle	Shaded area(㎡)	Reflection area(㎡)	Light shelf Angle	Shaded area(㎡)	Reflection area(㎡)
0.3 / 0.6	0°	0.600 / 1.200	0.600 / 1.200	20°	0.201 / 0.402	0.600 / 1.200
	10°	0.406 / 0.813	0.600 / 1.200	30°	0.011 / 0.021	0.000 / 0.000

4. Conclusion

This research is to build basic data for light shelf design on spatial type, and draws performance evaluation and an optimal measure according to gambrel ceiling and pyramid ceiling and light shelf variables. The findings in this research are as follows:

First, the spatial depth meeting standard illuminance upon non-installation and installation of light shelf, irrelevant of ceiling height, is demonstrated equally, in terms of 3m of spatial depth and 6m of inclined ceiling in the case of the winter solstice. However, a case that spatial depth meeting standard illuminance declines, compared to the non-installation of light shelf, occurs by the angle and width of light shelf, which is a factor to be careful. Second, on the winter solstice, mean indoor illuminance is lower in the case of installing light shelf, compared to the non-installation of light shelf on the gambrel ceiling and pyramid ceiling. This is the result of light shelf's awning, and the awning induces an increase in indoor uniformity factor. Third, in the case of the winter solstice and gambrel ceiling and pyramid ceiling spaces, the awning areas decreases, as light shelf angle increases. Due to low height on the winter solstice, the uniformity factor tends to decrease, since high illuminance light introduced indoors cannot be shaded. Fourth, on the winter solstice, optimal light shelf dimensions were equally drawn to be 1,200mm and less in width and 10˚ in angle, in consideration of lighting performance and uniformity factory, irrelevant of ceiling height, in the case of gambrel ceiling and pyramid ceiling.

This paper is a basic research on the light shelf design, which is a solution to lighting energy problem in a building. This research has significance in that light shelf's lighting performance was analyzed and an optimal measure was drawn, according to spatial type. However, this research has limitation in that it was conducted on specific context and types like gambrel ceiling and pyramid ceiling. Further research needs to be continuously carried out on various spatial types and external conditions.

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Received: August 13, 2014