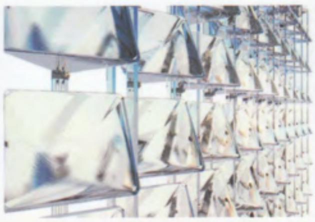
ENERGY FORUM

06 - 07 December 2012, Bressanone, Italy

Solar Building Skins




Economic Forum
Munich - Bolzano

Dynamic building envelope system: A control strategy for enhancing daylighting quality and reducing energy consumption

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Abstract

In order to meet a set of performance requirements, the notion of systems integration and dynamic performance is increasingly used in façade design. This study describes a dynamic façade system that protects from direct solar radiation and reflects glare-free sunlight to the ceiling, increasing daylight levels in areas away from the building's perimeter zone. The proposed control strategy of the system is defined as following:

a) Light shelf tilts according to the sun angle in order to direct light towards a predefined target area on the ceiling. b) Clerestory window static exterior blinds in fixed angle to support the light shelf operation. c) View window external blinds in fixed slats angle to allow visual connection to the exterior.

Advanced performance analysis is based on Radiance / Daysim simulations using a typical office space. Lighting energy consumption is estimated using continuous dimming. Results are compared to a reference static façade system to explore the impact of advanced fenestration systems on daylighting levels and electric energy consumption.

1. Introduction

Prior research on light shelves has mostly focused on the parameters, such as their dimensions and room geometry, that influence their performance [1]. Research on dynamic light shelves is relatively limited with most of the examples focusing on the dynamic character of daylighting systems [2]. Another study examined the external rotating part of a light shelf which contributes to 12% of energy saving compared to a static shelf [3]. This research will focus on the dynamic character of light shelf and its impact on the daylighting performances.

2. Evaluation study

2.1 Simulation cases

In order to assess the daylight performance of the light shelf in the matter of its ability to bring light deeper into the space, a digital model of a 7m deep office space was created. The horizontal light shelf divides the south facing window area into an upper and lower part with exterior blinds installed in both parts. To redirect light deeper into the space, the operation of the light shelf is based on its rotation according to the sun angle and the aiming point (5.62m) on the ceiling (fig. 1). The tilt angle is calculated in relation to the projected sun angle on the façade, based on equation [1]:

$$\theta=(\theta_{sun}-\omega)/2 \quad [1]$$

where θ_{sun} is the projected elevation angle and ω is a constant angle defined by the aiming point.

Figure 1: Office model section diagram

The calculated light shelf tilt angle for winter, summer solstice and fall equinox in geographical location Athens, Greece is shown in figure 2. Accordingly, tilt angles of the lower blinds are based on the balance of maximum visual contact and minimum heat gains as shown in figure 3.

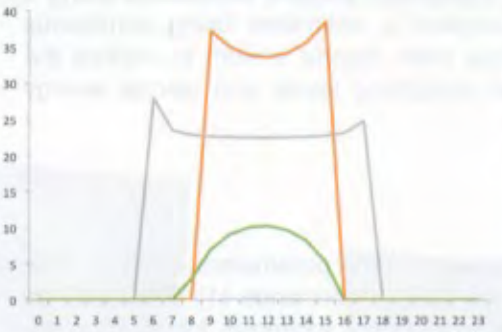

Figure 2: Sun tracking light shelf slat angle

Schedule: Light shelf			
	DST 21-Jun	DST 21-Sep	EET 21-Dec
10:00	34.9	22.5	9.1
11:00	33.8	22.5	10.0
12:00	33.6	22.4	10.2
13:00	34.1	22.5	9.7
14:00	35.6	22.6	8.2
15:00	38.4	22.7	5.3
16:00	0.0	23.1	0.0
17:00	0.0	24.8	0.0

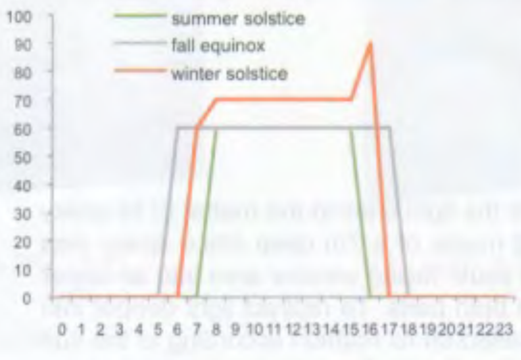

Figure 3: Automated blinds slat angle

Schedule: Automated blinds			
6:00	0	60	0
7:00	0	60	60
8:00	60	60	70
9:00	60	60	70
10:00	60	60	70
11:00	60	60	70
12:00	60	60	70
13:00	60	60	70
14:00	60	60	70
15:00	60	60	70
16:00	0	60	90
17:00	0	60	0

To allow the redirection of solar radiation at the deepest aiming point onto the ceiling, blocking direct radiation, the upper blinds are fixed at 8.1° slat angle. In order to assess the performance of the lighting systems and minimize the computational time, two series of annual simulations were performed in Daysim:

A: Upper part of the window: (lower window was excluded from the simulations)
Light shelf angle: 0°, 2°, 4°, 6°, 8°, 10°... 40°, 42°, 44° Upper blinds angle: 8,1°
B: Lower part of the window: (upper window was excluded from the simulations)
Light shelf angle: 0°, 10°, 20°, 30°, 40°, 44° Lower blinds: 0°, 10°, 20°, 30°, 40°, 50°

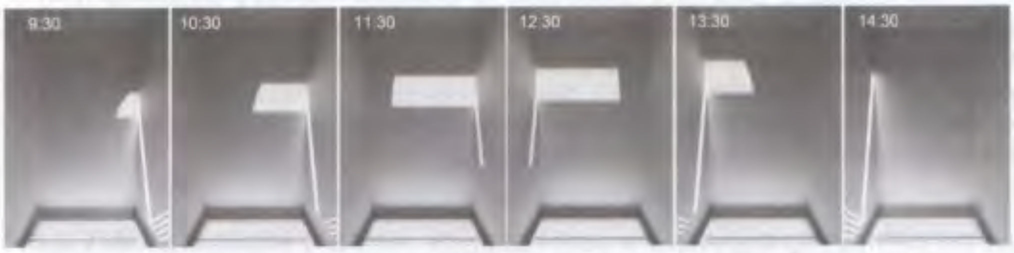

Figure 4: Perspective ceiling views. Date: December 21. ***Dynamic System****: Sun-tracking light shelf, lower blinds: 30°, upper blinds: 8.1°*

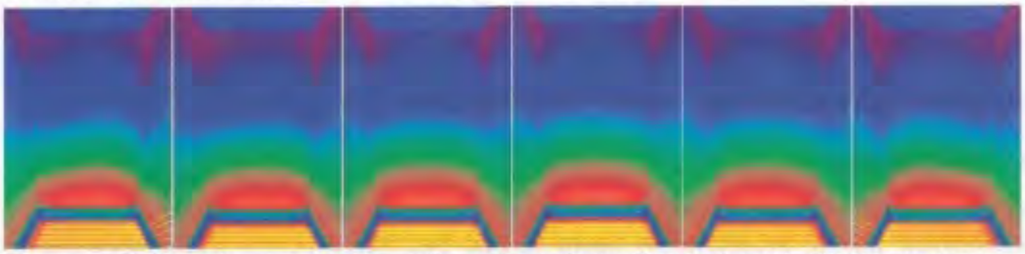
Figure 5: False color perspective ceiling views. Date: December 21. ***Static system:*** *No light shelf, blinds: 30°*

3. Results

3.1 Editing process

Main focus of the study has been the performance of the dynamic daylighting and shading system. Case **LS-BV** consists of:

a) the sun-tracking light shelf that operates based on the sun angle
b) clerestory exterior blinds in 8.1° tilt angle
c) automated exterior view blinds that allow for visual contact while minimizing heat gain as shown in figure 3.

The dynamic system was compared to two sets of reference cases:
A: Static Blinds cases **SB0, SB30, SB50**:

a) no light shelf
b) exterior blinds in same tilt along the height of the window. Tilt angle: 0°, 30°, 50°

B: Dynamic light shelf and static blinds cases **LS-SB0, LS-SB30, LS-SB50**:

a) the sun-tracking light shelf that operates based on the sun angle
b) clerestory exterior blinds in 8.1° tilt angle
c) static exterior blinds. Tilt angle: 0°, 30°, 50°

Using results from the upper window calculations, hourly luminance data was taken at representative points every 1m across the work plane surface. To calculate point luminance levels for every tilt angle of the sun-tracking light shelf, linear interpolation between adjacent tilt angles (I and i+2) was used according to equation [2]:

$$E(\theta)_{n,h}=0.5^{*}\ (E_{i+2}{}^{*}(\theta-i) + E_i{}^{*}(i+2-\theta))\ [2]$$

Using results from the lower window calculations that correspond to the same tilt angle of the sun-tracking light shelf as described above, a second set of luminance data was produced. Point luminance values from both sets of runs were added and compiled into a spreadsheet to establish luminance contributions from the sun-tracking light shelf, upper blinds in 8.1° tilt and lower blinds in 0°, 10°, 20°, 30°, 40°, 50° tilt. The calculated data was assembled to determine daylight autonomy (DA) values and the approximate percentage of environmental lighting levels met by daylight at any given time. It was then converted to percentages of lighting power consumption based on the EnergyPlus ideal continuous dimming system. There is a linear relationship between fractional input power f_P and fractional lighting output f_L. The latter is calculated according to the relationship:

$$f_L=\max[0, (500\text{-Daylight levels at a point})/500]$$

When the minimum lighting output is achieved (f_{Lmin}), there is a minimum power input f_{Pmin}. Both values depend on the type of the ballast. The relation between power f_P and f_L is :

$$\text{If } f_L<f_{Lmin} \rightarrow f_P=f_{Pmin}$$

$$\text{If } f_{Lmin}<=f_L<=f_L \rightarrow f_P=(f_L+(1-f_L)^{*}f_{Pmin}-f_{Lmin})/(1-f_{Lmin})$$

For the present calculation f_{Pmin} equals 0.15 while f_{Lmin} 0.05.

3.2 Discussion

Using the results, daylight autonomy (DA) values have been calculated for all seven measurement points, as shown in figure 4. For the first 3 points (2.5m from the façade) DA values of the dynamic system are higher (5.2% up to 48%) than those of the static blinds (50°). Compared to the static horizontal blinds, DA values of the dynamic system are about 18% lower. For measurement points 4 to 6, DA values for the dynamic system are higher than those of the static blinds, with 30° and 50° slat angle. All cases of the sun-tracking light shelf (LS-SB0, LS-SB30, LS-SB50) perform better than the fully automated system (LS-BV), due to the fact that the maximum possible tilt to allow visual contact (>60) was selected for the automated blinds (fig. 3).

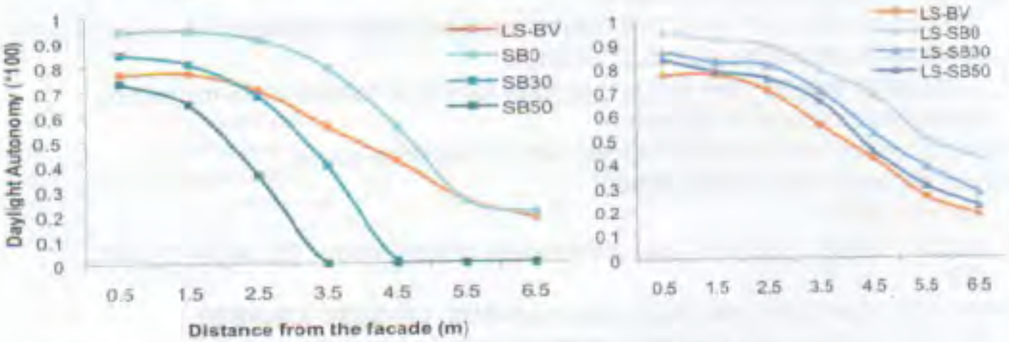

Figure 6: Daylight Autonomy for the seven measurement points.

Figure 7 shows monthly energy saving for the daylight and the non-daylight zone for the automated system (LS-BV) and the reference case (SB50). The automated system achieves up to 23% more energy savings than the reference case in the daylight zone. Higher energy savings (139%-153%) are achieved in the non-daylight zone. Glare was calculated for the summer solstice with the viewer sitting 5 meters from the façade facing the window (fig. 6). Daylight Glare Index (dgi) values for the fully dynamic system (LS-BV) are within the allowed range (<18: imperceptible). For cases LS-SB0 and LS-SB30 dgi values are above 18, in the morning and late afternoon. Dgi values for the static blinds cases (SB0, SB30) are within the perceptible glare range (18-24).

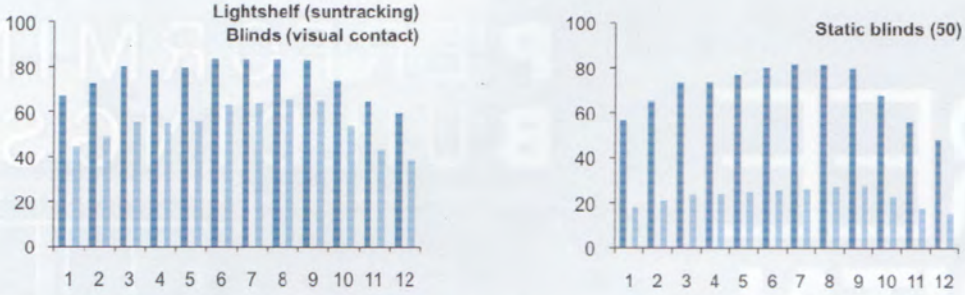

Figure 7: Monthly energy savings

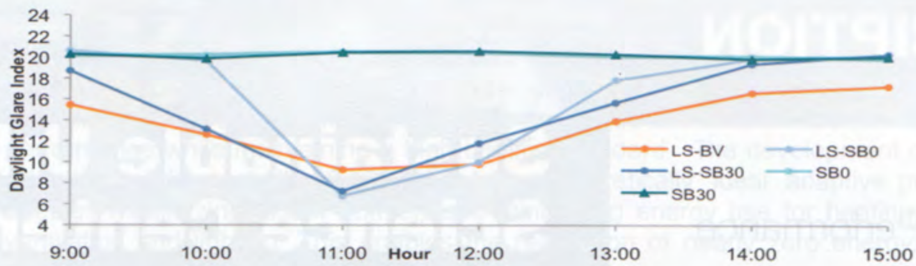

Figure 8: Glare calculations. Date: June 21

4. Conclusion

Dynamic lightshelves increase daylighting levels in non-daylight areas, away from the perimeter zone. Compared to static blinds, lightshelves performance increases DA values up to 50%, contributing to energy savings up to 153% without causing glare issues. Depending on the blinds tilt angle at the lower part of the window, DA values increase when the slat angle reduces. Nevertheless, fully dynamic systems with lightshelves and automated blinds that allow for visual contact reduce the risk of glare.

5. References

[1] Jianxin Hu, Jiangtao Du, Wayne Place, "The Assessment of Advanced Daylighting Systems in Multi-Story Office Buildings Using a Dynamic Method" World Renewable Energy Congress , 8-13 May 2011, Linkoping, Sweden

[2] Lee, E.S., D.L. DiBartolomeo, S.E. Selkowitz. (1998). Thermal and daylighting performance of an automated venetian blind and lighting system in a full-scale private office. Energy and Buildings. 29(1): 47-63.

[3] B. Raphael, "Active Control of Daylighting Features in Buildings", Computer Aided Civil and Infrastructure Engineering 00(2010) pp 1-13.

This research has been co-financed by the European Union (European Social Fund – ESF) and Greek national funds through the Operational Program "Education and Lifelong Learning" of the National Strategic Reference Framework (NSRF) - Research Funding Program: Heracleitus II. Investing in knowledge society through the European Social Fund.