COMPARATIVE ANALYSIS OF A PASSIVE AND ACTIVE DAYLIGHT REDIRECTING BLIND IN SUPPORT OF EARLY STAGE DESIGN

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ABSTRACT

A simulation case study is performed for a high-performance multi-storey open-plan double-perimeter zone office building in Golden, USA (40°N, 105°W) to compare the relative daylighting illuminance performance of passive and active daylight redirecting blinds. Key design parameters such as location/climate, glazing properties, building depth, façade orientation, window to wall ratio, and window head height are tested in different configurations to examine their effects on the daylighting illuminance in the office space. The spatial daylight autonomy metric $sDA_{300/50}$, defined as the percentage of the illumination analysis points in a space for which the daylight autonomy threshold of 300 lx is attained for more than 50 % of all hours between 08:00 and 18:00, is used to evaluate the annual daylight illuminance sufficiency over the floor area. Since the emphasis in this study is on providing early design stage support, a simplified radiosity model (calibrated with data collected on site) is used which yields an accuracy that is within the range of the uncertainties normally encountered in this early stage of the design process. The results show that for most of the combinations tested, the active blind performs as well as or better than the passive blind.

Keywords: daylight redirecting blinds, spatial daylight autonomy, early stage design, open-plan office space, perimeter zone

INTRODUCTION

Enhanced daylighting use is a promising energy efficiency solution that may significantly contribute to reducing lighting energy use in buildings enhance indoor environmental quality in workplaces. Electric lighting accounts for 12.3 %[1] of total electricity use in offices in Canada. The use of daylighting with controls like automated blinds and electric light switching and dimming contributes to reducing energy consumption [1-3] and can even play a role in reducing HVAC system sizes and peak building power load [4]. Daylighting can also have positive effects on building occupants such as increased productivity, mental functioning and attention, health, mood, and motivation [5-8].

One particular class of daylighting device, daylight redirecting blinds, is designed specifically to increase daylighting levels in buildings in addition to preventing unwanted solar gain and glare. As with all daylighting design, these blinds need to be evaluated on an annual basis in a specific climate to obtain an accurate assessment of their performance. However, because these blinds rely on many parameters such as complex geometry and may require automated controls to achieve their high illuminance performance, their angle-dependent optical characteristics cannot be represented or simulated accurately using the simple tools that are normally used at the beginning of the building design process when rapid assessments of design options are needed. Instead they currently require time- and resource-intensive,

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[1] http://oee.nrcan.gc.ca/corporate/statistics/neud/dpa/showTable.cfm?type=CP&sector=com&juris=ca&rn=20&page=0

simulation methods – such as the Radiance three-phase / five-phase method with support for bidirectional scattering distribution functions (BSDFs) [9]. These methods require many inputs (some of which are not yet known) and are often not interoperable with typical architectural design software, making them difficult to integrate into existing building design workflows at such an early stage of design [10]. Instead, architects place a high importance on rules of thumb, simple calculations, and simple, easy to learn and use simulation software that supports them in decision-making [11, 12].

Therefore design guidance for these daylight redirecting blinds is proposed in support of design decisions at the beginning of the building design process. As a project progresses from the initial design decisions supported by the proposed design guidance, and as an increasing number of design variables become fixed, more sophisticated tools can be introduced into the design process that parallel the increasing level of detail known of the building design.

METHODOLOGY

Since the emphasis in this study is on providing support to the early design stages of a building project, a simplified radiosity daylighting simulation model is used which yields an accuracy that is within the range of the uncertainties normally encountered in this early stage of the design process. The simulation model is developed to compute annual climate-based daylighting illuminance levels and validated using a case study. The simulation case study was performed for a high-performance multi-storey open-plan double-perimeter zone office building in Golden, USA (40°N, 105°W) to compare the relative daylighting illuminance performance of two types of daylight redirecting blinds. The first blind is passive/static (the LightLouver from LightLouver LLC) and the second is an active/motorized Venetian (the Vision Control from Unicel Architectural) (Figure 1). The blinds are installed in the equator-facing daylighting window, which is positioned above the line of sight of standing occupants. The radiosity model is calibrated using hourly illuminance data obtained onsite and sky irradiance data obtained from the onsite weather station. Sky irradiance data from EnergyPlus Weather files (EPW) is used for the annual simulations. This is used with the Perez model [13, 14] to calculate the illuminance values for the hourly time steps used in the simulations.

The active blind is controlled to maximize daylight transmittance. For each hourly time step, at insolation values of 100 W/m^2 or less (for cloudy skies) at the exterior window surface, the blinds are opened to the slat angle with the highest visible transmittance. At higher insolation values, the transmittance at slat angles from -85° (closed), in increments of 15°, up to the direct sun cut-off angle (maximum open slat angle for which direct sun is blocked) are determined and the blinds are set at the slat angle with the highest transmittance.

Figure 1 Left: LightLouver (Photo: Dennis Schroeder, NREL); right: Vision Control (Photo: Qian Peng)

The daylighting performance is evaluated using the spatial daylight autonomy (sDA) metric [15], which is defined as the percentage of the illumination analysis points in a space for which the daylight autonomy threshold of 300 lx is attained for more than 50 % of all hours between 08:00 and 18:00 (symbolized as $sDA_{300/50}$.). Two levels of daylight sufficiency are defined in the metric: a “nominally” daylit space attains an $sDA_{300/50}$ of 55 %; and a “preferred” daylit space attains an $sDA_{300/50}$ of 75 %.

The simulation model consists of a typical one-storey cross-section and includes the glazed North and South facades. The North façade view and daylighting windows are surfaces 11 and 12, respectively, in Figure 2. The South façade ones are surfaces 10, and 9, respectively. Key design parameters that relate to building site (climate, and building orientation), building geometry (window to wall ratio, window head height, and building depth), and fenestration (visible light transmittance of windows and blinds) are tested as described in Table 1, and Table 2 to examine their effects on daylighting illuminance in the office space. The results are generalized into simple correlations between these building design parameters and daylight illuminance sufficiency in the space. These correlations form the basis of the design guidance to be used in the early days of the building design process in lieu of simulations.

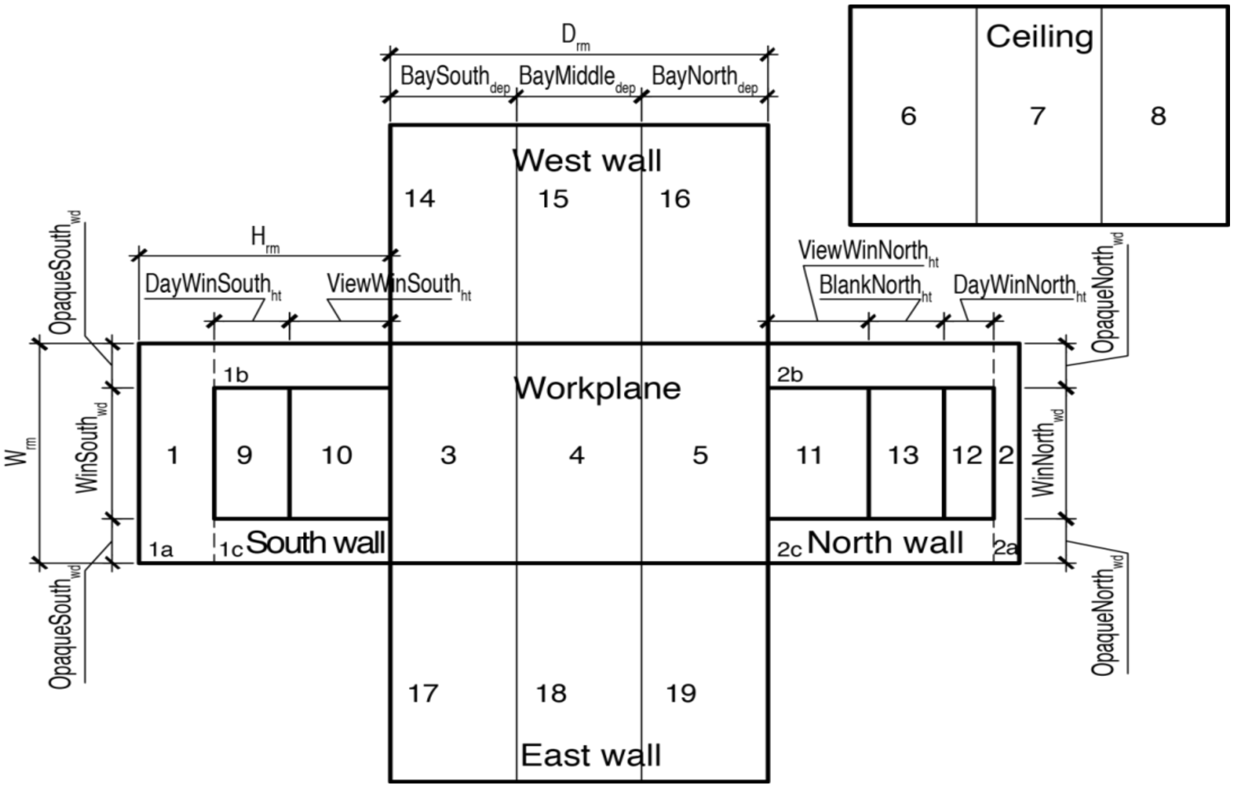
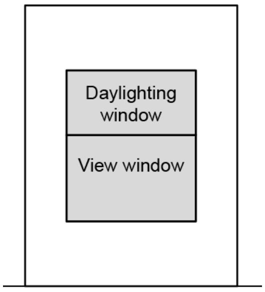
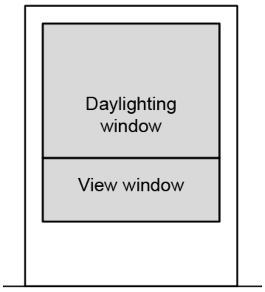


Figure 2: Representative cross-section unfolded, its surfaces labelled, and dimensioned

Parameter	**Values tested**
Building orientation (ψ)	-45°, -30°, -15°, 0, 15°, 30°, 45°
Daylight redirecting blind	LightLouver; Vision Control
Window Visible Light Transmittance	59 % (view window) and 70 % (daylighting window); 68 % (view window) and 76 % (daylighting window)
Building depth (D_{rm})	11 m, 12 m, 13 m, 14 m, 15 m, 16 m, 17 m, 18 m

Table 1: Summary of simulation parameters

<table>
<tr><td rowspan="17">

South interior elevation
Base bldg


South interior elevation
Config. A</td><td>Fenestration parameters (Refer to Figure 2)</td><td>Base bldg</td><td>A</td></tr>
<tr><td>D_{rm} (m)</td><td>18.000</td><td>18.000</td></tr>
<tr><td>W_{rm} (m)</td><td>3.000</td><td>3.000</td></tr>
<tr><td>H_{rm} (m)</td><td>3.048</td><td>3.048</td></tr>
<tr><td>$\mathrm{WinSouth}_{wd}$ (m)</td><td>1.829</td><td>2.500</td></tr>
<tr><td>$\mathrm{DayWinSouth}_{ht}$ (m)</td><td>0.914</td><td>1.900</td></tr>
<tr><td>$\mathrm{ViewWinSouth}_{ht}$ (m)</td><td>1.219</td><td>0.900</td></tr>
<tr><td>$\mathrm{WinNorth}_{wd}$ (m)</td><td>1.829</td><td>1.829</td></tr>
<tr><td>$\mathrm{DayWinNorth}_{ht}$ (m)</td><td>0.762</td><td>0.762</td></tr>
<tr><td>$\mathrm{ViewWinNorth}_{ht}$ (m)</td><td>1.219</td><td>1.219</td></tr>
<tr><td>$\mathrm{BlankNorth}_{ht}$ (m)</td><td>0.914</td><td>0.914</td></tr>
<tr><td>Window to wall ratio, South façade, WWR_s</td><td>0.328</td><td>0.589</td></tr>
<tr><td>Window to wall ratio, North façade, WWR_n</td><td>0.305</td><td>0.305</td></tr>
<tr><td>Window to wall ratio, South daylight window, WWR_{ds}</td><td>0.141</td><td>0.400</td></tr>
<tr><td>Window to wall ratio, South view window, WWR_{vs}</td><td>0.188</td><td>0.189</td></tr>
<tr><td>* Window head height, South façade WHH_s (m)</td><td>3.048</td><td>3.714</td></tr>
<tr><td>* Window head height, North façade WHH_n (m)</td><td>3.810</td><td>3.810</td></tr>
<tr><td></td><td colspan="3">* since the room cavity below the workplane is not modelled, the height of the workplane must be added to the window heights to obtain the room's WHH; (total room height is 3.963 m)</td></tr>
</table>

Table 2: Schematic elevations (left) and table (right) of fenestration (window to wall ratio and window head height) configurations studied

RESULTS

For all façade orientations and configurations tested, the Vision Control blind daylighting performance is better than or equal to that of the LightLouver – by up to 18 % (Table 3).

In configuration A, the daylighting window is made larger and the window head height is made higher than in the base building. This results in increased all blind / window visible light transmittance (VLT) / orientation combinations attaining $sDA_{300/50}$ values above 55 % making them "nominally daylit" spaces – compared to a best case $sDA_{300/50}$ of 46 % for the base building for Vision Control blind/high VLT windows/$\psi = 15°$ (Table 3).

Furthermore, using the same configuration A, but a different time period of evaluation (August 01 and 02; and February 12 and 13) and timestep (15 min), Chen, Yip and Athienitis [16, 17] show that when thermal performance is taken into account, increasing WWR_{ds} from 14 % to 40 % contributes to a decrease in winter space heating for the Vision Control blind using the high SHGC and high VLT windows (from 9.7 kWh/m facade width to 7.1 kWh/m facade width) while it is practically constant for the LightLouver (from 10.5 kWh/m facade width to 10.1 kWh/m facade width). For space cooling performance, the same increase in WWR_{ds} increases the space cooling load slightly for the Vision Control blind using the low SHGC and low VLT windows (from -1.8 kWh/m facade width to -2.0 kWh/m facade width) and increases it further for the LightLouver (from -1.9 kWh/m facade width to -2.6 kWh/m facade width). Thus, when increasing WWR_{ds} to 40 %, both blinds' daylighting performance increases equally, but the Vision Control blind has better thermal performance than the LightLouver.

Golden		ψ orientation (°)													
Building depth 18 m		-45		-30		-15		0		15		30		45	
Config. / blind		low VLT	high VLT	low VLT	high VLT	low VLT	high VLT	low VLT	high VLT	low VLT	high VLT	low VLT	high VLT	low VLT	high VLT
base bldg.	LL	28	35	33	41	39	44	39	44	33	44	33	41	28	35
	VC	33	35	39	41	44	44	39	44	39	46	33	41	30	35
A	LL	56	63	61	63	61	63	61	63	61	63	56	63	56	57
	VC	56	63	61	63	61	63	61	63	61	63	61	63	56	57

Table 3: Configuration comparison; $sDA_{300/50}$ [%] (LL is LightLouver; VC is Vision Control)

The maximum building depth for which the entire floor area is nominally daylit is determined for the base building and configuration A, representing a conservative and optimal case. The different orientations reach the nominally acceptable level of daylight sufficiency at different building depths depending on façade configuration and the blind used. This range is reflected in the results in (Table 4).

Golden (low VLT)	**Base building**	**Configuration A**
LightLouver	12.2 m – 14.0 m	18.7 m – 19.3 m
Vision Control	12.8 m – 14.5 m	18.7 m – 19.3 m

Table 4: Base bldg. and configuration A: maximum building depth at which daylighting illuminance is nominally acceptable (taking into account all tested ψ angles)

CONCLUSION

Two different daylight redirecting blinds were investigated in a comparative case study for daylighting performance taking into account design parameters that are important at the beginning of the design process. A simplified radiosity daylighting model was used that is capable of making predictions within the range of accuracy normally encountered in early stage design. A range of orientations, window visible light transmittance values, daylight redirecting blinds, and fenestration configurations was studied using this approach.

Active daylight redirecting blinds performed as well as or better than passive daylight redirecting blinds for the configurations tested. However, other criteria like visual glare and solar heat gain based on climate and orientation may affect blind selection. For example, a relatively simple, low-maintenance passive blind installed on the indoor side of a window may be acceptable for mild, temperate climates but may cause excessive overheating in climates with high cooling load.

The maximum depth of a double-perimeter open-plan space that is nominally daylit varies with orientation, window to wall ratio, window head height, visible transmittance, and daylight redirecting blind. These findings may be used as design guidance at the beginning of the design process when quick sketches and hand calculations are still common for design exploration before the building design has taken shape and the design team commits to developing specific design options and introducing simulation tools into the process.

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