Parametric Design Analysis of Passive and Active Daylight Redirecting Blinds for Schematic Design Support

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Abstract

Daylight redirecting blinds can help increase daylighting levels in buildings while preventing unwanted solar gain and glare. Since the simulation methods needed to accurately represent them are too time- and resource-intensive for early schematic design, design guidance is developed in support of design decisions that can be integrated into existing building design workflows. Passive and active blinds are analyzed comparatively over a range of parameters including building orientation, fenestration geometry, and building depth. The results for building geometry and interior daylight illuminance sufficiency can be used as design guidance in early schematic design in lieu of simulations.

Keywords: daylight redirecting blind, design guidance, daylighting, schematic design

1. Introduction

Daylighting has recently been the subject of renewed interest as one possible solution to the problem of increasing energy use in the building sector and concern over indoor environmental quality in workplaces. In Canada, the building sector is responsible for approximately 30 %[1] of total energy usage and within that, electric lighting accounts for 12.3 %[2] of total electricity use in offices. In the United States, the respective percentages are 40 %[3] and 39 %[4].

Studies have shown that daylighting with controls like automated blinds and electric light switching and dimming contributes to reducing electricity consumption by up to 40 % of total electricity or 50 % of perimeter electric lighting [1-3]. Daylighting can even play a role in reducing HVAC system sizes and peak building power load [4]. For building occupants, studies suggest correlations or connections between daylighting and positive effects such as increased productivity, mental functioning and attention, health, mood, and motivation [5-9].

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[1] http://oee.nrcan.gc.ca/corporate/statistics/neud/dpa/showTable.cfm?type=HB&sector=aaa&juris=ca&rn=2&page=6&CFID=33130633

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

[3] http://www.eia.gov/totalenergy/data/monthly/pdf/flow/total_energy.pdf

[4] http://www.eia.gov/consumption/commercial/data/archive/cbecs/cbecs2003/detailed_tables_2003/2003set19/2003html/e05.html

A good example is the numerous daylight redirecting blinds that propose to address the issue of energy savings, along with improved daylighting performance and occupant comfort. As with all daylighting design, these blinds need to be evaluated on a climate-based annual basis to obtain an accurate assessment of their performance. Because there are many different parameters on which they rely to attain their performance, their angle-dependent optical characteristics cannot be represented or simulated accurately using the simple tools that are normally used at the beginning of schematic design when rapid assessments of design possibilities are needed.

Instead, the state-of-the-art method to obtain annual climate-based daylight illuminance performance evaluations of interior spaces with daylight redirecting blinds is to use Radiance's three-phase or five-phase method [10, 11]. Since Radiance requires an entire set of building inputs – many elements of which are not yet known – it is often too demanding for inclusion at the beginning of schematic design. Usually the first 3d models in any building design process are exploratory, subject to frequent modification, and often incomplete – focusing on just one aspect of a building design such as massing or façade design. Because of this, specialized software like Radiance is difficult to integrate into most building design workflows [12]. 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 [13, 14].

Therefore, a tool in the form of design guidance is proposed. It will concentrate on the elements needed to start integrating daylight redirecting blinds into existing design workflows. These elements are related to building site (climate, building orientation), building geometry (window to wall ratio; window head height; and building depth) and fenestration optical properties (visible light transmittance of windows and blinds). Following this design guidance, a process of iteration and feedback can escalate a design to the level of detail where existing sophisticated simulation tools can be introduced effectively.

2. Methodology

A simplified, computationally efficient radiosity simulation model that can support annual climate-based daylighting simulations of daylight redirecting blinds is developed and validated using a case study. The case study building is a high-performance multi-storey open-plan double-perimeter zone office building in Golden, USA (40°N, 105°W). The radiosity model is calibrated using hourly illuminance measurements obtained onsite. All sky irradiance data is obtained from either the onsite weather station (for the model calibration) or from EnergyPlus Weather files (EPW) (for the annual simulations). This irradiance data is used in conjunction with the Perez model [15, 16] to calculate the illuminance values for each of the hourly timesteps used in the annual simulations.

Two representative models of passive and active daylight redirecting blinds are analyzed comparatively for daylight illuminance performance. They are the LightLouver from LightLouver LLC, and the Vision Control from Unicel Architectural and they are installed in the equator-facing daylighting window (i.e. a window that's above the line of sight of a standing occupant). The study encompasses a variety of parameters that hold great importance at the beginning of the schematic design process. See Table 1. The daylighting performance is evaluated with the spatial daylight autonomy (sDA) metric [17], 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. An $sDA_{300/50}$ of 55 % or more is considered a "nominally" daylit space; and an $sDA_{300/50}$ of 75 % or more is considered a "preferred" daylit space.

A typical bay is used for the simulations. An unfolded view identifying all dimensions is shown in Figure 1. Of particular note is that the open-plan space has operable windows on both the South-facing and North-facing facades, allowing for increased daylight penetration and cross-ventilation. The tested parameters are shown in Figure 2 and Table 2. The daylighting results may be used as design guidance to provide building designers with support at the beginning of the schematic design phase.

Table 1 Summary of simulation parameters

Parameter	Values tested
Building orientation	-45°, -30°, -15°, 0, 15°, 30°, 45°
Daylight redirecting blind	LightLouver; Vision Control
Window Visible Light Transmittance (VLT)	* 59 % and 70 %; * 68 % and 76 %
Building depth	11 m, 12 m, 13 m, 14 m, 15 m, 16 m, 17 m, 18 m
* Each pair of VLT values is used as a set: one is used by the view window, the other by the daylighting window	

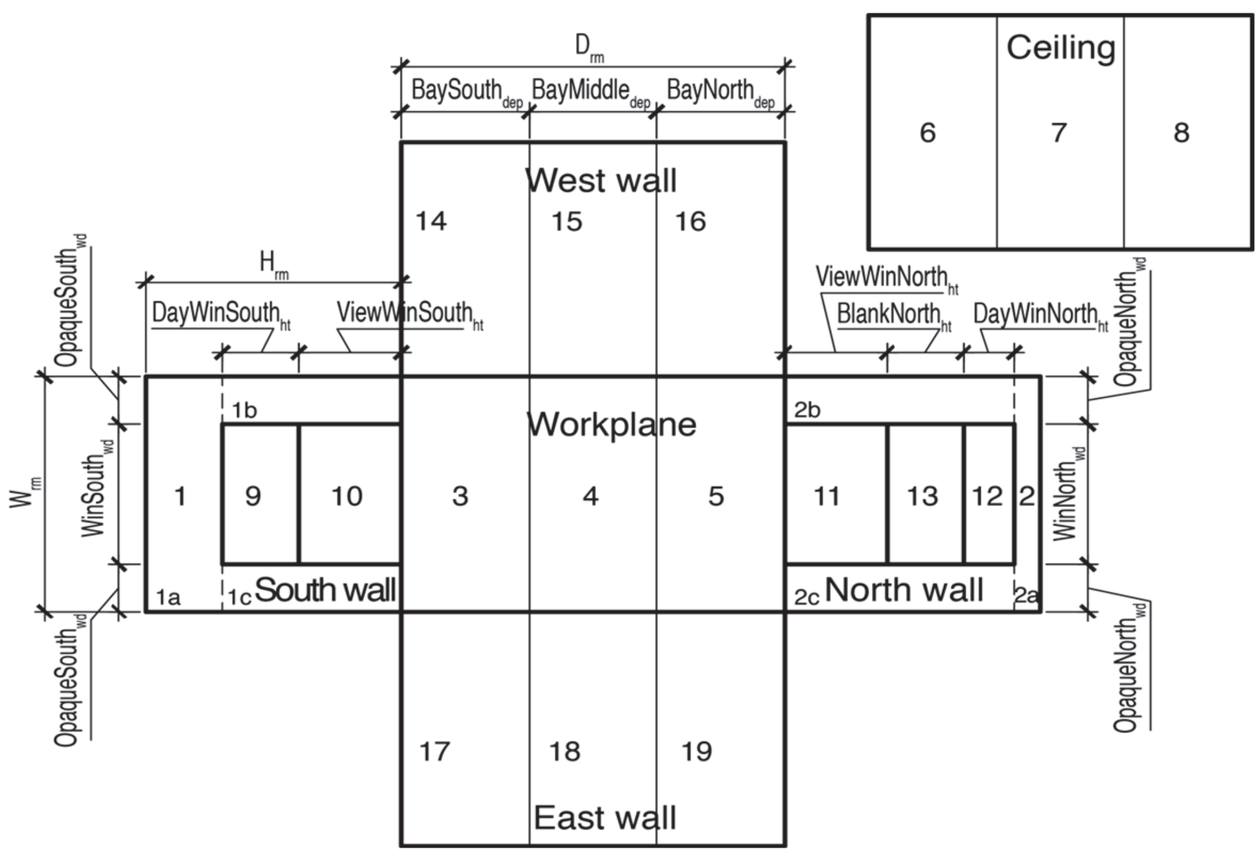

Figure 1 Representative cross-section unfolded, its surfaces labeled, and dimensioned

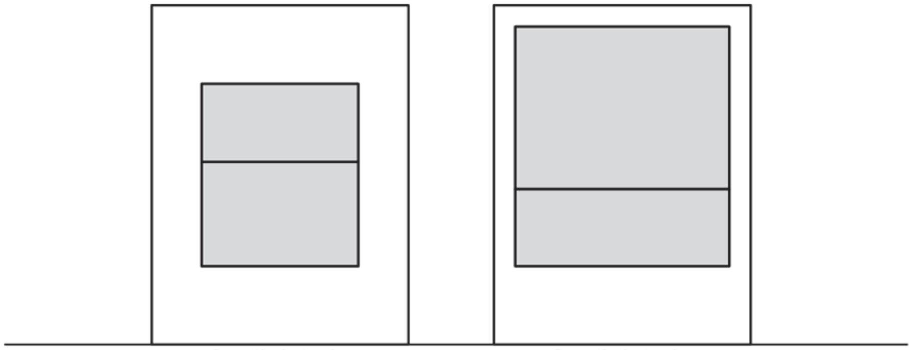

Figure 2 Schematic interior elevations showing window configurations

Table 2 Fenestration (window to wall ratio and window head height) configurations studied

Refer to Figure 1 for parameter definitions	Base bldg	Config. A
D_{rm} (m)	18.000	18.000
W_{rm} (m)	3.000	3.000
H_{rm} (m)	3.048	3.048
$WinSouth_{wd}$ (m)	1.829	2.500
$DayWinSouth_{ht}$ (m)	0.914	1.900
$ViewWinSouth_{ht}$ (m)	1.219	0.900
$WinNorth_{wd}$ (m)	1.829	1.829
$DayWinNorth_{ht}$ (m)	0.762	0.762
$ViewWinNorth_{ht}$ (m)	1.219	1.219
$BlankNorth_{ht}$ (m)	0.914	0.914
Window to wall ratio, South façade, WWR_s	0.328	0.589
Window to wall ratio, North façade, WWR_n	0.305	0.305
Window to wall ratio, South daylight window, WWR_{ds}	0.141	0.400
Window to wall ratio, South view window, WWR_{vs}	0.188	0.189
* Window head height, South façade WHH_s (m)	3.048	3.714
* 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)		

3. Results

For most combinations tested, the Vision Control blind daylighting performance is better than or equal to that of the LightLouver. Replacing the LightLouver with a Vision Control blind can increase daylighting performance by as much as 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 $sDA_{300/50}$ performance for all cases. For all of the blind/window visible light transmittance (VLT)/orientation combinations the $sDA_{300/50}$ is over 55 %, making them “nominally acceptable” for daylighting – compared to a best case $sDA_{300/50}$ of 46 % for the base building for Vision Control blind/high VLT windows/ψ = 15° (Table 3). An example is shown in Figure 4 for South orientation, low VLT windows, and LightLouver blind. This combination has a 56 % better daylighting performance than the base building configuration.

Table 3 Comparison of configurations for Golden; $sDA_{300/50}$ [%] (LL is LightLouver; VC is Vision Control)

Golden		ψ orientation (°)													
Building depth 18 m		-45		-30		-15		0		15		30		45	
Configuration / 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

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 [18, 19] 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.

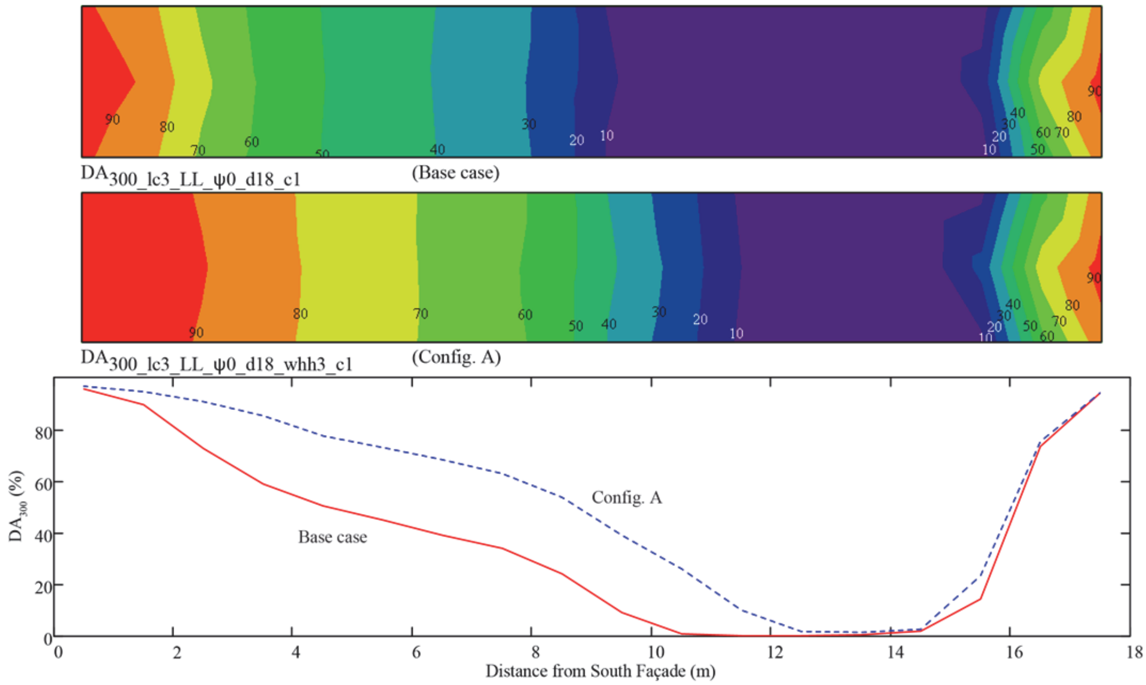

Figure 4 Base case and configuration A; Golden; low VLT; LightLouver; ψ = 0; DA_{300} contour (top, middle) and X-Y (bottom) plots [%]

4. Conclusions

Two different daylight redirecting blinds were investigated for daylighting performance taking into account building design parameters that have great importance at the beginning of schematic design: A simplified radiosity daylighting model was used that is capable of making predictions within the range of accuracy normally encountered in early stage design to facilitate rapid and comparative assessments of design options. A range of orientations, window visible light transmittance values, daylight redirecting blinds, and fenestration configurations was studied using this approach.

Generally, active daylight redirecting blinds performed as well as or better than passive daylight redirecting blinds for most configurations tested in this case study, across all the different parameters. For example, replacing the LightLouver passive blind as installed in the base building with the Vision Control active blind would result in a relative illuminance performance increase of 18 %. However, other important factors like visual glare and solar heat gain must be evaluated based on climate and orientation before a final blind selection is made for any particular project. A passive blind installed on the indoor side of a window may be acceptable for mild, temperate climates – especially with the benefits of simplicity, low maintenance, and convenient retro-fit possibilities – but may cause excessive overheating in climates with high cooling load.

These findings may be used as a first approximation at the beginning of the schematic design phase 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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7. Biography

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