Automated and Manual Solar Shading and Glare Control: A Design Framework for Meeting Occupant Comfort and Realized Energy Performance

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ABSTRACT

As building owners and designers focus on measured energy use, the automation of dynamic solar shading and glare control systems is becoming more attractive to ensure predictable performance over time. However, most building occupants expect the ability to adjust window coverings and other shading devices to achieve their personal visual preference. How does a building designer accommodate occupant preference without compromising daylighting performance?

This paper presents a framework for design decision making for daylighting performance and occupant control relative to manual and automated control strategies for dynamic solar shading and glare management systems. It investigates a range of approaches to meeting daylight and energy performance goals and identifies strengths and weaknesses of each.

1. INTRODUCTION

It is known that daylight and views help to create healthy, comfortable, and productive work environments for users, and therefore the use of daylight is one of the hallmarks of contemporary sustainable design efforts. Furthermore, the significant inclusion of daylight in buildings holds tremendous potential to produce energy savings since 15-19% of the total electrical consumption in the United States is represented by lighting[1] (US-DOE 2006; US-EIA 2008). Unfortunately, these benefits are too often under-realized, in large part due to patterns of occupant behavior that can lead to blinds and roll-down fabric shades deployed in the “worst case scenario” position of blinds down and slats closed, essentially defeating the daylighting design intent. A 2005 report on sidelighting (daylight illuminance from vertical windows) and photo controlled electric lighting systems produced by the Heschong Mahone Group identified blind use by building occupants as a significant contributor to low realized lighting power savings ratios[2]. Manually operated blind systems can be very effective if properly used, however, they rely on and require continuous user attention to maintain complete glare control while achieving maximum daylight performance. Due to the extremely dynamic nature of daylight and sunlight, automation of glare control and solar shading may provide the most persistent daylight performance where variable direct sunlight is present during large portions of the occupied times. Automated glare control has the possibility of being deployed when needed and retracting without user intervention when direct sunlight is no longer present to allow for unimpeded diffuse daylight. In many cases, this will deliver longer periods of effective daylight contribution, increased lighting power savings, and longer durations of unobstructed views to the exterior. Manually operated blinds can provide for effective glare control and daylight performance if users actively operate them relative to sky conditions. Manually operated blinds empower users to adjust blinds based on their task requirements, privacy needs, and visual preference.

For the purpose of this paper we will distinguish between solar shading and glare control as follows: Solar shading is the control of direct sunlight during times when the building is likely to be (or is) in cooling mode. Glare control means meeting visual comfort requirements (blocking line of sight to the disc of the sun and managing excessive brightness and contrast in the visual field) during all occupied hours. Building design offers the potential for daylight and thermal performance, though the realization of maximum energy savings through reduced lighting, cooling, and heating poses a significant operational challenge. The following sections provide for a simplified design framework for designing with automated and manual glare control and solar shading.

Fig. 1: Range of blind deployments at a campus building. (photo: Craig F. Johnson)

2. BLIND USE AND DAYLIGHT POTENTIAL: SIMULATION CASE

Blind usage may be the greatest determinant of operational daylight performance in buildings. User behavior relative to operable blinds and shades is complex (fig. 1), though simulation tools exist to identify likely patterns of glare and to approximate potential user response. To illustrate predicted annual daylight performance under a range of blind usage scenarios a simple digital model was constructed of an open office-type shared work area illuminated by south-facing glazing from one side located in Seattle, WA. This model consists of fourteen workstations in two rows with a perimeter to core depth of 30’-0” (10m), a ceiling height of 10’-6” (3.2m) with two rows of partitions and a 4’-0” (1.2m) aisle way at the core (fig. 2). Interior partitions are 42” parallel to perimeter glazing and 48” perpendicular to windows. Perimeter glazing includes a “view” window from 2’-6” to 7’-0” and a “daylight” window from 7’-2” to 9’-8”. This glazing pattern represents a configuration roughly analogous to 40% of total opaque envelope. Glazing is simulated with a visible light transmission (T_{vis}) of 68%.

2.1 Shadow Studies

To establish the locations, duration, and times of direct sunlight penetration, we used the shadow casting module in the building simulation program Ecotect[3]. A single window was isolated (fig. 3) to identify peak glare conditions at each workstation. This was indicated by the maximum annual area coverage of direct beam sunlight within the workstation on a surface roughly corresponding to seated eye height (48” (1.2m) above finished floor). The presence of direct sunlight at eye height can be correlated with a high likelihood of direct line of sight to the disc of the sun- a common cause of disability glare in interior environments. This analysis indicates that a single south facing window can become a glare source at every workstation within the open office at some point during the year (fig. 4). When factored across multiple windows, the individual instances of glare from the disc of the sun grow exponentially. Considering that the instances of glare do not match temporally between workstations, it is unlikely that a consensus model for continuous and optimum manual operation of blinds will evolve without considerable effort by occupants, especially at locations where windows are off the north-south axis.

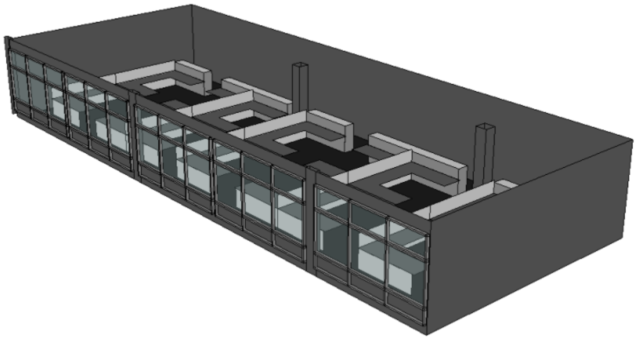


Fig. 2: Open Office Model: Axonometric View

2.2 Blinds Operation Scenarios: Annual Daylight Simulations

To establish the effect of a range of blind operation scenarios we exported our model into the Radiance[4] based annual climate-based daylight simulation tool DAYSIM[5]. Continuous Daylight Autonomy[6] calculations were done under five blinds operation scenarios (fig. 5). These include: (1) No blinds; (2) Automated blinds that deploy when direct solar radiation exceeds 50 Wm^{-2} at the window and retracts when direct sunlight is no longer present (blinds deploy with diffuse transmittance of 20%); (3) Manually operated blinds with a blend of active and passive users (the DAYSIM interface describes a passive user as “a user who keeps the blinds

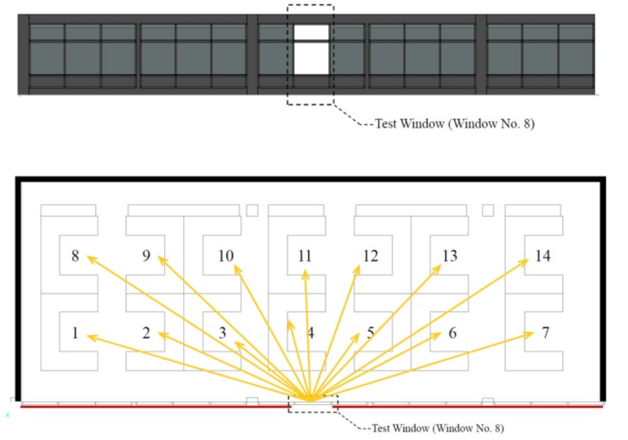
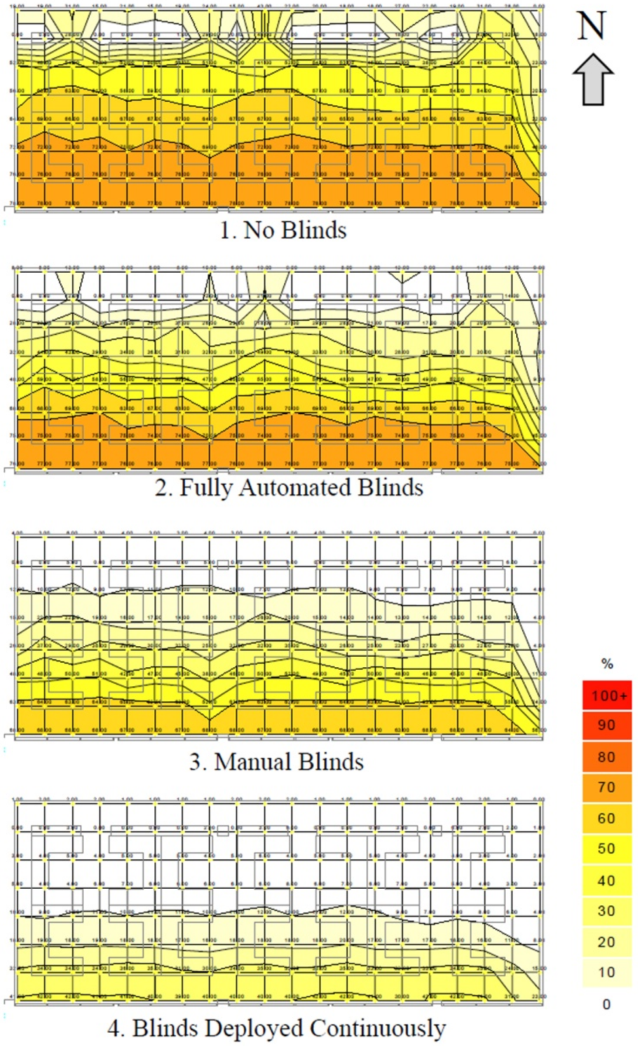


Fig 3. Test window elevation and plan showing locations of direct sunlight penetration.

Window No. 8 (South)		
Workstation No.	**Peak Direct Sunlight Coverage***	
	Day	**Time**
1	10 Oct	7:45
2	10 Oct	8:30
3	15 Oct	9:00
4	20 Oct	11:00
5	10 Oct	14:30
6	5 Oct	15:15
7	5 Oct	16:45
8	10 Feb	8:45
9	1 Feb	9:30
10	15 Nov	10:00
11	1 Dec	11:30
12	15 Nov	13:30
13	5 Feb	15:00
14	10 Feb	15:45

* As indicated by the maximum annual area coverage of direct beam sunlight within the workstation on a surface roughly corresponding to seated eye height (48" above finished floor).

Fig 4. Maximum area of direct sun exposure at workstations.



1. No Blinds

2. Fully Automated Blinds

3. Manual Blinds

4. Blinds Deployed Continuously

Fig 5. Iso-lux contour maps: continuous daylight autonomy.

	Blinds Control Scenario	**User Behavior**	**% of Zone with Daylight Autonomy (DA-con) > 40**	**Direct Sun/Glare Control**	**Average Diffuse Transmittance of Deployed Blinds**	**User Control**	**Notes**
1	No Blinds	None	**75%**	Never	N/A	None	Unmitigated Glare/ Extreme Visual Discomfort
2	Fully Automated Blinds	None	**52%**	At presence of Direct Sunlight (50 Wm-2)	25%	No User Intervention Required.	Continuous Optimum Blinds Deployment and Retraction
3	Manually operated blinds	Blend of Passive** and Active*** Users	**36%**	Mix of 2 & 3	25%	Control requires user intervention	Partially Optimum Blinds Deployment and Retraction
4	Blinds continuously deployed	Passive* User	**10%**	Always	10%	Blinds Continuously Deployed and Closed	Blinds Continuously Deployed at Darkest Setting

*Passive User as defined by DAYSIM (keeps the blinds lowered throughout the year to avoid direct sunlight)

**Active User as defined by DAYSIM (opens the blinds in the morning (upon arrival), and lowers them when direct sunlight above 50 Wm-2 hits the seating position (to avoid direct glare)

Note: Continuous Daylight Autonomy at 400lux from 07:00 - 19:00

Fig. 6. Blinds Control Scenarios and Simulated Performance

lowered throughout the year to avoid direct sunlight" and an active user as one who "opens the blinds in the morning (upon arrival), and lowers them when direct sunlight above 50 Wm^{-2} hits the seating position (to avoid direct glare)" (blinds deploy with diffuse transmittance of 20%); (4) Blinds continuously deployed at a "worst case scenario" (diffuse transmittance of 10%) representing fully closed venetian blinds or completely deployed fabric shades). Continuous daylight autonomy refers to the percentage of time that a horizontal illuminance criteria requirement that is met by daylight on an annual basis (DA_{con}) during a specified occupancy time including partial credit for meeting a percentage of the criterion. In this case we have established an ambient light level goal of 400 lux with an occupancy time of 7am through 7pm (07:00-19:00). The results of this simulation are indicated in Fig. 6 and show substantial variation in annual daylight performance.

3. DESIGN FRAMEWORK CONTEXT

3.1 Occupancy Considerations: Private Versus Shared Work Spaces

Patterns of occupant behavior relative to space type can provide the primary basis for prioritizing manual vs. automated controls. The greatest distinction lies between shared work environments and spaces where an individual occupies a discreet architectural volume such as a private office. Designers must consider the occupancy profile (shared work environments vs. private) and its implications on the likely patterns of blind usage (active and optimal manual operation of blinds and shades vs. sub-optimal deployment). Within this context, the choice of manual/automated, interior/exterior, and active/passive systems stems from three primary concerns. These are (1) daylighting and visual comfort goals, (2) lighting power conservation potential, and (3) the degree to which optimum solar shading (or the lack thereof) performance forms the basis for the sizing of other systems (i.e. "integrated design"). Broadly speaking, the case for automation is much stronger in shared work environments for reasons outlined below.

3.2 Shared Work Environments

Shared work environments confront the designer with a high degree of complexity both in terms of solar geometry relative to multiple workstations simultaneously and across time and with respect to group occupant behavior. At the same time, daylighting and solar shading often offer much more conservation potential in these spaces due to longer periods of continuous occupancy, higher lighting power consumption, and larger glass areas needed to provide effective daylight illumination to greater floor plate depths.

The primary challenge of shared work environments is that they must be designed to meet the visual comfort requirements of all users simultaneously, despite continuously changing environmental conditions. In shared work environments the geometric relationship between multiple windows and multiple workstations becomes complex rapidly. In building orientations subject to direct sunlight, a single window can become a glare source at multiple (or all) workstations during multiple times throughout the day and year (figs. 3 and 4). Considering a typical open office zone with a continuous band of perimeter windows and two rows of workstations, the number of discreet blinds deployments, adjustments and retractions becomes exponential. This means that multiple blinds must be adjusted multiple times per day to ensure visual comfort and maintain daylight performance across time, sky conditions, and/or whether the building is in cooling mode. This is especially critical where glazing areas are increased to provide daylight illuminance in deep section spaces, and where consequently, undesirable heat gains must be reliably controlled, often outside the building envelope. In such cases automation may be necessary to ensure that solar shading requirements are met persistently and sufficiently to enable reductions in cooling system size.

Furthermore, the location of workstations within a shared work environment can create a complex hierarchy that affects patterns of blind usage. Users with immediate access to blind/shade controls have the capability of adjusting blinds to their visual and thermal comfort preference with relative ease, presuming that blinds controls are easy to access and use. However, the deployment of blinds to meet the visual preference of one user may be in conflict with the wishes of another user. Due to typically larger floor plate depths there is likely to be a higher contrast and lower uniformity of light distribution in shared work environments. This can lead to a scenario where occupants at the perimeter deploy blinds to manage glare and disable daylight distribution and views for occupants deeper within the volume. In cases where no workstations are directly adjacent to the perimeter and where users are unable to adjust blinds according to glare conditions without having to leave their immediate workstation, the outlook for active blinds usage (and therefore optimized) control by users is pessimistic.

In some shared work spaces the hierarchy of who has the responsible for, or is permitted to adjust the blinds may be unclear, especially in cases where no workstation exhibits clear “ownership” of individual blind controls. This can lead to a consensus developed around blinds being continuously deployed to control for the peak glare condition for each workstation. Since as described above, each window is likely at one time or another, to cause glare at each workstation, this can lead to all blinds being permanently deployed down. Occupants regularly deploy blinds when glare is present, since this is critical to their ability to use their workstations in a productive manner. However, they are less apt to re-adjust or retract blinds or shades when glare conditions have passed, especially in cases where blinds will need to be deployed and retracted very regularly for short time intervals (e.g. east or west facing glazing). Except where an exceptionally active occupant culture has developed around blinds usage, daylight performance (and subsequently lighting power savings) is likely to be far below potentials identified in the design phase.

An educated, motivated, and empowered user group may be the state-of-the-art in building controls. However achieving maximum performance requires the designer to effectively communicate the design intent and the crucial role that user behavior can play in the successful operation of a high-performance building. The designer must also provide a design that enables ergonomic optimum operation of blinds and shades including pull-cords, chains, wands, motor control, and switching. Perhaps a user information feedback system might aid occupants in optimum manual operation of blinds and shades. However, given current user expectations of interaction with building systems, automation of glare control (where crucial to overall performance) can ensure that a building will operate in a way that will meet daylight performance criteria persistently over time regardless of user behavior.

A hybrid model can be constructed (fig. 9) that provides automation at critical points within a system, while allowing users to manually control glare at others. Successful implementation requires the development of performance priorities relative to persistent daylight delivery, persistent solar control, and blinds control for visual preference and deliberate space darkening. In such a system the designer must develop an aperture system that will provide resilient daylight performance (via active automated or passive means) regardless of the configuration of user operated components. In side-lit spaces this may take the form of a “daylight” window with an automated shading system designed to comprehensively illuminate a space and a “view” window with a manual blinds system that can be closed without substantially reducing the effective distribution of daylight illuminance.

2.3 Individual Work Environments (Private Offices)

Private office-type work environments present substantially less complexity than shared work spaces to the designer wishing to provide effective daylight distribution and solar and glare control. This is for two primary reasons. Presuming that a single workstation occurs within the private office volume, it is unlikely that glare control requirements will be at cross purposes with the visual preference of the single occupant. Secondly, “ownership” of blinds control is clear (even if operational intent may not be). The occupant can, given the smaller spaces and likely proximity of blinds controls, adjust blinds with relative ease and convenience, as needed to meet his or her individual visual preference without compromising visual comfort or daylighting performance for other occupants.

Since private office spaces tend to be smaller (usually with section depths less than 12’-0”(~4m) it is possible to provide for effective daylight illumination over time with far lower glass to opaque wall area than most shared work environments where section depths routinely exceed 30’-0” (~10m). This opportunity for reduced glazing area at private offices offers the potential for much less heat transfer through glazing, consequently diminishing the need for the type of continuous solar shading delivered by an automated exterior solar shading system. Beyond this, since most private offices tend to be occupied less frequently than open office zones, the potential for lighting power savings through photo controlled electric lighting is diminished once occupancy/vacancy sensing is considered. Though, in buildings where private offices at the perimeter constitute the majority of program area there may be still substantial lighting power savings potential from daylight.

In general, daylight performance at a private office will have little to no impact on adjacent visual task areas to the interior. However in some cases “re-lites” or light transmitting partitions may be included to attempt to “borrow” daylight from perimeter private offices to inter spaces beyond. To meet this objective the use of automated blinds or shades may be preferable to ensure daylight performance and glare control regardless of whether the private office is occupied at any given time.

4. <u>SIMPLIFIED DESIGN DECISION FLOWCHART</u>

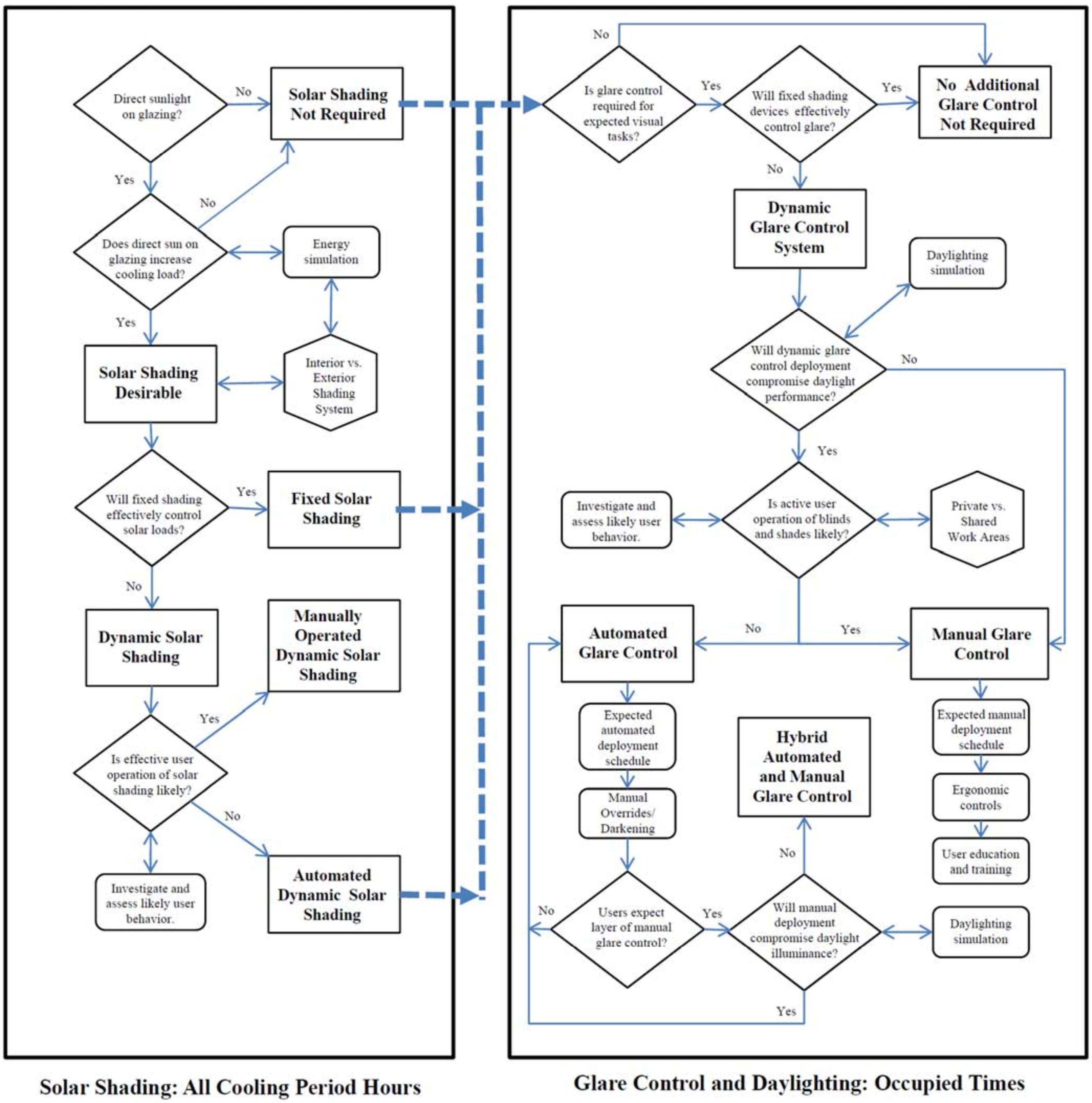


Fig. 7. The simplified design decision flowchart for solar shading and glare control offers a potential model for identifying key decision points in designing such systems.

5. CASE STUDY: LOTT CLEAN WATER ALLIANCE

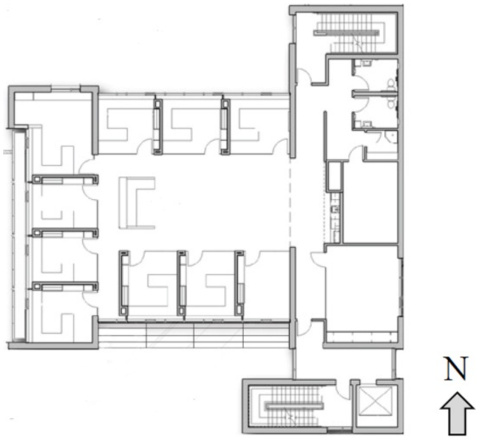


Fig. 8. Typical Office Floor Plan (Drawing: The Miller Hull Partnership)

5.1 Project Overview

The LOTT Clean Water Alliance Regional Services Center is a 25,000 square foot (2323m^2) office building, laboratory, water treatment, and educational facility located in Olympia, WA designed by the Miller Hull Partnership[7] of Seattle, WA. It was completed in 2010 and has been certified LEED Platinum and is targeting net-zero energy operation. At the office areas daylight and views to the exterior play a crucial role in meeting energy performance and indoor environmental quality goals. Each office floor plate has glazing to the south, west and east, with private offices at the perimeter, entirely transparent glass office walls, and a shared interior work area (Fig. 8). The overall floor plate depth from north to south is approximately 42’-0” (12.8m). To meet daylighting, solar shading, glare control, and visual comfort simultaneously at all areas, the design team used a mix of fixed solar shading, automated dynamic exterior solar shading, interior automated venetian blinds, and manually operable roll-down fabric shades. The deployment of these systems varies from façade to façade relative to patterns of sunlight, cooling requirements, the desire for occupant control, and daylight distribution goals.

5.2 South-Facing Office Façade

Energy simulation indicated that solar loads at south-facing glazing could be effectively controlled with fixed exterior horizontal sun shades. To allow for effective daylight distribution these were placed at 8’-0” (1m) above finished floor allowing for 3’-0” (1m) of unobstructed “daylight” glazing above (Fig. 9). This glazing enables diffuse daylight to pass through the private office and wash the ceiling of the share work area in the center of the floor plate. However, this unobstructed glazing consequently allows the potential for glare from unmitigated direct beam sunlight during some portions of the year. To ensure visual comfort and persistent daylight performance the design team included automated interior venetian blinds at this window. These venetian blinds retract during periods of overcast and deploy to an optimum slat angle during clear skies based on sun position as determined by a pre-programmed algorithm and an astronomical time clock. In the “vision” window (below the fixed horizontal sunshade) is a manually operated interior roll-down fabric shade (3% opacity). This configuration allows occupants of the private office to adjust the fabric shades to control glare without impeding daylight distribution to occupants within the central shared work area (Fig. 10).

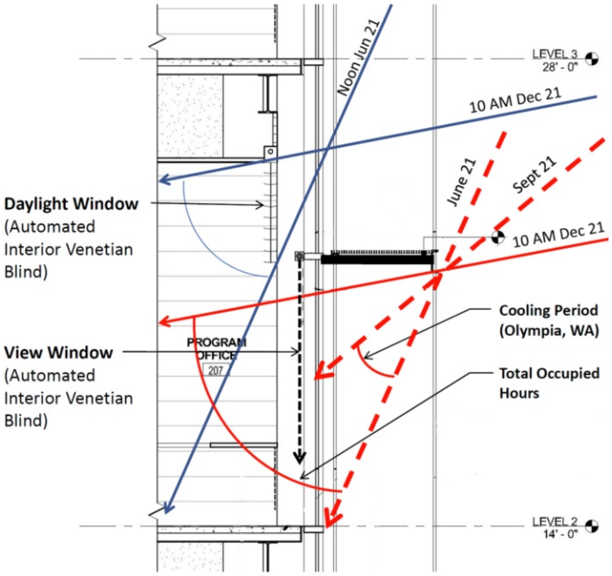


Fig. 9. Horizontal exterior sun shades, interior automated venetian blinds, and interior roll-down fabric shades at the south façade.

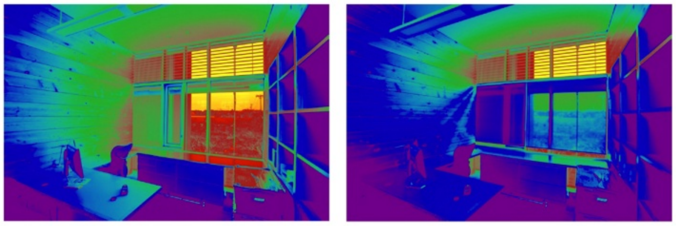


Fig. 10. False color luminance map showing south-facing offices with and without manual roll-down fabric shades deployed.

5.3 West-Facing Office Façade

Energy simulation indicated that to meet energy performance goals direct sunlight must be continuously controlled at west-facing glass during the cooling period. To meet this objective, the design team chose exterior automated venetian blinds that would automatically be deployed when sun was present and retracted when glass was in shade or during overcast periods. To enable occupants to adjust blinds based on their visual preference (Fig. 11), interior roll-down fabric shades were installed at a datum of 8’-0” (2.4m) allowing for 2’-6” (0.8m) of unobstructed glazing to deliver daylight to the central shared work areas (except when exterior venetian blinds are deployed).

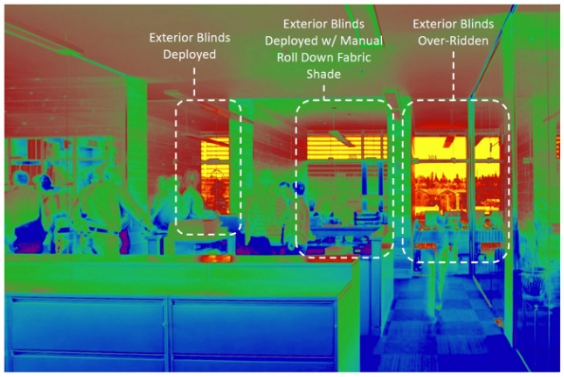


Fig. 11. False color luminance map showing range blind deployment configuration per user preference.

5.4 North-Facing Office Façade

Since almost no direct sunlight is present on north-facing glazing during regular occupied hours, solar shading was not included at this orientation. However, roll-down fabric shades were provided to enable occupants to manage brightness within their view to the exterior. Again, these were mounted at 8’-0” (2.4m) allowing for 2’-6” (1m) of unobstructed glass to ensure daylight distribution to the central shared work area (Fig. 12).

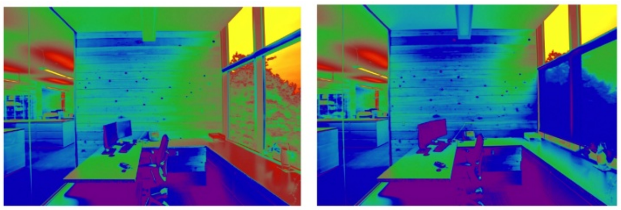


Fig. 12. North-facing offices with and without manual roll-down fabric shades deployed.

6. CONCLUSIONS

Blinds and shades operation can have a tremendous impact on realized building performance. Designers wishing to effectively create high performance buildings must develop clear intent about the performance potential and ongoing operational deployment of solar shading and glare control based on space programming, heating, cooling, lighting, visual comfort, and energy goals. Furthermore, designers, owners and building operators must understand (or develop) likely user behavior and expectations to increase the likelihood of realized performance. Three models for this include fully automated exterior blinds systems, manual blinds systems controlled entirely by occupants, and hybrid system.

7. ACKNOWLEDGEMENTS

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8. REFERENCES

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