Innovative Façade Systems for Low-energy Commercial Buildings

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Cover photo: Skyscraper in Shiodome, Japan. Photo: LBNL.

abstract

Glazing and façade systems have very large impacts on all aspects of commercial building performance. They directly influence peak heating and cooling loads, and indirectly influence lighting loads when daylighting is considered. In addition to being a major determinant of annual energy use, they can have significant impacts on peak cooling system sizing, electric load shape, and peak electric demand. Because they are prominent architectural and design elements and because they influence occupant preference, satisfaction and comfort, the design optimization challenge is more complex than with many other building systems.

Façade designs that deliberately recognize the fundamental *synergistic* relationships between the façade, lighting, and mechanical systems have the potential to deliver high performance over the life of the building. These "integrated" façade systems represent a key opportunity for commercial buildings to significantly reduce energy and demand, helping to move us toward our goal of net zero energy buildings by 2030.

Provision of information – technology concepts, measured data, case study information, simulation tools, etc. – can enable architects and engineers to define integrated façade solutions and draw from a wide variety of innovative technologies to achieve ambitious energy efficiency goals.

This research is directed toward providing such information and is the result of an on-going collaborative research and development (R&D) program, supported by the U.S. Department of Energy and the California Energy Commission Public Interest Energy Research (PIER) program.

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1. introduction

The challenges that we face in the near term are clear: global climate change and world-wide competition for dwindling resources that drive our economy, security, and future well-being. Meeting the challenge of reducing building energy use to net zero is one of many "stabilization wedges" we can use toward reducing carbon emissions to 2005 levels, as suggested by Pacala and Socolow [1]. Buildings are responsible for 39% of the total energy use in the U.S. Commercial buildings account for almost half of that percentage, or 18% of the U.S. total. Heating, cooling, and lighting constitute 57% of the total energy end uses in commercial buildings and facades can have a large influence over these loads.

High-performance, low-energy facades solutions actively recognize and optimize the synergistic impacts that facades have on lighting and heating, ventilation, and air-conditioning (HVAC) energy end uses, achieving greater energy-efficiency, peak demand reductions and occupant comfort than conventional piecemeal solutions. Such solutions are typically a result of both conscientious design and astute use of innovative technologies.

We provide a brief summary of where we are along the pathway towards achieving optimal solutions then describe how we might begin to more aggressively meet net zero energy building goals in the near term.

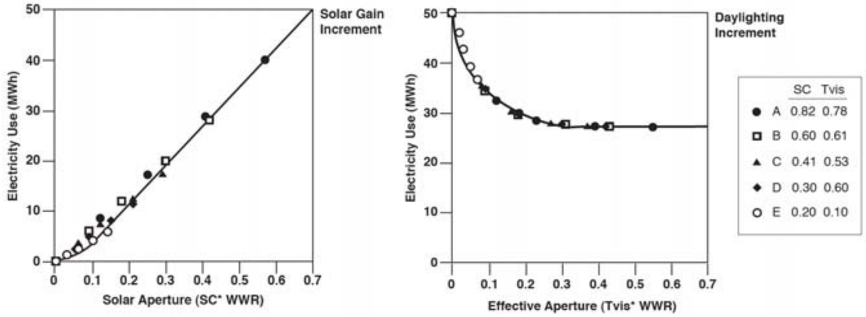
1.1. Historical Context: Market Push Using Building Energy Codes

Historically, energy codes and standards have slowly pushed the U.S. toward cost-effective, energy-efficient façade solutions which have helped to improve overall building energy efficiency. Unfortunately, the fundamental relationships underlying the codes have been obscured by the code process, making it difficult for architects and engineers to understand how to attain more optimal solutions.

In the early 1980s, federally funded research contributed to major revisions to the then ASHRAE Standard 90, resulting in Standard 90.1-1989 which incorporated prescriptive and performance based criteria for facade design. The revisions were based in part on a DOE-2 building energy simulation study [2] involving tens of thousands of parametric runs of commercial buildings situated in various climates. The study applied regression analysis on these data and quantified trade-off relationships between the facade, lighting, and HVAC systems. Equations resulting from this study are still seen in the ASHRAE 90.1-2004 Appendix C. Due to its complex presentation, it is unlikely that architects and engineers (A/Es) will understand the simple synergistic relationship it is trying to convey.

This trade-off synergistic relationship applies to the perimeter zones of typical commercial buildings in both hot and cold climates throughout the U.S. with high internal loads and conventional HVAC and lighting systems:

- Decrease window area and/or its solar transmission and cooling energy use is decreased.
- Increase window area and/or its daylight transmission and lighting energy use and associated heat gains are decreased.



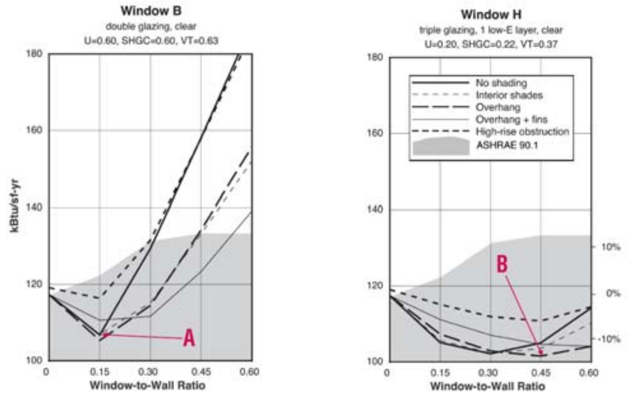
Cooling energy use increases with increased window area or solar transmittance of the glass (left). Lighting energy use decreases then levels out with increased window area or visible transmittance of the glass (right). The combination of the two results in relationships shown in the adjacent figures.

Minimum total perimeter zone *source* or primary energy use is achieved through a balance between these two competing objectives.

ASHRAE 90.1 and California Title-24 energy codes have mandated minimum requirements for window solar transmission and thermal properties and put a cap on window area (i.e., solar heat gain coefficient (SHGC), U-value, and window-to-wall area ratio (WWR), respectively). For daylighting, the 90.1-2004 code makes no explicit reference to the window's daylight transmission properties (e.g., minimum visible glass transmittance, Tvis) nor lighting controls for daylight harvesting, other than provisions for manual lighting control – on-off and bi-level switching. The 2005 version of Title-24 made significant revisions, incorporating requirements for photosensor-based daylighting controls but also made no reference to daylight admission through the windows. The synergistic relationship is ignored.

For skylights, which are significantly less complex than windows, there has been more progress. The synergistic trade-off relationship was quantified for skylighting in the early 1980s, where parametric DOE-2 simulations were conducted to identify ideal skylight size, spacing, and daylight and thermal properties to minimize HVAC and lighting energy use with daylighting controls [3]. A Skylight Handbook was developed by LBNL with simple accompanying software, which was later transformed into SkyCalc, a PC-based tool with an Excel interface [4]. In 2005, California's Title-24 began mandating use of skylights in single-story, large commercial structures such as big-box retail buildings and daylighting controls.

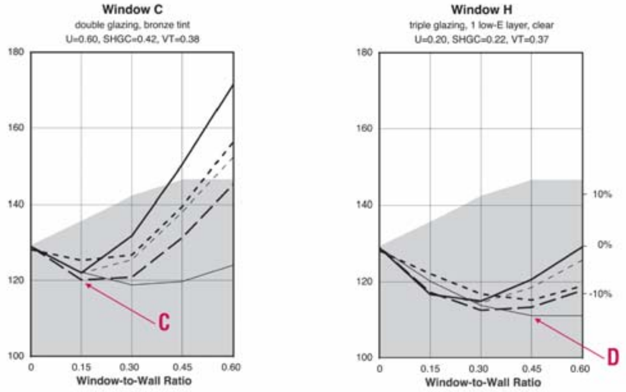
More recently, Standard 189, which is being jointly developed by ASHRAE, USGBC, BSR, and IESNA, makes more explicit references to thermal-daylighting trade-offs by imposing stringent solar control measures (e.g., solar heat gain, exterior shading) but also requiring that the façade meet minimum daylighting requirements (e.g., effective aperture, illuminance targets). Draft versions of ASHRAE 90.1-2010 are also considering incorporation of daylight criteria by setting a minimum value for the light-to-solar-heat-gain ratio (Tvis/SHGC), while simultaneously constraining SHGC and U-value.



Cold Climates: Chicago, Illinois

A: With clear double glazing, a very small south-facing window with daylighting controls yields the least annual energy use – 10% below ASHRAE 90.1-2004, irrespective of interior or exterior shading.

B. With triple-pane, low-e clear glazing, an overhang, and daylighting controls, you can use larger windows and reduce annual energy use by 24% below code.



Hot Climates: Houston, Texas

C. With bronze tinted double glazing, a very small south-facing window with daylighting controls yields least annual energy use if no shading is used.

D. With triple-pane, low-e clear glazing, an overhang and fins, and daylighting controls, you can use larger windows and reduce annual energy use by 24% below code.

Note: Annual (primary) energy use includes heating, cooling, lighting, and all other energy end uses in a typical commercial office building. A site-to-source efficiency factor of 3:1 was used for electricity and 1:1 for natural gas.

These activities target conventional design and primarily new construction practices in the U.S., are directed toward measures that affect the core and shell of the building, and are prioritized based on the magnitude of energy savings and life-cycle cost criteria. Until recently, small- to moderate-area windows were promoted because only thermal impacts of windows were recognized. Low-e glass and thermally-broken window framing systems met the cost criteria, were supported by standardized rating systems and tools across the industry, and so have been widely promoted and supported by the codes over the decades.

Other promising emerging technology measures have fallen into the Catch-22 chasm in the technology adoption life cycle. If not mandated by code, these emerging technologies may be used by some early adopters, but not by the majority mainstream end users who require good references to make their buying decisions – particularly in the risk-averse building industry [5]. Without demand and volume, manufacturers are unable to lower the cost of new products, making it difficult to meet the two to five year payback criteria demanded by typical building owners and developers.

1.2. Attaining Net Zero Energy Building (ZEB) Goals

Building energy simulation studies have more recently been commissioned by the U.S. Department of Energy (DOE) to better understand the most effective ways to reach zero-energy building (ZEB) goals by 2025. These studies focused on estimating technical rather than market potential, putting aside for the moment cost and implementation barriers.

The National Renewable Energy Laboratory (NREL) completed an EnergyPlus simulation study in 2007 [6] to investigate the potential to reach ZEB goals across the entire U.S. commercial buildings sector with advanced technologies. The study estimated the maximum efficiency potential to reduce building energy use to net zero using a combination of efficiency measures. NREL found that *no single technology* was found to produce dramatic improvements in efficiency needed to reach ZEB for a large fraction of the commercial building sector. Use of *combinations* of efficiency measures resulted in larger reductions than use of individual technologies alone.

In isolation, highly insulated, switchable electrochromic facades, automated to minimize lighting and cooling energy use through its variable solar and daylight transmission properties, reduced sector-wide average energy use intensity by 7.5% if the base stock met 90.1-2004 Standard. These levels were comparable to a 10% reduction if lighting efficiency was increased from 80 lumens per Watt (fluorescent) to 160 lumens per Watt (projected for solid state lighting efficiency), or a 7% reduction if opaque insulation levels were significantly increased to ASHRAE/ IESNA/ USGBC/ BSR Standard 189 levels. This study established the value of highly insulated dynamic windows in combination with other efficiency measures in reaching ZEB goals.

Other façade-related technologies were reviewed, including daylighting controls, insulation, massing, and orientation, also indicating that such strategies all contribute to reaching the overall goal of net zero energy buildings.

1.3. Achieving Aggressive Energy-Efficiency Objectives in the Near Term

Given the wide gap between energy efficiency standards and codes and the technical potential of reaching ZEB goals, there remains significant untapped near-term opportunity to capture large energy use and peak demand savings in the commercial building stock. This opportunity can be addressed collectively by a wide variety of activities from development of standardized rating systems for emerging technologies that can be referenced by codes and standards to simulation tools that can be used by small and large A/E firms across the U.S. in the early stages of design to make more informed decisions.

From the technology perspective, the challenge is to identify, develop as needed and then evaluate and optimize robust, off-the-shelf solutions that meet the basic practical constraints for typical commercial buildings. The technical challenges are admittance of adequate daylight while limiting HVAC loads and glare. There is a range of potential solutions with different cost, performance and applicability to various climates, building types and site conditions. The design challenge for architects and engineers is to quickly identify and evaluate the cost-benefit tradeoffs of solutions that address factors such as cooling, daylight, glare, view, cost, and maintenance.

Approaches to address these challenges should be directed at both the "supply" and "demand" side of the industry:

- develop the tools and performance data that allow designers to navigate the complex decision-making process to select the best available solutions, and
- accelerate market adoption of energy-efficient façade technologies by providing critical third-party performance data to end users and/or supporting further development of the technology toward energy-efficiency goals in collaboration with manufacturers.

These two approaches were used in this multi-year project, supported by the U.S. Department of Energy and the California Energy Commission Public Interest Energy Research (PIER) program. Unique sources of information derived from this R&D include:

Simulation Tools

A series of tools have been and will continue to be developed to enable evaluation of integrated façade designs in the early stages of design. The web-based tool enables quick comparisons of performance within a subset of possible design permutations. A commercial fenestration (COMFEN) PC-based tool enables A/Es to make more detailed performance comparisons of a wide variety of façade designs, engaging SketchUp at the front end and the EnergyPlus building energy simulation program for the calculation engine.

In the back room, so to speak, there is a significant international effort to improve the accuracy of simulation tools used to predict the daylight and heat gain impacts of complex fenestration systems (CFS), such as Venetian blinds, roller shade fabrics, acid-etched or fritted glass, metal scrims, etc. that transmit, reflect, and/or diffuse light in a complex pattern. Simple, transparent glass is well characterized by energy simulation tools. CFS are poorly characterized to a greater or lesser degree using non-standardized methods. R&D activities are directed towards creating a comprehensive solar-optical database of CFS products that can then be modeled using simulation tools in a routine manner.

Monitored Performance Data on Emerging Technologies

Critical third-party monitored performance data have been collected on the energy and comfort impacts of commercially-available and emerging technologies in a full-scale, private office mockup under real sun and sky conditions. Evidence-based information, derived from rigorous scientific studies in combination with accurate building simulation tools, can help stakeholders make more informed investment and purchasing decisions. Anecdotal observations from hands-on "road testing" of the technology were also made; e.g., how the technology works and considerations for use.

For commercially-available technologies, these data are not meant to duplicate existing information already publicly available on the manufacturers' websites (e.g., technical specifications, range of product offerings, etc.), but rather to provide independent information on performance impacts.

For emerging technologies, measured performance data and observations provided feedback to manufacturers, enabling industry to improve the design and/or operation of products to better address whole building energy efficiency goals in concert with the lighting and HVAC systems, peak demand control requirements affecting HVAC sizing and reliability of the electrical grid system, indoor environmental quality requirements for occupant comfort and satisfaction, and engineering details of implementation to achieve optimal performance.

1.4. Organization of this Document

This document is a product of an on-going R&D investigation and is directed toward stakeholders – architects, engineers, building owners, and facility managers – desiring succinct, technically-oriented information about commercially-available and emerging façade technologies that can be used to achieve aggressive energy-efficiency goals through an integrated synergistic approach to façade design.

This material is organized as follows:

Section 2 Concepts: Since optimization of solar heat gains, daylighting, direct sun control, glare, and view often requires a compromise between these competing objectives, an overview of the various energy-efficiency and comfort-related concepts associated with high-performance, integrated façade design is given.

Section 3 Technologies: A wide variety of innovative facade technologies are available to the architectural industry for design. In this section, the fundamental concepts behind a class or category of technologies are explained along with general guidelines for use. Monitored performance data from a full-scale office testbed mockup are given as well as anecdotal observations from working hands-on with the actual technology.

Section 4 Resources: Links to simulation tools and other resources that provide more detailed performance data and information.

Periodic updates to this material will be made in the future to reflect new findings.

2. concepts for low-energy facades

The conceptual approaches described below are focused on energy- and comfort-related trade-off relationships between the façade, lighting, and HVAC systems. As discussed in the Introduction, fundamentally, facades affect:

- solar heat gains, conductive loads, long-wave radiative heat transfer, and convective heat transfer through the building envelope, and
- admission of daylight and sunlight affecting illuminance quantity and distribution within the building interior.

The magnitude of these quantities vary with climate (i.e., temperature, wind, humidity, precipitation, sky conditions, etc.), exposure to sunlight or façade orientation, siting, massing, urban context, etc. The significance of these quantities depends on the basic or desired environmental requirements needed to occupy the building and then the efficiency and operation of the supporting building equipment needed to meet these requirements.

In support of these technical concepts, architectural interpretations of the concepts are folded into the below discussion. Photographic examples are given for a series of architectural and technological concepts to show the diversity of solutions architects and engineers have generated in response to site, climatic, and programmatic constraints, and sustainability goals.

Net-zero architecture cannot be created by first creating architectural forms and then applying engineering principles – but rather must be integrated into a single process. Design teams that are beginning to take on the challenge of creating net-zero energy buildings are quickly discovering that achieving such a goal can be extremely difficult. Fundamental changes in professional practice have been evolving slowly where the ideal project has the resources and schedule to enable architects to generate and weigh concepts in the early stages of design using supporting building performance data in collaboration with the engineering team.

Over the past several years, there have been a rich and creative range of responses to the challenge of sustainable architecture, particularly in Europe where the impetus towards low-energy use has been strongly motivated by the need to meet the lower greenhouse gas emission requirements dictated by the Kyoto Protocol. These innovative examples appear to have balanced both pragmatic constraints with inspiring or even whimsical architecture. Architects are engaging performance in various ways. In some cases the design approach is to explicitly reveal energy performance strategies such as exterior shading, building integrated photovoltaics (PVs) and stack ventilation. In other cases, performance strategies are more subtly integrated with explorations of form, material, surface, response to program, context, and any number of other design factors.

These examples illustrate "what architects are doing now" to reduce energy usage in buildings and are meant to stimulate the reader to both admire the wealth of solutions and critically appraise where we have been and where we might go in the future. The examples are recently built projects, conceived on the drafting tables five to ten years ago and have now been occupied for a few years. The strategies have varying degrees of effectiveness and must be carefully studied relative to the particular circumstances of each project. The actual energy efficient and comfort performance of these examples is not addressed – it is important to understand that these examples may or may not deliver high performance.

2.1. Use Massing and Orientation to Enhance Daylight and Control Solar Heat Gains

Architects interested in applying passive strategies to create low-energy building have long understood the importance of massing and orientation. Because it is much easier to manage heat gain and daylighting on north and south exposures, extending the building along the east-west axis increases these exposures, while the east and west exposures are reduced.

For south exposures (in the Northern Hemisphere), the depth that daylight can be effectively distributed within the interior can influence floorplate depth and layout of service and core spaces. Conventional window designs can effectively daylight a zone to a depth of 1.5 times the head height of the window (approximately 15 ft deep with a 9 ft high window). Sunlight-redirecting systems have even greater potential in open plan office areas in sunny climates. At the same time, view windows can be more easily shaded than east and west exposures. Since northern exposures have infrequent exposure to direct sun, narrow floor plates with a north-south exposure can be very effectively daylit while limiting solar heat gains.

Narrow floor plates are also amenable for natural ventilation, where façades are oriented in the prevailing wind direction and cross ventilation is permitted (e.g., residential towers in Hawaii).

Of course many projects have site constraints, especially those in urban settings, so these strategies must be applied creatively. In some cases, site constraints force the building orientation in difficult directions. An awareness of the implications of massing and orientation allows design teams to realize the advantages when possible, and when it isn't possible, to seek other strategies to mitigate the impacts. Because other strategies are likely to be less effective and can be expensive, maximizing the benefits of massing and orientation in the earliest stages of design concepts can have a very significant impact on building performance.

SOKA BAU, Wiesbaden, Germany, Thomas Herzog Architect, view from north. Photo: Mark Perepelitza

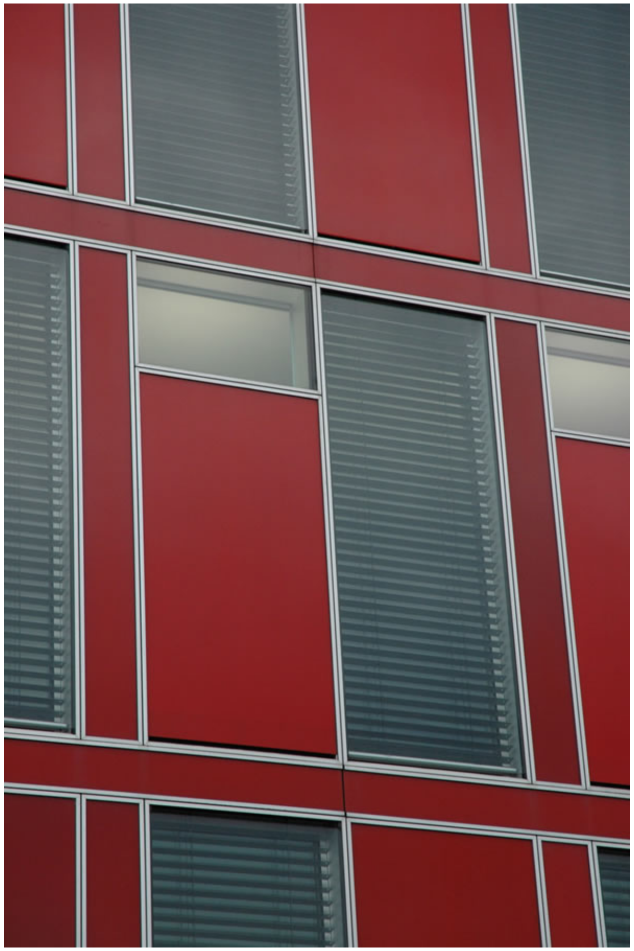
SOKA BAU, aerial photograph, Google Earth

Tools like Ecotect are providing architects with rich illustrations depicting, for example, the total annual incident solar radiation or available daylight on a façade. Google's Sketchup enables quick visualizations of shadow patterns on a façade. Animation tools help clients to visualize the sun's daily and seasonal path relative to the site. To use these tools effectively for design, architects should obtain performance criteria or guidance from the engineering team on *when* the façade should be shaded. For residential homes in the Northern U.S., for example, a good rule of thumb is that windows should be shaded in the summer and allowed to admit direct sun during the winter. For commercial buildings, passive heating during the winter may increase energy use even in cold climates like Chicago, where a perimeter zone may be in a cooling mode year round. Similar guidance should be provided for daylighting and natural ventilation schemes.

2.2. Use Window Area Judiciously to Achieve Transparency

Because buildings not only provide shelter from severe weather, but also support the activities of daily life, connections between inside and outside are essential. Window systems provide these connections, but also bring significant issues of managing heat gain and loss, as well as modulating daylighting to useful levels. In most traditional buildings, windows were used selectively and included multiple filtering systems for managing light and heat (for example shutters) and air (via operable windows.)

For the past 100 years, architects have in various forms pursued the ideal of an all-glass building. With the evolution of modern heating and cooling technology, the indoor climate became far less dependent on the performance of the building envelope – although we now realize the huge ecological cost of that approach. The development of insulated glazing, thermally improved metal framing systems, and spectrally-selective low-emittance glass coatings have significantly improved the performance of highly glazed buildings with a clear (white, low-iron preferably) transparent appearance to boot. All-glass, transparent facades were viewed as very desirable in the 1990s and early 2000s. In Europe, further performance improvements on the all-glass transparent façade were sought through dynamic exterior solar control systems and ventilated double-skin wall assemblies with automated shading in the cavity.



Capricorn Haus, Düsseldorf, Germany, Gatermann Schossig Architects. Continuous daylight glazing, but reduced overall glazing area in a unitized, double-skin facade. Photo: Mark Perepelitza

Zollverein School of Management and Design, Essen, Germany, SANAA Architect. Random but distributed window openings in the concrete building shell provide light and views with significantly reduced glazing area. Photo: Mark Perepelitza

While strategies such as double skin facades can be used to manage heat gain and loss and daylighting for highly-glazed, transparent buildings, it is much more economical to use transparency strategically. If windows are provided where views are most desirable, and high on the wall to provide good daylighting, the overall window area can be kept below 50% of the exterior wall area without compromising the quality of the space. A handful of contemporary architects have designed high-profile buildings where this strategy has been combined with other explorations of form, material, and surface. In recent conversations, several prominent London architects noted this as a significant trend triggered by a focus on high-performance buildings.

With the aid of technological advances, the architect has the ability to design all-glass facades with comparable energy performance to facades with small to moderate window area. The larger the window area, the more care must be taken to craft an energy-efficient and comfortable solution. Larger windows can provide more useable daylight and views out but solar heat gains, direct sun, and glare must be controlled.

As discussed in Section 1, for typical commercial office buildings with high internal loads (i.e., occupants, lighting, plug loads, etc.) and conventional HVAC systems, perimeter zone energy use and peak demand can be minimized by optimizing the balance between exclusion of solar gains and admission of daylight in both hot and cold climates. More simply put:

- Decrease window area and/or its solar transmission and cooling energy use is decreased.
- Increase window area and/or its daylight transmission and lighting energy use and associated heat gains are decreased.
- Since these are diametrically opposed objectives, find the right balance between the two competing objectives to minimize energy use.

The balance is dependent on the relative efficiencies of the HVAC versus lighting system and site specific building conditions. For very efficient lighting systems and conventional inefficient HVAC systems, for example, control of window heat gains may be of greater importance in a commercial office building. For very efficient HVAC systems or in mild climates where HVAC energy use is low, it may be more important to optimize the façade for daylighting.

Different building types, occupancy patterns, and climates can alter this basic relationship or increase or decrease the importance of optimization. An airplane hangar with high-bay lighting and no air conditioning in a mild climate may welcome both window heat gains and daylight to minimize heating and lighting energy use. Use of double-glazed, spectrally-selective low-e , north-facing windows and daylighting controls in a 12-month occupied school classroom enables one to use small or large window areas with less than a 5% difference in annual energy use in a cold climate.

Simulation tools can help architects and engineers quantify this relationship. A parametric analysis where window area is varied, for example, can help designers understand how sensitive lighting and HVAC energy use is to design permutations for a particular building (see examples in Section 1).

For the above analysis, optimum façade solutions are determined on a perimeter zone basis for each window orientation assuming system-level HVAC energy use, not at the central plant of the whole building where inefficient operations and losses through distribution can confound the relationship. Also, some energy consultants compare the cost-effectiveness of façade measures against other energy-efficiency measures on a whole building basis, lumping core and perimeter zone energy use together, thereby diluting the impact of façade-related measures over a larger floor area for core-dominated floor plans (e.g., 100x100 ft floor plate). This reflects the short-term perspective where added incremental costs for energy efficiency measures must be justified based on recovery of operating costs alone. Given the longevity of the three main building systems – HVAC, lighting, and facades – optimization is ideally dealt with on a perimeter zone basis with the assumption that the lighting and HVAC system can and will be upgraded with more efficient systems sooner than the façade over the life of the building. Investments in more efficient façade designs over the long term can be well worth the increase in initial capital cost on a societal if not a life-cycle basis.

2.3. Design the Façade to Provide Useful Daylight

Daylighting has the potential to replace a significant portion of artificial lighting which is typically the largest use of electricity in buildings, but beyond performance, daylight is a fundamental design element.

With the development of large scale glass production in 19th century, effective use of daylighting became common in office buildings, schools, and homes, but nearly became a lost art with the emergence electric lighting. Although it never disappeared from the best modern architecture, common use of daylighting has reemerged to support sustainable buildings.

Effective use of daylighting should be a driver in the early design process in determining the building massing and orientation, as well as initial envelope transparency concepts. The three primary objectives for effective daylighting are distributing sufficient daylight to as much of the floor area as possible, managing glare, and incorporating a lighting control system to minimize electricity use.

The classic problem that plagues sidelit perimeter zones is that occupants sitting nearest the window will lower the shades to avoid discomfort from direct sun or glare. When conventional top-down shades are lowered or closed, they tend to eliminate much of the useful daylight and view, causing occupants farther from the window to rely more on the electric lighting system. Often, shades are left lowered for days or weeks at a time, irrespective of sunny or cloudy conditions. For reading and writing tasks involving paper, discomfort glare from windows is less of an issue than for tasks involving computer displays, where particular care must be taken to keep luminance (brightness) levels well controlled.

The concept of *useful or efficient daylighting* is to distribute the flux more uniformly to balance the luminance conditions in the overall space, lowering dark and light spatial contrasts, so that interior daylit conditions are visually comfortable. This can be accomplished most effectively by reflecting daylight to the ceiling plane at greater depths from the window, bringing in daylight from two opposing sides of the room if possible, or combining sidelighting with toplighting.

To minimize lighting and HVAC energy use, designers can also restrict the total amount of daylight on the interior to within a narrow useable range (ideally more daylight during overcast, gloomy conditions and less during sunny conditions, while still meeting the desired setpoint illuminance level). Actively controlled shading systems and switchable windows are capable of meeting this criterion.

Provision of some type of lighting controls, whether it be manual switches dictated by code or automated daylight controls which dim the electric lighting system in proportion to available daylight, are essential for capturing lighting energy savings and reducing the heat gain from lights. Such controls, in combination with solar heat gain control measures, can significantly reduce costly peak electric demand in a building, while helping to improve electric grid reliability and avoid brownouts or blackouts in regions like California or New York with constrained capacity to meet peak demands.

Nord/LB, Hannover, Germany, Behnisch Architekten
Heliostats supplement daylighting at this building, but light is primarily provided through the generous glazing and transparent interior partition walls. Automated exterior venetian blinds manage both heat gain and glare. Photo: Roland Halbe

2.4. Control Direct Sunlight

Since the luminance of the sun orb is several billion cd/m^2 and transmitted vertical solar radiation levels can be as high as 400-600 W/m^2 through even an advanced spectrally-selective low-e (unshaded) window on a sunny day, direct sun can cause significant thermal and visual discomfort in work areas if not properly controlled.

Lighting and HVAC consultants typically make the following assumptions about control of direct sunlight in areas of long-term occupancy:

- For visual comfort, it is assumed that occupants can use interior shades to block the orb of the sun from direct view (e.g., Illuminating Engineering Society (IES) RP-1 Standard for Office Lighting). This is particularly important if the occupant is unable to reorient their task or view point because the task is fixed or if task visibility is severely compromised by bright sunlight (e.g., computer displays).

- For thermal comfort, ASHRAE Standard 55 and most predictive thermal discomfort models assume that the occupant is not directly irradiated by a large-area source (the sun). Arens et al. [7] developed a method to estimate effective mean radiant temperature (MRT) based on radiation levels, finding that incident direct irradiance levels of less than 40-100 W/m^2 were unlikely to cause discomfort in a conventionally conditioned space.[1]

Making provisions to block direct sun is a fairly simple concept but it is surprising how many new innovative buildings have been constructed that fail to address this issue. When retrofitted with measures to block direct sun, the resultant façade often defeats the intended energy-efficiency or amenity features of the original design (daylighting, natural ventilation, view out, etc.).

Opaque shading systems such as an aluminum slat on a Venetian blind tilted to block direct sunlight can provide such solar control. Open-weave fabrics or perforated metal scrims with openness factors greater than 5% may not provide sufficient control of direct sun. Use of translucent glazings or panels to block direct sun can result in intolerable glare in sunny climates.

In this building, a 50%-open exterior metal scrim was assumed to be sufficient to control direct sun –after the occupants moved in, interior shades had to be installed to address complaints of thermal and visual discomfort. Photo: LBNL

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[1] Assumptions: PMV limit of 0.5, 21-23°C room air temperature, 1.2 met, 0.9 clo, maximum MRT to 25.8-28°C.

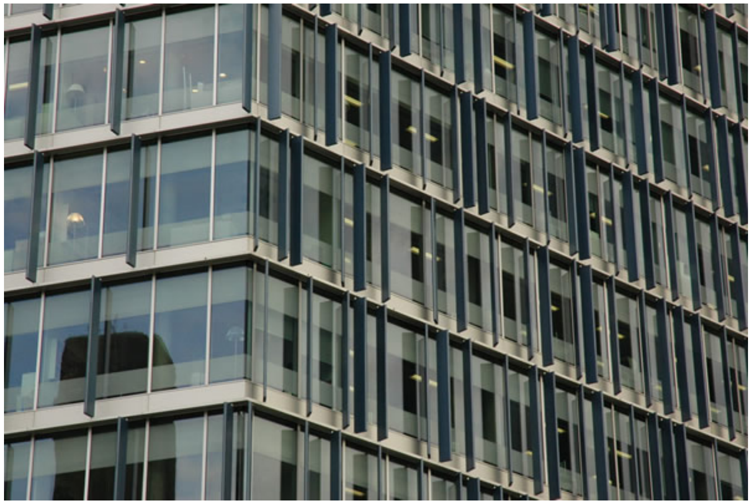
2.5. Enable Use of Low-Energy Cooling Strategies

Low-energy cooling strategies provide significant opportunities to reduce or even eliminate the need for conventional refrigerent-based chiller systems and their inefficient distribution systems. Underfloor air distribution (UFAD) systems, radiant cooling, and natural ventilation strategies all require very careful control of façade solar and thermal heat gains to ensure comfort conditions are maintained. To maintain comfort conditions with these cooling strategies, window heat gains must be kept below 4 W/ft^2-floor in a 15-20 ft deep perimeter zone [8]. Solar heat gains tend to be the predominant load during peak conditions and therefore must be carefully controlled while keeping in mind daylight-heat gain trade-offs (Section 2.2) – lighting and heating energy use, for some building types, could increase if daylight and sunlight are too severely restricted.

Strategies for solar control range in type, scale, and materials. At one end of the spectrum are fine grained planar systems such as screens, scrims, and frits that are used either directly on the glazing, or on one or more layers, sometimes to create a diaphanous effect. At the other end of the spectrum are horizontal and vertical elements at the floor by floor scale (such as a brise soleil) that cast strong shadows and shade that varies seasonally. In between are a range of horizontal and vertical elements (such as louvers) that provide rhythm or texture to the facade through shading that varies through the day and seasonally.

Translucent materials are often used to provide daylighting and a diffused connection between interior and exterior that changes over the course of the day. In some cases the materials are used to bring color to the façade. Note, use of translucent materials for solar control can result in intolerable glare under sunny conditions.

Dynamic or automated shading systems can be used to control peak solar load when critical and balance daylight and heat gain trade-offs during non-critical peak periods.



Blue Fin Building, London, UK, Allies and Morrison Architects. A semi-random arrangement of vertical fins provides sun shading. Photo: Mark Perepelitza

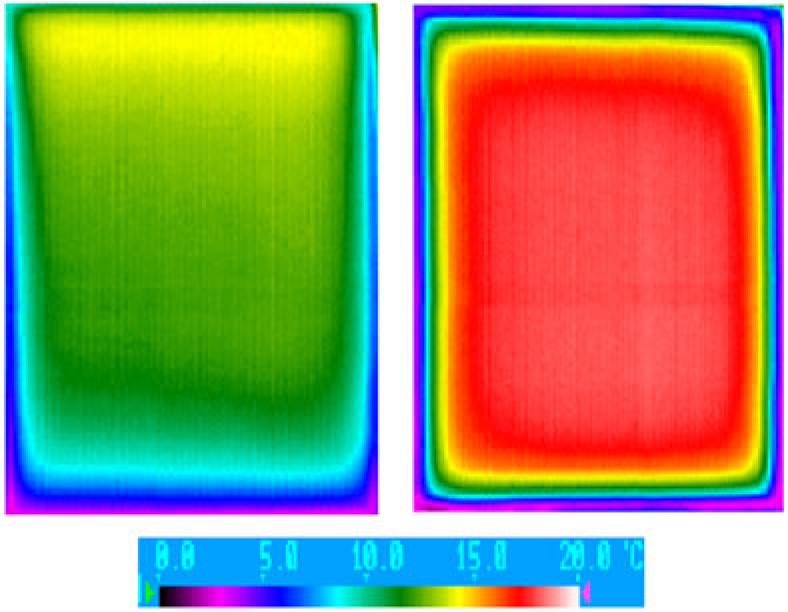
Copenhagen, Denmark, 3xn Architects. A uniform pattern of horizontal louvers provides sun shading but the dark color is not effective at redirecting daylighting. Photo: Mark Perepelitza

2.6. Eliminate the Need for Perimeter Heating and Cooling

In cold climates, highly insulated or high-R windows and frames raise the interior surface temperature of the glazing and frame, lessening thermal discomfort due to large differences in mean radiant temperature between the occupant and surrounding window surfaces. Perimeter heating systems, typically placed at the window wall, can be eliminated if these differences are minimized. Condensation is also reduced.

The same can be said for perimeter cooling. Hot, tinted, single-pane windows, windows retrofit with a dark tinted film, dark absorbing window shades, and windows with non-thermally broken frames can all cause occupants sitting near the window to be thermal uncomfortable. The larger the window, the larger the effect. The phenomenon is similar to radiation from a hot oven – radiation is the principle cause of the warm thermal sensation, not differences in air temperature. Perimeter cooling systems are needed to create a zone of cool air near the window to combat this effect.

In both hot and cold climates, highly insulated windows with thermally-broken frames can significantly improve comfort conditions and eliminate the need for perimeter heating and cooling systems.



The window on the left is a double glazed unit with low-E and an insulating spacer. The window on the right is a quadruple glazed unit with three different low-E coatings, krypton gas between the panes, and a partially insulating spacer. Such a high performance window is called a "superwindow".

The falsecolor image shows the surface temperature of the window, where the windows are being cooled on the back side with wind at -17.8°C (0°F). Image: LBNL

3. technology options

This section provides information on the technical basis or concepts behind a specific category or class of façade technologies, notes on application, and data on performance. The information is intended to be delivered in a succinct format with references to more detailed sources of information, if available.

Perhaps the most unique aspect of this section is provision of measured data from the Lawrence Berkeley National Laboratory (LBNL) Windows Testbed Facility illustrating the performance of the technology in a real-world situation. As noted in the Introduction, third party data are often critical for informed decisionmaking and can help to accelerate market adoption of a new technology, particularly in a risk-averse building industry. Architects often do not have the resources to test a new technology and determine the pros and cons of use. Emerging façade technologies were selected, installed, and evaluated over a solstice-to-solstice period under real sun and sky conditions. For some technologies, the field test was conducted in collaboration with the manufacturer to provide feedback on product performance and to give guidance on potential improvements to the engineering of the product. Anecdotal observations on how well the technology worked or considerations for use are also included.

These field studies provide relevant data particularly but not exclusively for commercial buildings with large-area transparent windows (the window luminance data, for example, are applicable to both small and large windows). The south-facing façade was designed as such for several practical reasons (e.g., increases accuracy of the cooling load measurement) and provides the opportunity to maximize daylight potential even under cloudy sky conditions. Interpretation of the data below however must be made carefully:

- The vision portion of the façade had a window-to-wall area ratio (WWR) of 0.59 and a visible transmittance (Tvis) of 0.62. Therefore, lighting energy savings will typically be small. The reference case, against which all innovative technologies were compared, was defined as a state-of-the-art window with a shade deployed to block direct sun.
- Discomfort glare from the window, particularly facing the window, will tend to be high.
- Successful high-performance solutions will yield both large lighting energy savings *and* visually comfortable conditions (e.g., discomfort occurs for less than 10% of the day) without significantly raising window cooling loads.
- High-performance solutions will also reduce peak window cooling loads and lighting energy demand, enabling use of low-energy cooling strategies such as radiant cooling or natural ventilation and contribute to increasing the reliability of the nation’s aging utility grid system.
- Some innovative interior shading systems produced small energy savings but increased visual comfort, making it difficult to interpret the results. If the reference case shades were controlled to provide the same level of visual comfort, then the innovative solutions would likely produce greater lighting energy savings, for example. Parametric simulations are needed to quantify these trade-offs in performance.

The technologies reviewed in this section were selected on the basis of a few pragmatic criteria:

- Broad applicability to both new and retrofit construction
- Representative of a class of devices or technical concept
- In the case where the technology was more costly, high performance potential with the possibility of lower cost in a mature market

Additional technologies will be added to this section as new field tests are performed. Field tests at LBNL in spaces designed to emulate a typical private office with south-facing windows. Details of the set-up, experimental method, performance measures, and outcomes are given in an accompanying document [9].

3.1. Spectrally-Selective, Low-E Glass or Films

Technical Concepts

- Spectrally selective (SS) low-e glass or films selectively admit visible light (daylight) while reflecting ultraviolet and infrared radiation (solar heat) through the use of transparent low-emittance coatings on glass or films.
- Spectral selectively can also be achieved less efficiently by the absorptive properties of green or blue tinted glass.
- Products with good spectral selectivity are characterized by ratios of visible transmittance to solar heat gain coefficient (Tvis/SHGC) that are in the range of 1.25-2.0.
- Since selective coatings also have low emissivity, the U-value of the window unit is also lowered, reducing conductive heat gains through the window.

Performance Impacts

- Because SS low-e windows are able to transmit more daylight for the same amount of solar heat gains as conventional low-e, tinted, or reflective windows, these windows can reduce both HVAC *and* lighting energy use and peak demand.
- Peak cooling and lighting electricity use is reduced, enabling downsizing of HVAC capacity and increased utility grid reliability.
- Moderate- to large-area windows with a high visible transmittance can increase daylight discomfort glare. To mitigate the effects of direct sun and glare, occupants often lower conventional interior shades and leave them lowered, decreasing the inherent daylight potential of the façade design and blocking views out. Careful sizing and placement of the window, use of innovative shading strategies, and other measures can help to preserve the daylight potential of high transmittance windows.
- Thermal discomfort can be decreased due to the low U-value of the window.

Applications

- Spectrally-selective windows are fast becoming the norm for commercial building applications and are cost competitive with conventional low-e, tinted, and reflective windows.
- Products can be used in any glazed opening: vertical windows and skylights.
- Sputtered, soft, low-e coatings have better performance than pyrolitic coatings, but must be protected in an insulating glass unit (IGU), suspended film, or laminated configuration. The low-e coating is typically placed on the number 2 (inner) surface of the outboard glazing pane. A suspended film between two panes of glass creates a lighter-weight IGU with a lower U-value.
- Spectrally-selective glue-on window films are available for retrofit applications but their performance is typically inferior to SS-low-e IGUs.
- Windows can be produced in laminate configurations for hurricane or bomb blast protection.

Measured Performance

- Measurements of net heat flow through four selective glazings were compared to clear double glazing in a field test using the Mobile Window Thermal Test Facility. Data were compared to Window 4.1 calculations and agreement between simulated and measured data was found to be good. These findings indicate that one can accurately simulate the solar and thermal heat gain impacts of SS low-e windows. For more information, see: http://gaia.lbl.gov/btech/papers/37747.pdf
- A detailed review of spectrally selective low-e glass is given in: http://www1.eere.energy.gov/femp/pdfs/fta_glazings.pdf

3.2. Translucent, Diffusing Glass or Panels

Technical Concepts

- Unshaded windows transmit sunlight in a downward direction in the area adjacent to vertical windows, causing severe contrast and glare. To minimize discomfort, occupants typically close interior shades, reducing daylight and potential lighting energy savings. Diffusing or translucent glass or panels can transmit daylight in a diffuse, non-directional pattern, changing the direction and therefore the distribution of daylight within the interior.
- Manufacturers assert that translucent systems for sidelighting can reduce glare and improve penetration of daylight under sunny and diffuse sky conditions, if the optical properties of the translucent system are perfectly diffusing (i.e., incident daylight is transmitted equally in all directions within the interior).
- Translucent systems are placed in the upper clerestory portion of the window wall to provide daylight, while vision glass with operable shades in the lower view portion of the window wall enables view out.

Performance Impacts

- Translucent systems can decrease lighting energy use if glare is adequately controlled.
- Depending on its construction, translucent panels with a low SHGC and U-value can also decrease HVAC energy use.
- Translucent and partially translucent systems, such as fritted or etched glass, can cause significant visual discomfort under sunny conditions, particularly if the system is within the occupants' direct field of view. For this reason, translucent systems have historically been used primarily for skylights or in clerestory windows with high ceilings like gymnasiums.

Laban Dance Center, London, UK, Herzog de Meuron Architects. Color tinted translucent polycarbonate is used for the majority of the outer skin with glass windows interspersed. In the dance studios the walls glow during the day, and at night the entire building exterior glows with the color and silhouettes of activity within. Studies of the buildings energy performance and visual comfort have shown mixed results. Photo: Mark Perepelitza

Applications

- Products can be used in any glazed opening: vertical windows and skylights.
- The size, visible transmittance, and placement of a translucent system in a clerestory configuration must be designed carefully. If sized too small and/or the transmittance is too low, there will be little impact on lighting energy use. If sized too large or the transmittance is too high, occupants may experience visual discomfort if the window is within their field of view An interior shade may then be required to control glare, which in turn could eliminate useful daylight.
- Translucent panels or glazings are produced using a variety of techniques. Plastics, such as fiberglass reinforced panels or polycarbonates, are inexpensive. Etched glass or laminate

glazings with a white polyvinyl butyral (PVB) interlayer are more durable than plastics but tend to be heavier.

- Translucent insulating glass units (IGU) are 1-inch to 3-inch insulating glass units with light diffusing material, such as UV-stable, glass fiber diffusing veils, inserted between two panes of glass. These systems have very low U-values and claim to have superior light diffusion capabilities compared to plastics or etched glass translucent products.

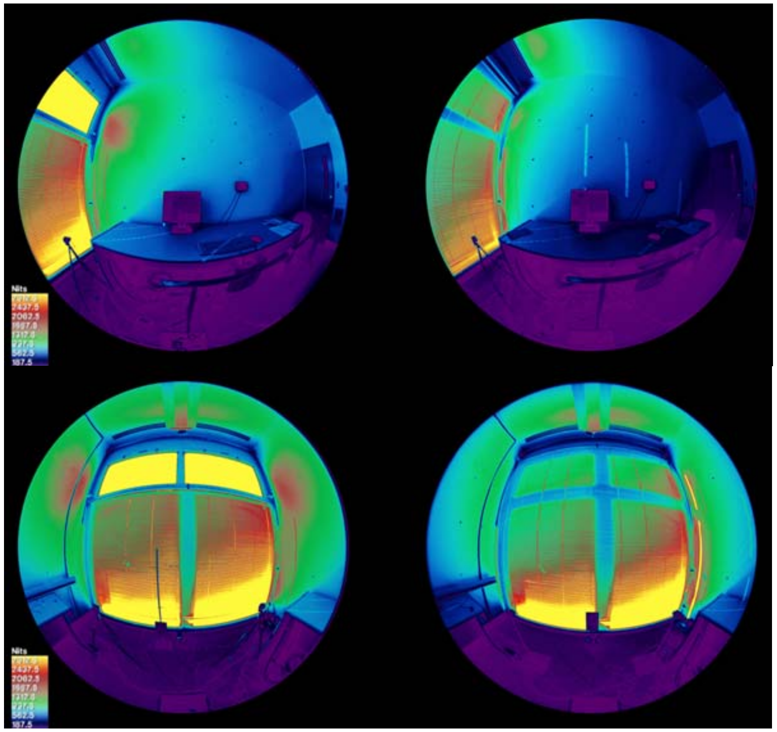
Translucent clerestory panels, Kirkwood Community College Recreation Center, Cedar Rapids, Iowa, Architect: Neumann Monson, Iowa City, Iowa. Photo: Farshid Assassi, Assassi Productions, Santa Barbara, California at www.advancedglazings.com

- Ceramic-fritted glazings with dot or line patterns fall under a different category of glazings because they are partially transparent and diffusing. These glazings are used principally to reduce the solar heat gain coefficient (SHGC) of the window to meet energy codes. If insufficiently dense, fritted glass can cause visual and thermal discomfort because the transparent regions of the glazing transmit direct sun. Depending on the area and placement of the transparent regions, fritted glass should be combined with additional shading systems to reduce glare.

Glass pavilion in Hamburg, Germany. A graphic pattern of frits provides some reduction of solar heat gain. Photo: Mark Perepelitza

Measured Performance

- In a solstice-to-solstice full-scale field test in a sunny climate (see datasheet on next page), a translucent clerestory panel with a lower shaded vision window was found to yield virtually the same lighting energy use as a conventional shaded window with the same large area.
- The brightness of the panel was however excessively bright for a significant fraction of the monitored period (exceeded threshold of 2000 cd/m² for an average of 3.6 hr/day with an average luminance of 4700 cd/m² when above the threshold), despite its overall transmittance being low (Tvis glass + panel ≅ 0.30).



Translucent clerestory panel (left) and conventional Venetian blind (right) on January 17, 10:02 AM. Yellow = luminance levels ≥3000 cd/m².

- Window cooling loads were reduced by 17% and peak cooling loads were reduced by 14% due to the lower SHGC and U-value of the translucent panel compared to the reference window. To reduce discomfort glare in spaces where computer-based tasks are performed, a lower transmittance panel would need to be specified, which would increase lighting energy use but reduce cooling loads.
- The translucent panel completely obscured views out but unobstructed views out were possible through the lower window.
- The simple, planar translucent system had the very distinct advantage of low maintenance compared to conventional shading systems.

Interior view of test room with translucent panel in the upper daylighting zone and a conventional venetian blind in the lower view zone. Photo: LBNL.

Translucent clerestory panels

10x9 ft south-facing window in a 10x15x11 ft private office, Berkeley, CA (latitude 38°N)

Reference Case

Single, fully-lowered interior Venetian blind with 1-inch wide concave down, matte-white slats

Manually operated: Slat angle adjusted seasonally to block direct sun

Test Case

Translucent panel in upper zone, fully-lowered interior Venetian blind in lower zone.

2.75-inch deep, white panel (Tv=0.47, SHGC=0.44, U-value=0.2 Btu/h-ft2-°F).

1-inch wide, matte-white blind seasonally controlled to block direct sun.

Window height above floor
  Lower: 0.7-6.5 ft high
  Upper: 6.5-9.0 ft
  Width: 10 ft

Daylighting controls

1 W/ft^2, single zone, 20-100% power, 50 fc setpoint, 10 ft from window

Lighting Energy Use

	Lighting Energy Use	
	Monitored days (6:00-18:00)	35
	Glass: WWR=0.59, Tvis=0.62	
1	ASHRAE 90.1-2004, no light controls (Wh/day)	1800
2	Reference with daylighting controls (Wh/day)	616
	Test case with daylighting controls* (Wh/day)	636
3	Savings, ASHRAE 90.1-2004	65%
	Savings, reference with daylighting controls	-5%
4	90.1-2004 Annual Energy Use Intensity (kWh/ft^2-yr)	3.00
	Reference: Annual EUI (kWh/ft^2-yr)	1.03
	Test: Annual EUI (kWh/ft^2-yr)	1.06
5	90.1-2004 Lighting Power Density (W/ft^2)	1.00
	Test case with daylighting controls: LPD (W/ft^2)	0.35

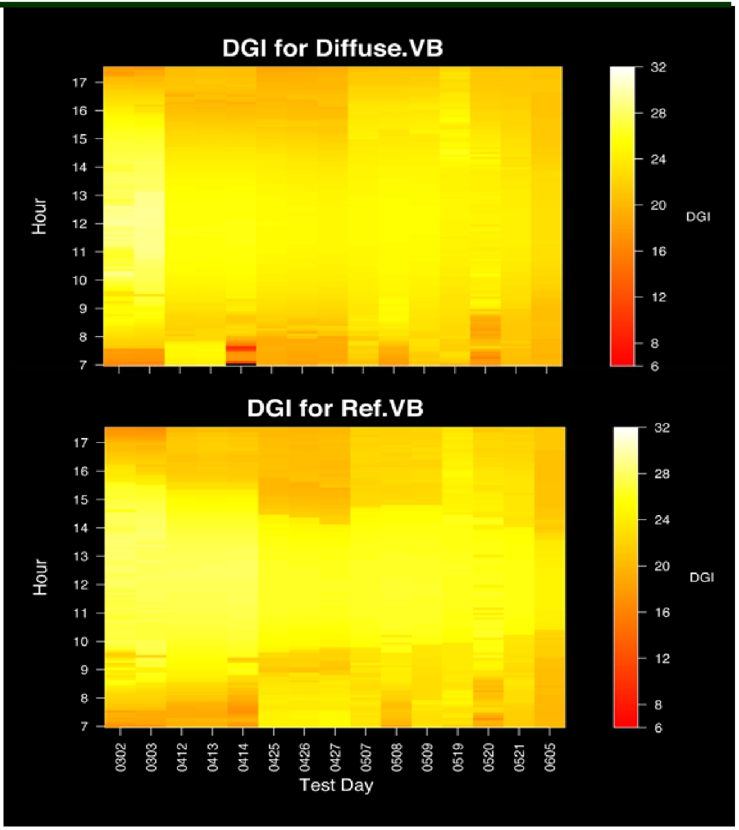
Daylight Illuminance

	Daylight Illuminance	(fc)	(lux)
6	Average (6:00-18:00)	93	1005
	Standard deviation	36	387
	2.5 ft high, 10 ft from window		

Cooling Load due to the Window

	Cooling Load due to the Window	
	Monitored days (6:00-18:00)	29
	Whole window: WWR=0.73	
	Center of glass: SHGC=0.40, U-value=0.30 Btu/h-ft^2-°F	
7	Avg Reduction in Cooling Load from Window	15%

		W/ft^2-wdw	W/ft^2-flr
8	Peak Cooling Load from Window		
	Reference case	15.9	9.3
	Test case	13.8	8.0
	Savings		14%



9 **Discomfort glare index** (above), 4-ft high, 4-ft from window, centered, facing window on select days over 6-month period. Falsecolor: 16=perceptible, 20=acceptable, 24=uncomfortable, 28=intolerable.

Visual Discomfort

10	Avg window luminance, Lw, 4 ft high, 7.5 ft from center & facing window		
	Percentage of day Lw>2000 cd/m^2 (computer tasks)		30%
	Average Lw (cd/m^2) when Lw > 2000 cd/m^2		2607
11	Avg Lw on clear, sunny days, n=18	%day>2000 cd/m^2	cd/m^2
	Upper zone	30%	4702
	Middle zone	47%	2913
	Lower zone	44%	3363
	4 ft high, 5 ft from window, 4 ft from west sidewall, facing west		

3.3. Interior Operable Shades

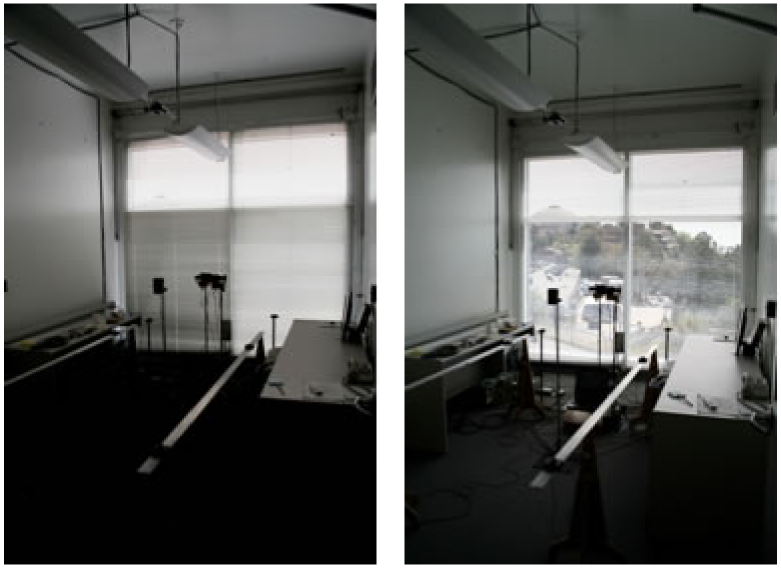
3.3.1. Zoned, Conventional Venetian Blinds

Technical Concepts

- Use of interior Venetian blinds is prevalent in U.S. commercial buildings for both new and retrofit construction. A simple, low-cost variant on this system is a conventional Venetian blind that is subdivided into two separate horizontal zones, where the slats in the upper clerestory zone can be set to a different angle than the slats in the lower view zone, enabling daylight to be admitted in the clerestory region when the lower region is closed to control glare.
- Because the slat angles in the upper region are more open than the lower region, this system can provide more daylight under sunny conditions than a conventional blind whose entire height must be closed to control direct sun and glare.
- The upper slat angle is offset from the lower slat angle in a fixed relationship by virtue of how the slats sit on the string ladders (see image below). The fixed angular relationship is set at the factory and is not user adjustable.

Close-up view of the division between upper and lower zones.

- The blind can be operated by the end user in a similar manner to a conventional blind: slat angle is adjusted using a rod and the shade height is adjusted by pulling on a string. The two zones are supported via a single header mounted at the ceiling.



Interior view of test room with zoned blind. Left: upper slats are set to admit daylight and lower slats block sun. Right: lower slats are set to permit view out and upper slats are slightly closed. Photos: LBNL.

Performance Impacts

- Zoned, manually-operated, interior shading systems can potentially reduce lighting energy use and if carefully designed, also minimize discomfort glare. The balance between these two performance parameters is highly dependent on the design of the façade, shade, and interior space design, the task being performed, and user operation of the shades.
- The primary benefit from use of these systems is the improvement in daylight quality within approximately 10 feet from the window wall. This is not a daylight-redirecting system which reflects sunlight toward the building core.
- With respect to quality of light, distribution of daylight near the window may be more uniform and comfortable since the more open upper zone diffuses daylight onto the ceiling. This counters the distribution of daylight from conventional

sidelighting where most of the flux is dumped on the floor. For occupants seated farther from the window, however, the upper zone may be a direct source of glare if the window can be seen directly, as in open plan office area with low partitions.

- Because the upper zone is not as closed as the lower zone, window heat gains can be increased or decreased, assuming that the reference case is a fully shaded window. Compared to an unshaded window, both conventional blinds and the zoned blind can significantly reduce window heat gains primarily by reflecting visible solar radiation back out the window.

Applications

- The zoned blind can be installed in the same location and manner as a conventional blind. It has value on orientations exposed to direct sun, primarily the south, east, and west exposures. On the north, if blinds are closed to reduce sky glare, the upper zone can also help to admit diffuse daylight. It is best applied in private offices or open plan areas where occupants further from the window have ways to avoid direct views of the window (e.g., changing position of task).
- The height of the upper daylighting zone must be sized adequately to admit sufficient daylight. A good rule of thumb derived from energy simulations is to size the daylight opening so that the product of window area and glass transmittance is between 0.20-0.30.
- To increase daylight potential, mount the blind header so that the stack height of the blind does not obstruct the vision window when the blind is fully raised. The stack height is slightly bulkier and taller than a standard blind’s stack height.
- The color, geometry, and treatment of the slats in the upper and lower zones can differ. The top surface of the upper zone slats may be more reflective to enhance daylighting. The underside of the upper and lower slats may be less reflective or darker in color to reduce glare. Some manufacturers offer a low-E coating on the underside of the slats in the lower zone to reduce radiative heat transfer to the interior and improve thermal comfort. Venetian blinds with optically-treated slats are discussed in a separate section.
- It may be difficult to get perfect alignment of slat angles across a wide façade with multiple side-by-side blinds. Expect some variation in the angle between the upper and lower zones between different blinds or request that the manufacturer provide some ability to fine tune these slat angles in the field.
- Perforated slats can permit view out in the lower region but slats with an openness factor (ratio of open area to opaque area) greater than around 3-4% can transmit high intensity direct sunlight, causing significant visual and thermal discomfort particularly in sunny climates.
- Educational information should be provided to users so that they understand the design intent behind the zoned blind and adjust the blind accordingly.

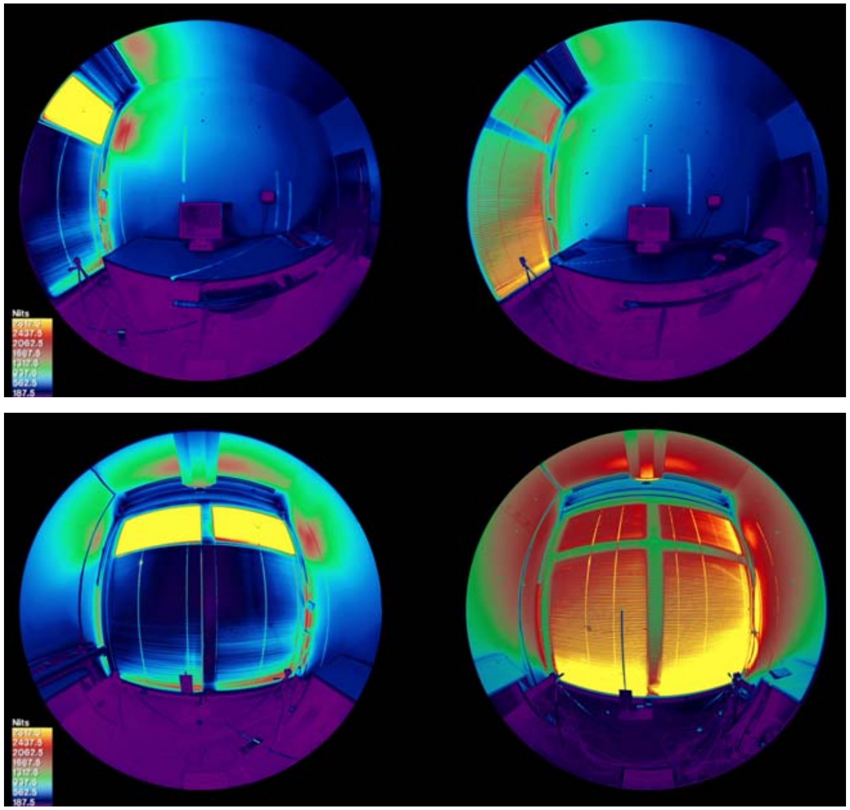
Measured Performance

- In a solstice-to-solstice full-scale field test in a sunny climate (see datasheet below), lighting energy use was increased by 11% using a zoned blind compared to a conventional blind set to block direct sun with the same daylighting control system. The 1-inch wide slats of the zoned blind had a matte white finish on its upper surface and a low-e metallic finish on its lower surface. The reference blind was a common 1-inch wide matte white blind. Both the reference and zoned blinds reduced lighting energy use by 66% and 62%, respectively, if the reference lighting system had no controls (always on).
- Window cooling was increased by 8% and peak cooling was increased by 3% compared to a conventional blind with the same daylighting control system, most likely due to the greater openness of the upper zone.
- Under clear sky conditions, the upper window zone was found to be too bright for a large fraction of the day (i.e., average 39% of a 12-hour was found to be greater than 2000 cd/m^2, a

threshold value defined by contrasts with a computer-based task) for a view facing and within 4 feet of the window. Discomfort glare was computed to be within the range of "just acceptable" to "just intolerable" levels for views facing the window if the task involved use of a computer. If the occupant's view was parallel to the window, facing the sidewall, discomfort glare was imperceptible.

- Anecdotally, the daylight quality resulting from this zoned blind was found to be quite pleasant under sunny conditions.

Close-up view of upper and lower sections of zoned blind when lower zone is set to its most closed angle. This would have closely approximated the winter condition – the slats in the lower zone would have been slightly more open so as to block very low sun angles. Photo: LBNL.



Zoned Venetian blinds (left) and conventional Venetian blinds (right) on January 2, 10:02 AM. Yellow = luminance levels ≥3000 cd/m².

Zoned, interior Venetian blinds

10x9 ft south-facing window in a 10x15x11 ft private office, Berkeley, CA (latitude 38°N)

Reference Case

Single, fully-lowered interior Venetian blind with 1-inch wide concave down, matte-white slats

Manually operated: Slat angle adjusted seasonally to block direct sun

Test Case

Two-zone, fully-lowered interior Venetian blind

1-inch wide concave down curved aluminum slats with matte white upper and low-e brushed metallic lower surface

Lower zone slat angle adjusted seasonally to block direct sun, upper zone ganged slats are more open.

Window height above floor
  Lower: 0.7-6.5 ft high
  Upper: 6.5-9.0 ft
  Width: 10 ft

Daylighting controls

1 W/ft^2, single zone, 20-100% power, 50 fc setpoint, 10 ft from window

Lighting Energy Use

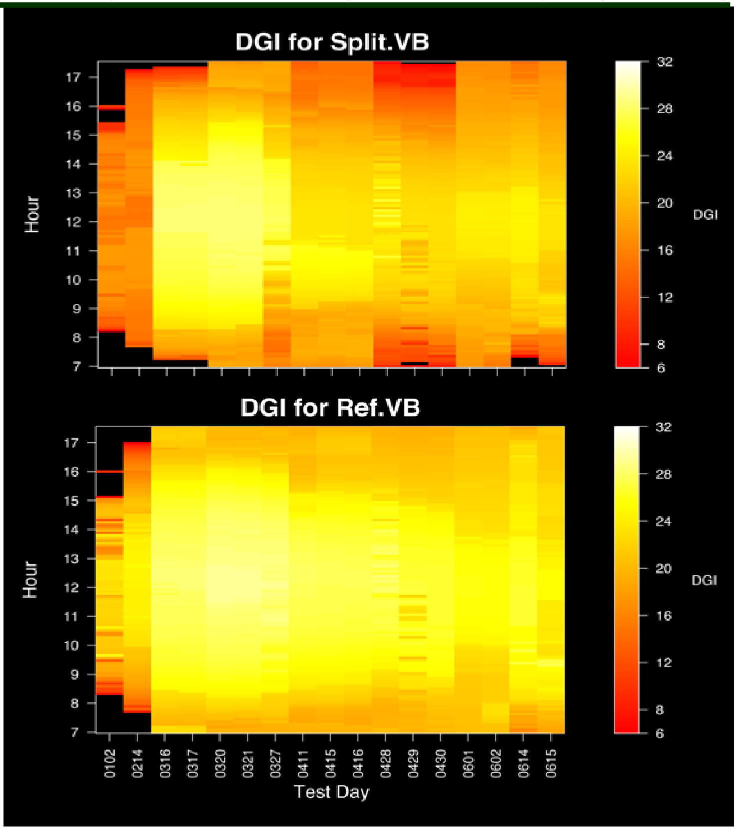
	Monitored days (6:00-18:00)	39
	Glass: WWR=0.59, Tvis=0.62	
1	ASHRAE 90.1-2004, no light controls (Wh/day)	1800
2	Reference with daylighting controls (Wh/day)	616
	Test case with daylighting controls* (Wh/day)	675
3	Savings, ASHRAE 90.1-2004	62%
	Savings, reference with daylighting controls	-11%
4	90.1-2004 Annual Energy Use Intensity (kWh/ft^2-yr)	3.00
	Reference: Annual EUI (kWh/ft^2-yr)	1.03
	Test: Annual EUI (kWh/ft^2-yr)	1.13
5	90.1-2004 Lighting Power Density (W/ft^2)	1.00
	Test case with daylighting controls: LPD (W/ft^2)	0.38

Daylight Illuminance

		(fc)	(lux)
6	Average (6:00-18:00)	82	886
	Standard deviation	28	306
	2.5 ft high, 10 ft from window		

Cooling Load due to the Window

	Monitored days (6:00-18:00)		32
	Whole window: WWR=0.73		
	Center of glass: SHGC=0.40, U-value=0.30 Btu/h-ft^2-°F		
7	Avg Reduction in Cooling Load from Window		-3%
8	Peak Cooling Load from Window	W/ft^2-wdw	W/ft^2-flr
	Reference case	15.9	9.3
	Test case	16.1	9.4
	Savings		-8%



9 **Discomfort glare index** (above), 4-ft high, 4-ft from window, centered, facing window on select days over 6-month period. Falsecolor: 16=perceptible, 20=acceptable, 24=uncomfortable, 28=intolerable.

Visual Discomfort

10	Avg window luminance, Lw, 4 ft high, 7.5 ft from center & facing window		
	Percentage of day Lw>2000 cd/m^2 (computer tasks)		19%
	Average Lw (cd/m^2) when Lw > 2000 cd/m^2		2473
11	Avg Lw on clear, sunny days, n=18	%day>2000 cd/m^2	cd/m^2
	Upper zone	39%	3722
	Middle zone	23%	2929
	Lower zone	44%	3286
	4 ft high, 5 ft from window, 4 ft from west sidewall, facing west		

3.3.2. Zoned, Optical Venetian Blinds

Technical Concepts

- In this category, there are several technical concepts that can improve performance over conventional horizontal Venetian blinds: a) zoning of the system into upper and lower sections, b) increasing or altering the surface reflectance of the slat material to optimize daylight output, and c) shaping of the horizontal slat profile to improve daylighting, solar heat gain rejection, and access to views out.
- Like the conventional zoned blind, these blinds are mounted and operated by the occupant similarly to a conventional horizontal Venetian blind. The blinds can be further optimized by being motorized and controlled automatically. Automated systems are discussed in Section 3.3.3.

Zoning

- Like conventional zoned blinds, zoned optical interior Venetian blinds can also be subdivided into an upper and lower section, but are not necessarily coupled: the upper slat angles for some systems can be independently controlled from the lower slat angles for more optimal control with some added cost for mounting a second header rail.

Slat reflectance

- Generally, high-reflectance slats in the upper clerestory zone of the window are designed to increase the amount of daylight flux distributed to the ceiling under direct sun conditions. The sunlit plane of the ceiling acts like a light fixture and reflects light down to work surfaces if the ceiling is of high reflectance. Some manufacturers use a simple, concave-up mirrored slat surface. Others use a mirrored prismatic material for the slats (typically linear grooves along the length of the slat), which can efficiently reflect and refract sunlight for incident angles that are perpendicular to the linear grooves and help to reduce hot spots of sunlight created by mirrored devices.

Slats with a prismatic surface treatment.

- Use of shiny, optically-treated slats in the lower view section can be used in some building applications to reduce solar heat gains. These systems must be carefully operated or placed to avoid glare; e.g., in open plan areas where workstations are located a few feet from the window and direct views of this lower section are obstructed by a partition. If viewed directly, the brightness of the reflected sunlight in this lower zone can cause significant discomfort glare.

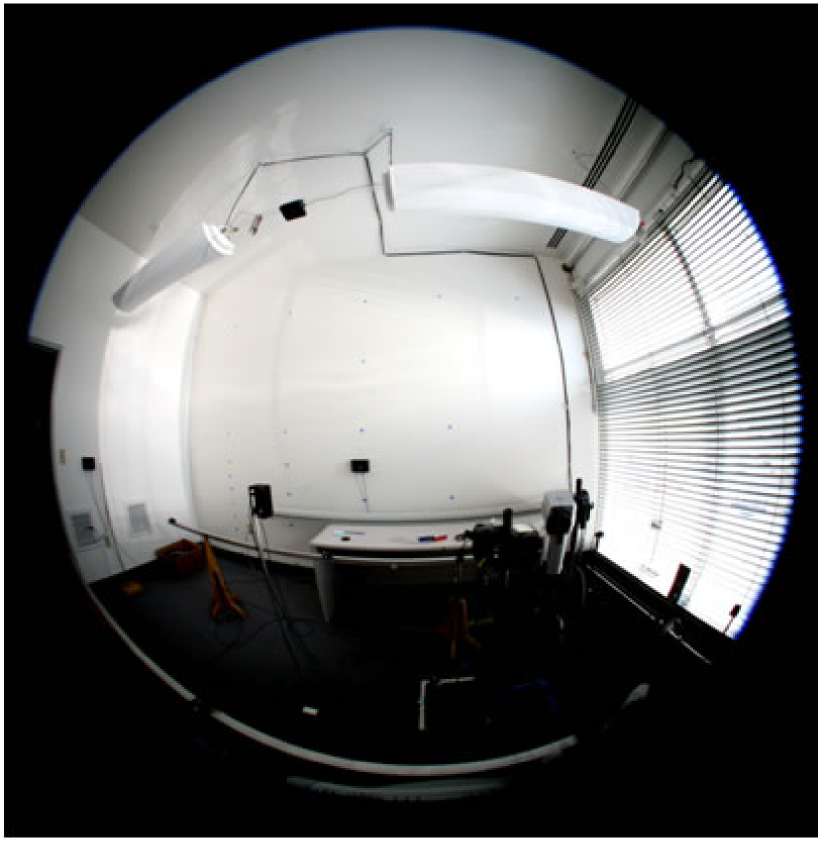
Engineered slat profile

- The geometry and spacing between slats can also be engineered. Some systems use a concave up, mirrored slat to reflect sunlight to the ceiling in the upper region. Other systems shape the slat so that its sectional profile blocks or reflects direct sunlight.
- The slat geometry is typically optimized for solar profile angles that are within an approximately 20-30° range of azimuthal angles on either side of a plane normal to the window (e.g, for a south-facing window, azimuth angles within 20-30° of due

south). In other words, ray-tracing diagrams showing how the slat geometry works for different solar altitude angles are not representative of the full range of azimuthal angles (±90°) seen by a window. Performance at oblique azimuth angles outside this range can be significantly less efficient, producing less daylight at the ceiling plane to offset lighting requirements at the desk. Sun coming from the east is reflected to the west side walls of the space in a south-facing private office, for example. This is important to understand since it can affect the number of hours of optimal performance and total lighting energy savings. There are a larger number of hours when the sun is in this "sweet spot" or range of optimal sun angles for south-facing facades and significantly less for east/ west orientations. For north-facing orientations, the sun is rarely if ever in this range and when it is, the building is often unoccupied (very early summer AM/ late PM).

– Product literature may be vague as to how exactly blinds with engineered slats should be manually operated. To ensure comfort, such blinds will need to be manually adjusted to block direct sun when solar angles are oblique and/or of low altitude: e.g., early morning or late afternoon hours during the summer for a south-facing facade. If the occupant forgets to adjust the blind back to the optimal position, then the full benefit of the blinds will not be realized. It is possible that if the view is desirable, however, users will learn over time to position the blind to maximize the full benefit of such blinds.

– For slats with unique profiles, the geometry is typically engineered for a specific range of latitudes (which then defines the range of solar profile angles). The daylight and solar rejection properties may be less optimal for latitudes (e.g., equator or North Pole) that significantly differ from the design conditions (e.g., 40°N). If the manufacturer does not provide such information, then examining the ray-tracing diagrams can give some clue as to which solar profile or altitude angles yield best performance. Ideally, these diagrams could be provided to illustrate the range in performance from winter to summer solstice for a specific site condition.



The upper zone of this sunlight-redirecting horizontal blind reflects incoming oblique west sun to the back and east side wall of this south-facing test room. This system is better matched to open plan offices with few full-height walls to obstruct sunlight reflected deep in the space.

Performance Impacts

– For the optimal range of solar angles for which a reflective slat system has been designed, lighting energy use is likely to be reduced in the 10-15 foot deep zone from the window with improved lighting quality if operated properly.

- Like the zoned conventional blind, the improvement in lighting quality is possibly the most significant benefit of zoned optical blind systems. The blind in the upper zone can help to balance the distribution of sunlight within the space, which can increase visual comfort.
- On the other hand, the most significant concern with optically-treated blinds is the potential negative impact on visual comfort if viewed directly. If the slat surface in the lower view zone has a specular component (i.e., slightly mirrored), then glare off the blind itself may be a significant issue under sunny conditions. If the upper zone does not adequately shield views of its mirrored slat surface, occupants further from the window could also experience glare. Reflected daylight off the underside of the slat can also cause glare if the surface is of high reflectance.

Specular reflections of sunlight off shiny slat surfaces can cause glare discomfort glare.

- The impact on heating and cooling will depend on the particulars of the blind: its geometry, slat surface treatment, position, and window design. If the slats in the lower zone are reflective, window heat gains could be reduced if the surface of the interior glass pane has a low visible reflectance (clear, not dark tinted glass, for example).
- For some engineered slat designs, the primary benefit of these innovative systems is lighting energy savings *and* access to unobstructed views out: the engineered slat is designed to be set to a horizontal slat angle for view while direct sun is blocked for the majority of incident solar angles. Conventional Venetian blinds must be closed to block direct sun, which blocks views out and reduces daylight – on a sunny winter's day, for example, the slats of a conventional blind on a south façade must be closed all day to block low angle sun. With some engineered slats, the blind only has to be closed during the early and late hours of the day.
- For blinds engineered to be set at a horizontal slat angle, direct views of the sky through the open spaces between the slats can cause glare as well. Use of tinted as opposed to transparent, clear glass can mitigate the glare but tints reduce overall daylight potential.
- Like the reflective blind, impacts of engineered slats on heating and cooling depend on the particulars of the blind. Some slat profiles have a W- or V-shape to reflect visible light out the window for some solar angles.

Applications

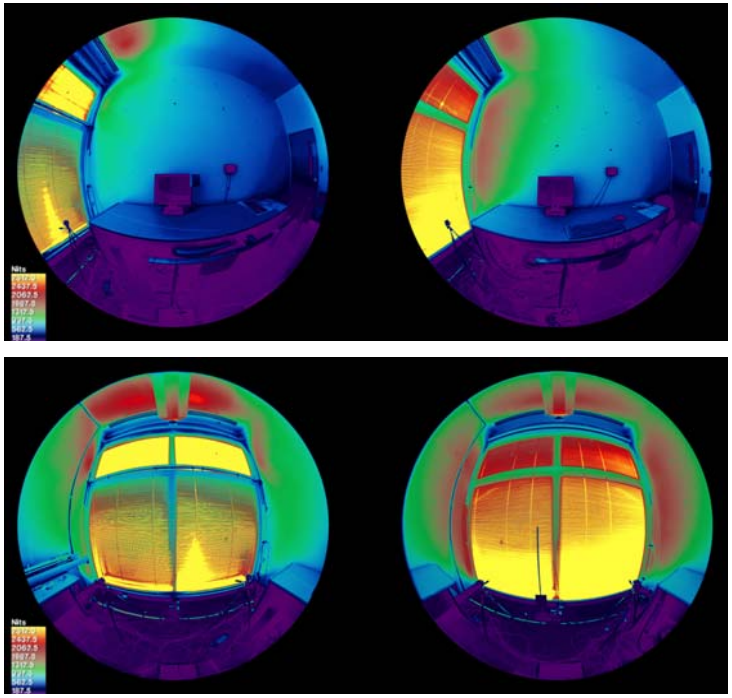
- Applications are similar to that given for the zoned, conventional blind.
- Reflective slats must be periodically dusted or cleaned of fingerprints, etc. to maintain optical performance. Concave-up slats also accumulate dust and must be dusted periodically.

Measured Performance

Zoned Venetian blind with prismatic slats

- In a solstice-to-solstice full-scale field test in a sunny climate (see datasheet on next page), lighting energy use was increased by 9% using a zoned blind with concave up prismatic slats compared to a conventional Venetian blind with the same daylighting control system. Lighting energy use savings were 65% compared to a reference case with no lighting controls (lights always on).
- Window cooling loads were increased by 2% compared to a conventional blind with the same daylighting control system. The peak cooling load due to window heat gains was unchanged.
- Discomfort glare was minimal when facing the side wall. Glare from the system was significant facing the window at a distance of 4 ft from the window. The upper and lower regions were too bright for computer-based tasks for 16-29% of the day. Small-area reflections of sunlight off the lower zone's prismatic slat surface also caused glare.
- The 1-inch wide concave up slats of the two-zone blind had: a) lower zone: a prismatic surface on the upper surface of the slats and a matte white surface on the underside of the slat and b) upper zone: matte white on the upper surface and prismatic surface on the underside of the slat. The slat angles could be controlled independently so the lower slats were set to block direct sun on a seasonal basis while the upper slats were set to a more open angle. The reference blind was a common 1-inch wide matte white blind set to block direct sun throughout the majority of the day.

Zoned blind with prismatic surfaced concave-up slats.



Zoned optical Venetian blinds (left) and conventional Venetian blinds (right) on January 12, 10:02 AM. Yellow = luminance levels ≥3000 cd/m².

Zoned, optical Venetian blinds

10x9 ft south-facing window in a 10x15x11 ft private office, Berkeley, CA (latitude 38°N)

Reference Case

Single, fully-lowered interior Venetian blind with 1-inch wide concave down, matte-white slats

Manually operated: Slat angle adjusted seasonally to block direct sun

Test Case

Two-zone, fully-lowered interior optical blind system

1-inch wide, concave up slats with prisms on top and white on lower surface of slats in lower zone and reverse surface treatments in upper zone.

Lower zone adjusted seasonally to block diect sun. Upper independently controlled for daylight.

Window height above floor
  Lower: 0.7-6.5 ft high
  Upper: 6.5-9.0 ft
  Width: 10 ft

Daylighting controls

1 W/ft^2, single zone, 20-100% power, 50 fc setpoint, 10 ft from window

Lighting Energy Use

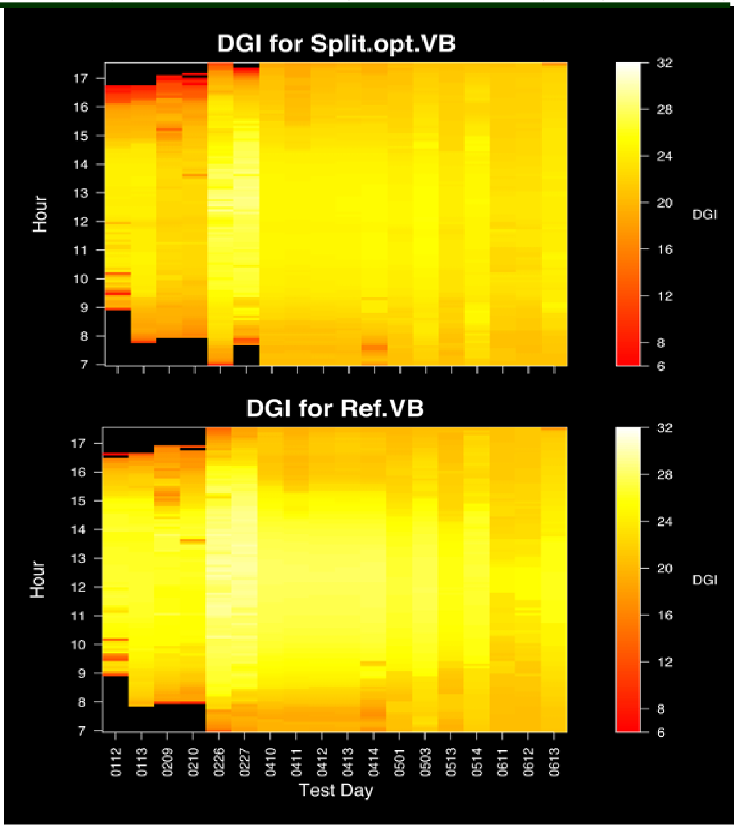
	Monitored days (6:00-18:00)	36
	Glass: WWR=0.59, Tvis=0.62	
1	ASHRAE 90.1-2004, no light controls (Wh/day)	1800
2	Reference with daylighting controls (Wh/day)	616
	Test case with daylighting controls* (Wh/day)	626
3	Savings, ASHRAE 90.1-2004	65%
	Savings, reference with daylighting controls	-9%
4	90.1-2004 Annual Energy Use Intensity (kWh/ft^2-yr)	3.00
	Reference: Annual EUI (kWh/ft^2-yr)	1.03
	Test: Annual EUI (kWh/ft^2-yr)	1.04
5	90.1-2004 Lighting Power Density (W/ft^2)	1.00
	Test case with daylighting controls: LPD (W/ft^2)	0.35

Daylight Illuminance

		(fc)	(lux)
6	Average (6:00-18:00)	80	859
	Standard deviation	25	266
	2.5 ft high, 10 ft from window		

Cooling Load due to the Window

	Monitored days (6:00-18:00)		32
	Whole window: WWR=0.73		
	Center of glass: SHGC=0.40, U-value=0.30 Btu/h-ft^2-°F		
7	Avg Reduction in Cooling Load from Window		-1%
8	Peak Cooling Load from Window	W/ft^2-wdw	W/ft^2-flr
	Reference case	15.9	9.3
	Test case	15.8	9.2
	Savings		2%



9 **Discomfort glare index** (above), 4-ft high, 4-ft from window, centered, facing window on select days over 6-month period. Falsecolor: 16=perceptible, 20=acceptable, 24=uncomfortable, 28=intolerable.

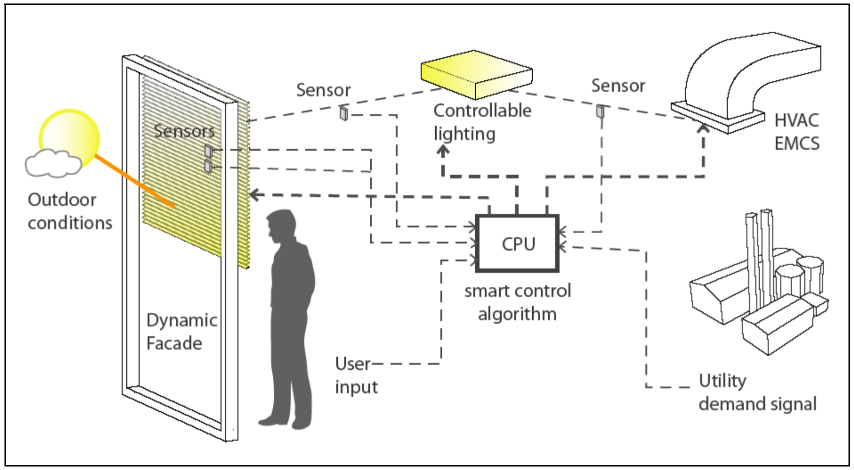
Visual Discomfort

10	Avg window luminance, Lw, 4 ft high, 7.5 ft from center & facing window		
	Percentage of day Lw>2000 cd/m^2 (computer tasks)		31%
	Average Lw (cd/m^2) when Lw > 2000 cd/m^2		2554
11	Avg Lw on clear, sunny days, n=23	%day>2000 cd/m^2	cd/m^2
	Upper zone	16%	3099
	Middle zone	28%	2495
	Lower zone	29%	3066
	4 ft high, 5 ft from window, 4 ft from west sidewall, facing west		

3.3.3. Automated Interior Venetian Blinds

Technical Concepts

- The performance of interior shading systems is very much dependent on how occupants operate the shades. Field studies have found that occupants tend to lower or close shades when uncomfortable then leave the shades in this position for days, weeks, even months at a time reducing useful daylight. Automation of motorized blinds provides several advantages over manually-operated blinds, the primary being reliable energy-efficient performance:
    - direct sun, daylight, and solar heat gains can be managed in real time in response to outdoor solar conditions, HVAC mode of operation (heating or cooling), occupancy, facility-wide schedules, natural ventilation requirements, etc. to achieve greater energy efficiency;
    - comfort and view requirements may be more consistently addressed, improving indoor environmental quality;
    - the system can be adjusted based on external facility-wide events such as real-time utility rates or electricity demand response criteria, and
    - setpoints can be adjusted over the life of the building to suit occupant preferences, change in occupant preferences, lighting and HVAC equipment changes, etc.
- Motorization enables automation of both the lift and tilt of blinds. Direct sun is occluded automatically by adjusting the tilt angle of the slats using simple solar geometry calculations and an exterior sensor that determines the sky condition (cloudy or sunny). These systems have been commercially available for decades and have traditionally been used in high end applications.
- Less common are control systems that manage daylight, glare, solar heat gains, and views out by adjusting slat angle and/or height. Control algorithms for these parameters can be based on predictive models, sensor data, occupant input, or combinations of these inputs. Heuristic algorithms (e.g., fuzzy logic, genetic algorithms, Bayesian algorithms, etc.) can be applied to resolve competing criteria and select the best shade position for the application. At present, such systems are only starting to be developed and commercialized.
- Automation has been applied to conventional and innovative blind systems (e.g., zoned blinds, blinds with mirrored slats, blinds with engineered slats, etc.) for both vertical windows and skylights.



Performance Impacts

- Automated shading systems can yield greater lighting and HVAC energy savings, improve comfort, and increase access to views out compared to manually-operated systems since adjustments can be made more reliably on a real-time basis.
- Lighting energy use can be significantly reduced if glare can be managed without sacrificing daylight. Automated shading enables the inherent daylight potential of a façade design to be realized by actively managing daylight-glare trade-offs. When direct sun, solar heat gains, and glare must be controlled, the blind is closed. When cloudy or outdoor light levels are low, the

blind is opened (via height and/or slat angle adjustments). Automation compensates for the inertia of busy occupants who fail to open the shades back up for daylighting and view.

For sunlight-redirecting blinds, automation can be used to determine the location of the sun and tilt the slat so that beam sunlight is directed toward a specified depth on the ceiling plane. This can extend lighting energy use savings over a deeper perimeter zone.

Interior views of sunlight-redirecting blind as the slat angle is adjusted from open to closed.

- Cooling energy use and peak cooling demand can be significantly reduced with this more reliable mode of control if compared to an unshaded window. If compared to a *shaded* window under occupied conditions, cooling energy reductions are likely to be small for conventional interior shading systems.
- Thermal and visual discomfort due to direct sun can be eliminated with proper controls and selection of slat reflectances.
- Views to the outdoors can be increased if the shade is retracted or the slats are set to horizontal in the absence of glare or sunlight.
- Natural ventilation via windows can be implemented more reliably with automated shading, particularly nighttime ventilation schemes where shades are retracted to minimize obstructions to the ventilation opening. During the day, natural ventilation schemes compete with solar control, glare, and daylighting objectives – shades extended for solar control, for example, inhibit air flow and may be distracting if the air flow causes the shade to flutter and make noise. Between-pane shading systems should be used.
- The type of shading device, control algorithm, method of implementation (e.g., number and placement of sensors, etc.), features (e.g., setpoint tuning, user override capability), façade design, and interior conditions will dictate the magnitude of energy savings.
- Automation can increase user dissatisfaction with their environment in a number of ways. End users control shades for a wide variety of reasons that cannot always be codified: privacy, view, based on task (phone, meeting or computer), etc. and are used to having autonomous control of a simple device like an interior shade. For private offices, automation can be tailored to individual preferences and manually-overridden, but these are typically high-end applications. For open plan offices, occupants do not have the same expectations and may be more accepting of automation as long as comfort requirements are met. Motor noise and visual distraction from shade movement are also sources of user dissatisfaction and should be minimized.
- In a laboratory study of user satisfaction with automated Venetian blinds, researchers found that user satisfaction increased if they were permitted to adjust the setpoints for control. Other studies that employed learning control algorithms found that user rejection decreased significantly while maintaining the same level of energy efficiency.

Applications

- Automated interior Venetian blinds can be applied to any façade for both new and retrofit construction. Power must be supplied at the perimeter. A hard-wired sensor and control network is typical of most products to ensure reliability of performance.
- Performance benefits are likely to be significant if the window is moderate to large in area, exposed to direct sunlight (south, east, and west-facing orientations), and not shaded by exterior overhangs and the like. Use of dimmable lighting controls will deliver reliable lighting energy savings.
- Lighting energy use savings are likely to be greater in spaces where computer-based tasks are not the primary task or if discomfort glare from the window can be minimized using alternate means: orienting the occupants' views parallel to the window, instead of facing the window, specifying light colored wall and ceiling finishes to minimize contrast between the window and surrounding surfaces, or specifying glass with moderate daylight transmittance properties (e.g., visible transmittance of 0.40-60 rather than 0.60-90).
- The reflectance of an interior shading device determines the efficiency of daylighting and solar heat gain rejection. A black or dark colored shade, which is often used with transparent facades to reduce the cluttered exterior appearance of the façade, will increase window heat gains compared to a light colored shade, for example. Darker materials reduce glare but can increase the sense of gloom during the winter.

- Perforated slats can permit views out when the blind is closed, but slats with an openness factor (ratio of open area to opaque area) greater than 3-4% can transmit high intensity direct sunlight, causing significant visual and thermal discomfort. Automation of such slats will not improve performance.
- Obvious drawbacks of automation include:
  - increased cost for design, materials, maintenance, and operations over the life of the building,
  - increased complexity that requires a greater level of technical expertise to design, install, and maintain,
  - possible user dissatisfaction or rejection of the system if the algorithm and its execution are not properly designed and implemented.
- As with any technology, it is important to get the details right to achieve performance objectives. This starts with proper selection of the shade, glass, and algorithm and ends with coordinated follow-through on its execution – proper location and commissioning of sensors, zones, etc. For retrofit applications where the interior shade is a tenant improvement, use of automated shading requires a knowledgeable team for successful completion.

Automated sunlight-redirecting blind where the upper and lower slats are controlled simultaneously with a single header motor. The upper concave slats have a mirrored upper surface which reflects daylight towards the core of the building. Photos: LBNL.

View of the window facing the sunlight-redirecting blinds (left) and view of ceiling and back wall view of the test space (right).

Measured Performance

1. *Automated, sunlight-redirecting blinds*

- In a solstice-to-solstice full-scale field test in a sunny climate (see datasheet below), lighting energy use was decreased by 5% with the use of an automated zoned optical blind compared to a conventional Venetian blind with the same daylighting control system. Lighting energy use savings were 69% compared to a reference blind case with no lighting controls (lights always on) or an average lighting power density of 0.31 W/ft^2 for this large-area south-facing window (1.0 W/ft^2 is standard).

- The automated system provided superior visual comfort conditions from a conservative viewpoint facing the window at 4 ft from the window compared to a reference blind, which was fully lowered and operated to block direct sun on a seasonal basis. The brightness of the reference window was too bright for computer-based tasks for 37% of the day while the automated system was too bright for 9% of the day. Under clear sky conditions, the upper zone of the optical blind exceeded brightness limits only 5% of the time compared to 32% of the time with the reference blind.

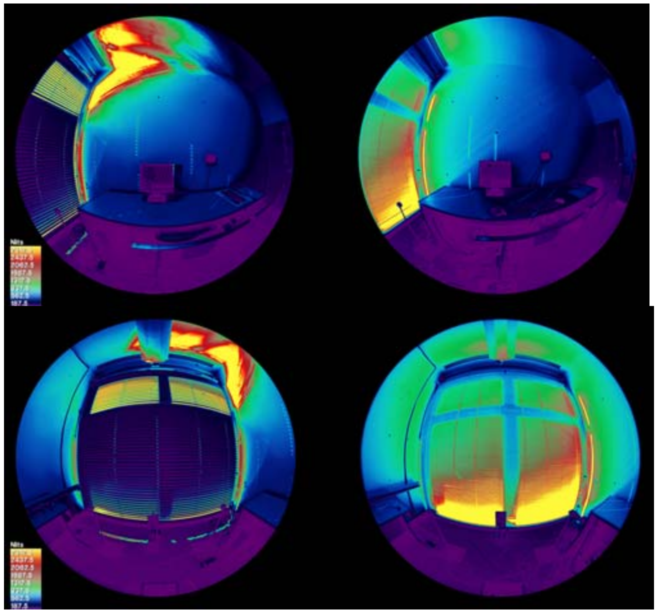
- Glare for 37% of a 12-hour day (4.4 hr) is not an acceptable work environment. If the reference blind's slats were more closed to reduce glare, lighting energy savings would increase.

- Cooling loads due to the window and peak cooling loads were reduced by 4-5%.

- View was blocked completely in the lower section of the blind year-round under sunny conditions because the slats of the upper zone were ganged with the lower slats on the same string ladder. The blind could be raised slightly for unobstructed views out. Under cloudy conditions, automation raised the blind fully to permit views out and on occasion, direct sky views were too bright and caused discomfort glare.

- The automated mirrored blind was scheduled to be fully lowered and to adjust its angle on both a seasonal and time-of-day basis (two adjustments per day) when sunny and to be fully raised when not sunny. The manufacturer of the blind offers a considerably more sophisticated control system. The control system that was tested was a lower cost system that required minimal commissioning. This mirrored system has the potential to daylight a deeper perimeter zone using the more sophisticated package.

- The mirrored blind was an impressive, nicely engineered but bulky piece of hardware. The control system, provided by a separate vendor, left a lot to be desired both in terms of the user-interface and the finesse of how the blind was controlled. The system was noisy and abrupt in motion. A detailed discussion of the pros and cons of various types of motors, accuracy of motor controllers, and quality of motion is given in [9]. When weighing cost against product features, it is worthwhile to see the product in hand and to understand in detail its technical features.



Sunlight-redirecting Venetian blinds (left) and conventional Venetian blinds (right) on February 4, 10:02 AM. Yellow = luminance levels ≥3000 cd/m^2.

Automated, sunlight-redirecting blinds

10x9 ft south-facing window in a 10x15x11 ft private office, Berkeley, CA (latitude 38°N)

Reference Case

Single, fully-lowered interior Venetian blind with 1-inch wide concave down, matte-white slats

Manually operated: Slat angle adjusted seasonally to block direct sun

Test Case

Two-zone, motorized interior blinds. 3.25-inch wide concave up slats with mirror on top and matte gray on lower surface in upper zone and white/gray slats in lower zone.

Automated: Slats scheduled to block sun in lower zone but reflect sunlight into room in upper zone. Retracts when no sun.

Window height above floor
Lower: 0.7-6.5 ft high
Upper: 6.5-9.0 ft
Width: 10 ft

Daylighting controls

1 W/ft^2, single zone, 20-100% power, 50 fc setpoint, 10 ft from window

Lighting Energy Use

	Monitored days (6:00-18:00)	51
	Glass: WWR=0.59, Tvis=0.62	
1	ASHRAE 90.1-2004, no light controls (Wh/day)	1800
2	Reference with daylighting controls (Wh/day)	616
	Test case with daylighting controls* (Wh/day)	553
3	Savings, ASHRAE 90.1-2004	69%
	Savings, reference with daylighting controls	5%
4	90.1-2004 Annual Energy Use Intensity (kWh/ft^2-yr)	3.00
	Reference: Annual EUI (kWh/ft^2-yr)	1.03
	Test: Annual EUI (kWh/ft^2-yr)	0.92
5	90.1-2004 Lighting Power Density (W/ft^2)	1.00
	Test case with daylighting controls: LPD (W/ft^2)	0.31

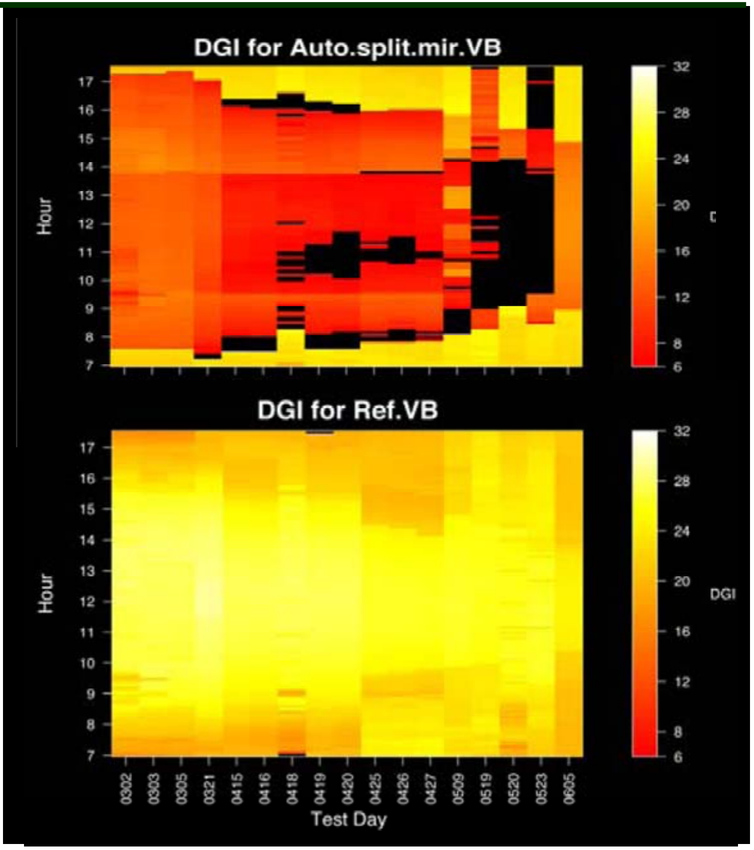
Daylight Illuminance

		(fc)	(lux)
6	Average (6:00-18:00)	69	739
	Standard deviation	30	327
	2.5 ft high, 10 ft from window		

Cooling Load due to the Window

	Monitored days (6:00-18:00)	39
	Whole window: WWR=0.73	
	Center of glass: SHGC=0.40, U-value=0.30 Btu/h-ft^2-°F	
7	Avg Reduction in Cooling Load from Window	-1%

		W/ft^2-wdw	W/ft^2-flr
8	Peak Cooling Load from Window		
	Reference case	15.9	9.3
	Test case	16.9	9.8
	Savings		-7%



9 **Discomfort glare index** (above), 4-ft high, 4-ft from window, centered, facing window on select days over 6-month period. Falsecolor: 16=perceptible, 20=acceptable, 24=uncomfortable, 28=intolerable.

Visual Discomfort

10	Avg window luminance, Lw, 4 ft high, 7.5 ft from center & facing window		
	Percentage of day Lw>2000 cd/m^2 (computer tasks)		9%
	Average Lw (cd/m^2) when Lw > 2000 cd/m^2		2788
11	Avg Lw on clear, sunny days, n=28	%day>2000 cd/m^2	cd/m^2
	Upper zone	5%	2572
	Middle zone	1%	2189
	Lower zone	0%	2180
	4 ft high, 5 ft from window, 4 ft from west sidewall, facing west		

2. *Automated, integrated Venetian blind and lighting control system*

- In a solstice-to-solstice full-scale field test in a sunny climate (see datasheet below), lighting energy use was decreased by 1% with the use of an automated conventional Venetian blind-lighting control system compared to a manually-operated Venetian blind (same type as the automated blind) with the same daylighting control system.
- Lighting energy use savings were 63% compared to a reference case with no lighting controls (lights always on) or an average lighting power density of 0.37 W/ft^2 for this large-area south-facing window.
- Cooling loads due to the window were increased by 2% and peak cooling loads were unchanged.
- Like the automated sunlight-redirecting blind, the automated blind provided superior visual comfort conditions. Window brightness was kept within acceptable levels at all times throughout the day, while the reference blind exceeded threshold brightness levels for 37% of the day. If the reference blind was controlled to the same level of comfort, lighting energy savings would likely be significantly greater.
- The prototype control system was developed at LBNL and was designed to block direct sun and then further close the blind to maintain workplane illuminance levels within a specified range. Both the reference and test case blinds were always in the fully-lowered position. This prototype control system minimizes both lighting energy use and window heat gains. The system must be integrated with the lighting control system and relies on the same ceiling-mounted photosensor as the daylight dimming system to implement control. More information on this system can be found in [9].

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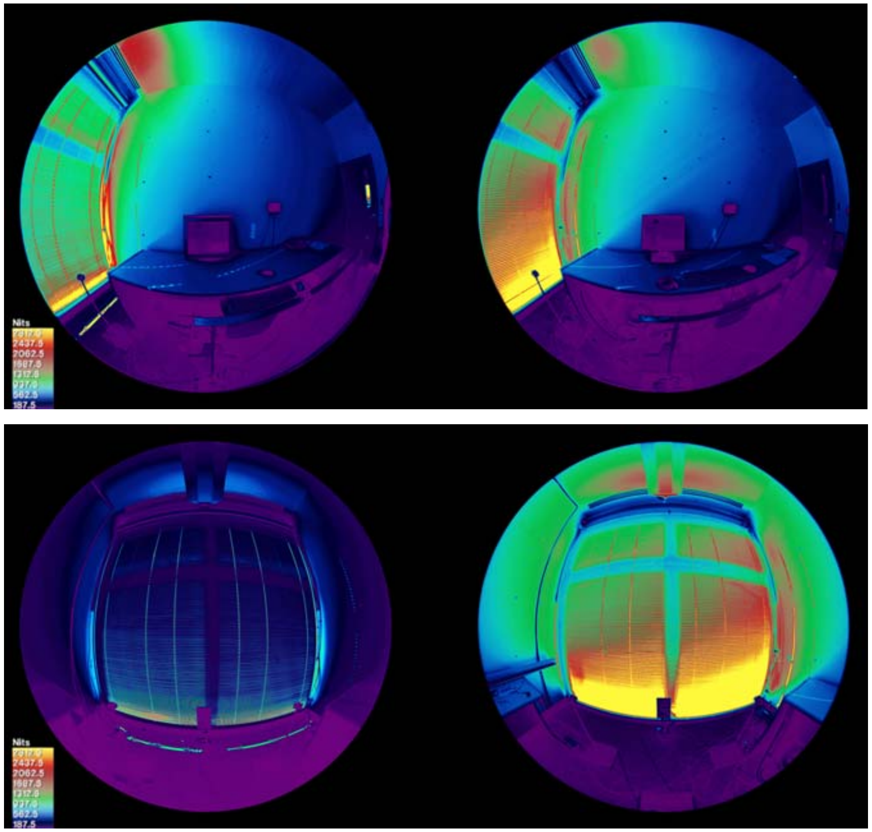


Automated Venetian blinds (left) and conventional Venetian blinds (right) on February 14, 11:02 AM. Yellow = luminance levels ≥3000 cd/m^2.

Automated Venetian blind - lighting control system

10x9 ft south-facing window in a 10x15x11 ft private office, Berkeley, CA (latitude 38°N)

Reference Case

Single, fully-lowered interior Venetian blind with 1-inch wide concave down, matte-white slats

Manually operated: Slat angle adjusted seasonally to block direct sun

Test Case

Single, fully-lowered, motorized, interior Venetian blind

Automated: 1-inch wide, matte white Venetian blind controlled every 1-min if needed to block direct sun, control glare, and maintain daylight illuminance levels to within 570-670 lux through adjustment of slat angle.

Window height above floor
Lower: 0.7-6.5 ft high
Upper: 6.5-9.0 ft
Width: 10 ft

Daylighting controls

1 W/ft², single zone, 20-100% power, 50 fc setpoint, 10 ft from window

Lighting Energy Use

	Monitored days (6:00-18:00)	26
	Glass: WWR=0.59, Tvis=0.62	
1	ASHRAE 90.1-2004, no light controls (Wh/day)	1800
2	Reference with daylighting controls (Wh/day)	616
	Test case with daylighting controls* (Wh/day)	664
3	Savings, ASHRAE 90.1-2004	63%
	Savings, reference with daylighting controls	1%
4	90.1-2004 Annual Energy Use Intensity (kWh/ft²-yr)	3.00
	Reference: Annual EUI (kWh/ft²-yr)	1.03
	Test: Annual EUI (kWh/ft²-yr)	1.11
5	90.1-2004 Lighting Power Density (W/ft²)	1.00
	Test case with daylighting controls: LPD (W/ft²)	0.37

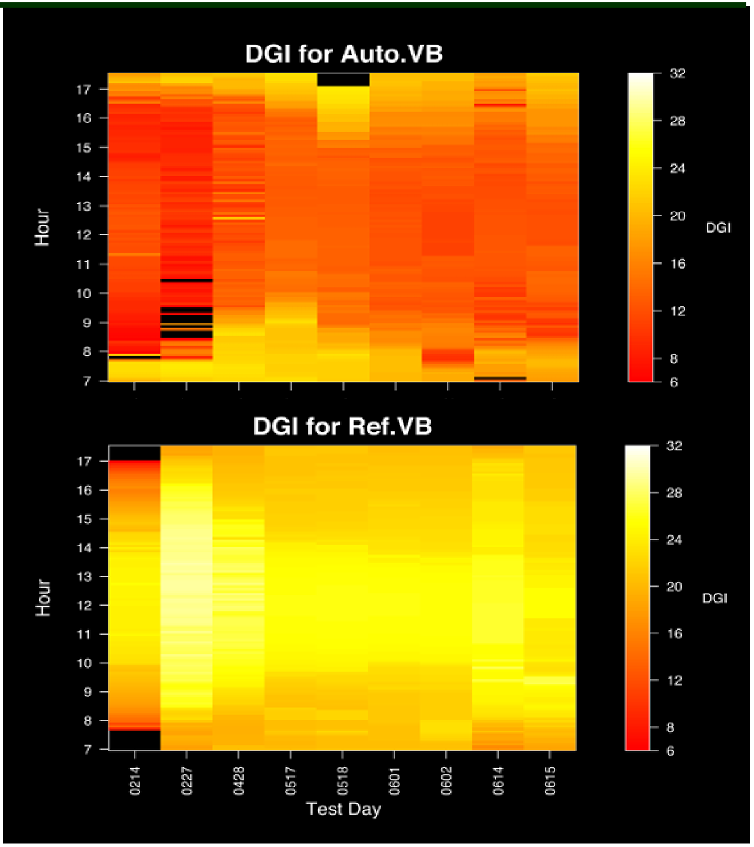
Daylight Illuminance

		(fc)	(lux)
6	Average (6:00-18:00)	62	672
	Standard deviation	52	562
	2.5 ft high, 10 ft from window		

Cooling Load due to the Window

	Monitored days (6:00-18:00)	15
	Whole window: WWR=0.73	
	Center of glass: SHGC=0.40, U-value=0.30 Btu/h-ft²-°F	
7	Avg Reduction in Cooling Load from Window	22%

		W/ft²-wdw	W/ft²-flr
8	Peak Cooling Load from Window		
	Reference case	15.9	9.3
	Test case	13.7	8.0
	Savings		15%



9 **Discomfort glare index** (above), 4-ft high, 4-ft from window, centered, facing window on select days over 6-month period. Falsecolor: 16=perceptible, 20=acceptable, 24=uncomfortable, 28=intolerable.

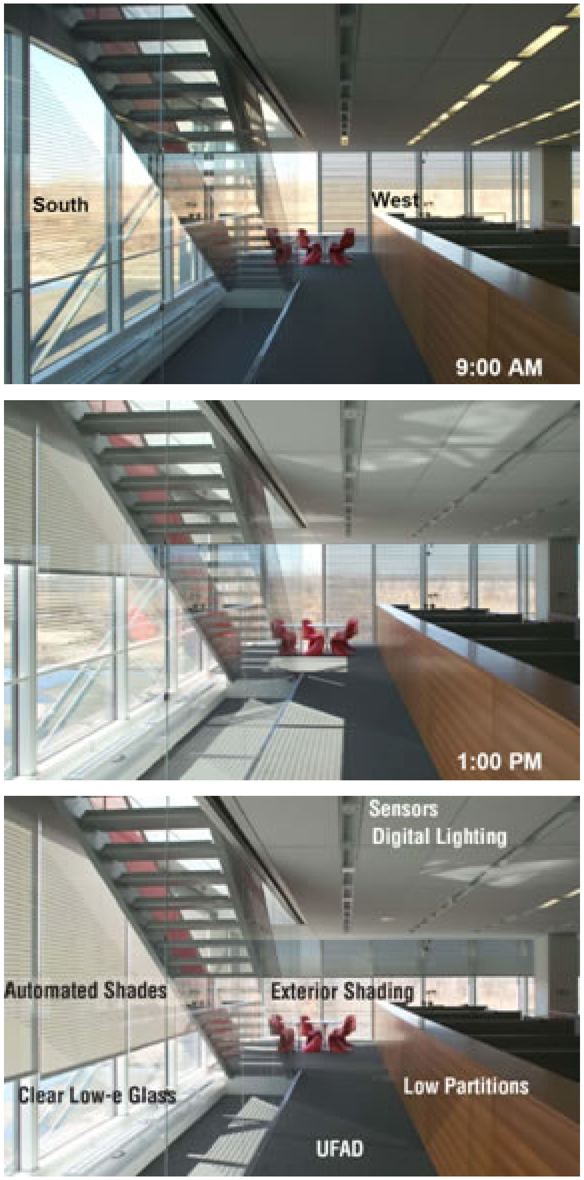
Visual Discomfort

10	Avg window luminance, Lw, 4 ft high, 7.5 ft from center & facing window		
	Percentage of day Lw>2000 cd/m² (computer tasks)		0%
	Average Lw (cd/m²) when Lw > 2000 cd/m²		2355
11	Avg Lw on clear, sunny days, n=9	%day>2000 cd/m²	cd/m²
	Upper zone	0%	0
	Middle zone	0%	0
	Lower zone	0%	2024
	4 ft high, 5 ft from window, 4 ft from west sidewall, facing west		

3.3.4. Automated Interior Roller Shades

Technical Concepts

- The technical concepts and advantages associated with automated roller shades are the same given for automated Venetian blinds (see Section 3.3.3).
- Automated roller shades are raised and lowered to mitigate the effects of the outdoor environment and permit unobstructed views out. This technology has been on the market for decades and has evolved over time as the building controls industry has matured. Today's commercially-available systems can be simple or very sophisticated, including options like wireless controls and monitoring and diagnostics tools for facility managers.
- The roller shade has the distinct advantage of mechanical simplicity over automated Venetian blind systems. Fabric is extended or raised using a tubular motor that spans the width of the window. The motors can be coupled so that multiple shade bands can be controlled using the same motor, reducing cost. The fabric cannot modulate intensity or direction of daylight when lowered, however, while a blind can through adjustment of slat angle.
- The orb of the sun cannot be completely blocked unless a black-out shade fabric is used and this can create visual discomfort, particularly contrast, shadow patterns, and glare if the weave of the fabric is not sufficiently dense. An openness factor between 1-3% is sufficient for most applications; greater openness (4-10%) could be used on north-facing or other facades in urban canyons with low direct sun exposure. The density of weave diminishes the effects of direct sun but also daylight.



Automated shades and digital lighting controls for The New York Times Headquarters Building. Photo: David Joseph.

- To increase daylight, roller shades can be controlled so that direct sun is allowed to penetrate a specified depth from the window below the bottom edge of the shade or fully retracted to admit diffuse skylight. Reliability in raising the shade is where automation provides its greatest benefit, since manual operation results in the shades being lowered over the window for more hours than required.
- The choice of fabric determines overall performance and quality of space as much as the automation scheme. When fabric shades are lowered, they permit a filtered view out when outdoor light levels are greater than indoors. Use of dark colored fabrics on the interior face of the shade can enhance view out through the fabric and reduce glare discomfort when the shade is backlit by direct sun. Thermal discomfort can occur with more open weave fabrics due to sunlight passing through holes in the fabric. A dark fabric can become hot when irradiated and increase thermal discomfort as well. Use of a lighter color on the outward face of the shade can reflect visible light out the window, lowering window heat gains.

Performance Impacts

- The potential performance impacts are the same as that given for automated interior Venetian blinds (Section 3.3.3). The magnitude of performance will of course vary with the type of fabric used and mode of operation.

Applications

- Applications are the same as that given for automated interior Venetian blinds (Section 3.3.3).
- Automated roller shades are able to span wider distances and taller facades. For inclined facades, automated roller shades can be run in tracks. For horizontal skylights, shades can be operated via cables.

Measured Performance

- Automated roller shades were compared to a reference roller shade with the same type of fabric set at a 30-inch height above the floor year round. In a solstice-to-solstice full-scale field test in a sunny climate (see datasheet below), lighting energy use was decreased by 39%, while window cooling loads were increased by 8%. Peak window cooling loads were reduced by 3%.
- Both the reference and automated roller shade controlled average window brightness facing the window at a distance of 4 ft from the window within acceptable levels to perform computer based tasks for the *entire* monitored period. Under clear sky sunny conditions, however, the lower region of the window (uncovered with the reference case, and covered some times of the day with the automated shade) exceeded threshold brightness levels for 15% of the day for the automated system and 52% of the day for the reference shade with significantly brighter levels on average with the reference shade when the brightness threshold of 2000 cd/m^2 was exceeded (2610 cd/m^2 versus 3470 cd/m^2).
- Unlike the other comparisons made for other technologies in this report, in this case visual comfort was almost the same between the reference and test cases, illustrating that when discomfort glare is controlled to the same level between cases, lighting energy savings can be significant with innovative systems.
- This system was implemented with the same LBNL prototype control algorithm as that used for the automated, integrated Venetian blind and lighting control system (Section 3.3.3). The shade blocked direct sun to a depth of 3 feet from the window and maintained daylight illuminance levels within a pre-defined range. A DC-motorized roller shade was provided by a manufacturer and this system provided quiet, accurate control of shade height on a very reliable basis.
- Monitored daylighting performance of two alternate commercially-available systems tested in a full-scale mockup of The New York Times Headquarters are given in [10].

Automated interior roller shades

10x9 ft south-facing window in a 10x15x11 ft private office, Berkeley, CA (latitude 38°N)

Reference Case

Single, 3%-open, light gray, basket-weave fabric roller shade

Manually operated: lowered to 30 inch height above floor all year.

Test Case

Single, 3%-open, light gray, basket-weave fabric motorized interior roller shade

Automated: Adjust shade height to block direct sun to 3 ft deep from window and control daylight to within 570-670 lux at rear of room.

Window height above floor

Lower:	0.7-6.5 ft high
Upper:	6.5-9.0 ft
Width:	10 ft

Daylighting controls

1 W/ft², single zone, 20-100% power, 50 fc setpoint, 10 ft from window

Lighting Energy Use

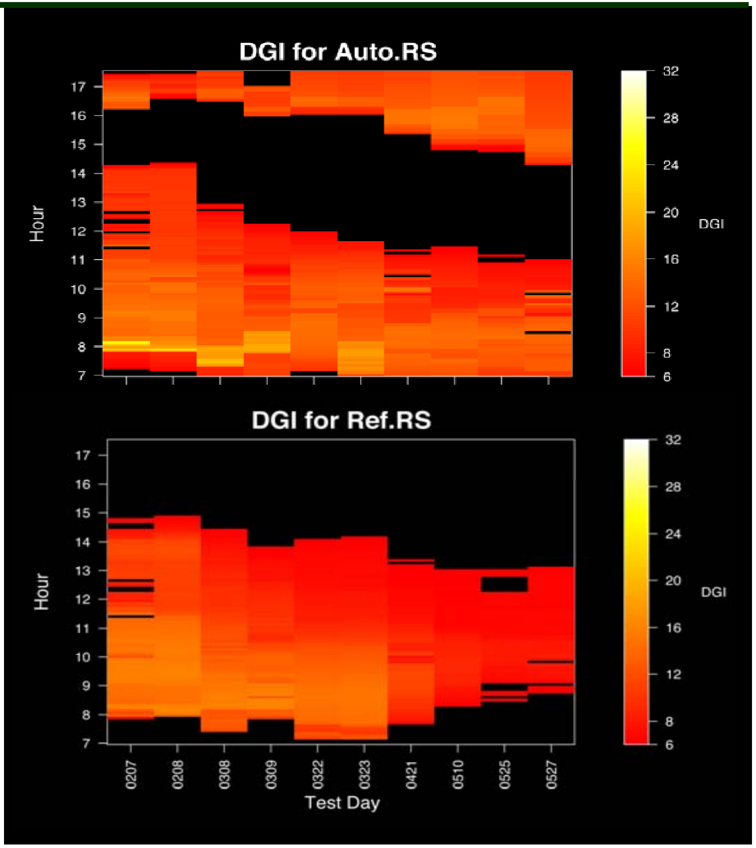
	Monitored days (6:00-18:00)	29
	Glass: WWR=0.59, Tvis=0.62	
1	ASHRAE 90.1-2004, no light controls (Wh/day)	1800
2	Reference with daylighting controls (Wh/day)	1024
	Test case with daylighting controls* (Wh/day)	682
3	Savings, ASHRAE 90.1-2004	62%
	Savings, reference with daylighting controls	39%
4	90.1-2004 Annual Energy Use Intensity (kWh/ft²-yr)	3.00
	Reference: Annual EUI (kWh/ft²-yr)	1.71
	Test: Annual EUI (kWh/ft²-yr)	1.14
5	90.1-2004 Lighting Power Density (W/ft²)	1.00
	Test case with daylighting controls: LPD (W/ft²)	0.38

Daylight Illuminance

		(fc)	(lux)
6	Average (6:00-18:00)	40	432
	Standard deviation	14	149
	2.5 ft high, 10 ft from window		

Cooling Load due to the Window

	Monitored days (6:00-18:00)		18
	Whole window: WWR=0.73		
	Center of glass: SHGC=0.40, U-value=0.30 Btu/h-ft²-°F		
7	Avg Reduction in Cooling Load from Window		3%
8	Peak Cooling Load from Window	W/ft²-wdw	W/ft²-flr
	Reference case	16.8	9.8
	Test case	15.2	8.9
	Savings		7%



9 **Discomfort glare index** (above), 4-ft high, 4-ft from window, centered, facing window on select days over 6-month period. Falsecolor: 16=perceptible, 20=acceptable, 24=uncomfortable, 28=intolerable.

Visual Discomfort

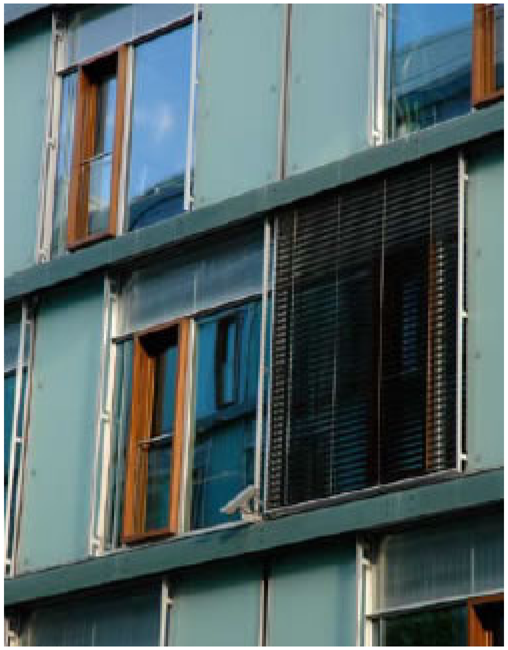
10	Avg window luminance, Lw, 4 ft high, 7.5 ft from center & facing window		
	Percentage of day Lw>2000 cd/m² (computer tasks)		0%
	Average Lw (cd/m²) when Lw > 2000 cd/m²		0
11	Avg Lw on clear, sunny days, n=12	%day>2000 cd/m²	cd/m²
	Upper zone	8%	3770
	Middle zone	16%	2666
	Lower zone	15%	2610
	4 ft high, 5 ft from window, 4 ft from west sidewall, facing west		

3.4. Exterior Operable Shading

3.4.1. Operable, Exterior Louver or Venetian Blind Systems

Technical Concepts

- This category includes exterior louver or Venetian blind systems with adjustable slats and that can be raised and lowered manually by the occupants or facility manager.
- Operable exterior horizontal louver or Venetian blind systems can reduce window solar heat gains significantly compared to interior shading systems, enabling use of low-energy cooling strategies such as radiant cooling, displacement ventilation, or natural ventilation in commercial buildings. Direct sun and reflected radiation from the ground and surrounding buildings are blocked by the shading system, significantly lowering the total solar radiation incident on the window glass. Radiative heat gains from the shading system itself can be minimized through use of low-E glazing and thermally-improved window frames. The header of the blind can be mounted on the underside of the header of the window setback or flush with the outside of the window wall. Free air flow around the blind can help to reduce conductive heat gains.
- Lighting energy use can be reduced in the perimeter zone at almost the same depth from the window wall as an interior shade if the exterior shade is hung just outside the window. Sunlight-redirecting schemes with exterior louvers are typically less successful than interior daylighting systems due to dirt, ice, snow, and weathering of the slats.
- The distance of the system from the exterior wall can impact performance. Systems placed farther away from the window (enabling use of casement windows, for example, or placement of a walkway between the building and the louvers) will significantly reduce interior daylight levels. For privacy in these cases, additional interior shades may be required.



Jakob Kaiser Haus, Berlin Germany, Busmann + Haberer Architects
Automated exterior blinds integrated into the façade. Photo: Mark Perepelitza

- For systems that can be raised and lowered, the operable blind has a distinct advantage over fixed shading since it can be raised to admit more daylight. This is unlikely to occur on a daily basis, given evidence that occupants do not operate even interior shades regularly. Occupants or the facility manager may choose to raise or lower the shades on a seasonal basis. For such schemes, the heat balance of the perimeter zones must be considered. For residential occupancies with low internal loads, the shade could be lowered during the summer season, then raised during the winter season for both daylighting and passive heating. For commercial occupancies with high internal loads, the exterior blinds should be lowered during the winter to reduce peak solar heat gains on clear sunny days for south-facing perimeter zones.

- Dividing the exterior blind system into separate solar control and daylighting zones can improve performance; e.g., the upper daylighting zone slats can be set to a more open angle than the lower slats either independently as two separately mounted blinds one above the other or dependently as a ganged single blind to increase daylighting
- Similar to innovative interior shading systems (Section 3.3.2), the geometry of the exterior slat profile can be shaped to block direct sun and/or permit view out for more hours of the day than conventional louvered systems.
- Like interior shades, exterior shading can be used to reduce discomfort glare but doing so will reduce daylight levels in the space. Since discomfort glare can occur with the shades up during bright cloudy days and times of day when the sun is not in the plane of the window, the shades could end up being lowered year round. This is more likely to occur if the visible transmittance of window glass is high (Tvis>0.50), if the window area is large and within direct view of the occupants, and if the tasks being performed in the space require tight control of contrast and brightness levels (e.g., computer-based tasks). The slats could also be more closed to block views of the sky. To increase daylight, a loosely woven interior shade can be used instead to reduce glare (and retain daylight) when the exterior blinds are raised or, when the blinds are lowered, can enable use of a more open slat angle.

Performance Impacts

- Like any manually-operated shading system, performance is largely dependent on how the shades are operated and the specifics of the actual building. Simulation tools should be used to estimate reductions in peak cooling load and to evaluate impacts on daylighting, discomfort glare, and views out.

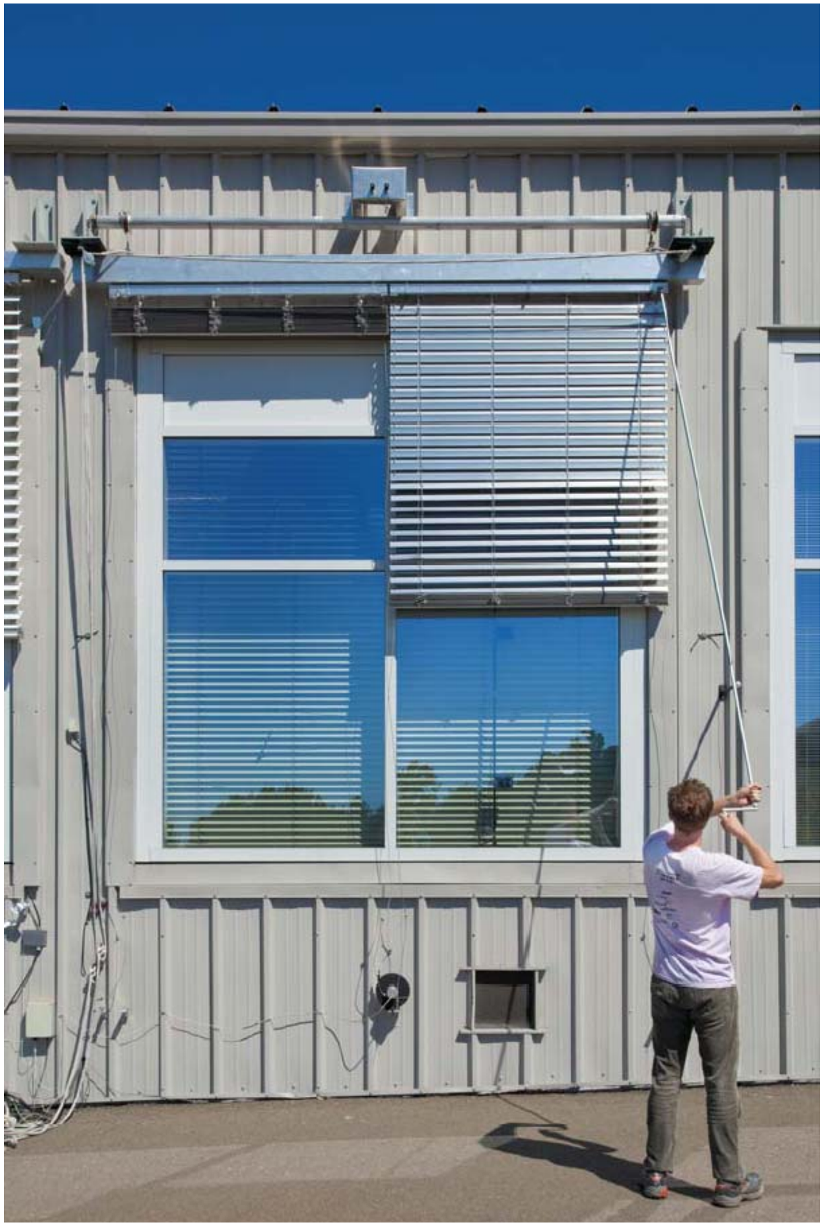
Single zone (left) and dual zone (right) exterior Venetian blinds on the LBNL Windows Testbed Facility. Photo: LBNL.

- Manually-operated exterior louvered systems provide significant solar control and are used widely throughout Europe on non-air-conditioned, low- to mid-rise, historic and new commercial buildings. The European climate is moderate and typically overcast, so these systems can provide a practical, low cost and energy-efficient solution for maintaining comfortable thermal conditions during periodic sunny summer conditions. When asked how reliably occupants operate these systems, one EU engineer stated that occupants quickly learn by experience to operate the shades to avoid thermal discomfort.
- Because exterior shading systems significantly reduce peak window loads, they can also enable use of low-energy cooling strategies and/or downsizing of chiller capacity and lowering of capital investment.

- The impacts on lighting energy use is less clear and will be dependent on how the blind is operated to control glare, views out, and privacy. With innovative exterior blind systems such as those with an engineered slat profile, lighting energy use is likely to be less because the slats can be kept at a more open horizontal angle for greater periods during the day.

Applications

- Operable exterior louvers or blinds are most applicable in sunny, hot climates where solar control is vital. Because these systems significantly lower peak window heat gains, they also enable use of low-energy cooling strategies in the perimeter zones of commercial buildings with aggressive low-energy or net zero-energy goals. If the façade is already significantly shaded by surrounding buildings, then benefits will be less.
- Exterior Venetian blinds can be manually raised and lowered using a long rod attached to the header of the blind. The rod is rotated using a hand crank and can be operated from an exterior balcony or the ground. Slat angles can be adjusted using the same hand crank. The system can also be operated from the interior using a pass-thru coupling through the wall.
- Each slat is prevented from excessive swaying and fluttering in the wind by a series of vertical cables that pass through the slats and are tensioned from the top header to below the bottom rail. The entire assembly is kept from striking the façade under windy conditions by spacing the blind away from the façade. The systems are designed for applications where wind speeds are anticipated to be low (less than 30 miles per hour). The shade should be raised during periods of high wind to avoid damage to the blind system or finish of the façade.



Raising and lowering of an exterior blind using a crank attached to a coupling at the head of the blind. Photo: LBNL.

Interior view of conventional exterior venetian blind.

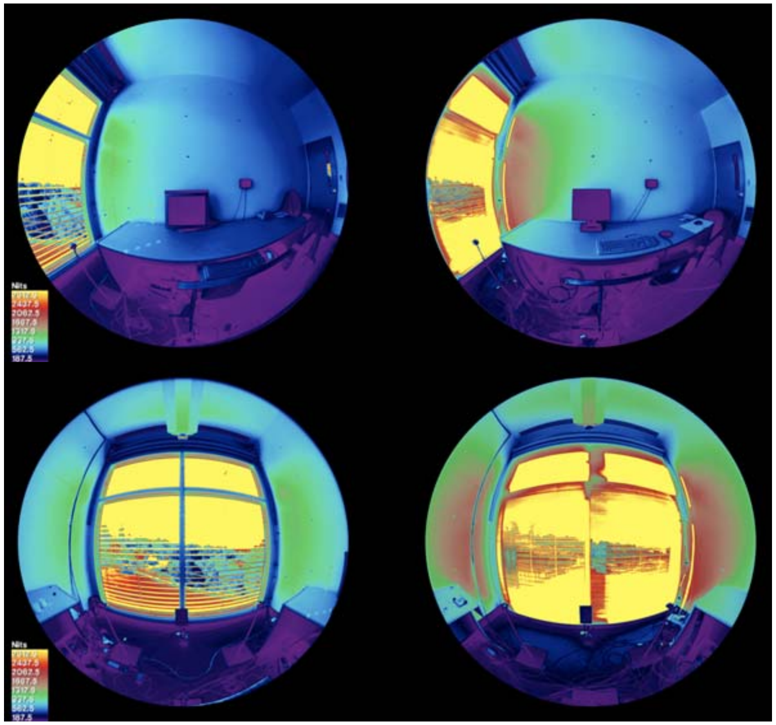
- The slats of commercially-available exterior blind systems are typically wider and heavier than conventional interior blinds to stand up to the forces of weather. The total weight of the blind should be figured into the design of the attachment to the façade. If installed on the ground floor, anticipate possible vandalism or use of the blind as a ladder. Some slats are designed to be flexible so that if inadvertently bent, the blind does not have to be replaced.
- The width and height of the blind is limited so across a wide glazed window, the slat angles may differ slightly between adjacent blinds. Occupants may operate the blinds differently in adjacent spaces. This can give the exterior façade a less uniform appearance.

100-mm (3.9-inch) slats with semi-gloss white finish on top and bottom surfaces resting on braided plastic string ladders. Flat Trevira-polyester ribbons are used for lift function (above). Translucent Perlon cable at end of slats (below) tensioned at base using stainless steel clip. Photos: LBNL.

Measured Performance

1. *Conventional exterior Venetian blind*

- A conventional exterior blind operated seasonally to block direct sun (but never raised) reduced window heat gains significantly to levels that would enable use of low-energy cooling strategies, but slightly increased lighting energy use and did not adequately control worst-case window glare.
- In a sunny climate with a south-facing large-area window with spectrally selective low-e glass, total cooling loads due to the window were reduced by 77% over a solstice-to-solstice period compared to a conventional interior Venetian blind controlled in the same manner.
- Peak cooling loads due to the window were reduced by 77% on clear sunny winter days.
- For those designing facades for low-energy cooling systems, target values for peak window loads is approximately 4 W/ft^2-floor for a 20 ft deep perimeter zone. For peak incident vertical irradiation levels of around 1000 W/m^2, peak cooling loads due to the window were 24.6 W/m^2-floor (2.3 W/ft^2-floor) for a 15-ft deep zone or 3.9 W/ft^2 of window area with the exterior blind. These levels are sufficiently low enough to meet the criteria for low-energy cooling systems (see Section 2.5).
- Lighting energy use was increased by 7%. Still, the average lighting power density was 0.41 W/ft^2 compared to a reference case with no lighting controls (1 W/ft^2).
- The brightness of the window was due to diffuse daylight reflected off of the semi-glossy white top and underside surfaces of the concave down slats and by direct views out through the slats of the sky and surrounding surfaces. The average brightness of the window exceeded the threshold value (2000 cd/m^2) for 22% of the day with average luminance values of 2570 cd/m^2 when exceeding the threshold.
- Under clear sky conditions, the upper- and mid-height zones of the blind exceeded the brightness threshold for 38% and 46% of the day, respectively. These values are given for a conservative worst case viewpoint facing the window at a distance of 4 ft from the window for computer-based tasks.
- The slat angle of the blind was set seasonally to block or just cut off direct sun throughout the day for this sunny climate. During the summer, the slat angle was set to nearly horizontal so views out were minimally obstructed for this latitude (37°N). During the winter, the slat angle was set to 56°, which obscured horizontal views out but enabled direct views of the ground for occupants sitting near the window.



Exterior Venetian blinds (left) and interior Venetian blinds (right) on March 19, 10:02 AM. Yellow = luminance levels ≥3000 cd/m^2.

Conventional, exterior Venetian blinds

10x9 ft south-facing window in a 10x15x11 ft private office, Berkeley, CA (latitude 38°N)

Reference Case

Single, fully-lowered interior Venetian blind with 1-inch wide concave down, matte-white slats

Manually operated: Slat angle adjusted seasonally to block direct sun

Test Case

Single, fully-lowered exterior Venetian blind

100-mm wide concave down curved aluminum slats with slightly shiny upper and lower white painted surfaces

Manually operated: Slat angle adjusted seasonally to block direct sun

Window height above floor
   Lower: 0.7-6.5 ft high
   Upper: 6.5-9.0 ft
   Width: 10 ft

Daylighting controls

1 W/ft^2, single zone, 20-100% power, 50 fc setpoint, 10 ft from window

Lighting Energy Use

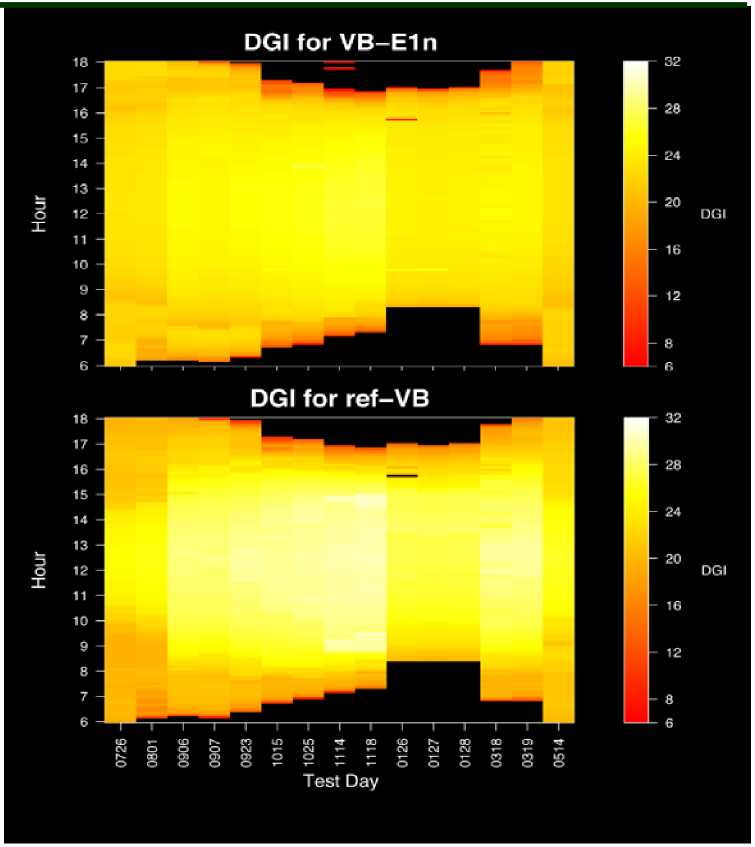
	Monitored days (6:00-18:00)	54
	Glass: WWR=0.59, Tvis=0.62	
1	ASHRAE 90.1-2004, no light controls (Wh/day)	1800
2	Reference with daylighting controls (Wh/day)	730
	Test case with daylighting controls* (Wh/day)	730
3	Savings, ASHRAE 90.1-2004	59%
	Savings, reference with daylighting controls	-7%
4	90.1-2004 Annual Energy Use Intensity (kWh/ft^2-yr)	3.00
	Reference: Annual EUI (kWh/ft^2-yr)	1.22
	Test: Annual EUI (kWh/ft^2-yr)	1.22
5	90.1-2004 Lighting Power Density (W/ft^2)	1.00
	Test case with daylighting controls: LPD (W/ft^2)	0.41

Daylight Illuminance

		(fc)	(lux)
6	Average (6:00-18:00)	71	763
	Standard deviation	30	319
	2.5 ft high, 10 ft from window		

Cooling Load due to the Window

	Monitored days (6:00-18:00)		17
	Whole window: WWR=0.73		
	Center of glass: SHGC=0.40, U-value=0.30 Btu/h-ft^2-°F		
7	Avg Reduction in Cooling Load from Window		77%
8	Peak Cooling Load from Window	W/ft^2-wdw	W/ft^2-flr
	Reference case	18.1	10.5
	Test case	3.9	2.3
	Savings		77%



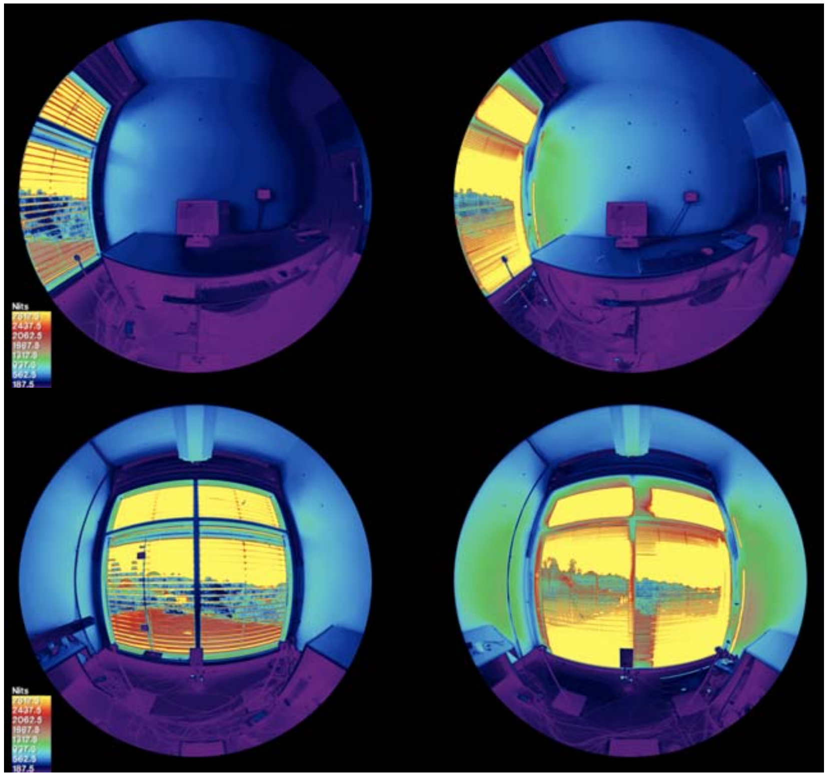
9 **Discomfort glare index** (above), 4-ft high, 4-ft from window, centered, facing window on select days over 6-month period. Falsecolor: 16=perceptible, 20=acceptable, 24=uncomfortable, 28=intolerable.

Visual Discomfort

10	Avg window luminance, Lw, 4 ft high, 7.5 ft from center & facing window		
	Percentage of day Lw>2000 cd/m^2 (computer tasks)		22%
	Average Lw (cd/m^2) when Lw > 2000 cd/m^2		2570
11	Avg Lw on clear, sunny days, n=28	%day>2000 cd/m^2	cd/m^2
	Upper zone	38%	3045
	Middle zone	46%	2842
	Lower zone	5%	2361
	4 ft high, 5 ft from window, 4 ft from west sidewall, facing west		

2. ***Zoned, exterior Venetian blind***

- Using the same type of conventional exterior blind tested in Section 3.4.1(1), two exterior blinds were hung, one above the other, and operated independently so that more daylight was admitted in the upper zone during the winter season. Low-angle direct sun was permitted into the space through the upper window when the solar profile angle was less than 22°.
- Lighting energy use was increased by 11% compared to the conventional interior blind controlled to just block direct sun throughout the day. The average daytime lighting power density was reduced to 0.37 W/ft^2-floor compared to a case with no lighting controls (1 W/ft^2).
- Window cooling loads were decreased by 66% and peak window cooling loads were decreased by 69% compared to an interior blind.
- With the more open blind in the upper region, peak cooling load reductions were not as large as the single-zone blind controlled to block direct sun and solar heat gains but were still sufficiently low to meet the 4 W/ft^2-floor low-energy criteria, even with a large-area south-facing window.
- Peak conditions occurred on clear sunny winter days near the winter solstice for this south-facing facade. Peak cooling loads due to the window were 35.8 W/m^2-floor (3.3 W/ft^2-floor for a 15-ft deep zone or 5.7 W/ft^2 of window area with the exterior blind. These levels are sufficiently low enough to meet the criteria for low-energy cooling systems.
- Discomfort glare from the window occurred for 32% of the day on average over the monitored period and on clear sunny days, the upper zone luminance exceeded threshold values 52% of the day. Glare was nearly comparable but not as bad as that from the conventional interior blind.



Zoned, exterior Venetian blinds (left) and interior Venetian blinds (right) on September 7, 10:02 AM. Yellow = luminance levels ≥3000 cd/m^2.

- Both the interior and exterior blinds would need to be more closed to control glare. This would further reduce window heat gains, in the case of the exterior blind, but would diminish daylight, increase lighting energy use, and block views out.

Zoned, exterior Venetian blind

10x9 ft south-facing window in a 10x15x11 ft private office, Berkeley, CA (latitude 38°N)

Reference Case

Single, fully-lowered interior Venetian blind with 1-inch wide concave down, matte-white slats

Manually operated: Slat angle adjusted seasonally to block direct sun

Test Case

Two, fully-lowered exterior blinds with independent zone control

100-mm wide concave down curved aluminum slats with slightly shiny upper and lower white painted surfaces

Slats adjusted seasonally to block direct sun in upper & lower zones with upper slightly more open.

Window height above floor
Lower: 0.7-6.5 ft high
Upper: 6.5-9.0 ft
Width: 10 ft

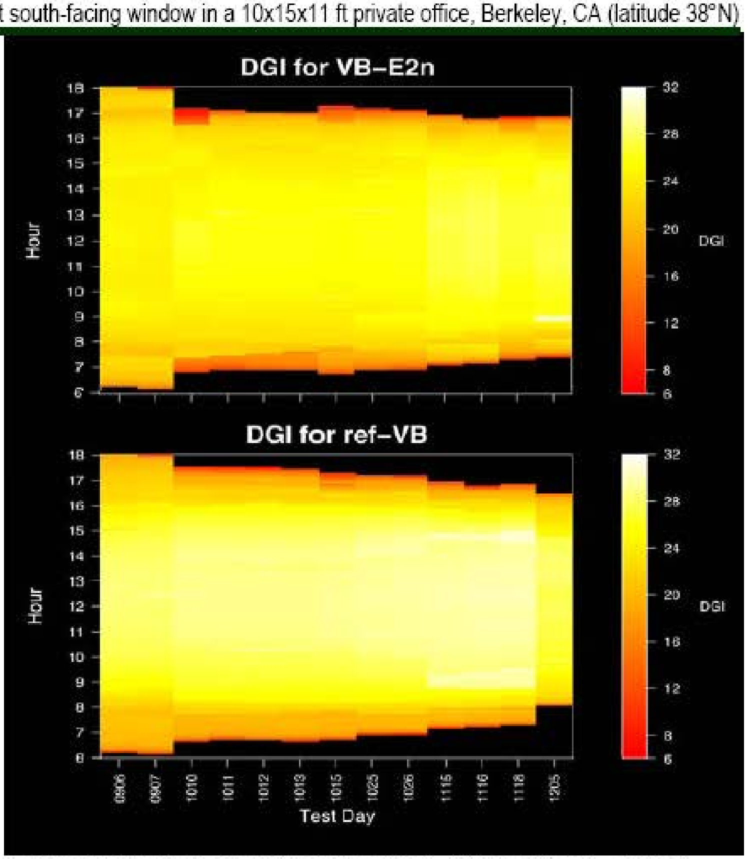
Daylighting controls

1 W/ft^2, single zone, 20-100% power, 50 fc setpoint, 10 ft from window

Lighting Energy Use	
Monitored days (6:00-18:00)	31
Glass: WWR=0.59, Tvis=0.62	
1 ASHRAE 90.1-2004, no light controls (Wh/day)	1800
2 Reference with daylighting controls (Wh/day)	730
Test case with daylighting controls* (Wh/day)	670
3 Savings, ASHRAE 90.1-2004	63%
Savings, reference with daylighting controls	-11%
4 90.1-2004 Annual Energy Use Intensity (kWh/ft^2-yr)	3.00
Reference: Annual EUI (kWh/ft^2-yr)	1.22
Test: Annual EUI (kWh/ft^2-yr)	1.12
5 90.1-2004 Lighting Power Density (W/ft^2)	1.00
Test case with daylighting controls: LPD (W/ft^2)	0.37

Daylight Illuminance	(fc)	(lux)
6 Average (6:00-18:00)	79	855
Standard deviation	25	269
2.5 ft high, 10 ft from window		

Cooling Load due to the Window		
Monitored days (6:00-18:00)		28
Whole window: WWR=0.73		
Center of glass: SHGC=0.40, U-value=0.30 Btu/h-ft^2-°F		
7 Avg Reduction in Cooling Load from Window		66%
8 Peak Cooling Load from Window	W/ft^2-wdw	W/ft^2-flr
Reference case	18.1	10.5
Test case	5.7	3.3
Savings		69%



9 **Discomfort glare index** (above), 4-ft high, 4-ft from window, centered, facing window on select days over 6-month period. Falsecolor: 16=perceptible, 20=acceptable, 24=uncomfortable, 28=intolerable.

Visual Discomfort		
10 Avg window luminance, Lw, 4 ft high, 7.5 ft from center & facing window		
Percentage of day Lw>2000 cd/m^2 (computer tasks)		32%
Average Lw (cd/m^2) when Lw > 2000 cd/m^2		2674
11 Avg Lw on clear, sunny days, n=17	%day>2000 cd/m^2	cd/m^2
Upper zone	52%	3403
Middle zone	41%	2626
Lower zone	2%	3598
4 ft high, 5 ft from window, 4 ft from west sidewall, facing west		

3. *Zoned, optical exterior louver system*

- An innovative, static, zoned louver system provided excellent solar heat gain control, visually comfortable conditions, and significant reductions in lighting energy savings compared to an interior Venetian blind with no daylighting controls. Partial horizontal views out were possible year round in the middle and lower regions of the blind.
- In a sunny climate with a south-facing large-area window with spectrally selective low-e glass, total cooling loads due to the window were reduced by the innovative blind by 74% over a solstice-to-solstice period by this innovative blind compared to a conventional interior Venetian blind controlled seasonally to block direct sun throughout the day.
- The exterior blind consisted of three horizontal zones hung from a single header. Slats in each zone had a dependent angular relationship with the other two zones. The blind was set to a fixed angle and fully lowered position for the entire monitored period. Each slat had an inverted V-shaped profile with a slightly polished aluminum top surface and matte light gray painted under-surface. The height of each zone was defined by the manufacturer and were approximately equal over the height of the blind. Slat angles were more closed at the top and more open toward the bottom.
- Peak cooling loads due to the window were reduced by 71% on clear sunny winter days). Peak cooling loads due to the window were 31.4 W/m^2-floor (2.9 W/ft^2)-floor for a 15-ft deep zone or 5.0 W/ft^2 of window area with the exterior blind. These levels are sufficiently low enough to meet the criteria for low-energy cooling systems.

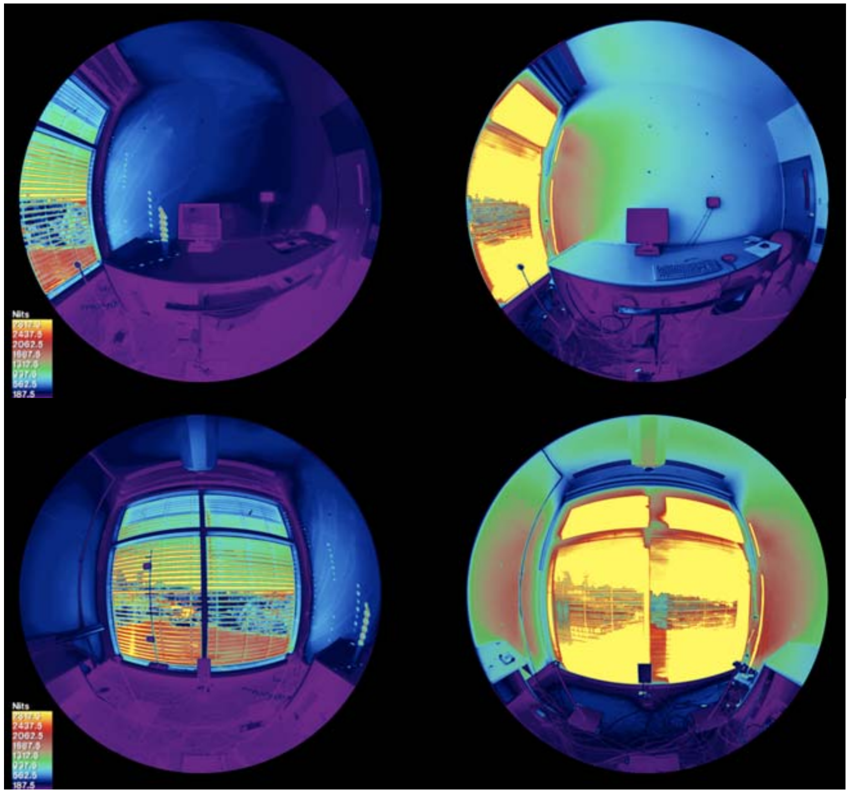
Exterior view of zoned, optical exterior louver system. Photo: LBNL.

Interior view of three-zone optical blind

Horizontal junction between zones

Exterior view of three-zone optical blind. Photos: LBNL.

- Lighting energy use was increased by 25%, but the average lighting power density was still low at 0.47 W/ft^2 compared to a reference case with no lighting controls (1 W/ft^2).
- The overall window luminance exceeded the threshold value (2000 cd/m^2) for computer-based tasks for 6% of the day with average luminance values of 2302 cd/m^2 when exceeding the threshold.
- Under clear sky conditions, the optical blind provided superior brightness control of the upper, mid- and lower regions of the blind compared to the reference blind. The way the blind was positioned, occupants did not have a direct view of the shiny upper surface of the slats except in the lower region. One would have expected bright reflected sunlight off of these lower slats to cause glare but threshold brightness levels were exceeded for 9% of the day with an average level of 3735 cd/m^2 when exceeding the threshold, compared to 53% and 4977 cd/m^2 for the reference blind on clear sunny days.
- If the conventional interior blind was controlled for glare, lighting energy savings would increase.
- The blind could be fully raised and the slat angles could be adjusted as desired by the occupant.



Three zone optical exterior louvers (left) and interior Venetian blinds (right) on March 22, 10:02 AM. Yellow = luminance levels ≥3000 cd/m^2.

Zoned, optical exterior louver system

10x9 ft south-facing window in a 10x15x11 ft private office, Berkeley, CA (latitude 38°N)

Reference Case

Single, fully-lowered interior Venetian blind with 1-inch wide concave down, matte-white slats

Manually operated: Slat angle adjusted seasonally to block direct sun

Test Case

Three-zone, fully-lowered exterior optical louver system

7-mm wide upside-down V shaped slats with shiny aluminum finish on top surface and light gray paint on lower surface

Fixed blind: slat angle progressively more closed from lower to upper zones. .

Window height above floor

Lower: 0.7-6.5 ft high

Upper: 6.5-9.0 ft

Width: 10 ft

Daylighting controls

1 W/ft^2, single zone, 20-100% power, 50 fc setpoint, 10 ft from window

Lighting Energy Use

	Monitored days (6:00-18:00)	59
	Glass: WWR=0.59, Tvis=0.62	
1	ASHRAE 90.1-2004, no light controls (Wh/day)	1800
2	Reference with daylighting controls (Wh/day)	730
	Test case with daylighting controls* (Wh/day)	848
3	Savings, ASHRAE 90.1-2004	53%
	Savings, reference with daylighting controls	-25%
4	90.1-2004 Annual Energy Use Intensity (kWh/ft^2-yr)	3.00
	Reference: Annual EUI (kWh/ft^2-yr)	1.22
	Test: Annual EUI (kWh/ft^2-yr)	1.41
5	90.1-2004 Lighting Power Density (W/ft^2)	1.00
	Test case with daylighting controls: LPD (W/ft^2)	0.47

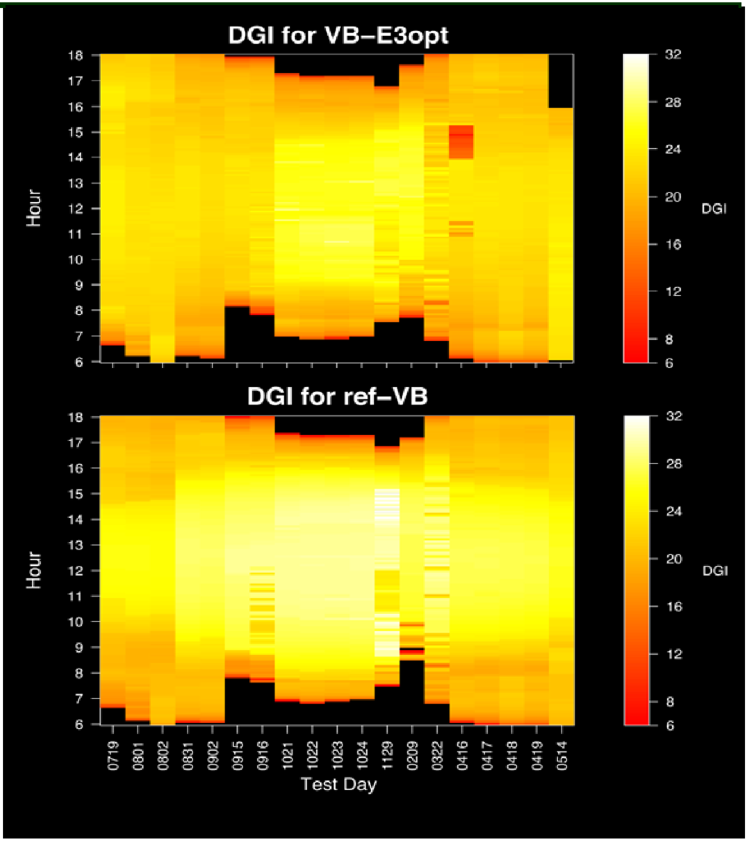
Daylight Illuminance

		(fc)	(lux)
6	Average (6:00-18:00)	49	528
	Standard deviation	27	286
	2.5 ft high, 10 ft from window		

Cooling Load due to the Window

	Monitored days (6:00-18:00)	43
	Whole window: WWR=0.73	
	Center of glass: SHGC=0.40, U-value=0.30 Btu/h-ft^2-°F	
7	Avg Reduction in Cooling Load from Window	74%

		W/ft^2-wdw	W/ft^2-flr
8	Peak Cooling Load from Window		
	Reference case	18.1	10.5
	Test case	5.0	2.9
	Savings		71%



9 **Discomfort glare index** (above), 4-ft high, 4-ft from window, centered, facing window on select days over 6-month period. Falsecolor: 16=perceptible, 20=acceptable, 24=uncomfortable, 28=intolerable.

Visual Discomfort

10	Avg window luminance, Lw, 4 ft high, 7.5 ft from center & facing window		
	Percentage of day Lw>2000 cd/m^2 (computer tasks)		6%
	Average Lw (cd/m^2) when Lw > 2000 cd/m^2		2302
11	Avg Lw on clear, sunny days, n=25	%day>2000 cd/m^2	cd/m^2
	Upper zone	2%	2740
	Middle zone	10%	2800
	Lower zone	9%	3735
	4 ft high, 5 ft from window, 4 ft from west sidewall, facing west		

3.4.2. Automated, Exterior Louver or Venetian Blind Systems

Technical Concepts

- The technical concepts and advantages associated with automated exterior louver and blind systems are the same given for automated interior Venetian blinds (see Section 3.3.3). Control algorithms for commercial systems are typically designed to block direct sun in order to minimize window solar heat gains but some systems have algorithms to enhance daylighting. Algorithms based on heating and cooling schedules, occupancy, security, and ventilation schemes can also be incorporated for a specific site.
- Like their manually-operated counterparts (Section 3.4.1), automated exterior horizontal Venetian blinds are attached to the head of the window and hung off the façade. A single AC motor in the header of the blind provides both lift and slat angle adjustments. Blinds are fully raised when wind limits are exceeded (e.g., > 30 mph).
- Automated exterior louver systems function similarly to automated blinds but typically are not retractable (see photo on right). These systems have a wider range of mounting and actuation methods. The louvers can be large in scale (2 ft wide with spans of up to 10 ft, depending on wind conditions and weight of slat type) and made of a wide range of materials from fabric, perforated metal, or patterned glass to photovoltaic panels. Slat geometry is typically flat, curved, or curved on both sides. The range in slat angles may be limited to 0-90°, depending on the method of mounting and actuating the louvers. Louvers can be both horizontally or vertically mounted. These systems are typically used in high-end applications.

Automated louver systems on the European Commission Headquarters, Berlaymont, Brussels, Belgium. Photo: Colt International Limited.

- Perforated or fritted slats can permit views out but slats with an openness factor (ratio of open area to opaque area) greater than 3-4% can transmit high intensity direct sunlight, causing significant visual and thermal discomfort. Similarly, fritted slats can cause glare. Automation of such slats will not improve performance.

Performance Impacts

- Like automated interior shades, automated exterior shading systems can yield significant HVAC energy savings, improve comfort, and increase access to views out compared to manually-operated systems since adjustments can be made more reliably on a real-time basis.

- Lighting energy use savings are dependent on details like how far the shading system is spaced away from the window, what glazing is used, and what are the reflectance properties of the slats. If sunlight is redirected into the space, window heat loads will be increased. Actively controlling the shade to minimize lighting energy use and solar heat gains would yield lowest energy use.
- Thermal and visual discomfort due to the effects of direct sun can be eliminated using a simple cutoff slat angle to just block direct sun. Discomfort glare can also be a result of reflected daylight off slat surfaces, transmitted sun or daylight through the slat itself (if not opaque), and transmitted daylight between the slats. Controlling glare from these sources will require a more closed slat angle even when the sun in not in the plane of the window. To maximize views out, discomfort glare is perhaps better addressed using an interior thin drape or shade since partial views out can still be preserved.
- If the blind is automated to simply block direct sun, the blind can be retracted during periods when the sun is not in the plane of the window (e.g., for a west-facing window, the blind would be retracted all morning or if non-retractable, the slats could be set to horizontal).
- Automating the blind to control discomfort glare is currently achieved, if at all, using crude measures (e.g., vertical illuminance thresholds). Depending on what threshold is used and the transmittance of the glazing, the blind could be lowered and closed for significantly more hours than if controlled to just block direct sun.
- Sunlight or the orb of the sun seen through the slat itself (perforated metal or glass) can be a severe source of glare and cannot be remedied once the slats have been selected and installed.
- Direct views of the sky or reflected light off nearby buildings can also be a significant source of glare – if the blind is lowered and the slat angle is tilted to block sky views, this source of glare is likely to be mitigated.
- Glare reflected off the slat itself can be mitigated by careful selection of surface reflectance. A dark color on the underside of the slat can increase the light-dark contrast between the outdoors and slat surface and reduce reflected daylight into the space. A matte, moderately-light slat may be better.

Applications

- Automated exterior shades can be used in both new and retrofit construction for east, west, and south-facing facades exposed to direct sun. Benefits will be significant if the window area is large and not shaded by other exterior shading systems or the surrounding environment (nearby buildings, etc.).
- Because exterior shading reduces cooling loads due to the window so significantly, larger windows can be used to provide daylight. Such solutions can yield the best of both worlds: low cooling and lighting energy use.
- As with automated interior shading systems, it is important to construct operational schedules to understand how the blind will be controlled on sunny and cloudy days, winter and summer days and how these operations affect daylight, glare, view, privacy, appearance of the façade, etc. For example, a design team may assume that the exterior blind will be automatically controlled to block direct sun on a west façade and that unobstructed views will be available all morning. Glare, privacy, and daylight is assumed to be controlled by the occupants using an interior drape. Such a scheme must be clearly conveyed to the lighting and HVAC designer at the schematic design and conveyed throughout the life of the building project to ensure proper selection of the interior shade material by the tenants and education of client and occupants.
- The engineering details of the system can impact performance. Some manufacturers restrict the range of tilt angle, the number of angles that one can position the slats to, and the number of

options for control. To avoid seeing the dirt accumulated on the top surface of the slat, for example, some clients prefer that the slat is never tilted in towards the interior.

- Automation can be provided by either the manufacturer of the blind or an independent controls engineering consultant. The system consists typically of an integrated microprocessor and motor controller located near the motor, which is then connected to PC-based software located in a central location within the building.
- The control system also accepts data from roof-mounted exterior sensors: an illuminance or irradiance sensor and an anemometer to measure local wind speed. Some systems use vertical illuminance sensors to determine whether conditions are sunny.
- Lower-cost control solutions provide facility managers with a simple hand-held interface to a schedule-based control system, where slat angles for an entire façade orientation are input on a monthly or seasonal basis.
- More expensive but flexible control solutions enable re-zoning of blind motor groups using software to match interior space requirements and offer more options to fine-tune control for each zone based on local and building-wide criteria, alter setpoints, and trend performance. These systems are typically run using a central control system or distributed system of control nodes.
- Details on the types of motors and considerations for use are given in [9].

A fixed-speed, runtime-controlled, AC box motor is coupled to a drive shaft assembly and shielded from the weather using a U-channel header (above). Power to the motor is delivered via a pigatail that in this case extended 500 mm from the end of the motor and was terminated with a Hirshmann connector. Ideally the electrical junction is placed inside the building or in a weatherproof junction box. Photo: LBNL.

Integrated microprocessor and runtime motor controller in a weatherproof box (left) is used to actuate the blinds (left). Brightness sensor and wind anemometer located on the roof (right). Photo: LBNL.

Measured Performance

1. Automated exterior Venetian blinds

- A conventional exterior Venetian blind was automated using a commercialized control system to adjust the slat angle to block direct sun. When cloudy or during periods of low daylight, the slat angle was set to approximately horizontal. The blind was fully lowered throughout the day and retracted only at night.

- The advantage of automation in this case was to ensure that direct sun was blocked at all times but permitted minimally obstructed views out on cloudy days:

    - On sunny days during the summer, the slat angles were very similar to the seasonally-controlled, static exterior blind (Section 3.4.1, Case 1) because solar altitudes were high throughout the period when the sun was in the plane of the window.

    - On sunny days during the winter, automation blocked low-angle direct sun during the early morning and late afternoon hours of the day and enabled a more open slat angle throughout the middle portion of the day, lessening obstructions to views out compared to the seasonally-operated blind.

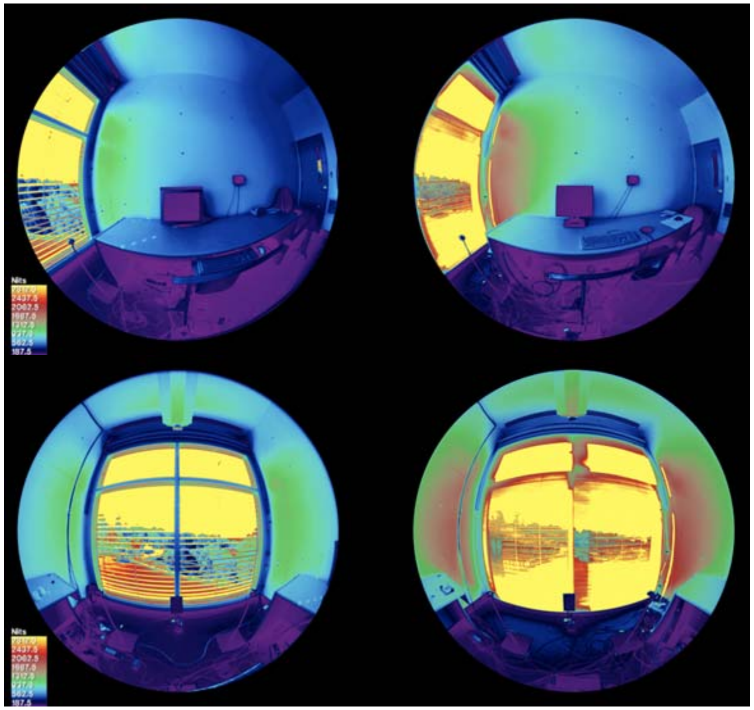
    - On cloudy days, automation provided less obstructed views out and more daylight.

- Monitored data showed that the system provided very similar levels of lighting energy use and window cooling load and peak window cooling load reductions as the manually-operated, seasonally-controlled exterior blind. Glare discomfort levels were also comparable. Like the manually-operated system, savings compared to an interior shade were very significant – this system reached the high performance levels required to meet net zero energy goals.

- The average brightness of the window exceeded the threshold value (2000 cd/m^2) for 25% of the day with average luminance values of 2553 cd/m^2 when exceeding the threshold.

- Under clear sky conditions, the upper- and mid-height zones of the blind exceeded the brightness threshold for 43% and 51% of the day, respectively. These values are given for a conservative worst case viewpoint facing the window at a distance of 4 ft from the window for computer-based tasks.

- During the summer, the slat angle was set to nearly horizontal on cloudy and sunny days so views out were minimally obstructed for this latitude (37°N). During the winter, the slat angle was no greater than 56° on sunny days and to horizontal on cloudy days.



Automated exterior Venetian blinds (left) and interior Venetian blinds (right) on March 22, 10:02 AM. Yellow = luminance levels ≥3000 cd/m^2.

Automated exterior Venetian blinds

10x9 ft south-facing window in a 10x15x11 ft private office, Berkeley, CA (latitude 38°N)

Reference Case

Single, fully-lowered interior Venetian blind with 1-inch wide concave down, matte-white slats

Manually operated: Slat angle adjusted seasonally to block direct sun

Test Case

Single, fully-lowered, motorized, exterior Venetian blind

100-mm wide concave down curved aluminum slats with slightly shiny upper and lower white painted surfaces; 5 slat angles

Automated: Slat angle adjusted to block direct sun

Window height above floor
Lower: 0.7-6.5 ft high
Upper: 6.5-9.0 ft
Width: 10 ft

Daylighting controls

1 W/ft^2, single zone, 20-100% power, 50 fc setpoint, 10 ft from window

Lighting Energy Use

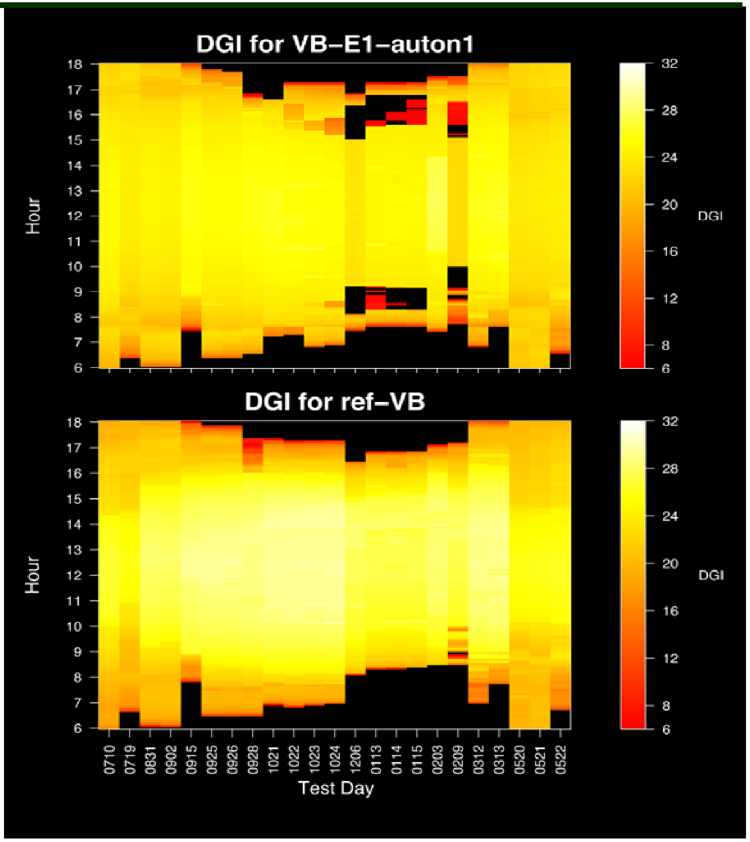
Monitored days (6:00-18:00)	89
Glass: WWR=0.59, Tvis=0.62	
1 ASHRAE 90.1-2004, no light controls (Wh/day)	1800
2 Reference with daylighting controls (Wh/day)	730
Test case with daylighting controls* (Wh/day)	760
3 Savings, ASHRAE 90.1-2004	58%
Savings, reference with daylighting controls	-4%
4 90.1-2004 Annual Energy Use Intensity (kWh/ft^2-yr)	3.00
Reference: Annual EUI (kWh/ft^2-yr)	1.22
Test: Annual EUI (kWh/ft^2-yr)	1.27
5 90.1-2004 Lighting Power Density (W/ft^2)	1.00
Test case with daylighting controls: LPD (W/ft^2)	0.42

Daylight Illuminance

	(fc)	(lux)
6 Average (6:00-18:00)	70	750
Standard deviation	30	327
2.5 ft high, 10 ft from window		

Cooling Load due to the Window

Monitored days (6:00-18:00)		20
Whole window: WWR=0.73		
Center of glass: SHGC=0.40, U-value=0.30 Btu/h-ft^2-°F		
7 Avg Reduction in Cooling Load from Window		79%
8 Peak Cooling Load from Window	W/ft^2-wdw	W/ft^2-flr
Reference case	18.1	10.5
Test case	4.5	2.6
Savings		74%



9 **Discomfort glare index** (above), 4-ft high, 4-ft from window, centered, facing window on select days over 6-month period. Falsecolor: 16=perceptible, 20=acceptable, 24=uncomfortable, 28=intolerable.

Visual Discomfort

10 Avg window luminance, Lw, 4 ft high, 7.5 ft from center & facing window		
Percentage of day Lw>2000 cd/m^2 (computer tasks)		25%
Average Lw (cd/m^2) when Lw > 2000 cd/m^2		2553
11 Avg Lw on clear, sunny days, n=35	%day>2000 cd/m^2	cd/m^2
Upper zone	43%	3363
Middle zone	51%	3066
Lower zone	13%	2219
4 ft high, 5 ft from window, 4 ft from west sidewall, facing west		

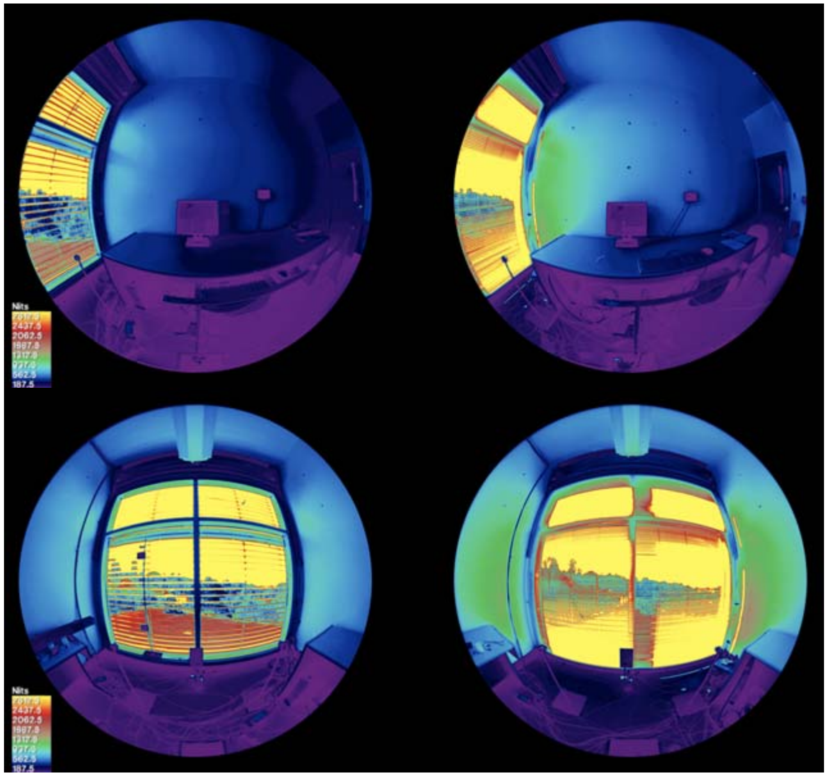
2. *Zoned, automated exterior Venetian blinds*

- This commercially-available, solar control/ daylighting system was evaluated using the same hardware configuration described in Section 3.4.1 for a zoned, manually-operated Venetian blind. Automation was designed to increase daylight admission through the upper clerestory zone.
- In the lower zone, the conventional exterior Venetian blind was automated using a commercialized control system to adjust the slat angle to block direct sun. When cloudy or during periods of low daylight, the slat angle was set to approximately horizontal. The blind was fully lowered throughout the day and retracted only at night.
- In the upper zone, the exterior blind was automated using a commercialized control system to adjust the slat angle to block direct sun with less overlap between slats than the lower zone. When cloudy or during periods of low daylight, the slat angle was set to approximately horizontal. The blind was fully lowered throughout the day and retracted only at night.
- For both blinds, there were three preset intermediate slat angles between the maximum horizontal slat angle (16°) and fully closed.
- Due to the limited range of angles, the automated system's control algorithm was rather conservative with daylight control in the upper zone and resulted in increased lighting energy use (-9%) compared to the reference interior blind with the same lighting control system. Savings compared to a non-daylit space was still considerable: 61% or 0.39 W/ft^2-floor compared to the reference interior blind controlled to block direct sun seasonally.
- Cooling load and peak cooling load savings were 74% and 74%, respectively, compared to the interior reference blind. Peak cooling loads were 3.0 W/ft^2-floor, which were within the 4 W/ft^2-floor criteria for low-energy cooling systems (Section 2.5).

Shading systems were taken down after 6 PM every 4-5 days and rotated with different shading systems so that more systems could be tested in a single solstice-to-solstice period. An electronic hoist was used to raise and lower the header beam. A secondary, backup hoist system of ropes was used to ensure safety.

- Discomfort glare occurred less frequently than the manually-operated system but the magnitude of glare was similar when brightness thresholds were exceeded in both the upper and lower zones.
- When retracted, the stack height of the upper and lower blinds will obstruct incoming daylight (see photo above). The full height of the stack could be accommodated in a cove above the top of the vision glass so that the views out are completely unobstructed.

- Note also that there is a gap between the header and the first row of slats down from the header (see photo above). This gap should occur above the head of the window to prevent stray sunlight from coming into the interior.



Zoned, automated exterior Venetian blind (left) and interior Venetian blinds (right) on September 7, 10:02 AM. Yellow = luminance levels ≥3000 cd/m^2.

Zoned, automated exterior Venetian blinds

10x9 ft south-facing window in a 10x15x11 ft private office, Berkeley, CA (latitude 38°N)

Reference Case

Single, fully-lowered interior Venetian blind with 1-inch wide concave down, matte-white slats

Manually operated: Slat angle adjusted seasonally to block direct sun

Test Case

Two, fully-lowered, motorized exterior blinds with independent zone control
100-mm wide concave down curved aluminum slats with slightly shiny upper and lower white painted surfaces

Automated: Lower & upper zone slats adjusted to block direct sun with upper slightly more open.

Window height above floor
Lower: 0.7-6.5 ft high
Upper: 6.5-9.0 ft
Width: 10 ft

Daylighting controls

1 W/ft^2, single zone, 20-100% power, 50 fc setpoint, 10 ft from window

Lighting Energy Use

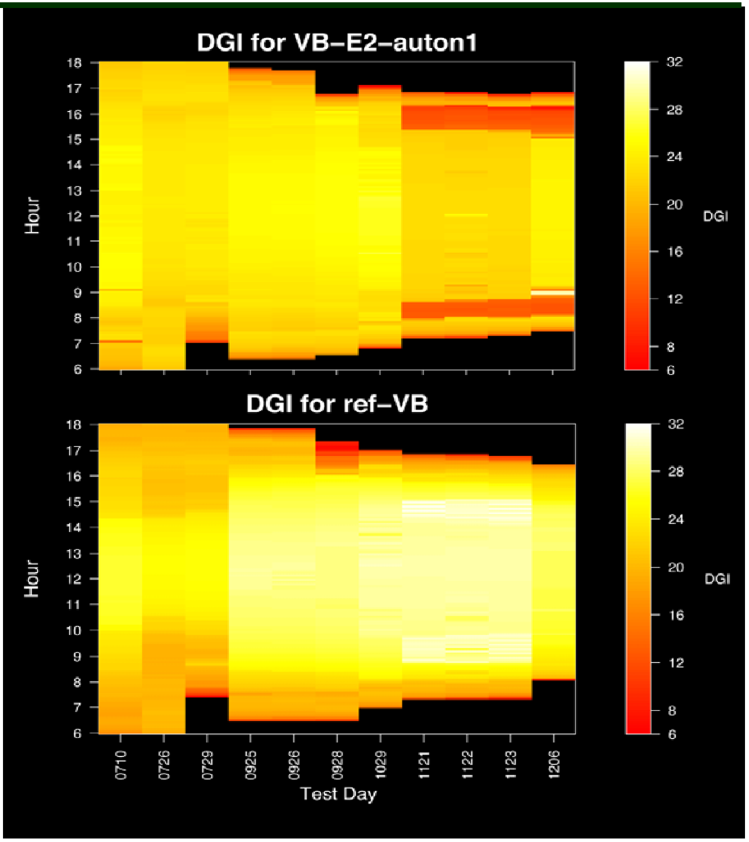
	Monitored days (6:00-18:00)	38
	Glass: WWR=0.59, Tvis=0.62	
1	ASHRAE 90.1-2004, no light controls (Wh/day)	1800
2	Reference with daylighting controls (Wh/day)	730
	Test case with daylighting controls* (Wh/day)	698
3	Savings, ASHRAE 90.1-2004	61%
	Savings, reference with daylighting controls	-9%
4	90.1-2004 Annual Energy Use Intensity (kWh/ft^2-yr)	3.00
	Reference: Annual EUI (kWh/ft^2-yr)	1.22
	Test: Annual EUI (kWh/ft^2-yr)	1.16
5	90.1-2004 Lighting Power Density (W/ft^2)	1.00
	Test case with daylighting controls: LPD (W/ft^2)	0.39

Daylight Illuminance

		(fc)	(lux)
6	Average (6:00-18:00)	66	707
	Standard deviation	24	258
	2.5 ft high, 10 ft from window		

Cooling Load due to the Window

	Monitored days (6:00-18:00)		20
	Whole window: WWR=0.73		
	Center of glass: SHGC=0.40, U-value=0.30 Btu/h-ft^2-°F		
7	Avg Reduction in Cooling Load from Window		74%
8	Peak Cooling Load from Window	W/ft^2-wdw	W/ft^2-flr
	Reference case	18.1	10.5
	Test case	5.1	3.0
	Savings		74%



9 **Discomfort glare index** (above), 4-ft high, 4-ft from window, centered, facing window on select days over 6-month period. Falsecolor: 16=perceptible, 20=acceptable, 24=uncomfortable, 28=intolerable.

Visual Discomfort

10	Avg window luminance, Lw, 4 ft high, 7.5 ft from center & facing window		
	Percentage of day Lw>2000 cd/m^2 (computer tasks)		19%
	Average Lw (cd/m^2) when Lw > 2000 cd/m^2		2627
11	Avg Lw on clear, sunny days, n=14	%day>2000 cd/m^2	cd/m^2
	Upper zone	39%	3388
	Middle zone	33%	2792
	Lower zone	6%	2122
	4 ft high, 5 ft from window, 4 ft from west sidewall, facing west		

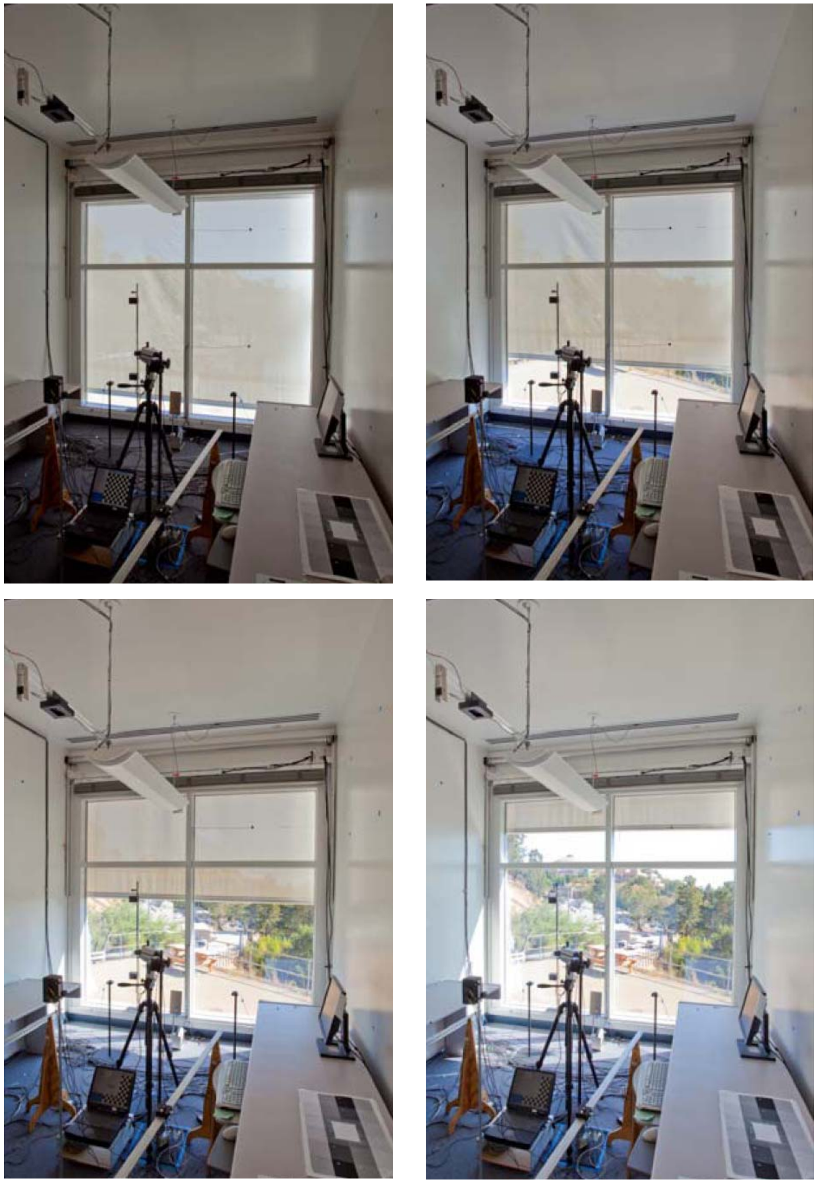
3.4.3. Automated, Exterior Roller Shades

Technical Concepts

- The technical concepts and advantages associated with automated exterior roller shades are similar to that given for automated interior roller shades (see Section 3.3.4). A fabric roller shade is raised and lowered vertically to control, direct sun, daylight, glare, privacy, view, etc.

Performance Impacts

- Effective solar control is dependent on the density of the fabric weave and the conservativeness of the control algorithm.
- Performance is critically dependent on fabric choice. A more open-weave fabric will admit more daylight and solar heat gains but may inadequately control direct sun and glare. A dark colored fabric facing the interior will reduce glare due to the brightness of the shade. A light colored fabric facing the interior can decrease gloom during the winter.
- The depth that direct sun is allowed to penetrate horizontally into the room is specified by the building owner or occupants. Lighting energy use will decrease and window heat gains will increase if direct sun is allowed 2-3 ft in from the window, for example, as opposed to blocking all direct sunlight from entering the building. Admitting some sunlight can provide a more dynamic lighting quality to the space. For the same depth of sunlight into the space, the height of the lower edge of the exterior shade can be higher than that needed for an interior roller shade, enabling more unobstructed views out.
- Like the automated exterior blind, the roller shade will be lowered for significantly more hours of the day if controlled to block direct sun and glare. A second, open weave interior roller shade or scrim could be used to cut glare.



Interior view of an automated exterior roller shade with 3%-open, light gray (both sides), basketweave fiberglass/ PVC fabric. The shade could be set to an almost fully raised height for an unobstructed view out, but the bright sky may cause glare discomfort.

Applications

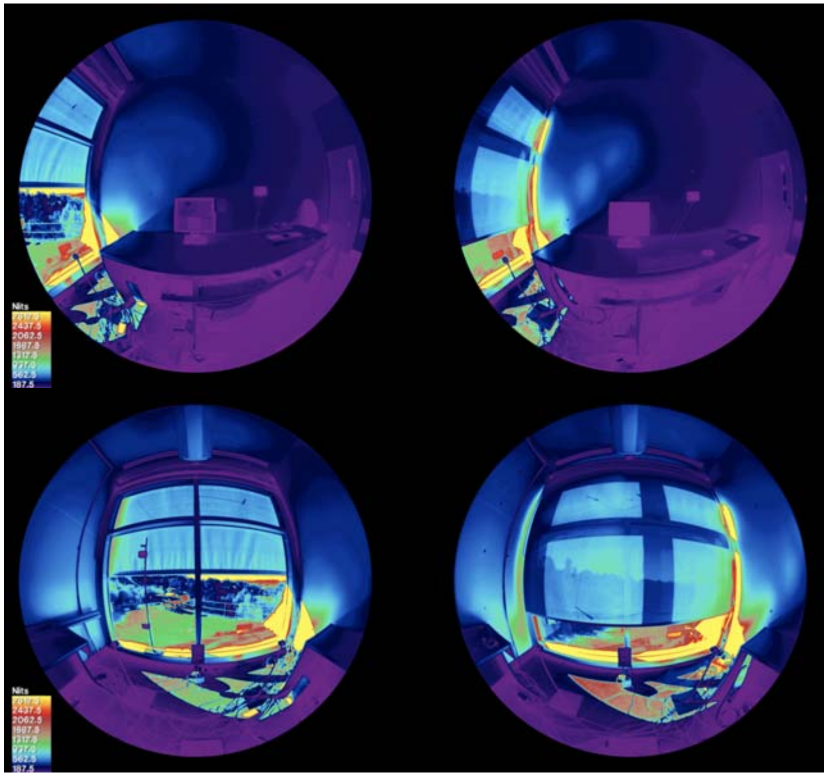
- Automated exterior roller shades are most applicable on east, west, and south-facing facades with significant solar exposure but low wind conditions (< 30 miles per hour).
- With an encoded motor, shade height adjustment can be almost continuous (e.g., 100 steps over full height of window).
- One could argue that the engineering of a motorized roller shade is more robust than an exterior Venetian blind system since it does not rely on point connections to the header (i.e., narrow, vertical tapes that are reeled up on the header shaft). The entire width of the fabric is rolled up and down using a tubular motor. The motor can be encoded and the microprocessor controller can be integrated within the tubular housing.
- The ends of the bottom hem bar are restrained with vertical guide wires to keep the fabric in plane with the building façade when windy. The fabric itself can act like a sail and ripple in the wind.
- The fabric of the roller shade will likely need to be replaced more frequently than a blind or louver system due to UV degradation.
- Automation is offered through either the manufacturer of the hardware or an independent controls engineering consultant. The system can be simple and scheduled using a time-clock or sophisticated, addressing numerous issues such as view, solar exclusion, daylighting, glare, response time for lowering and raising the shade (visual distraction), weather (wind, ice, snow), security, privacy, occupancy or scheduling, ventilation schemes, fire, egress, and other safety concerns.
- Exterior sensors are needed for control, similar to the automated exterior blinds.

Exterior view of automated exterior roller shade. Photo: LBNL.

The lower hem bar is restrained by a vertical guide wire that runs the height of the window. Photo: LBNL.

Measured Performance

- A light gray exterior roller shade was controlled every 1 minute to prevent direct sun from penetrating horizontally more than 3 ft from the interior face of the glazing and maintain daylight illuminance levels within 570-670 lux (53-62 fc) on the workplane at the rear of the room. The shade was lowered immediately when there was direct sun and retracted gradually if cloudy. It was "sunny" when a photometrically-correct vertical illuminance sensor value was greater than 30,000 lux.
- Compared to an interior roller shade set at a height of 30 inches (0.76 m) above the floor year round, the automated shade reduced cooling and peak cooling energy use by 69% and 73%, respectively. The peak cooling load was 3.0 W/ft^2-floor for this large-area window and this load is less than the 4 W/ft^2-floor limit needed for low-energy cooling strategies.
- Lighting energy use was reduced by 36% compared to the reference interior shade. If the occupant raised the interior shade, lighting savings would be less. Lighting savings were 67% or an average lighting power density of 0.33 W/ft^2 compared to a lighting system with no controls.
- The brightness of the window infrequently exceeded the threshold luminance level of 2000 cd/m^2: on average, only 2% of the day with an average level of 2374 cd/m^2 when the threshold was exceeded.
- Under clear sky conditions, the brightness in the upper and middle zones of the window exceeded the 2000 cd/m^2 threshold 4-5% of the day but the brightness of the lower zone (< 30 inches above the floor) exceeded the threshold 34% of the day with average levels of 2717 cd/m^2.



Automated exterior roller shade (left) and interior roller shade (right) on March 9, 9:02 AM. Yellow = luminance levels ≥3000 cd/m^2.

Automated exterior roller shades

10x9 ft south-facing window in a 10x15x11 ft private office, Berkeley, CA (latitude 38°N)

Reference Case

Single, 3%-open, light gray, basket-weave fabric roller shade

Manually operated: lowered to 30 inch height above floor all year.

Test Case

Single, 3%-open, light gray, basket-weave fabric motorized exterior roller shade

Automated: Adjust shade height to block direct sun to 3 ft deep from window and control daylight to within 570-670 lux at rear of room.

Window height above floor
Lower: 0.7-6.5 ft high
Upper: 6.5-9.0 ft
Width: 10 ft

Daylighting controls

1 W/ft², single zone, 20-100% power, 50 fc setpoint, 10 ft from window

Lighting Energy Use

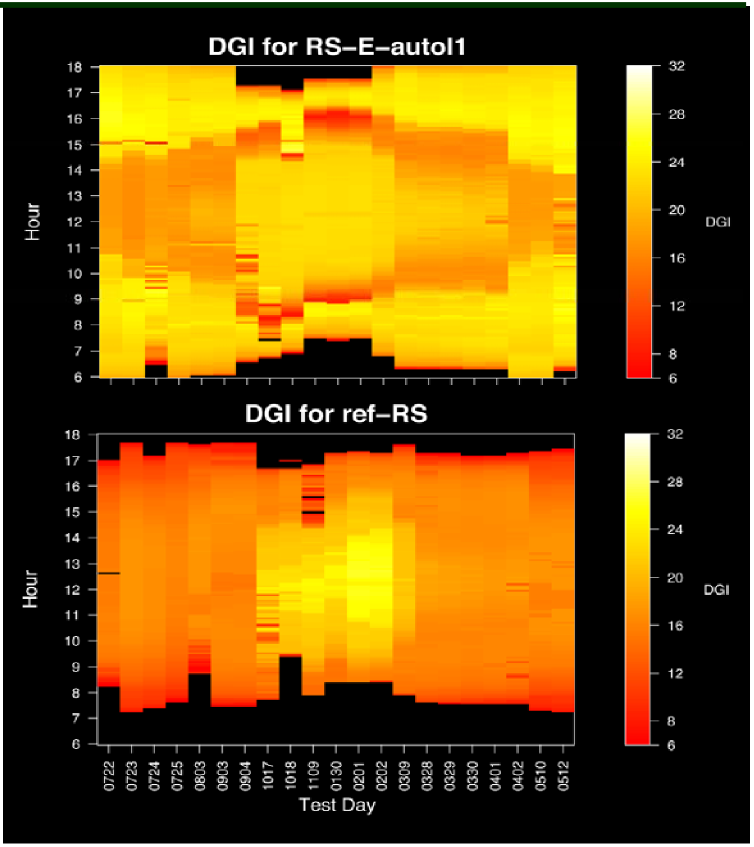
	Monitored days (6:00-18:00)	54
	Glass: WWR=0.59, Tvis=0.62	
1	ASHRAE 90.1-2004, no light controls (Wh/day)	1800
2	Reference with daylighting controls (Wh/day)	981
	Test case with daylighting controls* (Wh/day)	600
3	Savings, ASHRAE 90.1-2004	67%
	Savings, reference with daylighting controls	36%
4	90.1-2004 Annual Energy Use Intensity (kWh/ft²-yr)	3.00
	Reference: Annual EUI (kWh/ft²-yr)	1.63
	Test: Annual EUI (kWh/ft²-yr)	1.00
5	90.1-2004 Lighting Power Density (W/ft²)	1.00
	Test case with daylighting controls: LPD (W/ft²)	0.33

Daylight Illuminance

		(fc)	(lux)
6	Average (6:00-18:00)	47	504
	Standard deviation	12	129
	2.5 ft high, 10 ft from window		

Cooling Load due to the Window

	Monitored days (6:00-18:00)		33
	Whole window: WWR=0.73		
	Center of glass: SHGC=0.40, U-value=0.30 Btu/h-ft²-°F		
7	Avg Reduction in Cooling Load from Window		69%
8	Peak Cooling Load from Window	W/ft²-wdw	W/ft²-flr
	Reference case	18.6	10.8
	Test case	5.1	3.0
	Savings		73%



9 **Discomfort glare index** (above), 4-ft high, 4-ft from window, centered, facing window on select days over 6-month period. Falsecolor: 16=perceptible, 20=acceptable, 24=uncomfortable, 28=intolerable.

Visual Discomfort

10	Avg window luminance, Lw, 4 ft high, 7.5 ft from center & facing window		
	Percentage of day Lw>2000 cd/m² (computer tasks)		2%
	Average Lw (cd/m²) when Lw > 2000 cd/m²		2374
11	Avg Lw on clear, sunny days, n=28	%day>2000 cd/m²	cd/m²
	Upper zone	5%	3067
	Middle zone	4%	2563
	Lower zone	34%	2717
	4 ft high, 5 ft from window, 4 ft from west sidewall, facing west		

4. resources

Commercial Windows Book: Window Systems for High Performance Buildings

http://www.wwnorton.com/npb/nparch/carmody731219.html

Takes you to the WW Norton Books web site for an overview of this 400-page book; much of the information is available on the Commercial Windows web site.

Commercial Windows Website

www.commercialwindows.org

LBNL developed, in collaboration with the University of Minnesota, an on-line tool for A/Es or owners to optimize designs and estimate savings quickly from glazing, shading and daylighting strategies.

A companion extensive site for Residential Windows is at http://www.efficientwindows.org in collaboration with University of Minnesota and Alliance to Save Energy.

Commercial Fenestration Simulation Tool (COMFEN)

A free PC-based tool that calculates commercial window/ facade, heating and cooling energy use. Download software to create and assess energy performance of a wide range of façade systems; varying glazing, framing, shading systems, daylighting, etc. for a range of US cities; reports annual and monthly heating/cooling and lighting, daylighting, comfort, carbon impacts etc. Uses the EnergyPlus calculation engine.

http://windows.lbl.gov/software/

Advanced Daylighting Concepts: A Source Book on Daylighting Systems and Components:

http://gaia.lbl.gov/iea21/

Field data and how-it-works information on a number of innovative daylight-redirecting, solar control, and light diffusing systems catalogued by the IEA Task 21 International Daylighting project.

Quick Guide for Daylighting

http://windows.lbl.gov/pub/designguide/default.html

In the daylighting area we have a nice downloadable reference, Tips for Daylighting. This has been reprinted thousands of times by utility programs etc and is a good, quick checklist-type, “how-to-do-it” reference.

Double Envelope and All Glass Facades

http://gaia.lbl.gov/hpbf

The well-publicized use of all glass, double envelope facades in EU led to significant interest in the US market. What are the benefits and risks of this design approach? This site provides insights into the motivation behind use of these systems, the challenges of using them, and includes interviews with owners and specifiers on applicability to the US market.

Daylighting The New York Times Headquarters

http://windows.lbl.gov/comm_perf/newyorktimes.htm

Assessment of the benefits of dimmable lighting and automated roller shades in a full-scale mockup. The procurement specifications, commissioning package and other support tools developed for the owner to help "guarantee" success are downloadable from this site.

Switchable Electrochromic Windows

http://windows.lbl.gov/comm_perf/electrochromics

Consumer-oriented information on commercially-available, switchable electrochromic (EC) windows. A design guide provides information on how EC windows work and what benefits this technology can provide in commercial buildings.

National Public Radio's Richard Harris Interviews Stephen Selkowitz, LBNL

"Energy-Saving Windows: A Legacy Of '70s Oil Crisis"

National Public Radio, Morning Edition, October 15, 2008.

http://www.npr.org/templates/story/story.php?storyId=95309739

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