Tips for Daylighting with Windows

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Disclaimer

Acknowledgements

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The Commercial Building Partnerships (CBP) program is a public-private, cost-shared initiative that demonstrates cost-effective, replicable ways to achieve dramatic energy savings in commercial buildings. Through the program, companies and organizations, selected through a competitive process, team with DOE and national laboratory staff, who provide technical expertise to explore energy-saving ideas and strategies that are applied to specific building project(s) and that can be replicated across the market.

Using this Guide

These guidelines provide an integrated approach to the cost-effective design of perimeter zones in new commercial buildings and existing building retrofits. They function as a quick reference for building designers, through a set of easy steps and rules-of-thumb, emphasizing "how-to" practical details. References are given to more detailed sources of information, should the reader wish to go further.

The design method used in this document emphasizes that building decisions should be made within the context of the whole building as a single functioning system rather than as an assembly of distinct parts. This integrated design approach looks at the ramifications of each individual system decision on the whole building. For example, the decision on glazing selection will have an effect on lighting, mechanical systems, and interior design. Therefore, the entire design team should participate and influence this glazing decision—which typically rests with the architect alone. The benefit of an integrated design approach is a greater chance of success towards long-term comfort and sustained energy savings in the building.

Basic Guidelines

No guidelines can answer all possible questions from all types of users. However, this document addresses the most commonly occurring scenarios. The guidance here is limited by the medium; short paper documents can only go so far in assisting a designer with a unique project. This document has been carefully shaped to best meet the needs of a designer when time does not permit a more extensive form of assistance.

These guidelines are primarily applicable to typical commercial buildings with office-like occupancy (including schools, laboratories, and other working environments), standard construction, and windows as the primary source of natural light (skylights are not addressed).

These guidelines are distinguished from existing materials in their how-to focus and their explicit support of design integration. Background material (basic principles, for example) is not included.

The design professional is ultimately responsible for all design decisions. The user is assumed to have a basic knowledge of lighting and daylighting principles.

Advice is given in a simplified, rule-of-thumb format. More detailed and accurate assistance is best provided by an expert consultant or an advanced computer tool.

Contents

1 Integrated Approach

OBJECTIVE: Work as a team towards the shared goal of a high-performance daylighted building.

- Share decisions and information across the entire design team, from project conception through to occupancy.
- Design carefully with regards to limiting peak energy requirements, as the design will affect both first costs and annual operating costs for systems.

What is the Integrated Approach?

These guidelines are a concise reference for a design approach that emphasizes teamwork. A high-performance, cost-effective, comfortably daylighted building requires the design team to practice integration:

- Adopt a universal design approach, where the building is viewed as a whole and not just a collection of parts. Common practice often fails to address the critical interactions between the building facade (which admits heat and light) and the electric lighting system, resulting in an uncomfortable and inefficient building that is expensive and difficult to retrofit. The potential to eliminate or "design out" unnecessary systems through an integrated approach is an attractive and often achievable scenario.
- Share appropriate decisions across disciplines.
- Regularly evaluate decisions for any building-wide ramifications.

What is a high-performance building?

One that:

- Meets low energy design objectives.
- Maximizes occupant comfort and productivity.
- Minimizes occupant complaints.
- Maximizes building value to the owner.
- Yields a lifetime of energy efficiency and lower operating costs.

Why pursue daylighting?

Daylighting is the use of light from the sun and sky to complement or replace electric light. Appropriate fenestration and lighting controls are used to modulate daylight admittance and to reduce electric lighting, while meeting the occupants' lighting quality and quantity requirements. Daylighting is a beneficial design strategy for several reasons:

- Pleasant, comfortable daylighted spaces may increase occupant and owner satisfaction and may decrease absenteeism. Productive workers are a valuable business asset.

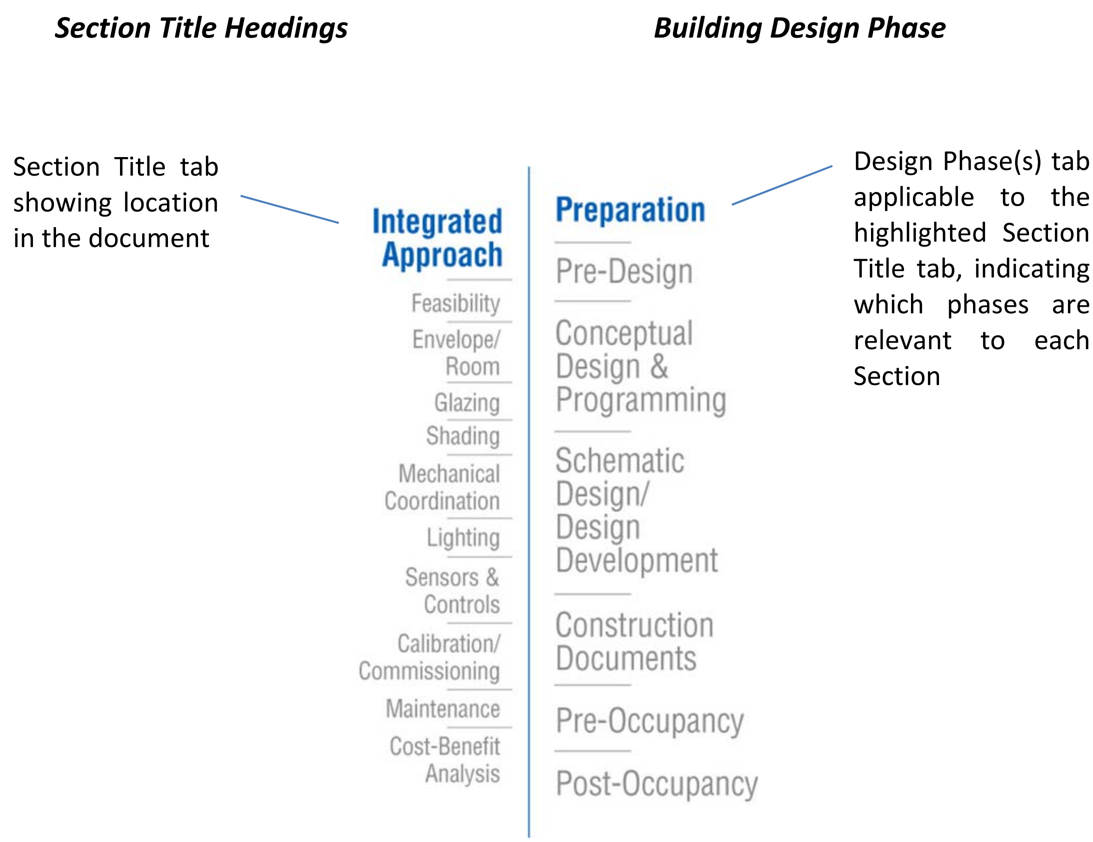
- Comfortable, pleasant, daylighted spaces may lease at better-than-average rates.
- Comfortable, pleasant spaces typically have lower tenant turnover rates.
- Lighting and its associated cooling energy use can constitute over 40% of a commercial building's total energy use. Daylighting is the most cost-effective strategy for targeting these uses (better than using an R-11 insulated wall). Both annual operating and mechanical system first costs can be substantially reduced as a result of installing smaller capacity systems or eliminating them through an integrated approach. Capacity reduction also reduces demand charge costs and feeds back upstream, improving grid security.
- The Uniform Building Code, BOCA, and State Energy Codes regulate the "proper" use of windows in buildings.
- Energy-efficient buildings generally provide higher returns on developer investment and yield higher cash flows.
- Smart decisions up front save retrofit dollars later.
- Energy-efficient daylighted buildings reduce adverse environmental impacts by reducing the use and need for power generating plants and their polluting by-products.
- Daylight contributes to a more sustainable design approach and lets users capitalize on the opportunity for energy savings from daylight dimming and other integrated controls strategies.

How to use this guide

Quick tips, tools, and **procedures** are supplied here to point designers towards appropriate decisions and to help the design team stay focused on integration and coordination. Information is restricted to daylighting issues; broader building concerns are left to the designers.

Twelve sections in these guidelines address the critical activities, from schematic design through occupancy, that influence daylighting performance. Each section contains specific design assistance with respect to that stage of design and flags important integration reminders.

The **Tab Index**, shown below, is included to support navigation through the guide and relate the various sections to the design phase within which they are applicable. This Tab appears on the top right of each section title page and the bottom right of each subsequent page in each section.



Traditionally, target audiences (such as architects, engineers, or owners) would be relevant at specific stages of the design process, but integrated design principles are such that all parties should remain engaged throughout. Where appropriate, specific roles within the integrated design team are identified as being crucial to specific aspects of project design.
Each section is formatted in the following manner:

KEY IDEAS

Lists design tips, rules of thumb, and other clear instructions.

PROVISOS

Notes particular exceptions from the Key Ideas.

INTEGRATION ISSUES

Reviews the design and energy-efficiency measure (EEM) selection process to emphasize integrated design objectives and outcomes. Highlights any areas of design coordination and impacts on other systems covered in this section, across a matrix of six design concerns: Architectural Design; Interior Design; Heating, Ventilating and

Air Conditioning (HVAC) System; Lighting System; Cost Effectiveness; and Occupant Comfort.

LINKS

Dynamic links are included from relevant highlighted text:

Daylighting the New York Times Headquarters Building

QR codes will take you to relevant online content; the image can be recognized by most “smart” phone-cameras using a barcode reader application, which will then take you to the website or upload the linked document. The QR code here links to the LBNL page for the New York Times Daylighting Project:

TOOLS & RESOURCES

Lists ways to analyze decisions or other places to go for help. In some cases, quick calculation tools are provided. Where simulation software is appropriate, this is also mentioned. We have aimed to provide a balance of the practical and the synthetic approaches which both contribute significantly to the design process.

Two principal online resources are referred to repeatedly: the Tips for Daylighting website, and the Commercial Windows website. Both contain design data, economic assessment tools, and reference material which usefully supports and expands upon information presented here.

Tips for Daylighting website
windows.lbl.gov/tips-for-daylighting

Commercial Windows website
www.commercialwindows.org/

CHECKLIST

Gives a sequenced reminder of important steps in the section. Includes activity recommendations broken down by available time.

At the end of each section we provide step-by-step guidance on necessary tasks or actions in the design and construction process, categorizing our tips as “Good Practice,” “Better Practice,” and “Best Practice.” These tasks reflect an increasing level of detail (and likely, cost) and are useful indicators of the recommended overall design approach.

Getting Started

These guidelines should function as a quick reference through all stages of design and building occupancy.

Pre-design (Mainly Retrofit application)

Use the rules-of-thumb in Section 11, COST-BENEFIT ANALYSIS, to quickly determine if daylighting holds good investment potential. See Section 2, DAYLIGHT FEASIBILITY, to quickly check that daylighting makes sense for site and program.

Conceptual Design, Programming

The goals established at this early planning stage will set the foundation for an integrated, energy-efficient building design.

- Establish performance goals together with the owner and make achieving these high-performance goals a priority.
- Include comfort (thermal and visual) goals.
- Identify any system-level goals (e.g., carbon neutral, emphasize natural ventilation, 100% daylit, no perimeter heating system).
- Aim for an effective daylighting design.
- Establish schedule and budget parameters: more time available allows for more analysis; allow for energy and lighting/glare analysis early in design stages; more budget allows for appropriate consultants.
- A focus on building massing and orientation emphasizes good solar access and minimized heat gain.
- Using narrow floor plates promotes effective use of daylight over a large fraction of net floor space.
- Conceptualize and program interior spaces by daylight and view needs. Organize spaces that see infrequent use in core zones.

The first design decisions are critical to energy efficiency and daylighting. Get started on the right foot by reviewing **Key Ideas** in ENVELOPE AND ROOM DECISIONS (Section 3), GLAZING SELECTION (Section 5), and SHADING STRATEGY (Section 5). It would be useful to refer to MECHANICAL COORDINATION (Section 6), LIGHTING COORDINATION (Section 7), and SENSOR AND CONTROLS (Section 8) to understand the implications of these systems in relation to the daylighting design.

Integrated Approach
Feasibility
Envelope/ Room
Glazing
Shading
Mechanical Coordination
Lighting
Sensors & Controls
Calibration/ Commissioning
Maintenance
Cost-Benefit Analysis

Preparation
Pre-Design
Conceptual Design & Programming
Schematic Design/ Design Development
Construction Documents
Pre-Occupancy
Post-Occupancy

Identify any major system comparisons to be made that would have the most impact on building design (e.g., natural ventilation versus mixed mode versus sealed air-conditioned building), and which might have different shading and solar control measures used. Perform integrated design and analysis of these options. Use the approaches highlighted in Section 11, COST-BENEFIT ANALYSIS, to quickly determine if daylighting holds good investment potential. The Tips for Daylighting website is kept up to date with content relevant to daylighting design and economic assessment of daylight harvesting systems. Refer to Section 2, DAYLIGHT FEASIBILITY, to quickly check that daylighting makes sense for a specific site and program.

Schematic Design / Design Development

Priorities at this stage should include:

- Review of project design goals to reestablish objectives.
- Refinement of envelope, room, and shading design.

Sections on ENVELOPE AND ROOM DECISIONS (Section 3), GLAZING SELECTION (Section 4), SHADING STRATEGY (Section 5), MECHANICAL COORDINATION (Section 6), and LIGHTING COORDINATION (Section 7) should now be viewed in detail, as should SENSORS AND CONTROLS (Section 8). This is a critical time for coordination among design team members, as it is the last opportunity to make design changes without compromising the design and/or incurring significant additional project costs.

Construction Documents

At this stage, the design is nearing completion, so any final modifications are likely to be minor. The following steps should be included as part of the completion process:

- Review project design goals to reestablish objectives.
- Ensure glazing, shading, lighting, and control systems are properly specified.
- Include calibration, commissioning, and maintenance plans as part of the construction documents (review those sections now).

Pre-Occupancy

Review Section 9, CALIBRATION AND COMMISSIONING, in detail, and take appropriate action.

Post-Occupancy

Review Section 10, MAINTENANCE, and keep it, along with the maintenance plan, on electronic and hardcopy file in the building.

References

The *ANSI Whole Systems Integrated Process Guide* provides greater depth on this subject and can be downloaded at [www.delvingdeeper.org/pdfs/wsip.pdf.](www.delvingdeeper.org/pdfs/wsip.pdf)

The Windows for High-Performance Commercial Buildings website (www.commercialwindows.org) contains information that can help users better understand what the project design objectives and limitations are likely to be and which tools are appropriate for the pre-design early-concept stage of a project, where theories and ideas can be tested. Use the Facade Design Tool to familiarize the project team with the interactions of the different daylighting systems.

Factor Ten Engineering Design Principles by the Rocky Mountain Institute (RMI, 2010) is an instructive insight into real integrated design practice, emphasizing the need to look at the whole system together to realize the benefits. It can be downloaded at www.rmi.org/Knowledge-Center/Library/2010-10_10xEPrinciples.

Integrative Design: A Disruptive Source of Expanding Returns to Investments in Energy Efficiency (RMI, 2010) provides greater detail on the same topic. It can be downloaded at www.rmi.org/Knowledge-Center/Library/2010-09_IntegrativeDesign.

Whole Building Design, by the National Institute of Building Sciences (NIBS, 2011) is an excellent resource for general information. Visit www.wbdg.org.

2 Daylight Feasibility

OBJECTIVE: Determine how much daylight you can use in various areas of your building.

- Because windows are not used simply to illuminate an interior space (e.g., they provide a view, outdoor connection, ventilation, egress), the issue is not whether or not to use a window, but whether one can capitalize on it to increase occupant comfort, satisfaction, and perhaps performance.
- Determine how much daylight can be used to offset electric lighting needs.

KEY IDEAS

- **Windows must see the light of day.** A high-density urban site may make daylighting difficult if the windows will not see much sky.
- **Glazing must transmit light.** A strong desire for very dark or reflective glazing generally diminishes the capacity to daylight in all but very sunny climates.
- **Install daylight-activated lighting controls.** To save energy, lights are dimmed or turned off with controls. Automated lighting controls in a daylighted building can have other cost-saving applications (e.g., occupancy, scheduling) and benefits.
- **Design daylight for the task.** If the occupants require very bright light, darkness, or a highly controllable lighting environment, tailor the design solutions to meet their needs.
- **Assess daylight feasibility for each different portion of the building.** Spaces with similar orientation, floor height, sky views, ground reflectance, and interior design can be treated together. Within a single building, the feasibility and cost-effectiveness of daylighting may vary greatly by orientation and space type.

PROVISOS

- A low-rise building can be adequately daylighted with skylights or roof clerestories (neither are addressed in any detail in these guidelines).

TOOLS & RESOURCES

Rapid Feasibility Study Calculation to Estimate Potential Lighting Energy Savings

(Feasibility = “how much glass” x “how transparent” x “obstructions blocking light”)

Complete this analysis for each major type of space in the building.

Step 1: Calculate the planned window-to-wall ratio (WWR) for a typical office space or bay.

Net glazing area (window area minus mullions and framing, or ~80% of rough opening) divided by gross exterior wall area (e.g., multiply width of the bay by floor-to-ceiling height) equals window-to-wall ratio (WWR).

____________ / _________________ = _________

net glazing area   gross interior wall area   WWR

Or:

If unknown, estimate for your building style; for example, using 0.35 for a typical, moderately strip-glazed building. For larger windows or curtain wall, use 0.50. For smaller punched windows, use 0.25.

Step 2: Make a preliminary glazing selection and note the visible transmittance (V_T).

If you don't know the glass properties, go to the Tips for Daylighting webpage to access typical product values.

Tips for Daylighting website
windows.lbl.gov/tips-for-daylighting

Step 3: Estimate the obstruction factor (OF).

Visualize a typical task location, 10 feet (3.3 meters, m) in from a window and centered on the window. What is the view through the predicted window from desk height? Pick a location that represents an average view for the building. Sketch the window elevation and shade in anticipated objects seen from this viewpoint; this can include objects such as trees that might be near to the window or buildings that might be a little further away but still impede the view of the sky. Select the obstruction factor, as shown in Figure 1.

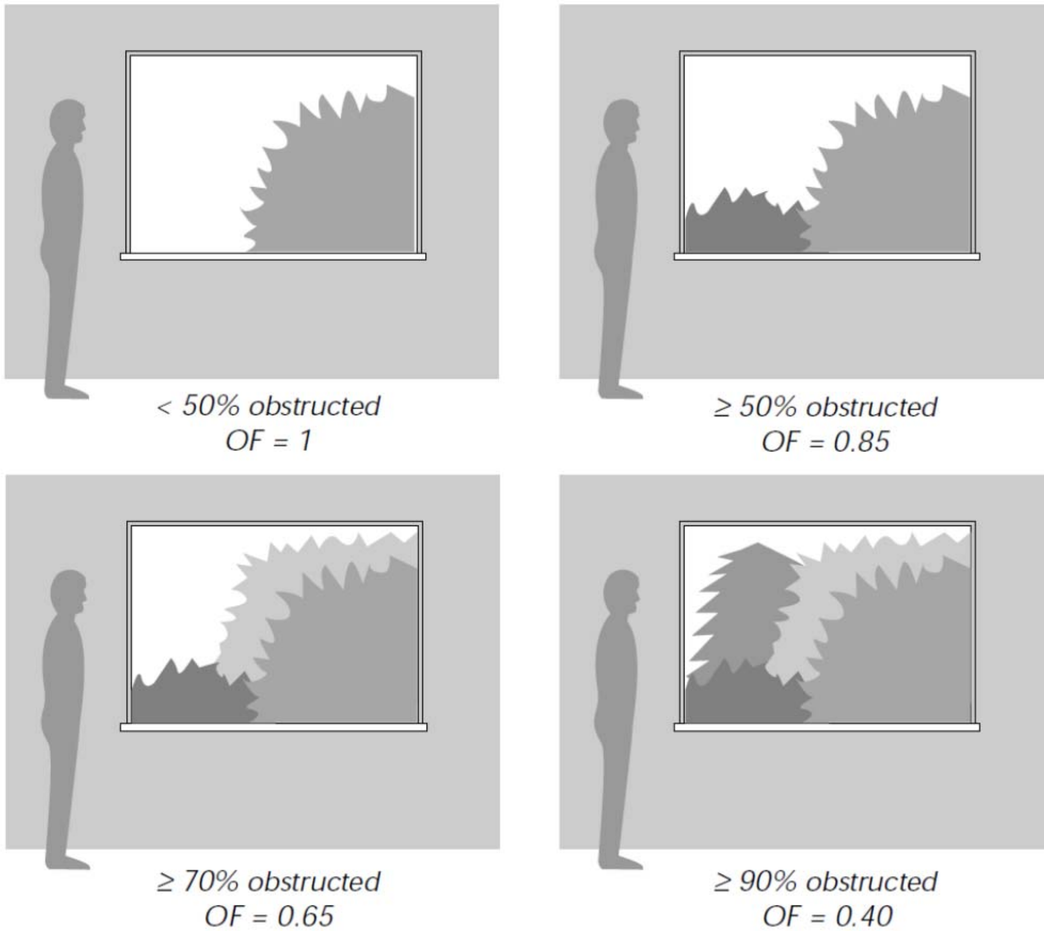


Figure 1: Estimating the obstruction factor

Step 4: Calculate the daylight feasibility factor.

Window-to-wall ratio multiplied by visible transmittance multiplied by obstruction factor equals feasibility factor.

______	x	______	x	______	=	________________
WWR		V_T		OF		Feasibility Factor

If the Feasibility Factor is ≥ 0.25, then daylighting has the potential for significant energy savings for this building zone.

If the Feasibility Factor is < 0.25, then consider removing obstructions, increasing window area, or increasing V_T. If these modifications are not possible, it is unlikely that daylighting will be a cost-effective energy-saving strategy. However, windows can still be designed to provide views and to control glare. Use these guidelines for glare-reducing ideas.

3 Envelope and Room Decisions

OBJECTIVE: Design siting, massing, façade, windows, and interior to maximize daylight effectiveness, provide occupant comfort, and minimize glare.

- These decisions determine the potential for useful daylight and energy savings.
- Architectural decisions of this nature can influence the building's lifetime energy use more than mechanical and lighting decisions.

KEY IDEAS

Building Form and Skin

- **Increase exposure to daylight.** The higher the skin-to-volume ratio, the greater percentage of floor space is available for daylighting. Long and narrow footprints are preferable to square ones, up to a limit, although a high skin-to-volume ratio may lead to a heating or cooling penalty.
- **Shape building for self-shading.** Building form can assist cooling by providing self-shading through wings and other mass articulations, balconies, deep reveals, or arcades.

Take a deep facade approach. A facade with some depth creates a buffer zone that can contain shading elements and other modifiers to filter glare and block sun, as

Figure 2 illustrates.

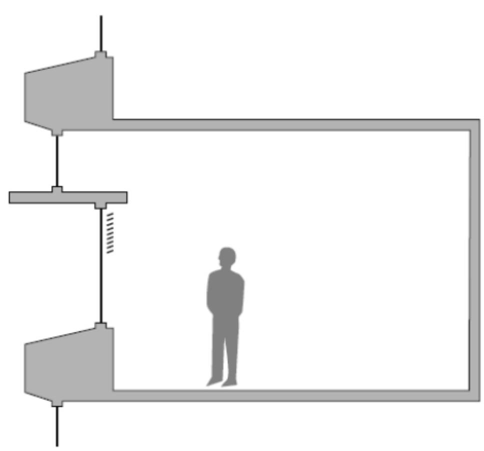


Figure 2: Section drawing illustrating a deep wall section providing some self-shading. This allows easy integration of a light shelf, creates surfaces that mitigate glare, and reduces noise

transmission. Sloped surfaces also help soften glare. A blind or shade can be added in the clerestory to manage glare from a low sun angle.

- **Capitalize on other building elements to integrate shading.** For example, air intakes, overhangs, louvers, fins, PV panels, and light shelves can be integrated both structurally and visually with the exterior structural system.
- **Incorporate envelope features that improve daylighting.** Deep reveals, splayed reveals (as shown in Figure 3), exterior fins, and similar characteristics of the envelope structure improve daylight distribution and control glare. These facade projections can also attenuate noise. Rounded edges soften light contrasts. Effective reveals are 9 to 12 inches (23 to 30 centimeters, cm) deep, at an angle of 60˚ to the window plane.

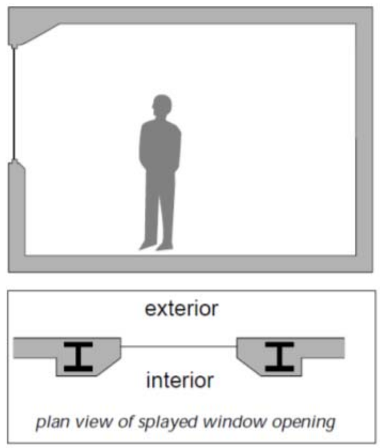


Figure 3: A splayed window opening, such as this one, helps to soften glare. These surfaces should be light-colored and provide an intermediate brightness between window and room surfaces, making an easier transition for the eye.

- **Balance daylight admittance.** Spaces with windows on two sides often have better daylighting distribution.
- **Keep private offices somewhat shallow.** Keep the depth of perimeter rooms within 1.5 to 2.0 times the window head height for adequate illumination levels and balanced distribution at the back of the room. If an office will have a mix of open plan office and private offices, consider locating the open office spaces along the facade and locating private offices away from the facade. This approach is consistent with the LEED goals of providing a large fraction of occupied spaces with daylighting and views.
- **Consider color and texture of exterior surfaces.** Light-colored surfaces will reflect more daylight than dark surfaces. Specular surfaces (e.g., glazed tile or mirrored glazing) may create glare if viewed directly. Diffuse ground-reflected daylight can increase daylight availability.

Windows

The challenge in providing daylight by effective use of windows is to allow adequate amounts of daylight as deep into the space as possible, with a distribution within the space that is visually comfortable and does not create glare. A designer can control window area, location type, glazing properties, shading systems, ceiling parameters, and interior design features to achieve these goals. The sections below provide some guidance on the importance of each of these design parameters.

- **The higher the window, the deeper the daylighting zone.** The practical depth of a daylighted zone is typically 1.5 to 2 times the window head height, as shown in Figure 4. With a reflective light shelf, this zone may be extended further. If a corridor is beyond this zone and separated with a partially glazed wall, it may be adequately lit with the spill light from the room. With standard window and ceiling heights (between 9 and 10 ft; 2.7 to 3 m), plan on adequate daylight within 20 feet (6.1 m) from the window.

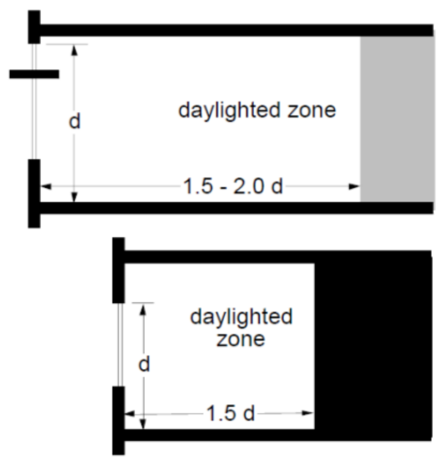


Figure 4: Typical daylight penetration rule-of-thumb

- **Strip windows provide more uniform daylight**. The easiest way to provide adequate, even daylighting is with a nearly continuous strip window (Figure 5). Punched windows are acceptable, but the breaks between windows can create contrasts of light and dark areas. This is not a problem if work areas are paired with windows or if other glare measures, such as splayed window openings, are taken.

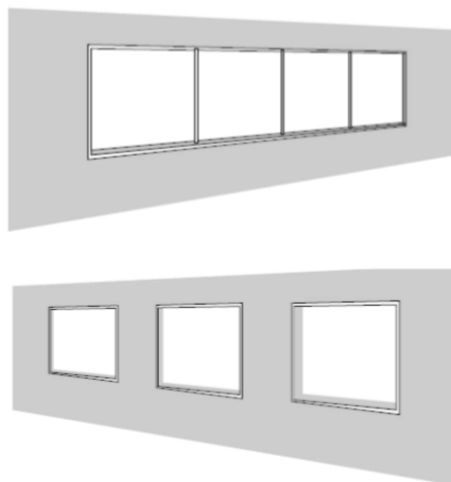


Figure 5: Strip windows are an easy way to provide uniform daylighting. Punched windows should be paired with work areas when possible.

- **Large windows require more control.** The larger the window, the more important glazing selection and shading effectiveness are to control glare and solar heat gain. Insulating Glazing Units (IGUs) with low-E coatings control winter heat loss and improve thermal comfort. See Tools & Resources, below, for additional sizing help.
- **Size the windows and select glazing at the same time**. The larger the glass area, the lower the required visible transmittance. Use the effective aperture (EA) approach to make these trade-offs (see Figure 6). Select glazing and window area to target an EA around 0.30. See Tools & Resources, below, for additional sizing help.

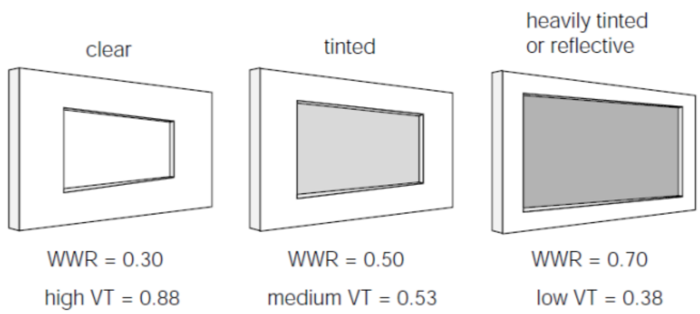


Figure 6: Effective Aperture (EA) is visible transmittance (VT) x window-to-wall ratio (WWR). These three examples all have the same EA of 0.26.

- **Keep occupants away from large areas of single-pane glass.** Avoid big windows very close to task areas since they can be a source of thermal discomfort.
- **Design separate apertures for view and daylight.** A good approach for excellent daylighting and glare control is the separation of view and light windows, as shown in Figure 7. Use high-transmission, clearer glazing in clerestory windows, and lower-transmission glazing in view windows to control glare.

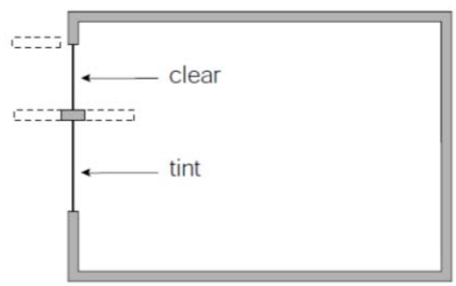


Figure 7: A section view illustrating different apertures for daylight and view: clear glazing above for maximum daylight, and some form of lower transmission glazing below for glare control. The structure between the two provides a visual break and an opportunity to attach a light shelf or shading device. Both apertures will likely require some form of solar control unless they are north facing.

- **Position windows to direct light onto the ceiling.** Taller ceilings and high windows provide the opportunity for better light distribution. Keep the ceiling smooth and light-colored. A sloped ceiling (high near the window, as shown in Figure 8) is one way to fit a high window within normal floor-to-floor heights.

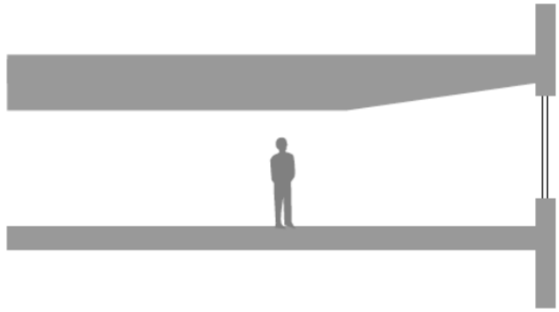


Figure 8: A sloping ceiling at the perimeter raises the window head without increasing floor-to-floor height.

- **Introduce more light-colored interior surfaces for good daylight distribution.** Deep reveals, and ceiling baffles, if they are light in color, keep daylighting more even. Interior walls and furniture systems also enhance interior light levels if they are light-colored.
- **Incorporate shading elements with windows.** Shading devices perform triple duty: they keep out the sun's heat, block uncomfortable glare from direct sun, and soften harsh daylight contrasts. See Section 5, SHADING STRATEGY, for more detail. Figure 9 shows how a well-designed exterior shading system can block sun but boost interior light levels compared to a simple overhang.

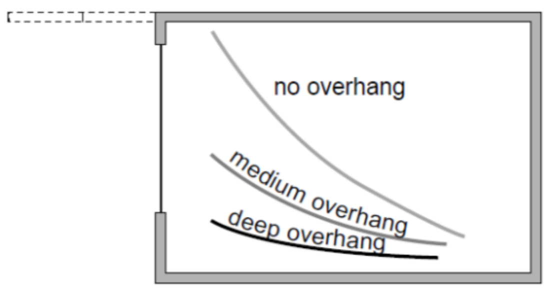


Figure 9: A room section with curves indicating the effects of shading systems on light levels according to room depth. Overhangs can block direct sun and reduce light and glare near the window, creating a softer gradient in the room; they can also reduce daylight availability.

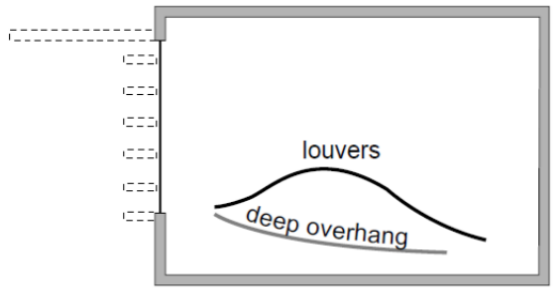


Figure 10: Illustration of the use of horizontal shapes to create a better distribution of daylight.

- **Use horizontal window shapes.** Horizontal shapes provide more even light distribution; vertical windows are more likely to create light/dark contrasts, although taller windows provide deeper penetration. Long and wide windows are generally perceived as less glaring than tall and narrow ones of the same area. Occupants generally prefer wider openings when the primary views of interest are of nearby objects or activities.
- **Place view windows wisely.** Complex views with changing activities are preferable to static views. The key is the information content of the view and its ability to capture interest/attention. Sky alone is not a preferred view. Views that include the horizon are better.
- **Locate windows near room surfaces** (beams, walls) that bounce the light inward for good distribution—these surfaces help reflect and redistribute daylight.
- **Windows on every orientation can provide useful daylight.** However, treat each window orientation differently for best results (see Figure 11).

    - North: High-quality consistent daylight with minimal heat gains, but thermal loss during heating conditions and associated comfort problems. Shading possibly needed only for early morning and late afternoon.
    - South: Good access to strong illumination (the original source), although varies through the day. Shading is “easy.”
    - East and West: Shading is difficult. Shading is critical for comfort on both sides and heat gain too, especially on the west.

- **Don’t waste glazing area where it can’t be seen,** such as below desk height. It wastes energy, causes discomfort (especially in winter), and provides little benefit.

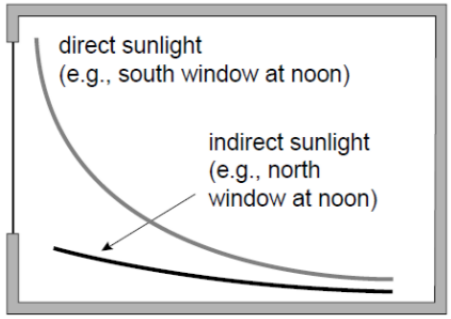


Figure 11: Illustration of light levels as a function of window orientation. Curves show light levels when window is facing the part of the sky that has the sun versus facing away from the sun (daylight only, no direct solar beam in the room).

About Clerestories (any window with its sill above eye level)

- Good for getting the light source out of a direct sightline. Good for effective ceiling illumination (which provides deeper penetration and good distribution). Good for computer visual display terminals (VDTs) and other glare-sensitive tasks.
- Loss of view; the only view may be of the glaring sky.
- An effective approach is the use of high-reflectance blinds with clerestory glazing. A 1-foot (0.3-m) high south clerestory with specular blinds can light a 150-square foot (14 square meter, m^2), 12-foot (3.7-m) deep office under sunny conditions.
- Higher windows provide better light distribution, as shown in Figure 12.

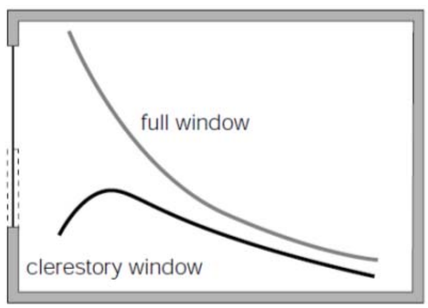


Figure 12: The curves indicate light levels for a full window and a clerestory, with the clerestory giving a softer gradient.

About Light Shelves (horizontal elements above eye level)

- Light shelves can improve illuminance distribution and reduce glare, as shown in Figures 13 and 14.

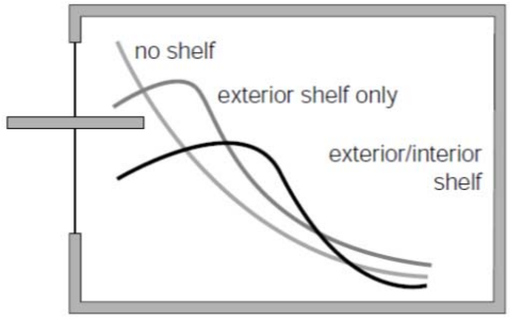


Figure 13: Illustration of how a light shelf improves daylight distribution and softens the light gradient within the room.

- Shelves double as shading devices, if designed to block direct sun.
- Best used on the building's south side, in a predominantly clear sky climate.
- Consider using clearer glass above for high daylight admission and tinted glass below for glare control.
- Exterior shelves are better than interior, but use both for best year-round distribution.
- The top of the shelf should be matte white or diffusely specular, and not visible from any point in the room.
- The ceiling should be smooth and light-colored.
- Consider using more advanced shapes and materials to redirect sun, block direct sun, and control glare.

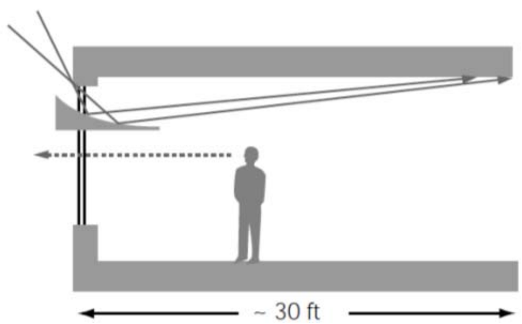


Figure 14: Direction of light at high level using a light shelf

Space Planning

- **Locate activities according to light requirements.** Put rooms with little need for daylight (e.g., infrequent use, service, washrooms, VDTs) in non-perimeter areas. Locate tasks with higher lighting needs nearer the windows. Group tasks by similar lighting requirements for efficient use of electric lighting, and by similar schedules and comfort needs. Accommodate user preference and satisfaction when space planning as far as possible.
- **Locate activities according to comfort requirements.** Place flexible tasks or low-occupancy spaces where there may be unavoidable glare, not enough daylight, or direct sun penetration. These spaces may at times be

thermally or visually uncomfortable. If tasks are fixed and inflexible, comfortable glare-free conditions are required.

- **Maintain daylight access.** Furniture layout should not block light for spaces farther from the window. Do not position full-height partitions, bookshelves, or files parallel to window wall if possible. Consider using low-level (< 4 ft; 1.2 m) furniture partitions to allow greater light penetration into the space.
- **Use light-transmitting materials for partitions where possible.** Use clear or translucent materials in the upper portion of high partitions. If this approach is taken in corridor walls, corridors may be adequately lighted just by this spill light.
- **Shield occupants from views of highly reflective surfaces outside,** such as mirrored-glass buildings, water, snow, and large white surfaces.
- **Shield sensitive occupants from bright windows.** In highly glare-sensitive areas (e.g., with wide use of computer screens), shield occupants from view of sky and provide glare-controlling window coverings.
- **Keep reflected view of bright windows out of computer screens.** Be very careful where screens are placed. Either keep them away from windows or block the screen and occupant's view of the window. Use partitions or position the screen with the window to the side and slightly turned away from window. Figure 15 illustrates how furniture placement affects optimal lighting for workers.

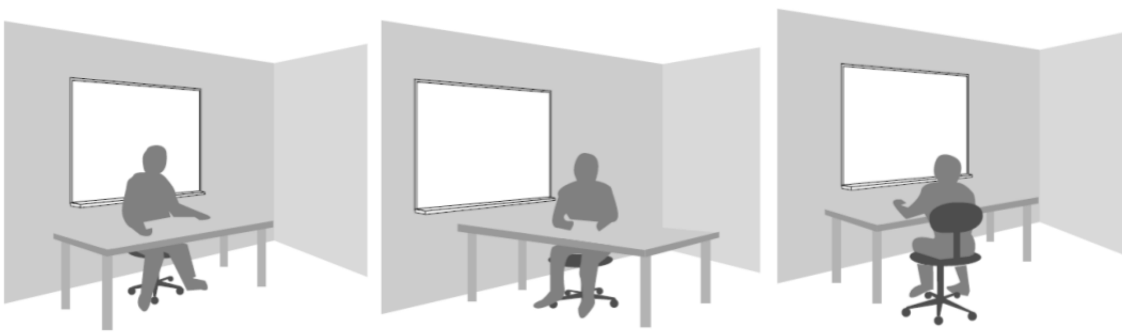


Figure 15: Illustrations of effects of, to the left, having a window behind a worker; you may shade your task, making it too dark to see easily. Also, your computer screen may be too difficult to see if light reflects from the window. In the center is the preferred seating arrangement. The task is well illuminated and the source is not in direct line of sight, as is the case on the right; this is very tiring for the eyes to have both in the same field of view.

- **Use west zones for service spaces.** Minimize use of exposed west zones as occupied work areas. Large areas of west glazing make for difficult daylighting, high cooling loads, and uncomfortable occupants.
- **Integrate personal shading / glare control systems into personal workspaces.**

Interior Design

- Don't use large areas of dark color. Generally avoid all dark colors except as accents, and keep them away from windows. Dark surfaces impede daylight penetration and cause glare when seen beside bright surfaces (such as windows or light-colored walls). For good distribution throughout the room, it is

Integrated Approach
Feasibility
Envelope/ Room
Glazing
Shading
Mechanical Coordination
Lighting
Sensors & Controls
Calibration/ Commissioning
Maintenance
Cost-Benefit Analysis
Preparation
Pre-Design
Conceptual Design & Programming
Schematic Design/ Design Development
Construction Documents
Pre-Occupancy
Post-Occupancy

especially important that the wall facing the window be light-colored. Mullions or other solid objects next to windows should be light-colored to avoid silhouette contrasts. Keep sills and other reveal surfaces light to improve daylight distribution and soften contrast. Dark artwork can reduce daylight effectiveness.

- Aim for recommended surface reflectances. Desirable reflectances (Illuminating Engineering Society recommendations) are: ceilings >80%; walls 50%–70% (higher if wall contains window); floors 20%–40%; and furniture 25%–45%.
- Choose matte over specular surface finishes. Matte finishes are recommended for good distribution of daylight and no reflected glare (hot spots).
- Use light-transmitting materials. Translucent or transparent partitions are best when possible—daylight can pass through to other spaces.
- Supply window coverings that allow individual control to accommodate different glare tolerances. Shading controls should be easily accessible to encourage their regular use. Interior window shading should be light-colored for the best cooling load reduction.
- Choose colors under the right light. Choose interior colors and finishes under daylight and under the proposed electric lamps to avoid surprises in color rendering.

INTEGRATION ISSUES

Architecture

Facade design must be driven by interior results as much as exterior appearance. Form, siting, and skin decisions strongly influence daylighting performance, cooling loads, and occupant comfort.

Interior

In daylighted spaces, it is critical that light colors be dominant, especially for walls and ceilings.

Window coverings should allow for some light penetration while providing sun and glare control and prevent unwanted solar gain. A priority should be to achieve an appropriate balance of solar gain and capacity of mechanical cooling systems, to ensure integrated systems efficiency.

Interior design must consider the role of interior finishes and objects as light modifiers within a daylighted space—these factors influence daylighting performance.

HVAC

High skin-to-volume ratio is good for daylighting but may adversely affect thermal balance.

Use building form and exterior shading to best reduce peak cooling load—this can save on HVAC first costs. Work with an engineer to establish the magnitude and relative importance of envelope decisions.

Lighting

Window design and exterior and interior modifiers determine the nature of daylight in the space. Lighting design and control strategy are critical.

Interior colors, furniture placement, and partition heights are critical to lighting design—make these decisions with lighting designer input.

Cost Effectiveness

High skin-to-volume ratio is good for daylighting, but may not yield a high enough ratio of rentable space and may be more costly to construct.

A deep or layered building skin is more expensive than thin cladding but offers long-term benefits if used to best advantage for sun and glare control. Analysis of building performance with energy simulation software and careful cost estimates are required for determining cost effectiveness.

Occupant Comfort

The best lighting and mechanical systems can't make up for architectural errors with respect to perimeter zone comfort. The priorities here should be to specify appropriate perimeter insulation and carefully consider where to locate and orient occupants. Window and room design must provide for thermal and visual comfort of the occupants.

Occupant satisfaction will depend on the fit between the environment and task needs. Know the intended use of the space before designing it.

Occupant Control

Occupants should be given the ability to make personalized adjustments to their workspaces to balance daily and seasonal changes in daylight availability, glare, as well as desire for views and privacy. Care should be taken to understand the range of conditions acceptable and preferred by occupants before selecting operable systems.

PROVISOS

- Dark-tinted glazings diminish the capacity to daylight.
- Sometimes daylighting with windows is simply not compatible with glare-sensitive tasks like computer work.
- Don't forget about lighting controls. Lowering the lighting power density may provide energy savings, but savings will be increased further through use of lighting controls.

TOOLS & RESOURCES

Leadership in Energy and Environmental Design (LEED)

The LEED Rating Systems are balloted every four years to establish the consensus standard for the new version. The comments below are specifically related to the LEED 2009 version of the rating systems, which are currently being utilized by industry.

There are different approaches to assess the performance of a daylight design and/or to evaluate various parameters. Daylight simulation has become more prevalent in recent years, and it is starting to become a requirement or compliance for some building codes, as well as being part of the LEED Rating Systems. In addition to simulation, other calculations can be easily done, such as "Determining Required Net Glazing Area," which can effectively inform a daylight design.

The credits for daylighting in the different versions of the LEED Rating Systems and that relate to decisions on envelope and room design include the following:

- Indoor Environmental Quality Credit 8.1 – Daylight and Views – Daylight: Demonstrate with simulation* that 75% of all regularly occupied spaces receive a minimum of 25 footcandles (fc) and a maximum of 500 fc on September 21 at 9 a.m. and 3 p.m.
- Indoor Environmental Quality Credit 8.1 – Daylight and Views – Views: A daylight design approach increases the potential to meet the credit

Integrated Approach
Feasibility
Envelope/ Room
Glazing
Shading
Mechanical Coordination
Lighting
Sensors & Controls
Calibration/ Commissioning
Maintenance
Cost-Benefit Analysis

Preparation
Pre-Design
Conceptual Design & Programming
Schematic Design/ Design Development
Construction Documents
Pre-Occupancy
Post-Occupancy

requirements for a visual connection to the outdoors. Simulation is not required.

*This credit also has a prescriptive path to meeting the requirements where for windows above 30" above the floor, meet the following range criteria 0.150 < VLT x WFR < 0.180, where VLT = Visible Light Transmittance and WFR = Window-to-Floor Ratio.

The proposed 2013 simulation requirements for the Daylight and Views credit specific to daylight will be focused on analyzing Spatial Daylight Autonomy (the percentage of the occupied time for a year when a space can be illuminated by daylight alone). The requirement will be to demonstrate that 55%, 75%, or 90% of the regularly occupied spaces achieve spatial daylight autonomy.

Determining Required Net Glazing Area

- **Use this information as a starting point for estimating required window size.** Alternatively, use the equation to roughly find the average daylight factor (indoor horizontal illuminance divided by outdoor horizontal illuminance) for a given window size. The equation assumes that room depth is no more than 2.5 times window head height. It also assumes an overcast sky. For regions with predominantly clear skies, window area can be smaller than is calculated here.
- **The equation below yields the required net glazing area.** To translate this to total window area, which includes framing and mullions, multiply by 1.25.

$$\text{Required Net Glazing Area} = \frac{2 \times \text{Average Daylight Factor} \times \text{Total Area of Interior Surfaces} \times \left(1 - \text{Area-Weighted Average Reflectance of all Interior Surfaces}\right)}{\text{Visible Transmittance} \times \text{Vertical Angle of Sky Visible from Center of Window}}$$

- **Average Daylight Factor.** Use:

  1 if low-light spaces are desired.

  2 if average spaces are desired.

  5 if bright spaces are desired.

Note: The Daylight Factor concept has limitations as a metric for developing and assessing daylighting solutions, but it also has value, so we use it here and refer to it elsewhere in this guide.

- **Total Area of Interior Surfaces.** Add up total surface area of walls, ceiling, and floor.

- **Area-Weighted Average Reflectance.** Ratio between 0 and 1. Add up total surface area of walls, ceiling, floor, windows, partitions, and furniture, and calculate the weighted average reflectance (see equation), or use 0.5 as a default.

$$\text{Area-Weighted Average Reflectance} = \frac{\text{Wall Area X Wall Reflectance}}{\text{Total Surface Area}} + \frac{\text{Ceiling Area X Ceiling Reflectance}}{\text{Total Surface Area}} + \text{...etc.}$$

- **Visible Transmittance.** Use:

  0.70 for small windows.

  0.50 for medium windows.

  0.30 for large windows.

- **Vertical Angle of Sky.** Estimate the angle, as shown in Figure 16, from the center of the window. Value between 0 and 90. If no obstruction, the vertical angle is 90˚.

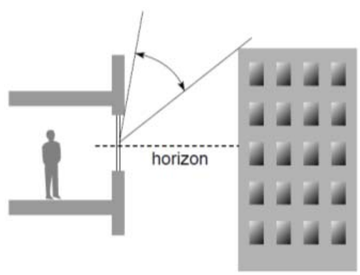


Figure 16: Vertical angle of sky. Source: “A Sequence for Daylighting Design,” J. Lynes, Lighting Research and Technology, 1979.

Five methods to quantify daylighting levels and energy impacts

1. **Computer Daylighting Models.** Daylighting simulation software can deliver increasingly fast and accurate results in the hands of a skilled user. Most lighting simulation software can also perform daylight calculations. Limitations on the range of conditions that can be assessed and their accuracy vary by software. Typical limitations arise from either the inability to generate a suitably complex model or the inability to accurately define reflectance and transmission properties of a material. Choosing the right software depends on fully understanding your daylight simulation needs.

   Relying on calculations or past experience alone may not yield satisfactory results in the final product because of the complex, dynamic qualities of daylight. Scale models (item 2 in this list) are useful tools, but there is a limit to what information they can provide to the designer. Software typically used for this analysis includes the following:

   COMFEN is a single-zone facade energy analysis tool that can be used to evaluate a range of facade configurations in order to understand the impact of different design variables on facade performance. A more detailed description can be found in section 12, TOOLS AND RESOURCES SUMMARY, or

Integrated Approach
Feasibility
Envelope/ Room
Glazing
Shading
Mechanical Coordination
Lighting
Sensors & Controls
Calibration/ Commissioning
Maintenance
Cost-Benefit Analysis
Preparation
Pre-Design
Conceptual Design & Programming
Schematic Design/ Design Development
Construction Documents
Pre-Occupancy
Post-Occupancy

downloaded along with the program from the COMFEN website: http://windows.lbl.gov/software/comfen/comfen.html.

RADIANCE is a ray tracing program that calculates light levels at specific points in a simulated daylit space using space geometry, glazing properties, luminaire specifications, and other site-specific information. It can be downloaded from http://radsite.lbl.gov/radiance/. It is a powerful tool that can produce physically based rendering of designs that are close to what the user will experience in the space. Radiance is an engine that utilizes a command line input so it is only suitable for dedicated users, but its capabilities can be assessed via DAYSIM, COMFEN, and other tools.

DAYSIM is a RADIANCE-based program that calculates annual availability of daylight in buildings and estimates how building occupants will react to it in terms of how they control the space lighting and blinds. It will also calculate energy savings from automated lighting controls such as occupancy sensors and daylight dimming and calculate annual glare and useful daylight illuminance. It is available from www.daysim.com.

AGI32 is a software tool for making photometric predictions, assisting the designer in creating optimum lighting designs. It includes an architectural visualization capability, where a virtual mock-up provides the designer with a visual feedback of their modeling and analysis. It is available from www.agi32.com.

The Windows for High-Performance Commercial Buildings design tool at www.commercialwindows.org is based on COMFEN and is useful at the pre-design stage for experimentation and idea testing. A book and user guide accompanies the website; they outline the principles and background and provide a knowledge base for the reader. The website contains greater technical detail on daylighting specifics.

During the design process, the architect and lighting designer should work together to assess the nature of the anticipated daylighted space and confirm their intuition with observations of window glare, daylight quality, and distribution.

When using simulation models, care must be taken to determine and define the parameters to be used in the model: for thermal performance, construction material and wall thickness are key factors; for daylighting, size of windows and depth of reveals are important. See section 12, TOOLS AND RESOURCES SUMMARY, at the back of this guide for further information on daylight simulation tools.

2. **Scale Model.** Simulation is slowly replacing the physical model as the primary architectural design tool, but physical models are still used for determining daylight levels in a space at all design stages. A rough assessment of how well the design mitigates glare and controls direct sun can also be made. Models such as those shown in Figure 17 are helpful for fine-tuning decisions, for convincing clients, and for flagging potential construction problems.

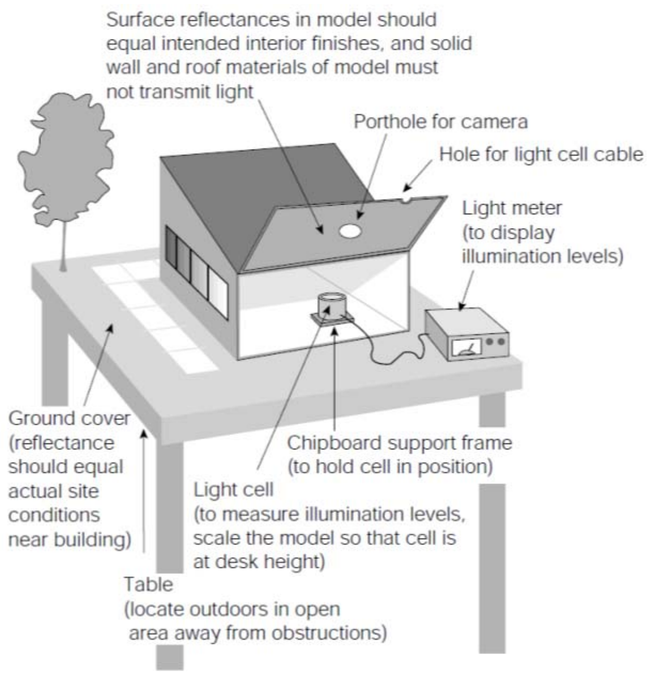


Figure 17: Scale models studied outdoors show the quality of lighting, flag glare problems, and provide measured daylight readings. Source: *Concepts in Architectural Lighting,* by M. D. Egan, McGraw-Hill, 2001.

The most important thing when constructing a model is to ensure that materials and joints are completely opaque. Cover joints with black tape; paint or cover exterior surfaces if not opaque. Also, ensure that all 3-D features are included on the model. Add furniture and other details for realism and scale. If possible, measure illumination and calculate the daylight factor (horizontal indoor illuminance divided by horizontal outdoor illuminance) for several different task locations. These tools may be available from your local utility company. If you have not included glazing in the model, multiply your readings by the visible transmittance of the intended glazing.

3. **Search for a nearby heliodon.** This apparatus is used to mock up solar conditions either indoors with an artificial sun or outdoors using the real sun and sky. It will allow the collection of data for a scale model under conditions representing a full year (as opposed to scale models studied outdoors for which data would be collected for a day at a time). Facilities with heliodons should be able to assist in understanding their own specific best uses and limitations.
4. **Ask at local utility or architecture school for possible assistance.** Otherwise, see the books listed below for more tips.
5. **Whole-Building Energy Software.** Refine window sizing, early glazing decisions, building form, and siting with preliminary mechanical load calculations. See the list of energy analysis software in the Mechanical Coordination section of these guidelines. Calculation of daylight availability in whole-building energy software is only an approximation of daylight illuminance. For best accuracy it may be necessary to couple daylight simulation software with whole-building energy simulation software.

Integrated Approach
Feasibility
Envelope/ Room
Glazing
Shading
Mechanical Coordination
Lighting
Sensors & Controls
Calibration/ Commissioning
Maintenance
Cost-Benefit Analysis

Preparation
Pre-Design
Conceptual Design & Programming
Schematic Design/ Design Development
Construction Documents
Pre-Occupancy
Post-Occupancy

- **IESNA** Visit the Illuminating Engineering Society website at www.iesna.org for daylighting publications.
- **ASHRAE** The American Society of Heating, Refrigerating, and Air Conditioning Engineers offers a wide range of reference materials. Visit www.ashrae.org.
- **Utility Company** Inquire at local utility about possible incentives and design assistance.
- **Papers and Books**

A Guide for Building Daylight Scale Models, by Magali Bodart, Arnaud Deneyer, André De Herde, and Paul Wouters (Unit of Architecture, University of Louvain, 2006).

Concepts in Architectural Lighting, by M. David Egan (McGraw-Hill, 2001) has a helpful section on window and interior design.

Daylight Performance of Buildings, by Marc Fontoynont (Routledge, 1999) is a compendium of 60 building case studies that were observed and measured, consisting of a range of building types from different eras. It is available from online bookstores.

Daylight Design of Buildings: A Handbook for Architects and Engineers, by Nick Baker and Koen Steemers (Routledge 2002) builds on the research carried out by Marc Fontoynont (above), using examples from the case study buildings.

Daylighting Performance and Design, by Gregg D. Ander (Van Nostrand Reinhold, 2003).

Daylight in Buildings: A Source Book on Daylighting Systems and Components (IEA, 2000) is a good general guide. It can be downloaded at www.iea-shc.org/task21/.

Sunlighting as Formgiver for Architecture, by William M. C. Lam (Van Nostrand Reinhold, 1986) has been discontinued in print but is available from the author's website at www.wmclam.com/images/pdfs/safa/safa_complete.pdf.

Also see section 12, TOOLS AND RESOURCES SUMMARY, for additional sources.

✓ CHECKLIST

1. Know the true north orientation of the site and include it on all plan drawings. Lot property lines are typically given relative to true north.
2. For new construction, if the site allows, the first attempt at building placement should be with the long axis running east to west.
3. Minimize apertures on the east and west; especially on the west. Low sun angles for these orientations make shading extremely difficult without blocking the entire window.
4. Study the potential for (a) an articulated form that yields a high percentage of perimeter space, (b) an envelope structure and cladding that can integrate shading, and (c) opportunities for the building to shade itself.
5. Develop initial thoughts about shading strategy and glazing type.

6. Determine whether your project budget will allow consideration of a light shelf or exterior projecting shading elements.
7. Begin window design with both interior considerations and exterior appearance concerns simultaneously. Place windows primarily to provide view and light. Size and place windows for best glare-free daylighting with minimal energy penalty. A mechanical engineer should perform preliminary calculations at this point to help in window design and to determine the importance of glazing and shading decisions yet to come. If a light shelf or exterior shading are under consideration, include these elements in the calculations.
8. Build a rough digital model to explore options or use referenced websites to examine alternative building design options.
9. Build a rough physical model to study daylighting effects with the proposed skin, ceiling height, and room depth.
10. Interior design should begin to select light colors for finishes and window coverings. Remember that rendering of interior colors will be affected by glass color.
11. Identify which occupant tasks best benefit from daylight before laying out task locations on floors. Put tasks requiring low, uniform light levels or with periodic occupancy (e.g., telephone closet) in the building core.
12. Discuss daylighting concepts with a lighting designer or consultant to ensure that electric lighting layout and controls address daylight needs at the start of the lighting design process.
13. Check coordination issues with lighting, structural, and mechanical design. Keep the ceiling as smooth and high as possible.

Envelope and Room Decisions

Good Practice

1. Minimize window area on the east and west; especially on the west.
2. Keep window area to a 30%–40% window-to-wall ratio.
3. If tenants are unknown, use a strip window.
4. If tenants are known and punched windows are used, plan task areas to correspond with windows.
5. Keep interior finishes light-colored.
6. Try to increase surface area of the window opening, and splay these surfaces if possible.

Better Practice

In addition to the above:

1. If preliminary glazing decision has been made, use engineer's early calculations to refine window area.
2. Explore envelope alternatives that could incorporate shading elements or light shelves.
3. Investigate appropriate computer design tools, and websites such as those mentioned above.
4. Build a simple model and view it outdoors to assess lighting quality and glare.
5. Visit similar buildings and observe occupant behavior and light levels.

Best Practice

In addition to the above:

1. Build a more accurate model, and view and photograph outdoors. Whole-building models can be developed more quickly by photographing the building and importing the images into tools that will do a lot of the work for you. If photometric equipment is available, measure the daylight in the model. Refine the design as necessary.
2. Commission an optimization study at single zone level (COMFEN is perfect for this task) or at whole-building level. An engineer looks for opportunities for equipment downsizing or elimination of unnecessary systems.
3. Hire a daylighting consultant.

12 Tools and Resources Summary

Section	**Target User Group(s)**
Integrated Design	
ENERGY STAR A joint program of U.S. Environmental Protection Agency and U.S. Department of Energy that aims to promote energy-efficient products and practices. The program offers incentives for decreasing energy use through adapting energy-efficient windows and skylights. The website is a good resource for current U.S. standards and to find examples of buildings that meet energy efficient goals. www.energystar.gov/	**Building Owner/Operator, Engineer**
DesignBuilder A whole-building model that can be used also as a learning/teaching tool due to its simple operation. The software can produce daylight contour plots and daylight factor calculations based on the RADIANCE raytracing software. A feature of the program is generating reports for eligibility to various daylighting credits. The software can be integrated with EnergyPlus for more sophisticated lighting controls and energy savings calculations. For more information, visit www.designbuilder.co.uk/.	**Energy Modeler, Engineer, Lighting Designer**
Energy Plus and Simergy A whole-building energy simulation program used by researchers and professionals to model energy and water use in buildings. The tool can model lighting control, glazing, shading, and dynamic window management and daylighting effects. Learning to manipulate the program takes time, and an expert might be consulted and hired to perform the simulations. The program has the ability to optimize building features in order to reduce water and energy consumption. A new easier-to-use graphical user interface to EnergyPlus, Simergy, was released late in 2012. For more information, visit http://apps1.eere.energy.gov/buildings/energyplus/.	**Energy Modeler, Engineer**
Federal Green Construction Guide for Specifiers www.wbdg.org/ccb/	**Architect**
IES Advanced Energy Design Guides (various building types). For more information, visit www.ies.org/store/AEDG.cfm/.	**Architect, Building Owner/Operator, Engineer**
PECI Advanced Energy Retrofit Guides (various building types). For more information, visit www.peci.org/advanced-energy-retrofit-guides/.	**Architect, Building Owner/Operator, Engineer**
United States Green Building Council for details of current LEED requirements related to daylighting and seminars by your local chapter on daylighting design. Visit new.usgbc.org/.	**Architect, Building Owner/Operator, Engineer**

Daylight Feasibility	
Advanced Lighting Guidelines now online, the New Building Institute resource for guidelines on lighting for commercial buildings, visit www.algonline.org/	**Architect, Lighting Designer**
COMFEN, short for *commercial fenestration*, is a single-zone facade analysis tool that can be used to evaluate a range of facade configurations in order to understand the impact of different design variables on facade performance. After defining a building type, location, and zone properties (dimensions and loads from equipment and people and fenestration layout), several additional scenarios can be quickly created and compared side-by-side. Orientation, window-to-wall ratio (WWR), glazing type, and/or shading can easily be varied in order to assess their impact on energy use, peak loads, daylighting, and thermal and visual comfort. Some Radiance analysis can be completed from within COMFEN to assess glare. Visit http://windows.lbl.gov/software/comfen/comfen.html.	**Architect, Building Owner, Engineer**
Daylighting Pattern Guide This tool was developed by the New Buildings Institute to guide commercial building designers and professionals in planning daylit spaces. The guide consists of visual aids showing the effects of design variables to daylight distribution. Results are developed from case studies and simulation of different daylit spaces throughout the country. The key design choices compared in the guide include orientation, glazing layout, area, shading strategies, and more. For more information, visit http://patternguide.advancedbuildings.net/.	**Architect, Lighting Designer**
DAYSIM Daylighting analysis tool based on RADIANCE that can calculate the annual availability of daylight in buildings. The program considers occupant behavior and how they control the space lighting and blinds. The tool can be used to calculate savings from automated lighting controls such as occupancy sensors and daylight dimming. The tool can also calculate annual glare and useful daylight illuminance. For more information, visit www.daysim.com/.	**Architect, Lighting Designer**
ECOTECT A 3-D design tool that incorporates lighting, solar radiation, and cost analysis features developed by Autodesk. The software can interface with Radiance, EnergyPlus and other analysis tools. The software is used for whole-building analysis to model total energy and water use; in terms of daylighting the software can simulate illuminance levels, daylight factors, and incident solar radiation on building surfaces. For more information, visit http://usa.autodesk.com/ecotect-analysis/.	**Architect, Lighting Designer**
Integrated Environmental Solutions Virtual Environment An integrated building simulation program that supports whole-building modeling and also detailed focus on individual building systems. For more information, visit www.iesve.com/.	**Architect, Lighting Designer, Engineer**

IEA Task21 This technical guide and accompanying website are a excellent general resource for information and data on daylighting design and provides detailed technical guidance on controls, performance evaluation, and design tools. For more information, visit http://archive.iea-shc.org/publications/downloads/8-8-1%20Application%20Guide.pdf. **RADIANCE** A suite of programs to analyze and visualize light levels used for lighting design. It translates scene geometry, luminaire data, and material properties into radiance values. This tool can be used to simulate concept designs before construction. For more information, visit http://radsite.lbl.gov/radiance/framew.html. **SOLAR TOOL** This parametric software supports sizing and placement of exterior shading systems such as overhangs, blinds, and louvers, and is therefore a useful precursor to some of the more detailed modeling software options. For more information, visit http://apps1.eere.energy.gov/buildings/tools_directory/software.cfm/ID=376/. **VECTORWORKS** This software allows visualization of effects of direct solar radiation for any location or time of year. It also supports the understanding of daylight distribution and light levels (illuminance and luminance). For more information, visit www.vectorworks.net/.	**Architect, Lighting Designer** **Architect, Lighting Designer** **Architect, Lighting Designer** **Architect, Lighting Designer**
Envelope and Room	
Window Systems for High Performance Buildings - Facade Design Tool This tool allows the user to compare annual energy, peak demand, daylight illuminance, and other performance metrics for different design choices. Design parameters included in the tool are facade orientation, window area, daylight controls, interior shades, and window type. For more information, visit www.commercialwindows.org/fdt.php.	**Architect, Lighting Designer, Energy Modeler, Engineer**
Shading	
ParaSol A design tool to determine the effects of shading and glazing to solar radiation and to the building's energy load. The results show the total and direct solar energy per month, energy demand, and maximum heating and cooling load, which can be saved into a spreadsheet. For more information, visit www.parasol.se. **Polar Sun Chart Path Program** This website will plot the sun paths that apply to your building project. http://solardat.uoregon.edu/PolarSunChartProgram.php.	**Architect, Energy Modeler, Engineer** **Architect, Lighting Designer**

Sustainable by Design A web-based interface that shows a visual representation of external shading designs and solar design parameters. The interface is simple and can be used for quick references and to visualize the effects of common design decisions such as overhang width and height. The tool does not contain energy or cost metrics. For more information, visit www.susdesign.com/.	**Architect, Lighting Designer**
SketchUp A software tool that is a simple, accessible route to creating a project design, and allows the user to incorporate all necessary architectural details relating to provision of good quality daylight through the use of shading design. For more information, visit www.sketchup.com/.	**Architect, Lighting Designer**
SunTools (for SketchUp) A software plug-in that provides further support to the SketchUp software suite by allowing the user to understand the impacts of building at different latitudes, using sun path, sun position, and sun penetration algorithms. Available as a free download from several websites: search on "Sun Tools" to find the latest version.	**Architect, Lighting Designer**
Glazing	
Commercial Windows An online facade design tool, which allows users to pick from numerous facade options, varying window area, glass types, shading systems etc. Based on COMFEN, results are reported in terms of energy savings, peak demand, cost savings and reductions in emissions. For more information, visit www.commercialwindows.org/.	**Architect, Lighting Designer, Energy Modeler, Engineer**
FENSIZE A user-friendly tool that quickly calculated the thermal and solar properties of windows, skylights, and other fenestration products. The tool can be used as a quick reference to fenestration properties and to generate standard project and product reports. The tool can also target window properties that would meet building codes and Energy Star criteria. Whole-building properties are not part of the analysis. For more information, visit www.fenestration.com/index.php.	**Architect, Lighting Designer, Energy Modeler, Engineer**
Frame Simulator The program is used to analyzed the heat flow through the window system, glazed area and frame. The program can calculate surface temperatures which is related to condensation problems. For more information, visit www.dartwin.it/en/sw/frame-simulator/.	**Energy Modeler, Engineer**
Optics This software supports detailed analysis of glazing using the optical and radiative properties of specified glazing units, and other add-ons such as solar coatings or tinted treatments. For more information, visit http://windows.lbl.gov/software/optics/optics.html.	**Architect, Lighting Designer**

THERM A two-dimensional building model for heat-transfer for building components such as windows. The program is used to evaluate the energy efficiency of building materials and their temperature patterns. Other software use THERM as a basis for their energy models. For more information, visit http://windows.lbl.gov/software/therm/therm.html. **Window** This program calculates the thermal performance indices of windows, such as U-value, solar heat gain coefficient and visible transmittance, and can be used in the project design process of for the development of new products. For more information, visit http://windows.lbl.gov/software/window/window.html.	**Energy Modeler, Engineer** **Architect, Energy Modeler, Engineer**
Lighting Coordination	
DIALux A software program used to simulate outdoor and indoor building lighting systems. The software can import and export files to CAD programs. The software has a wide database of international regulations and standards for different countries. This program is free and easy to learn and can be used for architectural and technical lighting design. For more information, visit www.dial.de/DIAL/en/dialux-international-download.html. **NECA/IES:** Installing Indoor Commercial Lighting Systems: www.necanet.org/store/products/index.cfm/NECA%20500R-06	**Architect, Lighting Designer** **Architect, Lighting Designer**
Sensors and Controls	
IES TM-23-11 Lighting Control Protocols: this is a reference document for lighting design teams that are also specifying integrated controls on their projects. www.ies.org/PDF/Store/TM-23-11_FINAL.pdf **LCA** The Lighting Controls Association is a resource for switching and dimming controls. Leading manufacturers of control systems are members of this association. The website has up-to-date publication and information about current lighting control technology. http://lightingcontrolsassociation.org/ **Sensor Placement and Optimization Tool (SPOT)** An online tool to assist with the placement of daylight harvesting sensors according to the type of daylighting systems will be operated, selection of appropriate algorithms and control system setting, with reporting in terms of light levels and energy savings. For more information, visit www.archenergy.com/SPOT/download.html.	**Engineer, Lighting Designer** **Engineer, Lighting Designer** **Architect, Engineer, Lighting Designer**
Calibration and Commissioning	
International Energy Agency - Daylighting Buildings in the 21st Century:	**Lighting Designer**

http://archive.iea-shc.org/publications/downloads/8-8-1%20Application%20Guide.pdf. **National Electrical Contractors Association**: Guide to Commissioning Lighting Controls: www.necanet.org/files/ACF363E.pdf **International Performance Measurement and Verification Protocol**: www.evo-world.org/ **See SPOT in the Sensors and Controls section above.**	 **Engineer, Commissioning Agent** **Engineer, Commissioning Agent**

13 Glossary

Altitude The vertical angular distance of a point in the sky (usually the sun) above the horizon. Altitude is measured positively from the horizon (0°) to the zenith (the point in the sky straight overhead, 90°).

Ambient Lighting General illumination, typically used to define lighting requirements for non-task specific areas, e.g., circulation areas.

Azimuth The horizontal angular distance between the vertical plane containing a point in the sky (usually the sun) and true south. In other words, the angle of sun from true south as seen in plan view. In some cases, this angle is defined relative to true north.

Baffle A single opaque or translucent element used to shield a source from direct view at certain angles.

Ballast Electrical device which supplies proper voltage, current, and wave form conditions to start and operate discharge lamps (fluorescent, mercury, high-intensity discharge).

Brightness The subjective perception of luminance.

Brightness Glare Glare resulting from high luminances or insufficiently shielded light sources in the field of view. Also called direct glare.

Candela (cd) A common unit of light output from a source, a measure of luminous intensity.

Candlepower The intensity of light produced by a source, measured in candelas.

Candlepower Distribution Curve A diagram plotted on polar coordinates which represents the variations in light output of a source throughout the directions into which the source emits light. Commonly used in lighting product brochures.

Color Rendition The effect of a light source on the color appearance of objects.

Commissioning A set of activities conducted during or after the construction phase aimed at verifying that the building, or pieces of its systems, function as designed. This is a comprehensive process of reviewing design documentation, verifying installation, testing equipment and system performance, training building operators, and analyzing the operation of building systems.

Contrast Glare Glare resulting from a large brightness difference in the field of view.

Cost/Benefit Analysis Any technique intended to relate the economic benefits of a solution to the costs incurred in providing the solution.

Cut-Off Angle The critical viewing angle beyond which a source can no longer be seen because of an obstruction, such as a baffle or overhang.

Daylight Factor The ratio of daylight illuminance on a horizontal point indoors to the horizontal illuminance outdoors, expressed as a percentage. Direct sunlight is excluded.

Deadband The thermal range within which mechanical systems are not operating.

Diffuse Lighting Indirect light (the source is often not visible) that comes from a variety of angles or directions.

Diffuser Any device that disperses light from a source, e.g., translucent glass.

Discount Rate A rate used to relate present and future dollars. This is a percentage used to reduce the value of future dollars in relation to present dollars, to account for the time value of money. Discount rate may be the interest rate or the desired rate of return.

Footcandle (fc) Unit of illuminance used in the inch-pound system. The metric unit is lux.

Footlambert Unit for luminance in the inch-pound system. The metric unit is the candelas per square meter (cd/m^2).

Glare The sensation produced by brightness within the visual field that is greater than the brightness to which the eye is adapted and thus causes annoyance, discomfort, or loss in visual performance and visibility.

Illuminance (fc, lux) Roughly, the amount of light falling on a surface.

Indirect Lighting Lighting achieved by reflection, usually from wall and ceiling surfaces.

Kilowatt (kW) Unit of electric power (the rate at which energy is used). Equals 1,000 watts.

Kilowatt-Hour Unit of energy. Equals 1,000 watt-hours.

Life Cycle The period of time between a baseline date and the time horizon, over which future costs or benefits will be incurred.

Light Shelf A horizontal element positioned above eye level to reflect daylight onto the ceiling.

Load shedding The process through which peak electricity requirement is reduced, normally through turndown in plant or component operations or shut down / switch off.

Louver A series of baffles used to shield a light source from view at certain angles.

Lumen (lm) A common unit of light output from a source.

Luminaire A complete electric lighting unit including housing, lamp, electrical components, diffusers, and focusers. Also called a fixture.

Luminance (cd/m^2) Roughly, the amount of light coming from a surface in a single direction; in other words, how bright it is.

Luminance Ratio Ratio between different brightnesses in the visual field.

Lux The metric unit for illuminance. The inch-pound unit is the footcandle.

Minimum Attractive Rate of Return The effective annual rate of return on an investment which just meets the investor's threshold of acceptability. It reflects the cost of using resources as well as the potential risk involved with the project.

Payback Period Time required for an investment to return its value to the investor.

Photometer/photosensor An instrument for measuring light.

Present Worth (or Value) The current value of an amount. Typically used to represent the value today of a future amount, by discounting the future amount to current dollars.

Rate of Return on Investment An interest rate which represents a measure of profit from an investment.

Reflectance The ratio of energy (light) bouncing away from a surface to the amount striking it, expressed as a percentage.

Reflected Glare Glare resulting from mirror-like reflections off of shiny surfaces.

Stationpoint The preferred location for placement of sensors and meters on the basis of their access to natural and artificial light.

Task Lighting Light provided for a specific task, versus general or ambient lighting.

Transmittance The ratio of energy (light) passing through a surface to the amount striking it, expressed as a percentage.

Thermal comfort criteria/standards The thermal range within which a person wearing a "normal" amount of clothing is neither too hot nor too cold.

U-value The metric by which heat flow through a material is measured; lower values indicate lower rates of transmission.

Veiling Reflection A condition where light reflected from a surface masks the details of that surface. A common occurrence when glossy magazines are read under bright, direct lighting.

Visual Acuity A measure of the eye's ability to distinguish fine details.

Visual Comfort Probability Rating of a lighting system expressed as a percentage of the people who will find it free of discomfort glare.

Visual Field What can be seen when head and eyes are kept fixed.

Visual Performance The quantitative assessment of a visual task, taking into consideration speed and accuracy.

Watt Metric unit of power.

Watt-hour Unit of energy corresponding to exerting one watt of power during one hour.

Workplane The plane at which work is performed, usually taken as horizontal and at desk height (30") above the floor.

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15 Appendix A

First Cost and Energy Savings

Costs units: $/sqft Energy units: $ /sqft /yr	New Construction						Retrofit					
	Minimum		Typical		Maximum		Minimum		Typical		Maximum	
Energy Efficiency Measure	Eqmt Cost ($/sqft)	Labor Cost ($/sqft)	Eqmt Cost ($/sqft)	Labor Cost ($/sqft)	Eqmt Cost ($/sqft)	Labor Cost ($/sqft)	Eqmt Cost ($/sqft)	Labor Cost ($/sqft)	Eqmt Cost ($/sqft)	Labor Cost ($/sqft)	Eqmt Cost ($/sqft)	Labor Cost ($/sqft)
	Total Installed Cost ($/sqft)		Total Installed Cost ($/sqft)		Total Installed Cost ($/sqft)		Total Installed Cost ($/sqft)		Total Installed Cost ($/sqft)		Total Installed Cost ($/sqft)	
	Energy Saving ($/sqft/yr)		Energy Saving ($/sqft/yr)		Energy Saving ($/sqft/yr)		Energy Saving ($/sqft/yr)		Energy Saving ($/sqft/yr)		Energy Saving ($/sqft/yr)	
Stepped Dimming	0.63	0.25	0.86	0.38	1.09	0.50	0.63	1.08	0.86	2.17	1.09	4.33
	0.88		1.23		1.59		1.71		3.02		5.42	
	0.85		0.56		0.51		0.85		0.56		0.51	
Continuous Dimming	1.10	0.50	1.50	0.75	1.90	1.00	1.10	1.08	1.50	2.17	1.90	4.33
	1.60		2.25		2.90		2.18		3.67		6.23	
	0.98		0.62		0.27		0.98		0.62		0.27	
Internal Manual Shading	1.68	0.00	2.64	0.00	6.00	0.00	1.68	0.00	2.64	0.00	6.00	0.00
	1.68		2.64		6.00		1.68		2.64		6.00	
	0.79		0.19		0.01		0.79		0.19		0.01	
Internal Adaptive Shading	6.48	0.00	6.96	0.00	7.44	0.00	6.48	0.00	6.96	0.00	7.44	0.00
	6.48		6.96		7.44		6.48		6.96		7.44	
	0.23		0.09		0.06		0.23		0.09		0.06	
High Performance Glazing	0.24	0.00	3.42	0.00	9.97	0.00	0.66	0.00	4.63	0.00	13.87	0.00
	0.24		3.42		9.97		0.66		4.63		13.87	
	0.68		0.17		0.01		0.68		0.17		0.01	
External Static Shading	1.39	2.40	5.60	2.40	11.20	2.40	1.39	2.40	5.60	2.40	11.20	2.40
	3.79		8.00		13.60		3.79		8.00		13.60	
	0.88		0.26		0.02		0.88		0.26		0.02	
External Auto / Motorized Shading	13.33	4.90	16.67	4.90	20.00	4.90	13.33	4.90	16.67	4.90	20.00	4.90
	18.23		21.57		24.90		18.23		21.57		24.90	
	2.48		0.68		0.05		2.48		0.68		0.05	

Year of material and labor cost data: 2011, indicative labor cost from California (which has generally higher commercial equipment / plant installation labor rates than elsewhere in the United States[8]). Cost data is on $ / square foot, energy savings quoted in $ / square foot / year for three climate zones (reference locations, Phoenix; Washington, D.C.; and

[8] U.S. Bureau of Labor Statistics. www.bls.gov/oes/current/oessrcst.htm.

Minneapolis), cardinal point facade orientations and a range of window sizes. Maximum and minimum energy savings reflect performance in extreme climates, with "typical" being a calculation of the mean across all three climate zones. Energy savings estimates include impacts on electricity use for lighting and cooling and on gas use for heating.

Table A-1: Equipment and Labor Costs and Energy Savings by System Type

Table A-1 highlights costs and energy savings associated with each of the listed EEMs. Costs are quoted in dollars per square foot of serviced floor area and include equipment and labor (including installation) costs separately and in total. Energy savings are quoted in dollars per square foot per year. So for instance, for Stepped Dimming in New Construction (red highlighted numbers), the total typical installed cost is estimated at $1.23 per square foot ($0.85 for equipment and $0.38 for labor), and the typical energy cost savings are estimated at $0.56 per square foot. For that example, the simple payback would be less than 2.5 years.