

# TIPS FOR DAYLIGHTING



W I T H W I N D O W S

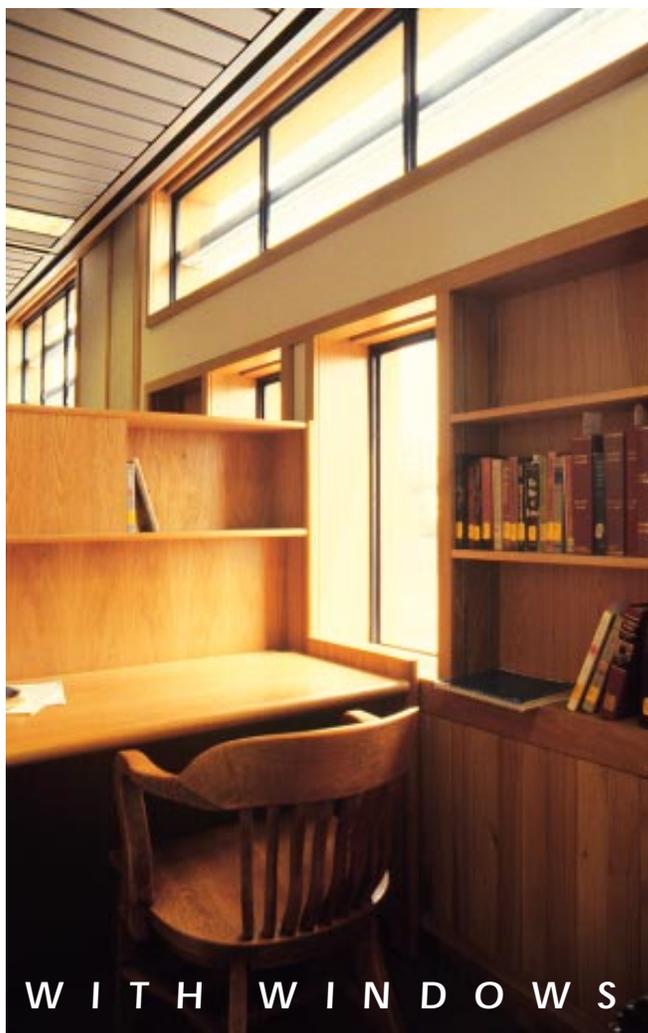
## The Integrated Approach

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Ernest Orlando Lawrence Berkeley National Laboratory

# TIPS FOR DAYLIGHTING



## The Integrated Approach

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Opposite: *Sacramento Municipal Utility District Customer Service Center, Sacramento, CA.*

# Tips for Daylighting with Windows

These guidelines provide an integrated approach to the cost-effective design of perimeter zones in new commercial buildings. They function as a quick reference for 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.

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.

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 glazing selection will have an effect on lighting, mechanical, and interior design. Therefore, the entire design team should participate in and influence this 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.

Begin with Section 1 to review how these guidelines work.



Section 1:	The Integrated Approach (Summary)
Section 2:	Daylight Feasibility
Section 3:	Envelope and Room Decisions
Section 4:	Glazing Selection
Section 5:	Shading Strategy
Section 6:	Mechanical Coordination
Section 7:	Lighting Coordination
Section 8:	Sensors and Controls
Section 9:	Calibration and Commissioning
Section 10:	Maintenance
Section 11:	Cost Benefit Analysis
Appendix:	Glossary
	References
	Tools & Resources Summary

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## ***Provisos***

These guidelines cannot answer all questions for all projects, however they aim to address the most frequently raised questions for most projects.

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

These guidelines are primarily applicable to new construction. They may apply to some retrofit projects, if used with caution.

These guidelines were developed for California climates and latitudes, however advice may be appropriate in other regions.

These guidelines are distinguished from existing material 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.

## ***Acknowledgments***

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# The 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 occupancy.

### ■ What is the Integrated Approach?

These Guidelines provide 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 holistic 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.
- Share appropriate decisions across disciplines.
- Regularly evaluate decisions for any building-wide ramifications.

### ■ What is a high-performance building?

One that

- Meets design objectives.
- Maximizes occupant comfort and productivity.
- Minimizes occupant complaints and tenant turnover.
- 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 constitute 30 to 40% of a commercial building's total energy use. Daylighting is the most cost-effective strategy for targeting these uses. Both annual operating and mechanical system first costs can be substantially reduced.
- 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.

### ■ How do these guidelines work?

Quick tips, tools, and procedures are supplied here to point designers toward appropriate decisions and to help the design team stay focused on integration. 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.

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 Key Ideas.

#### **Integration Issues**

Highlights any overlap for the design issues covered in this section. Where other design disciplines and goals will be affected by decisions made in this stage, a note is made 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.

#### **Tools and Resources**

Lists ways to analyze decisions or other places to go for help. In some cases, quick calculation tools are provided.

#### **Checklist**

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

### **■ Getting Started**

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

#### **Pre-design, Programming**

The goals established at this early planning stage will set the foundation for an integrated, comfortable, and energy-efficient building design. Establish performance goals together with the owner and make achieving these high performance goals a priority. Aim for an effective daylighting design. Establish schedule and budget parameters: more time available allows for more analysis; more budget allows for appropriate consultants. Use the easy tool in the COST/BENEFIT section to quickly determine if daylighting holds good investment potential. See the DAYLIGHT FEASIBILITY section to quickly check that daylighting makes sense for site and program.

#### **Schematic Design**

The first design decisions are critical to energy efficiency and daylighting. Get started on the right foot by reviewing Key Ideas in the ENVELOPE AND ROOM DECISIONS and SHADING STRATEGY sections. If you have not done so already, check DAYLIGHT FEASIBILITY and do a quick COST/BENEFIT analysis. LIGHTING, MECHANICAL, and CONTROLS sections should be browsed now.

#### **Design Development**

Refine envelope, room, and shading design. See ENVELOPE AND ROOM DECISIONS and SHADING STRATEGY for further detail and check the lists of *Tools and Resources* to improve design. See GLAZING SELECTION if not addressed yet. Sections on MECHANICAL COORDINATION and LIGHTING COORDINATION should now be viewed in detail, as should SENSORS AND CONTROLS. This is a critical time for coordination among design team members.

#### **Construction Documents**

Make sure 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 the CALIBRATION AND COMMISSIONING section in detail, and take appropriate action.

#### **Post-Occupancy**

Review MAINTENANCE section and keep it, along with the maintenance plan, on file in the building.

# Daylight Feasibility

## OBJECTIVE

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

- Because daylight is not used simply to illuminate an interior space (e.g., 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 productivity.
- 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 glazing generally diminishes the capacity to daylight in all but very sunny climates.
- **Install daylight-activated 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 (occupancy, scheduling, etc.) 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, sky views, ground reflectance, and design can be treated together. Within a single building, the feasibility and cost-effectiveness of daylighting may vary greatly.

## PROVISIO

- A low-rise building in a dense area can be adequately daylighted with skylights (skylights are not addressed in these guidelines).

## TOOLS & RESOURCES

### *“Two-Minute” Feasibility Study*

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

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

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-floor height) equals window-to-wall ratio (WWR).

$$\frac{\text{net glazing area}}{\text{gross exterior wall area}} = \text{WWR}$$

If unknown, use 0.35 for a typical, moderately strip-glazed building. If larger windows are anticipated, use 0.50. For smaller punched windows, use 0.25.

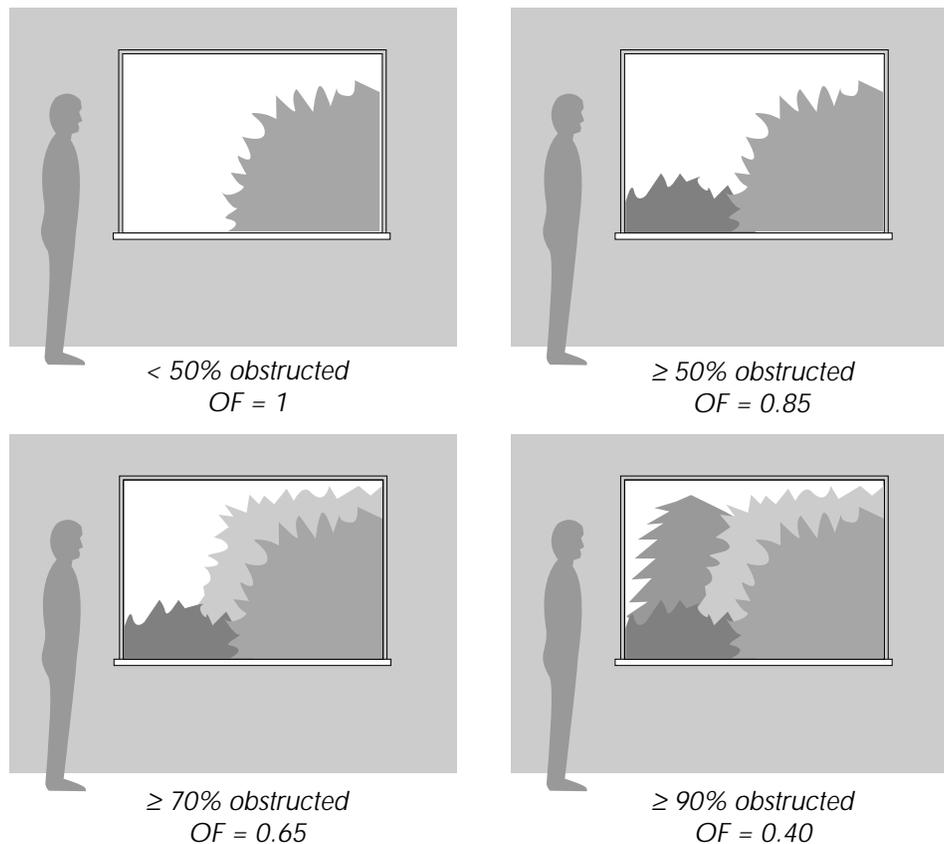
#### **Step 2: Make a preliminary glazing selection and note the visible transmittance (VT).**

Generic Glazing type (1/4" panes)	Typical VT	Generic Glazing type (1/4" panes)	Typical VT
Single pane clear	0.89	Double pane tint - bronze	0.47
Single pane tint - green or blue-green	0.70	Double pane tint - gray	0.39
Single pane tint - blue	0.57	Double pane light reflective	0.30
Single pane tint - bronze	0.53	Double pane medium reflective	0.20
Single pane tint - gray	0.42	Double pane high reflective	0.10
Single pane tint - extra dark	0.14	Double pane low-E clear	0.70
Single pane light reflective	0.35	Double pane low-E tint - green or blue-green	0.63
Single pane medium reflective	0.25	Double pane low-E tint - blue	0.49
Single pane high reflective	0.12	Double pane low-E tint - bronze	0.45
Double pane clear *	0.80	Double pane low-E tint - gray	0.37
Double pane tint - green or blue-green	0.65	Suspended low-E film products	0.27-0.60
Double pane tint - blue	0.51		

\* Double pane numbers also apply to laminates.

#### **Step 3: Estimate the obstruction factor (OF).**

Visualize a typical task location, 10 feet (3.3 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. Select the obstruction factor as shown in diagram on page 3.



#### **Step 4: Calculate the feasibility factor.**

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

$$\frac{\text{WWR}}{\text{WWR}} \times \frac{V_T}{V_T} \times \frac{\text{OF}}{\text{OF}} = \frac{\text{Feasibility Factor}}{\text{Feasibility Factor}}$$

If Feasibility Factor  $\geq 0.25$ , then daylighting has the potential for significant energy savings. If Feasibility Factor  $< 0.25$ , 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.

Source: *Daylighting Manual*, Public Works, Canada, March 1990.

# Envelope & Room Decisions

## SECTION 3

## Tips for Daylighting with Windows

## OBJECTIVE

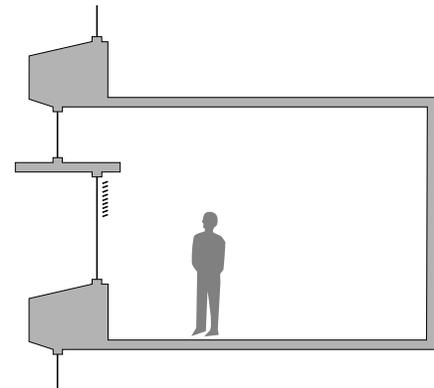
*Design siting, massing, facade, windows, and interior to maximize daylight effectiveness, provide occupant comfort, and minimize glare.*

- 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.

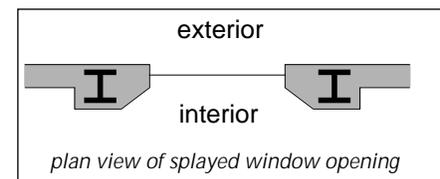
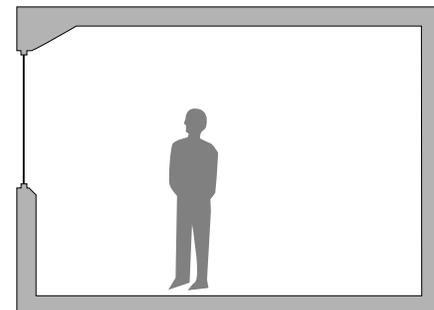
## KEY IDEAS

### Building Form and Skin

- **Increase exposure to daylight.** The higher the skin-to-volume ratio, the greater percentage of floor space available for daylighting. Long and narrow footprints are preferable to square ones, up to a limit, although a high skin-to-volume ratio may mean a heating or cooling penalty. North and south exposures are generally preferred compared to east or west.
- **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.
- **Capitalize on other building elements to integrate shading.** For example, overhangs, louvers, fins, 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, 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 (23-30 cm) deep, at an angle of 60° to the window plane.
- **Balance daylight admittance.** Spaces with windows on two sides often have better daylighting distribution.
- **Keep private offices somewhat shallow.** Keep depth of rooms within 1.5-2.0 times window head height for adequate illumination levels and balanced distribution.



*Deep wall section provides self-shading, allows easy integration of light shelf, creates surfaces that mitigate glare, and reduces noise transmission. Sloped surfaces also help soften glare.*

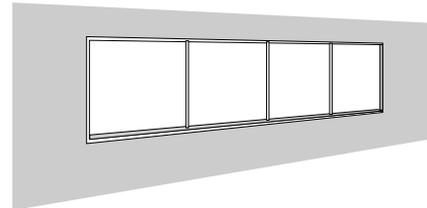


*Sloped surfaces, such as this splayed window opening, help soften glare. These surfaces should be light-colored and provide an intermediate brightness between window and room surfaces, making an easier transition for the eye.*

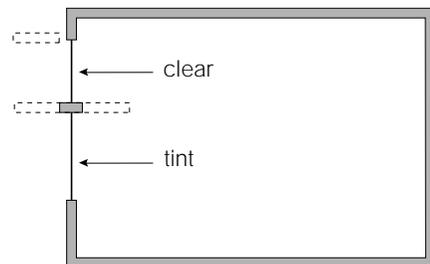
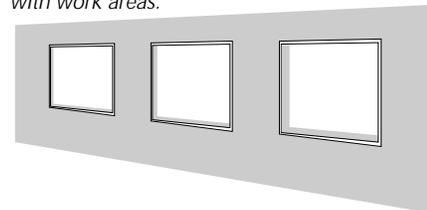
- **Consider color and texture of exterior surfaces.** Light-colored surfaces will reflect more daylight than dark surfaces. Specular surfaces (e.g., glazed tile or mirrored glazing) may create glare if viewed directly from an office. Diffuse ground-reflected daylight can increase daylight availability.

## Windows

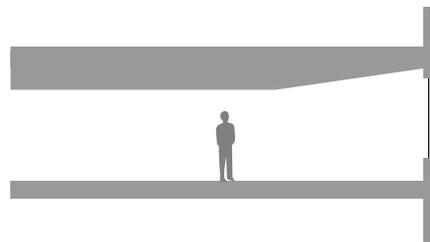
- **The higher the window, the deeper the daylighting zone.** The practical depth of a daylighted zone is typically limited to 1.5 times the window head height. With a reflective light shelf, this zone may be extended up to 2.5 times the head height. If a corridor is beyond this zone and separated with a partially glazed wall, it may be adequately lit with the spill light from the room. With standard window and ceiling heights, plan on adequate daylight within 15 feet (4.6 m) from the window.
- **Strip windows provide more uniform daylight.** The easiest way to provide adequate, even daylighting is with a nearly continuous strip window. 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 are taken.
- **Large windows require more control.** The larger the window, the more important glazing selection and shading effectiveness are to control glare and heat gain. Use double pane to control winter heat loss and improve thermal comfort. See Tools & Resources for 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 (see illustration on page 3-3). Select glazing and window area to target an EA around 0.30. See Tools & Resources for sizing help.
- **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.
- **Use separate apertures for view and daylight.** A good approach for excellent daylighting and glare control is the separation of view and light windows. Use high transmission, clearer glazing in clerestory windows, and lower transmission glazing in view windows to control glare.
- **Position windows to direct light onto the ceiling.** For good distribution, use taller ceilings and high windows. Keep the ceiling smooth and light-colored. A sloped ceiling (high near the window) is one way to fit a high window within normal floor-to-floor heights.
- **Introduce more light-colored surfaces** for good distribution. Deep reveals, ceiling baffles, exterior fins and shelves, if they are light in color, keep daylighting more even.



Strip windows are an easy way for uniform daylighting. Punched windows should be paired with work areas.

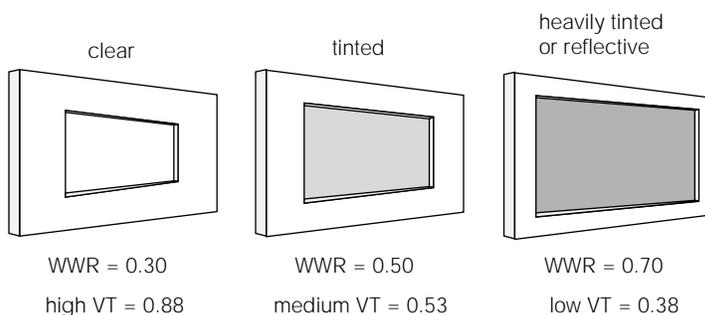


Different apertures for daylight and view: clear glazing above for maximum daylight, tinted glazing below for glare control. The structure between the two provides a visual break and an opportunity to attach a light shelf or shading device.

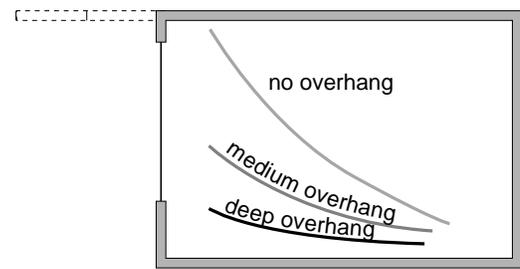


A sloping ceiling at perimeter raises the window head without increasing floor-to-floor height

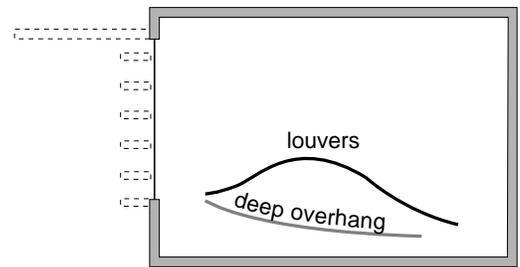
- **Incorporate shading elements with windows.** Shading devices perform triple duty: they keep out the sun's heat, block uncomfortable direct sun, and soften harsh daylight contrasts. See Section 5, SHADING STRATEGY, for more detail.
- **Use horizontal window shapes.** Horizontal shapes provide more even distribution—vertical windows are more likely to create light/dark contrasts, although taller windows mean 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) 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.
  - 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. Windows facing generally north and south create the fewest problems.
- **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.



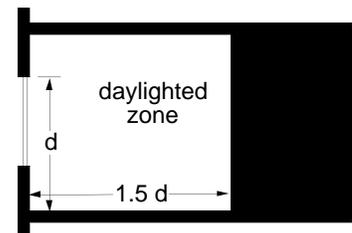
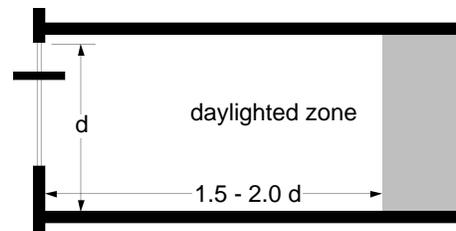
Effective Aperture (EA) is visible transmittance (VT) x window-to-wall ratio (WWR). These three windows all have the same EA.



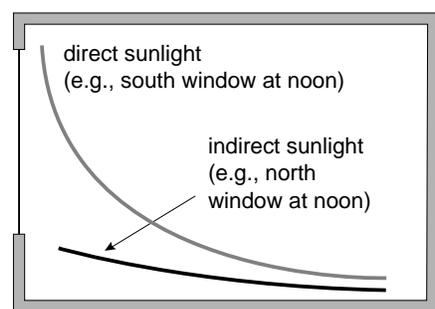
The curves indicate light levels. Overhangs reduce light and glare near the window, creating a softer gradient in the room.



Break up the overhang for better distribution.



A rule of thumb for daylight penetration with typical depth and ceiling height is 1.5 times head height for standard windows, 1.5 to 2.0 times head height with light shelf, for south-facing windows under direct sunlight.



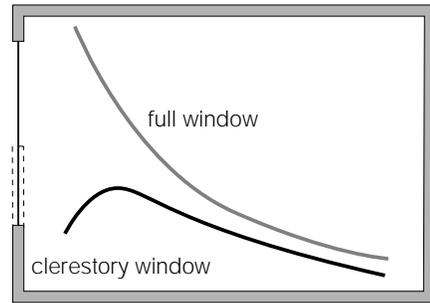
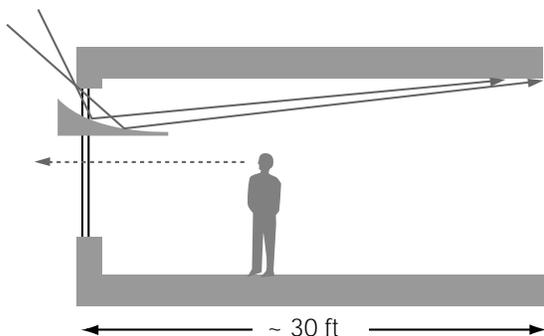
Curves show light levels when a window is facing the part of the sky that has the sun versus the sky away from the sun (daylight only, no direct beam in the room).

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

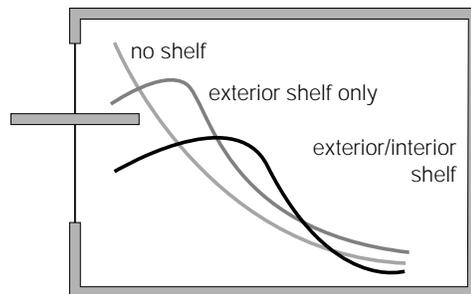
- Good for getting the light source out of direct sightline. Good for effective ceiling illumination (which provides deeper penetration and good distribution). Good for computer visual display terminals (VDTs) and other glare sensitive tasks.
- Loss of view—only view may be of the glaring sky.
- An effective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

**About Light Shelves** (horizontal elements above eye level)

- Light shelves can improve illuminance distribution and reduce glare.
- Shelves double as shading devices, if designed to block direct sun.
- Best used on the south in a predominantly clear sky climate.
- Consider using clearer glass (with sun control) 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 (see Beltran et al. in REFERENCES section for ideas).



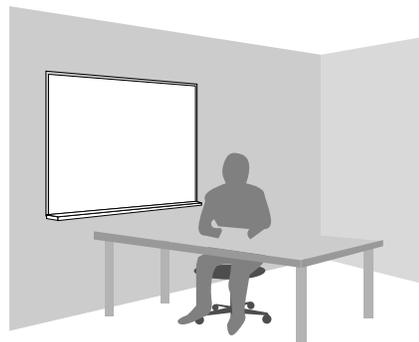
High windows provide better distribution. These curves indicate light levels. Notice the softer gradient with the clerestory.



A light shelf improves distribution of daylight. Notice the softer gradient with a light shelf.



When the window is behind your back, you may shade your task and make it too dark to see easily. However, your computer screen may be difficult to see if it reflects light from the window.



The most comfortable seating is with the window to the side—task is well illuminated and the source is not in direct line of sight.

## Space Planning

- **Locate activities according to light requirements.** Put rooms with little need for daylight (infrequent use, service, wash-rooms, 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 is dictated by a worker's value to the organization (e.g., a high-level worker placed near the window).
- **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.
- **Use light-transmitting materials for partitions** where possible. Use clear or translucent materials in the upper portion of full-height 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 VDTs), 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 VDTs 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.
- **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.



*Facing the bright window creates a harsh contrast in comparison to your relatively dark task—this is very tiring for the eye to have both in the same field of view.*

## 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. For good distribution throughout the room, it is 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): ceilings >80%; walls 50-70% (higher if wall contains window); floors 20-40%; 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. Interior window shading should be light-colored for 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.
- 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. Consult with an engineer to establish 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. Computer analysis of building performance along with 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. Window and room design must provide for thermal and visual comfort of the occupant.
- Occupant satisfaction will depend on the fit between environment and task needs. Know the intended use of the space before design.

## **PROVISOS**

- Dark tinted glazings diminish the capacity to daylight.
- Don't forget to look into lighting controls—their absence will not allow you to increase energy efficiency. (Be sure to work through the remaining sections of these guidelines.)

## TOOLS & RESOURCES

### *Determining Required Net Glazing Area*

- **Use this 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 a rectangular room whose 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 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.

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

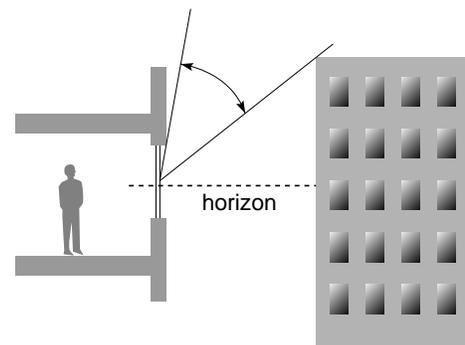
- **Average Daylight Factor.** Use:
  - 1 if low-light spaces are desired
  - 2 if average spaces are desired
  - 4 if bright spaces are desired
- **Total Area of Interior Surfaces.** Add up total surface area of walls, ceiling, and floor.
- **Area-Weighted Average Reflectance.** Ratio between 0 and 1. Add up total surface area of walls, ceiling, floor, windows, partitions, and furniture, and calculate weighted average reflectance (see equation), or

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

use 0.5 as default.

- **Visible Transmittance.** See  $V_T$  Table in Section 2, DAYLIGHT FEASIBILITY, or 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, from center of window. Value between 0 and 90. If no obstruction, vertical angle is 90°.



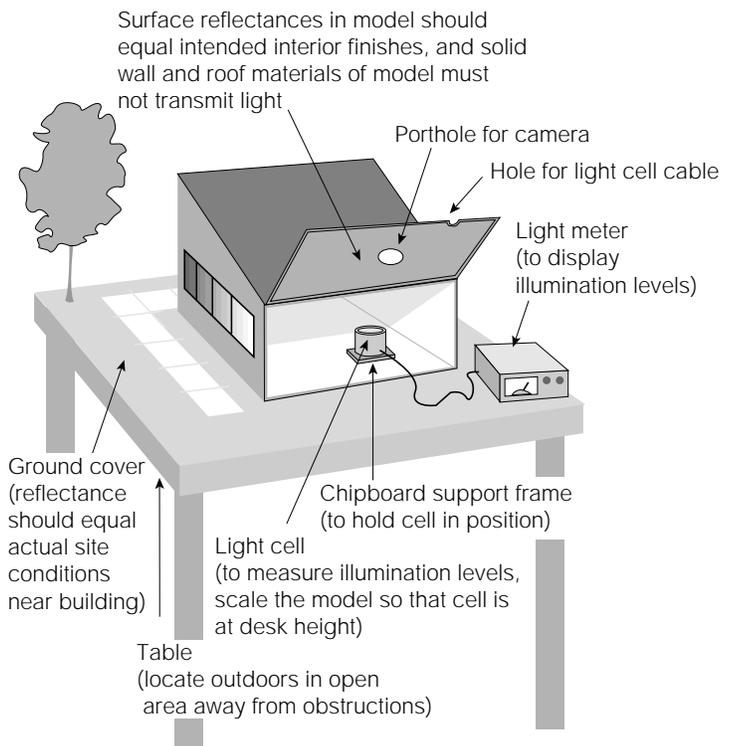
*Vertical Angle of Sky*

Source: "A Sequence for Daylighting Design," J. Lynes, *Lighting Research and Technology*, 1979.

## Four methods to quantify daylighting levels and energy impacts

**1. Scale Model.** A physical model is a simple, quick, and inexpensive tool for determining approximate daylight levels in a space and is useful at all stages of design. A rough assessment of how well the design mitigates glare and controls direct sun can also be made. Models are helpful for fine tuning decisions, for convincing clients, and for flagging potential construction problems.

- a. Ensure materials and joints are opaque—cover joints with black tape; paint or cover exterior surfaces if not opaque. Note: White foamcore is not opaque and needs to be covered with opaque material.
- b. Be sure to model all 3D features of the windows, like sills and reveals.
- c. Glazing can be left out if you don't have a sample of the actual glazing, but see item *i.* below. If diffusing materials are intended, use tracing paper or a uniformly translucent plastic for glazing.
- d. If possible, build in a modular fashion to allow easy variations. Scale: 1"=1' for small rooms, 1/2"=1' for larger rooms.
- e. Cut a porthole in the sidewall adjacent to window for eye and camera.
- f. Take outdoors, preferably to actual site or some place where sky exposure and obstructions are similar, position in proper orientation, and observe interior for several minutes as your eye adapts to the lower interior illuminance level. Qualitatively assess four things: character of the space, adequacy of illumination, glare, and balance across the room depth. Be sure to measure under an appropriate variety of sun and sky conditions (e.g., clear, overcast, etc.).
- g. Take photographs with a wide-angle lens and fast film—results are highly realistic and helpful for analysis later. Black and white film is recommended if model colors are not the intended final colors.
- h. Add furniture and other details for realism and scale. If you have access to photometric equipment, measure illumination and calculate daylight factor (horizontal indoor illuminance divided by horizontal outdoor illuminance) for several different task locations.
- i. If you have not included glazing in the model, multiply your readings by the visible transmittance of intended glazing.
- j. Ask at local utility or architecture school for possible assistance. Otherwise, see books listed below for more tips.



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, 1983.

2. **Daylighting Calculations by Hand.** This is an alternative to photometry in a scale model, when it's important to quantify daylight illumination levels. Several standard procedures exist. A lighting designer should be familiar with them. Or obtain instructional literature (see sources below).
3. **Computer Daylighting Models.** Daylighting software typically delivers faster, more accurate results than illumination calculations done by hand. Consult a lighting designer or request a "Daylighting Design Tool Survey" from the Windows and Daylighting Group at Lawrence Berkeley National Laboratory (510-486-5605).
4. **Engineering 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.

### ***Other Resources***

- **IES** Contact the Illuminating Engineering Society at (212) 248-5000, ext. 112 for publications on daylighting, or visit the IESNA world wide web site at <http://www.iesna.org>.
- **ASHRAE** The American Society of Heating, Refrigerating, and Air Conditioning Engineers offers a wide range of reference materials. Call (800) 527-4723 for a publications list, or visit the ASHRAE world wide web site at <http://www.ashrae.org>.
- **Utility Company.** Inquire at local utility about possible incentives and design assistance.

- **Books**

*Concepts in Architectural Lighting*, by M. David Egan (McGraw-Hill, 1983) has a helpful section on window and interior design.

*Concepts and Practice of Architectural Daylighting*, by Fuller Moore (Van Nostrand Reinhold, 1985) is an excellent and thorough resource. Includes a good treatment of basic principles.

*Daylighting Performance and Design*, by Gregg D. Ander (New York: Van Nostrand Reinhold, 1995)

*Sunlighting as Formgiver for Architecture*, by William M.C. Lam (New York: Van Nostrand Reinhold, 1986)

- See annotated TOOLS & 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. If the site allows, the first attempt at building placement should be with the long axis running east-west.
3. Minimize apertures on the east and especially the west. Low sun angles for these orientations makes 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 model to study daylighting effects with the proposed skin, ceiling height, and room depth.
9. Interior design should begin selecting light colors for finishes and window coverings. Remember that rendering of interior colors will be affected by glass color.
10. 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.
11. Discuss daylighting concepts with lighting designer or consultant to ensure that electric lighting layout and controls address daylight needs at the start of the lighting design process.
12. Check coordination issues with lighting, structural, and mechanical design. Keep ceiling as smooth and high as possible.

### If you have...

#### no time

1. Minimize window area on east and especially on 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 window opening and splay these surfaces if possible.

#### a little time

In addition to 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. Build a simple model and view it outdoors for lighting quality and glare.

#### more time

In addition to above:

1. Build a more accurate model and view/photograph outdoors. If photometric equipment is available, measure the daylight in the model. Refine design as necessary.
2. Mechanical engineer models variations in siting, form, footprint, and skin materials in an optimization study. Engineer looks for equipment downsizing opportunities.
3. Hire a daylighting consultant or investigate computer design tools.

# Glazing Selection

## SECTION 4

## Tips for Daylighting with Windows

## OBJECTIVE

***Make an informed glazing selection from all design perspectives.***

- Choose glazing to maximize daylight effectiveness and occupant comfort, and minimize energy use, while still meeting architectural objectives.

## KEY IDEAS

### *Glazing Technology*

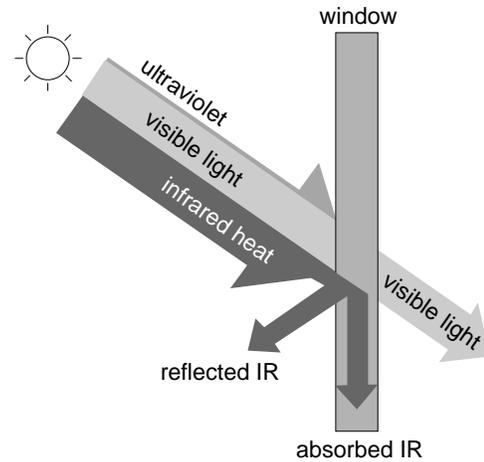
**Examine ALL glazing properties when choosing a product.** Glazing selection should be a careful process of evaluating and weighing tradeoffs. Review all of the critical characteristics of glazing, listed in product brochures, for a good all-around selection. See a brief explanation of these properties below:

- **Visible Transmittance**, or daylight transmittance, is the percentage of visible light striking the glazing that will pass through. Visible transmittance values account for the eyes' relative sensitivity to different wavelengths of light. Glazings with a high visible transmittance appear relatively clear and provide sufficient daylight and unaltered views; however, they can create glare problems. Glazings with low visible transmittance are best used in highly glare-sensitive conditions, but can create "gloomy" interiors under some weather conditions and diminished views. They are unsuitable for many daylighting applications since they do not provide enough light for typical visual tasks. Note that some glazings can have a high visible transmittance but obscure views, e.g. frosted or patterned glass.
- **Visible reflectance**, or daylight reflectance, indicates to what degree the glazing appears like a mirror, from both inside and out. It is the percentage of light striking the glazing that is reflected back. Most manufacturers provide both outside reflectance (exterior daytime view) and inside reflectance (interior mirror effect at night). All smooth glass is somewhat reflective; various treatments such as metallic coatings increase the reflectance. High reflectance brings with it low visible transmittance and all the interior disadvantages that may be associated with that characteristic.
- **Solar Heat Gain Coefficient (SHGC) or Shading Coefficient (SC)** are indicators of total solar heat gain. SHGC, which is replacing SC, is the ratio of total transmitted solar heat to incident solar energy, typically ranging from 0.9 to 0.1, where lower values indicate lower solar gain. These indices are dimensionless numbers between 0 and 1 that indicate the total heat transfer of the sun's radiation. SC is the ratio of solar gain of a particular glazing as compared to a benchmark glazing (1/8" or 3 mm clear glass) under identical conditions. These properties are widely used in cooling load calculations. To convert between these properties,  $SC \approx 1.15 \times SHGC$ .
- **U-Value** ( $W/m^2 \cdot K$ ,  $Btu/h \cdot ft^2 \cdot ^\circ F$ ) is a measure of heat transfer through the glazing due to a temperature difference between the indoors and outdoors. U-Value is the *rate* of the heat flow, therefore *lower* numbers are better. **R-Value** is the *resistance* to heat flow ( $R = 1/U$ ), with *higher* numbers indicating better insulation. Glazing products usually list U-Value. Center-of-glass U-values are generally lower than whole-window U-values, which account for the effect of the frame and mullions. This property is important for reducing heating load in cold climates, for reducing cooling load in extremely hot climates, in any application where comfort near the windows is desired, and where condensation on glass must be avoided.

- **Ultraviolet Transmittance** indicates the percentage of ultraviolet radiation (a small portion of the sun's energy) striking the glazing that passes through. Ultraviolet radiation (UV) is responsible for sunburn of people and plants, and contributes to fabric fading and damage to artwork. Many energy-efficient glazings also help reduce UV transmission.
- **Spectral Selectivity** refers to the ability of a glazing material to respond differently to different wavelengths of solar energy – in other words, to admit visible light while rejecting unwanted invisible infrared heat. Newer products on the market have achieved this characteristic, permitting much clearer glass than previously available for solar control glazings. A glazing with a relatively high visible transmittance and a low solar heat gain coefficient indicates that a glazing is selective. Spectrally selective glazings use special absorbing tints or coatings, and are typically either neutral in color or have a blue or blue/green appearance.
- **Glazing Color** affects the appearance of view (bronze will dull a blue sky, for example) and the appearance of interior finishes. Examine carpet, fabric and paint samples in daylight that comes through the intended glazing to be sure colors are not changed undesirably. Glazing color is also a dominant determinant of the exterior appearance of the building facade. Color is the property that often dominates glazing selection and can thus unnecessarily constrain or complicate daylighting design. For example, a strong color preference for gray or bronze may make a good glazing selection more difficult. Staying more flexible with respect to color will keep more opportunities open.
- **Sound Transmission** is an important glazing system property in some projects, and many energy-efficient glazings deliver improved acoustic performance as a side benefit. Outdoor-to-indoor transmission class (OITC) is the property used to express sound attenuation characteristics. The higher the OITC rating, the better the unit will insulate against sound. Multilayer assemblies, especially those with a laminated layer, generally have high OITC ratings.

### Selection Process

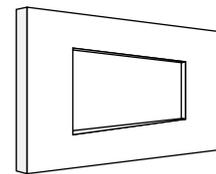
- **Choose between dual-pane and single-pane glazing.** This is the critical first decision in glazing selection. Although higher in first cost, dual-pane insulating glazing typically improves comfort in perimeter zones, offers greater flex-



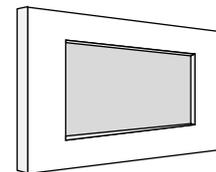
*An ideal spectrally selective glazing admits only the part of the sun's energy that is useful for daylighting.*

ibility in product selection, improves acoustic performance, and reduces mechanical loads. Most new energy-efficient buildings should use insulating glazing. Single-pane glazing with exterior shading can be effective in mild climates if there is significant solar radiation.

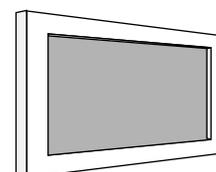
- **Choose a spectrally selective glazing.** Select a moderate visible transmittance for glare control (50-70% is a good starting point, depending on visual tasks, window size and glare sensitivity; the larger the windows or the more critical the glare control, the lower the desirable visible transmittance). Examine manufacturer literature for good glazing candidates. Find the product tables for insulating or single pane units, depending on your initial selection, and look for products with your desired visible transmittance and the lowest possible solar heat gain coefficient.
- **Balance the conflict between glare and useful light.** A physical model studied outdoors is a good tool to qualitatively assess glare. If glare is an anticipated problem, and if an architectural solution to glare is not possible (moving windows out of the field of view, using deep reveals, shading systems, and other physical modifiers), then select a glazing visible transmittance that is a compromise between glare and light. A visible transmittance as low as 25% may still provide adequate daylight.
- **Window size and glazing selection can trade off with each other.** Use the **effective aperture** approach when making these decisions: Larger window area requires lower visible transmittance; smaller windows requires high visible transmittance. See the illustration. A good target value for effective aperture is between 0.20 and 0.30.
- **Big windows require better glazing.** The bigger the window, the lower the required solar heat gain coefficient and visible transmittance. The bigger the window, the greater the need for insulating glazing. Large areas of inefficient glazing bring major comfort and energy cost penalties, cooling system penalties, and may not be permitted by building codes.
- **Don't assume that dark glass provides good solar control.** Many dark glazings block more light than heat, and therefore only minimally reduce cooling load. Dark glass can produce a gloomy interior atmosphere and may affect productivity and absenteeism. Consult product brochures or manufacturer representatives to be sure you are aware of the range of product choices today. Dark glass not only reduces daylight, it also increases occupant discomfort on



Clear Glass  
WWR = 0.30  
high VT = 0.88



Tinted Glass  
WWR = 0.50  
medium VT = 0.53



Heavily Tinted  
or Reflective  
WWR = 0.70  
low VT = 0.38

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

a sunny day, particularly in single glazed form. The glass absorbs solar energy and heats up, turning it into a virtual furnace for anyone sitting near it. Today, solar control is available in much clearer glazings.

- **Don't count on glazing alone to reduce heat gain and discomfort.** If direct solar beams come into the building, they still create a mechanical cooling load and discomfort for occupants in their path. Exterior shading combined with a good glazing selection is the best window strategy. Interior shading options can also help control solar heat gain.
- **Vary glazing selection by facade, if possible.** A lower solar heat gain coefficient on the south, east and especially west windows will reduce the cooling load.
- **Check Building Codes.** Some codes restrict the allowable area of glazing or thermal properties or both. Often tradeoffs are possible: more area is permitted if better glazing is specified.

## INTEGRATION ISSUES

### ARCHITECTURE

A good glazing for daylighting, with a relatively high visible transmittance, will appear fairly transparent from the outside. A desire for an opaque or mirrored facade is often not compatible with daylighting.

### INTERIOR

Glazing color strongly affects color rendering of interior finishes in daylighted areas.

Color and visible transmittance affect the view and the occupants' sense of connection with the outdoors. High transmittance glass in a neutral or soft color helps make windows effective links to the world outside.

Low transmittance glazing makes interiors feel gloomy when overcast or sunlight levels are low. However, it may be useful to control glare in some circumstances.

### HVAC

Glazing characteristics are a large factor in heating and cooling loads. A mechanical engineer should help determine optimal glazing properties for an efficient mechanical system. High performance glazing generally reduces annual energy use, peak loads, individual zone fluctuations, wide differences in coincident zone loads, and occupant complaints.

Examine equipment downsizing opportunities with glazing improvements. Model the entire fenestration system correctly when calculating cooling load and optimum glazing properties. In particular, include any exterior shading in the model as this reduces the importance of a low glazing solar heat gain coefficient.

Insulating glass may eliminate the need for a perimeter heating system.

### LIGHTING

Visible transmittance determines how much daylight will be admitted, once the window size is set. The lighting designer must assess expected daylight levels before final glazing selection. If daylighting levels are not satisfactory, choose an alternate glazing with a different visible transmittance or increase glazing area.

Glazing color affects color temperature of the daylight and should be considered when matching electric sources in daylighted zones.

## COST-EFFECTIVENESS

High performance glazings cost more than their standard alternatives but may pay for themselves in four ways: reduced energy bills, reduced first costs in mechanical equipment, increased occupant productivity, and avoided future retrofit costs (in added mechanical equipment or window fixes, due to commonly unanticipated occupant discomfort). Mechanical load calculations can provide an estimate of the first two savings opportunities. Case study and anecdotal evidence supports the second two benefits.

## OCCUPANT COMFORT

Single pane glass near an occupant can create a hot or cold sensation regardless of interior air temperature. When it is cold outdoors, the body radiates heat to the cold glass surface and is chilled. Sun striking glass, especially a tinted unit, heats the unit up well above skin temperature, which then radiates heat to the body and induces a sense of overheating. The mechanical system cannot easily overcome these situations, since it typically adjusts air temperature only and not the temperature of the glass.

Cold glass will also induce a chilly downdraft.

When windows will be near occupants, insulating glazing is the best choice for comfort. Tinted glass in an insulating unit does not cause the radiation problem described above since the tinted piece is typically in the outboard pane.

Glazing with a high visible transmittance can cause glare if preventive measures are not taken. Some examples of glare avoidance discussed elsewhere in these guidelines include user-operated shading devices, architectural modifiers, and balancing window brightness with other light sources.

## **!** PROVISOS

- Renovations in historic buildings typically need extra care in glazing selection, as historic preservation rules usually require the look of the facade to remain the same. This means any new glazing must appear the same as the original, in most cases, clear. Select an advanced, insulating, spectrally selective glazing for an efficient, comfortable and daylighted renovation.
- Some tinted glazings cannot tolerate partial shading due to the thermal stresses caused by a large temperature range across a single piece of glass. Consult the glazing manufacturer regarding the building's shading scheme.
- A strong desire for extremely dark or mirrored glazing is not normally compatible with daylighting design.
- Consult glazing suppliers for information on structural aspects of glazing. Specific applications may require tempered, laminated, or other glazings to meet performance requirements.
- Simplified mechanical load calculations do not accurately model the energy behavior of windows, due to the complexity of that behavior and the oversimplification inherent in commonly used glazing properties.

For example, rough approximate mechanical calculations frequently indicate that single pane glazing is more desirable than insulating glazing for California commercial buildings; while more sophisticated modeling software reveals the opposite conclusion with respect to peak cooling load, annual energy use, and comfort. Do not rely on these simplified calculations in making a decision; use them as guidelines only.

# ↑ TOOLS & RESOURCES

- Manufacturer Technical Literature and Product Representatives** are free sources of information and assistance. Begin with section 08810 in Sweets Catalog to identify product choices and suppliers. Many of the brochures in this section contain useful general information on glazing in addition to product-specific data. Most manufacturers will readily supply samples (typically 12" by 12" or smaller) and copies of their Sweets brochures. Some manufacturers will also perform energy calculations for you.
- National Fenestration Rating Council** compiles a directory of window products with associated thermal, solar, and optical properties. While the emphasis is on residential applications, much of the information is useful for commercial buildings. NFRC data and window labels provide a consistent and accurate way to compare product properties (similar to refrigerator labels). See [www.nfrc.org](http://www.nfrc.org).
- Scale Model.** A model studied outdoors can be an accurate and easy way to anticipate glare potential and evaluate daylight levels and direct sun control. See Section 3, ENVELOPE AND ROOM DECISIONS, for information on measuring daylight in a model, which requires that you have access to photometric equipment (light meters). If light levels are not satisfactory, make an alternate glazing selection for a different visible transmittance or adjust window size. A glare study is easier to conduct. Follow the model-building instructions given in ENVELOPE AND ROOM DECISIONS. If possible, include the actual glazing material (get a sample from the manufacturer) or a material to closely approximate the color and transmittance of the glazing. Take the model to an outdoor site with similar sky view as the actual site, get in a comfortable seated position, and look through the eye hole. Cup hands around eyes or wear an opaque drape over head so that no outside light enters the peephole or interferes with your focus. Observe the space for at least five minutes and assess the visual comfort. If windows appear uncomfortably bright, or if the contrast gradient is too harsh through the room, take a corrective measure such as an adjustment to the visible transmittance or an architectural solution as discussed elsewhere. Daylighted spaces are dynamic: Use the model under a range of sun positions and weather conditions to get a better feel for the range of expected conditions.

- Software.** Mechanical engineer's standard calculations are useful for comparing peak loads and annual energy use with different glazing options. Remember that this software can only approximate the behavior of glazings and buildings.

The *Window 4.1* program is public domain software that accurately analyzes

**Architectural Glass Products**

08810/CAR  
SysLine 3146

Insulating Reflective Glass  
with LoE-178 on #3 Surface

08810/CAR  
SysLine 3146

**IG Series Performance Data**

Product Description	Color	Type	U-factor	SHGC	VT	Solar Heat Gain Coefficient		Visible Transmittance		Light Transmittance		Solar Heat Gain Coefficient	Visible Transmittance	Light Transmittance
						SHGC	VT	SHGC	VT	SHGC	VT			
IGU-178	Clear	178	0.27	0.54	0.78	0.27	0.54	0.78	0.78	0.78	0.78	0.78	0.78	0.78
IGU-178	Clear	178	0.27	0.54	0.78	0.27	0.54	0.78	0.78	0.78	0.78	0.78	0.78	0.78

**TI Series Performance Data**

Product Description	Color	Type	U-factor	SHGC	VT	Solar Heat Gain Coefficient		Visible Transmittance		Light Transmittance		Solar Heat Gain Coefficient	Visible Transmittance	Light Transmittance
						SHGC	VT	SHGC	VT	SHGC	VT			
TIU-178	Clear	178	0.27	0.54	0.78	0.27	0.54	0.78	0.78	0.78	0.78	0.78	0.78	0.78
TIU-178	Clear	178	0.27	0.54	0.78	0.27	0.54	0.78	0.78	0.78	0.78	0.78	0.78	0.78

**LP Series Performance Data**

Product Description	Color	Type	U-factor	SHGC	VT	Solar Heat Gain Coefficient		Visible Transmittance		Light Transmittance		Solar Heat Gain Coefficient	Visible Transmittance	Light Transmittance
						SHGC	VT	SHGC	VT	SHGC	VT			
LP-178	Clear	178	0.27	0.54	0.78	0.27	0.54	0.78	0.78	0.78	0.78	0.78	0.78	0.78
LP-178	Clear	178	0.27	0.54	0.78	0.27	0.54	0.78	0.78	0.78	0.78	0.78	0.78	0.78

the thermal properties of fenestration products. It is widely used in the glazing industry, but is intended to serve designers as well when choosing between different product options. Available through the National Fenestration Rating Council (301-589-NFRC) or Bostik Construction Products (800-523-6530). Information can also be obtained from websites: see [www.nfrc.org](http://www.nfrc.org) and [eande.lbl.gov/BTP/WDG/THERM](http://eande.lbl.gov/BTP/WDG/THERM).

The *DOE2.1E* program is an advanced building simulation package. Because it has a variety of features to accurately model glazing and shading properties, dynamic window management and daylighting effects, it is one of the best software tools available to assist in energy-efficient design, although it requires time and expertise (or hiring a consultant). Use this program to make an optimal glazing selection. Versions of DOE-2 are available from a variety of software vendors. Contact the Lawrence Berkeley National Laboratory at (510) 486-5605 for a list.

- **Books.** There are only a few up-to-date materials available to designers on glazing. The best source for timely information may be the architectural journals, which occasionally run glazing articles in their technical sections.

*ASHRAE Handbook of Fundamentals* (American Society of Heating, Refrigerating and Air Conditioning Engineers 1993) is a source for technical information and generic glazing properties.

*Low-E Glazing Design Guide* by Timothy Johnson (Butterworth-Heinemann 1991) addresses technical issues and offers some application information as well.

*Residential Windows* by John Carmody, Stephen Selkowitz, and Lisa Heschong (Norton 1996) is a guide to new technologies and energy performance.

- **Utility Company.** Inquire at local utility about possible design assistance or financial incentives.

## CHECKLIST

1. Review your fenestration decisions to date, as these will guide the glazing selection.
2. Use the effective aperture target as discussed to determine the range of desirable visible transmittances, based on your window-to-wall ratio.
3. Decide between insulating glazing options (or in some circumstances, single glazing). Mechanical engineer's calculations, comfort concerns, and construction budget data will help in this decision.
4. Identify to what extent color, reflectance, UV transmittance, and sound will influence glazing selection.
5. Determine, via mechanical engineer or building code requirements, the desirable range of values for U-Value and solar heat gain coefficient. If the building has good exterior shading, glazing solar control becomes less critical.
6. Review product literature and select candidate glazings that meet the above criteria.
7. Evaluate glare potential, ideally with a physical model, and take preventive measures if necessary.
8. Contact product representatives for samples, further information, assistance and pricing.

## **If you have...**

### **no time**

1. Size windows for a 30% window-to-wall ratio.
2. Specify glazing with visible transmittance 50-70%, solar heat gain coefficient 0.50 or lower (or to code maximum, whichever is lowest), and U-Value to meet code. Choice of color may be limited.
3. Present above criteria to glazing representatives from two or more manufacturers for further assistance in finding products that match. Request representatives to perform energy calculations for you (free) if undecided between products. Consult project engineer on heating/ cooling system sizing issues.

### **a little time**

1. See glazing brochures in Sweets Section 08810 and select some options yourself for the above criteria (glazing products and their energy properties are listed in tables), then call specific glazing representatives for more information, pricing, and free performance calculations for your project.
2. For a broader range of options, determine a set of alternative scenarios (different size windows, different potential glazings), perhaps with mechanical engineer's assistance. Engineer evaluates these alternative designs, using standard load software and derives optimum values for U-value, solar heat gain coefficient, and visible transmittance. Present these values to glazing representatives for a product match.

### **more time**

1. Determine an optimum set of values for U-value, solar heat gain coefficient, and visible transmittance through more rigorous computer modeling with software such as DOE-2 that can compute energy savings from daylighting in addition to standard building performance energy calculations. This usually requires hiring an energy consultant with DOE-2 experience.
2. This consultant should also assist in predicting occupant satisfaction (comfort) and in fine-tuning the proposed window area and type with respect to other criteria such as acoustics, glare, view, color, etc. Consultant could also prepare building code compliance documentation. Present results of this optimization study to glazing representatives for a product match, or select glazing yourself from Sweets brochures.

# Shading Strategy

## SECTION 5

## Tips for Daylighting with Windows

### OBJECTIVE

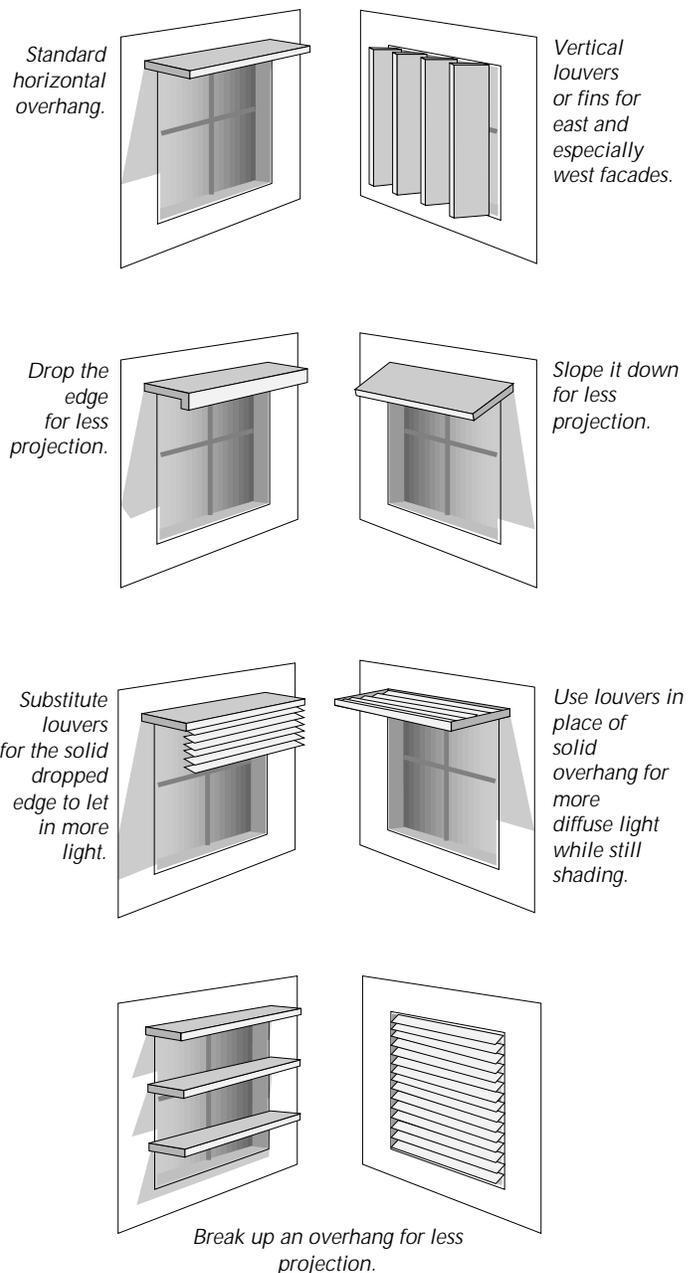
#### ***Control intense direct sunlight to ensure a comfortable workspace.***

- This is critical for occupant visual and thermal comfort and for minimizing mechanical cooling loads.
- Direct sun is acceptable in less demanding spaces, such as circulation zones, lobbies, eating areas, etc.

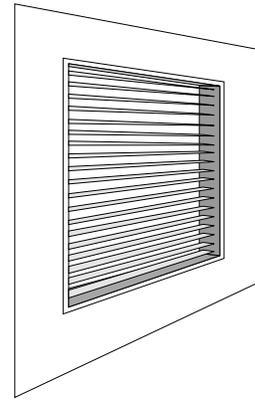
## KEY IDEAS

### ***Exterior Devices***

- **Use exterior shading**, either a device attached to the building skin or an extension of the skin itself, to keep out unwanted solar heat. Exterior systems are typically more effective than interior systems in blocking solar heat gain.
- **Design the building to shade itself.** If shading attachments are not aesthetically acceptable, use the building form itself for exterior shading. Set the window back in a deeper wall section or extend elements of the skin to visually blend with envelope structural features.
- **Use a horizontal form for south windows.** For example, awnings, overhangs, recessed windows. Also somewhat useful on the east and west. Serves no function on the north.
- **Use a vertical form on east and west windows.** For example, vertical fins or recessed windows. Also useful on north to block early morning and late afternoon low sun.
- **Give west and south windows shading priority.** Morning sun is usually not a serious heat gain problem. If your budget is tight, invest in west and south shading only.
- **Design shading for glare relief as well.** Use exterior shading to reduce glare by partially blocking occupants' view of the too-bright sky. Exterior surfaces also help smooth out interior daylight distribution.



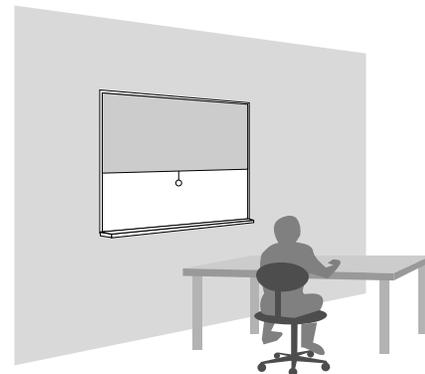
- **The shade's color modifies light and heat.** Exterior shading systems should be light colored if diffuse daylight transmittance is desired, and dark colored if maximum reduction in light and heat gain is desired.
- **Fixed versus movable shading.** Use fixed devices if your budget is tight. Use movable devices for more efficient use of daylight and to allow occupant adjustment; first cost and maintenance costs are higher than with fixed devices. Use movable devices that are automatically controlled via a sun sensor for the best energy savings. Reliable systems have been in use around the world for years and have only recently become available as cost-effective options in the United States.



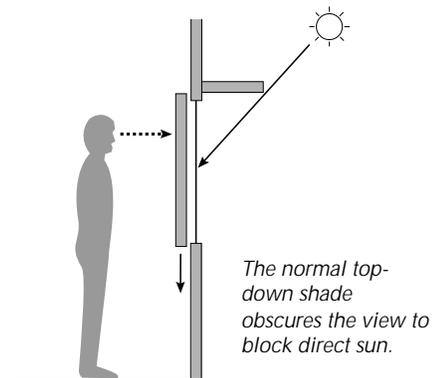
An exterior shade screen fits neatly within window framing, a bit away from the glass. Design for easy removal for cleaning.

### In the Window Plane

- **Use exterior shades for a smooth facade.** Exterior shade screens are highly effective on all facades and permit filtered view.
- **Use roller shades for a movable alternative.** Open weave exterior shades are not as effective, but acceptable.
- **Don't rely on dark glazing.** Glazing treatments (reflective coatings, heavy tints, and reflective retrofit film) can be effective at reducing heat transfer. They allow direct sun penetration but with reduced intensity. This may not be an effective shading strategy from an occupant's perspective unless the transmittance is very low to control glare, e.g., 5-10%. Fritted glass, with a durable diffusing or patterned layer fused to the glass surface, can also provide some degree of sun control, depending upon the coating and glass substrate properties, but may also increase glare.
- **Between glass systems.** Several manufacturers offer shading systems (e.g., blinds) located between glazing layers. Some are fixed and others are adjustable. See related comments on interior devices below.



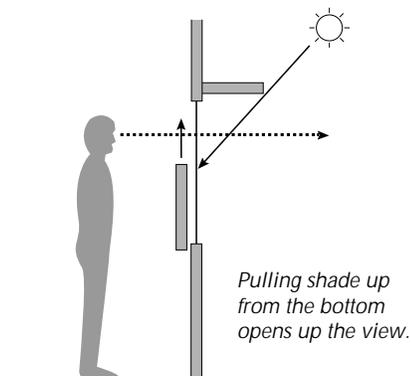
Shades, blinds, and draperies are the categories of interior shading products.



The normal top-down shade obscures the view to block direct sun.

### Interior Devices

- **Interior shading alone has limited ability to control solar gain.** All interior systems are less effective than a good exterior system because they allow the sun's heat to enter the building. They also depend on user behavior, which can't be relied upon.
- **If interior devices are the only shading, specify light colors** in order to reflect the sun's heat back out. Light-colored



Pulling shade up from the bottom opens up the view.

blinds or louvers are best. Light-colored woven or translucent shades are acceptable, but may not control glare under bright summer conditions.

- **Interior shading is best used for glare control and backup shading.** Supply user-operated devices that occupants can adjust to their individual comfort needs.
- **Use devices that still allow daylight in.** Blinds and open-weave shades are good choices for filtering but not blocking all light.
- **Don't use dark devices unless exterior shading is used.** Dark-colored interior devices offer only small energy savings. Open-weave shades are easiest to see through if their interior surface is dark, but perform best if their exterior surface is light colored.

## INTEGRATION ISSUES

### ARCHITECTURE

Projections work well with an articulated or layered facade and can integrate well with structural members. Exterior screens can make windows look dark.

If interior devices are the only shading, many occupants will always keep them closed. This can mean the window is permanently no longer transparent.

Use exterior shading to avoid the facade clutter of variously adjusted interior coverings.

### INTERIOR

Choose light-colored window coverings for best energy savings and comfort.

Choose interior window treatments that allow occupants to make adjustments for individual comfort needs.

### HVAC

Good shading provides cooling load reductions. The mechanical engineer should perform calculations that include shaded windows, but acknowledge that not all shading systems will be deployed when needed.

### LIGHTING

Shading devices modify the intensity and distribution of daylight entering the space. Lighting design scheme and placement of control zones may be affected.

### COST-EFFECTIVENESS

Proper shading devices can be partially or fully paid for by reduced cooling equipment and cooling energy costs. However the likelihood of proper use by occupants must be accounted for. Mechanical engineer should calculate these savings. Compare to any additional construction costs for the shades and calculate simple payback for the shading.

Automated movable systems can have an added maintenance cost and a higher first cost relative to other shading schemes. However, the operation should be more reliable than with manually operated systems. Careful calculation of expected energy savings are needed to determine cost-effectiveness for this approach.

## OCCUPANT COMFORT

Direct sun in the workplace is almost always a comfort problem. Uncomfortable occupants will be less productive, close their window coverings, bring in energy-using portable fans, and reduce thermostat setting if possible. Good shading means occupants will have minimal complaints.

Shading reduces glare. Exterior elements partially shield occupants' view of the bright sky. Screens, glazing treatments, and shades reduce the brightness of the window. Exterior elements and venetian blinds reduce contrast by sending some light deeper into the space (improving distribution).

## **!** PROVISOS

A controlled and limited use of sunlight may be appropriate in some cases.

Direct sunlight:

- aids the growth of plants.
- provides strong illumination that enhances details, texture, shape, and color.
- gives a dynamic vitality to a space through its daily variation—especially beneficial in relieving institutional monotony in schools, hospitals, and public buildings.
- provides a visual and emotional link to the outdoor world.
- provides a real and suggested warmth in winter.

Direct sunlight may be more appropriate in circulation areas, transition areas and other spaces that do not contain critical visual tasks. Be sure to account for the peak cooling and annual cooling cost of such designs.

Be sure to balance the needs for sun control against the usefulness of daylight admittance. Some sun control strategies may severely reduce daylighting opportunities.

## ↑ TOOLS & RESOURCES

- **Sizing Equations.** Use the equations given on page 5-7 for a simple start at sizing overhangs and fins.
- **LOF Sun Angle Calculator.** A more thorough and accurate method uses this easy manual tool (available for \$10 from Libbey Owens Ford, Exhibit and Display Center, Toledo, OH, (419) 470-6600). A booklet explaining how to use the tool for sizing is included.
- **Scale Model.** Test your preliminary shading scheme with a simple model. Evaluate whether glare and direct sun are successfully controlled, and make adjustments as necessary. Model studies are especially useful for complex architectural shading forms, which are hard to analyze on paper. Proper model studies are not difficult but do require some knowledge of solar geometry. A simple approach is to use a sundial (see next page). Document results with a camera. Alternatively, contact your local utility or school of architecture for possible assistance or consult one of the books below.
- **Shading Masks.** Use this simple graphic method to study and document shading device performance over the entire year, all captured in a single diagram that is easy to construct. See *Architectural Graphic Standards* for instructions.
- **Engineering Software.** Once the shading scheme is established (geometry of exterior elements is determined or an interior system is selected), use mechanical engineer's standard software to calculate cooling load with and without the proposed shading. The mechanical engineer or energy consultant must accurately model the impacts of the shading scheme. Computed savings can then be compared to added costs for the shading, for a simple payback calculation. This will be a conservative estimate, as there is no credit taken for savings associated with comfort (unshaded occupants will turn down thermostats or bring in electric fans).
- **Manufacturer Technical Literature and Product Reps** are free sources of information. Begin with "sun control" section in Sweets catalog to identify product choices and suppliers.

- **Books**

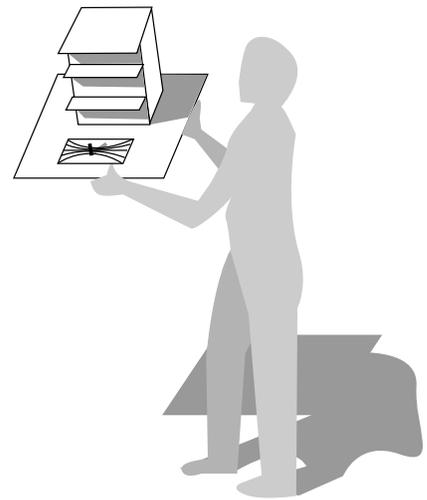
*Sun, Wind, and Light* by G.Z. Brown (John Wiley & Sons, 1985) offers more thorough explanations of some tools and ideas described here, in a friendly format.

*Architectural Graphic Standards* (John Hoke ed., AIA and Wiley & Sons 1994) has a section on shading masks, with instructions.

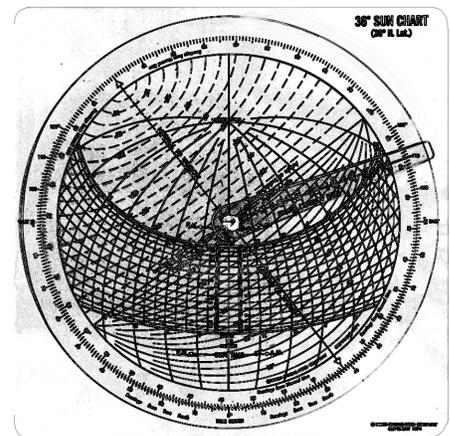
*Solar Control and Shading Devices* by Olgyay and Olgyay (Princeton University Press, 1957) looks a bit dated, but still contains sound information and a nice collection of shading mask examples.

*ASHRAE Handbook of Fundamentals* (American Society of Heating, Refrigerating, and Air Conditioning Engineers, any edition) is a highly technical source for generic solar heat gain coefficient data and all other aspects of building and fenestration energy behavior.

*Residential Windows* by John Carmody, Stephen Selkowitz, and Lisa Heschong (Norton 1996) includes a section on using shading systems.



Physical model study with a sundial.



For more exact sizing, use the LOF Sun Angle Calculator.

# Sundials

Scale models can be studied outdoors under direct sun or indoors using a lamp as a simulated sun. To position the model accurately relative to the sun, place a sundial beside the model and adjust the model position until the desired time is shown on the sundial.

a) Build a simple model with accurate geometry. You can study the whole building or just a portion of the facade.

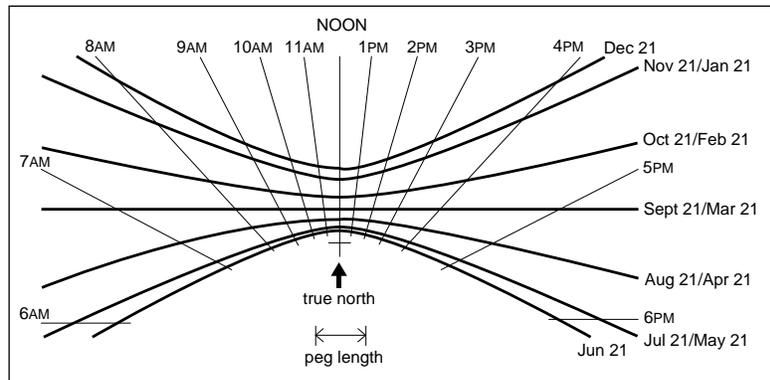
b) Select the sundial with latitude closest to your site (use  $32^\circ$  for Southern California,  $36^\circ$  for Central,  $40^\circ$  for Northern). Mount a copy of the sundial on your model (enlarge for more accurate positioning). It should be horizontal, oriented properly with true south on the model, and in a position where it will not be shaded by the model (flat roof or southern portion of model base are good places). Note that true north is typically depicted on city property line zoning maps, not magnetic north.

c) Make a peg the length shown and mount it on the cross mark just under the June 21 curve (a straight pin works well for this).

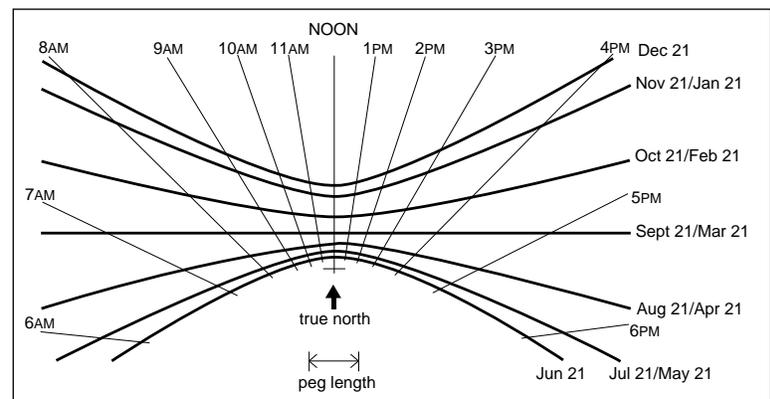
d) Take the model in the sun and tilt it so that the end of the peg's shadow falls at various intersections of the time and day lines. For example, when the model is tilted so that the peg shadow ends at the intersection of the 3 PM line and the October 21/February 21 curve, then the sun and shadow effects you observe are exactly as they will be at that time on both those days. You can now quickly see how well your shading scheme works all year round.

e) Have an assistant take photographs. Adjust design details as necessary.

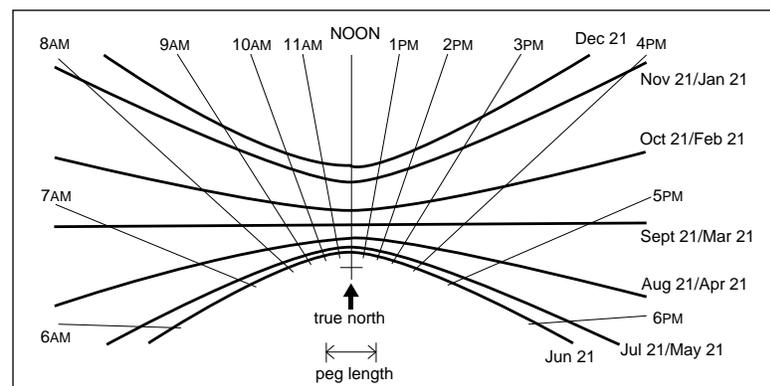
Source: G.Z. Brown, *Sun, Wind and Light: Architectural Design Strategies*, Wiley & Sons, 1985.



**Sun Path 32°N**



**Sun Path 36°N**



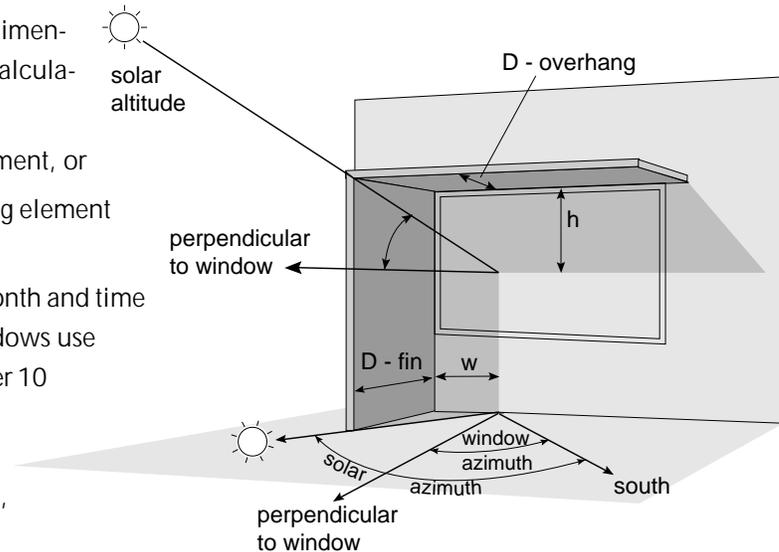
**Sun Path 40°N**

# Sizing Overhangs and Fins

Use these equations to find starting dimensions for shading elements. Do the calculations to find:

- depth required for a shading element, or
- extent of shadow cast by a shading element with given depth.

1. For each facade, select a critical month and time for shading. Suggested: south windows use September noon, east use September 10 am, west use September 3 pm, or ask mechanical engineer for estimate of peak cooling time in east, south, and west zones.



2. Find solar altitude and azimuth for target month/hour from the sun path diagrams (page 8).
3. Use the formulas below to size overhang, fin, or both. Results are a **minimum** starting point.
4. If overhang is too big, try breaking it into several smaller elements or dropping part of it down for an equivalent depth, as shown in Key Ideas.
5. If sizing overhang for east or west window, you may notice that a fin must be added for adequate shading; otherwise overhang becomes unreasonably deep.
6. Test solution with a physical model and sundial (page 6).
7. Improvements: Extend ends of overhang wider than window or use a continuous element. Make overhang deeper or add another horizontal element part-way down the window. Add vertical elements to the scheme.

$$\text{For an overhang: } h = \frac{D \times \tan(\text{solar altitude})}{\cos(\text{solar azimuth} - \text{window azimuth}) \ddagger}$$

- For total shade at your target month/hour, set  $h$  to height of window from sill to head and solve for  $D$ , required overhang depth.
- For partial shade, set  $h$  to acceptable height of shadow (perhaps 2/3 of window height) and solve for  $D$ , required overhang depth.
- With a given overhang, set  $D$  to its depth and find  $h$ , the height of shadow it will cast at your target month/hour.

$$\text{For a fin: } w = D \times \tan(\text{solar azimuth} - \text{window azimuth}) \ddagger$$

- Solve for either  $w$ , width of shadow, or  $D$ , depth of fin, as with the overhang equation

‡ Be sure to observe proper signs. If both solar and window azimuths are on the same side of the south vector, then both values are positive. If they are on opposite sides of south, then set one azimuth as negative. For example: solar azimuth - (-window azimuth) = solar azimuth + window azimuth.

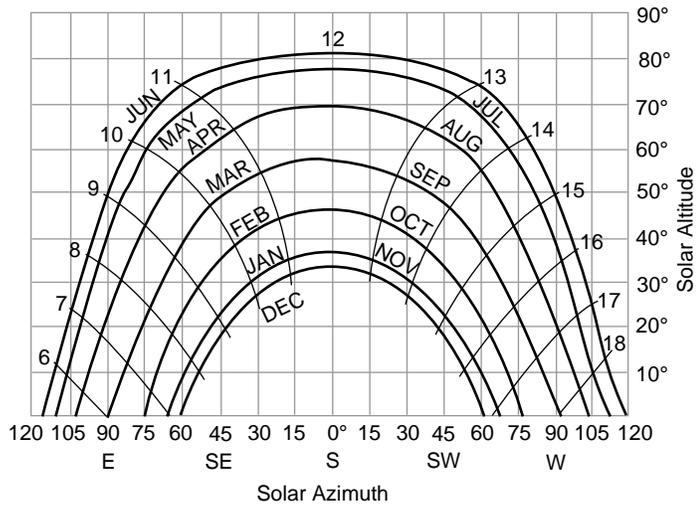
Source: David Ballast, *The Architect's Handbook of Formulas, Tables, and Mathematical Calculations*, Prentice Hall, 1988.

# Sun Path Diagrams

Use a Sun Path Diagram to find solar altitude and azimuth for any given time, to help in sizing shading devices.

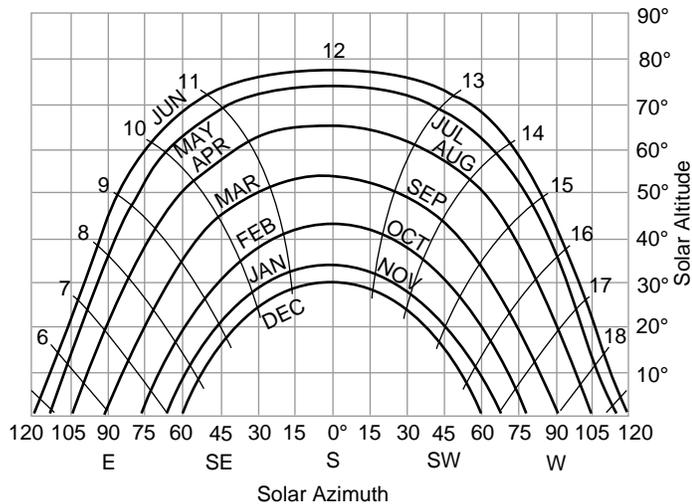
Choose the sun path diagram with latitude closest to your site (use 32° for Southern California, 36° for Central, and 40° for Northern).

Find the intersection of the two curves corresponding to the month and hour of interest. From this point, read solar altitude from scale at right and read solar azimuth from scale below. This is the sun's position at that month and hour.

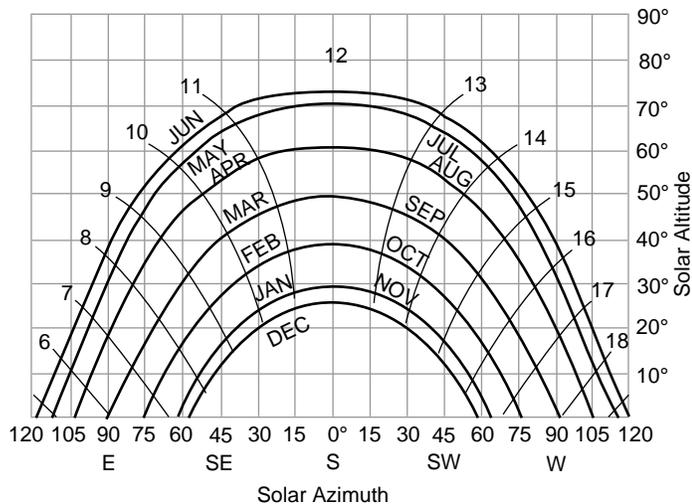


**Sun Path 32°N**

Source: Claude Robbins, *Daylighting: Design and Analysis*, Van Nostrand Reinhold, 1986.



**Sun Path 36°N**



**Sun Path 40°N**

## CHECKLIST

1. Characterize your shading needs. Long axis running east-west: shading is relatively simple (overhang or deep reveal on south may be all that's needed). Large area of glazing on west: shading becomes more critical and more difficult if daylight is to be maintained. Budget design time accordingly. You must know your true north orientation.
2. Review options for shading and select a basic approach (exterior vs. interior, an architectural projection, an off-the-shelf attachment, blinds, drapes, shades). A different strategy may be appropriate for each facade.
3. For exterior schemes, calculate preliminary size of projections. Use rules of thumb given here or use LOF Sun Angle Calculator method.
4. Refine with LOF Sun Angle Calculator (if still working on paper) or through quick physical model studies (for easier 3-D analysis).
5. Select an interior shading product and get solar heat gain coefficient data from manufacturer literature or product reps (see Sweets for starters). See ASHRAE Fundamentals for tables of generic products.
6. Get solar heat gain coefficient data for preliminary glazing selection from manufacturer literature, product reps, or generic table in Section 4, GLAZING SELECTION, or in ASHRAE Fundamentals.
7. Mechanical engineer calculates cooling load by hand or with computer model, accounting for exterior shading elements and proper solar heat gain coefficients for glass plus interior coverings. For venetian blinds, see ASHRAE Fundamentals for proper treatment of angle-dependent solar heat gain coefficient.
8. Mechanical engineer provides a rough estimate of savings due to shading. Get preliminary first cost estimate for shading and compute simple payback.
9. Provide description of shading scheme to lighting designer.

## **If you have...**

### **no time**

1. Minimize window area on east and west.
2. Use sizing rule of thumb for a horizontal projection or reveal on south windows.
3. Use sizing rule of thumb for a vertical projection or reveal on west windows.
4. If no exterior shading is possible, a lower solar heat gain coefficient for the glazing will be mandatory (see Section 4, GLAZING SELECTION), and interior shading will be required as well.
5. For best occupant comfort, provide either a light-colored venetian blind or light-colored translucent shade on all windows in occupied areas. For energy savings, these are desirable to include even with exterior shading; they are mandatory if there is no exterior shading.

### **a little time**

In addition to above:

1. Use the LOF Sun Angle Calculator method for preliminary sizing of exterior projections instead of rule of thumb, or to refine schematic design after using rule of thumb.
2. Browse through Sweets catalog for ideas on shading strategies and products.
3. If undecided on best shading approach to take, a mechanical engineer's simple calculations can help compare cooling reductions with different options.

### **more time**

In addition to above:

1. Build a physical model and test under sun for best final design of exterior shading.
2. Mechanical engineer takes special care to properly model shading elements and solar heat gain coefficients in computer calculations.
3. If large area of east or west glazing, mechanical engineer performs more complex calculations to determine cost-effectiveness of an automated exterior system.
4. Mechanical engineer helps explore opportunities for cooling equipment downsizing through optimum shading. Refine shading design to yield smallest possible cooling equipment.

# Mechanical Coordination

## OBJECTIVE

*Design an efficient mechanical system to take best advantage of cooling load reductions due to daylighting and shading.*

- Mechanical savings are a key element in the cost-effectiveness of daylighting.
- Efficient mechanical system design requires good coordination between the mechanical engineer and the rest of the design team.

## KEY IDEAS

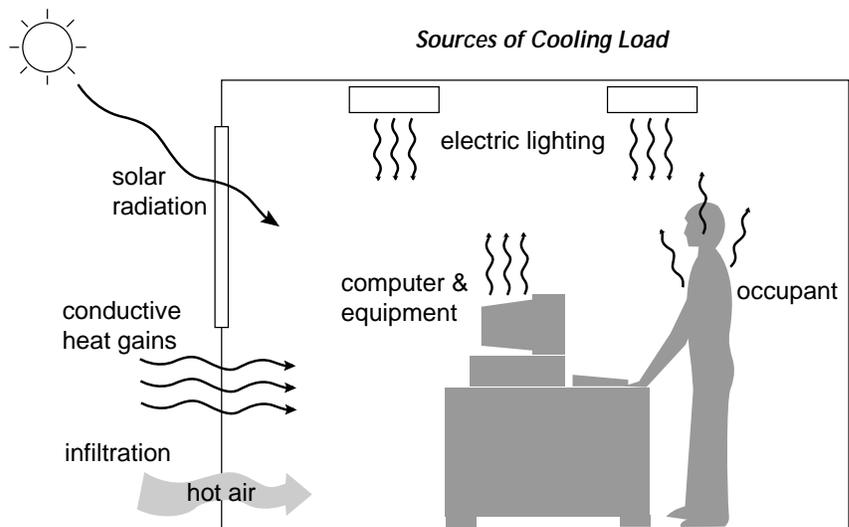
### Help Guide Early Architectural Decisions

- **Try to reduce cooling loads.**

Look for opportunities where architectural decisions can save operating costs, reduce mechanical first costs, and reduce mechanical space requirements. Reducing cooling loads provides many benefits. Smaller mechanical rooms and shafts yield more leasable space. Smaller plenums allow higher ceilings (an interior amenity, also helpful for daylighting performance) or possibly additional

floors within building height allowance. Smaller equipment is less visible on roof and easier to accommodate within normal floor-to-floor heights.

- **Calculate building energy use starting in schematic design**, even if this requires many assumptions about unknown details, and refine the calculation as the building becomes more defined. This early data can be critical in guiding architectural decisions, before important siting and envelope decisions are set.
- **Mechanical engineer should be an integral team player from the beginning.** Integrated design means all team members influence important building elements, and mechanical concerns can help keep architectural decisions on the right track. This is a departure from the traditional model of building design procedure, where the mechanical engineer enters the design process after major architectural decisions are already established. Mechanical expertise is not fully capitalized if not used in all design stages.
- **Assist in an optimal glazing selection.** Stay up to date on glazing technologies - dark or reflective glazings are no longer the only choices for solar heat reduction. Consider carefully the radiant effect of windows on comfort when weighing the benefit of an improved U-value or the disadvantages of a darkly tinted glazing. The mechanical system typically will respond to air temperature, yet occupant comfort in perimeter zones is highly affected by mean radiant temperature. Glazing with a poor U-value has a cold surface temperature in winter, while a dark (highly absorptive) glazing can get very hot in direct sun.



- **Encourage the use of effective shading.** Cooling loads and occupant comfort will benefit. Mechanical equipment savings may offset some costs of shading devices.
- **Remember that windows and skylights are not necessarily an HVAC penalty.** Careful daylighting design with shading can result in lower cooling loads than with electric lighting, even if glazing area is large. Proper modeling with energy analysis software that calculates daylighting with dimming controls is needed to show this.
- **Use accurate glazing and exterior shading device properties in final load calculations, not generic values.** Use manufacturer's data for architect's preliminary glazing and shading device selection. Model it accurately in calculations to estimate the full mechanical benefit from reduced solar load. Since there is no guarantee that interior shades will be closed at appropriate times, mechanical engineers typically do not include these devices in their calculations.
- **Keep ceilings uncluttered.** Try to place the lighting system's ceiling-mounted photosensor so that incoming daylight remains unobstructed by HVAC or other equipment.
- **Flag potential conflicts early,** such as inadequate space allocation, poor location or access for equipment rooms, and crowded ceiling plenums.

### ***Reduce First Costs***

- **Calculate peak cooling load and energy use with reduced perimeter electric lighting load and size mechanical system accordingly.** Be sure to specify proven and reliable daylight controls that will dim or switch electric lighting during peak cooling conditions.
- **Examine cooling system downsizing opportunities with various glazing and shading options.** Work with architect in possible fine-tuning of window sizing, window location, shading strategy and glazing selection for a smaller and more efficient system.
- **Insulating glazing may eliminate the need for a terminal reheat system at the perimeter in moderate climates.** Winter morning warm-up may be accomplished by the central heating system with appropriate controls. In addition to the energy savings, first costs may be lower with improved glazing versus the added mechanical equipment.

## ***Reduce Operating Costs***

- **Calculate the annual energy saved with improved fenestration elements.** Even if there are no mechanical first cost savings, reduced operating costs decreases the payback period. Calculations will show some of the benefit of exterior over interior shading, lower solar heat gain coefficient glazings, and daylighting controls. Be sure to account for cost savings from lower demand charges if appropriate.
- **Select an effective energy management system** to optimize building operation and tie together all HVAC, lighting and automated shading controls.
- **Set a larger temperature dead band for circulation spaces.** Let these and other non-critical spaces drift more than task areas.

## ***Maintain Thermal Comfort***

- **Window and shading design are strongly linked to perimeter zone comfort, regardless of air temperature.** Hot or cold glass behaves like a radiant panel and affects occupant comfort independent of air temperature. The asymmetric nature of this heat gain or loss is an added discomfort. Occupants will respond by adjusting the thermostat, wasting energy without satisfactorily improving comfort. Similarly, unshaded direct sun striking occupants causes discomfort independent of air temperature. Consider comfort as seriously as energy when advising architect on fenestration design.
- **Consider the effect of the window's mean radiant temperature on thermal comfort.** Dark tinted glazings or absorptive window films increase the window's surface temperature significantly in summer. Poorly insulated windows (high U-value) decrease the surface temperature in winter. Since the mechanical system controls the room's air temperature, occupants near the windows can be very uncomfortable. As noted above, a low U-value and low solar absorption will keep the glazing surfaces closer to room temperature. Radiant heating and cooling systems can provide some advantages in control of the thermal environment but are not yet commonly used in buildings.

## **INTEGRATION ISSUES**

### **ARCHITECTURE**

Provide adequate space for mechanical equipment or system efficiency may be impaired. Allow for adequate maintenance access.

Architectural decisions that reduce heating and cooling loads mean less space required for equipment—smaller mechanical rooms, smaller shafts, less ceiling plenum height.

Resolve aesthetic concerns with visible mechanical elements such as exposed ducts, diffusers and grilles, facade louvers and rooftop units.

### **INTERIOR**

Tall partitions may disturb intended air flow for open plan offices.

Diffusers, grilles, exposed ductwork and thermostats may be important visual elements to coordinate. Contractors should be given accurate placement specifications that meet functional and aesthetic desires.

### **LIGHTING**

Diffusers and light fixtures should be coordinated; fixtures may disrupt the intended air flow if surface-mounted or pendant-hung, or if placed too close to diffusers.

Account for effect of lighting control on lower heat gains from electric lighting.

### **COST-EFFECTIVENESS**

An efficient mechanical system reduces operating costs.

A building with reduced mechanical loads requires less mechanical equipment space and therefore yields more leasable space.

A thermally comfortable building retains tenants.

A cost/benefit study will show the tradeoffs available between architectural and mechanical elements; advanced glazings and effective shading devices can reduce mechanical first and operating costs.

### **OCCUPANT COMFORT**

Remember that thermostats don't respond to surface temperatures.

Increase thermal comfort by washing large glazing areas with conditioned air (reduces radiant heat transfer). However, there may be a cost penalty associated with such a design.

## **PROVISOS**

- Simple load calculations do not accurately model the energy behavior of windows, due to the complexity of window behavior and properties. Use these tools to understand general trends. Use more refined tools that properly model glazing, shading, and daylight to help make final decisions.
- Energy calculations sometimes indicate that single pane glazing is more desirable than insulating glazing for commercial buildings in mild climates. This has not been empirically supported. Remember that modeling software does not always account for all of the complex physical behavior of buildings.

- Solar heat gain coefficients for interior devices should be selected to represent achievable performance. Additionally, manually operated interior shading should not be considered a reliable means for solar heat gain reduction due to unpredictability of user behavior.

## TOOLS & RESOURCES

- **ASHRAE** The American Society of Heating, Refrigerating and Air Conditioning Engineers offers a wide range of technical support materials, including the monthly *ASHRAE Journal*. Call 800-527-4723 for a publications list. For *ASHRAE Journal* subscriptions, call above number or 404-636-8400.
- **Books** ASHRAE has many book titles available addressing maintenance (see above), including the useful *ASHRAE 1995 HVAC Applications Handbook* and *1993 Fundamentals Handbook. Mechanical and Electrical Equipment for Buildings, 8th Ed.* by B. Stein, J. Reynolds and W. McGuinness (Wiley and Sons 1992) is a good general reference.  
*Building Control Systems* by V. Bradshaw (Wiley and Sons 1985) is another helpful general reference.
- **Utility Company** Many utilities offer incentives for energy-efficient mechanical equipment. Inquire at your local utility about new construction or retrofit programs.
- **Load Calculations by Hand** This method is cumbersome and rough, but acceptable for a first cut at peak energy demand. ASHRAE publications and the books above are good sources for instructions.
- **Energy Analysis Software** These programs simulate building energy use, a useful way to compare energy-efficient alternatives, estimate energy costs, perform life cycle cost analysis, show Title 24 compliance, estimate peak power demands, disaggregate energy end uses, and—most commonly—compute loads for HVAC equipment sizing. These programs require extensive learning time and subsequent user experience. Simpler, easier-to-use analysis software exists but is not helpful for daylighting design. Partial list of energy simulation software (not all may model daylighting or are approved to show compliance):

*DOE2.1E	Lawrence Berkeley National Laboratory	(510) 486-5711
*ADM-DOE2	ADM Associates	(916) 363-8383
*CECDOEDC	California Energy Commission	(916) 654-5106
*DOE-24/Comply-24	Gabel-Dodd Associates	(510) 428-0803
*DOE-PLus	ITEM Systems	(206) 382-1440
*PRC-DOE-2	Partnership for Resource Conservation	(303) 499-8611
*Micro DOE2	Acrosoft International	(303) 696-6888
*VisualDOE-2.0 for Windows	Elex & Associates	(415) 957-1977
BLAST	BLAST Support Office	(800) 842-5278
Trace 600	The Trane Company	(608) 787-3926
HAP	Carrier Corporation	(800) 253-1794
ASHRAE/IESNA Std.90.1 Compliance & ASHRAE Publications		(800) 527-4723

\* For a list of software companies selling versions of DOE-2, contact LBNL.

- **Consult the Uniform Building Code and Uniform Mechanical Code** for compliance issues. In California, consult the Title 24 energy codes.
- **Energy Consultants** Helpful for additional daylighting expertise, software analysis, Title 24 compliance and mechanical system optimization. Easiest to find through the California Association of Building Energy Consultants (CABEC), 2150 River Plaza Drive, Suite 315, Sacramento, CA 95833-3880, (916) 921-2223.

## **CHECKLIST**

1. Discuss comfort and loads with architect prior to final envelope design.
2. Do energy calculations early to assist in glazing selection, shading scheme and other architectural opportunities to reduce loads.
3. Refine these calculations as design develops. Remember to use actual glazing properties, accurately modeled shading, and full credit for lighting reductions due to daylight controls.
4. Use energy simulation data in cost/benefit analysis to explore tradeoffs between envelope improvements, and mechanical first and operating costs.
5. Look for further opportunities to reduce peak loads and energy use throughout schematic design and design development.
6. Plan for HVAC controls, an energy management system, integration with other building system controls, commissioning protocols, and maintenance procedures concurrent with mechanical system design.
7. Flag potential space and ceiling conflicts.
8. Coordinate visible mechanical elements with other design team members.

### **If you have...**

#### **no time**

1. Discuss ramifications and opportunities of envelope decisions on comfort and energy with design team during early schematic design.
2. Select energy management strategies that are compatible with lighting controls.
3. Do preliminary load calculations part way through schematic design, using assumptions where necessary, to assist architectural decisions.

#### **a little time**

In addition to above:

1. Do load calculations with credit taken for daylighting controls and with shading and glazing properly modeled.
2. Plan for maintenance procedures, controls integration and commissioning now.

#### **more time**

In addition to above:

1. Perform several rounds of load calculations, starting from early schematics, to maximize benefit of energy analysis to architectural decisions.
2. Use software that can model daylighting. Consider the use of an outside energy consultant if this software expertise is not available to the design team.

# Lighting Coordination

## SECTION 7

## Tips for Daylighting with Windows

### OBJECTIVE

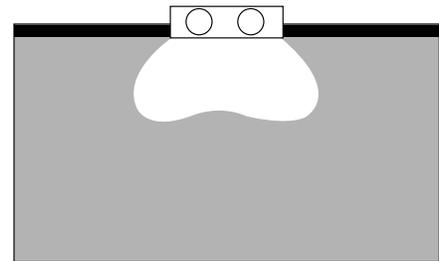
*Design the lighting system to best integrate with daylight and provide controls for high-performance, comfortable, and energy-efficient lighting.*

- The cost-effectiveness of daylighting depends on lighting energy savings.
- Effective controls help capture maximum savings from daylighting.
- Lighting design must include daylight from the beginning.

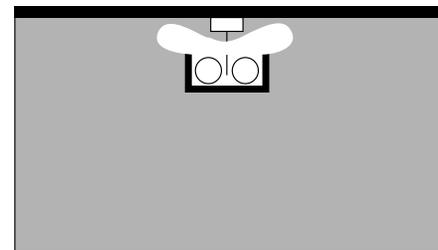
### KEY IDEAS

#### *Use a Lighting Strategy that Integrates with Daylight*

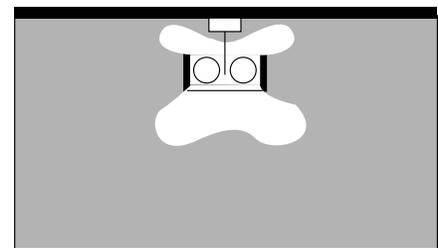
- **Make daylight integration part of lighting design from the beginning.** Lighting strategy, fixture selection, and method of control are all affected by the goal of daylight integration. For buildings primarily occupied during the day (schools, retail) that do not have tasks requiring higher illumination at night, design the electric lighting to augment daylight.
- **Choose a task/ambient strategy for easy integration with daylighting.** Daylighting can provide required ambient lighting for most operating hours. Provide user-controllable task lights to assure that task illumination requirements are met at all locations when supplemental lighting is necessary. Users near windows will often use daylight as their primary task source. In general, design ambient illumination levels to be significantly less than task levels (but not less than 1/3 of task levels).
- **Use direct/indirect lighting to avoid glare and match daylight distribution.** Direct/indirect lighting keeps the brightest light sources out of view, and is a good pair with daylight spatial distribution. These systems require a clean, high reflectance ceiling and adequate ceiling height. Don't use pendant-style direct/indirect fixtures if ceiling height is less than 9' (2.9 m). For best light distribution, pendants should be hung at least 1'-6" (0.46 m) from the ceiling. A direct/indirect system will generally be more efficient at providing task illuminance than an indirect system.



*Direct lighting, typical candlepower distribution from ceiling-mounted luminaire*



*Indirect lighting, typical candlepower distribution from suspended luminaire*



*Direct/Indirect lighting, typical candlepower distribution from suspended luminaire*

- **Balance the light in a deep room.** In daylighted spaces greater than 15 ft (4.6 m) in depth, provide vertical illumination on back wall (using ceiling fixtures within two feet of wall or with wallwashers) with a cool color temperature greater than 4000°K to balance luminance differences between the front and back and prevent a gloomy feeling. Use walls or partitions with high-reflectance, light-colored surfaces.
- **Organize fixture layout to match daylighting distribution.** To ensure adequate illumination, group fixtures by areas of similar daylight availability (e.g., in rows parallel to window wall). Arrange lighting circuits in zones parallel to window wall for daylighting even if controls are not specified, to allow the possibility for controls to be added as retrofit. Recircuiting is generally difficult and costly in a retrofit project. However, retrofits for daylighting control are possible even with non-optimal circuiting, due to newer dimming and ballast control technology.

### ***Choose the Right Hardware***

- **Use 32-Watt T8 tri-phosphor fluorescent lamps and dimming ballasts.** Fluorescent lighting is the source of choice for both dimming and switching applications, because it can be efficiently dimmed over a wide range without changes in color and can be turned on and off virtually instantaneously. Most dimming fluorescent ballasts dim to 10-20% light output (@ 30% power), but “architectural” dimmers dim to 1% (these dimmers come at a cost premium).
- **Try to match the cool color temperature of daylight.** For best color temperature pairing with daylight, specify fluorescent lamps with a minimum color temperature of 4100°K.
- **Avoid high-intensity discharge lamps.** Most HID sources (metal halide, high pressure sodium and mercury vapor) are not appropriate for dimming applications because they suffer color shifts as they dim and have a more limited dimming range. (They can be used with appropriate switching in high bay spaces such as warehouses.)
- **Avoid lamps that do not dim well.** Don't specify 34-watt T12 lamps if planning to use dimming controls, because they do not dim reliably.
- **Choose energy-efficient hardware.** No matter what the lighting strategy, always choose the most cost-effective lighting technologies and the most effective controls available within the design budget.

## **Maximize Visual Comfort**

- **Follow recommended practice guidelines regarding glare from downlights.** To minimize direct glare, electric lighting should generally have a minimum Visual Comfort Probability (VCP) of 80% for computer-based tasks and 70% for other office tasks. Note that VCP is not defined for indirect lighting or any fixture with an upward component. VCP is defined as the percentage of people who find the lighting free of discomfort glare.
- **Keep ambient lighting low for computer screens.** If computers are present, ambient lighting should not exceed 30 fc (300 lux). But make sure that user-controlled task lighting is available for hard copy tasks. A rule of thumb for spaces with video display terminals (VDTs): provide as little light as possible on computer screens, 15-30 fc (150-300 lux) for surround lighting, and 50 fc (500 lux) on adjacent hard copy tasks. See IES RP-1 Guidelines and other IES literature (see TOOLS & RESOURCES) for assistance.
- **Keep lamp reflectance out of computer screens.** Limit the potential for reflected glare from ceiling lights in computer screens. If ceiling downlights are used, limit high angle brightness to no more than 850 candelas per square meter at 55 degrees altitude (preferably) and at 65 degrees (definitely). When installing computers, verify that the placement of the computer does not result in reflected images of ceiling fixtures in screen. If reflections are evident, adjust position or locations of screen or apply anti-reflection filters to computer screen face.
- **Watch ceiling brightness with computers.** Indirect or direct/indirect lighting is good for VDT users, but observe some rules about the ceiling brightness. Ceiling luminance for VDT tasks ideally has a ratio across the ceiling of less than 4 to 1. Ceiling and wall surface luminances should be less than 850 candelas per square meter at any angle, as averaged over a 2 by 2-foot (0.6m by 0.6m) area. In open plan areas, VDT workspaces benefit from lower, uniform lighting.
- **Avoid brightness glare from exposed lamps in the field of view.** Obstruct direct views of sources to avoid glare. Direct/indirect lighting is one method. Careful space planning is another.
- **Use lighting strategies to balance window glare if anticipated.** Keep luminance of interior environment high to balance window brightness if there are no architectural modifiers such as deep reveals, shading devices or elements to filter daylight. (See GLAZING SELECTION and SHADING STRATEGY to control window glare.) A slight wall or ceiling wash towards the back of the space (farthest area from window) is generally effective. A small increase in energy use for this purpose is acceptable.

- **Lighting quality comes before energy efficiency.** Don't reduce occupant comfort or satisfaction for higher energy savings. An occupant's productivity is far more expensive than the energy she uses.

## **Coordination**

- **Flag potential conflicts early**, such as furniture or colors that will interfere with light distribution, poor location or access for electrical rooms, and crowded ceiling plenums. Pick bright surround colors. Keep ceilings and walls as bright as possible.
- **Balance window glare with well-placed lighting.** Slightly raise the luminance of walls and ceiling regions away from the windows, to soften the contrast between the two. As noted above, this is especially important in deeper spaces.
- **Include calibration and maintenance plans in the construction documents.** Develop a set of recommended procedures and schedules for control system calibration, other lighting system commissioning, operation, maintenance and replacement, and format in a clear and easy-to-use package. Make this documentation part of the lighting construction documents. Provide documentation that can be passed along to the ultimate occupants of the space so that they can understand how to best use the lighting systems and controls.

## **INTEGRATION ISSUES**

### **ARCHITECTURE**

Location of the windows directly influences lighting control strategies and placement of photocell sensors. Coordinate with lighting design.

Quality of the perimeter spaces depends on blending and balance between daylight (a strongly directional light from the side providing high illumination and cool color) and the very different nature of electric lighting.

### **INTERIOR**

Interior surfaces, and especially the ceiling, must be light colored.

Coordinate workstations with window placement and fixture locations, especially for glare-sensitive workspaces (e.g., computers). Align view direction of VDT parallel to the window wall.

Locations of partitions and other tall furniture should not interfere with penetration of daylight. This may require re-orienting partitions or using translucent panels rather than opaque.

## HVAC

Lighting designer should supply a reasonable estimation of lighting power reduction due to daylight controls for the purpose of cooling load calculations. Expect the perimeter zones to have less than peak electric lighting loads at peak cooling periods (e.g., summer noon).

Locations of lighting fixtures and supply/return registers should be coordinated so as not to disrupt air flow.

## LIGHTING

Incorporating a daylighting strategy does not have a negative effect on lighting design. In fact, lighting quality is typically higher in a carefully daylighted space.

## COST-EFFECTIVENESS

Direct/indirect systems using pendant fixtures are typically a 50% cost premium over direct lighting fixtures. However, cost-effectiveness of a lighting system may ultimately depend on occupant satisfaction and owner avoidance of future retrofits.

Many efficient lighting technologies have short paybacks and often qualify for utility rebates or incentives, due to the very large percentage of building energy use consumed by lighting. Costs of some newer technologies (e.g., dimmable electronic ballasts) are falling rapidly with time. Be sure to use current cost estimates in your analysis.

## OCCUPANT COMFORT

A lighting system is not successful if occupants cannot comfortably perform their tasks.

Task illuminance under direct lighting is highly sensitive to the task location with respect to fixture and partition locations. Because lighting is fixed in place often long before furniture and partitions are installed, and because furnishing may be relocated in the future, direct lighting systems have a higher chance of leading to occupant dissatisfaction versus indirect systems.

## PROVISOS

- Relying on calculations or past experience alone may not yield satisfactory results in the final product because of the complex, dynamic qualities of daylight. It is strongly recommended that the architect and lighting designer work together with an outdoor physical scale model to assess the nature of the anticipated daylighted space. Confirm intuition with your observations of window glare, daylight quality, and distribution.
- Designing for a maximum of 1.5 watts per square foot for installed lighting is an easily achievable target. With efficient equipment and sensitive design, high quality lighting can be achieved at 1.0 watt per square foot or even lower.
- Do not use pendant-style fixtures with ceilings less than 9 ft (2.74 m).
- Simple changes in a building, like wall redecoration or furniture relocation, can have a strong influence on complicated lighting systems. If such changes are anticipated, a more flexible approach to lighting is recommended.

## TOOLS & RESOURCES

- **Design Professionals** Use a lighting specialist whenever daylighting controls are planned. Lighting designers (as opposed to electrical engineers) are recommended in general for a higher quality end result. Cost for added service is recouped in improved performance and occupant satisfaction, and gives the best chance at gaining energy savings.
- **Books** There are many titles available on general lighting design, but little to assist high performance lighting design with daylight controls. The IES may be the best source for literature.  
*Advanced Lighting Guidelines: 1993*, from the U.S. Department of Energy, is a thorough and informative guide to all aspects of various lighting technologies.
- **IES** The Illuminating Engineering Society is a resource for literature, standards, codes, guidelines and a monthly journal covering lighting, daylighting and visual comfort. These materials provide useful and up-to-date technical information. Local chapters also may offer classes or other resources. For publications, call (212) 248-5000, ext. 112.
- **EPRI** The Electric Power Research Institute has a collection of fact sheets, brochures, guidelines and software available. Call EPRI Lighting Information Office (800) 525-8555.
- **California Energy Commission** The CEC administers California Energy Code (Title 24) and offers good literature and design guidelines to assist with compliance, along with the code documents. Contact the CEC at (916) 654-4287 to request a publications list.
- **LBNL Lighting Systems Research Group** is a good source of information on all aspects of energy-efficient lighting practices. For a publications list, contact Pat Ross at (510) 486-6845, or visit the Group's website at <http://eande.lbl.gov/BTP>.
- **Lighting Research Center**, at Rensselaer Polytechnic Institute, is source of general information about lighting products and practice. Contact them at (518) 276-8716 or <http://www.lrc.rpi.edu>.
- **Utility Company** Many utilities offer workshops, design assistance, publications, and sometimes incentives for energy-efficient lighting equipment. Inquire at your local utility about new construction or retrofit programs.
- **International Association for Energy-efficient Lighting** The IAEEEL issues a useful quarterly newsletter free of charge. Write to IAEEEL, c/o NUTEK, S-11786, Stockholm, Sweden and request placement on the newsletter mailing list.
- **Calculation Methods** Well-established methods exist for calculating light levels with a proposed design. The best source for reference material on this topic is the IES (see above (i.e., the IESNA magazine *Lighting Design + Application*, Software Survey, September 1996)). Many lighting designers use daylighting software such as Lumen Micro and LightScope (available from Lighting Technologies, Inc., 303-449-1822), Luxicon (available from Cooper Lighting, 708-806-3553), LightCAD and BEEM (available from EPRI, 612-938-6014), and Adeline and Radiance (available from LBNL, 510-486-4757) in place of tedious hand calculations. A package that is capable of addressing daylight and electric light integration is recommended. For a list of lighting design software with daylight capabilities, request a "Daylighting Design Tool Survey" from the Windows and Daylighting Group at the Lawrence Berkeley Laboratory (510) 486-5605.
- **Scale Models** A physical model, built accurately with materials that match intended finish reflectances and viewed outdoors, is a good tool to assess window glare, daylight distribution, and quality of the daylighted environment. This is a quick and easy study activity useful for the architect and the lighting designer to perform together. See ENVELOPE AND ROOM DECISIONS for more information.

- **Full Scale Mock-ups** This is the only method for truly viewing the intended lighting scheme before construction. This can be costly and time-consuming unless the local utility or lighting manufacturer offers assistance, but is easily justified, at least for large projects.

## CHECKLIST

1. Review fenestration design and intended space plan for initial assessment of daylighting and glare concerns.
2. Estimate daylight levels through calculations, computer modeling or physical model photometry.
3. Select lighting strategy and type of control, depending on above two decisions.
4. Lay out the lighting system, coordinating with window placement and daylighting control zones. Be sure to produce an installed lighting power density lower than the energy code maximum.
5. Estimate electric lighting illuminance levels. Determine daylight and electric lighting distribution throughout each lighting zone and ensure that dimming zones maintain the required levels and distribution.
6. Select the most efficient technologies available within project budget that meet design objectives. Check with utility about lighting programs.
7. Calculate expected electric lighting savings due to daylight controls, for use in a cost/benefit analysis (see Section 11, COST/BENEFIT ANALYSIS). Provide expected lighting power reduction at peak times to mechanical engineer for cooling load calculations.
8. Review glare issues with architect. If window design or selection of window coverings is not anticipated to be adequate, compensate for window glare by balancing interior luminance distribution with the lighting design.
9. Flag potential conflicts with interior design, plenum elements, etc.
10. Include performance specifications, control system documentation, calibration instructions, other commissioning recommendations and maintenance plan with the lighting design documents.

### If you have...

#### no time

1. Design a lighting system at a maximum of 1.5 watts per square foot, with supplemental task lighting if necessary, fixtures grouped with windows and by daylighting zone, and special attention to glare in computer workspaces.
2. Estimate daylight levels before final system design and selection of control strategy.
3. Check for utility rebates before final design and specification.
4. Include previously described documentation with the construction documents.

#### a little time

In addition to above:

1. Include a lighting specialist on the design team.
2. Review glare concerns with the architect and take appropriate measures.

#### more time

In addition to above:

1. Consider a direct/indirect lighting strategy while exploring other alternatives.
2. Use lighting software and/or physical model photometry to estimate daylight levels and nature of the daylighted space.
3. Consider a full-scale mock-up of a typical workspace.

# Sensors & Controls

## OBJECTIVE

***Design and install a control system to dim lights and/or turn them off when there is adequate daylight.***

- Reduce lighting energy consumption with automatic controls.
- Use a lighting specialist for best results with the control system.

## KEY IDEAS

### *General*

- **Sensors “measure” light** by looking at a wide area of the office floor and work surfaces from a point on the ceiling. The sensor’s signal is then used by the control system to dim or turn off the electric lights according to the available daylight. These simple components are needed to save energy in daylighted spaces.
- **Controls can respond to many variables.** To save lighting energy, controls are typically designed to respond to daylight and a host of other inputs (e.g., occupancy sensors, weekend/holiday/nighttime schedules, etc.).
- **Include all control documentation in the construction documents.** This should include clearly developed control schematics, control sequences, calibration instructions, maintenance plans and checklists, and clear testing procedures.
- **Lighting controls and sensors must be properly calibrated and commissioned** prior to occupancy. This helps ensure energy savings and reduces the likelihood of complaints from occupants.
- **Take special care to document integrated control systems.** Control schematics are critical where different building systems (e.g., lighting, mechanical, etc.) come together. Identify responsibilities where integrated systems overlap, such as who adjusts each component, which warranties apply where, etc.

### *Type of Lighting Control*

- **Choose either dimming or switching hardware** for a particular lighting zone. The choice of dimming or switching (on/off) equipment is partly dictated by the control strategies selected:

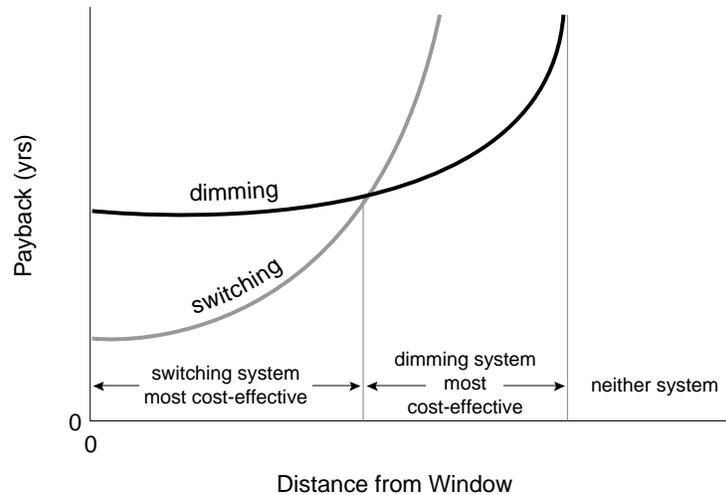
*Daylighting.* Lights are dimmed in response to interior daylight levels.

*Scheduling.* Lights are turned on, off, or dimmed according to day/night/holiday whole-building schedules.

*Lumen Maintenance.* Captures savings by dimming new lamps until their light output has dropped down to the design level through aging and dirt depreciation. Lumen maintenance employs the same hardware used for daylight dimming and saves 10 to 15% annually.

*Tuning.* Fine tune lighting levels after occupancy. Fine tuning is a control strategy where lighting is dimmed to meet local ambient or task lighting needs, and may save 10 to 15% of lighting energy.

- **Choose dimming hardware if daylighting, lumen maintenance, or tuning are the selected control strategies.** With the cost of dimming ballasts still high but falling, dimming control is at least twice as expensive as switching control but it is the best for implementing these strategies. It is also generally the most acceptable to occupants, because changes in the electric light levels are least disturbing. Daylighting and lumen maintenance strategies integrate well, since they use the same hardware. Dimming is generally not



*Dimming/Switching payback chart*

cost-effective in non-daylit areas unless coupled with scheduling controls. Dimming can capture all possible daylighting savings. For spaces with adequate daylight all day long and for non-critical visual tasks, switching may be acceptable, since the lights may adjust only once or twice during stable daylight hours.

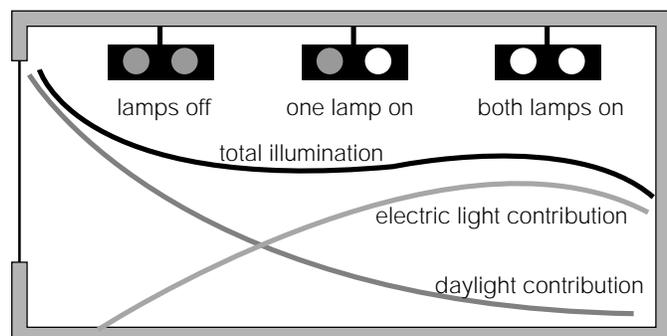
- **For all OTHER strategies, choose switching hardware.** Scheduling (either with automatic time controls or occupant sensors) can be implemented effectively with switching controls. Switching technologies are inexpensive, have a short payback period, and typically do not require special expertise to install. They are compatible with other lighting systems and are easily adjusted.
- **Select switching for daylight control with caution.** This hardware is less expensive than dimming, but has the disadvantage of abrupt light level changes. Switching is acceptable in intermittently occupied spaces or in spaces with fairly constant and adequate daylight all day (e.g., clear weather, large windows). In zones less than five feet deep from windows, simple on/off switching is the most cost-effective, especially if daylight is abundant. Do not use switching when it is anticipated that lights will turn on and off during occupied hours; case studies show occupants find this disruptive and will disable the system.
- **Do not count on manual controls.** Manual switching capability is already required by Title 24, but it is generally not well used by the typical office occupant. Use automatic controls to ensure that projected savings are actually achieved over time.
- **Use dual-level switching.** This wall-mounted switch reduces light levels by turning off individual lamps in 2-, 3-, or 4-lamp fixtures. This is the minimum switching requirement specified by California code. Dual-level or multi-level switching can also be activated by daylight sensors at less cost than dimming, but with better acceptance than simple on-off controls.

- **Use programmable time controls** for a more sophisticated form of scheduling control than simple timeclocks. This is good for facilities with many different daily schedules. Sweep-off control (after an initial warning, automatically sweeps off lights after the building closing hour) is effectively implemented with programmable controls and a manual override via wall switch or phone. This control strategy typically yields at least 15% savings in lighting energy and is helpful for picking up lights left on by after-hour workers or cleaning crews. If sweep-off control is used, wire lighting circuits back to the electric panel for operation by building controls.
- **Use occupancy sensors.** These are easily installed in wallboxes in lieu of manual switches. But only use wallbox occupant sensors if the sensor will have an unobstructed view of the space. If the sensor is obstructed, use a ceiling-mounted sensor instead. Occupancy control yields 15-30% savings and is highly cost-effective. Some units come with integrated photocells for both daylight and occupancy sensing.
- **Zones with daylighting should be separately switched from other zones,** even if daylight controls are not installed—this may be required by Title 24. This allows for future installation of daylighting controls if the project budget does not allow them in initial construction.

## Zoning

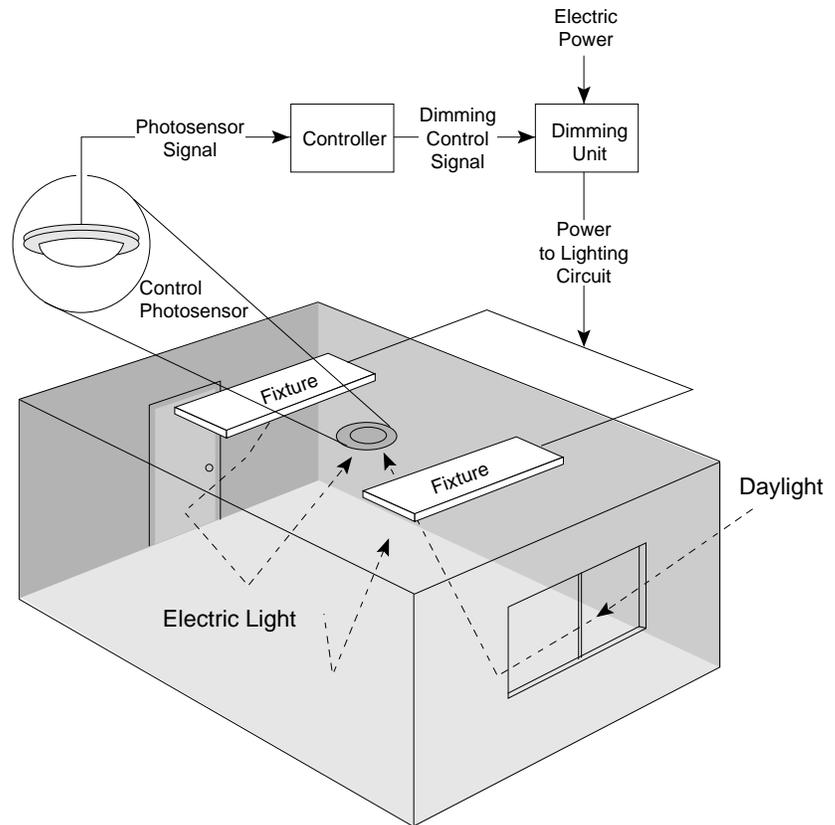
- **Control zones should match areas of similar daylight availability and space function** (e.g., conference, computer, etc.). In open plan areas with a uniform window facade, group fixtures in runs parallel to the window with separate control for each row in from the window (for strip windows), or in groups associated with each window (punched windows).
- **Design control zones to correspond to window shading device zones.** For example, if an individual office contains manually operable drapes or blinds, the entire office would generally form (at least) one control zone.
- **Limit the number of zones where possible.** Costs go up with the number of control zones, so make zones as large as practical. However, too large a zone can lead to some areas being underlit.
- **Any circulation space running along a window-wall should be a separate control zone.** If this area is well-daylit, its lighting can often be switched off.

*Schematic representation of lighting in a room with stepped lighting controls. The curves show relative light levels from both daylight and electric light. As the daylight level falls off with distance from the window, the electric lighting makes up the difference so that total illumination is evenly maintained at design levels throughout the room.*



## Daylight Control Algorithm

- Daylight control algorithms accommodate complexity.** They are the “smarts” that tell the electric lights what to do. Since the intensity and spatial distribution of daylight changes over time, these smarts have been designed to provide sufficient light under these complex conditions.
- Open- and closed-loop are the two basic algorithms for daylight controls.** “Open-loop” and “closed-loop” are common control terms that indicate whether (closed) or not (open) information is fed back to the system to achieve control objectives. Open-loop systems cannot compensate for electric light losses (lumen maintenance strategy), but afford greater flexibility in calibration than most closed-loop systems. They are also more “forgiving” to errors in sensor placement or field of view. Some closed-loop systems that work with daylight may cause electric light levels to drop below design light level under some conditions, especially if the photocell is located too close to the window or is able to “see” out the window.
- For switching systems, it is recommended that both the time delay and setpoint deadband be independently adjustable.** With variable cloudy conditions, the deadband adjustment alone may be insufficient to prevent system oscillation between the ON and OFF state (“hunting”).
- For switching systems, control trigger points should be carefully set to avoid occupant dissatisfaction.** The light level at which the device switches off should be at least twice the level at which it switches on (i.e., twice the light level produced by the luminaire) to ensure that the design illuminance is met at all times.
- System should be slow in response to sudden daylight changes.** The dimming response time (the time it takes for the system to respond to a sudden change in light level) is typically set around 30 seconds, to avoid unnecessary response to temporary conditions like moving clouds.



*Schematic diagram of a room with a photoelectric dimming system. The ceiling-mounted photosensor reads both electric light and daylight in the space, and adjusts the electric lighting as required to maintain the design level of total lighting.*

## ***Sensor Location***

- **Place sensor appropriate to the task location.** In a room with only one task area, place the ceiling-mounted sensor above the task. In a room with more than one task area, place the ceiling-mounted sensor above the task that best represents the daylight available. Some controllers support inputs from more than one photosensor. This allows daylight to be sampled at more than one location.
- **Sensor placement is determined by the daylight control algorithm.** For closed-loop control systems, locate the sensor at a distance from the window equivalent to approximately two-thirds the depth of the daylight control zone. Photosensor location is less critical with open-loop systems, and can be compensated for during commissioning. With a light shelf and an open-loop control system, locate sensor above the shelf.
- **Sensor placement differs with the type of lighting system.** With indirect and direct/indirect lighting systems, the photosensor should be located in the plane of the fixtures aimed downwards. Make sure that the sensors cannot directly “view” the electric lights they control. For direct lighting systems, recess the photosensor(s) in the ceiling.
- **Sensor field of view is important.** The photosensor’s field of view should not be too narrow and restricted or the sensor will be too sensitive to small incidental changes (papers moving on desk, people nearby, etc.). A ceiling-mounted closed loop sensor should have a large field of view and be shielded from direct light from the window. Some sensors come with sun shields for cases where the cell can not be placed far enough from the window. For switching systems, the photosensor (often a photorelay) is located so that it “views” the external daylight source with minimal (or no) view of the electric lights that it controls.

## ***Hardware***

- **Choose dimming electronic ballasts,** now available from several vendors. All dimming ballasts operate fluorescent lamps in rapid-start mode, i.e., the fluorescent lamp cathodes are supplied with power at all times during operation.
- **Choose a system with sufficient control flexibility.** Switching systems should allow independent control of the ON setpoint light level (the light level on the photorelay that causes the lights to switch ON) and the OFF setpoint.
- **Combine occupant sensors with photocells.** Many occupant sensors (especially wallbox units) include daylight photosensors, although this may not be an optimum location for sensing task daylight. If the

photosensor determines that the daylight level is adequate, the occupant sensor will not turn on the lights automatically when the occupant enters. The occupant may manually switch on the lights if desired.

- **Choose manual-on, automatic-off occupant sensors.** Several manufacturers now offer these sensors on the principle that occupants need help only in turning lights off, not on. The occupant must turn the lights on, and the sensor turns them off when occupant is absent. Some come with integrated daylight sensors.
- **Ensure compatibility of hardware components and controls;** especially when using controls from several different manufacturers (ballasts, ballast controllers, sensors, lamps, etc.).

### ***Occupant Satisfaction***

- **In general, dimming hardware is preferred by occupants** because the changes are less noticeable. If lighting changes are too abrupt, case study experience shows occupants tend to be disturbed or otherwise unsatisfied with the system. If the lighting controls are not expected to operate more than once or twice during occupancy (for example, if daylight levels are adequate all day such that the system perhaps operates only morning and evening), then switching hardware may be equally acceptable.
- **Switching hardware will be more acceptable if coupled with split-wired lighting.** Split-wiring, also known as stepped switching, allows lights to be switched in discrete steps (OFF, 1/2, FULL or OFF, 1/3, 2/3, FULL), so the changes are not so abrupt.
- **Avoid daylight controls on downlights.** Switching hardware with daylighting control is generally not acceptable for downlight fixtures, especially if fixtures are turned on and off (rather than split-wired), because occupants find automatic switching of electric lighting to be disruptively noticeable.
- **Occupants will disable a system they find unsatisfactory.** There may be any number of causes for negative user reaction to automatic controls. Choose an approach to controls that will most likely meet user needs, and ensure that the system will be installed and calibrated so that it operates properly. An unpredictable or poorly functioning system is a major cause of occupant dissatisfaction. Another problem may be the occupants' sense that the system is beyond their control. In these cases, visible manual controls are important, and manual overrides, while they may result in lower savings, will increase user satisfaction. Another problem witnessed in case studies is that an office with lights on signals that its occupant is in the building. Dimming strategies may be useful here. These issues should be discussed with the building owner during design and followed up with occupant education during the commissioning and occupancy phases.

## **INTEGRATION ISSUES**

### **ARCHITECTURE**

Window location, task location, and shading strategy affect control zoning.

### **INTERIOR**

Space planning, finishes, and furnishings are strongly tied to control zoning.

### **HVAC**

Perform load calculations accurately, with lights dimmed at peak cooling conditions. The lighting designer should supply expected lighting power reductions to the HVAC designer, or use advanced energy analysis software that can model daylight controls.

### **LIGHTING**

Control system and hardware must be compatible with other lighting equipment.

### **COST-EFFECTIVENESS**

Most building controls designed for energy efficiency are highly cost-effective, especially when supported by utility incentives. Simple lighting controls such as occupancy sensors are especially cost-effective.

### **OCCUPANT COMFORT**

Tolerance for fluctuation in electric lighting levels varies. We experience lighting fluctuation all the time in the natural environment but tend to find changes in the artificial environment disturbing.

Some people are uncomfortable with a highly automated environment. Others may want lights on for non-task reasons (e.g., employee is "in" the office). These and other reasons can cause occupants to disable the system. Discuss these issues with building owner, building manager, and occupants.

## **PROVISOS**

- Never turn off lights automatically at night in an occupied space without a prior warning, such as flashing the lights ten minutes before shut off. This gives occupants a chance to manually override the shut off.
- Calibration of automatic daylighting systems and occupant sensors should always be performed after furniture installation is complete (see CALIBRATION & COMMISSIONING).
- Daylight levels are hard to predict, however it's important to have a good estimate of expected daylight in order to choose between dimming and the less expensive switching hardware. Photometry in a scale model is recommended, although a hand or computer-based calculation is acceptable.
- Savings from daylighting controls depend on their regular and maximum use. This in turn depends on adequate daylight entering the space. Be sure window glare has been properly addressed during design so that occupants will not always be deploying opaque window coverings to control glare.

- Be sure automated lighting controls will be acceptable to the building occupants on principle. Dissatisfied occupants frequently disable lighting control systems for a variety of reasons, only some of which are related to comfort or visual performance.
- Occupants may inadvertently disable controls by rearranging furniture, placing portable heaters near occupancy sensors, etc. Avoid this by educating occupants as to the function and operation of the control system.
- Note this section does not treat mechanical HVAC controls, as these are not generally linked directly with daylight controls. However, other lighting controls can be integrated with mechanical controls (occupancy sensors are a good example).

## TOOLS & RESOURCES

- **Design Professionals** The use of a lighting designer with experience in daylighting controls is highly recommended.
- **Manufacturers** This is the primary source of assistance available for control system products. The more complex the system, the more critical it is to work closely with the manufacturer through design, calibration and commissioning.
- **IES** The Illuminating Engineering Society is a resource for literature, standards, codes, guidelines, and a monthly journal covering lighting, daylighting, and visual comfort. These materials address a large range of useful and up-to-date technical information. Local chapters also may offer classes or other resources. For publications, call (212) 248-5000, ext. 112.
- **EPRI** The Electric Power Research Institute has a strong collection of fact sheets, brochures, guidelines, and software available. Call EPRI Lighting Information Office (800) 525-8555.
- **California Energy Commission** The CEC administers California Energy Code (Title 24) and offers good literature and design guidelines to assist with compliance, along with code documents. Contact the CEC at (916) 654-4287 to request a publications list. Many lighting controls are already required by Title 24.
- **International Association for Energy-Efficient Lighting** The IAEEEL issues a useful quarterly newsletter free of charge. Write to IAEEEL, c/o NUTEK, S-11786, Stockholm, Sweden and request placement on the newsletter mailing list.
- **LBNL Lighting Systems Research Group** is a good source of information on all aspects of energy-efficient lighting practices. For a publications list, contact Pat Ross at (510) 486-6845, or visit the Group's website at <http://eande.lbl.gov/BTP>.
- **Lighting Research Center**, at Rensselaer Polytechnic Institute, is source of general information about lighting products and practice. Contact them at (518) 276-8716 or <http://www.lrc.rpi.edu>.
- **Calculation Methods** Accurate estimation of energy and peak demand savings due to daylighting controls is complicated and is best accomplished with advanced energy simulation software that can model daylighting. The best source for reference material on this topic is the IES (see above (i.e., the IESNA magazine *Lighting Design + Application*, Software Survey, September 1996)). Many lighting designers

use daylighting software such as Lumen Micro and LightScope (available from Lighting Technologies, Inc., 303-449-1822), Luxicon (available from Cooper Lighting, 708-806-3553), LightCAD and BEEM (available from EPRI, 612-938-6014), and Adeline and Radiance (available from LBNL, 510-486-4757) in place of tedious hand calculations. For a list of lighting design software with daylight capabilities, request a “Daylighting Design Tool Survey” from the Windows and Daylighting Group at the Lawrence Berkeley Laboratory (510) 486-5605.

- **ASHRAE** The American Society of Heating, Refrigerating, and Air Conditioning Engineers offers a wide range of technical support materials for mechanical systems, including the monthly *ASHRAE Journal*. Up-to-date controls information may be found in this literature. Call 800-527-4723 for a publications list. For *ASHRAE Journal* subscription information, call above number or 404-636-8400.
- **Utility Company** Some utilities offer workshops, design assistance, publications, and sometimes incentives for controls in both new and retrofit projects. Inquire at your local utility about these programs.
- **Books** Controls are changing so rapidly, especially in DDC (direct digital controls) and HVAC applications, that books on the topic are often quickly out of date. The most current information comes from manufacturers, the IES, and ASHRAE. Check the *Consulting-Specifying Engineer Magazine* (708-390-2387) or the ASHRAE Journal.

*Control Systems for Heating, Ventilating and Air Conditioning, 5th Ed.*, by R. Haines and D. Little (Van Nostrand Reinhold 1993).

*Advanced Lighting Guidelines: 1993*, from the U.S. Department of Energy, is a thorough and informative guide to all aspects of various lighting technologies.

## CHECKLIST

1. Discuss controls, occupant behavior, and occupant expectations with building owner.
2. Select either switching or dimming hardware for each zone, depending on control strategy.
3. Meet or exceed all Title 24 lighting control requirements.
4. Don't rely on manual controls for savings.
5. Programmable time controls, occupancy sensors, and lumen maintenance are all good strategies for energy efficiency on top of daylighting.
6. If daylight controls get cut from the budget at this point, switch daylighted zones separately anyway, to allow for daylighting controls in the future.
7. Lay out control zones to match daylight availability and space usage.
8. Choose the most appropriate daylight control algorithm.
9. Specify proper sensor locations, depending on lighting system, task locations, control algorithm, and sensor field of view.
10. Choose the right hardware.
11. Take extra time to coordinate any integration between control systems, such as an occupancy sensor that triggers both lights and a VAV damper.
12. Include full documentation of controls, along with calibration and maintenance plans, in the construction documents.
13. Address occupant satisfaction and education during the commissioning and occupancy phases.

## If you have...

### no time

1. Dispense with daylighting controls at this stage if you have not previously used them in a project. Perhaps they can be installed in the future.
2. Design the lighting system to accommodate the addition of daylighting controls in the future.
3. Follow Title 24 control requirements.

### a little time

1. Include a lighting designer on the project team.
2. Use dimming daylight controls as much as possible in perimeter zones.
3. If budget is restricted and daylight is abundant, use stepped switching instead of dimming hardware in perimeter zones.
4. Use simple on-off switching elsewhere.
5. Use occupancy sensors wherever appropriate.
6. Use time clock controls for after-hours savings.
7. Follow or exceed Title 24 control requirements.
8. Take care to anticipate occupant dissatisfaction with controls.
9. Make the control documents, including calibration and maintenance plans, part of the construction documents.

### more time

1. Include a lighting designer on the project team.
2. Perform computer analysis to accurately estimate control savings and use results in a cost/benefit analysis to help determine best combination and types of control strategies.
3. Use dimming daylight controls as much as possible in perimeter zones.
4. Use daylighting controls in a lumen maintenance strategy as well.
5. Use occupancy sensors wherever appropriate. Combine with the photocell in perimeter zones.
6. Use programmable time clocks and sweep-off control for after-hours savings.
7. Follow or exceed Title 24 control requirements.
8. Work with building owner to resolve any anticipated trouble with occupant acceptance of the control system.
9. Explore opportunities to integrate with mechanical controls and tie into energy management control system, if any.
10. Make the control documents, including calibration and maintenance plans, part of the construction documents.
11. Verify that occupants are satisfied with the controls after calibration and occupancy. Educate occupants and building manager about the function and purpose of the sensors and the control system.

# Calibration & Commissioning

## OBJECTIVE

*Commissioning ensures that all lighting control systems function as close to design intent as possible after installation and before occupancy.*

This is an especially important and mandatory phase of work.



## KEY IDEAS

### General

- **Establish budget, responsibility and commitment to commissioning from the earliest project phase.** Plan for this critical step from the beginning. Identify special areas of concern to the commissioning phase as they arise during programming and design phases.
- **Solve problems before occupancy through commissioning.** Many operations problems are there from start-up. Successful commissioning eliminates these problems before occupants arrive and gets the building off on the right track.
- **Use the commissioning phase also as a training period for Operations and Maintenance (O&M) staff.** Use this time to acquaint O&M personnel with building systems.
- **Carefully follow all appropriate commissioning steps.** This is a general sequence of activity:
  1. Visually inspect that each piece of equipment is in the right place, installed correctly, and calibrated to meet design specifications.
  2. Verify that all sensors have been properly placed.
  3. Verify local control of each piece of equipment.
  4. Test interactions between equipment pieces.
  5. Test system-wide operation under different anticipated scenarios.
- **Do not end the commissioning phase until the building is handed off to O&M personnel.** A successful hand-off includes:
  - Documentation of building systems for O&M staff use.
  - Description of O&M plans, schedule, and responsibilities.
  - Performance standards for all building systems.
  - Training of O&M staff.
- **Leave adequate documentation behind for O&M staff.** The following materials should be left on file in the building, easily accessible and in an easy-to-use format:
  - An index or directory of all documents on hand.
  - Equipment specifications, line diagrams, manufacturer's warranties, and contact information.
  - Operating manuals.
  - Maintenance procedures.
  - Test, calibration, and balance reports.
  - All construction documents, including as-builts.
  - Emergency procedures.

## ***Calibrating Lighting Controls with Photocell Sensors***

- **Establish baseline conditions.** Calibration will set the relationship between the light level detected by the control photosensor and the output of the electric lights that the photosensor controls.
- **Make sure actual electric lighting is as expected.** The response of any light-sensing control system must be calibrated after installation to ensure that the response of the electric lighting system is appropriate to the design lighting conditions in the building space.
- **Make sure actual daylighting is as expected.** The daylight levels in any space are highly dependent on local conditions (window size and transmittance, shading device and strategy, percentage of clear versus cloudy hours, room reflectances, etc.). It is not possible to “factory set” daylight linked controls and obtain optimum or even acceptable control system response without calibrating the system response upon installation.
- **Make sure system is in good working order.** Calibrating the system helps to uncover any installation errors and provides an opportunity for the system to be repaired before the vendor leaves the job.

### ***When to Calibrate Lighting Controls***

- **As soon as possible after system completion.** While it is better to commission after the furniture is in place, fine tuning can be done later when tenant improvements are made.
- **Lumen maintenance calibration should be performed shortly after installation,** after initial breaking in of lamps (fluorescent lamps should be burned for at least 100 hours at full light output to ensure stable lamp operation). In a retrofit installation, fixtures should be cleaned, relamped, and lamps burned in prior to calibration.
- **Re-calibrate after changes in a space.** Photosensors must be re-calibrated when room paint, carpet, wall art or furniture is modified.
- **For an open-loop system, calibrate during the day** when the sun is shining and not blocked by clouds (unless overcast skies predominate the region). There should be no direct sun shining into the space. Choose a time when daylight is plentiful but not enough to meet the design illumination without some supplemental electric lighting. There should be enough daylight to cause significant but not full dimming of the electric lights.
- **For a closed-loop system, calibrate at night.**
- **Coordinate lighting commissioning with other subsystem commissioning activities (e.g., mechanical system).**

## ***How to Calibrate Lighting Controls***

- **In general, follow manufacturer’s calibration instructions**, or request that commissioning be included with installation. Commissioning of controls generally requires specialized knowledge and skills. The following guidelines may be additionally useful for experienced electricians.
- **Calibrate each independently controllable zone (control group) separately.**
- **Select an appropriate stationpoint in each zone.** For each control zone, select one location that is representative of the daylighting and electric lighting conditions for that entire zone. This might be a desk that is a “typical” distance away from the nearest windows. A desk within eight feet of the control photosensor is a particularly convenient choice. These selected locations (at desktop height, or 30” above the floor, typically) are known as “stationpoints.” For large control zones (over 500 square feet), it may be desirable to use more than one stationpoint to represent the entire zone. For an open plan space with partitions, select the partitioned space nearest the photocell.
- **Open-loop calibration requires daylight.** If the system is open-loop, you must calibrate when there is daylight. See “when to calibrate” above. Calibrate an open-loop system as follows:
  - Have occupant adjust any window shades to a comfortable position. (If no occupant, use your best judgment).
  - If the system has a “maximum light” adjustment, have an assistant cover the photocell. Place your photometer at the stationpoint and adjust the output of the electric lights until the photometer reads the design light level (typically 500 lux, or 50 footcandles for office tasks). It may take up to a minute for the system to respond to the photocell being covered.
  - If system has a “minimum light” adjustment, uncover photocell and shine a flashlight on control photosensor. Use an assistant if necessary. After a minute, observe nearby fixtures; they should be substantially dimmed. If any appear to be flickering or unstable, increase the “minimum light” adjustment until flickering just disappears.
  - Now check the system sensitivity by uncovering the photocell and waiting a minute until the electric lights stabilize. Observe the reading on the photometer at the stationpoint. Adjust the sensitivity (adjustment typically at photocell or wall-mounted control box) until the photometer reads the design light level (typically 50 footcandles).

- Check the robustness of the calibration by adjusting the blinds and see if the photometer still reads the design light level. It should, to within a few footcandles.
  - Now use your eyes to check for comfort. Does the space appear gloomy or uncomfortably dim? If so, adjust the system sensitivity so that the photometer reads slightly higher than the design level (perhaps another 10 footcandles).
  - Mark up the reflected ceiling diagram to record stationpoint locations and a log for the readings, so that calibration can be checked from time to time after occupancy.
- **Closed-loop systems require nighttime calibration.** Calibrate a closed-loop system as follows:
    - Turn on the electric lights and adjust the setpoint until the electric lights are at maximum intensity. Verify this by checking the photometer at the stationpoint. Note this maximum light level reading. It should be about 40% over the design light level, assuming a 70% maintenance factor, new lamps and clean fixtures. Wait until thermal stabilization has been reached. This can take up to one hour. Recheck maximum reading. Now back off on the setpoint until the photometer reads 70% of the maximum reading.
    - If system has a “minimum light” adjustment, uncover photocell and shine flashlight on control photosensor. Use an assistant if necessary. After a minute, observe nearby fixtures; they should be substantially dimmed. If any appear to be flickering or unstable, increase the “minimum light” adjustment until flickering just disappears.
    - Mark up the reflected ceiling diagram to record stationpoint locations and a log for the readings, so that calibration can be checked from time to time after occupancy.
    - Return during the day with your photometer and do some spot checks at various stationpoints. They should read close to the design light level. Increase light level as appropriate to avoid dark workstations.

### ***Commissioning Automated Shades, Blinds, or other Window Coverings***

- **Follow manufacturer’s instructions** or request that commissioning be included with installation.
- **File any maintenance literature.** Keep manufacturer’s recommended maintenance procedures for the shades on file with other O&M documents.

## INTEGRATION ISSUES

### ARCHITECTURE

Calibration and commissioning activities have little impact on architectural design. If architect is coordinating all construction documents (CDs), ensure that calibration and commissioning plans are included in the CDs. The same goes for maintenance plans.

### INTERIOR

Coordinate schedule of interior completion with the commissioning schedule. System calibration is better accomplished if furniture and finishes are already in place.

### HVAC

Commissioning is an important phase for proper mechanical systems operation in a high performance building. Commissioning is especially important with advanced control systems.

### LIGHTING

Daylighting controls require calibration. Other lighting controls (not covered in these guidelines) should also be evaluated in the commissioning phase.

### COST EFFECTIVENESS

Cost effectiveness of daylighting relies on proper operation of lighting controls and satisfaction of occupants. Calibration is critical for maintaining the value of any added investment for daylight design.

In general, commissioning has been shown to very cost effective in the few buildings documented.

### OCCUPANT COMFORT

Check that occupants are satisfied with the lighting controls. If not, they may disable the system. Adjust the controls in response to occupant feedback. If occupants are resistant to automated controls, or if occupants dislike working under daylight alone, educate them as to the environmental benefits of daylighting. Explore the source of their dissatisfaction before their minds are set against daylight controls.

## PROVISOS

- *CAUTION:* Any electrical work must be performed by qualified personnel, following all appropriate safety procedures.
- Commissioning is a relatively new procedure not yet standardized. The design and construction industry is still working out how to do it, who should do it, and how it integrates with the construction and O&M phases. Make sure the building owner understands the benefits of proper commissioning.
- If the lighting system is calibrated before furniture is installed, control system response after occupancy could be unsatisfactory and would have to be re-calibrated.
- Calibration procedures vary from system to system. Guidelines given here should be used as general protocol only. Always follow manufacturer's calibration procedure first, then consult these guidelines for additional information. If there is a contradiction between the two, manufacturer instructions take precedence. Contact the manufacturer for clarification, if necessary.

- Commissioning generally requires specialized knowledge and skills. Hire someone qualified to make electrical adjustments. Control systems often contain high voltages that may be lethal.
- When controls are not functioning properly, occupants will disable them.
- Do not forget to re-commission after major changes such as space conversions, retrofits, and equipment replacements.

## TOOLS & RESOURCES

- **Manufacturers** This is generally the only source of assistance available for calibration of daylighting controls and commissioning of advanced HVAC control systems. It is advisable to make an agreement with the supplier regarding proper installation and calibration to design specifications. In fact, manufacturer selection might be based on the level of calibration support promised.
- **The National Environmental Balancing Bureau (NEBB)** (301) 977-9589 has a Procedural Guideline and also certifies firms that provide commissioning services.
- **ASHRAE** The American Society of Heating, Refrigerating and Air Conditioning Engineers offers a wide range of technical support materials for mechanical systems, including the monthly *ASHRAE Journal*. Up-to-date commissioning guidelines are often found in this literature. Call 800-527-4723 for a publications list. For *ASHRAE Journal* subscription information, call above number or 404-636-8400.
- **AEE** The Association of Energy Engineers publishes a number of periodicals on subjects ranging from energy management to lighting efficiency and environmental compliance. Call (770) 447-5083 for a publications list, or visit the AEE world wide web site at <http://www.aeecenter.org>.
- **Books** *ASHRAE Applications Handbook* (American Society of Heating, Refrigerating and Air Conditioning Engineers 1991) is a good source for testing, adjusting and balancing procedures. See also ASHRAE Guideline 1-1989, *Guideline for Commissioning of HVAC Systems*.
- **Utility Company** Some utilities offer incentives for commissioning in both new and retrofit projects. Inquire at your local utility about these programs.
- **Lighting Calibration Tools** Recommended tools for calibrating lighting controls:
  - Photometer in recent calibration (need not be expensive).
  - Powerful flashlight.
  - Opaque material to cover photosensor.
  - Reflected ceiling diagram showing locations of control zones.
  - Walkie-talkies if calibration controls are not line-of-sight with control zone(s) to be calibrated.
- **Diagnostic Tools** Calibration and commissioning are greatly assisted by appropriate measurement tools. A variety of devices ranging from data loggers to hand-held survey instruments can measure everything from simple dry bulb temperature to building power consumption. Many tools are inexpensive and easy to use. A good source for information is the monthly *Sensors Magazine*. Subscription information: PO Box 1285, Northbrook, IL 60065-1285. Publisher: Helmers Publishing, Inc., 174 Concord St., PO Box 874, Peterborough, NH 03458-0874, (603)924-9631.
- **Consultants** Specialized or unusual sensors and controls may require particular expertise. If the product manufacturer(s) will not provide assistance beyond installation, an outside specialist in calibration or commissioning activities may be advisable.

## CHECKLIST

1. Establish time, budget and responsibilities for the commissioning phase early in the building design process.
2. Have operation and maintenance staff on board during commissioning, for training.
3. Gather all building documentation, including the operation and maintenance plan and the system performance standards, in an orderly file, preferably stored in the building operator's office.
4. Confirm system performance standards (design light level, for example) before proceeding with calibration.
5. Review all calibration and other commissioning steps outlined in the construction documents with installers. These steps should follow the guidelines presented above, unless manufacturer instructions indicate otherwise.
6. Calibrate lighting controls after interior finishes and furniture are in place.
7. Commission HVAC system anytime after installation.
8. Commission automatic shades, if any, immediately after installation with help from the manufacturer/installer.
9. Verify proper interactions, if any, between those three systems.
10. Check occupant comfort and satisfaction shortly after occupancy. In particular, ensure occupants understand the purpose of automated lighting controls and will not disable them.
11. Commissioning team should remain available until the O&M staff is comfortable with all building systems, and the building is functioning as close to design specifications as possible.
12. Keep any tools acquired for calibration, such as a photometer, for use by O&M staff.

### If you have...

#### no time

1. Be sure all systems are installed per design and manufacturer specifications.
2. Follow lighting calibration instructions given here, with assistance from the manufacturer if possible.
3. Be sure all available building and product documentation available is on file in the building.

#### a little time

In addition to above:

1. Perform a thorough daylighting calibration. Secure agreement from manufacturer for assistance before purchase.
2. Have the mechanical system commissioned as thoroughly as budget allows, perhaps through some cooperative effort of manufacturer, installer and mechanical engineer. At a minimum, ensure space conditions are as intended.

#### more time

In addition to above:

1. Establish a dedicated commissioning team with appropriate expertise in daylighting controls, mechanical commissioning and energy management control systems. This team should include representation from controls manufacturers.
2. Commissioning phase should overlap both installation and occupancy. Commissioning team should be involved in training of O&M staff.
3. Include a comfort evaluation shortly after occupancy in the commissioning phase. This should also address any dissatisfaction or misunderstanding among occupants about the lighting controls.

# Maintenance

## OBJECTIVE

*Insure effective lifetime performance in energy efficiency and occupant comfort by keeping building systems operating to design specifications.*

- As the building ages and occupants change, follow scheduled maintenance procedures to sustain building value and performance.

## KEY IDEAS

### *General*

- **Make maintenance a priority.** Budget constraints and operations and maintenance (O&M) understaffing are a major cause for the poor operations of many buildings, leading to high, long term energy cost and equipment penalties. Allocate a budget for timely repair and preventive maintenance. Train personnel.
- **Keep documentation on file and update regularly.** Develop a set of easy-to-use recommended procedures and maintenance schedules and keep readily accessible in the building, along with manufacturer literature and warranties. Keep as-built drawings in the mechanical room and in the operating engineer's office. Update as required. Log all maintenance or replacement activities, modifications to original systems, space usage changes and other notable operations events. Keep track of the cost and effectiveness of upgrades and support this assessment, if possible, with any utility bill reductions due to the upgrade.
- **Proper commissioning gets O&M off on the right track.** When commissioning is successful, the building begins its occupancy phase with all systems functioning as close to design intent as possible. An accurate baseline for performance is established to guide O&M activities through the life of the building. O&M staff should be involved in commissioning, to assist in their training and to ease the hand-off of the building from commissioning personnel to O&M staff.
- **Involve building occupants.** Keep occupants informed of O&M activities when their comfort is a factor. Inform new occupants about design intent and use of control features (e.g., lighting controls). Locate occupants receptive to daylight utilization near the windows if possible. Suggestions or complaints can be used for trouble shooting. Occupants can be good team players for increased energy efficiency, if they are made aware of energy penalties in individual behavior patterns and encouraged to participate in reducing overall building energy use.
- **Keep an eye out for further energy efficiency opportunities.** When equipment needs replacing, review energy efficient technologies that may not have been available or affordable when the building was constructed. Also, check with the local utility for any possible incentives for replacement equipment. Evaluate energy impact of any proposed architectural changes such as additions, retrofits or major changes in space usage. Periodically review O&M procedures for possible improvement.

## ***Envelope and Lighting***

- **Keep all light-reflecting surfaces clean.** Elements in the building intended to assist daylight penetration or distribution should be regularly cleaned of dirt: windows, skylights, light shelves, exterior reflectors, sills, blinds, and ceiling.
- **Clean light fixtures once a year.** It is good building practice to clean the fixtures approximately once a year in relatively clean office environments, more often otherwise. Since lamps are typically replaced once every three years, fixtures are cleaned three times for each new set of lamps. Clean the photo sensor.
- **Re-lamp in groups.** When using standard-color lamps (cool white, white, etc.) it is generally cost effective to do a group re-lamping at 50-60% into the rated lamp life. If T8s are used and labor costs are low, it may be more cost-effective to spot re-lamp. When group re-lamping, functioning lamps should be appropriately marked and stored for spot-re-lamping needs. Group re-lamping is especially important to ensure effectiveness of lumen maintenance. At a minimum, wipe the fixture reflector and lens clean during re-lamping.
- **Replacement lamps should follow the original specification.** If lamp type or manufacturer is changed, check ballast-lamp compatibility.
- **Check that all controls are functioning as intended.** Make sure timeclocks, occupancy sensors, photocells, and nighttime setbacks are working properly and haven't been disabled or thrown off by building changes. Check at intervals recommended by manufacturer or as changes are made to the building.
- **Recalibrate controls when interior is modified.** Recalibrate light control system with each space change (furniture location or color, paint, carpet, etc.). See section on commissioning and calibration.
- **Rebalance the air if occupancy or window/lighting system is changed.** For example, if the equipment load has been reduced considerably, the supply air can be cut back based on new calculations.
- **Changes to space usage should follow design intent.** Ceilings should be kept uncluttered, furniture placement should not block daylight, interior colors to be predominately light, and so on.
- **Make sure occupants are not disabling photocells.** If so, find out why and explore a solution together with the occupant(s) in question. Educate occupants as to the benefits of daylighting.



## **INTEGRATION ISSUES**

### **ARCHITECTURE**

Design building with maintenance in mind. Location and accessibility of equipment, complexity of systems, and longevity of materials and products are important factors.

### **COST EFFECTIVENESS**

Poor O&M practices are cheap in the short term but can be costly in the long run. Poor O&M can waste energy, reduce equipment life, and reduce occupant comfort. Building owners or managers must use experience and educated guesswork to estimate the cost/benefit of proper O&M. Empirical evidence supports the claim that proper O&M is highly cost effective.

### **OCCUPANT COMFORT**

Comfort is dependent on systems operating as designed. Poor maintenance or lack of adjustment when space usage is changed often leads to occupant discomfort and complaints.

## ! PROVISOS

- Occupant comfort and productivity are more important than energy savings. O&M activities to preserve or increase energy efficiency should never impinge on comfort.
- Indoor air quality is a common occupant complaint. Treatment of this concern may conflict with original energy efficiency intentions of the mechanical system. Give indoor air quality priority.

## ↑ TOOLS & RESOURCES

- **ASHRAE** The American Society of Heating, Refrigerating and Air Conditioning Engineers offers a wide range of technical support materials, including the monthly *ASHRAE Journal*. Up-to-date maintenance information is often found in this literature. Call 800-527-4723 for a publications list. For *ASHRAE Journal* subscription information, call above number or 404-636-8400.
- **AEE** The Association of Energy Engineers publishes a number of periodicals on subjects ranging from energy management to lighting efficiency and environmental compliance. Call (770) 447-5083 for a publications list, or visit the AEE world wide web site at <http://www.aeecenter.org>.
- **BOMA** The Building Owners and Managers Association offers publications on a variety of topics, including a large selection of economic materials. Request a publications list from BOMA, PO Box 79330, Baltimore, MD, 21279-0330, (800) 426-6292.
- **Books** ASHRAE has many book titles available addressing maintenance (see above), including the useful *ASHRAE 1995 HVAC Applications Handbook*.  
*Energy Management Handbook* by W. Turner (Fairmont Press 1993) is somewhat dry but very thoroughly covers maintenance issues for all building systems.
- **Utility Company** Many utilities offer incentives for energy efficient equipment replacements. Inquire at your local utility about retrofit programs for lamp, ballast, and control system upgrades.
- **Diagnostic Tools** Troubleshooting, searching for energy improvements, and simple routine maintenance are greatly assisted by appropriate measurement tools. Devices ranging from data loggers to hand-held survey instruments can measure everything from dry bulb temperature to building power consumption. Many tools are inexpensive and easy to use. A good source for information is the monthly *Sensors Magazine*. Subscription information: PO Box 1285, Northbrook, IL 60065-1285. Publisher: Helmers Publishing, Inc., 174 Concord St., PO Box 874, Peterborough, NH 03458-0874, (603)924-9631.
- **Consultants** Outside specialists in optimum O&M and energy management are an option. For lighting control specialists, check with the manufacturer's support services or a local lighting engineer.



## CHECKLIST

1. Verify that O&M documents are on file. If not, create this file. What should be there:
  - An index or directory of all documents on hand.
  - Operating manuals and manufacturer warranties.
  - Performance standards for all building systems.
  - Maintenance procedures.
  - Responsibilities of the O&M staff.
  - Test, calibration and balance reports.
  - All construction documents, including as-builts.
  - Emergency procedures.
  - O&M staff training procedures.
2. Promptly update documents with each equipment modification or replacement.
3. Regularly follow all maintenance procedures as prescribed in the O&M documents.
4. Log all maintenance activities and changes in space usage.
5. Modify the recommended maintenance procedures or schedule if appropriate. Note this change in the O&M documents.
6. Keep photometer on hand and in good working order. Recalibrate before a required sensor recalibration.
7. Acquire diagnostic tools if regular maintenance alone isn't leading to specified system performance.
8. Choose energy efficient equipment when replacements are due. Contact utility company for possible replacement incentives.
9. Watch for further energy efficiency opportunities.
10. Monitor building energy data for any sign of savings erosion or any unusual energy use patterns. Find the problem and take corrective measures.
11. Engage building occupants as energy efficiency team players.

### If you have...

#### no time

1. Follow recommended O&M procedures according to recommended schedule, to the best of building operator's ability.
2. Promptly repair any equipment failures.
3. When replacements are due, choose the most energy efficient equipment available within allowed budget.

#### a little time

In addition to above:

1. Perform a comprehensive window and lighting systems evaluation once a year.
2. Periodically evaluate individual spaces for adequate performance of local controls.

#### more time

In addition to above:

1. Maintain a dedicated, full time O&M staff; size of the staff should correspond with building size and complexity.
2. Perform continuous local evaluations, sweeping through the building space by space. Complete the loop within a maximum of one year.
3. Enable O&M staff to work directly with occupants in reviewing individual energy efficiency opportunities.
4. Keep O&M staff informed of utility incentive programs and current equipment and control technologies.

# Cost/Benefit Analysis

## OBJECTIVE

***Make design decisions that deliver the best value to the building owner and future tenants.***

- Cost benefit analysis normally clarifies the trade-offs between first costs and operating costs. Unless the owner or designer can assign a monetary value for incremental benefits such as improved comfort, productivity, or well-being, they are not normally considered.
- Examine economic consequences at all stages, starting with planning, and continuing through occupancy, maintenance, and demolition.

## KEY IDEAS

- **Treat the building as a form of investment**, where the best investment scenario is probably not intuitively obvious. There will be complex trade-offs between many factors. As with any investment, cost/benefit analysis is appropriate.
- **Use cost/benefit analysis as a sales tool for energy efficiency.** Encourage the building owner, if necessary, to examine building costs over time. Energy-efficient buildings sometimes have higher first costs than more traditional designs; however, they generally have a much lower life-cycle cost.
- **Understand the owner's economic objectives before starting design.** Clarify the owner's economic horizon and financial requirements for this investment. This will set the criteria for how well your energy efficiency design strategies need to perform and to what degree these strategies may increase the building's first cost.
- **Treat amenity and comfort as a value.** Try to develop, with assistance from the owner, a value system for occupant comfort, productivity, increased building amenity due to daylighting, and other factors that are difficult to quantify. These are potential benefits from daylighting which can far outweigh energy savings in financial value. A reasonable assumption for these benefits, expressed in a dollars-per-square-foot value, can be directly included in cost/benefit analysis.
- **Gather your data.** What you generally need for energy efficiency cost/benefit analysis:
  - Characterization of the owner's investment criteria (available funds, discount rate, desired payback period, length of ownership)
  - Energy cost and escalation rates
  - Building energy performance
  - Construction costs
  - Maintenance and repair costs
  - Replacement schedule and costs

A more complex analysis may include more factors, such as financing costs, taxes, salvage costs, and more.

- **Get benefit information.** The judicious use of the proper window area, glazing type, and shading systems in conjunction with efficient lighting and controls will yield:
  - Decreased window solar heat gains
  - Decreased lighting energy
  - Decreased lighting heat gains
  - Improved visual and thermal comfort
- **Determine analysis objective.** The depth of cost information required depends on which of two typical objectives your cost/benefit analysis will target:
  - Assess consequences of a given decision.
  - Choose among alternatives.

In the first, comprehensive cost data will be required. In the second, only differential cost data are required.

## **INTEGRATION ISSUES**

### **ARCHITECTURE**

Using good performance simulation data with a cost/benefit analysis is the only way to review HVAC/lighting/envelope trade-offs. Added envelope and lighting features for daylighting and shading may be compensated for in first and operating cost savings.

### **INTERIOR**

Cost/benefit analysis for daylighting design has relatively little impact on interior decisions.

### **HVAC**

Use cost/benefit analysis to accurately examine how reductions in heat gains from the lighting and envelope system affect HVAC first costs and operating costs.

### **LIGHTING**

Many energy-efficient lighting technologies and controls pay back quickly.

Savings prediction of daylighting technologies and envelope/lighting design strategies for daylight integration are not so clear-cut. Life-cycle cost analysis is recommended.

### **COST-EFFECTIVENESS**

Cost effectiveness of energy-efficient design is best derived from a life-cycle analysis. Inclusion of hard-to-quantify factors such as comfort, productivity, tenant retention, and building amenity is recommended.

### **OCCUPANT COMFORT**

An emphasis on low first cost is often at the price of future occupant comfort. Discomfort is typically a long-term expense.

Uncomfortable occupants may lead to long-term increases in operating costs due to thermostat adjustments by occupants or portable heaters and fans adding to plug loads. Complaints often lead to a high rate of tenant

turnover and costly mechanical or envelope retrofits. Uncomfortable occupants are less productive.

There are real economic benefits to occupant comfort, although they are hard to quantify. Nonetheless, some recognition of comfort should be included in cost/benefit analysis.

## PROVISOS

- The ability to predict cost effectiveness is limited without actual building performance calculations, which are best done with advanced computer modeling software that includes daylighting analysis.
- True savings are impossible to predict exactly, due to major variables such as user behavior, future modifications to the building or site, important changes during construction, changes in utility rates, and lack of proper operation and maintenance.

## TOOLS & RESOURCES

- **Nomographs** A quick and simplified tool for cost/benefit analysis is included here, in the pages that follow. Use this tool in the early design stages to help determine the relative impact daylighting might have for your project. If the nomographs indicate a potentially high investment benefit from daylighting, then further design refinement and more extensive cost/benefit analysis would be worthwhile.
- **Simple Payback Analysis** This is commonly performed when the building owner is interested in technologies that pay for themselves in as short a time period as possible. Payback Period equals Initial Cost of the Technology (or differential cost over its equivalent) divided by Annual Energy Savings due to this Technology. If you have access to the savings and cost information, you can easily perform this calculation yourself. A mechanical engineer's standard load calculation can provide energy information, while manufacturers can give you cost estimates. In other cases, you may not need computer analysis of performance. For example, simple payback analysis can be used to choose between two different pieces of lighting equipment, simply by using the power rating of the equipment, an estimate of how many hours per year the equipment will run, the typical electricity charge (ask local utility), and the product cost (ask a manufacturer's representative).
- **Life-Cycle Cost Analysis** This is a preferred method of cost analysis, because it takes into account the time value of money. However, it is too complex to be explained here. Check with an appropriate expert or your local utility, or consult the large array of literature available on this subject, such as the documents noted below.
- **Consultant** A detailed cost/benefit study requires specialized knowledge in both energy modeling and economic analysis. A consultant with experience in these areas is recommended for projects where the building owner's financial concerns are paramount.
- **Utility Company** Your local utility may provide design assistance or financial incentives. Many utilities have customer service educational centers equipped with rotating displays, seminars, and staff available to answer questions on specific projects.
- **NTIS** Many documents and guidelines are available from the National Technical Information Service. Write to NTIS, Springfield, Virginia 22161 for a publications list.

- **AIA** "Life Cycle Cost Analysis - A Guide for Architects" (American Institute of Architects, Washington D.C. 1977) is a useful handbook. Contact your local AIA chapter for this and any other relevant AIA publications. Or ask for a publications list from the national office: (800) 365-ARCH.
- **BOMA** The Building Owners and Managers Association offers publications on a variety of topics, including a large selection of economic materials. Request a publications list from BOMA, PO Box 79330, Baltimore, MD, 21279-0330, (800) 426-6292.
- **Computer Tools** "Building Life-Cycle Cost" program (BLCC) is available from NTIS at the above address.
- **Books** There are many titles available on cost/benefit analysis, covering the general topic as well as specific applications. Consult an architectural bookstore.

*Building Control Systems* by V. Bradshaw (Wiley and Sons 1985) includes a thorough treatment of economics.

*Energy Management Handbook* by W. Turner (Fairmont Press 1993) has an economics chapter.

## **CHECKLIST**

1. Begin thinking about cost-effectiveness in early design. Once you have an idea of building shape and size, intended usage, floor-to-ceiling height, and possible window configuration, you are ready to do a preliminary analysis.
2. Gather necessary economic data as discussed above.
3. Use the Nomograph Tool here for a preliminary check on daylighting savings and cost-effectiveness. Use the tool to compare design alternatives under consideration.
4. Contact local utility for information on possible incentives.
5. If owner desires more exact cost/benefit analysis, contact utility for possible assistance.
6. Discuss further analysis with mechanical engineer.
7. Or, explore possibility of hiring a consultant.

### **If you have...**

#### **no time**

1. Use the nomographs here, using default values given. Discuss results with building owner.

#### **a little time**

1. Use the nomographs here with better values for design details, energy costs, and owner's investment criteria. Discuss results with building owner.
2. If mechanical engineer's load software can include daylighting, calculate energy performance at an early stage (make assumptions about design details not yet resolved). Use that computed value of annual energy savings in Nomograph 4, in place of the annual savings found in the other nomographs. Discuss results with building owner.

#### **more time**

1. Perform a more exact cost benefit analysis. Locate either a source of consulting assistance or learn to do it yourself. See the list of resources on page 11-3.

---

## **NOMOGRAPH TOOL**

### **The Nomograph Cost/Benefit Tool for Daylighting**

A nomograph is a graphic way to present a formula that has several variables. Rather than doing the calculation mathematically, a nomograph user can “walk” through a diagram. This is an easy alternative to working out an equation, plus the graphic presentation nicely illustrates the relative importance of various parameters to the overall solution.

These nomographs are a preliminary tool for roughly assessing the potential impact of daylighting on the energy use of non-residential buildings. Use these nomographs to help decide whether or not daylighting makes much sense to pursue further. Or use them to make a decision between early design alternatives.

Cost/benefit analysis for energy-efficient design typically requires complex computer modeling to predict the building’s energy performance. These nomographs offer a simplified and easier alternative, because they have the computer analysis already built into them. The nomographs were developed after extensive computer modeling of a generic non-residential building. Many design assumptions had to be made for this model. Even though your project may differ significantly from this model, the results of a nomograph analysis should be reasonable, as long as your project is not a major departure from standard practice design. The computer analysis used Seattle (high latitude, predominately overcast) as the location for the generic building. Most other U.S. locations would achieve better daylighting performance, therefore many projects would find these nomograph results to be conservative.

### **Limitations to the Nomograph Tool**

This tool will not deliver a guaranteed answer about cost-effectiveness.

This tool only takes into account the electric lighting energy reductions due to daylighting. It does not account for the beneficial reductions in HVAC cooling energy use (i.e., chiller and fan use) due to heat gain reductions from the electric lighting and window system. This will lead to a conservative estimate of cost-effectiveness. If the nomographs indicate good potential savings with daylight, then a more detailed analysis that includes the impact on HVAC first and operating costs due to daylighting should be performed.

This tool becomes less useful as design progresses. As the building develops further, greater accuracy is expected. A more detailed analysis tool, modeling the specifics of the building and including important factors left out by the nomographs, will deliver the level of information necessary to make late design decisions.

### **How to Use the Nomograph Tool**

This is a seven step process. Your first time through may take an hour. Once you are familiar with the nomographs, you will be able to compare different design options and investment scenarios in just minutes. Each step is thoroughly explained in the pages that follow.

Use a photocopy of the worksheet provided to record values as you go. The first three nomographs are in preparation for the last four. The values from Nomographs 1-3 will be needed for the more complicated Nomographs 4-7.

Nomographs 4-6 determine savings associated with the energy use reduction due to daylighting. You can stop there if you simply want to find these numbers to compare different design strategies, for example.

Use Nomograph 7 to complete the cost/benefit calculation. This nomograph provides a range of economic information, including justifiable investment. In order to complete your study, you will need to obtain (from another source) the differential construction costs for the proposed daylighting scheme over a non-daylighted equivalent.

# Nomograph Worksheet

	ITEM	YOUR PROJECT	DEFAULT VALUE
1	Latitude		See list in Step 1
2	Daily Occupancy Schedule		8 am - 6 pm
3	Gross Area per Floor (ft <sup>2</sup> )		
4	Typical Floor Shape (Width-to-Length Ratio)		1:1.5 (see Step 3)
5	Daylight Zone Depth		15 feet (see Step 3)
6	Lighting Control Type		One Step (see Step 2)
7	Illumination Level (fc)		50 (see Step 2)
8	Useful Window Ratio		0.65 (see Step 2)
9	Glazing Visible Transmittance (VT)		0.60 (see Step 2)
10	Useful Window Ratio x VT		0.39 (see Step 2)
11	Annual Hours of Occupancy		2500
12	Installed Lighting Load (W/ft <sup>2</sup> )		1.5 (see Step 5)
13	Electricity Cost (\$/kWh)		0.09 (Ask local utility)
14	Gross Total Building Area (ft <sup>2</sup> )		
15	Non-Lighting Electric Loads (W/ft <sup>2</sup> ) (HVAC, plug loads, etc)		3.5 (see Step 6)
16	Peak Demand Rate(\$/kwh-month)		(Ask local utility) (See Step 6)
17	Daylit Hours (%)		Find in Step 1
18	Control Effectiveness (%)		Find in Step 2
19	Dimming Factor (%)		80 (see Step 4)
20	Daylit Area (%)		Find in Step 3
21	Annual Energy Savings due to Daylight (%)		Find in Step 4
22	Daylight Peak Load Savings (%)		Find in Step 4
23	Non-Daylit Lighting Energy Consumption (kWh/ft <sup>2</sup> - year)		Find in Step 5
24	Non-Daylit Lighting Energy Cost (\$/ft <sup>2</sup> - year)		Find in Step 5
25	Daylighting Energy Consumption Savings (kWh/ft <sup>2</sup> - year)		Find in Step 5
26	Daylighting Energy Cost Savings (\$/ft <sup>2</sup> - year)		Find in Step 5
27	Annual Daylighting Energy Savings (\$)		Find in Step 5
28	Non-Daylit Peak Demand (kW)		Find in Step 6
29	Non-Daylit Monthly Demand Charge (\$/ft <sup>2</sup> - month)		Find in Step 6
30	Non-Daylit Annual Demand Charge (\$/ft <sup>2</sup> - year)		Find in Step 6
31	Daylit Peak Demand Savings (kW)		Find in Step 6
32	Daylit Monthly Demand Savings (\$/ft <sup>2</sup> - month)		Find in Step 6
33	Daylit Annual Demand Savings (\$/ft <sup>2</sup> - year)		Find in Step 6
34	Total Annual Savings (\$/ft <sup>2</sup> - year)		Find in Step 6
35	Justifiable Investment (\$/ft <sup>2</sup> or \$/project)		Find in Step 7
36	First Year Savings (\$/ft <sup>2</sup> or \$/project)		Find in Step 7 (or same as line 34)
37	Payback Period (years)		10 (ask building owner) (Step 7)
38	Rate of Return or Discount Rate (%)		8 (ask building owner) (Step 7)
39	Energy Escalation Rate (%)		8 (ask local utility)

## STEP 1

***Determine what percentage of occupied hours will find daylight available.***

### ■ FIRST

Find the latitude of your site, or choose closest California city:

San Diego:	32°	Fresno:	36°	Chico:	39°
Santa Ana:	33°	Modesto:	37°	Redding:	40°
Los Angeles:	34°	San Francisco:	37°	Eureka:	41°
Bakersfield:	35°	Stockton:	38°		
San Luis Obispo:	35°	Sacramento:	38°		

—> Record latitude in Line 1 of the worksheet.

### ■ SECOND

Estimate the typical daily schedule of occupancy (default 8 a.m. to 6 p.m.).

—> Record schedule in Line 2 of the worksheet.

### ■ THIRD

If you see your daily schedule on one of the curves (e.g., 9 a.m. - 7 p.m.) in Nomograph 1A, then:

- Find your latitude at the bottom and move up vertically until you intersect your schedule curve.
- Then move left and read your Annual Daylight Hours %.

—> Record Annual Daylight Hours % in Line 17 of the worksheet.

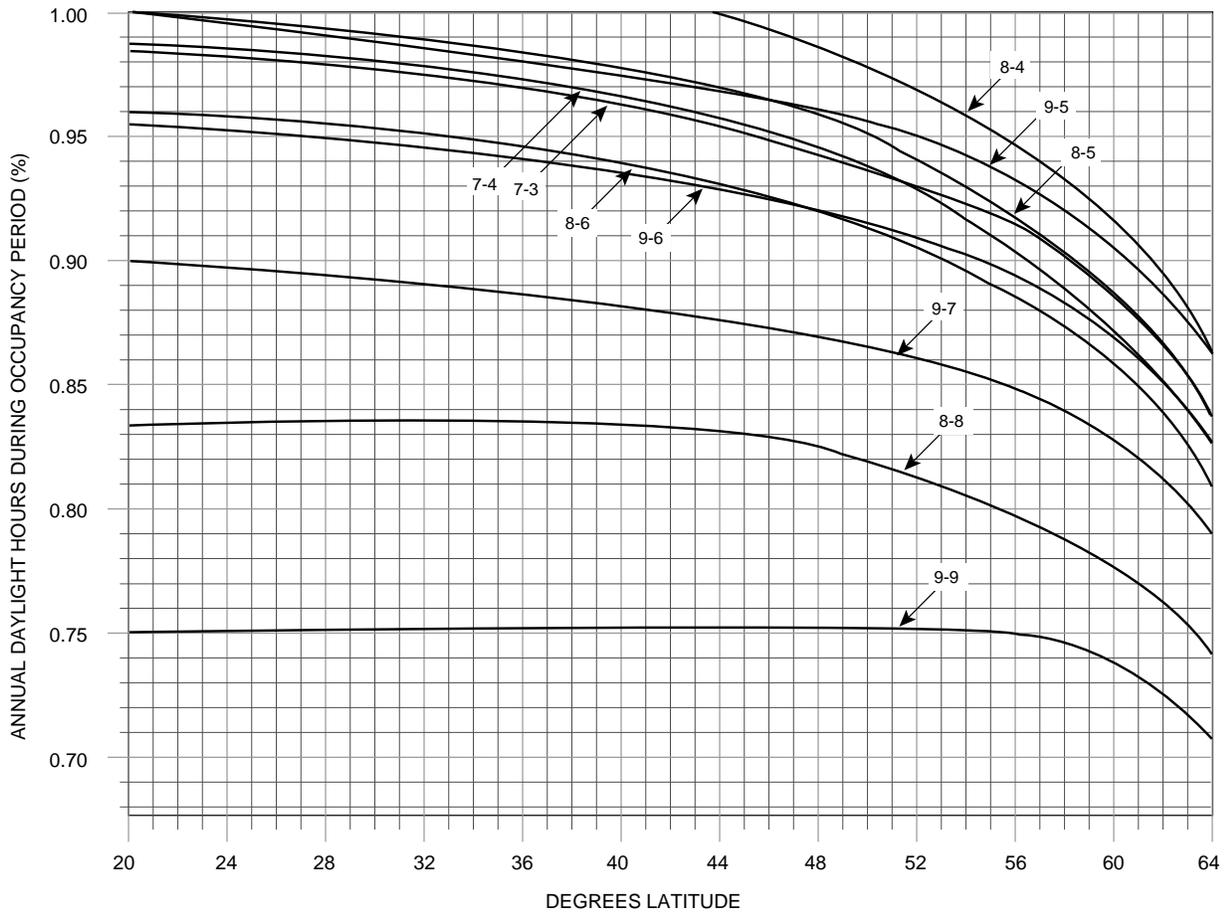
### OR

If you *do not* see your daily schedule in Nomograph 1A, use Nomograph 1B.

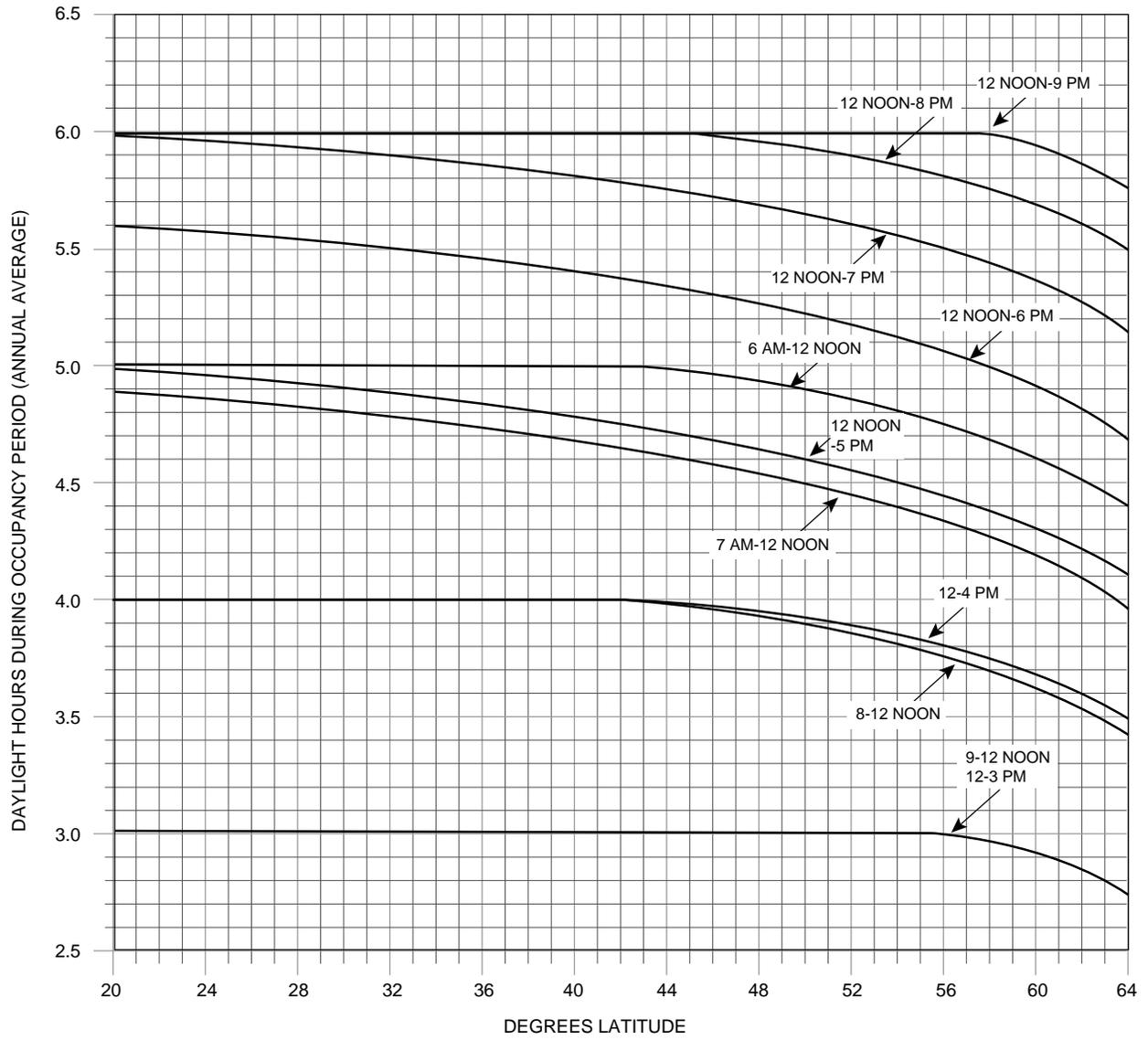
- Find your latitude at the bottom and move up vertically until you intersect your *morning* schedule curve.
- Then move left and read your Daylight Hours Annual Average.
- Repeat for afternoon schedule.
- Add both daylight hours together.
- Divide by total number of daily occupancy hours.
- Multiply by 100 to get Annual Daylight Hours %.

—> Record Annual Daylight Hours % in Line 17 of the worksheet.

*Note: Daylight Savings Time has already been accounted for in these nomographs.*



Nomograph 1A



Nomograph 1B

## STEP 2

### *Find the percentage savings due to daylighting controls.*

---

#### ■ FIRST

Make an assumption for Lighting Control Type:

- One-Step control is least expensive, but it causes abrupt light changes and can be distracting. It is often an acceptable choice for areas with plenty of expected daylight constantly through the day.
- Continuous dimming is most expensive, but is less disturbing to occupants and tends to deliver higher energy savings.

—> Record Lighting Control Type in Line 6 of the worksheet.

#### ■ SECOND

Make an Illumination Level assumption.

- 30 footcandles (fc) is a good ambient light level. Choose this for spaces with lower lighting needs, such as computer VDT environments.
- 50 fc is appropriate for typical desk work.
- 70 fc is a higher light level appropriate for close, detailed tasks.

—> Record Illumination Level in Line 7 of the worksheet.

#### ■ THIRD

Calculate Useful Window Ratio for a typical office or bay:

$$\text{Useful Window Ratio} = \frac{\text{Net glazed window area above the workplane (e.g. above 30" from floor)}}{\text{Total interior window wall area from floor to ceiling}}$$

—> Record Useful Window Ratio in Line 8 of the worksheet.

#### ■ FOURTH

Choose a Glazing Visible Transmittance (VT)

- If unknown, see the list in Section 2 (Daylight Feasibility) of these Guidelines.

—> Record Glazing Visible Transmittance in Line 9 of the worksheet.

#### ■ FIFTH

Multiply Useful Window Ratio x Glazing Visible Transmittance (VT)

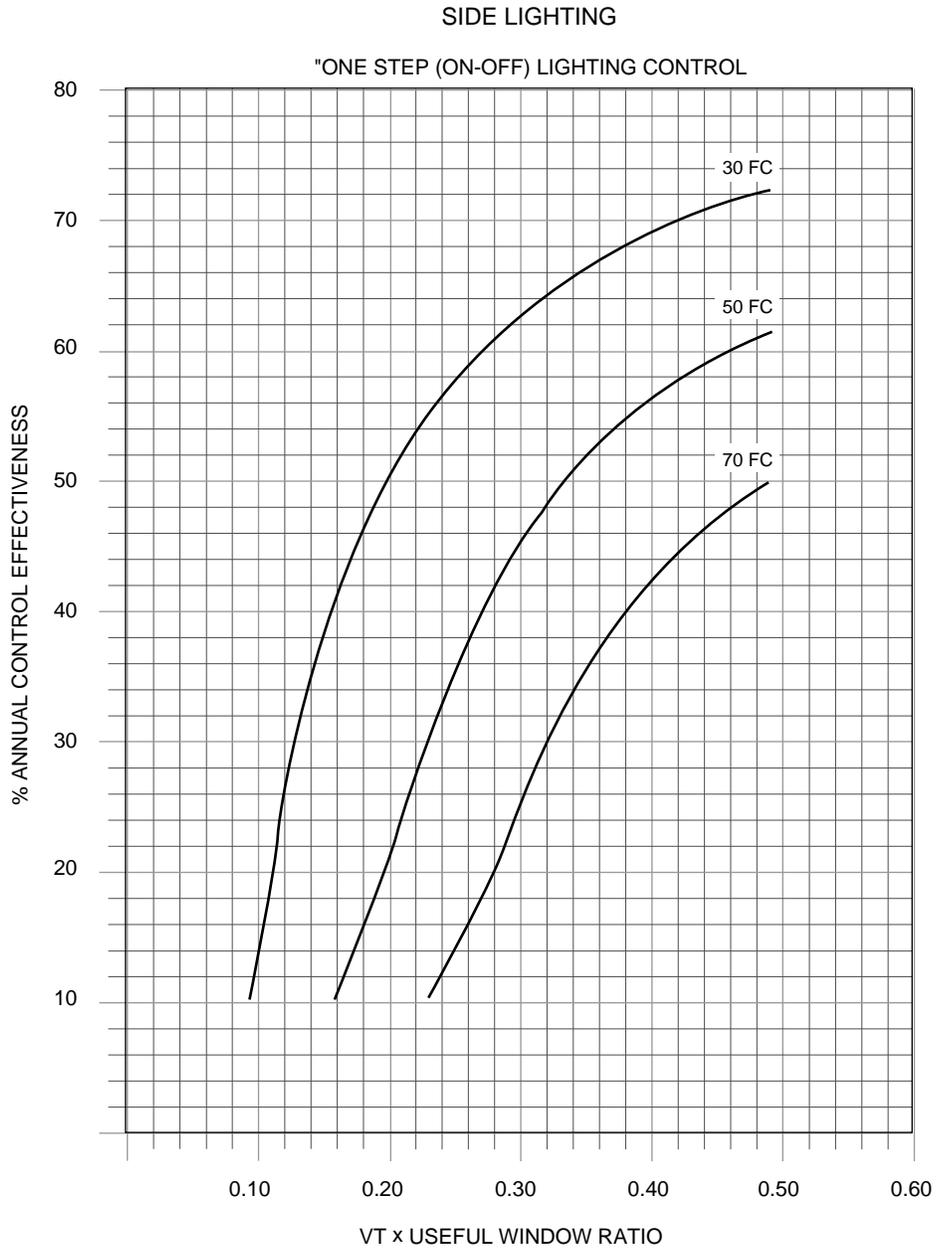
—> Record in Line 10 of the worksheet.

#### ■ SIXTH

Use one of the nomographs to find Control Effectiveness %.

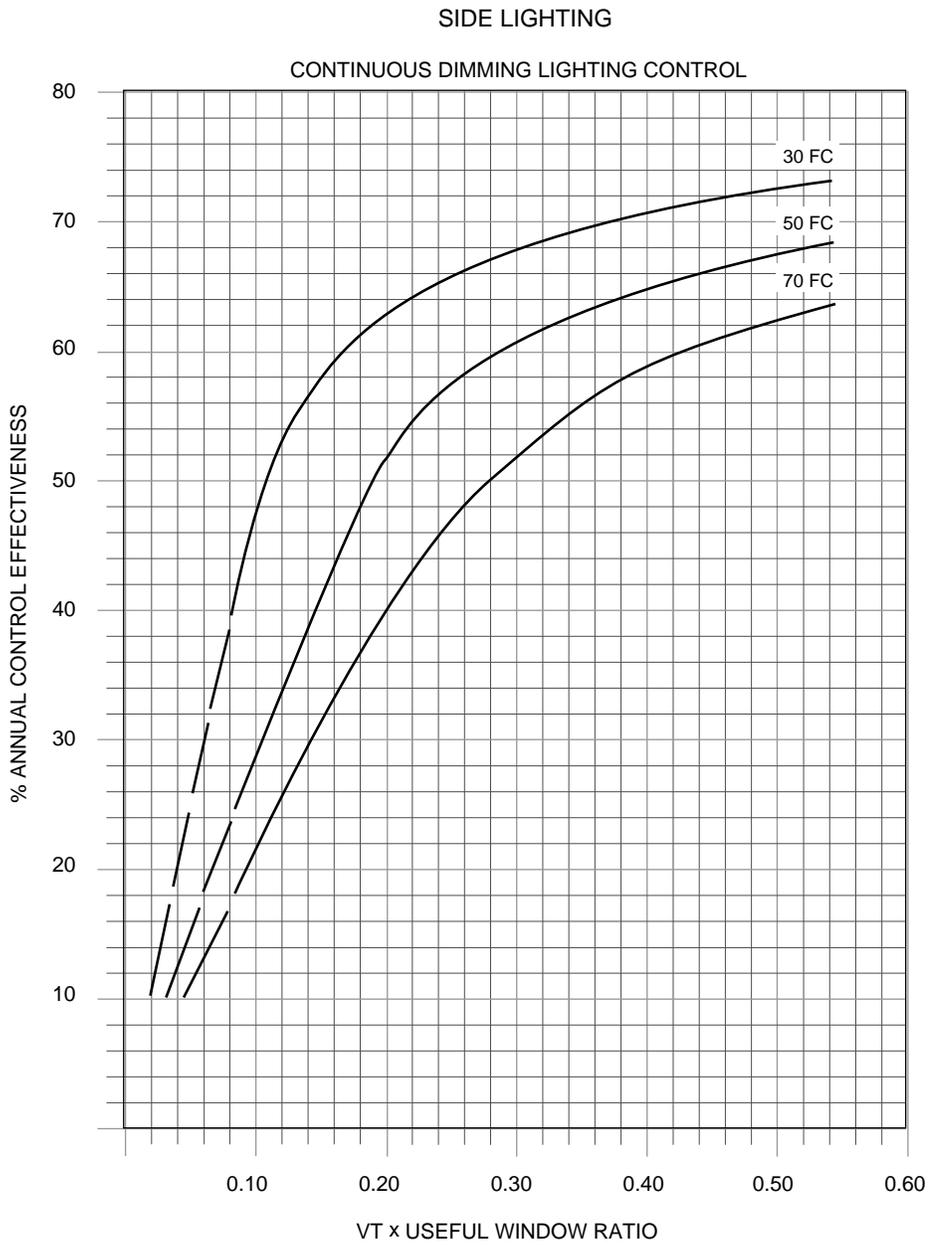
- Use Nomograph 2A if you assume One-Step controls.
- Use Nomograph 2B if you assume Continuous Dimming controls.
- Begin at the bottom with your value for Useful Window Ratio x Glazing Visible Transmittance (worksheet Line 10).
- Move up to intersect your Illumination Level curve (worksheet Line 7).
- Move left to read your Control Effectiveness %.

—> Record Control Effectiveness % in Line 18 of the worksheet.



**Nomograph 2A**

*One-Step Controls*



**Nomograph 2B**

*Continuous Dimming*

## STEP 3

*Find the percentage of total floor area that can be daylighted.*

---

### ■ FIRST

Make an assumption of how deep your daylighted zone will be.

- If small private offices will predominate along the perimeter walls, or if window head height is 7 feet or lower, assume a 10-foot zone.
- If office layout is unknown, assume a 15-foot zone. This is a typical daylighted zone depth.
- If layout is to be open-plan with low partitions, or if ceiling is higher than 9 feet with a correspondingly high window head, assume a 20-foot zone.

—> Record Daylighting Zone Depth in Line 5 of the worksheet.

### ■ SECOND

If building is not a rectangular box, then calculate Daylit Area % directly from floor plans.

- For a typical floor:

$$\text{Daylit Area \%} = \frac{\text{Daylighting Zone Depth (ft)} \times \text{Total Perimeter Length (ft)}}{\text{Total Floor Area}}$$

—> Record Daylit Area % in Line 20 of the worksheet.

### OR

Use one of the nomographs to find Daylit Area %.

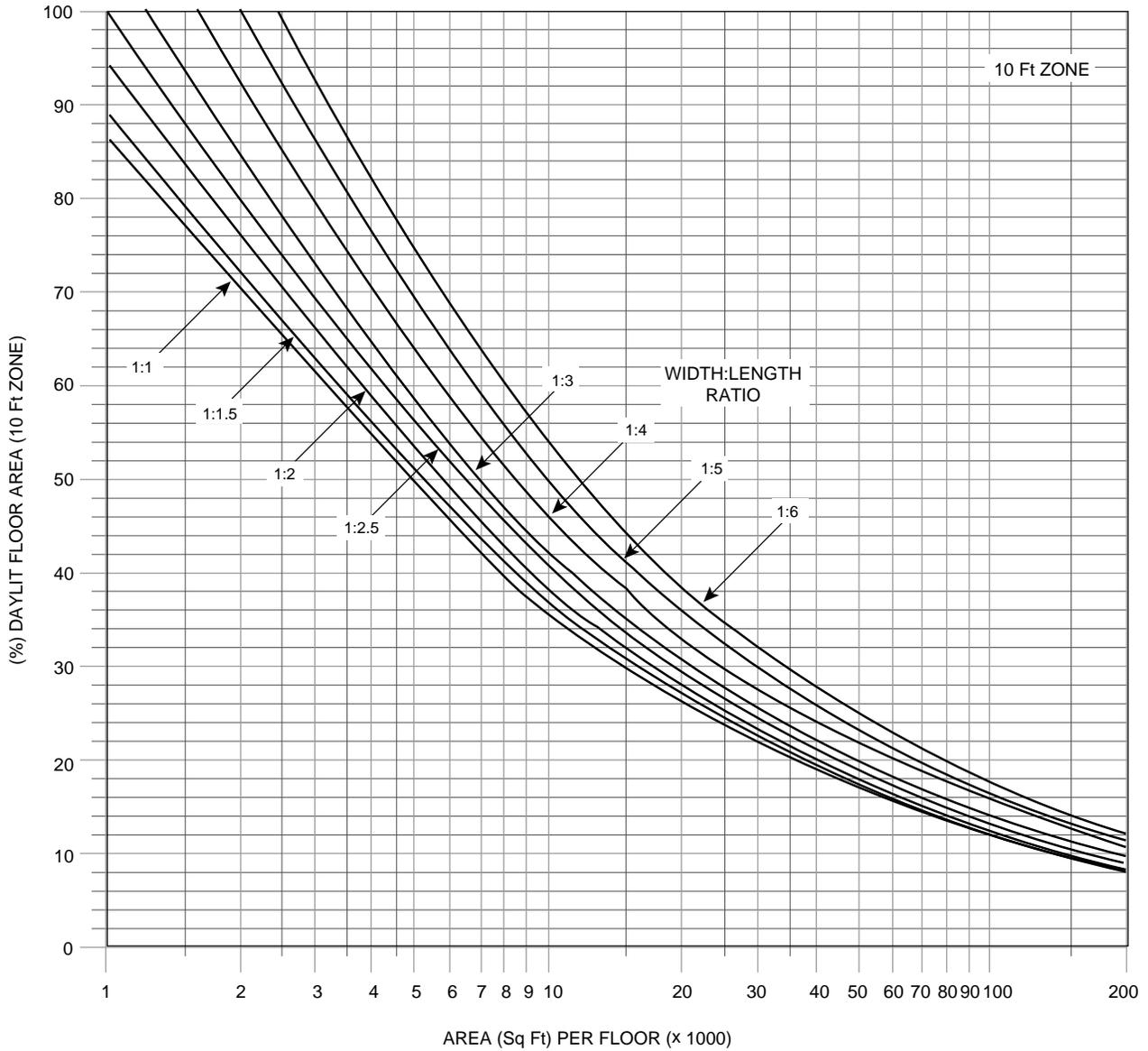
- Calculate your Width-to-Length Ratio. For example, if a typical floor is 100 ft by 150 ft, the ratio is 1:1.5.

—> Record Width-to-Length Ratio in Line 4 of the worksheet.

—> Record the square footage of a typical floor in Line 3 of the worksheet.

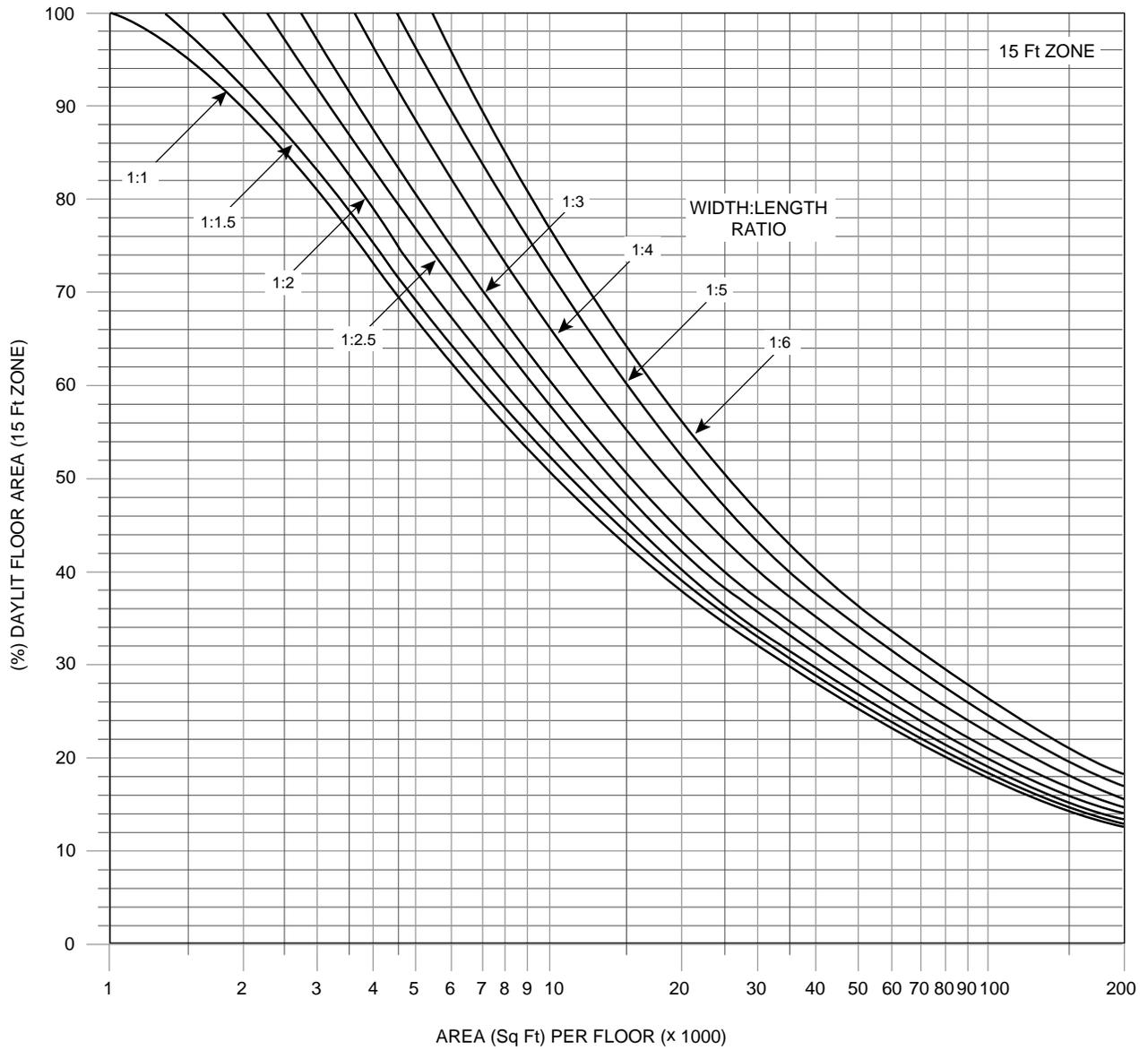
- Selecting one of the nomographs, start at the bottom with your Area per Floor (divided by 1000), move up to intersect your Width-to-Length Ratio curve, and move left to read Daylit Area %.
- Use Nomograph 3A for a 10-foot Daylighting Zone Depth.
- Use Nomograph 3B for a 15-foot Daylighting Zone Depth.
- Use Nomograph 3C for a 20-foot Daylighting Zone Depth.

—> Record Daylit Area % in Line 20 of the worksheet.



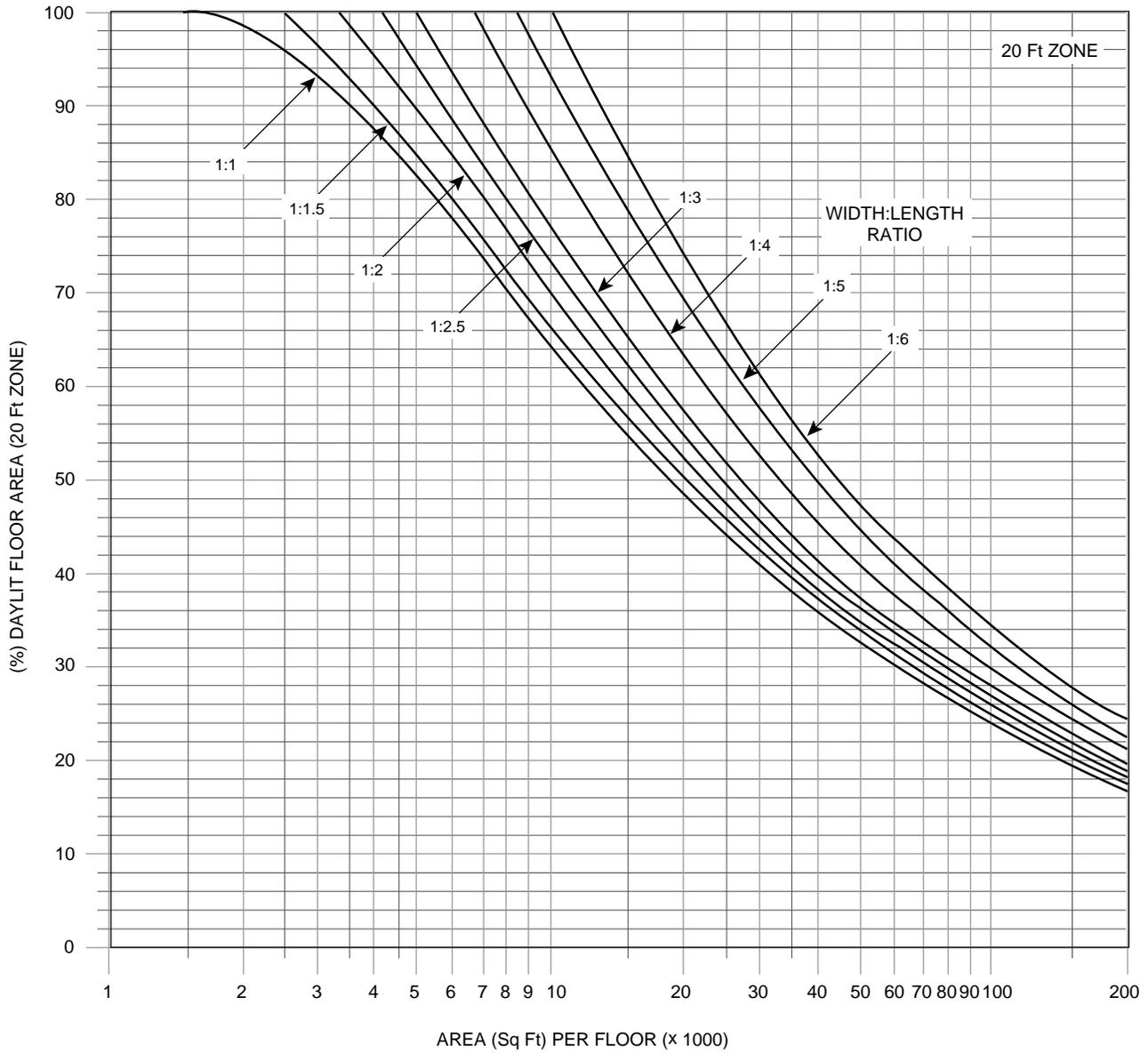
**Nomograph 3A**

*Ten-Foot Daylighting Zone Depth*



**Nomograph 3B**

*Fifteen-Foot Daylighting Zone Depth*



Nomograph 3C

*Twenty-Foot Daylighting Zone Depth*

## STEP 4

*Find the potential energy and load savings from daylighting (% reduction over a non-daylighted building).*

---

### ■ FIRST

Calculate Dimming Factor—the maximum reduction of electric lighting power in daylighted zones.

- If you (or your lighting designer) know the type of control hardware and control strategy intended, then simply compute:

$$\text{Dimming Factor \%} = \left[ 1 - \left( \frac{\text{Minimum lighting power when fully dimmed}}{\text{Maximum lighting power when on full}} \right) \right] \times 100$$

- If controls are unknown, use the default given in the worksheet.

—> Record Dimming Factor % in Line 19 of the worksheet.

### ■ SECOND

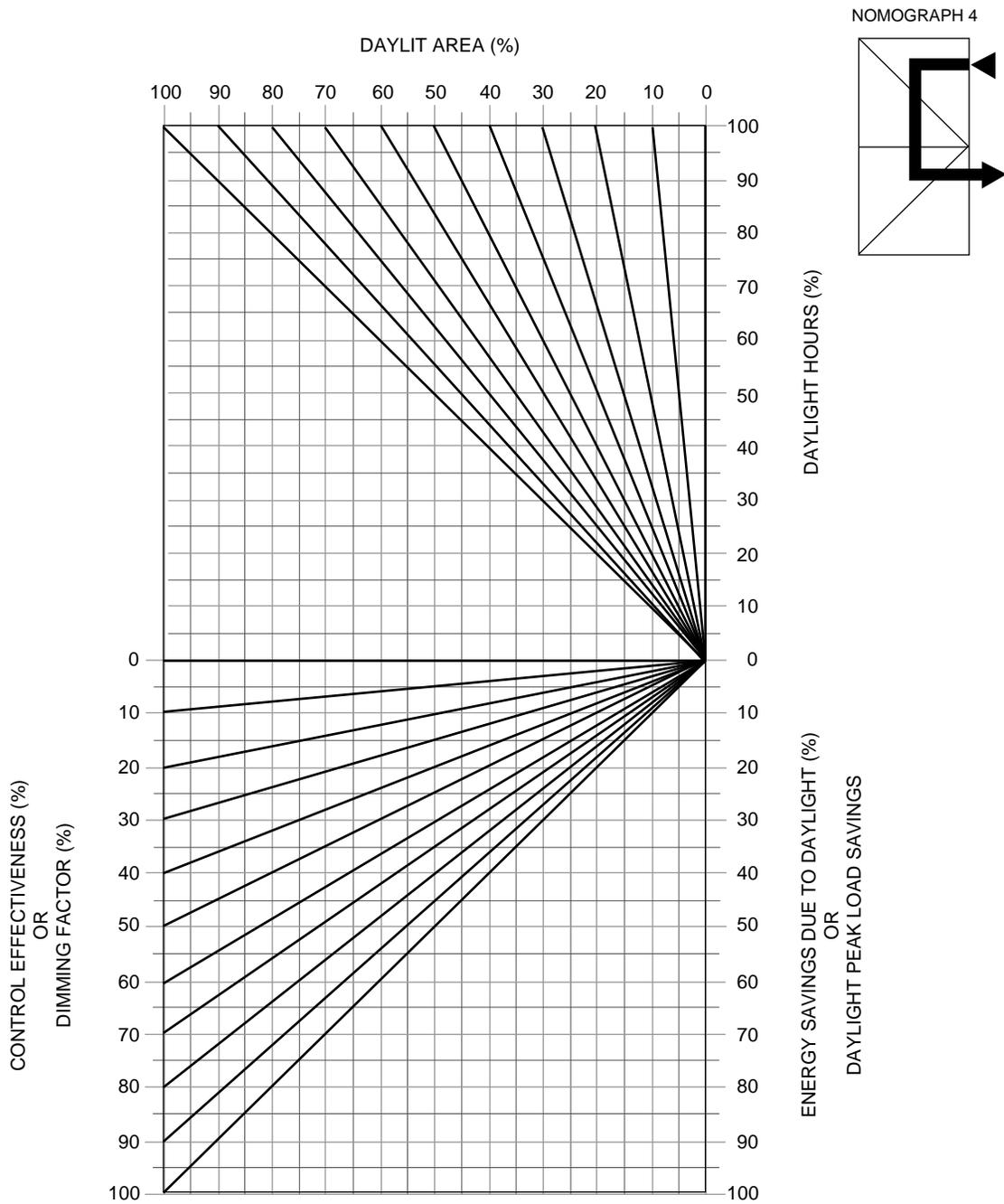
Use Nomograph 4 to find potential energy savings and load savings.

- See the key for the proper way to move through the nomograph.
- Begin at upper right at your Daylight Hours % (worksheet Line 17).
- Move left to the intersection with the diagonal line corresponding to your Daylit Area % (worksheet Line 20).
- Move down to the diagonal line for your Control Effectiveness % (worksheet Line 18).
- Move right and read your Energy Savings due to Daylight (%). This is the percentage of annual energy saved by daylighting over a non-daylighted building.

—> Record Annual Energy Savings due to Daylight in Line 21 of the worksheet.

- Repeat the first two steps.
- Move down to the diagonal line for your Dimming Factor % (worksheet Line 19).
- Move right and read your Daylight Peak Load Savings (%). This is the percentage of peak demand saved by daylighting over a non-daylighted building.

—> Record Daylight Peak Load Savings in Line 22 of the worksheet.



Nomograph 4

## STEP 5

### *Find lighting energy and cost savings due to daylighting.*

#### ■ FIRST

Estimate Installed Lighting Load (watts/ft<sup>2</sup>), including both task and ambient lighting.

- Lighting designer can provide this information.
- Or, select from this list of Title 24 allowable lighting power densities:

office	1.5	religious	2.0
medical	1.5	auditorium, convention	2.0
grocery	1.8	restaurant	1.5
industrial (work)	1.2	retail	2.0
industrial (storage)	0.8	school	1.8

—> Record Installed Lighting Load in Line 12 of the worksheet.

#### ■ SECOND

Use Nomograph 5 to find lighting energy and lighting costs for a *non-daylighted* building.

- Determine your Annual Hours of Occupancy by asking your client/building owner, or use the default value of 2500 hours.

—> Record this in Line 11 of the worksheet.

- Enter at upper left, as shown in the key, with Annual Hours of Occupancy (worksheet Line 11).
- Move up to intersect the 100% Daylight Hours line.
- Move right to intersect your Installed Lighting Load line (worksheet Line 12).
- Move down to intersect the 100% Control Effectiveness line.
- Move left to intersect the 100% Daylit Area line.
- Move down and read the value at your intersection with the KWHRS/FT<sup>2</sup>-YR scale. This is how many kilowatt-hours per square foot per year are required to electrically light the building.

—> Record this in Line 23 of the worksheet—Non-Daylit Lighting Energy Consumption.

- Determine your electricity cost (\$/KWH) by asking your local utility, or use the default value of \$0.10/KWH

—> Record this in Line 13 of the worksheet.

- Continue down to intersect your Electricity Cost line (worksheet Line 13).
- Move right and read your intersecting value on the Lighting Cost/Savings scale. This is the cost per square foot per year to electrically light the building.

—> Record this in Line 24 of the worksheet—Non-Daylit Lighting Energy Cost.

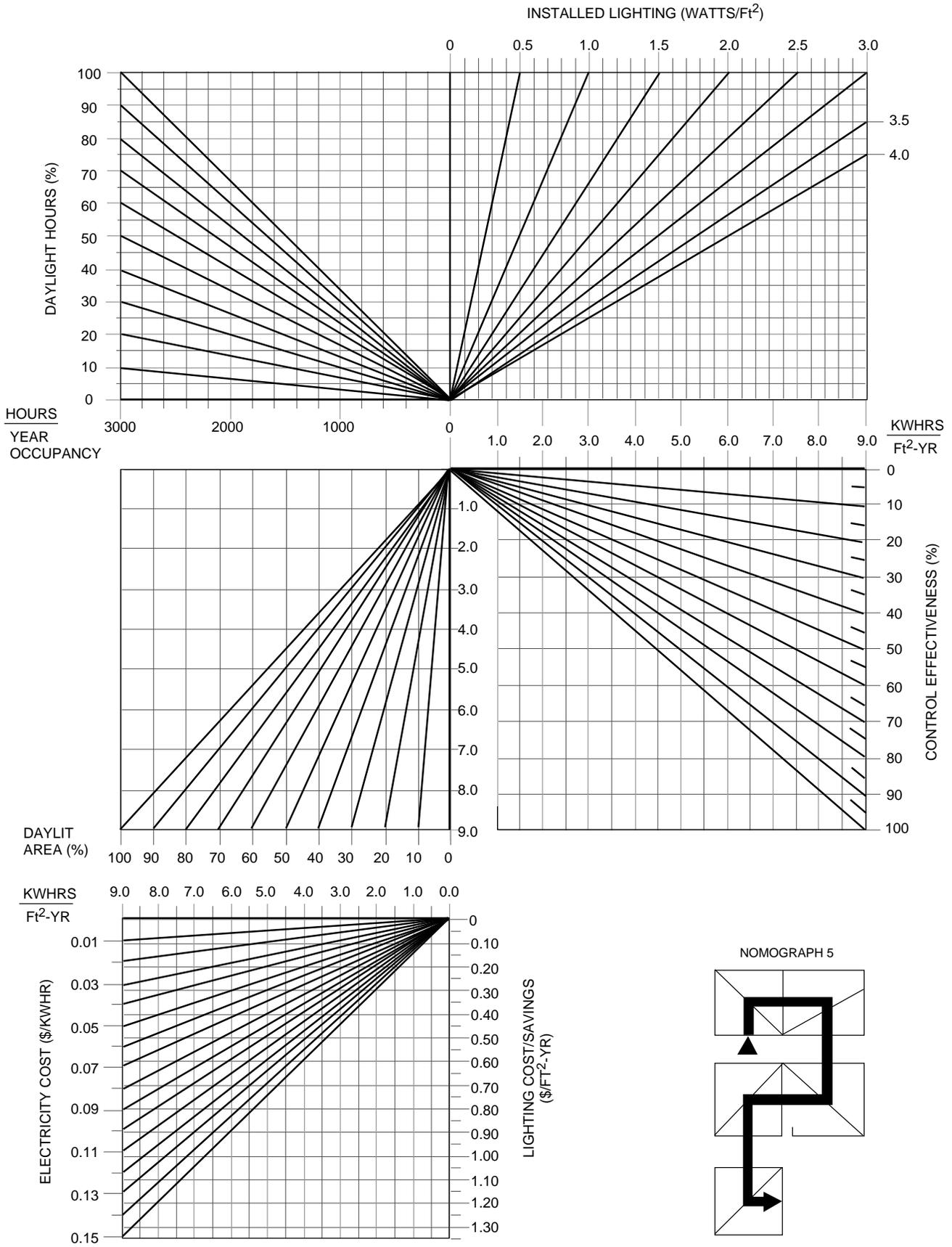
#### ■ THIRD

Use Nomograph 5 again, this time to find lighting energy and lighting costs for a daylighted building.

- Enter at upper left, as before, with your Annual Hours of Occupancy (worksheet Line 11).
- Move up to intersect your Daylight Hours % line (worksheet Line 17).
- Move right to intersect your Installed Lighting Load line (worksheet Line 12).
- Move down to intersect your Control Effectiveness % line (worksheet Line 18).
- Move left to intersect the Daylit Area % line (worksheet Line 20).
- Move down and read the value at your intersection with the KWHRS/FT<sup>2</sup>-YR scale. This is how many kilowatt-hours per square foot per year daylighting will save for the building.

—> Record this in Line 25 of the worksheet—Daylighting Energy Consumption Savings

*continued on Page 21*



Nomograph 5

## STEP 5, continued

### *Find lighting energy and cost savings due to daylighting.*

#### ■ THIRD, continued

- Continue down to intersect your Electricity Cost line (worksheet Line 13).
  - Move right and read your intersecting value on the Lighting Cost/Savings scale. This is the lighting cost savings per square foot per year from daylighting.
- > Record this in Line 26 of the worksheet—Daylighting Energy Cost Savings
- Multiply the above value (Line 26) by Building Area (Line 14). This is the annual lighting energy savings from daylighting.
- > Record this in Line 27 of the worksheet—Annual Daylighting Energy Savings.

## STEP 6

### *Find the reduction in peak electrical demand and associated cost savings with daylighting.*

#### ■ FIRST

Estimate the electric load (W/ft<sup>2</sup>) of all non-lighting activities like mechanical heating and cooling, ventilation, office equipment use, etc.

- Mechanical engineer can provide this information.
  - Or, assume 3.5 W/ft<sup>2</sup>.
- > Record Non-Lighting Electric Loads in Line 15 of the worksheet.

#### ■ SECOND

Find the peak demand rate for local utility. Call the utility for current rate, or use one of these values:

San Diego Gas & Electric	\$19
Los Angeles Dept of Water & Power	9
Pacific Gas & Electric	13
Southern California Edison	17

—> Record Peak Demand Rate in Line 16 of the worksheet.

#### ■ THIRD

Use Nomograph 6 to find lighting electrical demand and demand costs for a *non-daylighted* building.

- Enter at the middle left Lighting Load scale (*not* the top right start point shown in the key, but rather at the point in the key where the path forks in two directions), with your Installed Lighting Load value (worksheet Line 12).
- Move diagonally down to the right (parallel with the dashed lines), then move right to the vertical scale Building Electric Load.
- Move down this scale the number of watts per square foot you have in Non-Lighting Load (worksheet Line 15). In other words, end up at the value that equals your lighting plus non-lighting load.
- Move right to the diagonal line for your Total Building Area (worksheet Line 14). If building area exceeds 10,000 ft<sup>2</sup>, then use a multiplier. For example, if you have a 700,000 ft<sup>2</sup> building, use the 7000 ft<sup>2</sup> line and multiply your final result by 100.

*continued on Page 22*

- Move up and read the value at your intersection with the KW Peak Demand scale. If you used a multiplier for your Building Area, multiply this value by that factor.
- > Record this in Line 28 of the worksheet—Non-Daylit Peak Demand.
- Now return to your entry point at the middle left with your Installed Lighting Load (worksheet Line 12).
- Move down vertically to the diagonal line for your Peak Demand Rate (worksheet Line 16).
- Move right to the first vertical scale, \$/ft<sup>2</sup> -month. This is the monthly demand charge for electric lighting.
- > Record this in Line 29 of the worksheet—Non-Daylit Monthly Demand Charge.
- Continue right to the second vertical scale, \$/ft<sup>2</sup> -year. This is the annual demand charge for electric lighting.
- > Record this in Line 30 of the worksheet—Non-Daylit Annual Demand Charge.

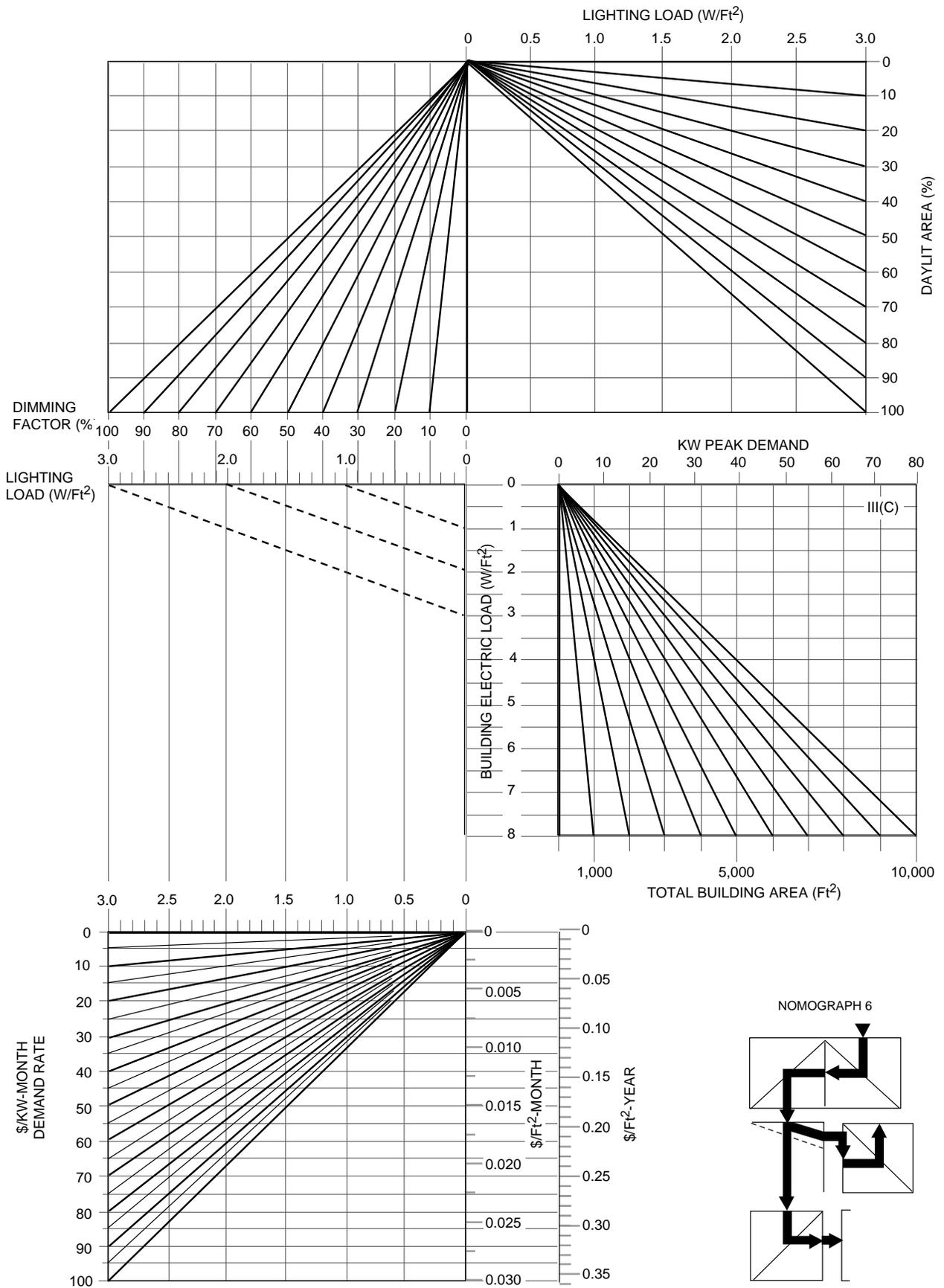
## ■ FOURTH

Use Nomograph 6 again, this time to find lighting energy and lighting costs for a *daylighted* building.

- Now start at the upper right as shown in the key, with your Installed Lighting Load value (worksheet Line 12).
- Move down to the diagonal line for your Daylit Area % (worksheet Line 20).
- Move left to the diagonal line for your Dimming Factor % (worksheet Line 19).
- Move down to the Lighting Load scale and mark your point of intersection (this will not be your actual lighting load, it's just a reference point).
- Move diagonally down to the right (parallel with the dashed lines), then horizontally to the vertical scale Building Electrical Load.
- Do *not* move down along this scale as before to add in other loads, but rather move directly right to the diagonal line for your Building Area. If building exceeds 10,000 ft<sup>2</sup>, use a multiplier as before.
- Move up and read the value at your intersection with the KW Peak Demand scale. This is the peak demand *reduction* due to daylighting. If you used a multiplier for your Building Area, multiply this value by that factor.
- > Record this in Line 31 of the worksheet—Daylit Peak Demand Savings.
- Return to the point you marked on the Lighting Load scale.
- Move down to the diagonal line for your Peak Demand Rate (worksheet Line 16).
- Move right to the first vertical scale, \$/ft<sup>2</sup> -month. This is the monthly demand savings due to daylighting.
- > Record this in Line 32 of the worksheet—Daylit Monthly Demand Savings.
- Continue right to the second vertical scale, \$/ft<sup>2</sup> -year. This is the annual demand savings due to daylighting.
- > Record this in Line 33 of the worksheet—Daylit Annual Demand Savings.
- Now calculate the total savings per year due to daylighting. Simply add Daylighting Energy Cost Savings (worksheet Line 26) and Daylit Peak Demand Savings (worksheet Line 33) together.
- > Record this in Line 34 of the worksheet—Total Annual Savings.

Note: You may wish to perform this procedure separately for different summer and winter demand charges, if your local utility has seasonal rate structures.

Note: The annual savings yielded here (the final value read from the nomograph) is simply 12 times the monthly value. If demand charges are not in place all 12 months of the year, calculate annual savings manually. For example, if demand charges only apply for 6 months, then multiply your monthly value by six for the annual value, rather than reading from the scale in the nomograph.



Nomograph 6

## STEP 7

### *Assess attractiveness of investment in daylighting strategies.*

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The full economic impact of an energy efficiency design decision is difficult to anticipate due to so many unknowns in how a proposed building will actually be constructed and operated. The nomographs you have used up to this point were developed with many simplifying assumptions. This means that the performance expectations you have determined through the nomographs are only a rough estimate of the energy performance your proposed building may actual exhibit. Because economic analysis must be based on predicted energy performance, any investment information determined in this final step will be equally rough. Further complicating this is the fact that investment decisions are complex due to unknowns on the financial horizon, such as future inflation rates, future alternative earnings for this investor, and rises in the cost of energy. The designer is cautioned to make use of this final nomograph with care.

#### ■ Option 1: Simple Payback Calculation

This rough, quick analysis procedure is frequently used when the investor (the building owner) is primarily interested in a short payback period. Payback period is the time it takes for a more expensive technology to pay for itself through the operations savings it yields over its less costly equivalent. You can calculate justifiable investment based on a desired payback length taking the simple steps below. The nomograph is not used in this option.

- Begin with Total Annual Savings due to daylighting (worksheet Line 34).
- If possible, assign an economic value (in \$/ft<sup>2</sup> -year) for the non-energy benefits of daylighting. Some examples: increased rental value of daylit spaces, increased occupant productivity, increased resale value of the building. Add this into Total Annual Savings.
- Determine the maximum acceptable payback period, in years.

—> Record Payback Period in Line 37 of the worksheet.

- Multiply Total Annual Savings (\$/ft<sup>2</sup> -year) by Payback Period (years). This equals the maximum justifiable investment for daylighting, in \$/ft<sup>2</sup>. This will typically only be spent in the daylighted zones, not the whole building.

#### ■ Option 2: Maximum Justifiable Investment Given a Desired Payback Period

Use Nomograph 7 to determine the maximum investment, or first cost, that is justifiable based upon projected savings and a given payback period. The "Justifiable Investment" is not the sum that is generally spent throughout the building, but is more likely the sum spent on lighting controls in the perimeter zone. The additional costs for improved glazing, glare control, and direct sun control for glazed areas can be included, but remember that this analysis does not account for reductions in cooling energy. This method includes the discounted value of future savings and the effects of escalating energy costs.

- Begin at the Discount Rate scale, with your value from worksheet Line 38.
- Move up to the curve for your Energy Escalation Rate (worksheet Line 39).
- Move right to the curve corresponding to desired Payback Period (worksheet Line 37).
- Move down to the region of diagonal lines for First Year Savings. Choose the line that corresponds to your value for Total Annual Savings (worksheet Line 34).
- Move left and record the value at your intersection with the Justifiable Investment scale. This is the maximum added cost for daylighting design to yield a sensible investment. Note that this cost will typically only be spent in the daylighted zones, not the whole building.

—> Record Justifiable Investment in Line 35 of the worksheet.

### ■ Option 3: Minimum Savings Required to Justify a Given Investment

This is the inverse of Option 2. For a given desired payback period and given the added first cost for daylighting design, find the first year savings necessary to justify that investment using Nomograph 7.

- Begin at the Discount Rate scale, with your value from worksheet Line 38.
- Move up to the curve for your Energy Escalation Rate (worksheet Line 39).
- Move right to the curve corresponding to desired Payback Period (worksheet Line 37).
- Move down until you intersect the *horizontal* line on the left-hand scale marked Justifiable Investment that corresponds to the given investment. Mark this point.
- The point should be within the range of diagonal lines corresponding to First Year Savings. Interpolate your required First Year Savings. Your daylighting design must yield this in order to justify the given investment.
- If that point is not within the range First Year Savings diagonal lines, then try a lower discount rate or a longer payback period.

—> Record First Year Savings in Line 36 of the worksheet.

### ■ Option 4: Required Payback Period Given First Year Savings and Available Investment

Given the annual savings and funds available for investment, find the number of years required to pay back that investment using Nomograph 7.

- Begin at the Discount Rate scale, with your value from worksheet Line 38.
- Move up to the curve for your Energy Escalation Rate (worksheet Line 39).
- Move to the right and intersect the vertical scale (running from 0.75 to 1.40). Mark that value for use in a moment.
- Go to the Justifiable Investment scale, find the value of your available investment (worksheet Line 35) and move right to intersect the diagonal line for your First Year Savings (worksheet Line 36, or use value in Line 34).
- Move up until you intersect the horizontal line corresponding to the value you marked before. That point of intersection should fall within the range of curves for payback period Number of Years. Interpolate your required payback between the two curves nearest your point. If your point is not within the region of curves, then your payback is greater than 100 years.

—> Record Required Payback in Line 37 of the worksheet.

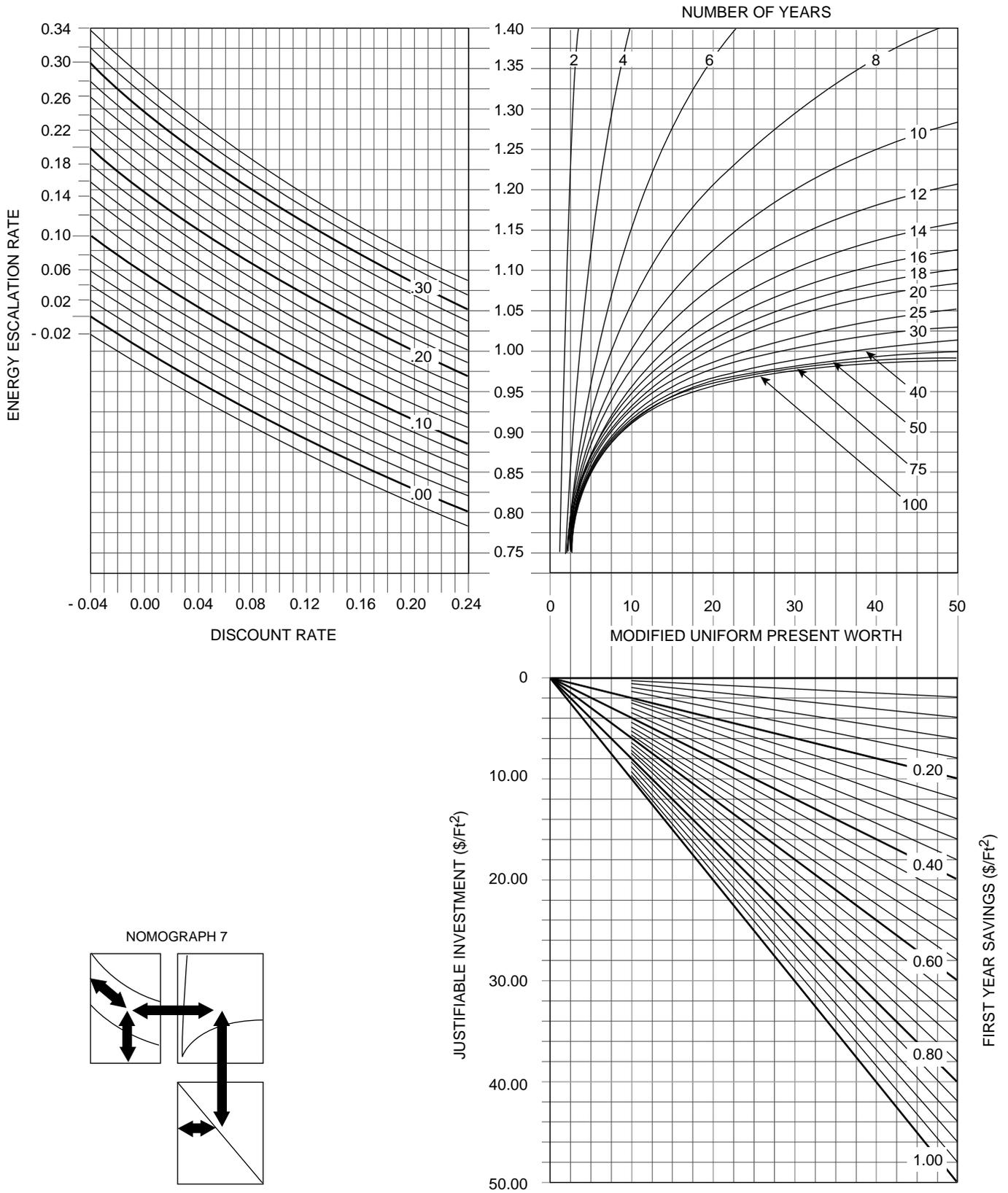
### ■ Option 5: Rate of Return on Investment

Given an investment value, annual savings, and payback period, find the rate of return on initial investment using Nomograph 7.

- Start at the Justifiable Investment scale, find the value of your intended investment (worksheet Line 35) and move right to intersect the diagonal line for your First Year Savings (worksheet Line 36, or use value in Line 34).
- Move up to the curve for your given payback period (worksheet Line 37).
- Move left to the curve for your energy escalation rate (worksheet Line 39).
- Move down and read the value at your intersection with the Discount Rate scale. This is the Rate of Return on Investment.

—> Record this value in Line 38 of the worksheet.

This concludes this Nomograph Cost/Benefit Tool for Daylighting. For detailed information, consult the original research: S.E. Selkowitz and M. Gabel. 1984. "LBL Daylighting Nomographs," LBL-13534, Lawrence Berkeley Laboratory, Berkeley CA, 94704. (510) 486-6845.



Nomograph 7

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## Glossary

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**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.

**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.

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

**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** A common unit of light output from a source.

**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 over its area of light distribution. 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 re-viewing 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 illumination on a horizontal point indoors to the horizontal illumination outdoors, expressed as a percentage. Direct sunlight is excluded.

**Diffuse Lighting** Lighting that does not come from any particular direction.

**Diffuser** Any device that scatters light from a source.

**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.

**Effective Aperture** The product of visible transmittance and window-to-wall ratio.

**Footcandle** A common unit of illuminance used in the U.S. The metric unit is the lux.

**Footlambert** The U.S. unit for luminance. The metric unit is the nit.

**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** Amount of light incident on a surface.

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

**Kilowatt** Unit of electric power (the rate at which energy is used). Equals 1000 Watts.

**Kilowatt-Hour** Unit of energy. Equals 1000 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.

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

**Lumen** 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** Amount of light coming from a surface; in other words, how bright it is.

**Luminance Ratio** Ratio between different brightnesses in the visual field.

**Lux** The metric unit for illuminance. The U.S. 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.

**Nit** Metric unit for luminance. The U.S. unit is the footlambert.

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

**Photometer** 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 in shiny surfaces.

**Shading Coefficient** the ratio of the total solar heat gain through a window to that through 1/8" (3 mm) clear glass.

**Solar Heat Gain Coefficient** Solar heat gain through the total window system relative to the incident solar radiation.

**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.

**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 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** Unit of power.

**Watt-Hour** Unit of energy.

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

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## Tools & Resources Summary

Tips for Daylighting with Windows

### Books

Title	Best Use	Comments
<b>Architectural Graphic Standards, Ninth Ed.</b> , John Hoke ed. (AIA and Wiley & Sons 1994).	Shading masks.	
<b>ASHRAE Handbook of Fundamentals</b> (American Society of Heating, Refrigerating and Air-Conditioning Engineers 1993).	The standard technical reference for calculation procedures, material properties, weather tables and much more.	Extremely tough reading—suitable for technical audience only.
<b>ASHRAE HVAC Applications Handbook</b> (American Society of Heating, Refrigerating and Air-Conditioning Engineers 1995)	Assistance for mechanical system design and maintenance procedures.	Geared for engineers.
<b>Building Control Systems</b> by V. Bradshaw (Wiley and Sons 1985).	General reference for all building systems. Especially useful for load calculation method, economic analysis method, and basic principles.	
“ <b>Building Systems Automation-Integration,</b> ” Proceedings of the 1991 and 1992 International Symposiums (University of Wisconsin-Madison 1993).	One of the only integrated controls case studies around.	Mostly a series of research reports and theory related to design tools on the distant horizon.
<b>The Building Systems Integration Handbook</b> edited by Richard D. Rush (Wiley and Sons 1986).	Good information on designing integrated building systems, with many case studies.	Prepared and sponsored by the American Institute of Architects.
<b>Concepts and Practice of Architectural Daylighting</b> by F. Moore (Van Nostrand Reinhold 1985).	Helpful for physical models. Includes good explanation of basic lighting principles.	Readable. Nice example buildings. Geared for architects.
<b>Concepts in Architectural Lighting</b> by M.D. Egan (McGraw-Hill 1983).	General tips in window and interior design for good daylighting. Good treatment of basic lighting principles.	Easy to read, friendly graphics. For architects and lighting designers.
<b>Daylight in Architecture</b> by B. Evans (McGraw-Hill 1981).	General design tips.	Geared for architects. The Egan and Moore books are better.
<b>Daylighting: Design and Analysis</b> by C. Robbins (Van Nostrand Reinhold 1986).	Physical models. Includes many tables of sky data and other detailed information.	Technical. Not well-suited for the average designer.

**Books**, *continued*

<i>Title</i>	<i>Best Use</i>	<i>Comments</i>
<b><i>Energy Management Handbook</i></b> by W. Turner (Fairmont Press 1993).	Good for economic method, detailed maintenance procedures, and controls. Also covers basic principles, comfort, envelope and system technical details, codes and energy analysis.	Thorough but dry. Controls section nicely addresses integration. Maintenance section covers all building systems in detail.
<b>“Life Cycle Cost Analysis - A Guide for Architects”</b> (AIA, Washington D.C. 1977).	Method and tables.	A useful handbook.
<b><i>Low-E Glazing Design Guide</i></b> by Timothy Johnson (Butterworth-Heinemann 1991).	Thorough background on high performance glazings. Some attention to applications.	Focuses heavily on manufacturing and other highly technical glazing details. Not well-suited for the average designer.
<b><i>Mechanical and Electrical Equipment for Buildings, 7th Ed.</i></b> by B. Stein, J. Reynolds and W. McGuinness (Wiley and Sons 1986, also out now in an 8th edition).	Good general reference for mechanical and electrical systems. Includes basic principles and energy efficiency emphasis.	Technical yet readable. Thorough.
<b><i>Proceedings of the 1986 International Daylighting Conference</i></b> edited by Stephen Zdepski and Ross McCluney.	Conference papers on many aspects of daylighting theory and practice.	Technical and thorough.
<b><i>Residential Windows</i></b> by John Carmody, Stephen Selkowitz, and Lisa Heschang (Norton 1996).	Excellent guide to new window technologies and their energy performance.	Good balance of readability and technical information.
<b><i>Small Office Building Handbook: Design for Reducing First Costs and Utility Costs</i></b> by Burt Hill Kosar Rittelman Associates (Van Nostrand Reinhold 1985).	Simplified, friendly guidelines for basic decisions. Appropriate for more than just office buildings, but small buildings only.	Geared for architects. Uses rules of thumb, checklists, “strategy sets,” worksheets, and emphasizes beginning-to-end integration.
<b><i>Solar Control and Shading Devices</i></b> by Olgyay and Olgyay (Princeton University Press 1957).	Shading masks.	Example buildings are dated but still useful.
<b><i>Sun, Wind and Light: Architectural Design Strategies</i></b> by G.Z. Brown (Wiley & Sons 1985).	Basic and simple architectural design principles and methods. Most appropriate for smaller buildings.	Appealing graphics. Geared for architects.
<b><i>Sunlighting as Formgiver for Architecture</i></b> by William M.C. Lam (Van Nostrand Reinhold 1986).	Case studies.	

## Simple Calculations

<i>Name</i>	<i>Best Use</i>	<i>Comments</i>
<b>Two-Minute Feasibility Study</b> (in these guidelines)	Pre-design or early schematic check that daylighting makes sense.	A good way to get started.
<b>Window Sizing Equation</b> (in these guidelines)	Early schematic starting point for window design.	
<b>Cost/Benefit Nomographs</b> (in these guidelines)	Rough idea of whether daylighting makes economic sense. Can use as a very early feasibility check or later in schematics for ballpark analysis.	Not useful once design is significantly developed - proceed with more sophisticated method after that point.
<b>Overhang and Fin Sizing Equations</b> (in these guidelines)	Starting point for shading devices.	Follow up with scale model testing.
<b>Shading Masks</b> (see <i>Architectural Graphic Standards</i> ).	To study shading effectiveness and document it at the same time.	An appealing graphic method that captures a lot of data in a single diagram.
<b>Simple Payback Analysis</b> (consult one of the books above)	Rough suggestion of how long an efficient technology will take to pay for itself in energy savings.	Can be quick.

## Complex Calculations and Software

<i>Name</i>	<i>Best Use</i>	<i>Comments</i>
<b>Daylighting Calculations by Hand</b> (information available through IES or use a lighting consultant).	An alternative to scale model photometry.	Tedious.
<b>Daylighting Software</b> (use a lighting consultant).	An alternative to scale model photometry.	Requires learning time and experience.
<b>Load Calculations by Hand</b> (information available through ASHRAE, various books above or through mechanical engineer).	Rough cut at peak demand, comparison of design alternatives.	Tedious. Not very accurate.

**Complex Calculations and Software**, *continued*

<i>Name</i>	<i>Best Use</i>	<i>Comments</i>
<b>Energy Analysis Software</b> (see list in Mechanical Coordination section)	Compare energy efficient alternatives, estimate energy costs, perform life cycle cost analysis, show Title 24 compliance, estimate peak power demands, disaggregate energy end uses, and compute loads for HVAC equipment sizing.	Advanced programs require extensive learning time and subsequent user experience. Simpler, easier-to-use analysis software exists but is not ideal for daylighting design. In those cases, lighting reduction due to daylighting must be estimated by the user.
<b>Life Cycle Cost Analysis</b> (use a consultant or see book list above).	For an accurate estimate of long term economic scenario for an energy efficient building, taking into account the time value of money.	Preferred method for economic analysis. Requires energy analysis data.
<b>“Building Life-Cycle Cost” program (BLCC)</b> (available from NTIS at address below).	Alternative to a hand calculation.	Requires energy analysis data.

**Physical Models**

<i>Name</i>	<i>Best Use</i>	<i>Comments</i>
<b>Models-General</b>	Study effectiveness of shading devices, qualitatively assess daylight and glare, measure daylight levels.	One of the best, easiest and most accurate tools available. Useful for both designers and their clients.
<b>Shading Models</b> (see Shading section)	Test performance of shading elements for all sun angles.	Use outdoors with sundial (in these guidelines).
<b>Daylight Models-Qualitative</b> (see Shading section)	View inside of model for daylight quality, glare, etc.	Use outdoors on an appropriate site.
<b>Daylight Models-Quantitative</b> (see Shading section)	Use photometric equipment to measure daylight levels.	Requires access to specialized equipment.

## Organizations and Consultants

<i>Name</i>	<i>Best Use</i>	<i>Comments</i>
<b>ASHRAE</b> The American Society of Heating, Refrigerating and Air Conditioning Engineers Publications: (800) 248-5000, x112.	Literature, standards, codes, guidelines and monthly journal covering mechanical systems, building envelope, energy efficiency, indoor air quality and much more.	A large range of useful information and design guidelines available. Local chapters also may offer classes or other resources.
<b>IES</b> Illuminating Engineering Society Publications: (212) 248-5000, ext. 112.	Literature, standards, codes, guidelines and monthly journal covering lighting and daylighting.	A large range of useful information and design guidelines available. Local chapters also may offer classes or other resources.
<b>AIA</b> American Institute of Architects Publications: (800) 365-ARCH.	Literature, guidelines, codes, standards, monthly journal.	A small percentage of AIA materials address energy efficiency, daylighting or other high performance building topics. Local chapters may offer classes or additional resources.
<b>Utility Company</b>	Design assistance, incentives.	Always check with local utility about either new construction and retrofit programs before proceeding with any design project.
<b>Manufacturers</b>	Technical literature and specs, samples, pricing, energy calculations.	Many brochures can be found in Sweets Catalog.
<b>Energy Consultants</b> (California Association of Building Energy Consultants, 916-921-2223).	Daylighting expertise, software analysis, Title 24 compliance and mechanical system optimization	
<b>California Energy Commission</b> (CEC) (916) 654-4287.	Literature, code language, design guidelines geared for California Title 24 energy code compliance.	
<b>Electric Power Research Institute</b> (EPRI) (800) 525-8555.	Fact sheets, brochures, guidelines and software addressing lighting and mechanical technologies.	Especially strong offerings in lighting technologies and lighting controls.
<b>National Technical Information Service</b> Write to NTIS in Springfield, Virginia 22161 for a publications list.	Technical documents and guidelines.	A few materials are geared towards building performance.
<b>BOMA</b> The Building Owners and Managers Association Publications: (800) 426-6292.	Economic material and other publications geared to owners and operators.	