
# Tips for Daylighting with Windows

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# Disclaimer



# Acknowledgements

The original version of this guide was published in 1997, authored by Jennifer Schumann with Eleanor Lee, Francis Rubinstein and Stephen Selkowitz of the Building Technologies Program, Environmental Energy Technologies Division of the Lawrence Berkeley National Laboratory. This second edition, completed in 2013, includes selected updates to the technical content and a new chapter on Cost-Benefit Analysis and was supported by the Commercial Buildings Partnership (CBP) Program, through the Assistant Secretary for Energy Efficiency and Renewable Energy, Building Technologies Program of the U.S. Department of Energy under Contract No. DE-AC02-05CH11231. This update was completed by Alastair Robinson and Stephen Selkowitz, with new content and technical review from Dragan Curcija, Michael Donn, Steve Greenberg, Eleanor Lee, Andrew McNeil, Cynthia Regnier, and Francis Rubinstein.

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

## Using this Guide

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

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

## Basic Guidelines

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

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

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

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

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

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# 6 Mechanical Coordination

**OBJECTIVE: Design a mechanical system to serve a low-energy building and create a comfortable environment, optimizing the use of daylighting and shading design elements.**

- Cooling energy savings are a key factor in the cost-effectiveness of daylighting.
- Low-energy daylighting and lighting systems can affect mechanical system selection, potentially reducing system costs; reduction in costs of utility connection arising from careful design is another consideration.
- Efficient, low-energy mechanical system design requires good coordination between the mechanical engineer and the rest of the design team.
- Use caution to ensure that unmanaged daylight apertures do not exacerbate solar heat gain.

## KEY IDEAS

### Help Guide Early Architectural Decisions

- **Reduce cooling loads aggressively.** Look for opportunities where architectural decisions can save operating costs, reduce mechanical first costs, and reduce mechanical space requirements. Figure 29 shows some areas to consider. Reducing cooling loads provides many benefits. Size shading to reduce direct solar gain in the cooling season. 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 the building height allowance. Smaller equipment is less visible on the roof and easier to accommodate within normal floor-to-floor heights.

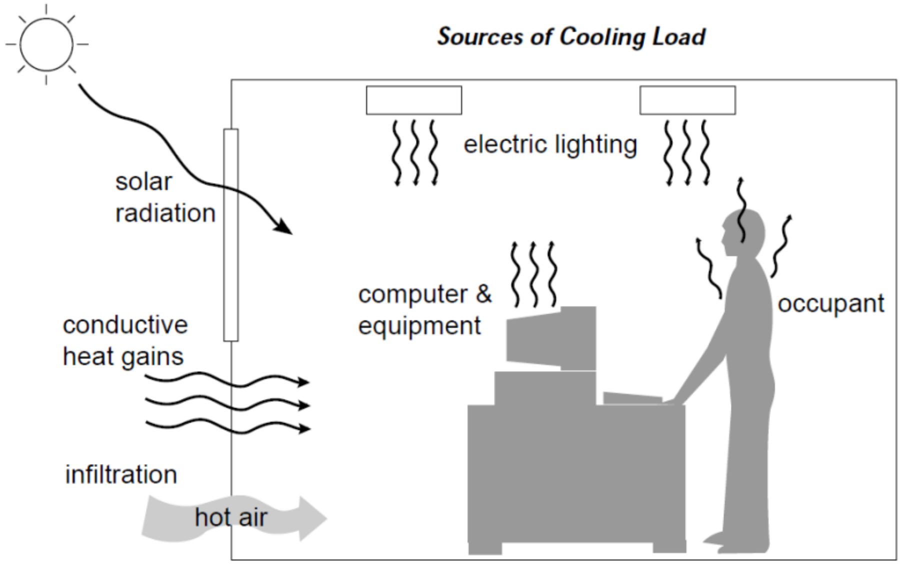


Figure 29: Multiple sources of cooling load

- Look for opportunities to have shading elements perform more than one duty (e.g., integrated shading and lightshelf package, shading and PV support frame, shading and natural ventilation intakes).
- Utilize architectural/engineering features that support natural ventilation where appropriate (where conditions are able to provide cooling for a significant portion of the year).
- Adopt shading design with the aim of reducing cooling plant capacity.
- Design for specified plug load heat gains.
- Select glazing on the basis of design heat and cooling balance, and with an understanding of the necessary heat exchange with the external conditions.
- A lower lighting power density with daylighting dimming and other lighting controls can reduce internal heat gains.

- **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. These early data can be critical in guiding architectural decisions, before important siting and envelope decisions are set.
- **The 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. Their understanding of design goals and input on interactions between building systems may lead to identification of an optimal systems balance and trade-offs available for reducing the number of energy systems, their capacities, and their overall energy use. 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.** High performance glazing is like any other technology: forever developing. Dark or reflective glazings are no longer the only choices for solar heat reduction. Most glazings today use

spectrally selective coatings that reject near-infrared energy but transmit most daylight. Consider carefully the radiant effect of windows 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.

- **Explore the potential of effective exterior and interior 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 will 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 it remains unobstructed by HVAC or other equipment. Ensure that proper installation and commissioning are completed.
- **Flag potential conflicts early,** such as inadequate space allocation, poor location or access for equipment rooms, and crowded ceiling plenums.

## Reduce First Costs

- **Calculate the peak cooling load and energy use with reduced perimeter electric lighting load, and size the mechanical system accordingly.** Be sure to specify proven and reliable daylight controls that will dim or switch electric lighting during peak cooling conditions. Ask vendors to provide details of previous installations, including performance monitoring data. Also ask for references for previous clients who you may contact.
- **Examine cooling system downsizing or alternate system selection opportunities with various glazing and shading options.** Work with the architect to possibly fine-tune 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 than they are with added mechanical equipment.
- **Aggressive targets for low-energy building cooling loads may result in significantly different HVAC system selection,** such as radiant cooling systems, which could have cost or comfort benefits.



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

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

## Reduce Operating Costs

- **Calculate the annual energy saved with improved fenestration elements.** Even if there are no mechanical first cost savings, reduced operating costs decrease the payback period. Calculations will show some of the benefit of exterior over interior shading, lower solar heat gain coefficient glazings, and daylighting controls. Glazing selection should consider the impact on peak energy demands, as peak reduction will have capacity and demand cost benefits; be sure to account for these where appropriate. Reduction in building peak demand also improves grid security.
- **Select an effective energy management system** to optimize building systems operation and tie together all HVAC, lighting, and automated shading controls. Investing in an energy information system (EIS) that suits the needs and priorities of the design is a way to further understanding of how systems operation can be optimized to reduce energy use and cost. A good guide as to what products are currently available and how they work can be found in the Energy Information Handbook, available online at http://eis.lbl.gov.
- **Set a larger temperature deadband for circulation spaces.** Areas in which people spend relatively little time may be considered unoccupied spaces (residency of less than 15 minutes at any one time), where maintaining tight thermal comfort criteria is not as critical. Temperature set points can be relaxed for these spaces to lower energy use. Let these and other non-critical spaces drift more than task areas.
- **Where elements of natural ventilation, radiant heating/cooling or under-floor air distribution are utilized, adaptive comfort criteria should be used to define thermal comfort standards.** These criteria should determine mechanical systems deadbands.

## 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 the architect on fenestration design. Low-energy design may make radiant HVAC systems (panels, slab) viable, which will help to provide additional comfort and at lower energy rates.
- **Consider the effects of the window's surface temperature on thermal comfort.** Dark tinted glazings or absorptive window films increase the window's surface 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. Good low-energy design can make them viable, however, as their impact in the space becomes more influential in delivering the required energy outputs and acceptable thermal comfort conditions.



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Post-Occupancy

- **Design only goes so far in reducing energy – occupant behavior plays a big role.** Ongoing occupant feedback and education can be a positive influence if occupant control strategies are effectively utilized. If they are ignored, the benefits of the design may not be realized.

# INTEGRATION ISSUES

## Integrated Design Process

The objective of integrated design is to view the building as a whole and understand the interactions between systems. In doing so, the design team is able to make logical decisions about building design and all the systems that support it, with the aim of capitalizing on system synergies and use of multi-purpose features whilst minimizing systems conflicts. Through this approach, it should be possible to optimize performance to minimum life-cycle cost and lowest energy use intensity. The process should continually restate objectives and goals, refocusing the design team at each stage of the design process and building a collective mindset amongst the team. Using this approach, it is less likely that the design will be subject to drift.

## Architecture

Provide adequate space for mechanical equipment, or system efficiency may be impaired, and allow for adequate maintenance access. Architectural decisions that reduce heating and cooling loads mean less space required for equipment—smaller mechanical rooms, smaller shafts, and 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 offices. Diffusers, grilles, exposed ductwork, and thermostats may be important visual elements to coordinate. Contractors should be given accurate placement specifications that meet both functional and aesthetic desires. Diffuser location should take into consideration any potential for draft or radiative comfort issues (see Occupant Comfort, below).

## 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 the 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 trade-offs available between architectural and mechanical elements; advanced glazings and effective shading devices can reduce mechanical first costs and operating costs.

### Occupant Comfort

Remember that thermostats don't respond to surface temperatures. Don't put them in direct sun or over computers. Increase thermal comfort by focusing on the radiative component of glazing in the glazing selection. Consider the use of radiant conditioning systems, such as radiant panels, to increase comfort where discomfort is largely due to radiative asymmetry; or as a last resort, wash large glazing areas with conditioned air to reduce radiant heat transfer. This approach is not recommended as a first course of action due to the increased energy used to provide the conditioned air.

## PROVISOS

- Rule-of-thumb or simplified load calculations do not accurately model the energy behavior of today's high-performance windows, due to the complexity of window behavior and properties. Use these tools initially if needed to understand general trends. Use more refined tools that properly model glazing, shading, and daylight for design development trade-offs and to help make final decisions.
- Energy calculations sometimes indicate that glazing with a higher U-value uses less energy in 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 with different associated visible transmittances should be explored and the best combination selected to achieve desired 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*. See www.ashrae.org/ for a publications list. For *ASHRAE Journal* subscription information, see www.ashrae.org/publications/page/540.
- **Books** ASHRAE has many book titles available addressing maintenance (see above), including the useful *ASHRAE 2011 HVAC Applications Handbook* and *2009 Fundamentals Handbook.*

  *Mechanical and Electrical Equipment for Buildings*, 10th ed. by W. Grondzik, A. Kwok, B. Stein, and J. Reynolds (Wiley, 2005) is a good general reference.

*Building Control Systems*, 2nd Ed. by V. Bradshaw (Wiley, 1993) 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 code compliance, estimate peak power demands, disaggregate energy end uses, and—most commonly—compute loads for HVAC equipment sizing. They require extensive learning time and subsequent user experience. Simpler, easier-to-use analysis software exists but it does not have the level of accuracy required in the most detailed phases of daylighting design.

  **EnergyPlus** is the best example. A DOE-developed simulation tool, it models all facets of building energy systems, but this ability results in inherent complexity, and only people with the appropriate training will be able to utilize it effectively and derive consistent, reliable results. Therefore for detailed HVAC modeling, a mechanical design or energy modeling firm should be engaged to do this work. The software is available at: http://apps1.eere.energy.gov/buildings/energyplus/. LBNL has released a new easy-to-use interface for EnergyPlus called Simergy. It is available at http://buildings.lbl.gov/simulation-research-group.

- **ASHRAE/IESNA** Standard 90.1 Compliance and ASHRAE Publications www.ashrae.org/
- **Consult the International Building Code and International Mechanical Code** (www.iccsafe.org/) for compliance issues.
- **Consult Local or State Energy Codes** A reference to state energy codes is available through the U.S. Department of Energy's Energy Efficiency & Renewable Energy website (www.energycodes.gov/adoption/states).
- **Energy Consultants** Helpful for additional daylighting expertise, software analysis, code or standard compliance, and mechanical system optimization.

## CHECKLIST

1. Ensure that the project's mechanical engineer is involved in the decision-making process.
2. Do mechanical 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 reflect shading (both designed and that resulting from other structures or objects), and full credit for lighting reductions due to daylight controls.
4. Use energy simulation data in the cost/benefit analysis to explore trade-offs 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, and consider the potential role of the building within a smart grid.
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.
9. Discuss comfort and loads with project team prior to final envelope design.

## Integrating Mechanical Design

### Good Practice

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

### Better Practice

In addition to the 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.

### Best Practice

In addition to the 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 building energy use and daylight. Consider the use of an outside energy consultant if this software expertise is not available to the design team.

# 7 Lighting Coordination

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

- Lighting design must include daylight from the beginning
- The cost-effectiveness of daylighting depends primarily on lighting energy savings
- Cost effectiveness may be further supported by reducing electricity demand and providing the facility for demand response
- Effective controls help capture maximum savings from daylighting

## 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 (e.g., 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' 6". For best light distribution, pendants should be hung at least 1' 6" from the ceiling. A direct/indirect system will generally be more efficient at providing task illuminance than an indirect system.

Figure 30 illustrates some ceiling-mounted lighting options.

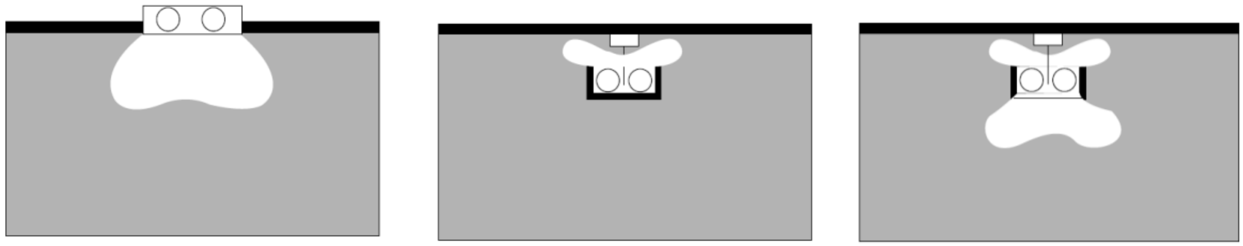

Figure 30: Illustrations of typical candlepower distribution for different ceiling-mounted lighting designs; left, direct lighting; center, indirect lighting; right, direct/indirect lighting

- **Balance the light in a deep room.** In daylighted spaces greater than 15 feet in depth, provide vertical illumination on the back wall (using ceiling fixtures within two feet of wall or with wallwashers) to balance luminances and prevent a gloomy feeling. Use walls or partitions with high reflectance, light-colored surfaces.
- **Organize fixture layout and controls to match daylighting distribution.** To ensure adequate illumination, group fixtures by areas of similar daylight availability (e.g., in rows parallel to the window wall). Luminaires should be associated with each window. Arrange lighting circuits in zones parallel to the 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 and wireless controls.

## Choose the Right Hardware

- **Use efficient lamps, such as T8s and T5 tri-phosphor fluorescent lamps or LEDs 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).
- **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 downlight glare**. 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 users of 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. Download the IES RP-1 Guidelines (see details in section 12, TOOLS AND RESOURCES SUMMARY) or view other IES literature 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 the screen or apply anti-reflection filters to the computer screen face.
- **Watch ceiling brightness with computers.** Indirect or direct/indirect lighting is good for computer users, but observe some rules about the ceiling brightness. Ceiling luminance for on-screen 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 (0.6 m by 0.6 m) 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 Section 4, GLAZING SELECTION, and Section 5, 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.
- **Balance lighting quality and energy efficiency.** Occupant comfort or satisfaction needs to be balanced with higher energy savings. Higher energy savings may not be cost-effective if they come at the expense of occupant productivity.

## 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.** Assemble a set of recommended procedures and schedules for 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. The International Performance Measurement and Verification Protocol (IPMVP) is an excellent guide to the

various elements of commissioning and performance monitoring; for more details visit www.evo-world.org/.

# 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 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 VDT view direction parallel to the window wall.

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

## HVAC

The lighting designer should supply a reasonable estimation of how much lighting power reduction is 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). Reduction of peak cooling loads should be an objective of the integrated design process, with elimination of unnecessary systems the ultimate reward. To unlock energy savings through integrated design, use energy modeling to determine the impacts of lighting on cooling loads. Estimates on lighting-associated cooling loads should inform estimates for required cooling capacity; carefully reviewing lighting design may help identify opportunities for cooling capacity reduction. Locations of lighting fixtures and supply/return registers should be coordinated so as not to disrupt air flow.

## Cost Effectiveness

Cost of fixtures ranges widely depending on the aims of the designer/installer and depending what they wish to achieve. 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, due to the very large percentage of building energy use consumed by lighting. Costs of other technologies (e.g., dimmable electronic ballasts) continue to fall. Be sure to use current cost estimates in your analysis. Details of rebates can be found in the

Database of State Incentives for Renewables and Efficiency, available online at www.dsireusa.org.

### 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 furnishings may be relocated in the future, direct lighting systems may be more likely to lead to occupant dissatisfaction than indirect systems will. An appropriate solution is to allow occupants to control overhead lighting for their workspace or office, or to provide supplementary task lights. For the latter to work, overhead lighting must not be too bright; it is better to set lighting levels to achieve an acceptable but low work surface light incidence.

## PROVISOS

- Designing for 30–50 fc with a maximum of 0.9 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 0.6 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 lighting systems in distinct spaces. If such changes are anticipated, a more flexible approach to lighting is recommended.
- Consider dimming controls for all daylighting systems, as they are more versatile, less annoying, and provide larger savings. Costs have been high but are falling.

## TOOLS & RESOURCES

- **Design Professionals** Use a lighting specialist whenever daylighting controls are planned. Lighting designers (as distinct from electrical engineers) are recommended in general for a higher-quality end result. The cost for the added service is easily recouped in ensured performance and occupant satisfaction, and lighting designers offer the best chance to achieve energy savings.
- **Books** There are many titles available on general lighting design, but less to assist high-performance lighting design with daylight controls. The IES may be the best source for literature. The lighting designer should distinguish between recommended and standard illuminance levels in the reference materials, reflecting the fact that there is an acceptable visual comfort range.

  For a list of currently recommended titles, visit the Tips for Daylighting website:

[windows.lbl.gov/tips-for-daylighting](windows.lbl.gov/tips-for-daylighting)

*Advanced Lighting Guidelines*, 2009, from the U.S. Department of Energy, is a thorough and informative guide to all aspects of various lighting technologies. It is also online at [www.algonline.org/](www.algonline.org/).

- **IESNA** 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, up-to-date technical information. Local chapters also may offer classes or other resources. The IES handbook is an invaluable reference for detailed technical guidance and information. For publications visit their website at [www.iesna.org.](www.iesna.org)
- **EPRI** The Electric Power Research Institute has a strong collection of fact sheets, brochures, guidelines, and software available. Visit their website at [http://lro.epri.com](http://lro.epri.com) for more details.
- **LBNL Lighting Systems Research Group** is a good source of information on all aspects of energy-efficient lighting practices. For a publications list, visit the group's website at [http://lighting.lbl.gov.](http://lighting.lbl.gov)
- **Lighting Research Center,** at Rensselaer Polytechnic Institute, is source of general information about lighting products and practice. Contact them at [www.lrc.rpi.edu](www.lrc.rpi.edu).
- **California Lighting Technology Center,** at the University of California, Davis, is a good source of information on energy-efficient lighting and daylighting technologies. Contact them at [www.cltc.ucdavis.edu](www.cltc.ucdavis.edu).
- **Utility Company** Many utilities offer incentives for energy-efficient lighting equipment. Inquire at your local utility about new construction or retrofit programs.
- **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). Many lighting designers use software (DIALux, and AGI32 are good examples) in place of tedious hand calculations. A package which is capable of addressing daylight and electric light integration is recommended.
- **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 Section 3, 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 a local utility or lighting manufacturer offers assistance. As an example of what is possible with large building owners, see the experience of the *New York Times*, with a complete lighting and daylighting mock-up with extensive

testing. For more details on their daylighting efforts, see http://windows.lbl.gov/comm_perf/newyorktimes.htm.

## CHECKLIST

1. Review the fenestration design and intended space plan for an initial estimate 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 two points above.
4. Lay out the lighting system, coordinating with window placement and daylighting control zones. Strive for an installed lighting power density lower than the energy code maximum.
5. Estimate electric lighting illuminance levels. Determine daylight and electric lighting distribution throughout the lighting zone and ensure that dimming zones maintain a uniform distribution.
6. Select the most efficient technologies available that meet design objectives and are within the project budget. Check with your utility about lighting programs.
7. Calculate the expected electric lighting savings due to daylight controls, for use in a cost-benefit analysis (see Section 11, COST-BENEFIT ANALYSIS). Review cooling load estimates arising from electric light savings. and assess opportunities for cooling capacity reduction. Provide the expected lighting power reduction at peak times to the mechanical engineer for cooling load calculations.
8. Review glare issues with design team. 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 or other elements.
10. Include performance specifications, control system documentation, calibration instructions, other commissioning recommendations, and a maintenance plan with the lighting design documents.

## LINKS

Achieving Energy Savings with Highly-Controlled Lighting in an Open-Plan Office

http://gaia.lbl.gov/btech/papers/3831.pdf

# Lighting Coordination

### Good Practice

1. Design a direct/indirect lighting system at no more than 0.9 watt per square foot, with supplemental task lighting if necessary, fixtures grouped with



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

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

windows and by daylighting zone, and special attention to glare in computer workspaces.

2. Estimate daylight levels before final system design and control strategy selection.
3. Check for utility rebates before the final design and specification.
4. Include previously described documentation with the construction documents.

### Better Practice

In addition to the above:

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

### Best Practice

In addition to the above:

1. Consider multiple lighting alternatives.
2. Use lighting software and/or physical model photometry to estimate daylight levels and the nature of the daylighted space.
3. Construct and evaluate a full-scale mock-up of a typical workspace.

# 12 Tools and Resources Summary

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

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

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

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

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

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

# 13 Glossary

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

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

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

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

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

**Brightness** The subjective perception of luminance.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

**Photometer/photosensor** An instrument for measuring light.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

**Watt** Metric unit of power.

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

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

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| See above in the *Lighting Coordination* section. | |
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# 15 Appendix A

## First Cost and Energy Savings

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

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

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

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

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

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